Other books by René Raaijmakers

Natlab, Kraamkamer van ASML, NXP en de cd
(Natlab: The Birthplace of ASML, NXP, and the CD – in Dutch,
with co-author Paul van Gerven)

ASML's Architects

René Raaijmakers

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In the early 1970s, engineers at the Philips Research Laboratory in the Netherlands build a machine that promises to be a license to print money. They don't realize they've created a monster that will do nothing but devour money for twenty long years.

"Let's just get started, and solve each issue one by one"
Evert Polak (1944–2014)

First English edition

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ASML's Architects

ASML's Architects is the translated and updated version of the book *De architecten van ASML* (2017) chronicling ASML's genesis. The book covers the era from the pioneering 1960s through the mid-1990s, when ASML definitively broke onto the world stage.

Part two is in the making. Stay in the loop by joining our mailing list at *asmlbook@techwatch.nl*.

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Preface

In the early 1990s, as a young technology journalist in the Netherlands, I visited Silicon Valley. There, surprisingly, at a conference in San Jose was where I first encountered ASML, a Dutch company that was embroiled in a technology race with the then-unassailable giants Canon and Nikon.

As a student and fledgling journalist in the land of Philips, I'd never heard anything but complaints about the Japanese and the Koreans and the disruptive effect their unfair methods were having. But in the Fairmont Hotel in San Jose, my countrymen told me a different story. Whatever else happened, they were going to crush their Asian competitors.

It surprised and delighted me that a machinery manufacturer from a small town in the Dutch deep south was playing such a crucial role in information technology. After that first meeting in the US, I kept a close watch on the engineers in Veldhoven. ASML intrigued me: a small high-tech player from my own homeland was determining the pace of the computer chip industry. What's more, the company oozed enthusiasm.

It must have been somewhere around the turn of the century that I began to play with the idea of writing a book about ASML's genesis. It seemed like a fascinating endeavor to lay bare the roots of a Dutch fighting machine that had just beaten the Japanese heavyweights Canon and Nikon.

How can a tiny company succeed where a colossus like Philips threw in the towel? True, after 1984 it took ASML another seventeen years to grow (seemingly from nothing) into the market's unrivaled leader, but it was a success story to die for. I often wondered: who was behind it, and how had they pulled it off?

Yet for years the project sat in cold storage. The dot-com crisis dealt a heavy blow to my company, Techwatch. I'd founded it in 1999 to publish my own magazine, *Bits&Chips*. Hit by the severe recession, my bank account was constantly overdrawn in 2002 and 2003, and my three employees and I had to pull out all the stops to keep the place afloat—and what's more, I had to write the lion's share of my magazine myself.

Despite all that, in 2003 I visited Wim Hendriksen for a first interview for the ASML book. Wim was part of the first wave of employees who came on board shortly after the joint venture's founding in 1984. He kept repeating one claim: "ASML as it is today—it was planned that way from the start." The company's current culture, its frank, confrontational style of communication, its reckless—"all or nothing"—quest to dominate the market, the revolutionary idea to farm everything out: the seeds were all planted in the earliest days of ASML's existence.

Every self-respecting journalist takes a claim like that with a hefty grain of salt. Can you conceive the culture and essence of a company that makes extremely complex products in the space of a few months—when the preceding years were a shambles? Can it be true that in the spring and summer of 1984 a culture was sown that would still exist thirty years later? I found it hard to believe. It's the nature of human memory to distort the past, and by then I'd gained enough experience to know how differently different people can view the same events.

The death of ASML's former CEO Willem Maris at the end of 2010 was the push I needed to seriously commit to this project. I decided to publish a *Bits&Chips* special issue on ASML and interviewed several insiders for it. One thing became abundantly clear: ASML's history is anything but a straight and neatly paved road. On its way to the top, the technology company has gone through some very deep valleys. And many of the stories and anecdotes making the rounds in the Netherlands' high-tech circles turned out to be quite different in reality. I discovered that the company's history was riddled from start to finish with the bizarrest of turns. In short: ASML was such a thrilling story that I couldn't leave it untold.

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What did I have in mind when I started? To explain that, I need to tell you a little about my work in the nineties as a freelance science and technology journalist. I enjoyed popularizing difficult subjects, but over the years my interest turned increasingly to the people involved. In particular, it was endlessly fascinating to listen to the absolute kings of technological innovation: the researchers at Philips' physics laboratory, Natlab. It was my great luck to speak with those brainiacs regularly in the nineties, mostly to fuel my contributions to the science insert of a respected national newspaper, the *NRC Handelsblad*. Whenever the bastion of cutting-edge research had an interesting story to tell, I was usually the first one they called.

Those interviews were definitely experiences. They touched on not only the technology, but also market opportunities and what the inventions and systems meant for society. Natlab's scientists and engineers had the most fascinating stories. Searches that took years, intense collaboration and, above all, a lot of bureaucratic tussles with managers and product divisions. The Natlabbers often had a strident opinion of Philips' bureaucracy, too, and the ineptitude and incompetence at the top. And they were perennially skeptical of commercialization.

Engineers are often dismissed as nerds. In popular stereotype, they're socially awkward people, folks who fall somewhere on the autism spectrum. But the engineers I encountered—certainly the inventors at Natlab—had extremely multifaceted interests, cavernous knowledge, and usually a strong opinion on the impact of their work. They brought the technical world to life for me. And rarely were they the awkward dorks of stereotype; rather, they were well-rounded and socially fluent people.

To be clear: often they were, indeed, nerds of the first order. The inventor of ASML's electric positioning table, Rob Munnig Schmidt, has kept searching for the ultimate audio amplifier even in retirement; Natlab director Hajo Meyer made another fifty concert violins after he retired, using a scientific approach he described in academic articles on acoustics; Natlab director Marino Carasso still solders microcontrollers onto PCBs in the basement of his canalside home in Amsterdam.

Because I also wanted to take in the feel of the whole company, from the office desk to the factory floor, I spoke not only with founders, geniuses, and senior management, but also with secretaries, research assistants, machinery operators, service techs, and members of the worker representation council. The trade union official responsible for ASML in its early days also granted me a few hours of his time. All these people often had a very different view of the world than did the company's management.

So that's what I had in mind when I was mulling the shape of this book: capturing on paper how all those people had experienced the ASML adventure. I couldn't avoid the technology on which ASML built its success, but I knew that a story about the people, the culture, the money, and the organization would be far more compelling. Because however brilliant the technology may be, it ultimately forms only a part of ASML's success—even if technological supremacy was an absolute prerequisite every step of the way.

* * *

But if I wanted to write a book about the people of ASML, how much of the technology should I include? After all, the stars of the story—including senior management—are all engineers, and the company owes its existence to innovations and technological frontiersmanship. That was my biggest struggle in the whole project: I wanted to write a book that would be accessible to everyone, but I couldn't avoid the technology.

And so, in the fall of 2016, I decided to write two books: a management book and a technical book. I saw the management book as a way to introduce a wider audience to the most extraordinary high-tech company the Netherlands has ever known.

The version of the book you're reading is the technical one. Several people advised me not to publish this version: too much work, and a commercial clunker. But the reactions I got from readers after we published the (pretty darn technical) book *Natlab – Kraamkamer van ASML, NXP en de cd* (Natlab: The Birthplace of ASML, NXP, and the CD) told a different story. For people with an interest in science and technology, the more difficult passages posed no problem at all.

Even so, this book is also, first and foremost, a book about people, the engineers behind ASML. I popularize the technology and science as much as I can, to keep technically inclined readers who don't have the background from tripping over the text. That means engineers who do have the background won't find any real depth in this book—for them, there's plenty of other technical reading material available. I only emphasize the technology when I think it's essential to the story, or of historical importance.

As it happens, no one's written an extensive popular history of chip lithography yet. There are a library's worth of books about the semiconductor industry, but these tomes say surprisingly little about the strategic technology at its foundation. That's why in this technical edition I also talk about developments in the rest of the world—though Japan receives relatively short shrift.

For me, the human element was essential. That's also the reason why I called this book *ASML's Architects*. The name refers to the development of both the wafer stepper *and* the business.

In science and technology, everyone always refers modestly to the shoulders of giants on which they stand. Researchers and inventors try to downplay their contributions by pointing out they're building on what their predecessors created. I went looking for those giants, and in this book I've tried to shed some light on their contributions.

* * *

It takes teamwork to build complex machines. That's why this version emphasizes the people behind the technology—the engineers. The very first lithographic machine that was developed in the Netherlands, the photorepeater, wouldn't have been as perfect if Frits Klostermann and Ad Bouwer hadn't pushed themselves and each other to their very limits.

This approach has always been crucial. The intensive exchange of ideas—also known as reviewing in today's jargon—is indispensable in making complex systems like steppers, and it's a central theme running through ASML's entire history. The way the company's engineers still do this, the way they hold their discussions on the absolute cutting edge of both the science and propriety, has been taken to truly legendary extremes.

I wanted to bring this engineering culture to life. That means this book isn't a quest to name every participant and the credit each is due, either. I've limited myself to the key players, and even there I know a few are missing.

After so many years, it's hard to get a grip on the exact historical course the technology took. Only rarely are brilliant inventions attributable to individuals, and even they usually drew their inspiration from their teams. Even the names on the patents (and their order) don't always do the reality justice.

Most of all, I wanted to make the technical world accessible. To that end, I've highlighted a number of extraordinary or exciting events and discoveries, and only briefly noted the parts that seemed to me more boring—or simply left them out.

* * *

I spent seven years working on this book. I loved reliving the entire adventure from my perspective. The amazing events, the roller coaster ASML has been on for its entire life, the paranoia in the chip industry, and especially the many interviewees and the openness with which they spoke with me, have repeatedly given me that extra push and motivated me to take the time I needed for the book. One interviewee was even glad for the opportunity to confess. He felt he'd behaved so badly during his years of research that the thought of a printed confession helped to ease his sense of guilt.

Running your own company—in my case, a publishing house—is sometimes hard, but more often it's a blessing. Because when you're writing a book, a company like mine provides an extraordinary number of conveniences. For example, it takes at least half a year to transcribe three-hundred-plus hours of interviews. I could turn all that work over to our student interns. And business kept running as usual during the many months when I spent the bulk of my time writing. Last but not least, it's just plain exhilarating to be in an environment where you can tell the occasional anecdote and share your struggles in the knowledge that your colleagues will understand you.

* * *

To me, the most intriguing task was testing Wim Hendriksen's claim that ASML as it is today was planned that way from the start. Objectively speaking, ASML had a chief architect and that was Gjalt Smit. He was the one who defined the company in its first months. That this architect was full of himself and had a nearly evangelical zeal to crow about his ASML adventure didn't make things easier. At first, I was worried the whole story would turn into a hagiography, and in that case there's only one thing a journalist can do: launch an exhaustive search for opposing voices and less adoring perspectives.

And what do you know: Gjalt Smit was decidedly no saint. His arguments with shareholder Arthur del Prado were notorious—Smit has never given any details on those, and Del Prado also declined to discuss their struggle, but former colleagues had been present. And only just this past year did it become clear to me that three and a half years into ASML, Smit's expiration date had arrived. He was the right man at the right time. After that, many people were glad to see him go. To be honest, I was relieved: Smit turned out to be human, too.

But even though Smit was spat out by many at the end of his ASML tenure, everyone affirms that he delivered a miraculous effort. He planted the seed—whatever the cost and at lightning speed—that enabled ASML to grow from an insignificant minor player to a global superpower. The world got a taste of that even during Smit's short reign. In 1984 ASML was a nobody; at the start of 1987, the *New York Times* mentioned the company in the same breath as Canon and Nikon.

The first fifty employees who came from Philips formed ASML's technological DNA. The most extraordinary thing is that Gjalt Smit turned that burned-out jumble into an impassioned team, and a completely different culture emerged. Dozens of people confirm that the credit belongs to him. The words that Smit used in 1984 and 1985 apparently made such an impression on his colleagues that many of them were able to recite his words back to me verbatim in interviews. I, too, experienced how talented Gjalt Smit is at stakeholder management. When it became clear to him that this book was a serious project, he regularly carved out time during his trips from his home in Switzerland to the Netherlands to speak with me and answer my questions.

ASML is also the story of a merciless work culture. Around the turn of the millennium, I interviewed one of the millionaires who said farewell to the company after cashing in his shares. He was years away from retirement age, so I asked him why he'd left ASML. It was a fantastic company, wasn't it? But at that time he was worn out, and this is how he described it: "Look, eighteen-wheelers are built to do sixty miles an hour. You can make them do ninety, but then you wear them out faster. At ASML, I spent seventeen years doing ninety."

ASML is a success story, and for that reason alone this book differs substantially from the books that have been written about other major Dutch companies such as the ABN AMRO bank (*De prooi* – The quarry), Philips (*Kortsluiting* – Short circuit), and AOL rival World Online (*Nina*). There, the sources are people with lingering resentment and scores left to settle. In my case, I was often talking with people who looked back proudly on their experiences and were eager to share them with me. But even this success story has notes of doubt, revenge, euphoria, and hubris.

The extraordinary thing about this story is that people so often wanted to talk frankly about their own character flaws, miscalculations, and mistakes. To me, ASML's success is built on candor, and I've made grateful use of that openness and honesty.

I confronted many people with less flattering memories. The extraordinary thing is that though they occasionally protested, no one tried to put a different twist on the story.

In the project's final months I realized there's no such thing as partial transparency. I was given access to piles of confidential information that gave me ammunition for further questions. That, I believe, is the major value of, and the courageous thing about, honesty: you transcend yourself by making yourself vulnerable.

All in all, I still think it's an amazing story. Amazing that ASML made it in the first place; amazing to see what you can accomplish with the right people, the right knowledge, a giant sack of money, and the right decisions. Amazing, too, how companies can be entirely dependent on events over which they have absolutely no control. In that regard, I agree with what Gjalt Smit wrote in his own, unpublished memoir on ASML: "I strongly doubt that given the same parameters today the same company would emerge again—if, indeed, any company at all."

René Raaijmakers

Introduction

Thirty-some years ago, the entire lithography market for chips was controlled by GCA and Nikon. The entire market? No—a tiny machinery manufacturer in the unassuming Netherlands kept bravely resisting the gorillas and made life decidedly difficult for the Americans and the Japanese.

The boys from Holland weren't satisfied with the status quo. They wanted to conquer the world. It took nearly ten years before there was real progress on that front, but by the mid-nineties a rise to prominence could finally begin that, another decade later, would result in absolute control of the market.

After that the technology company continued fearlessly on. Now, another ten-plus years later, ASML makes machines that can print such fine-scale structures at such immense speed that no other company in the world can match them. The tiny Dutch town of Veldhoven sets the pace of information technology; it dictates the speed at which chips across the world grow in computing power and information density.

ASML is now an unparalleled success. Its share price has been higher than that of its former parent, Philips, for years. It's the superlative case on many fronts: it's the Netherlands' largest exporter, it provides the most jobs in the country's technical sector (counting its high-tech ecosystem), and it's the world's biggest machinery manufacturer for the chipmaking industry.

With a chip lithography market share of 70 to 80 percent, ASML has been leaving Canon and Nikon in the dust for years. But not only that. It's still investing heavily in the development of ever-smaller chip structures. The current efforts to do that using extreme ultraviolet light are so complex that no other company dares to invest seriously in it. It's an effort we can safely compare to the American Apollo project, and it probably even outshines that.

In the past decade, the company has moved up in the general public's awareness—largely thanks to its performance on the stock exchange and the publicity that has generated. But the general public knows very little about how ASML made it so far, where it derives its strength, and what lay the groundwork for its rise to prominence. This book aims to change that.

Part 1

Wafer Stepper Prehistory
1962–1969

1. **A Strange Insect**

Leo Tummers asks the young engineer Frits Klostermann to build him a chip. Natlab doesn't yet have the micropatterning technology the endeavor requires, so Klostermann decides that first, they need to build a new machine.

At the start of the sixties, the Philips Physics Laboratory—Natlab for short—is a superuniversity where only the best and brightest are welcome. At its facility on Philips' industrial campus in Eindhoven, the Netherlands, these whiz kids are free to conduct research under ideal conditions: they don't have to teach class, and Natlab's budgets are virtually unlimited.

More and more technology is going into products, and Natlab plays a starring role as Philips' innovation machine. Everything the lab touches seems to turn to gold. A battery of products serves as proof: televisions, radios, fluorescent lights, tape recorders—and the list goes on. Progress seems unstoppable, and meanwhile plans have been made to move the lab to the neighboring town of Waalre to enable further growth.

In 1961 Frits Philips, the son of founder Anton, takes the helm of the global company, which at that time has 230 thousand employees and a revenue of $2 billion. Philips is utterly convinced that its research lab in Waalre will swell to three thousand employees. It welcomes young technical talent with open arms.

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Frits Klostermann is twenty-nine when he signs on with the illustrious lab in September 1962. Bright young minds usually start a few years earlier, but he has a long road behind him.

Klostermann is the youngest member of a family whose roots lie in the North German city of Oldenburg. The family began trading in textiles, leather, and shoe care supplies in the Netherlands at the start of the nineteenth century. Klostermann begins elementary school in 1939, but dyslexia hounds him. Reading, arithmetic: everything is hard. But he grows out of it. After completing high school with an emphasis on math and physics, he enrolls in the engineering program at a local community college, and spends his practicum year working in German and English machine factories. He graduates with honors, and the dean of the college strongly encourages him to study physics at the Delft University of Technology—the Dutch equivalent of MIT.

Klostermann isn't eligible for government student aid in the Netherlands, because he's still a German citizen. But the dean of the community college arranges an interest-free loan from a regional student loan provider. He's on his way to Delft.

After he graduates, Klostermann applies to Natlab on the advice of his TU Delft professor. And that's how the young engineer winds up in Leo Tummers' group, where he first hears of integrated circuits—ICs, or chips for short.

Tummers, section director Piet Haaijman, and managing director Evert Verwey form the trio that sets the course for Natlab's semiconductor research in the sixties and seventies. When Klostermann arrives, the atmosphere in Tummers' group is excited. A few months earlier, Haaijman brought back a chip from his fact-finding tour of the United States: a single slice of semiconductor crystal onto which various electronic components have been soldered and integrated. It's created quite a stir. The chip's import is evident: the Americans have made a giant leap forward in reducing the cost of electronics. The three men realize they've missed the boat, and Tummers orders several of his researchers to drop everything and throw themselves at the new technology.

Tummers has permanently installed a microscope with Haaijman's chip on it in his group's wing of the building.[1] As a statement, there to be seen by anyone who still has doubts about the future. "Look at this," he tells Klostermann. "If they did it, we can do it, too." Klostermann peers through the microscope and sees, for the first time, what a chip looks like: some kind of strange insect, glittering in all the colors of the rainbow.

For most of the researchers who arrive at Natlab in the fifties and sixties, the first year is a relaxed one. They do a little looking around, spend a few gentle months getting up to speed, and then choose the project that most interests them. Klostermann also starts off by getting up to speed, but the crystalline insect injects a sense of urgency. The head of his research group intends to catch up to the Americans.

Tummers asks Klostermann to put a shift register on an integrated circuit. At the time, a shift register consists of separate elements soldered together: transistors, resistors, diodes, and capacitors. Klostermann's task is to integrate all those components and connections on one small piece of silicon. In other words, to turn them into a chip.

* * *

Meanwhile, in the US the Pentagon and NASA are pumping billions into chips. For more than a decade, the American military apparatus has witnessed the major advantages that miniaturization offers. It's the era of the Apollo missions and the intercontinental Minuteman missiles. The defense industry is spurring its scientific and industrial colleagues to place all their bets on the new technology. The increasing demand for chips is also kicking the development of chip production equipment into overdrive.

There, too, the defense and aerospace industries play a galvanizing role. For example, at the end of 1960 the US Air Force awards Texas Instruments a $2.1 million contract to develop custom processes and instrumentation for ICs. The first specialized chip machinery manufacturers arise in that period. Chip production steadily grows, giving the Americans a head start over the Europeans. They achieve greater yields and succeed in dramatically lowering their prices in a short time.

The European industry is also throwing itself into chips, but in the early sixties the effort transpires almost entirely behind the closed doors of behemoths such as Philips, Siemens, and Telefunken. These companies have deep pockets, but they lack the electrifying ecosystem being created by countless specialized startups in Silicon Valley (appendix 1).

At Natlab, the technology to make semiconductor components such as diodes and transistors is well within reach. Researchers need only snap their fingers and the glass blowers and job shop technicians jump to provide them with measuring instruments, vacuum bell jar evaporators, diffusion furnaces, and other equipment.

Klostermann is surrounded by inspiration in his quest to build an integrated circuit; his officemates Albert Schmitz and Piet Jochems have already earned their stripes in transistor manufacture. His biggest problem is the photographic equipment. Natlab lacks the optical instruments to make contact masks that contain very tiny patterns. Those masks are required to lithographically print the patterns onto silicon wafers.

Klostermann can have the masks made in the US, but that will take months. And so he decides to develop an imaging device himself. In a few months' time, the young engineer creates his first configuration. "A simple projection system has been constructed, which seems to produce photographic images of sufficient quality," Klostermann writes in his report on the final quarter of 1962.

* * *

In the year that Klostermann spends thinking about his system, the David Mann division (appendix 2) of the Geophysical Corporation of America (GCA) has developed a similar device: the photorepeater. By then, the company has even sold dozens. Several chip manufacturers are using Mann's photorepeater to make the contact masks they use to print transistor patterns onto silicon wafers.

At Natlab, Haaijman asks Klostermann to switch his focus to photomask production and to transfer to Henk Jonker's photochemical research group. There, he'll be able to throw all his effort into his step-and-repeat camera.

But when Klostermann arrives in the group, he discovers that Jonker's priorities lie entirely elsewhere. Jonker puts Klostermann's efforts on hold. Instead, he'll run the technical service group tasked with producing contact masks and advanced photographic negatives for a variety of customers.

The scientist Klostermann is now a manager. He follows Jonker's orders without argument. Not that the young engineer is eager to run a service department; but he's a principled man who respects authority, not someone who thumbs his nose at the hierarchy so common to his era. He understands there's work that has to be done. What's more, he and Jonker get along well. The two are on a first-name basis from the start.

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Henk Jonker knows that Klostermann has his heart set on making his own step-and-repeat camera for integrated circuits, but that plan isn't fast enough for Jonker. It could take years to build such a complex device. He knows that Philips' Electronics Components and Materials division—Elcoma for short, the predecessor to Philips Semiconductors—has already bought a David Mann repeater for its fab in Nijmegen, to make the contact masks for transistors.

Jonker chooses the same practical path. He wants to catch up to the Americans by buying Mann devices, too. Klostermann disagrees; he wants to build his own machine. But he doesn't protest. He knows his boss is a man of few words, someone who brooks no argument. Jonker is eager to move forward, and in May 1963 he places an order with Mann for a photorepeater.

A month later, the David Mann Model 1080 arrives in Eindhoven, and Klostermann fires it up. The step-and-repeat camera has a traditional design and build. The single-barrel projection system shrinks the images by a factor of ten or three using a microscope objective on a high-resolution plate from Kodak. The glass photographic plate lies on a carriage like the ones commonly used in lathes: with a hand-scraped prismatic cast-iron guideway.

Movement in both coordinate directions is accomplished using lead screws. In one direction, the operator has to manually twist the screws. Once everything's in place, the photorepeater can image a whole row of patterns. A small motor moves the carriage holding the photosensitive plate past the microscope objective. The flash is controlled by a pulse counter that receives its signals from a rotation sensor on the lead screw. After the set number of pulses, the controller triggers the xenon lamp. The lamp flashes—click, click, click, click—burning the patterns into the photosensitive slide on the fly.

Klostermann has little trouble using Mann's step-and-repeat camera, but he doesn't have time to work on the design for his own imaging device. The touted freedom enjoyed by Natlab scientists is nowhere to be found; he's responsible for an entire service department, with all the accompanying bureaucracy and administrative headaches. His world has narrowed to eliminating dust and vibrations (appendix 3). There's no room for building new gadgets.

The young engineer's plans have been hijacked, but the American photorepeater does give him the chance to thoroughly study the state of the art. He seizes that opportunity with both hands. He tests the Mann device carefully, repeats the same test patterns multiple times, and measures everything against the SIP and Leitz coordinate measuring machines available at the lab. Using a fountain pen, he fills dozens of pages in his lab journal with long columns of results. He estimates his measurement error to be 0.5 microns at most. Across distances of dozens of millimeters he finds repetition errors of a few microns, though the photorepeater's spec says that error should be under 1.25 microns.

Klostermann is not impressed. He can respect the fact that Mann's the first company in the world to deliver this kind of system, but his engineer's genes tell him it can be done much better.

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In November 1964, Klostermann travels to the US to visit several instrument manufacturers. He goes to seven companies and sees photorepeaters, precision cameras, and measurement instruments. On November 19 in Burlington, Massachusetts he shakes hands with Burton Wheeler, who runs GCA's David Mann division. He inspects the Americans' equipment and discusses with them the shortcomings of their photorepeater, which at this point he's been using for a year and a half.

And oh, woe: Mann hasn't been resting on its laurels. He learns that the American specialists have already sold a first four-barrel photorepeater. It uses the same principle that Klostermann envisioned a few years earlier, namely achieving high precision by imaging in parallel. Mann's machine has a price tag of $37,500. Klostermann writes it all down in a trip report he sends to twenty of his Natlab colleagues.

2. **Philips Elcoma**

Philips' semiconductor division is bumping up against the limits of the available photolithographic equipment. Frits Klostermann finally gets the green light to realize his dream.

In the second half of the sixties, Philips Elcoma's semiconductor fab in Nijmegen decides to expand beyond transistors and start making integrated circuits. They desperately need a faster and more sophisticated method for making contact masks.[2] The fab is hitting the limits of the David Mann repeater.[3] The American photorepeaters they've been using in Eindhoven and Nijmegen have passed their prime. They aren't accurate enough, and what's more, they're too labor-intensive—someone has to constantly man them.

Elcoma's technical managers regularly discuss this kind of technological challenge with Natlab's group leaders and directors. Both groups have contacts all over the world. Their chats are also a good opportunity to bring the semiconductor fab up to speed on the latest research. That means Elcoma's always extremely well informed about Natlab's optical and mechanical achievements. The research guys are always happy to brag about their hydrostatic bearings and pneumatic technology.

At some point Mat Wijburg, the director of Elcoma's mask center in Nijmegen, lays eyes on the notes from these discussions. His response is condescending. "They brag about their oil and air bearings, but they aren't using them to make machines that help us make chips," he sneers. His comments travel to Natlab in Eindhoven, where they prompt discussions between the two divisions.

Ultimately a decision is reached: the lab will build a photorepeater, and Elcoma's applied integrated components group will make the electronics, assisted by Natlab's electrical support team.

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In the fall of 1966, Klostermann gets the green light to build his photorepeater. For four long years, the catch-up sprint his former boss Tummers had in mind has failed to occur. Meanwhile, Klostermann has gained extensive experience in lithography. Through all his grappling with lenses, photographic materials, and flash lamps, he's learned the strengths and weaknesses of David Mann's instruments through and through.

Klostermann is raring to go. He's determined to create the perfect photorepeater. To his surprise, his boss Jonker gives him complete freedom—and a generous budget to boot. The engineer expresses his amazement at this to his colleagues.

Klostermann has to figure out how to project the patterns for integrated circuits onto photographic plates. Those plates can then be used to burn the patterns into chips using contact printing. On a glass plate negative, hundreds to thousands of circuits measuring 0.5 to 1 millimeter on a side must be imaged one by one. With massive numbers like these, the exposure process must also be fast if it's going to be economically viable. Each circuit is made of components just a few microns in size, so above all the process must be extremely accurate.

The ideas he put down on paper four years ago are back on the table. Klostermann wants to anchor six reduction lenses together in a single block and thereby expose six different slides for a single chip at once, each with a different pattern—one for each of the layers in the chip.[4] "It should be ready for use in April 1967," he notes in his reports.

Klostermann chooses the same operating principle Mann's using in its step-and-repeat camera, times six: an imaging system with six flash lamps and six vertically oriented objectives that shrink and project the six mask patterns onto six photosensitive plates that are moved forward by a mechanical carriage. As the carriage moves, a displacement measurement system must pass trigger pulses to the flash lamps, thereby simultaneously creating rows of miniaturized patterns on each of the six photographic plates.[5]

In the fall of 1966, Klostermann tests an initial setup for a single-barrel photorepeater. For the first time, his hands aren't tied, and he can truly play in the technological wonderland that is Natlab. Almost everything is at his disposal. And anything that isn't, he can have made for him.

To assess the sharpness and distortion of various flat-field microscope objectives, Klostermann's assistants use these lenses to take microphotos of test patterns. Some twenty candidates are run through the system in the fall of 1966. "The best results are achieved using optics specially developed by Zeiss for use in microelectronics," Klostermann reports.

Natlab is particularly blessed with in-house precision technology that can't be bought elsewhere. In the mid-sixties, researcher Hendrik de Lang in the optical research group develops a linear grating measurement system that's extremely precise for its time: an optoelectronic ruler that can measure displacement to an accuracy of one-tenth micron (appendix 4).[6] Using the information provided by the grating measurement system, Klostermann's photorepeater knows exactly when it needs to flash.

The optics are another story. Klostermann's standards are high. He wants objectives with a larger field of view than Zeiss's provide. Philips can't deliver them. Natlab has optics expertise in house, but nowhere at Philips is there a team that can expertly construct and then reliably mass-produce objectives.

And so Klostermann drafts a package of requirements and knocks on Carl Zeiss's door in Oberkochen, West Germany. But the company isn't interested in making a custom lens just for him. The quantities Natlab needs aren't worth the Germans' effort. Klostermann can choose from Zeiss's standard assortment, and that's it.

But Natlab has connections throughout the world. In France there's LEP, a branch of Natlab that handles many aerospace projects for the French government in those days. LEP in turn has contacts at CERCO, a small optics specialist in Paris, which has been doing custom work for LEP for years.[7]

At CERCO, Klostermann encounters a dozen polishers and other craftsmen led by Edgar Hugues. The tiny company does a lot of work for the military market. The men at Philips LEP walk in whenever they please and more or less dictate what CERCO's going to do for them. Klostermann and his six photorepeater lenses fit right in. As soon as CERCO understands what he wants, the company goes to work.

3. **David Mann**

Natlab's construction of its own step-and-repeat camera—isolated from the outside world, safe inside the walls of mother Philips—is in striking contrast to development in the US. There the approach is quite different, and the learning curves are as opposite as night and day. David Mann already put a simple device on the market back in 1961. It's a little rickety, but good enough to make the transistors of the time. At Mann it isn't engineers and academics who drive the pace and shape of development, but dozens of customers knocking on the precision specialist's door with their specific problems.

Development is incremental. In the early sixties, Mann's engineers start out using rotating nuts on lead screws, for example. Only later do they transition, just as Klostermann does, to using linear encoders to achieve greater accuracy.

In the US, Mann's success spurs several companies to follow suit in the sixties. An engineer from IBM starts his own company, JADE, to make step-and-repeat cameras. Dekacon, Electromask, OPTOmechanisms, Royal Zenith, R. W. Borrowdale, and Yale Micro-Module also step into the budding market. Spectra Physics even introduces a repeater with nine objectives that's equipped with a laser-based measurement system and a granite stage resting on air bearings. Mann will later turn to laser interferometry as well, after Hewlett-Packard introduces a reliable laser.

Despite the competition, Mann maintains a market share of 60 to 70 percent throughout the sixties, also in Japan. In those days the company is known for its superb quality, and its engineers enjoy a good reputation. "Burton Wheeler, the general manager, was known to be greatly concerned that only the best quality equipment should leave the factory gates," Rebecca Henderson later wrote in a Harvard University report.[8] But the market is small, and at Mann the machines are manually assembled in a tiny workshop by a few dozen engineers.

Just like Klostermann, the team at Mann struggles with the extremely high requirements that microscopic imaging places on the optics. In the early sixties, the Americans are still ordering the objectives for their step-and-repeat cameras from microscope maker Bausch & Lomb. The company sends large series of lenses to Mann, where they cherry-pick the best units and send the rest back.

But Bausch & Lomb has a hard time delivering the required quality. Some of the batches that arrive at Mann don't contain a single usable lens, and as their volumes grow, the engineers' irritation increases. The precision specialists start searching for an alternative and find a distributor in New York that has Nikon lenses of good quality. The Japanese objectives have another advantage: they're camera lenses, developed for a larger field of view. They can image an area with a diameter of nearly eight millimeters—and the resolution is significantly better, too. The new lenses enable Mann to start offering step-and-repeat cameras for larger chips in 1969.[9]

4. **Ad Bouwer**

Frits Klostermann recruits headstrong designer Ad Bouwer to help him build his step-and-repeat camera. The device will go on to make money hand over fist for Elcoma.

Frits Klostermann aspires to perfection, and he takes the time he needs to achieve it. He has access to both theory—the scientists at Natlab in Eindhoven—and practice—the technicians at the chip fab in Nijmegen. He's immersed in an environment that enables him to build the ultimate photorepeater right out of the gate.

To build his six-barrel repeater, Klostermann approaches Ad Bouwer in the precision engineering group (PEG) in the fall of 1966. Usually, Natlab researchers take their requests to the drafting room, which then guides the PEG's engineers. But Klostermann is a control freak, more engineer than scientist, and he has practical experience in mechanical manufacturing. He knows his machine requires extreme accuracy and wants to make sure everything goes just as it should. So he prefers to talk directly to the people who are going to turn his ideas into something tangible.

When Bouwer presents his first sketches, he discovers that Klostermann isn't your average researcher. Bouwer is used to tossing out his thoughts on the fly: this is what you need, this is what will work, so this is what we'll make. But that's far too slipshod for Klostermann. This stickler for perfection wants Bouwer to justify every decision down to the last detail. He demands an almost mathematical defense, which stuns Bouwer nearly speechless. Klostermann quizzes him for hours on his proposed approach. Bouwer suffers through every minute.

* * *

Just like Klostermann, Bouwer has slowly but surely climbed his way up the ladder. In the fifties he attends Philips' company school, and thanks to his outstanding intellect is allowed to specialize in instrument-making. At Natlab he matures into one of the company's best instrument makers. Fifteen years later he's managing the PEG. Bouwer the engineer will go on to generate patents for ASML, and in the late nineties he'll even make the drawings for the first EUV wafer scanner prototype.

Bouwer is a gentle man, but his vast experience in building instruments makes him immensely self-confident. It's hard for anyone to change his mind. Other scientists he's worked with for years at the lab never argue with him. In his first conversations with Klostermann, he stubbornly clings to his designs and ideas.

However good Bouwer may be, Klostermann finds the designer's methods sloppy. The instrument maker usually hand-draws a few sketches and schematics, says a few words to explain them, then puts his team of engineers to work. To ensure that things get documented, Natlab's house photographer usually creates extended photo collections of all the PEG's creations—after the fact, once the work's been done.

Klostermann isn't satisfied with that. The obstinate researcher refuses to be convinced by a little hand-drawn scribbling, arguments that seem vague in his eyes, and a much too breezy appeal to experience. The practical Bouwer brings him down to earth. "Sure, you can specify a tolerance of one micron on a drawing, but that's of no use to them in the shop," he fires at Klostermann. The two meet every two weeks and often spend an entire afternoon arguing before they reach agreement—but they always manage to reach it. Sometimes one man wins the day, sometimes the other. It's a new situation for Bouwer, but as time passes he grows to value his intense discussions with Klostermann.

* * *

Natlab may be a bastion of unfettered research in the sixties, but it's also an institute steeped in rank and class—and Klostermann is a perfect example. In an era when the Dutch are chipping away at rigid social boundaries, he expects his assistants to call him "sir." They think he's stiff. A second cultural divide is based on education.

Natlab's scientists have earned their degrees at the prominent universities in Delft, Amsterdam, Utrecht, and Groningen—all of them Philips' primary suppliers of talent in the decades after the war.

The hierarchy continues above Klostermann. He and Jonker may call each other by their first names, but Jonker never addresses Klostermann's assistants directly; he doesn't even say hello when he passes them in the hall. Messages for lower employees always pass through Klostermann. Klostermann and Bouwer address each other formally, even though they occupy roughly the same level in Natlab's informal hierarchy.

Klostermann's German roots also give him a courteous side, which he puts to good use. The development of the photorepeater isn't an official project, but using his charm and power of persuasion, Klostermann succeeds in roping a large number of researchers from other groups into helping him build it. Some researchers and assistants spend days or even weeks working for him, in addition to their official duties.

But no one escapes Klostermann's critical side. He can be incredibly difficult. In discussions he's extremely stubborn and slow to capitulate.

His lengthy arguments with Bouwer also continue. How can they make the instrument stable? How can they achieve speed without sacrificing accuracy? What's already on hand at Natlab? In those days computer numerical control and laser-based measurement systems have yet to catch on in grinding, turning, and milling. Machining is first and foremost craftmanship. With a lot of blood, sweat, and tears the PEG achieves a precision of one-hundredth millimeter on a grinder—and that's better than they can manage on the mills and lathes of the time.

But Klostermann and Bouwer are in luck. In the mid-sixties, three technologies become available at Natlab in a short time which make it possible to dramatically improve accuracy: the previously mentioned linear grating measurement system, hydrostatic bearings, and air bearings. None of them are commercially available, but Natlab's job shops can deliver them. The trio

Philips' step-and-repeat camera. The bottom of three lenses is visible, and below them the positioning table for the wafers. To the left of the lens heads are the reflection phase gratings for reading out the displacement in the x and y directions. Below each phase grating is an optical read head.

of technologies turn out to be crucial in giving the photorepeater the desired precision.

Using Natlab's hydraulic bearing technology, Jos de Gast in Evert Muijderman's mechanical group develops a linear slide system that moves almost entirely free of friction: a block of steel that floats on a thin layer of oil. This film, just thirty microns deep, ensures the moving metal parts don't touch one another. An oil pump circulates the fluid at a pressure between twenty and thirty bars. Just as a ship floats on water, so the steel block floats on the oil.

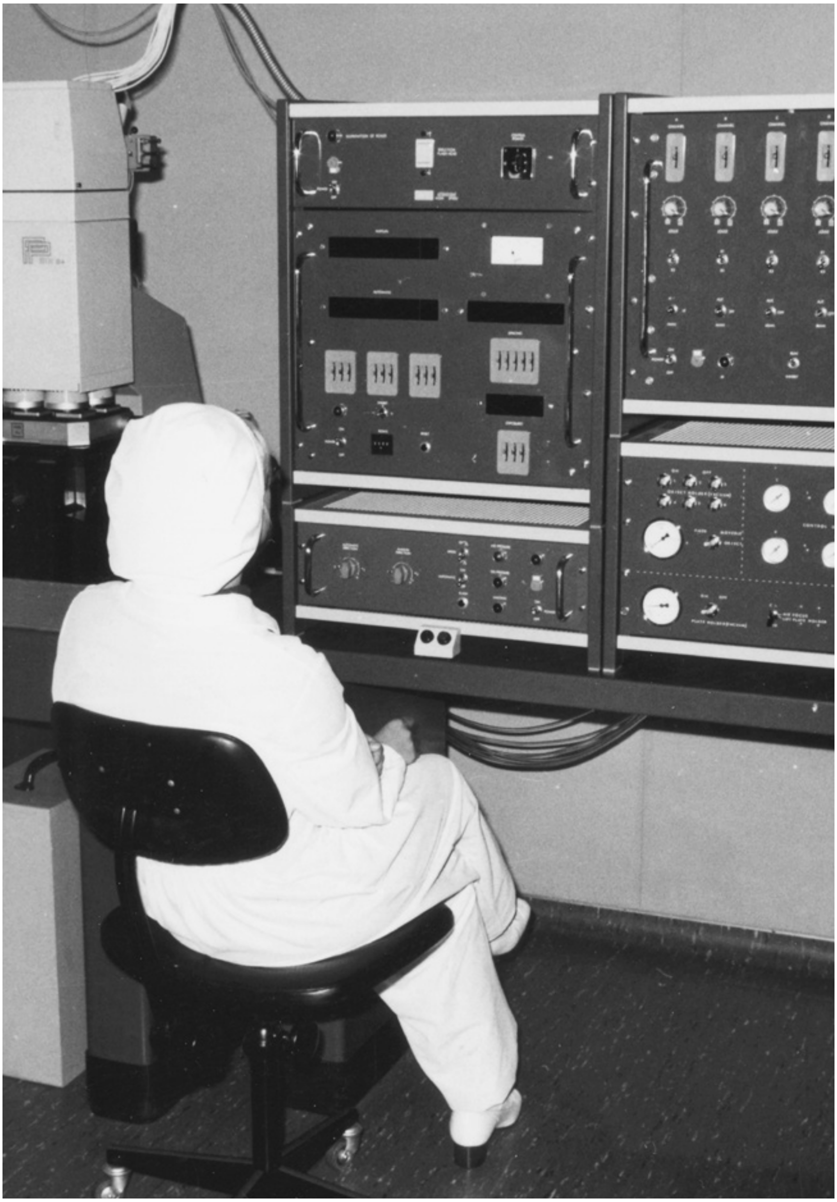
De Gast's carriages don't wear down. They float even when they're not moving, because the oil film is under constant pressure—hence the term hydro*static* bearings. They aren't plagued by stick-slip,[10] the jerk a mass undergoes when it transitions from standstill to motion; a light tick of the finger is enough to get the whole thing moving.

No friction, no wear: it's clear these carriages on hydrostatic bearings are way ahead of their time. Natlab's technology is far superior to the cast-iron slide system the David Mann photorepeater uses. The Mann system is lubricated, but at the microscopic level the metal carriage and slideway do in fact make contact.[11]

* * *

Klostermann learns the importance of a flat carriage from Mat Wijburg, the director of the mask center at Elcoma's chip fab in Nijmegen. Elcoma has bought David Mann's six-barrel photorepeater to make high-frequency transistors for radios.[12] But when the mask center starts using the newest Mann repeater, it's wildly unreliable. The first mask set the device creates has a high yield during chip production, but soon thereafter the quality of the masks plummets.

Wijburg has no idea what's going wrong and replaces the six microscope lenses by better Reichert objectives. That raises the yield, but the unpredictability is still there. Then Wijburg realizes the device may be suffering from thermal effects, making it deform. He plasters thermometers all over the step-and-repeat camera.



Philips' step-and-repeat camera (left) with operator. The dark cabinets on the right house all the control electronics, which were designed and built by Philips Elcoma in Nijmegen.

And indeed: the electric motor turns out to warm the slideway on one side, which causes it to warp. As a result the wafer table doesn't move linearly during the exposure phase, but describes a very mildly circular course. Right after the device has been turned on, the yield is decent, but after a while the repeater produces unusable masks. Wijburg stabilizes the machine by cooling it with compressed air.

But Klostermann and Bouwer are targeting a much higher precision. They're working on a device that can image not only transistor patterns, but also entire microelectronic circuits. They need an accuracy that's much higher than the precision with which the slide systems of the time can be manufactured. The system must deviate by less than one-tenth micron from straight. If a carriage's path is warped, it torpedoes registration accuracy, the degree to which the different masks for a single chip align with one another.

There's always some deformation, but Bouwer discovers the system is so sensitive he can affect the path the carriage takes by tightening or loosening the restraining bolts that anchor the slideway to the granite base. Any change rotates the bottom (fixed) part of the slideway, and the induced tension is sufficient to correct the carriage's rotational deviation by a few tenths of a micron—just the amount they need.

Klostermann and Bouwer determine to their satisfaction that the carriages' lateral deviation is less than 0.03 microns over a length of 100 millimeters. Over a path of 47 millimeters, the carriages rotate less than 0.5 microradians, resulting in a registration error that's less than 0.16 microns. They can live with that.

* * *

Another problem is keeping the projected image in focus on the layer of photoresist on the glass plate negatives. Klostermann has opted to use a numerical aperture of 0.2 to 0.4, fairly large in those days. That gives him a high resolution, and thus sharp images, but it limits the distance over which he can achieve that sharpness (the depth of focus). That's because the depth of focus is inversely proportional to the square of the numerical aperture. That makes it a real hassle to get the patterns into perfect focus on each photographic plate. Klostermann has to find a way to keep the distance from all six objectives to the photoresist within a tolerance of roughly two microns.

The photographic plates are the major disruptive factor. Kodak's ultra-flat version has an out-of-flatness tolerance of ten microns over a length of twenty-five millimeters. He realizes that all six lenses can separately track the glass surface at a fixed distance if they can independently float, like six hovercrafts, on compressed air. He describes it a year later in the *Philips Technical Review* this way: "This difficulty has been overcome by continuously correcting the image distance *b* while the photographic plate is moving, using the local surface of the plate itself as reference level."[13] To do that, he needs a setup in which the lenses have a little bit of play in the vertical direction. Bouwer translates his request into a mechanical solution. He hangs the lenses in a diaphragm, which allows them to flex up and down. The solution is simple, but effective. With a supply pressure of two bars, they can fix the gap height at twenty microns from the photographic plates. The gap height in the air bearing changes by one micron per tenth of a bar, and that makes it easy to keep the distance constant within one micron. Air bearings are the third precision technology trump card from Natlab that Klostermann uses in his imaging device.

* * *

Klostermann also writes about the performance of his six-barrel step-and-repeat camera in the *Philips Technical Review*. The pattern deviation for the six photomasks imaged simultaneously (the registration error) is within 0.1 microns across the entire surface. For photomasks imaged *successively*, the error in alignment can reach 0.25 microns over a field that's thirty millimeters on a side. The system can be equipped with two types of lenses, for a reduction factor of 10x or 4x. The resulting field sizes are 4.3 and 10 millimeters, respectively, with details two and three microns wide, respectively. Within a diameter of 1.6 millimeters from the center, the step-and-repeat camera can even image lines that are one micron wide. These are impressive numbers for the time.

In late May 1967, Klostermann and Bouwer are given the chance to demonstrate their six-barrel step-and-repeat camera prototype at Natlab's research exhibition. The event lets the lab's scientists show off their latest creations and share their visions for the future. A stand at this annual exhibition is an honor only accorded a select company. The members of Philips' executive board traditionally attend to soak up the latest technology.

The crowd around the Philips step-and-repeat camera is immense. Even board member Dick Noordhof stops by. Klostermann and Bouwer gush about their machine's performance, but before they even finish, a table down the way draws Noordhof's attention. On display is a new washing machine with an automatic balancing system. The board member walks off, his whole entourage in tow, leaving Klostermann and Bouwer behind in a state of shock. A run-of-the-mill consumer product that will be rolling off the assembly line by the ten thousand holds greater appeal for the Philips manager than a complex, cutting-edge device for making computer chips.

* * *

But Philips' chip fabs know exactly what to make of the repeater. In the summer of 1967, Elcoma's fab receives the first photomasks that Natlab makes using the six-barrel device. The fab wants a machine of its own, and a month later the lab is already building a second one. In January 1968 Bouwer, Klostermann, and an assistant install this double six-barrel step-and-repeat camera in Nijmegen.[14] The process goes off without a hitch.

At Elcoma they're crazy about the thing. In contrast to the Mann device, the Philips photorepeater isn't plagued by deformation. The temperature-controlled oil flow turns out not only to be the perfect lubricant, but also to keep the machine's temperature stable. Once the original masks, the masters, have been aligned, the photorepeater can image a set of six masks fully automatically in three hours. After that, working photomasks for use in production are contact-copied onto durable chrome with an antireflective coating. The device is far ahead of its time, and director Mat Wijburg receives mask orders from every nook and cranny of the Philips conglomerate. Natlab, too, is a customer. Wijburg's workshop even makes masks for British companies and for Fairchild in the US. The masks sell for $1,400 per set. The step-and-repeat camera is earning the center money hand over fist.

5. **The Violin Maker**

As one of Natlab's section directors, former war refugee Hajo Meyer recognizes the value of the optical precision technology that a few years later will serve as a seedbed for the wafer stepper.

In 1950, Hendrik Casimir at Natlab interviews a recent graduate named Hans-Joachim Meyer. Forty-one-year-old Casimir has been leading Philips' research lab for four years. Before that, he attained widespread renown as a scientist. To the sorrow of many, he turned his back on his academic career to focus on managing Philips' now famous laboratory.

Meyer and Casimir click from the start. They're soon engaged in an animated discussion. In 1949 Meyer devoured Aage Bohr's articles on the characteristics of atomic nuclei. On his advisor's recommendation, he read Casimir's articles on the quadrupole moment—the discovery that propelled Casimir to worldwide fame as a theoretical physicist. Young Meyer is thus well versed in the intellectual legacy of the man across from him. What's more, the material inspires him. His eyes twinkle as he talks about it, and that makes a favorable impression on Casimir.

Meyer's sparkling enthusiasm is all the more impressive in light of the young physicist's background. Casimir is interviewing a twenty-six-year-old man who lost both his parents in the recent war, escaped multiple deportations, and barely survived the concentration camp at Auschwitz.

* * *

Hajo Meyer is fourteen when he hears that he may no longer attend high school in his home town of Bielefeld because he's Jewish. It's November 1938, shortly after Kristallnacht in Nazi Germany. In the panic that follows, Meyer's parents put him on the train to Amsterdam in the Netherlands, which is not yet occupied. He will never see them again.

Young Hajo arrives at Bergen aan Zee and passes through five refugee centers. He's bored to death and finds work at a smithy, but the police send him away. Refugees aren't allowed to work. His mother, who speaks good Dutch, lends a helping hand from Germany. She writes to the Dutch Committee for Jewish Refugees, and her son is subsequently admitted to the Jewish Work Village in Wieringermeer, a vocational training center for refugees. There the fourteen-year-old may attend vocational school, where he decides to learn machining.

It's heaven for the inquisitive teen. Most of the center's residents are adults, among them many intellectuals from Germany and Austria. They're learning a trade so they can emigrate elsewhere: America, Australia, somewhere far away. Meyer befriends a math student from Vienna who tutors him, evening after evening. He also studies physics.

Meyer's crazy about engineering and music, and in the letters he writes to his parents he begs for car magazines. He can't get enough of the world around him. He visits movie theaters and museums, enjoys music, and eagerly absorbs all the knowledge that surrounds him. "I've finished my math book," he writes on October 3, 1939. "Can you send me a new one? If so, make sure you buy a very good one, for self-study."

A convoy of buses disrupts the apparent peace in 1941. A year earlier the Germans invaded the Netherlands, and now they're closing down the work village. They send most of its residents to the Mauthausen concentration camp in Austria. Meyer, now sixteen, is miraculously spared this fate. He's allowed to go to Amsterdam, where he may attend the Jewish vocational school after acing its technical admission exams. By then he's a committed atheist, and he doesn't really fit into the orthodox environment that surrounds him. But the young man's eagerness to learn stands out, catching people's attention, and a loving foster family takes him in.

Through friends, Meyer gains admittance to the Jewish Montessori high school in Amsterdam. There he receives afternoon lessons from the crème de la crème among Dutch intellectuals, all of them

Jewish professors fired from their university positions. His foster parents arrange for a well-to-do Amsterdam family to pay his tuition. Amazingly enough, the Gestapo decides the private Montessori school may hold final exams. After passing them, Meyer goes into hiding in the tiny town of Blaricum. The Germans eventually catch him anyway and put him on a train to Auschwitz.

After a few weeks of backbreaking work in the Polish concentration camp, the Germans order him to the Gleiwitz I railroad labor camp. They need skilled labor, and because Meyer has experience as a machinist, he may repair train cars. It's his salvation. The eighteen-year-old works alongside German and Polish craftsmen—in a prisoner's uniform, but the factory is heated. As a Jew, Meyer's diet is restricted to the meager and tasteless Auschwitz rations, but now and then local Polish girls sneak him some extra bread.

Twice he escapes the gas chamber. The first time, the Germans overlook him during selection. The second time—in January 1945, ten months after his arrival—the advancing Soviets force the SSers to flee, but not until they've marched the camp's residents all the way to the Oder river. "If it hadn't gone the way it did, I'd be glue, or fertilizer, or shoe polish now," Meyer later writes.

At the end of the war, the United Nations Relief and Rehabilitation Administration orders everyone to return to the country where they were first taken. And so a grievously ill and pencil-thin Meyer endures an arduous journey through Odessa and Marseille back to the Netherlands. His parents will not survive the war, but they do write a goodbye letter. They've been taken to Theresienstadt, where Meyer senior succumbs to poor health; he contracted tuberculosis a year earlier. His mother takes a cyanide pill she smuggled in with her, after she hears she's been ordered to Auschwitz.

After the war, the younger Meyer's excellent final exam scores win him a scholarship[15] to study physics at the University of Amsterdam. Because there's no money to pay for further study after he graduates, his professor tells him, "You go see Casimir."

* * *

The misery in Hajo Meyer's life isn't enough to break him. The twenty-six-year-old physicist is radiant, bristling with energy, and he talks just as enthusiastically about nuclear spin resonance as about art, music, and cars.

Casimir sees a kindred spirit in Meyer. "Well," he tells the young scientist, "it won't be easy for you at Philips as a theoretical physicist. So spend half your time as the editor of the *Philips Technical Review*." And so Meyer is introduced to a renowned institution: a scientific journal published in four languages that enjoys global fame. He travels the world with his little notebook, writes a lengthy article each month, and becomes familiar with Natlab's every nook and cranny.

Casimir wants the young researcher to gain a wide range of experience and pushes him toward experimental work, which at Natlab is considered more valuable than theory. So Meyer works in the cryogenics group, among others, and his manager tasks him with writing the very first reports on transistors. Meyer also visits AT&T's Bell Labs in Murray Hill, New Jersey, where he and section director Haaijman receive training in the use and manufacture of transistors (appendix 1).

After that, Meyer teaches other Natlab researchers the ins and outs of transistors and how to make them. To share that knowledge with Japanese colleagues, he also spends ten weeks at Matsushita, a company with which Philips has close ties.

* * *

The bond between Casimir and Meyer grows. Natlab's director is fond of the energetic, upbeat young man and he feels a kinship with the young researcher who, like himself, studied theoretical physics. Casimir regularly asks Meyer to visit him at home in nearby Heeze. Sometimes for a glass of wine, sometimes for dinner with their wives. They talk about Casimir's time with Niels Bohr in Copenhagen, about music, and about philosophical questions.

Meyer goes on to lead the lab's gas discharge group for a few years, and then in 1964 Casimir asks him to succeed Eddy de Haan as the director of the lab's vacuum tube research section. In addition to vacuum technology and electron guns, he'll also be responsible for optics.

As a section director, Meyer is exposed to the turmoil surrounding Hendrik de Lang, one of the few optical engineers at Natlab. De Lang studied under Frits Zernike, the inventor of the phase contrast microscope. He's an exceptionally bright and creative researcher. His specialty is the conversion of optical signals to electrical ones, a step that's crucial in signal processing and signal-based measurement and control.

De Lang is not an easy man. At the lab he's known for being infinitely stubborn and difficult. By the time Meyer becomes his boss, fifty patent proposals are stacked on De Lang's desk. None of them have ever been submitted, because the recalcitrant engineer is on fighting terms with everyone in the patent department.

Eddy de Haan has been De Lang's manager for years, and the problem weighs heavily on his shoulders. It's one of the first things he brings up while he's training Meyer to take over. "That De Lang's a very bright kid. But he picks a fight with everyone. See what you can do with these, because they're important," De Haan says as he hands Meyer the patent proposals.

One lovely weekend day that summer, Meyer settles into a patio chair to look through the pile. He's deeply impressed by the work. Meyer is interested in optics, but it's his experience as a craftsman and machinist that make him realize that machines using De Lang's inventions could achieve much greater precision. The section director is determined to protect that body of ideas for Philips.

Meyer's understanding of his optical patents earns De Lang's respect. All the patents are ultimately filed. A few years later, Meyer will create a research group that combines optics, precision mechanics, and photochemistry. It will turn out to be a crucial decision, one that seeds the ground for the development of the video long-play disc—the predecessor to the compact disc—and the wafer stepper, the lithographic chipmaking machine.

As the sixties progress, Meyer and De Lang develop a friendship. On a personal level, the director and the group leader share a love

Hans-Joachim "Hajo" Gustav Meyer

for music. Both play the violin. Meyer discovers that De Lang is a talented violin maker. *I bet I can do that, too*, he thinks. His experience as a machinist serves him well there. After he retires in 1984, he immerses himself in the craft and makes some fifty instruments, so good he's even able to sell them to professional concert violinists. He also publishes scientific articles on acoustics. Accordingly, many a Natlab researcher will later refer to Meyer as "the violin maker."

Part 2

A License to Print Money 1970–1975

6. **A Born Engineer**

Herman van Heek and Gijs Bouwhuis end up sharing an office—and their shock at how wasteful chip production is.

If anyone can appreciate the engineering that's gone into the photorepeater, it's Hajo Meyer. Just like Frits Klostermann and Ad Bouwer, Meyer knows what it means to build something with your hands. When Casimir appoints him section director in 1964, the multifaceted Meyer looks in wonder at the mechanical and optical brilliance around him. The air bearings, the hydrostatic carriages, and Hendrik de Lang's optical measurement system: it's a gold mine of precision technology expertise. Meyer admires how Klostermann and Bouwer are using Natlab inventions to build ingenious photomask production machines.

In the late sixties, Meyer reorganizes the research groups under his command. He pulls lithography out of the photochemistry group and moves it to the optics group.[1] He tags Frits Klostermann to head up the group developing the Plumbicon video camera tube.

On November 1, 1969 Herman van Heek and Gijs Bouwhuis take over Klostermann's old tasks. Bouwhuis worked in De Lang's optics group for years, but for Van Heek optics is completely new territory. The two will provide scientific support to the lab's photomask production team.

There are no big new challenges in the last months of 1969. The two focus mostly on the mask department's daily questions and problems. In those days, the ten women and three men there are busy making masks for printed circuit boards, cathode ray tube electron optics, and chips. Demand is high.

* * *

Herman van Heek comes from a Dutch family that made its fortune in the textile industry. Young Herman grows up in Amsterdam and later moves to Leiden, where his father has gotten a job as a professor of sociology. Herman's inventor's genes come from his mother's side. Her family boasts three engineers, including the famous professor Felix Vening Meinesz, the inventor of an optical instrument to measure gravity.

Van Heek studies physics at the university in Leiden and eventually ends up working at low temperatures in the Kamerlingh Onnes Laboratory. Seven of his eight predecessors found jobs at Philips, so naturally he calls the human resources department in Eindhoven at the end of his experimental years. An interview is soon scheduled with Natlab's various directors, and in 1964 he starts work there.

Where Klostermann is a disciplined, meticulous researcher, Van Heek and his Beatles haircut waltz much more frivolously through life. In his first five years at Philips, he discovers he doesn't have much affinity for scientific heavy lifting. The fervor with which some of Natlab's researchers stake out their territory isn't his thing. In fact, it repels him.

In contrast to Klostermann, Van Heek doesn't feel much for hierarchy and he isn't concerned with status—probably because, as a member of a wealthy family, he's used to moving in well-heeled circles. The newly minted researcher attends an activity for young academics early in his tenure at Philips, and Frits Philips recognizes him while he's filling his plate at the buffet. "So, Van Heek, I hear your family's factory has gone belly up," the founder's son calls out from down the line. The whole room hears his challenge. But Van Heek doesn't lose his cool. "The factory didn't go belly up," he calls back to the Philips heir. "My family decided they wanted to stop.[2] But our textile company lasted for eight generations; we'll see how far yours manages to get."

* * *

When he arrives at Natlab in 1964, Van Heek dives into a wide range of topics. He puts all kinds of semiconductor materials under the microscope, in a quest for computer memories that can provide an alternative to the magnetic-core memories that are still being manually assembled by women in those days. In Leo Tummers' group, he also works on sensors to measure action potentials in the brain, heart, and muscles. After that, he leaves to spend a year at Mullard Research Labs in England, where he puts together his first instrument: a near-infrared spectrometer to measure air pollution. When he returns to the Netherlands, his work in the gas discharge group is a flop. The scientific research bores him to tears. Atomic absorption, fluorescence measurements, the Zeeman effect: *whatever*. When he's feeling peevish, he ridicules his fellow researchers' behavior and their overblown egos. He has a hard time taking them seriously.

Van Heek just isn't cut out for research; he's a born engineer. He's much happier building something, such as the spectrometer he made at Mullard. In his view, Mother Nature is like a giant cupboard filled with physical effects and phenomena, and he derives pleasure from opening the right drawers to solve his problems.

When Van Heek talks to section director Meyer about his woes, Meyer advises him to apply for the position that's opened up at the mask center. And so the researcher-slash-engineer ends up in Piet Kramer's optics group, where he's put in charge of an applied department, one whose primary activity is photomask production. In those days nearly everyone at Natlab is working on miniaturization, and the mask department can't keep up with the huge demand for photomasks for all kinds of applications. The daily work of making the masks falls primarily to the assistants. As the team's scientific conscience, Van Heek immerses himself in the special problems that Natlab researchers and the production people in the industrial divisions bring to his doorstep.

Around 1969, Van Heek sets aside the rigor with which he reported to Natlab's management in his early years. He's matured into a self-confident engineer, one who doesn't see the point in writing more than two sentences to summarize his quarterly results for his bosses—he knows full well that Kramer and Meyer aren't interested in scientific ego trips and detailed research reports.

Van Heek likes to keep things light. He sees no need for pomp and gravity. In his reports, he even goes so far as to add humorous comments and wittily worded criticism. One of his first reports in the optics group ends with this comment: "The fact that my current lab space is a paltry eighty-five square feet and has no water or vacuum supply makes me feel like a gypsy every time I push my traveling setup down the hall from the water to the vacuum line."

* * *

His first year in the optics group isn't very exciting. Van Heek has to make sure the mask department has state-of-the-art instruments and technology, but the photorepeater is so advanced he has little need for anything else in terms of imaging. He decides to find out more about the steps that follow, when the photomasks are actually used in production, and what he learns makes him fall out of his chair. The chipmaking process turns out to be extremely, enormously wasteful.

By that time, chips consist of ten or so layers. Each layer needs its own photomask, but after roughly ten contact prints, the masks are damaged to the point of being unusable.[3] That means that for every wafer that rolls off the line at the fab in Nijmegen, a photomask gets tossed in the trash. That's a shame, but the worst part is that barely any of the chips on the wafer work. After just a few print runs, the masks are already riddled with errors. In Philips' chip fabs, they're happy if one in fifty ICs for a new design works. *There has to be a better way*, he thinks. That thought launches him on a several-month quest to find alternatives.

* * *

Like his officemate Van Heek, Gijs Bouwhuis isn't a born researcher. But Bouwhuis comes from a very different background. He doesn't have a university education. After attending his local vocational school, Bouwhuis joins the army in 1948, and after that he temporarily runs his ailing brother's liquor store. Washing bottles, keeping the books, that kind of thing. After his brother recovers, Bouwhuis takes the first job he can find: well-paid administrative work at the Netherlands Trading Society.

He's almost forgotten he also applied at Philips, but after a few months at the bank in Amsterdam an invitation lands in his mailbox. His engineer's heart starts to beat faster, and he decides to travel south to Philips' HR department for a career test. There they have a surprising message for him: they think Bouwhuis is best suited to be an interpreter. But the down-to-earth young man doesn't budge: he wants to be an engineer. In the end they hire him as a Natlab assistant in 1951.

In Piet van Alphen's optics group, Bouwhuis gets to play with light. He thoroughly learns the ropes in his first years there. He takes evening classes at the company's internal engineering school and is given the time to immerse himself in the material. He spends months in the library—at Natlab in those days, it was no problem at all to spend your work hours getting up to speed on the available knowledge. He devours technical articles and books, anything that covers optics—often in French, because at that time France is the stronghold of optical scholarship. Bouwhuis is given the opportunity to absorb it all, and to work through the math and physics that underlie optical phenomena. Under Van Alphen and later De Lang, he matures into Natlab's leading optical expert. He will make vital contributions to the video long-play disc—the predecessor to the compact disc—and to the wafer stepper.

* * *

Van Heek has witnessed the horrors of production at the Elcoma fab, and optical engineer Bouwhuis is also well acquainted with the problem's thorny nature. The appetite for smaller and smaller structures is insatiable, and at Natlab they've been knocking on his door to feed it for years. He's learned the limits of contact printing better than anyone. He calculates how close together masks and photoresist must be printed to minimize the problems caused by refraction along the edges of the microscopic details.

Because the photographic plates and the wafers are never perfectly flat, the fab is also plagued by Newton's rings, an interference pattern created by the reflection of light between two surfaces. Pressing down hard is a remedy for both problems, but it never works 100 percent. There are just too many irregularities. By this point Bouwhuis is completely fed up with contact printing. He knows the technology is on its last legs for chip fabrication. Now he and Van Heek need to come up with new solutions. They spend months discussing adjustments to the existing technology. They weigh their chances of success. Should they invest their energy in an automated inspection device that can quickly locate defects in the masks? Should they apply oil between the photomasks and wafers during contact printing? Bouwhuis thinks the latter idea is just a kludge.

At some point, the duo has nowhere left to turn. There are no more stopgap measures left to extend the lifespan of contact printing. The only solution is to move from copying the chip patterns at one-to-one scale to projecting them in miniature directly onto the silicon. It's the obvious answer, but its implementation is sufficiently complex that Van Heek and Bouwhuis haven't dared to try it so far.

That's because an extremely difficult problem rears its head. It takes several successive imaging rounds to make a chip, and all those exposures have to overlay one another very precisely. But how does the machine locate the exact placement of earlier exposures? Those earlier images are now hidden under a new layer of photoresist. That, in a nutshell, is the hellish puzzle that Van Heek and Bouwhuis must solve.

Fortunately, their predecessor Klostermann has already laid much of the groundwork. The brilliant thing about his six-barrel photorepeater is that the masks it generates align perfectly with each other. That's essential in the chip production process: patterns for each layer of the chip that line up accurately. At the fab, it's usually women whose hands do the work of very precisely lining up the glass and silicon and then exposing them. Van Heek and Bouwhuis are faced with the challenge of achieving that same precision, but their machine has to locate earlier patterns beneath the photoresist and project the new pattern onto them with immense accuracy—and then repeat that feat, many times in a row.

* * *

Van Heek discusses it with his bosses, Kramer and Meyer. They agree there's no point in trying to further improve the contact mask method. The idea to project directly onto silicon isn't all that crazy. Klostermann's photorepeater was a giant step forward for chip production a few years earlier. It enabled Philips Elcoma to transition from making individual transistors to making integrated circuits. Van Heek suggests that CERCO, the optics supplier for the photorepeater, could also help Natlab create optics that image the circuits directly onto the silicon.

Van Heek's idea to keep progressing down the optical path first embarked on by the photorepeater makes sense. Kramer and Meyer know that Philips' chip research and production efforts have both taken fantastic strides forward using Klostermann's device. Looking to the future, a machine that projects directly onto silicon makes sense both scientifically and commercially.

Kramer and Meyer also know that at the start of the sixties, Philips expressed its intent to become a global force in computers and transistors. Ten years later, it's obvious the company's future depends on integrated circuits. The companies at the forefront of chip technology can achieve economies of scale and minimize the cost of adding new features to their products. Philips has plenty of those: not only TVs and radios, but also switchboards and computers. Chips are the future of growth, so that's where companies are investing.

It's no surprise, then, that the Natlab managers' eyes start to shine when Van Heek and Bouwhuis present their ideas. The discussion is brief, the costs immaterial. "Go for it," they tell Van Heek.

7. **Travel Companions**

Herman van Heek and Gijs Bouwhuis draw inspiration from a trip to the US, where they encounter a vibrant semiconductor industry.

Herman van Heek and Gijs Bouwhuis have been in the optics group for a year when, in January 1971, they travel to the US to attend the first Society of Photographic Instrumentation Engineers (SPIE)[4] conference in Las Vegas. Van Heek is scheduled to give a presentation for Natlab, and he's dreading it. To him, events like these are just scientific pissing contests: symposia where researchers show everyone how brilliant they are.

By now, Van Heek and Bouwhuis have a pretty good idea of the options for exposing silicon without contact. And so the travel companions take full advantage of the opportunity to explore lithographic techniques in the US. They know that Perkin-Elmer and Ultratech are working on noncontact machines that can expose an entire wafer, with all its circuits, in one go. These one-to-one projection machines don't reduce the image; the device Van Heek and Bouwhuis have in mind will. The two men soak up inspiration at every turn.

* * *

In America, Van Heek and Bouwhuis encounter a vibrant semiconductor industry overflowing with entrepreneurial activity. The sixties have proven that chips provide virtually unlimited opportunities in countless markets. Many startups and established firms are jumping on the new technology, offering expertise, materials, equipment, and engineering services.

Miniaturization is the driving force behind the storm of developments. The appetite for larger memories and greater computing power is insatiable. Chip manufacturers are pulling out all the stops to print thinner lines and to squeeze the highest possible yield from their production process.

Whether it's the Americans, the Europeans, or the Japanese, everyone is plagued by the limitations of contact printing. Thinner lines also make the contact masks more vulnerable and cause more downtime. It's a complex balancing act, in which chip manufacturers are constantly tweaking their machines to push them to their limits. But it's clear to everyone that contact masks have passed their prime. The entire industry is urgently looking for an alternative.

The major chip makers—IBM, Fairchild, Texas Instruments, and AT&T—are all working on the problem and developing their own production equipment. But unlike in Europe, where the major labs at multinationals such as Philips, Siemens, and Telefunken drive progress in integrated circuits, the US is home to a thriving ecosystem in which small, innovative chip companies also play an important role.[5] Chip prices are falling, even as demand grows.

Particularly the small, rapidly growing semiconductor companies in the US need all their focus on development and production. So they knock on the doors of other companies for their chip machines, and Silicon Valley soon gives rise to a healthy market for production equipment in addition to a thriving chip industry. Both independent startups and established names jump on the opportunity. A new furnace, etcher, or evaporator is easily constructed.

But lithography is another story, even for companies with generous budgets. Just as the military provided the driving force behind semiconductor and chip development in the fifties, so the American defense department is the engine driving lithographic innovation in the sixties. Halfway through the decade, the growing issues with contact masks are evident, and in June 1967 Wright Patterson Air Force Base contracts Perkin-Elmer to develop a system to bypass contact printing. They want a device that will directly project the micropatterns onto a layer of photoresist on the wafer without making contact.

At that time, Perkin-Elmer is a leading American company. The instrument maker in Norwalk, Connecticut has extensive experience in custom optics for scientific work and the defense industry. The US Air Force wants a system that can image an entire mask containing hundreds to thousands of chip patterns in its entirety, one-to-one, onto a two-inch wafer—a disk smaller than the foot of a brandy snifter. In addition, the projector must be able to image 2.5-micron details.

Perkin-Elmer succeeds in quickly building the Microprojector—a formidable accomplishment for the time. The instrument can image 300 million picture elements—pixels—on a two-inch wafer, sufficient to provide the requested resolution of 2.5 microns. The Air Force is satisfied, but the alignment system makes the device shockingly expensive and Perkin-Elmer doesn't even try to commercialize it.[6] In addition to Perkin-Elmer, Ultratech has also built a machine for noncontact one-to-one wafer exposure. Lithographic developments like these have already permeated the American chip industry by the time Van Heek and Bouwhuis cross the Atlantic. During their trip, they discuss the Microprojector with companies such as General Electric and IBM.

8. **Technical Note 105/71**

Herman van Heek and Gijs Bouwhuis create the world's first wafer stepper. Van Heek is the system architect; Bouwhuis develops the brilliant aligning principle that puts Dutch lithography on the global map in the decades that follow.

During their trip, Herman van Heek and Gijs Bouwhuis hear that Perkin-Elmer's first attempt hasn't made it to market. Most of the Americans they meet tell them they no longer believe in optics. They say they've pinned their hopes on electron beams, which enable the direct writing of extremely small details.

Van Heek and Bouwhuis nonetheless continue work on an optical reduction projector. If they succeed in directly reducing an image onto silicon, they'll have the superior technology. All the problems with damaged contact masks will be a thing of the past. What's more, a noncontact reduction phase will also reduce errors and dust on the mask. They'll end up so small on the silicon that they usually won't cause any problems—and that will boost chip yield.

Their device must also be able to position the silicon wafer down to a fraction of a micron in order to expose the next pattern with extreme accuracy. That alignment is a major problem. Some ten successive exposures must overlay precisely.

The big question is, how will the machine locate the exact right spot on the silicon wafer? It's not an easy problem to solve: any mark or other pattern they make on the wafer will end up barely visible, thanks to all the intermediate chemical and physical processing. Add to that the fact it will be covered by a new layer of photoresist, required to expose the next pattern. Is it even possible to build a device that can project all the chip patterns, one after another, step by step, onto the wafer? And do it within a tolerance of a few tenths of a micron?

In the seventies, many major chip manufacturers are working on machines to tackle this problem. Almost all of them decide to use some kind of black-and-white feature on the wafer to determine location. But Bouwhuis comes up with a solution that's far more robust. He already has years of experience with phase gratings, which are used in displacement measurement systems such as the carriages of Klostermann's photorepeater.

Van Heek is also familiar with the technology. At the lab he runs a mini-factory that makes the scanning heads for devices like the photorepeater. These heads read a code composed of four-micron-wide dashes. The principle was conceived by Hendrik de Lang's group and refined by Bouwhuis.

A phase grating looks a little like a field of asparagus, with tiny mounds that are a quarter-wavelength high (the wavelength of the light used to read the gratings). Using optical polarization and phase contrast, a sensor can read the dashes. Van Heek and Bouwhuis are quick to see how these gratings and the associated optics can solve their problem. They realize that phase gratings are capable of surviving every step of the chipmaking process.

The answer is obvious to them. If they can deposit a mini-asparagus bed onto the wafer and align the mask and everything else using a polarized laser, then in theory they've solved their problem. The only disadvantage of phase gratings is that the required optics are extremely complex. But they don't hesitate for a second. They start experimenting with patterns of lines etched onto the wafer and similar patterns in the mask.

With his experience in optics, Bouwhuis knows he can demonstrate his principle in the lab, but he seriously doubts whether the technology will hold up in a demanding environment. "Here at Natlab it's easy to build it," he tells Van Heek. "But once the thing makes it to the fab, I'll be worried. There's no guarantee this kind of system will survive in those conditions."

* * *

In retrospect it seems simple, but in 1971 an optical solution for patterning chips is out of sync with the times. The Americans are excited about writing with electrons—it's slow, but it's significantly more accurate than optical imaging. And everyone expects the throughput of electron-beam lithography to improve.

Bouwhuis doesn't know much about electron beams, but all the glowing stories about e-beam patterning sow seeds of doubt. He seriously wonders whether it's worth the effort to start building a complex optical device for chip production. "If things keep going this way, then e-beam will be a serious competitor and we'll have done all this work for nothing," he tells Van Heek.

They conclude that whatever else happens, an optical device will need to be much faster than e-beam writers. Otherwise the machine will simply be too expensive and e-beam will definitely leave them in the dust. Across the full production process, wafers will have to run through their device ten or so times. Each time, the machine will create hundreds of patterns step by step. If their process isn't fast, they'll stop working on it.

And so Van Heek and Bouwhuis spend months exchanging thoughts and ideas. They sit in an office just two windows wide, desks side by side, looking out at the trees. There's just enough room for a file cabinet on each end.

Bouwhuis has a quiet, reserved personality, but he's turned himself into a walking encyclopedia of optics. Van Heek is the free spirit. Unhindered by any knowledge of optics, he suggests the craziest things. "Gijs, what if we put a ten-to-one reduction lens and a one-to-ten magnification lens back to back, to get one-to-one?" When Bouwhuis hears that kind of silliness, he gives Van Heek a short lecture and sends him to the library, where he can bring himself up to speed.

They don't talk to each other much. And when they do, it's about engineering. Bouwhuis isn't much of a talker to begin with, and he has little desire to be the center of attention. Van Heek avoids personal conversations with colleagues, mainly because he's worried they'll lead to disagreement, something he passionately detests.

After months of deliberation, the moment arrives. In May 1971 Bouwhuis, Van Heek, and Ad Bouwer describe in Technical Note

105/71 why they prefer to use optical step-and-repeat projection with image reduction over exposing an entire silicon wafer at one-to-one scale. After listing their deliberations, they write that they'll need $70,000 to build a prototype machine: $45,000 for the optics and the rest for the electronics and mechanics. "The optics group at Natlab prefers a repeater to a one-to-one projection system," the trio writes. "The crucial difference between the systems is the ability to meet future needs."

They soon have a name. Klostermann's photorepeater burns patterns onto glass plate negatives; Van Heek and Bouwhuis's machine projects those patterns directly onto silicon, so they call it the Silicon Repeater 1.

Van Heek, Bouwhuis, and Bouwer propose a system that combines the principles Natlab previously developed for the photorepeater and another system, the Opthycograph (appendix 5). The movement is "stop and go," they write. Their Silicon Repeater won't have a flash lamp, but a thousand-watt mercury lamp. The light will strike the wafer through a mirror condenser, mask, and lens. The lamp will burn continuously; a shutter mechanism will carefully dose the flashes.

Just like Klostermann, Van Heek and Bouwhuis are outsiders at Natlab. They don't act like researchers, but more like developers or engineers who want to solve a practical problem: namely, how to project patterns with details a few microns wide onto silicon wafers as fast as they can. Van Heek is the systems engineer and architect, Bouwhuis the optical expert.

One of the most difficult points is aligning the mask and wafer. As noted earlier, the principle of noncontact optical projection is more or less obvious, but the alignment problem is so intractable that Van Heek and Bouwhuis have spent a long time not wanting to consider it as a serious route to mass production. It's like landing on the moon. They know it can be done, but it'll take insane effort to make it happen. The challenges facing the device they want to make are considerable: it needs mercilessly high precision, and it also has to be reliable and quick.

For example, there are stringent criteria for the lens. To project the exposures for ten or more layers in precise overlay, the lens must be free of distortion.

But it all starts, literally and figuratively, with alignment. Before the machine fills an entire silicon wafer with patterns, it first has to know exactly where the wafer is. Then the wafer's coordinates have to be brought into exact agreement with those of the photomask. And it has to happen to an accuracy measured in fractions of microns. That isn't something you can do by hand; that would take far too much time.

Only then does the exposure process truly begin. Once the device knows precisely where the wafer is and knows the coordinates for every previous exposure, it must automatically expose the photoresist across the full silicon wafer. That means that before each exposure, the Silicon Repeater must position the table holding the wafer with an accuracy of a few tenths of a micron. The trick is to have the machine first discover roughly where the wafer is. They need coarse control to bring the alignment mark within range of the laser beam. Then the device has to align the marks on the wafer and the mask with extreme precision. Once it's done that, it knows exactly where the wafer is. Then it can fill the silicon with the next round of patterns.

Van Heek and Bouwhuis spend months discussing how to implement it, down to the smallest detail. In the beginning their boss Kramer joins in; he regularly pops into his people's offices to ask how things are going. The alignment marks aren't the only tricky point; there's also the optical path, the trajectory the laser must travel between the marks on the mask and the wafer. At some point one of them says they should have the positioning laser run through the projection lens: "It needs to go through that lens, not a separate one."

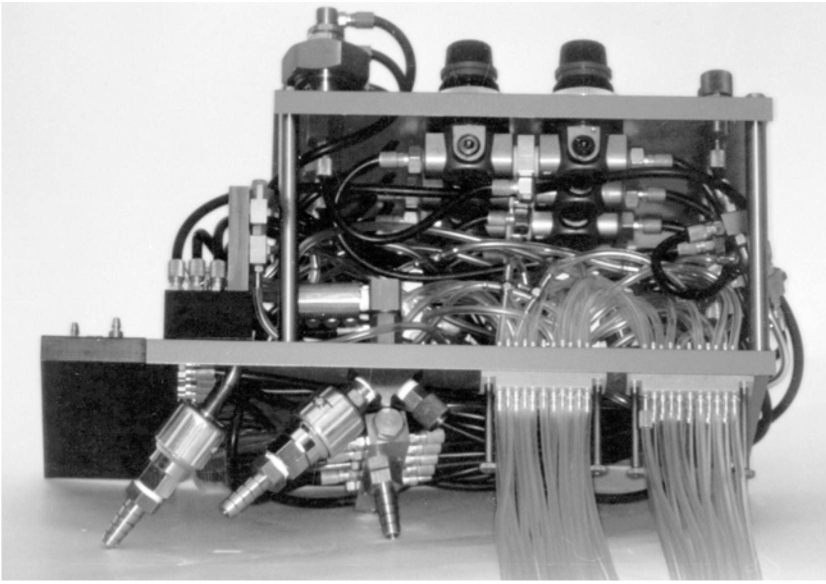
In the seventies, all their competitors are using separate optical paths for projection and alignment. This approach has a number of challenges. For one, it's vital to firmly anchor the two lenses to each other. Even then, errors always creep in. The idea to send the laser through the imaging optics is simple, but groundbreaking. Bouwhuis is the one who works it out and later authors the patent for through-the-lens alignment. The invention is one of the crown jewels that Philips will later transfer to its lithography joint venture with ASM International: ASML.

The combination of phase gratings and through-the-lens alignment is so revolutionary, so progressive and advanced, that it will keep ASML ahead of the competition for decades. Along with the linear motor—later conceived at Natlab—it forms the technological foundation for the company's success. It's one of the key inventions that will enable ASML to conquer the global market and grow into the major provider by far of lithographic processes for chips after 2000.

The projection system isn't the only optical challenge facing Van Heek and Bouwhuis. The process also involves a great deal of handling and precise movements. For example, the machine must automatically place the silicon wafers onto a positioning table (the same way you slide a pizza into an oven). The stage must grip the wafers using suction and then place them under the lens with extreme accuracy. Speed is important. Van Heek and Bouwhuis know that's the only way they can compete with electron-beam technology. A simple calculation tells them that the exposure itself takes up just a tenth of the total duration, so the place where they need to save time is in the handling and mechanics.

* * *

Van Heek's sure of it: to build what he lovingly calls his machine, he needs Bouwer. At the time, Bouwer is considered by far the best mechanical engineer at Natlab, and probably in all of Philips. From his first days as a young rookie at the Philips company school, he's fought for his place as the firm's top designer. He's an inventive man who knows better than anyone how to solve mechanical problems and how to translate engineers' needs into a finished product. Nijmegen, Hamburg, Caen: everywhere they have one of Natlab's photorepeaters, they gush about Bouwer's craftsmanship.



Part of the Silicon Repeater 1's pneumatic system. Many of the device's features, even moving the wafer table into horizontal position, were effected using compressed air.

Van Heek encounters a self-confident man who, at six-feet-four, is at least as tall as he is. Bouwer's superstar status allows him to be choosy. He hasn't always enjoyed previous collaborations, and when Van Heek knocks on his door, the designer spells out his requirements. "Listen," he says once he's heard Van Heek's speech. "If you want me to make it happen, then we'll do it my way. I don't want you to meddle with the wafer handling; you just stick to the optics." Van Heek isn't one for confrontation; besides, he wants the best designer to build his machine. He instantly agrees to Bouwer's conditions.

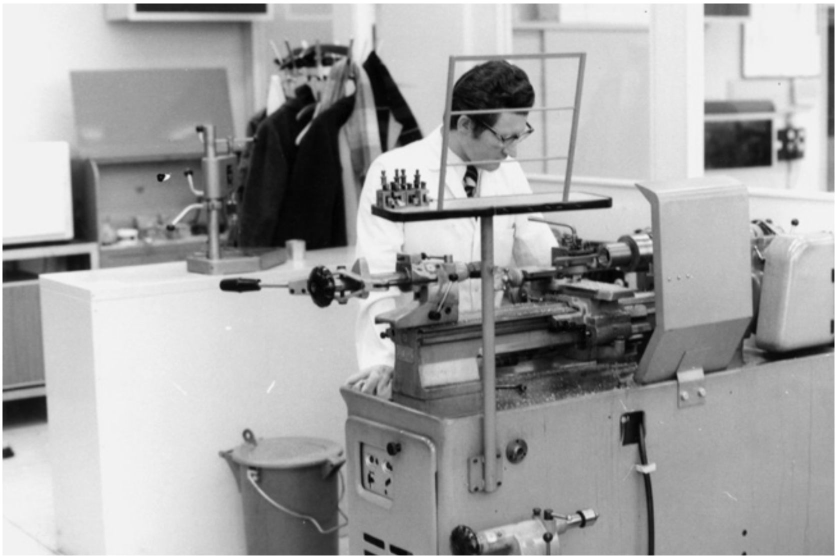
Bouwer wants to use compressed air for much of the machine's movement, a choice that isn't obvious. Van Heek's colleagues pepper him with uninvited counsel. "What do you mean, compressed air? You need to solve that with electronics!" But Van Heek stands squarely behind Bouwer. Natlab has an electronics design group, but it's a tiny, raucous, headstrong bunch. Van Heek has also considered whether Elcoma's electronic engineers in Nijmegen could do it, but he doesn't think he understands electronics well enough to guide development from afar.

* * *

So the partnership with Bouwer is practical. Van Heek wants to build a working prototype quickly, and the designer can deliver fast; he has a large number of standard components he can choose from to build the pneumatic controls, and that gets the project off to a running start.

There are other arguments for using compressed air. In the early seventies, Natlab is actively researching pneumatics. It's the glory days for Philips' factories, which can't produce color televisions fast enough, and using compressed gas for control shows great promise for automating production. Bouwer has a good relationship with Natlab's pneumatics group, and for them the Silicon Repeater is the ideal opportunity to demonstrate the advantages of compressed air. They promise to give him all the help he needs if he uses their technology.

And that's why the first Silicon Repeater's wafer handling system isn't made of electronic and electromagnetic components, but chiefly of pneumatic ones: a control system made of air valves and hoses to do all kinds of things, from grasping to positioning, clamping, releasing, and transporting.



Gerard Antonis at the lathe where components for the Silicon Repeater 1 were made. Antonis was Ad Bouwer's most talented instrument maker. Among other things, he was tasked with making the custom bearings to horizontally position the wafer table.

9. The Silicon Repeater

A wafer stepper is a license to print money, and the engineer tasked with building one isn't going to worry about the cost.

Natlab isn't capable of making advanced optics, but for everything else the research stronghold is a technological cornucopia. Researchers have access to top scientists in every technical discipline, as well as to the best glass blowers, machinists, instrument makers, and other craftsmen. The engineering crème de la crème stands ready in well-equipped workrooms to help build the wildest setups.

In theory, at least. In practice, not everyone is leaping to help. Herman van Heek discovers that fact during his attempts to have Natlab produce the control electronics for his wafer stepper. The electronics researchers are less than enthusiastic. The eggheads don't want to get their hands dirty. They prefer to concentrate on fundamental semiconductor research. They turn up their noses at something as banal as a machine control system, because that means drafting specifications and making printed circuit boards. A scientist can't make a name for himself doing that.

When Van Heek knocks on the door of the lab's electrical shop, they aren't interested in the job, either. The boss sniffs at the project; his assistants are already occupied, and he doesn't think much of Van Heek's proposal for the electronics design.

Van Heek doesn't let that discourage him. He's having a great time with his project, because he has full control over every decision. The solution for the machine's control system is soon found, at Elcoma. Just as for Klostermann's photorepeater, the electronic mechanization group in Nijmegen is happy to help. Natlab's directors discuss it directly with Elcoma's management. In exchange for a few Silicon Repeaters, Elcoma will build the control system, a six-feet-high rack filled with electronics. They're happy to take charge of future maintenance on it, too.

* * *

There's a good reason why Elcoma's electronic mechanization team is so eager to work on the Silicon Repeater. In chip manufacture, power is shifting from the people who make the machines to the people who design the production process—a new phenomenon inside Philips.

In the early seventies, Philips is still highly hierarchical. In the industrial divisions, the mechanization team is in charge of production resources. They develop the machines and equip the factories. Not-invented-here syndrome is strong. So Philips makes its own light bulb assembly carousels, its own glass-blowing machines for cathode ray tubes, its own fluorescent light assembly lines hundreds of yards long, and its own pick-and-place machines for mounting electronic components onto printed circuit boards.

But in the chip factories, the process engineers are chipping away at the dominance of the technical support teams and the machine designers. The balance of power is shifting. In the wafer fabs, it's no longer the machine designers who determine yields, but the guys with their hands on the controls. They know how dozens of processing steps affect one another, how to use the available machines to achieve a high yield. Complexity is growing in chip fabrication, and all the steps have to be perfectly attuned: applying photoresist, exposing, developing, etching, oxidizing, evaporating.

At Elcoma, too, power is shifting from the mechanization team to the engineers who set up the production process. More and more often, the process engineers are using specialized machines built elsewhere. And they're pleased with the results. When they buy outside of Philips, they also get customer-friendly service to boot. They're no longer dependent on surly colleagues, Philips' bureaucracy, or Natlab's arrogant researchers.

But in the early seventies, Elcoma's mechanization group is still a fount of cutting-edge expertise. They're using computers, writing software, and developing custom electronics. When they get Van Heek's request from Natlab to develop the control electronics for an entirely new lithography machine, they seize the opportunity. It's a way to put themselves back in center stage.

After the deal, Elcoma even stations an engineer in Van Heek's project group at Natlab. He'll make the electronics that coordinate movement in the stepper, process the displacement signals from the measuring heads, control the pneumatics, and manage simpler things like switching the lights on the control panel on and off. The engineer has the support of his own group back in Nijmegen, which develops the electronics and makes the printed circuit boards. They also write the software there.

When Van Heek sends his quarterly report to his boss, Kramer, and Natlab's management on September 22, 1971, he keeps it short and sweet. He clearly describes the partnership of equals between Elcoma and Natlab:

In January, Bouwhuis and I visited the United States of America to present the opthycograph to a wider audience. During this trip we had the opportunity to explore how people in other laboratories are tackling the problems associated with projection onto the Si wafer.

These new impressions gave rise to a proposal to solve the projection problem using a repeater that prints onto silicon. This approach has met with such agreement in Santen's group at Natlab and at Elcoma in Nijmegen that a joint Natlab–Elcoma project has been formed, to fabricate two identical silicon repeaters. Elcoma will provide the electronics and information processing, Natlab the optics, mechanics, and project coordination. The general ideas have already been worked out in great detail.

Van Heek and Bouwhuis are on a mission. They want to win the race against the e-beam. But competitors are in hot pursuit—they don't know exactly how many, but they estimate that maybe a handful of companies are exploring the same direction. That's no surprise; as noted above, the idea to directly expose wafers step by step is a straightforward one. Van Heek and Bouwhuis are convinced that's where the industry needs to go, even if they have no idea whether the solutions they're choosing are the best ones. "This is the direction we have to go in, even if it's tough and complex," they tell each other. "If we pull it off, we'll be leading the pack."

Natlab offers the two engineers a unique environment. There are only a few places in the world where developers are so fully immersed in the technology—and where they just have to ask and they're given help or components. Money is no object at comfortable Natlab. They can pursue the best technological solution in all freedom, with no thought to the cost.

Group leader Kramer and section director Meyer pledge their full commitment. They reserve $70,000 for material costs for the Silicon Repeater, but Van Heek knows that Philips' future depends on chips and in truth there's no real limit. His task is in fact to engineer a license to print money: a machine that spits out tiny, extravagantly expensive products as fast as it can.

To keep the momentum going, the system architect makes several rigorous decisions. He opts to use the exact same foundation for the Silicon Repeater that Klostermann used for the Opthycograph, a machine to draw masks whose operation is based on the same principles as the photorepeater: the same granite base, the x and y carriages on hydrostatic bearings, and the associated control system. That design is already complete and the shop is familiar with it; production and assembly will take just a few short months.

Not that it's the most elegant solution. Only one carriage moves the table holding the wafer. The carriage at right angles to it bears an appreciable weight: the projection lens and the mercury lamp. It's a heavy package that causes the machine to shudder after every step. It takes valuable time to dampen the vibration. But Van Heek pronounces it acceptable. After all, he only needs to make a functional prototype. Not a machine for use in the fab, but a device that shows that it's *possible* to step-and-repeat directly onto silicon.

Van Heek scrapes together what he can, wherever he can find it. He looks for quick solutions. At some point, spikes in the power grid start affecting the electronics in his machine. These are major disruptions caused by other Natlab researchers' experiments. Van Heek decides not to launch a detailed investigation into the source of the problems in the electronics—he can already see the sour faces of the electronics support team. Instead he takes the brute-force path and buys a ten-kilowatt motor, hooks it up to the power grid, and attaches a ten-kilowatt generator behind it. And there you go: a stable power supply.

Van Heek's homegrown power conditioner is a hulking thing and hideously expensive, but extremely effective. He puts the humming contraption outside the cleanroom. It feeds all the device's electronics; only the motor controlling the oil pressure in the carriages is still plugged into an outlet. He's fixed a major headache, and it's worth it.

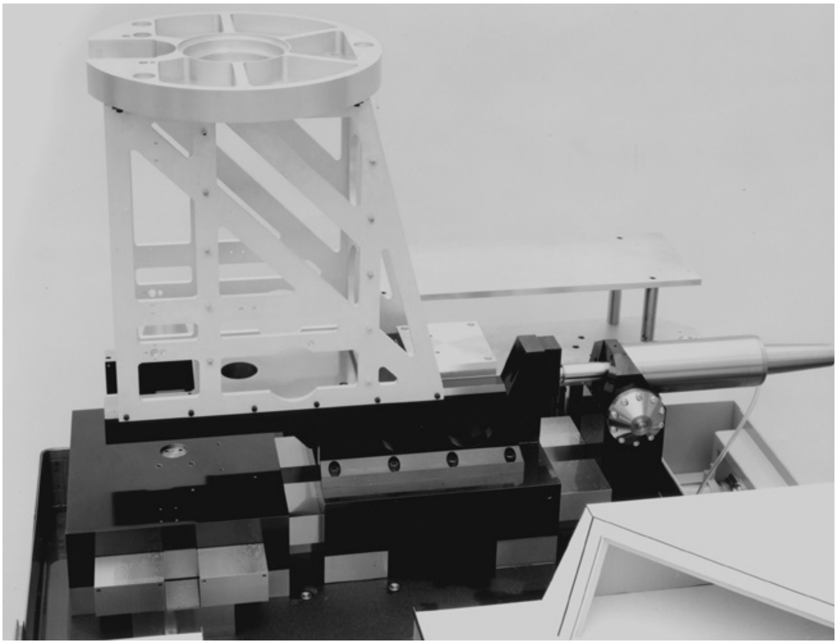
* * *

Thanks to his accommodating suppliers at Elcoma, Van Heek is well on his way to completing the control electronics. The exposure optics are of a completely different order. The entire project depends on an advanced lens system to image micron-sized details. The optics are the most crucial component.

Natlab has in-house optical expertise, but manufacturing objectives for microscopes and other instruments is another story. There's an optical grinding group and Natlab has its own skilled grinder, but he's not able to meet the requirements posed by lithography. There's no way around it: Van Heek will have to look elsewhere.

Klostermann's the one who puts Van Heek on the old optical trail to Paris. In those days, France is an optical and mathematical paradise, and at its center lies CERCO, the primary supplier for Natlab's French subsidiary, LEP. The tiny company enjoys a reputation as an optical polymath and supplier of lenses for extremely specialized applications, including aerospace and defense.

What's more, CERCO's CEO Edgar Hugues is the best kind of mad scientist, a man who likes experimenting just for the sake of it. He's inventive and has the ear of the optics gods at the French universities. He's a researcher's researcher, someone who gladly tries a thing just to try it. Nothing's too wild for him. At CERCO, the motto is "you ask, we deliver": Natlabbers can more or less



Herman van Heek used the base for the existing Opthycograph as the foundation for his Silicon Repeater. Here you see the base with the frame for the lens mounted on it. Beneath the frame are the hydrostatic x and y bearings. The cylinder on the right is the hydraulic motor that moves the lens in the y direction.

dictate their desires.[7] There's nothing they can think up that CERCO won't run with. And the French are master craftsmen. The computer crunches the numbers, but after that the grinding and polishing is done by hand.

Van Heek presents them with a demanding challenge. He wants a lens that can sharply image tiny details. For that, dispersion must be kept to a minimum: different wavelengths must refract at almost exactly the same angle to achieve sharp images.[8]

The solution is to use a tiny band of wavelengths from the mercury lamp's spectrum. Van Heek asks CERCO to construct a lens that can image the lamp's violet h-line (405 nanometers). The ultraviolet i-line (365 nanometers) seems like too much to ask.

Bouwhuis also posits the requirement that the magnification may not change when focusing the image. Taken all together, it's a massive challenge.

In the early seventies, Kramer's optics group makes heavy use of CERCO's services. In addition to the Silicon Repeater, the video long-play disc (VLP) requires increasingly specialized optics, such as aspheric lenses. A cadre of researchers travel back and forth to Paris. Van Heek, Bouwhuis, the new optical engineer Joseph Braat, and even Kramer pay visits to Monsieur Hugues. Where Klostermann and his colleagues usually traveled by train in the sixties, Kramer's group often takes one of Philips' private flights from Eindhoven to Paris.

* * *

When the Natlabbers are in Paris, they often discuss the lithographic optics from nine to eleven, then the aspherical VLP lenses until twelve-thirty. They usually also make the rounds of the factory, where in those days six people are busy grinding, polishing, and assembling lenses. During those kinds of mornings all they get is a measly cup of coffee, but afterward Hugues arranges a bountiful lunch in one of the neighboring restaurants.

CERCO's CEO is not only a highly talented optical engineer, but also a friendly, jovial man. He's not the kind of Frenchman who strictly separates business and pleasure. And so he takes Bouwhuis with him to visit an observatory, where they admire optical gratings used to view spectral lines. Occasionally he invites young Natlab engineers to dine with him at home and meet his daughters. One time he takes his visitors to the Crazy Horse Saloon on the Champs-Elysées. He even offers to take one of them along on a tour of the Mediterranean in his yacht—something the young researcher politely declines.

The conversations on these outings are in French. Monsieur Hugues doesn't speak English and most of the Natlabbers have no trouble speaking French; much of their optical knowledge has come from France.

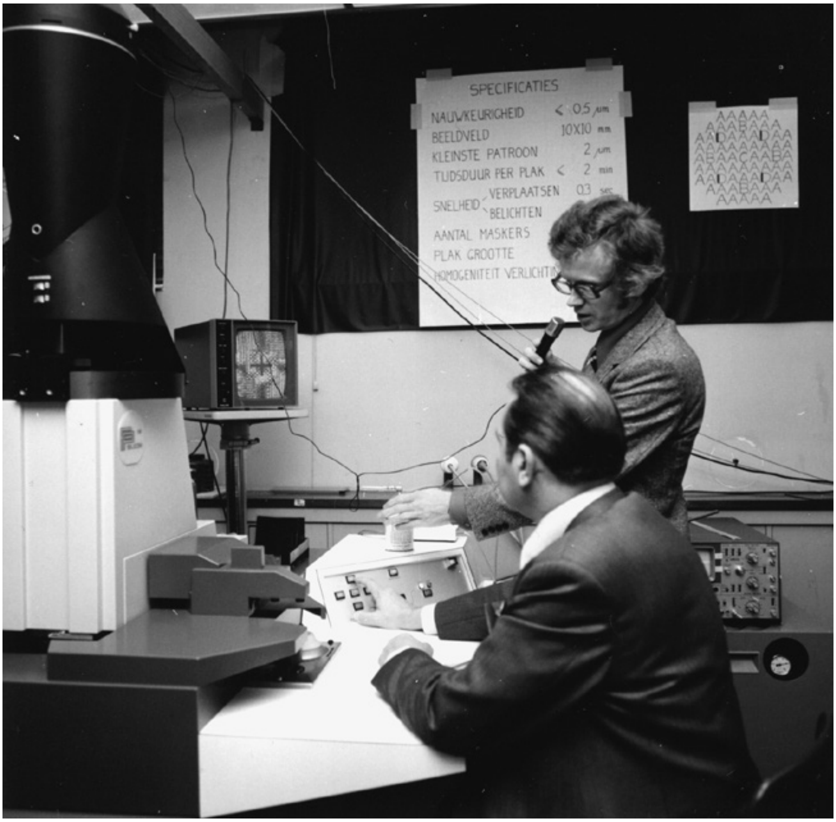

SPECIFICATIES
NAUWKEURIGHEID
BEELDVELD
KLEINSTE PATROON

When the very first wafer stepper, the Silicon Repeater 1, is completed in late 1973, Van Heek decides it's time to celebrate. Natlab's men have worked overtime to get the machine up and running, and he wants to show his colleagues' wives what's consumed so much of their husbands' time.

But Natlab is off limits to outsiders, even its researchers' wives. So Van Heek invites the women to come at a time that will face the least scrutiny: the Friday afternoon before Christmas. On December 21, 1973, the last day before vacation, a parade of women show up with the excuse that they're picking up their husbands. Van Heek hasn't said a word to his boss, Piet Kramer, because as their manager he can't grant them permission and Van Heek doesn't want to get him in trouble—that's why Kramer isn't there and is absent from all of the photos.

When this photo was taken, a chest of cheap German wine was cooling in the empty space beneath the stepper. The corks were popped after the technical presentation and enjoyed by all those present.

Standing, from left to right: Helmuth Werner, unknown (face not visible), Gerard Antonis, unknown Elcoma service technician, Frits Klostermann, Herman van Heek (to the left of the projection column), unknown Elcoma employee, Theo Lamboo, unknown Elcoma employee, Guido van de Looij. Victor van der Hulst is squatting in the foreground, and Ad Bouwer is seated.



Theo Lamboo (holding microphone) explains to Leo Tummers, the head of the IC group, the operation of the Silicon Repeater 1, Philips' first wafer stepper. The machine's specifications are hanging in the background. The monitor in the photo displays the gratings that have been applied to the silicon and the mask in order to position the wafer within a tolerance of one-tenth micron. ASML will later base its logo on this grating.

That same summer, the video long-play technology is also taking firmer shape. Kramer decides to spend an hour demonstrating his optics group's recent work to the Natlab community. He himself gives a forty-minute presentation on the VLP; Van Heek gets twenty minutes for the Silicon Repeater 1. Those lengths are roughly proportional to the number of people who are directly and indirectly involved in each project: the group of people working full-time on the VLP has swelled to about thirty, while the Silicon Repeater team is just one handful of engineers, plus the full assistance of ten colleagues in other groups.

* * *

The lectures attract a large Natlab audience. Van Heek initially interprets the short time allotted to him as evidence that the researchers aren't interested in something practical like a production machine—however advanced it may be—but he's surprised by the number of people who come to listen.

He tells them about the Silicon Repeater 1 and how sensitive the device is. "If someone stands beside the SiRe 1 for fifteen minutes, we can measure how much the machine deforms inside from the heat," he tells his audience. During the Silicon Repeater's development, Van Heek even contacts the Dutch national meteorology service, KNMI, to ask how quickly the air pressure can change in the Netherlands. The positioning of the wafer stage is already using interferometry and changes in air pressure affect the wavelength of the laser being used, which results in measurement errors. Using data from the KNMI on passing thunderstorms, they discover it isn't enough to check air pressure daily; Van Heek needs to measure it at least once an hour.

In late 1973 the Silicon Repeater 1 is ready, and the project's engineers and their assistants celebrate the fact with their wives on the Friday evening before Christmas. The optical group at Natlab has brilliantly developed a unique lithographic machine. A small team created the system and its major technological breakthroughs, drawing on the help of countless experts and assistants. Van Heek wants to thank them all.

At that time, their Silicon Repeater is superior. The machine reduces the two-inch-square mask pattern and images it on wafers just three or four inches in diameter. The tiniest details in a circuit are two microns, and at maximum sharpness the stepper can image chips that are seven millimeters square. It can also image larger ones (ten by ten millimeters), but the projection is less sharp. The stepper positions the wafers within a tolerance of one-tenth micron. Exposure takes half a second, and it takes another half-second to step from projection to projection. In three minutes, the machine can expose an entire wafer. There's nothing better available in the world, but it's still just a prototype.

* * *

Though Klostermann's photorepeater was a success at Philips' chip fabs, Natlab has trouble finding takers for its Silicon Repeater.[9] The steppers are barely being used at Philips Elcoma in Nijmegen. Van Heek sees it happening and realizes how vast the distance is between stepping and the contact printing the fab has been using for years. The wafer steppers are just too complex; they can't get the machines working in Nijmegen.

On a personal level, developing the Silicon Repeater has shown Van Heek where his passion lies: in building machines. He realizes there's not really a place for that at Natlab. *If I stay here until I retire, I'll spend my life without seeing a single practical result from my work*, he thinks. In his view, Natlabbers mostly invent things that other people take and run with. Their greatest accomplishments are reports and publications, and eventually they end up a professor somewhere. Scientific glory isn't what drives Van Heek; he wants to use technology to do real things in the real world.

Van Heek visits Nijmegen for a chat, because he thinks they might well need someone to further develop the Silicon Repeaters. But to his surprise the mechanization group at Elcoma informs him they have no plans to pursue machines like steppers in house. They prefer to buy them on the open market, because they aren't confident they can continue providing good service for machines they make themselves. He ultimately finds work in the optics department at Philips' cathode ray tube factories, where they design lenses. A few years later Van Heek will return to working on wafer steppers at Philips Science & Industry, after Natlab has transferred its lithography equipment to that product division.

Natlab promoted the Silicon Repeater 1 inside Philips using several technical brochures. This photo sporting a charming operator is one of the rare versions with a personal touch.

10. **American Style**

In the US, lithography suppliers Perkin-Elmer and GCA David Mann work closely with their customers. Pragmatic engineers at those firms are developing revolutionary products.

The problems that plagued the Microprojector that Perkin-Elmer built for the Air Force have gotten Harold Hemstreet, the general manager of the company's electro-optical division, thinking. The complex exposure device didn't make it to market. Are they looking in the wrong direction? Hemstreet takes his doubts to Abe Offner, one of Perkin-Elmer's most experienced optical designers.

After they talk, Offner decides to start experimenting with concave mirrors. Mirrors have a major advantage: they don't suffer from dispersion. Different wavelengths refract off the mirror's surface at the same angle, so that different colors can all contribute to the projected image.

By that time, chip fabrication requirements have gotten even stricter. If their machine is to have any chance in the market, it has to be able to image two-micron lines. Offner succeeds in creating a design that projects a pattern one-to-one onto a silicon wafer. The clever thing is that he combines two concave spherical mirrors in such a way that each mirror's aberration compensates for the other's within a small ring.[10]

The resulting machine uses part of that ring, a curved slit that's one millimeter wide and eighty millimeters long. It exposes the photoresist on the wafer in a continuous scanning movement. Compared to the Microprojector, Offner's solution is almost childlike. The device doesn't have the complex sixteen-lens optics they used to build the Air Force machine, but two simple mirrors. The system is so elegant that texts on optics still use it as an example.

John Bossung builds a prototype that convinces the Air Force to pump $100,000 into the project. At Perkin-Elmer, Hemstreet puts mechanical designer Jere Buckley and optical systems engineer Dave Markle to work designing a reliable machine that can be manufactured at a reasonable price. The pair present a basic design in November 1971. The Micralign is born.

But at that time they still have to solve a heap of problems. Buckley and Markle have to adapt the optics and the mechanics in such a way that the slit uniformly illuminates and scans the wafers. They call on ARC to build a heavy-duty mercury vapor lamp and Offner uses it to design a light source that will let them use a band of ultraviolet light to scan the wafers in ten to twelve seconds.

Despite all the ups and downs, Hemstreet continues to believe in the project. At some point he leans back in his chair and says to his people, "Someday we're going to sell a thousand of these machines." At the time everyone thinks Hemstreet's hallucinating. All they see are the roadblocks ahead of them. Pressure mounts as the scheduled launch in the summer of 1973 approaches.

When the machine once again hits a snag, the engineers discuss their problems deep into the night with Peter Moller, Perkin-Elmer's marketing director. He listen to all their woes and says, "I'll give you a trip to Bermuda when we sell the hundredth machine or a cup of coffee now." The entire team chooses the coffee.

Once Perkin-Elmer actually has a machine and can deliver, Moller visits a string of chip manufacturers: Texas Instruments, Raytheon, National Semiconductor, and Fairchild. The trips are a moderate success. Perkin-Elmer makes some wafers for TI and shows them to the other chip manufacturers. Most of them turn up their noses at the results. But Raytheon comes to the rescue. The company realizes Perkin-Elmer is having trouble with the photoresist. It sends an experienced process engineer to help the instrument maker. And so Perkin-Elmer learns that really knowing your customers' application is vital to selling them a machine.

In 1974 Texas Instruments buys the first Micralign for $98,000. Intel and Raytheon soon follow. In the fabs, operators have to get used to the new device. They have no idea how sensitive the machine is. Sometimes operators put their feet up on the Micralign's table while it's scanning—after which other engineers have to unravel the puzzle of why on earth the images are so blurry.

But the semiconductor fabs soon master the art and see that it saves huge amounts of money. These are the years when major chip makers are buying the photomasks for contact printing literally by the truckload. The Micralign enables them to eliminate that expense. The original masks last indefinitely. The savings are primarily the result of the higher yields; yields go up by dozens of percentage points. Texas Instruments lets Perkin-Elmer know that the Micralign has paid for itself in ten months. The manufacturer is flooded with orders, and soon customers have to wait a year for delivery.

In the years that follow, more and more chip manufacturers embrace the Micralign. The machine introduces a whole new approach to chip fabrication, and that has a major impact on the entire production chain. Integrated circuit manufacturers want to get the most out of their imaging equipment and pose increasing demands on their materials suppliers. Glass suppliers have to deliver flatter mask substrates, wafer suppliers flatter wafers. Mask manufacturers have to deliver their wares with zero defects. Mask prices skyrocket to $1,000 apiece, but the Micralign justifies the expense. The machine also paves the way for the first e-beam writers that Texas Instruments and IBM develop for making high-quality masks.

It's the Micralign that makes it possible to manufacture chips cheaply enough for personal computers. Intel uses it to make the 8086 processors it introduces in June 1978. A year later the company unveils the 8088—five millimeters on a side, with some thirty thousand transistors. IBM uses it to make its first PC.

In the late seventies, Perkin-Elmer is a chip machine powerhouse. It holds 90 percent of the photolithography market and is the largest producer of machines for the semiconductor industry. The Micralign is a perfect tool for IC manufacturers. The development of wafer steppers—at Natlab and at many American chip companies—has been back-burnered since the mid-seventies.

* * *

In a single clap, the Micralign scanner makes the wafer stepper idea obsolete—but it also tolls the bell for the photorepeater, the lithographic workhorse of the sixties and seventies. Perkin-Elmer's success is quickly picked up by the market leader in repeaters, David Mann.

It's 1975 when Mann's general manager, Burton "Burt" Wheeler, calls his management team together to discuss what the arrival of the new lithographic technology is going to mean for their business. Chip manufacturers that buy one of Perkin-Elmer's Micraligns rack up significant cost savings. The time when no one is buying photorepeaters anymore is steadily approaching. Mann's employees all agree: the company's market leadership is in peril.

Wheeler is a seasoned veteran of the precision business. He joins Mann in 1940, straight after his degree in mechanical engineering. When the company's founder and namesake dies in 1957, Wheeler succeeds him as general manager. After GCA acquires the company in 1959, he continues to lead the David Mann division. In the fifties the company is already producing legendary precision equipment, including instrumentation for America's first Explorer satellite.[11]

Wheeler's teammates are also highly experienced. Optical engineer Howard Lovering has many patents to his name. Wheeler's worked for years with project manager Griff Resor and Bill Tobey, an engineer who's moved into marketing and sales. They've had major success across multiple generations of photorepeaters.

* * *

During their strategic meeting on the Micralign, Wheeler and his team boil down the options to a single feasible product. They decide to modify one of their step-and-repeat camera models and turn it into a wafer stepper. That change will turn the optical instrument into one that no longer images the chip patterns onto glass contact masks, but onto silicon wafers.

Senior management thinks the process is too slow. Exposure proceeds step by step, and each wafer has to run through the process multiple times. In full keeping with the sentiment of the time, GCA's management is convinced that the successor to Perkin-Elmer's projection scanner is not a stepper, but an e-beam writer.

Nonetheless, Wheeler and his team decide to pursue their idea for a stepper. They have the freedom to do so, because the Mann division operates fairly autonomously within GCA. They pay frequent visits to customers and know that Fairchild and Texas Instruments are already building their own steppers. The idea to project chip patterns one-to-one directly onto silicon has permeated the entire industry.

But there's no commercial version available, and that's where Wheeler and his team see their chance. Mann's engineers know they have a major advantage compared to the chip makers who are developing steppers for their own use. They know the market, have the contacts, and maintain strong relationships with dozens of customers. "We know what our customers want better than anyone," Tobey tells his colleagues.

Mann's central role in the chip industry is also evidenced by its relationship with Philips. In 1971, Tobey hosts Van Heek and Bouwhuis, and the three discuss mask problems in vivid detail. Mann is also in the loop two years later, when the Natlab researchers are readying their prototype stepper. Philips is known for its technological expertise, and in the mid-seventies Tobey and Resor travel to Eindhoven to talk about a potential joint venture. But the romance fizzles before they've even left. When he gets back home, Tobey disappointedly tells his colleagues, "It was the Phillips way or no way. We'll move forward on our own." Philips has—as will later become evident—just turned its back on the deal of the decade.

Part 3

Death Throes
1976–1983

11. **Wim Troost**

Wim Troost rescues the wafer stepper from the scrap heap. If there's anyone who personifies Philips in the decades after the Second World War, it's him.

It's early 1978. The management teams at Natlab and Philips' Science & Industry division (S&I) have gathered in full for their annual meeting. During the Q&A session, Natlab's Piet Kramer and Hajo Meyer bring up a minor point. "Is anyone interested in our lithographic expertise?" they want to know. The researchers at Philips' laboratory are already working on an improved version of the wafer stepper. "It's no longer research at this point; it's engineering," Meyer says. "It's time for S&I to take it over."

Meanwhile, Perkin-Elmer is taking the market by storm. Its Micralign machines work much faster than wafer steppers and their simple design makes them much cheaper to boot. Both Natlab and Philips' chip fabs have bought the imaging machines[1]—a fact of which S&I's management is all too aware.

And so an uncomfortable silence falls after Kramer and Meyer ask their question. Is there no one among those assembled who wants to pursue the Silicon Repeater? Then someone raises his hand. It's Wim Troost, one of S&I's business unit directors.

Troost will go on to play a crucial role in the history of wafer steppers at Philips. He's the man who will fight for years against all odds to preserve optical lithography—at a time when the technology's future is highly uncertain. The whole world expects optical methods to provide only a temporary solution until imaging with electrons, ions, or x-rays soon takes over.

Who is this miraculous person who continues to defend the loss-making lithographic activities through thick and thin and keeps it all going using money from a hidden reserve? Why do Philips' bean counters continue to accept Troost's unprofitable hobby for years? What drives him to fight so hard for the steppers? The man has enough on his mind without them. He's generating half a billion dollars in profitable sales in the project and systems business, running factories with a thousand employees, and managing an international organization with an extremely diverse portfolio. But he just can't stand to see development on such an exotic device die.

* * *

Wim Troost comes into the world in 1925 in The Hague. When he's ten the family moves to Boompjesdijk, a tiny one-street, two-farm village housing eighty families on a dike in the southwestern province of Zeeland. There, Troost's father and uncle take over their father's bakery and grocery store. Wim attends high school and then vocational school there. He wants to attend the technical university in Delft when he finishes. But by then the Netherlands has been invaded, and he refuses to sign the declaration of loyalty and promise to take no action against the country's occupiers—a condition the Germans impose on students and professors before they may study or work at a university.

And so young Wim ends up back in Boompjesdijk. Working in his father's bakery isn't very romantic. He gathers the wood for the oven, bakes the bread at night, and then delivers it by bicycle to the neighboring families. People pay him using cash and ration coupons. In January 1944, on his nineteenth birthday, the Germans call him to labor duty—usually in preparation for relocation to Germany—and he goes into hiding in his birthplace, The Hague.

It's 1944, and there's hope the advancing Allies will soon liberate the country. When the troops' northward advance stalls, Troost finds himself on the wrong side of the three major Dutch rivers that form a watershed. At first his parents keep sending food, but that stops once the bridge at Moerdijk is destroyed. By the end of the ensuing winter famine, Troost has lost sixty-five pounds and his clothes no longer fit him.

Once young Wim has recovered from the war, his father gives him the family's last forty dollars to study physics in Delft in September 1945. After passing his foundational courses, he signs up to major in acoustics in 1947. To pay his bills, he takes a job as an assistant in a different department: control engineering. He's appointed head assistant, and the professor demands that he spend every possible moment at the lab.

* * *

During post-war reconstruction young engineers are in demand, Troost among them. Oil company Shell, steel producer Hoogovens, and the state-owned mines are rolling out the red carpet for young control technicians. Philips issues him several invitations. He visits Natlab and tours so many Philips departments that he starts to feel embarrassed by the hospitality they keep showing him every time.

Troost initially decides to work for Shell—he's afraid he'll just be a number at Philips. But he backs out when he hears that the oil company can send him to another country at any time. And so he goes to Philips after all, where they pay him $1,240 per year, plus an extra fifty-dollar bonus—nearly twice as much as Hoogovens is offering.

In September 1951 when Troost starts work at Philips' products for industrial applications division (PIT) in Eindhoven, he's taken aback: the people he spoke with when he interviewed are nowhere to be found. Some of his PIT colleagues are thoroughly surprised at the young academic's sudden appearance. But that's how things go at a behemoth like Philips: the multinational is a many-headed monster, and HR charts its own course in hiring new talent. Troost is given a tour, an employee directory, a stack of manuals, and descriptions of PIT's products. No one tells him what his job is. "Just read up and have a look around," his colleagues say. Then the young engineer discovers a contraption sequestered beneath a dusty cloth. It's a programmable PID controller, which an S&I employee has given up on. *Neat*, Troost thinks. He starts tinkering with it and manages to get it working.

After that, management is quick to assign Troost a few assistants. They'll be working on recorders: hulking things that spit out long strips of paper filled with lines indicating values for temperature, pressure, flow, and level.

Troost's colleagues at Philips are soon acquainted with his obstinate streak. One day he summarily fires an employee who's stolen a colleague's bicycle. When HR points out that he can't just up and fire a person, he argues bitterly with them, ending with "I don't care how you handle it on your end: this man no longer works for me."

In October 1967 Troost is appointed chief engineer and head of the R&D department. He introduces PIT to the transistor, digital technology, and later software. In the seventies PIT merges with S&I. There Troost leads the industrial data systems (IDS) business unit, a paradise for engineers who love control and automation.

Troost is an outsider among S&I's management. He's a workhorse for whom no job is too taxing. Employees gape at his nearly inexhaustible energy and superhuman work ethic. When things start to quiet down around five to five-thirty in the giant gray buildings on Philips' industrial campus, their boss is still at his desk. He often doesn't arrive home until nearly eight. One day when his children are still young, his wife informs him she's tired of waiting on him for dinner. After the meal, too, it's Philips that fills his time. Troost is often absorbed in paperwork until midnight.

When he isn't traveling, that is. There, too, he goes to extremes. In the seventies Troost has the highest annual travel expenses of any business unit director at S&I—and he's proud of it.

His attention to detail is legendary. Whenever Troost leaves Eindhoven, be it for work or vacation, he leaves behind a detailed travel plan with the telephone numbers of every hotel and venue he will visit. He's addicted to total control.

At work he speeds down the halls, a briefcase in each hand. He moves as quickly as he can, because to him walking is a waste of time. The briefcases contain meeting reports, letters, his internal mail, memos, journal articles, and more. Troost takes it all home to his renovated farmhouse in nearby Nuenen. After dinner, he reads every page—as his colleagues know from experience. Everything they give him to read, he devours. To him, it's far from a burden: his days are so filled with meetings that he views the daily avalanche of reading material as a wonderful way to relax.

Reader extraordinaire Troost is one of the few at Philips who reviews all the material before management meetings—not only for his own business unit, but also for every other S&I department. To him, that's the most natural thing in the world. At politically charged Philips, his colleagues aren't always pleased with his involvement. When they comment on it, he tells his fellow directors they're not there just for their own group, but also to listen and help each other make the right decisions.

Troost takes pleasure in catching people failing to keep their promises—braggarts most of all. "All that stuff you're saying sounds real nice, but I see a different story," he chides not only his employees, but also his fellow directors. When they look puzzled, he adds with visible relish: "The notes from the last meeting, page ten, second line down."

* * *

No is not a word in Troost's vocabulary. He opportunistically draws project after project into his domain. Some of his colleagues and employees view that as a lack of vision, but he's on a mission to cash in on every opportunity. Is someone proposing a complex, exotic project? Troost signs off on it. He's a man of principles and believes earnestly in the social values that Frits Philips proclaims in the sixties: that multinational companies have a duty to serve society and must provide and guarantee employment. He's a constant fixture at the HR department, always popping in to pluck people for his new projects from the card catalog of surplus employees.

Troost takes on everything that comes his way, and under his leadership IDS steadily grows. In those days, the world is testing the waters of automated control for processes and systems. The savings in manpower are appealing, even if the technologies are still in their infancy and many projects run firmly aground.

In the years that follow, Troost keeps expanding his quiver of projects. Companies eager to modernize their water treatment plants,

Wim Troost takes on every project that comes his way at Philips Science & Industry. In the late sixties S&I even helps automate the national observatory in the northeastern town of Dwingeloo. In this photo (August 1969), a company helicopter has just deposited the S&I director in the heather surrounding the observatory, on his way to the monthly powwow. The short note written in fountain pen on the back of the photo reveals that the project had its share of problems: "Dear Wim, in memory of technological panic and airborne peace."

Photo: Philips Nederland

power plants, or dairy plants can now knock on Philips' door instead of going to pioneers Siemens and AEG. Customers are welcomed with open arms. When the Dutch postal service asks for mail-sorting machines, Troost says, "Friends, there's an opportunity before us: we're going to sort mail." Then he descends upon the employee card catalog and gets down to work.

* * *

And so Troost's unit at S&I evolves into an engineering firm where no automation project is too crazy. The engineers in Eindhoven automate the observatory in Dwingeloo, develop the process control for Gasunie's natural gas compressor stations and Pernod's distillery in Paris, fill the Dutch countryside with sniffers for a national air pollution detection network, build systems for dairies and cheesemaking plants, automate water treatment plants, and outfit glass, cement, and concrete plants with computers.

In the mid-seventies, Troost's project business spreads its wings ever further across Europe. S&I automates dairy plants in Germany and Ireland, automates steel plants in Belgium, and sets up an environmental monitoring network in Italy.

* * *

But Troost doesn't just serve external customers. He also helps Philips' product divisions in their major industrialization projects. For those his department works with the mechanization group, a.k.a. the machine shop. Together they build many Horizontal 2000s, assembly lines for fluorescent lights that are some hundred yards long.

At Philips they keep extremely detailed books. S&I's business units for analysis, electron optics, welding, and numerical control all use a rigorous registration system with strict financial checks on costs, budgets, hourly wages, and revenue. Philips' bean counters have a harder time putting Troost's department under the microscope. His projects sometimes encounter delays, and requirements often change along the way.

This exception to the rule creates a certain degree of freedom. As a financial buffer for his unpredictable projects, Troost keeps a hidden reserve. All the project quotes he makes include a mechanization charge of 7 percent. Those extra funds rack up nicely and give Troost room to maneuver.

These reserves provide so much elbow room that Troost can even invest in activities that don't bring in a single cent. He's the one who decides, not Philips' top brass—unheard of at the multinational. When Troost takes over the stepper from Natlab, he keeps its development going using funds from his secret stash. The company's financial executives know about it, but can only look on in frustration. Though they frown on Troost's behavior, no one can touch him: they all depend on the business he's generating for them.

Within Philips, many a fellow director is ready to trip Troost up at the first opportunity. He defends his expenditures with the argument that building lithographic equipment falls under electrical mechanization, something that fits well with his portfolio. He keeps stepper development alive through all the years when orders keep failing to materialize—even from Philips' own chip fabs.

Usually no one interferes with Troost's hobbies, but now he has to run the gauntlet. Urbain Devoldere and Ad van der Linde in the finance department keep a close eye on him, as does S&I's commercial director, Ab de Boer. At some point during a management meeting, Van der Linde voices serious doubts about the content of Troost's mechanization activities. "Why are we even doing that at all?" Van der Linde says, referring to the steppers. "What on earth is Wim up to? Aren't we better off using our top engineers for our real line of business instead?"

Troost's response is harsh and emotional. He despises bean counters, whom he believes use double standards. Every time he lands another major project, he puts people to work who've been sitting on the bench at S&I. When the directors of other business units come to Van der Linde's aid, Troost lashes out. "Listen, I absorb all the people you've made redundant over the years. If I hadn't done that, you'd have run into major problems."

Time and again, Troost pulls himself out of these kinds of situations—mainly because his projects also generate significant revenue and profit for his fellow directors. Their units often provide the necessary components, equipment, and instruments. For example, at the end of the seventies the mail-sorting machine orders bring in revenue of $75 million at S&I, and handsome profits. His fellow directors simply can't afford to lose him.

12. **Troost's Letter**

Philips S&I wants to conquer the world with its lithographic technologies, and that optimism is reflected in its business plans.

After Natlab has made a deal with S&I to transfer the wafer stepper, the Philips grapevine swings into action. Kees Krijgsman and Jan Huart at Elcoma hear that Wim Troost is taking the steppers under his wing. Huart's been wrestling with a problem for quite some time. His fab has made several copies of Natlab's Silicon Repeater 1, but his people can't get the wafer steppers to work.

Huart picks up the phone and calls Troost. "Hey, Wim, all that lithography and steppers and all is great, but do you guys really understand the semiconductor industry well enough?" Huart doesn't mention his troubles with the Silicon Repeater.

Troost admits that his chip experience is modest. "I've looked around, but I haven't worked in the field," he answers curtly. Then Huart makes him a friendly offer. "Well, why don't you station one or two employees over here with me in the fab?" Troost doesn't realize it, but Huart's just fastened a monkey to his back.

Troost thumbs through the stack of surplus employees at HR and finds one Richard George. George is a temperamental Englishman who studied physics at London University's Queen Mary College. He ended up in Eindhoven through Philips' English subsidiary Pye Unicam.

George heads to Elcoma's mechanization group in Nijmegen, where he finds four wafer steppers, all of them copies of Natlab's Silicon Repeater 1. The Englishman previously worked in one of Philips' environmental divisions and knows almost nothing about steppers. He decides to subject the machines to extensive testing. He soon discovers the Silicon Repeater can't manage to accurately align the silicon wafers. The patterns for successive exposures don't overlay with sufficient precision, and so the resulting wafers don't work. In the end, Natlab's optics guru Gijs Bouwhuis has to be called in to fix the alignment systems at Elcoma.

*   *   *

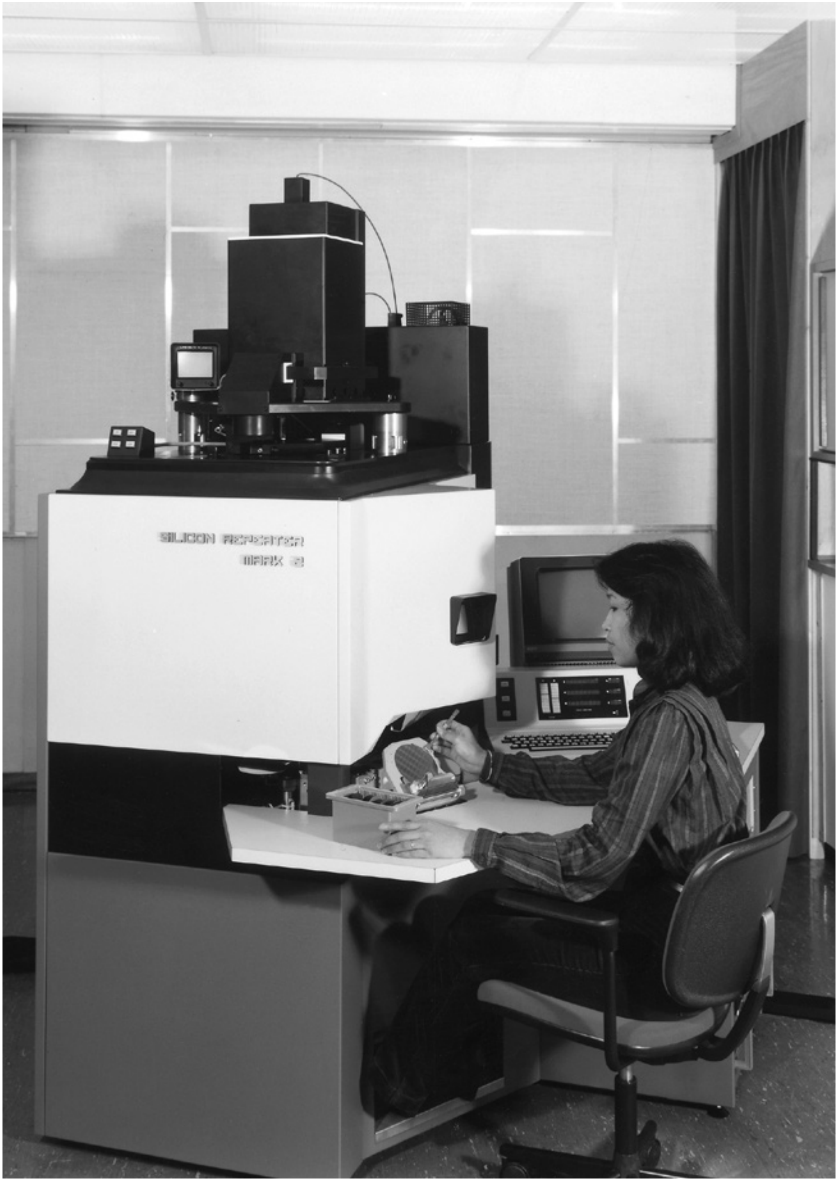
Huart's colleague Kees Krijgsman informs Troost that it's important to look beyond Elcoma for experience. In those days Philips is in close contact with IBM, which at the time is running the world's most advanced wafer fab in Burlington, Vermont. In 1978, IBM's fab is leading the semiconductor industry. That year, Big Blue produces the world's first 64-kilobit DRAMs—a strategic component for computers—and it's the first computer company to build these memory chips into its mainframes.

"It's all well and good to start out with the Silicon Repeater at Elcoma, but it would be really great if you could get a machine into IBM," Krijgsman tells Troost. Krijgsman often discusses his lithographic problems with Big Blue, and he knows the boys in Burlington are eager to examine lithographic tools from several suppliers. "If we can get IBM to look at our machine, too, then we'll know where we stand relative to the competition," Krijgsman says. He has a chat with IBM, and the company asks Troost to deliver a stepper. The deadline is clear: S&I must ship the machine on June 8, 1982.

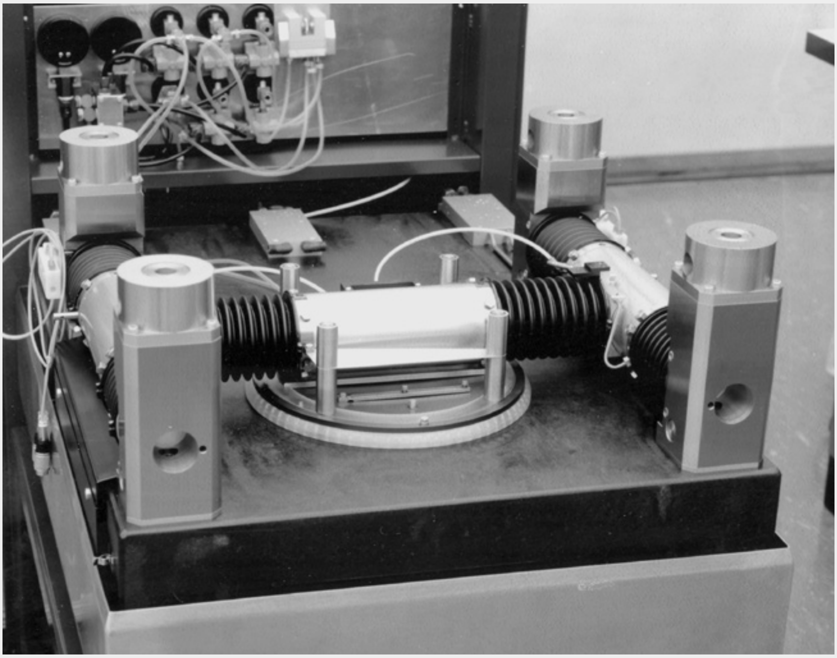
*   *   *

That same year, 1978, GCA David Mann brings the first stepper to market. The field is still wide open. S&I's hand is strong, too, now that it has Natlab's machine. What's more, Steef Wittekoek's team at Philips' research lab has already been working on the Silicon Repeater 2 (SiRe 2) for a couple of years, a much improved version of the device that was completed in late 1973.

The SiRe 2 sports countless advanced new features. For example, Wittekoek has redesigned the wafer table so it can not only displace the silicon wafer, but also rotate it very precisely. Ad Bouwer's created an H-shaped motor just for the task. In addition, the oil flow through the machine has been completely sealed, in contrast to the open-oil system in the SiRe 1, where the fluid from the hydrostatic bearings ran over the baseplate and was caught in a tray. At S&I, Richard George is tasked with making an industrial version of the Silicon Repeater 2.



The Silicon Repeater 2 was developed at Natlab in the mid-seventies under Steef Wittekoek's direction. The lab's chip researchers preferred to buy lithographic equipment from the US, but managing director Hajo Meyer forced his people to also use the SiRe 2.



The H-table

In the mid-seventies, Steef Wittekoek breathes new life into the stepper project at Natlab. He decides to alter the way the wafer is positioned. His starting point for the wafer stage is a square mirror block on which the wafer holder is mounted. A three-axis interferometer measures both the block's—and thus the wafer's—linear x and y position and its rotation, and it can correct them as well.

With that choice, Wittekoek packages the entire wafer positioning process in a structure that can rapidly move and stop. This also means the projection column no longer needs to move, as it had to do in the Silicon Repeater 1. He attaches the projection and exposure system securely to the granite base. The optical column now hangs over the wafer and doesn't need to move, only to expose.

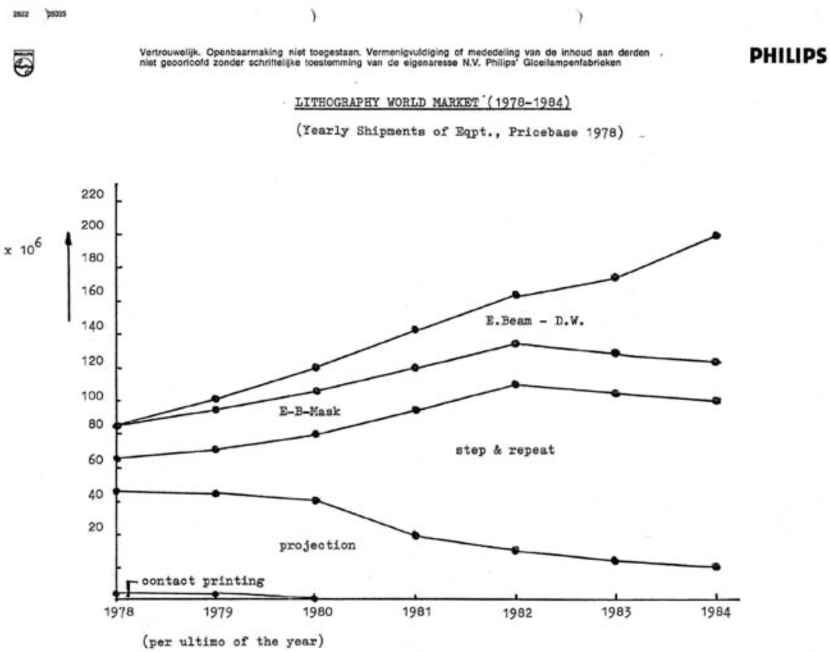
Ad Bouwer designs the stage's ingenious drive system: three motors working together in an H-shaped configuration that makes it possible not only to move in the x and y directions, but also to rotate very precisely around the z axis.

Troost recognizes that the Silicon Repeater 2 is very strategic technology, but he's also placing his bets on a second horse: the e-beam writer whose development he took over from Mullard Research Laboratories two years earlier.[2]

In the summer of 1978, Troost puts Ronald Beelaard in charge of stepper development; Beelaard's already responsible for e-beam lithography (appendix 6). S&I's management tells Beelaard to work with Ger Janssen in marketing to survey the landscape and assess S&I's chances in the lithography market. In August 1978 they send their business plan to the whole executive team. Their enthusiasm leaps off the page. Beelaard and Janssen write that Philips is in a unique position. It holds all the lithographical trump cards: e-beam writing and optical projection.[3]

In the late seventies, the chip industry is on the cusp of change. The first generations of microprocessors and memory chips have been produced using Perkin-Elmer's machines, but Moore's law (appendix 7), which states that the number of transistors doubles every two years, marches inexorably on. It's obvious projection scanners will soon be insufficient. Large-scale integration (LSI) is making way for a new generation of very-large-scale integration (VLSI) chips. Those require new machines—ones that are far more complex and expensive than Perkin-Elmer's scanners. Analysts expect these new machines to double the market for lithography, from $100 million in 1978 to $200 million in 1983, Beelaard and Janssen report.

When it comes to drawing tiny lines, optical projection can't hold a candle to electrons. Beelaard and Janssen are convinced that e-beam writers are going to dominate the market. "It is generally acknowledged that writing directly on the wafer with electron beams is the ideal lithographic approach for the 1980s," they write in their executive summary. Currently, however, the technology is too slow to be commercially feasible. "Therefore, a market has developed for optical step-and-repeat systems which will last until direct-writing e-beam throughput can be increased by a factor of twenty at least."



The business plan that Ronald Beelaard and Ger Janssen write for S&I's management reflects the expectations that hold sway in 1978 in the global chip market. After 1982, optical lithography will have passed its prime and direct e-beam writing will take over. The chart also shows that the e-beam production of optical masks is in sync with market expectations for optical lithography.

The numbers in the business plan reflect their optimism. The global market for steppers will grow from fifty machines in 1978 to two hundred in 1982, then stabilize: the same number will be sold in 1983 and 1984. In contrast, direct e-beam writing will steadily grow. In 1979 the first three machines will enter the market, and the number of e-beam systems sold worldwide will swell to fifty in 1984. "E-beam direct writing will grow faster, at the expense of step-and-repeat, if writing speeds increase faster than expected," Beelaard and Janssen note.

Beelaard and Janssen emphasize that Philips has state-of-the-art machines for both e-beam writing and optical step-and-repeat.

At S&I in Eindhoven, they're just about to deliver the first e-beam pattern generator, and another four orders are ready and waiting. And its steppers are at the advanced prototype stage.

The business plan is brimming with confidence. Philips will leave its competitors in the dust, because the company's two lithographic devices can be significantly improved through simple extensions. The e-beam machine's writing speed can be improved by a factor of five, and automated alignment will make the stepper more productive.[4] These steps will produce systems that are superior to those of the competition, according to Beelaard and Janssen.

The two engineers also outline the speed with which Philips will conquer the market. According to them, in 1980 the multinational will already occupy the number one position in the e-beam writer market for both masks and chips. In steppers, Beelaard and Janssen assign Philips a market share of 40 percent for that year. Nothing to sneeze at, but they grant 45 percent of the market to GCA. And Philips' 40 percent comes with conditions: the current production forecast is conservative, and it will only net Philips 20 percent of the market. So that will have to go up.

If Philips wants to capture a significant share of the e-beam market, the company will have to act right away, the pair writes. Competing manufacturers have already had e-beam mask writers on the market for a year and are profiting from customer experience. The longer Philips waits, the harder it will be to compete, they say.[5]

The stepper market has also taken off. GCA delivered its first steppers in 1978 and customers are ordering in volume. "The semiconductor industry is rushing to place orders on today's process equipment," the business plan states, noting that stepper delivery times have stretched to eighteen months.

* * *

When Richard George returns to S&I from his stint at Elcoma in Nijmegen, he's placed under Beelaard. Beelaard's vision is now clear: the Silicon Repeater needs a significant engineering makeover.

Right from the start, the positioning table for the silicon wafers generates intense discussion. Philips' steppers displace and align the wafer stage using hydraulics, but the required oil wreaks havoc on the chip manufacturing process. At eighty bars of pressure, even the tiniest leak will spray the whole room with a mist of oil. The contamination shuts chip production down for months afterward. S&I's engineers have seen it happen several times, as have Elcoma's chip makers. Everyone at Philips knows: oil is poison in IC production.

But hydraulics are superior technology, and at Philips superior technology doesn't go down without a fight. Ad Bouwer was already using hydraulic motors in the sixties to build chipmaking equipment at Natlab. He was far ahead of his time. Hydraulics provide stability and extremely precise positioning.

In the end it's Beelaard who, as head of the stepper endeavor, makes the call: Natlab's hydraulic table has to go. "Otherwise we'll never sell the thing," he tells his team. He's absolutely right. The industrial version of the SiRe 2—since rechristened the PAS 2000, for Philips Automatic Stepper—will have an electrically driven wafer table. Beelaard's decision gives the PAS 2000 team a clear goal.

George is tasked with re-engineering the stepper. He's aided by Frans Klaassen, an electrical engineer fresh out of college. Klaassen has worked mostly on fiber optics, optical instruments, and lasers. Not a great match, but George lets him design the electric table anyway. From the ground up.

George's team is small. Most of the attention in Beelaard's group goes to the e-beam machine, the great promise for the future. So Klaassen is on his own for the electric stage's design. That seems a little underpowered to George, so he decides to consult with Philips' Center for Manufacturing Technology (CFT). He and Klaassen take regular trips to the CFT to discuss what an electric stage might look like. There, precision specialists Wim van der Hoek and Rien Koster lend them a helping hand. Younger CFT colleagues work out their ideas.

The idea arises to build the table with both coarse and fine control. For the rapid x and y movements, Van der Hoek and Koster advise them to use long threaded spindles, called lead screws, which are set in lengthwise motion by rotating nuts.[6] For the fine-tuning, they decide to use a piezoelectric actuator with a stroke of ten microns.

Klaassen is still in his first week when he hears that Natlab's still working on steppers, too. The Silicon Repeater may have been transferred to S&I, but stepper research continues merrily on at the lab. When Klaassen and his boss visit Natlab for a look at their work, George warns him about a potential culture clash: "Frans, don't let it get to you, but they may be pretty negative."

* * *

George has good reason to warn his young colleague. In those days, the rivalry between the product divisions and Natlab is legendary. Even high-level meetings between the lab's directors and management at the industrial groups are often charged with hostility.

Their respective workplaces couldn't differ more. Natlab researchers are artists: pigheaded and cocky, free spirits who decide for themselves when they'll arrive and when they'll go home. Their work is their hobby. They view Natlab as their personal atelier.

The product divisions are housed in hulking buildings the same dreary gray as those of the research lab, but once inside it's like another planet: a meticulously organized brave new world of discipline and regularity, with codes for every part and order. A world where the punch clock is waiting when you arrive and the color of your coverall announces your department and pay grade. The production divisions are machines.

Perhaps the best expression of their extreme order is the twelve-digit numerical code. Every part, every nut, every valve, and every diagram for a machine, instrument, or other device that S&I makes has its own code, which employees call the 12NC. Machines are painstakingly documented with detailed diagrams, and every module or assembly has a main parts list, which in turn is divided into subparts lists. And so every product, every type of machine, has a corresponding forest of descriptions, drawings, and numbers—from the whole device's product number down to the numerical codes for each tiny detail.

There's a lot of work be done to get the e-beam writer and the stepper ready for life at S&I, and so the devices go back to the drawing board. Beelaard and his team catalog the research machines and translate everything to parts lists. They add in an estimate—more like a guesstimate—of what they will cost to manufacture. If they're going to sell the machines, they have to know where they'll break even.

Unlike in research, bureaucracy is vital in a production environment. There the stakes aren't a single working machine, but entire series of them. Each one must be predictable and reliable. Without strict discipline, the ordering and manufacturing processes will descend into chaos. Once a Natlab masterpiece lands in a product division, the great transformation begins.

So, too, for the e-beam writer and the stepper. Natlab's researchers toss the machines over the fence to S&I, poorly documented, with at best a few short descriptions, some photos, and a couple of scientific articles. S&I's engineers then roll up their sleeves and get down to diligent work to ready the machine for mass production. Everything has to fit together. The systems go back to the drawing board and every part is described in detail. Every sliver gets a 12NC.

During re-engineering, the product division's designers regularly add their own twist to the technology they've been given by Natlab. So it's not entirely unwarranted that the researchers accuse the industrial groups of trying to reinvent the wheel. From the product divisions' point of view, however, it's a bitter necessity. They have to make the products suitable for mass production. They're not building proof-of-concept models, but machines they will have to manufacture and maintain for years to come.

The mutual rivalry swells to a nearly unbridgeable chasm, with the self-righteous Natlabbers on one side and the opinionated product developers on the other. In reality, Natlab's arrogance is an indifference that has grown through the years. Almost no one ever consults the researchers once the technology has been turned over to the product divisions. They've acquired an attitude that says *we've done our job; if the industrial groups don't want our advice, then they can figure things out by themselves*.

For George and Klaassen the situation is extra complicated. There's no extended support team they can call on, and barely enough budget to thoroughly re-engineer the machine. Most of S&I's attention is on the e-beam writer, for which it already has three orders.

* * *

When George and Klaassen visit Natlab, they do indeed meet with cynicism. The researchers there think the wafer stage they've built is brilliant. S&I would be smart to reproduce it as is. Their attitude is understandable: Klaassen's still wet behind the ears, and now he's going to redesign something all by himself that Natlab worked on for more than a decade.

Klaassen notices the Natlab team's critical attitude, but it doesn't bother him. The senior researchers accept him, despite his age and lack of experience. What's more, he and Rob Munnig Schmidt, who's just joined Natlab himself, are largely on the same wavelength.

But in the months that follow, Klaassen doesn't get very far. His lead screws are accurate to a few microns, but the vibration after every displacement lasts too long. The machine has to settle down before the piezo motor can start its fine-tuning.

It's way too slow, he thinks. *This thing isn't going to work anytime soon*. What's more, his system is much too large. The entire parallelogram structure is six feet on a side: a little big for positioning silicon wafers the size of a coaster.

Munnig Schmidt's skepticism isn't helping. The young researcher regularly visits S&I to see what Klaassen's accomplished. He often waves a hand in dismissal: *Frans, that approach won't work*. There's not much discussion, because Klaassen knows Munnig Schmidt is right. *Rob may be arrogant, but he knows what he's talking about*.

Klaassen's actually pretty fond of his academic colleague. Munnig Schmidt is approachable and easy to get along with.

* * *

As 1979 progresses, the problems start piling up at S&I. George and Klaassen manage to get the electric wafer stage working, but it isn't good enough for a wafer stepper. Troost is in a bind. His stepper team is understaffed and he can't free up anyone to join them.

George and Klaassen don't have the knowledge they need to tackle the problem's complexity. The longer they work on it, the more they realize they desperately need Natlab's and Elcoma's expertise. The experience the lab has gained is simply missing at S&I. They can't just knock out a new design for a complex machine like this one with a couple of engineers. Slowly but surely, George and Klaassen realize there's no way to re-engineer the machine. Maybe they just need to reproduce the device as it is.

In addition, George can't get his boss to commit. Beelaard's fully occupied with the e-beam writers, for which S&I has already landed orders. A frustrated George lets his colleagues at Natlab know that S&I isn't going to make the deadline for IBM Burlington. The lab echoes the distress call back to S&I, and that works wonders.

After a few intense discussions, Troost takes action. In an infamous letter[7] he orders the engineers in charge of the wafer stepper project to make an exact copy of the Silicon Repeater 2. "In order to be able to deliver machines in the shortest possible time frame and in order to clear up any misunderstanding," his edict begins. Beelaard has lost the argument. They're going to use hydraulics after all, despite all the disadvantages.

George's ploy goes unpunished. Troost dislikes the little bastard, but when all's said and done he's a good engineer. The S&I director is allergic to hassle and above all wants to put everyone on the same page, so George stays at his post.

Troost orders the stepper team to avoid all risks and build five Silicon Repeaters with hydraulic table as a "Chinese copy" of the Natlab model. Only after they succeed in getting those five machines to work, will they start on the next generation. Troost emphasizes in his letter that an electric table is a much better solution, but the collaboration it requires between Natlab, the CFT, and S&I clearly makes it a long-term approach. He puts it this way in his letter: "To reconcile short-term and long-term objectives, we will—after ensuring we meet the schedule for the PAS 2000 using the hydraulic table—consult with Natlab and the CFT on how to proceed with building an electric table."

Troost has put everyone on the same page, thereby salvaging—at least for now—their deadline for IBM Burlington. But the real problems are yet to come.

13. **GCA Plays Its Trump Card**

David Mann develops the world's first commercial wafer stepper—laying the groundwork for unparalleled success.

The lines of communication are short at GCA David Mann. A scant handful of engineers are working on lithographic machines. After Burt Wheeler and his team lay eyes on the threat posed by Perkin-Elmer's scanners, they decide to build a wafer stepper. In just a few months they convert their step-and-repeat camera into a device that can directly expose silicon wafers. A new positioning table, a stop-and-go mechanism, and they're done. Operators have to manually place the wafer onto this first primitive Mann stepper. Every exposure is done by hand as well.

Compared to Natlab, GCA's methods are sloppy. For example, the Americans don't realize that changes in air pressure affect the accuracy of the wafer stage's positioning, while Natlab's Herman van Heek is already building a calibration mechanism into the very first Silicon Repeater. GCA's engineers will later regret their oversight, but at the time what they're doing is more than sufficient.

In 1978 they introduce the result: the DSW4800 (Direct Step to Wafer), the world's first commercially available wafer stepper. The machine uses the mercury g-line and Zeiss optics that image the chip patterns at a ten-to-one reduction onto a ten-by-ten-millimeter square. The catalog price is $450,000. The first machine sells for $370,000 to Texas Instruments' research division. They use it to develop the hype of the day, magnetic bubble memories.

GCA doesn't deliver top precision, but the Americans are the first to launch a commercial product. In contrast to Philips, they select an alignment system that doesn't go through the lens. It's much less accurate, but much simpler to produce than the alignment system Natlab's designed. That's a deliberate choice. Optical engineer Howard Lovering and his project manager, Griff Resor, are both familiar with the problems that Telefunken and Siemens have had in recent years developing through-the-lens alignment. Resor's seen that Philips has managed to pull it off, but GCA's engineers choose the safe route and keep their alignment mechanism simple.

GCA's approach is straightforward. The development team chooses the technologies they have on hand, such as lead screws for the stage. The result is once again much less accurate than the Silicon Repeater's oil-driven table and motors, but it's good enough and considerably cheaper. GCA just wants to go to market as fast as it can.

GCA's relationship with Zeiss began years earlier. David Mann bought the first lenses for its photorepeaters from Bausch & Lomb, then switched to Nikon in 1969.[8] But in the early seventies the company discovers an unpleasant quirk in its six-barrel step-and-repeat cameras using Nikon lenses: when the lenses' focus changes, the image size changes with it. As a result, the patterns in the mask set for a chip don't line up precisely. Lovering realizes he needs a lens whose image doesn't change when the machine brings the wafer into focus. That means the light must hit the resist at a ninety-degree angle.

A lens that can do that is called telecentric, and to find them Wheeler and Lovering travel to Germany to visit Zeiss. Zeiss's interest is piqued; the company starts making lenses for GCA's photorepeaters, and a few years later Mann also uses Zeiss optics in its first wafer stepper.

When Wheeler and Bill Tobey introduce the DSW4800 to customers, the reception is initially lukewarm. Texas Instruments starts using the machine for research and is enthusiastic, but after a while decides the system is too slow to buy it in volume. Tobey nonetheless manages to close deals with Intel, Fujitsu, and Mostek.

The product's launch doesn't go off without a hitch. Mann's stepper has trouble working with Perkin-Elmer's projection scanners. In those days nearly every chip fab has them, and they want to be able to shuttle wafers between the two machines.

But word spreads quickly about the qualities of GCA's steppers compared to Perkin-Elmer's projection aligners. In barely a year's time, Mann has the attention of the entire semiconductor industry. Other big names such as IBM, Fairchild, National Semiconductor, and even Siemens in Europe are quick to order a GCA stepper. Mann is the only company capable of delivering the machines, and very soon the company can't keep up with demand.

While S&I muddles on, trying to get its PAS 2000 working, Mann's device soars to unprecedented success in the late seventies and early eighties. GCA's stepper revenue skyrockets from $12 million in 1978 to more than $110 million in 1981. In that same period Mann's engineering staff swells from ten to more than sixty.[9] Mann's machine acquires a new name: the GCA stepper.

* * *

At the end of the eighties, a young Harvard doctoral student named Rebecca Henderson is researching the rise and fall of GCA's wafer stepper business. She can't quite put her finger on the success of the early years. Perkin-Elmer's one-to-one projection scanners are still effective at that time—and a good deal cheaper than wafer steppers. Yet the DSW4800 is an instant hit, and chip manufacturers start placing orders right away.

Henderson suggests several explanations. In its marketing materials, Mann compares itself favorably to Perkin-Elmer by emphasizing the superior resolution and high numerical aperture of its Zeiss optics. In contrast to the one-to-one Micralign, the DSW4800 also images dust and other mask errors in reduction, and that significantly increases yield. For chip manufacturers, these are very appealing arguments.

But marketing prowess and technical advantages can't be the only reasons, Henderson writes. She points out that Mann's steppers don't make Perkin-Elmer's scanners instantly redundant. Chip manufacturers keep using the much cheaper scanners well into the eighties. Elcoma doesn't even *start* using Perkin-Elmer's projection systems until 1978.

Even in the early eighties, the scanner's resolution and overlay are more than sufficient for the chips of the time. Japanese manufacturers conquer the memory market in the early eighties not with steppers, but with projection systems from Perkin-Elmer and Canon. In the late seventies, Motorola and Mostek do succeed in rapidly capturing a large share of the memory market with the help of DSW4800 steppers. In 1980 Motorola is even the first to launch 64-kilobit DRAM memories that have been manufactured with steppers.

As GCA David Mann's first sales director, Doug Marsh is witness to the successes that chip manufacturers are having with the DSW4800. The American, who will later run the sales division at ASML, sees that his customers are profiting from the precise overlay. Stepping is slow, but because the exposure patterns align better, waste is low and profits high.

The first DSW4800 doesn't yet have a reticle handler, the mechanism for managing the reduction masks (called reticles), but that doesn't bother memory manufacturers. These specialists in mass production buy a stepper for each layer in the DRAM chip so they don't have to switch masks. Once it's all up and running and there are no defects on the reticle, they leave the steppers alone and production can run smoothly for months.

Another explanation for the DSW4800's success is that the semiconductor industry is steeped in paranoia. Some chip makers prefer to play it safe. In the chip industry, the time between ordering a machine and firing up mass production is an eternity. It takes at least two years before a stepper is running at full capacity. Henderson says that at the end of the seventies, pretty much the entire industry is overestimating the requirements for future production. Almost no one wants to run the risk of missing a chip generation, and so everyone buys their machines from GCA.

14. **Knocking on the Government's Door**

Philips lobbies the Dutch government to subsidize the development of its lithographic systems, to no avail.

While GCA is going gangbusters, things in Eindhoven are less rosy. In 1980 it's crystal clear that S&I can't fulfill its towering ambitions for the lithography market. The business plan from 1978 says the product division is on track to deliver sixteen steppers and capture a market share of 20 percent. With a little extra effort twice that much is possible, the text enthuses. But now, more than two years later, not a single stepper has passed through the factory gates.

Even development is in chaos. S&I hasn't managed to get even one stepper up and running. At the end of 1979 Wim Troost ordered his engineers in no uncertain terms to first build an exact copy of the Natlab machine before they started cooking up new ideas. But a year later, their "Chinese copy" of the oil-based machine still isn't working.[10]

S&I's management begins to realize its engineers can't get a handle on the stepper's complexity. Chip-imaging systems might just be harder than airplanes and telephone switchboards. The handful who are working on the stepper are nowhere near enough. They've got dozens working on the e-beam writer.

Meanwhile, the Netherlands and Europe are falling ever further behind in the global electronics race. The Dutch government is also starting to worry. Philips and American manufacturers are having a hard time of it in the consumer electronics market. Sony, Matsushita, and JVC are emerging powers. It's the glory days of the VHS video recorder, and in 1979 Sony introduces a new blockbuster, the Walkman. Philips' top dogs pull a few strings and arrange for Ab de Boer to visit The Hague, the seat of the Dutch government, to explain lithography and its strategic importance for the Netherlands.

In October 1980 De Boer travels to the capital city with Troost and Theo Holtwijk, Elcoma's strategic planner. Holtwijk's task is to impart the strategic value of semiconductor technology to prime minister Dries van Agt and a sizeable contingent of ministers and government officials. After Holtwijk has deposited a few valve amplifiers, chips, and printed circuit boards on the table, he says, “Only the companies that succeed in using these to keep lowering the cost of production and add more and more features to their products can win the battle. The only way to keep running this race is to invest in lithography.”

* * *

After the meeting, De Boer asks Eduard Pannenborg, a member of Philips’ executive board and former Natlab director, to come to The Hague and add weight to their request for support. The situation De Boer outlines when he briefs Pannenborg is sunny. Philips is excellently equipped to conquer the market with both e-beam writers and steppers. “We expect the Centre Electronique Horloger in Switzerland to sign a contract any day now,” De Boer writes. Letters of intent have also been signed with the Leti research institute in France and Raytheon in America to provide them with an e-beam writer.

De Boer writes that S&I has five steppers under construction that will be operational in March or April 1981. He sketches a world in which semiconductor manufacturers are lining up to buy these machines from Philips. “Thanks in part to the long wait times for other lithography equipment, the IC industry is eager to sign contracts with Philips now,” De Boer tells Pannenborg. He says Motorola is interested in twenty-four steppers “and possibly up to forty,” Elcoma’s and Signetics’ own fabs need thirty to fifty steppers, and IBM is requesting “possibly thirty to forty units.” All at a price of $1 million apiece.

S&I’s stepper team is massively understaffed, but De Boer’s letter wisely avoids mentioning how hopeless the situation is. He does emphasize the urgency, however. “The fact that no mass-produced machines are currently operational forces us to include an escape clause in every contract we close. If we are to meet the requested delivery dates, we must significantly increase our manpower right away, and significant investments in materials are imperative."

De Boer asks Pannenborg to lobby the government to free up money for lithography. The S&I director writes that he will need $10 to $13 million per year from 1981 through 1983 and that he wants to hedge this risk through support from the EEC[11] or the Dutch government. "If we are able to get the stepper running within the proposed time limits, the actual risk will of course be far lower, encompassing only the development effort that anticipates revenue," he reassures Pannenborg. But the men from Philips fail to convince the Ministry of Economic Affairs.

15. **The Electric Wafer Table**

Rob Munnig Schmidt comes up with an electric table to replace the oil-based stage.

In the post-war years, pretty much every engineer is welcome at Natlab, whatever his educational level. Social handicaps are unimportant; only talent and drive matter. And so in the sixties and seventies the lab blossoms into a playground for a hodgepodge of geniuses: a grab bag of team players and loners, of socially maladjusted technophiles and warm personalities, of workaholics who ignore their own needs and brainiacs with formidable egos.

The actual power is held by Natlab's group leaders and section directors. During their job interviews, new researchers spend a full day on campus and speak with a handful of managers. The managers have just two criteria: enthusiasm and brilliance. And their word is final. If even one of them expresses reservations, the deal is off.

HR is just a formality. Everyone has to deal with the anonymous bureaucratic behemoth down the street, but the first draft happens in the field, through a widespread network of professors. Like Big Brother, Philips has eyes and ears at every university. In the post-war years, nearly every Dutch professor of engineering or science has a link with the electronics company. The network of professors spots talent and if necessary, gently but firmly maneuvers it toward Eindhoven.

* * *

And so, one fine day in 1977, a part-time professor named Evert Muijderman at the Delft University of Technology asks Rob Munnig Schmidt, "Do you already have an idea where you'll be working?" The Philips scout has noticed the young doctoral student's exceptional qualities. For his dissertation, Munnig Schmidt single-handedly designed a complete system, a portable infusion pump with an electronically controlled motor.

Munnig Schmidt is an idiosyncratic young man with a boundless interest in technology. To him, it's a world of wonders, and he bounces from one marvel to the next. His education in precision engineering feels more like a hobby than hard work, and in his free time he fiddles around with valve amplifiers and electronics. Yet he's not a typical nerd with his nose glued in his books. He talks a blue streak and plays in a band. In short, he's that rare specimen who combines technical talent with a healthy dose of social intelligence. His only fault is his considerable ego. He quickly dismisses fellow students who don't impress him. He's barely aware of the world outside the university walls. College is where you go to have fun; work happens on a different planet.

"Have you ever considered Philips?" Muijderman suggests. The only association Munnig Schmidt has with the company is light bulbs. But Muijderman explains they also have a large mechanical engineering division in Eindhoven. "How do I apply?" Munnig Schmidt asks. "Grab a pen," Muijderman replies, and he dictates a simple cover letter and a short résumé on the spot.

Two months later, Munnig Schmidt receives a letter from Philips HR. A taxi will pick him up at Eindhoven Central Station. A train ticket is enclosed.

Philips treats the naive twenty-six-year-old to the same VIP treatment it gives all its university-educated interviewees in those days. The taxi has been reserved for his personal use for the entire day, and it carries him from one group head or director to the next at Natlab and the CFT.

Munnig Schmidt discovers a company that's crazy in the best of ways. His very first conversation knocks him out of his chair. "Electronics!" shouts managing director Hajo Meyer excitedly when he hears that the young mechanical engineering student plays around with transistors and resistors in his free time. The temperamental director grabs the phone and completely upends his young guest's schedule in a few short calls. "Where are you sending him?" Meyer barks into the phone. "To the CFT? Nonsense, scrap that. He'll go to the optics group and electronics." Munnig Schmidt doesn't know what's hit him. He expected a simple, orderly day of interviews, but Meyer's turned the whole place upside down, just for him.

During his tour of the Philips campus it's the technology that most impresses the young engineer. The futuristic, robot-like systems he sees are nothing he's ever associated with the company. He's blown away. "Holy cow, it's fantastic there," he gushes to his wife that evening.

* * *

When Munnig Schmidt returns from vacation in August, there's an indecipherable letter from Philips waiting for him. "Am I hired, or not?" he asks his wife. They can't make head or tails of it, so he shows the letter to one of his professors. The professor scratches his head and draws the conclusion that he's looking at a formal letter of employment. The new recruit just has to pass a medical exam and sign his contract. He'll start out at $900 per month—non-negotiable—and may visit Philips' housing service to find a place to rent.

On December 1, 1977 Munnig Schmidt shows up for his first day of work. His contract doesn't say whether he's been hired to work at the CFT or at Natlab, so he knocks on the door at HR. Confusion ensues, but eventually he's told to report to the lab. When he arrives in the neighboring town of Waalre, no one's expecting him. After twiddling his thumbs for an hour, he sees Piet Kramer storming excitedly down the stairs. "I'm going to have to improvise a little," the section director apologizes. "Sorry, uh, it's kind of a mess, but, let's see, we have two things you could do. The first one is optical recording."

Munnig Schmidt starts to glow. As an audio hobbyist he's already read a fair bit on the topic. But Kramer doesn't want to talk about that, because the optics group is also working on the Silicon Repeater. Munnig Schmidt's never heard of the thing. That day he makes the rounds of four other groups. Just for show, it turns out. "I'll tell you about what we do, but they're going to put you to work for Kees Bulthuis on the Silicon Repeater," every group head tells him.

* * *

By the time the young academic signs on, Natlab is undergoing a metamorphosis. The intensely free research lab is morphing into a tight organization with clearly defined research projects. New employees used to make the rounds of all the research groups on their first day, after which they could choose a project themselves. But Munnig Schmidt's fate is already clear on his first workday. He has a knack for merging mechanics and electronics, and that will be useful in the Silicon Repeater project.

And so Munnig Schmidt is shown to the office of the man leading the chip lithography project. The two don't get off to a great start. Steef Wittekoek, a serious scientist, suddenly has to share his office—group leader Bulthuis's idea. In the hierarchy that is Natlab, only group heads and famous scientists have a room to themselves. Wittekoek is one of the latter, but his status evaporates when Munnig Schmidt arrives. Wittekoek's peace and quiet are also history. His fifteen-year-younger officemate is a chatterbox who doesn't know when to shut up.

Like every academic, the young researcher is given an assistant. Bulthuis assigns Munnig Schmidt one of a kind: Gerard van Rosmalen, a self-taught inventor who turns everything he touches into gold. Natlab hired Van Rosmalen after he showed his interviewers a gramophone record player he built himself. In the audio and video group he works on tiny mechanisms for the video longplay disc and, later, the compact disc player. Van Rosmalen may officially be an assistant, but in reality he's a mentor who will teach Munnig Schmidt all the tricks of the trade.

In his early years, Munnig Schmidt is deeply involved with the Silicon Repeater's hydraulic motors. He designs their control system, but gradually comes to realize that oil bearings aren't the right solution. The oil-sweating conduits are a major disadvantage: they pollute the cleanrooms in the chip fabs. Munnig Schmidt's lab always stinks of oil. And then comes a minor disaster. At some point the team hears an intense hissing over the drone of the oil pump. At the back of the machine, oil is spraying from the conduits at a pressure of seventy bars. In mere seconds the entire Silicon Repeater room has been thoroughly rustproofed.

It takes employees months to clean off all the oil. *Things can't go on like this*, Munnig Schmidt decides. He starts searching for an electric motor he can use to replace the H-shaped hydraulic wafer table, inch for inch. Every dimension and connection must be the same. The audio enthusiast designs a system that works like a loudspeaker, with an electromagnet that's moved by a permanent magnet. In his design, he flips that around: the permanent magnets move past a rail of electromagnets.

* * *

At the start of 1980, Richard George's team at S&I desperately needs help building its commercial version of the Silicon Repeater, the PAS 2000. Development's a mess there. Among other things, S&I is having terrible trouble with the electronics. George has just been ordered to build the PAS 2000 as a Chinese copy of the Silicon Repeater 2, as a stopgap measure.

Munnig Schmidt has been working for a while on the electronic control for this wafer stepper, and so Natlab's management comes up with the idea to move him from Natlab to S&I earlier than planned to work on the PAS 2000. In those days he's visiting S&I regularly, to help the engineers there build their Chinese copy. To his annoyance, he sees they've redesigned all the electronics from scratch, but aren't getting any further.

When Meyer suggests he move to S&I earlier than planned to work on the PAS 2000 there, Munnig Schmidt is not amused. S&I's bumbling work flashes before his eyes and boom, he's made his decision. *No fucking way*, the young engineer thinks. Two years at Natlab have only boosted his ego and self-confidence. "Sorry, I won't do it," he stiffly tells Meyer.

Munnig Schmidt explains that he joined Philips to do research, and that two and a half years at Natlab later he still hasn't gotten around to it. Instead of doing research he's done engineering work. To be blunt: he has no interest in industry and intends to complete the five years that were promised him at Natlab. Meyer stomps off to see Bulthuis, who in turn complains to Munnig Schmidt. “Hajo Meyer is mad as hell. What did you say to him?” the group head growls.

“Listen, Kees,” Munnig Schmidt says. “Those hydraulic motors in the Silicon Repeater are never going to make it into the factories. I have an idea for how to do it electrically.” The young researcher opens his lab journal, filled with two years of notes, and shows Bulthuis a sketch of his basic design for an electric linear motor.

Munnig Schmidt came up with the principle back in 1978, but Wittekoek never gave him enough time to work on it. After all, S&I’s priority is creating a mass-manufacturable version of the Silicon Repeater 2. That machine uses hydraulics, and Wim Troost very clearly commanded them to make a Chinese copy.

Bulthuis recognizes the import of Munnig Schmidt’s research work, and the old spirit of Natlab bubbles back to the surface: here’s a researcher with an idea that’s good for Philips. “Okay,” the group head growls, “work on it.”

* * *

Munnig Schmidt gets down to work with designer Ad Bouwer. Bouwer sketches diagrams and designs the coils for the electromagnets. Together they stack the iron strips for the core and glue them together. They also build an interferometer so they can measure the carriage’s position, and Munnig Schmidt designs the control electronics for the whole system.

Unfortunately, the result is a fiasco. Nothing about it works and Munnig Schmidt goes back to Bulthuis with his tail between his legs. The group head is not amused, but he doesn’t let it show. After their meeting Munnig Schmidt decides to work through his vacation. His wife, who has since been hired to research materials and laser technology at Natlab, keeps him company in the summer months of 1980.

And there he sits, Mr. Know-It-All. The smart aleck who always has a comeback ready. Barely a year earlier he sneered at Frans

Klaassen's mechanical table. In withering remarks he let Klaassen know in no uncertain terms that his system with its huge lead screws and piezoelectric actuators was doomed to fail. Now he's saddled with his own fiasco.

Munnig Schmidt has built an electric motor, but he doesn't really know how electromechanics works. He's a mechanical engineer, not an electromechanical one. The young engineer doesn't realize that he needs to take not only the Lorentz force into account (which makes the actuator move back and forth), but also the magnetic resistance, known as reluctance.[12]

Through trial and error, Munnig Schmidt refines his design. Wittekoek frees up funding for him and Bulthuis, whose office is a few doors down, keeps a close eye on his employee. Munnig Schmidt discovers he needs a commutator: he needs to separately control each electromagnet in the series to get the total movement to be smooth. He works out his design, orders coils, lines them up in a row, and controls each electromagnet with a separate booster. Bouwer helps him design it by working out the bearing system, and a few months later they've got it working.

Suddenly the linear motor is moving smoothly, without shocking or jerking, in a single fluid motion. The system also has the required static accuracy when it's standing still. The two characteristics are the heart of the design. To achieve smooth motion, Munnig Schmidt has two separate boosters work together for each motor. He makes sure their amplitudes gradually transition from one to the other and that accelerations and displacements are controlled.

Munnig Schmidt writes a patent proposal for what he will later view as his only invention with a tangible impact. His linear motors will enable many generations of lithography machines to achieve extremely rapid accelerations—and thus a much higher throughput than those of competitors. To this day, Munnig Schmidt's "actuation principle using electronic commutation" has enabled ASML to keep its chip lithography competitors at bay. But in 1980 Philips' patent office rejects his proposal, because it's too similar to principles that have already been invented.

S&I's Klaassen walks into Munnig Schmidt's office one day and sees that his Natlab colleague is able to demonstrate the principle for his new motor. *That Natlab thing is much better than what I've come up with*, he thinks. Yet Munnig Schmidt won't get the chance to finish what he's started. In early 1982, Meyer calls the Silicon Repeater team together. S&I is in crisis.

16. **The Rescue Mission**

George de Kruiff and Hajo Meyer save S&I's stepper project by stationing a team of Natlab researchers at a product division—for the first time in Philips' history.

Frans Klaassen discovers that making an identical copy of the Silicon Repeater isn't as easy as it seems. Natlab's attitude seems to be *here are the drawings; just copy these exactly and everything will be fine*. But the stepper is poorly documented, and that means S&I's engineers can't get a grip on the finer details. George and Klaassen are constantly knocking on Natlab's door to help them solve their problems. At the lab they tease the pair that the new name PAS 2000 means the machine won't be ready until—"pas" in Dutch—the year 2000.

At the lab Klaassen observes the approach used by Bouwer, the brilliant designer who guides Natlab's job shop with a good chat and a few quick sketches. The lines of communication are short at Natlab. If the shop doesn't understand something, Bouwer explains it and problem solved. No one takes the trouble to record small changes to systems or their electronics on the original diagrams. That's a bridge to cross if they ever need to.

Natlab has an excellent method to compensate for its lack of documentation: the house photographer captures everything on film. And so Bouwer's creations are recorded for posterity, in arresting black-and-white photos.

The engineers from the product division aren't off the hook, either. They can't resist improving on the designs. Copying just isn't in the genes among Dutch engineers, and S&I's culture is Dutch to its core. The division is quick to think everything can be done better.

But it's harder than they expected to make an S&I copy of the Silicon Repeater 2. Klaassen notices that as time passes, the product developers sink ever deeper into the swamp. They miss the finer points of the design, don't realize why Natlab designed the stepper the way it did, and underestimate the fallout of every tiny change. As a result their tweaks cascade into elusive problems. They've copied the hydraulic wafer stage inch for inch, but S&I's version is somehow incredibly slow. What's more, it's playing funny tricks. For example, the oil pump is transmitting its vibrations to the wafer stage via the eighty-bar oil circuit. You can't see it with the naked eye, but the vibration blurs the images. To make matters worse, the stepper team contains a couple of mediocre electronic engineers. George blames his boss, Beelaard. He believes Beelaard is hamstringing the optical lithography project by putting all his best people on the e-beam writer. And the Englishman doesn't have the diplomatic finesse to convince his boss otherwise. Besides, Beelaard has higher priorities: he already has orders for three e-beam devices.

For the production of electronic components, George's team is at the mercy of S&I's electrical engineering shop. There, the engineers working on the PAS 2000 encounter a group that's mired in bureaucracy. When Klaassen and his colleagues knock on the door and hold out their diagrams, the shop's mindless cogs in the machine often shake their heads. "Oh, that's not going to work," is the lead designer's usual response. Without asking he scribbles a few comments on the sheet, and without another word passes the drawings on to have them turned into printed circuit boards.

After a few months, George's team is handed an electronics board that doesn't work because the shop has no idea how the stepper works. It all generates enormous annoyance and frustration. The PAS 2000 team tries to get the thing working, but the engineers are hampered by their own obstinance and a lack of real teamwork. George and his people feel like the whole world is working against them.

But George's fifteen-member team also lacks the skill and the resources to get the job done. A major factor slowing things down is the electronics for the complex control system. The engineers have hardwired almost everything about it. That means they have to break out the soldering iron for every alteration. Flexible programmable alternatives are already available in those days, but George is barely aware of them.

* * *

By the start of 1982, it's becoming clear that S&I is going to miss its deadline to deliver the PAS 2000 to IBM in June. Team leader George is furious. He's been able to make a simple test pattern using the machine. He sends a Polaroid photo of the resist structures to management right afterward, but all things considered he knows this milestone is more luck than skill.

With this tragedy weighing him down, George skulks through the halls of S&I's bunker in a black mood. Then, suddenly, he sees George de Kruiff. The Englishman knows how much delivering the PAS 2000 to IBM means to S&I's technical director. He grabs De Kruiff by the arm and tells him straight up that the deadline is in grave danger. George is acting true to his defiant reputation: once again he's going over the heads of his boss, Beelaard, and his boss's boss, Troost.

De Kruiff listens, but what can he do? George suggests the technical director call a meeting with everyone who's got a dog in the race. He needs to talk with Wittekoek, the man running stepper research at Natlab, and Roel Kramer, who runs chip production at Elcoma.

A few days later De Kruiff calls the three men in. Beelaard and Troost aren't there when George explains the problem. The team leader shamelessly vents his frustration. He says he doesn't have enough people on his team, and the ones he has aren't good enough to build a successful machine. De Kruiff listens carefully, and when an hour turns out to be too short, he cancels his next meeting. Two hours turn into three; the technical director cancels another meeting, and then he calls Hajo Meyer at Natlab.

De Kruiff knows Meyer well. Meyer is the man who, in the sixties, understood the value of Natlab's precision technology and merged optical and photochemical expertise in the optics group. De Kruiff is one of the few division managers who's on good terms with the research lab. "Shell has its oil fields; we have Natlab and we should be damn proud of it," he often tells colleagues from other divisions when he hears them belittling the band of free spirits in Waalre.

George, Wittekoek, and Kramer are there for the lengthy telephone call and listen with breathless attention. At the end Meyer makes De Kruiff an offer: "George, I have an idea. I'll send all the stepper guys from the optics group to work in your building, under you." No Natlab director has ever done such a thing. Meyer's offering to station all the Natlab researchers who are important to the wafer stepper project at S&I to ensure delivery to IBM.

De Kruiff writes a note right away that Friday, March 19, 1982. "In the view of the experts (George, Kramer, Wittekoek) there are still a few problems with the PAS 2000 which are not fundamental," he writes. "But solving these problems in the available time requires the focused attention and effort of all the experts at Natlab and S&I." The letter proposes that George and Wittekoek lead the mixed project group and that the first PAS 2000 must be ready to ship to IBM on June 8, 1982. All the people from Natlab are expected at S&I on Tuesday. In the months that follow, the combined team must "solve the existing problems and gain experience with the customer's application."

At Natlab, Meyer announces the unpleasant message to the Silicon Repeater team. "S&I is in deep trouble," he says. "We've decided to mobilize all the available engineers to solve the problem together. I know you don't want to do it, and that you think S&I needs to fight its own battles, but we need to act like colleagues and help them out."

Meyers knows all too well that his researchers are less than charmed by this move. The Natlab researchers ask him to guarantee they can keep working together as a team. He does. At the end of the meeting, Wittekoek grabs a legal pad and writes a quick note to the management at Natlab and S&I: "Given the holistic interdependence of the entire issue and given how well the Natlab team works together, the most efficient solution would seem to be keeping this team together and grouping the work to be done around that."

When Meyer and De Kruiff run into each other in the years that follow, De Kruiff always lets Meyer know how grateful he is. The towering S&I director claps Natlab's diminutive thunderbolt on the shoulder and says, "Hajo, what you did back then, that was fantastic. You pulled us back from the abyss."

* * *

On Tuesday, March 23, 1982 Ad Bouwer, Henk Bartelings, Rob Munnig Schmidt, Jan van der Werf, and Steef Wittekoek reluctantly arrive at building TQ on the Philips campus. At Natlab they're used to doing whatever they want. If someone wants something from them—even if it's the top dog—they'll question it. "Is this a management decision, or have you really thought it through?" is a frequent expression.

But now the researchers feel like they've been demoted to errand boys. They're spoiled, never starting work before nine and spending the whole day frolicking in their technological playground. Their work is their hobby, and who knows when they'll leave for home.

The S&I product division marches to a whole different drum. There, everyone clocks in promptly at eight and leaves for home exactly at five. The Natlabbers ignore this nonsense from the start. Getting up early is unpleasant, so they wander in an hour later. Their bad behavior soon reaches management's ears, but technical director De Kruiff cuts all discussion off at the pass by saying, "The more civilized one is, the later one starts work."

Natlab's research culture is worlds away from S&I's product development world. In the product division's eyes, the researchers do sloppy work. The things they make at Natlab are just prototypes, after all. Prove it works, then run to the patent department. Write up a paper after that, and that's the end of it.

Compared to that, product development at S&I is highly bureaucratic. Every part, every module, every system has its twelve-digit 12NC code and accompanying parts lists, diagrams, and manuals. Devices and machines are documented down to the smallest detail using a pyramid of informative 12NCs, everything they need to process orders and direct the warehouse. All that documentation isn't just for making the machines; once they deliver, they need the numerical codes for after-sales service and repairs.

It's a necessary straitjacket at S&I. Not very flexible, but indispensable for mass-producing reliable, maintainable devices and instruments.

This difference in culture often creates friction: the industrial groups complain about sloppy Natlab, the research guys criticize the product divisions that never say a word and run off with every invention once it's been turned over to them.

S&I may chart a singularly unique course in electronics, but its stepper team doesn't have enough expertise to design a decent control system for the PAS 2000. The project is in a mess when the group of Natlab researchers arrive at the end of March.

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Cultural differences or not, S&I rolls out the red carpet for the men from Natlab. They're given their own office and free rein.

And rightly so, the Natlabbers believe. Their irritation at the forced transfer buttresses their arrogant attitude, turning them into veritable prima donnas. They belittle all they find at S&I, openly displaying their disdain for the ramshackle electronics. Munnig Schmidt has barely walked in the door when he theatrically dumps several electronic boards for the PAS 2000 into a nearby trashcan.

Munnig Schmidt and Henk Bartelings also regularly talk trash about Uncle Joe, one of the project's electronic engineers who owes his nickname to a dimwitted character on a Dutch radio show that's popular at the time. "Yet another Uncle Joe solution," the two roar out across the factory floor when they find one more thing that doesn't pass muster in their eyes. Everyone at S&I wears a white lab coat and goes to the shop to assemble their electronics, but Munnig Schmidt isn't having any of that. He pointedly plunks down in the middle of the production floor, soldering parts together in his everyday clothes.

To Frans Klaassen, who's grown up inside S&I, it all seems marvelous. He watches as Munnig Schmidt rudely dismisses the engineers that have been hindering his own work for years. Secretly, he enjoys it: here's a group who couldn't care less about the established order and who fling aside every obstacle in order to get the machine working. For his part, Bouwer discovers that the product developers at S&I are sloppy. He sees burrs on machined parts and components that aren't clean. "They've been hammering horseshoes and now they're suddenly supposed to craft watches," he scoffs.

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To make the deadline, the PAS 2000 team of Natlab researchers and S&I engineers sets up a new schedule, working sixteen hours a day in two shifts. Promptly at one-thirty in the afternoon, the second floor of TQ observes the afternoon prayer: a daily half-hour meeting in which the morning shift turns its work over to the afternoon shift. Every issue passes in revue. Fifteen people attend the meeting, and as time passes it grows in importance. The mood is energetic, the discussions intense. Slowly but surely, two camps emerge. Natlab has the upper hand, and amid all the verbal aggression several S&I employees discover they're no longer being taken seriously. At some point they stop showing up for the daily handoff.

All in all, the rescue mission takes three months. The team spends most of its time whipping the electronics and software into shape. They don't make the June 8 deadline, but on July 1, 1982 Philips finally delivers a stepper to IBM in Burlington.

On Friday, July 2, "everyone who helped to complete the first machine" is invited to the nearby Vlierhof Café for a beer to toast the future of the stepper project. "We hope to raise our second glass with satisfied customers," the invitation reads.

* * *

The machine that arrives in the US is in fact far from complete, but it is possible to run it through tests. Those meet the spec. The lens, the alignment system, and the stage are satisfactory. For the wafer handling, the team threw together a transport system in the final months using elastic bands to feed the silicon wafers into the stepper. A microscope objective pre-aligns the wafers to get them into the right orientation on the stage.

Stepper architect Herman van Heek has since joined S&I, and he installs the machine at Big Blue with Ale Sytsma and Rein Meyer. "The IBM plant in Vermont is the largest semiconductor memory fab in the world," Van Heek writes home. "Eight thousand people work there, some of them in a three-shift system. The factory looks very well run. Security is significantly more rigorous than we're used to at Philips." After three months of testing, IBM sends Philips its evaluation on November 1, 1982. Big Blue is most concerned about the optics. Focusing and imaging work fine, especially in the center of the field. The lens is even capable of imaging one-micron lines in a seven-by-seven-millimeter field. But in three of the four corners of the full field (ten by ten millimeters) they can't get the resolution right. Throughput also falls short of what Philips had promised, but the test team doesn't seem too worried about that.

Despite the laundry list of comments and improvements that IBM sends along with its evaluation, the computer behemoth says it's considering buying Philips' machine—under certain conditions. Among other things, by the second quarter of 1983 the PAS 2000 must be able to image equal 1.25-micron lines across the entire field.

A handful of requirements follow, but the most striking thing is the Americans don't have any insurmountable objections to the oil-based hydraulic drive system, even though they've found leaks. They do insist that the machine be fully "dry." "This means seal all oil connections completely," the report states.

In early 1983 IBM even sends a request for quotation. At the end of January, Ger Janssen in marketing flies to Burlington to go through all the details with the test team's manager. Philips must respond to the conclusions and recommendations in the evaluation report by mid-February, and based on their answers Big Blue will decide whether to buy the PAS 2000.

Janssen receives several recommendations for increasing the stepper's throughput. Surprisingly, their first tip is this: improve the machine's appearance. IBM doesn't think much of its shiny metal innards. They don't hurt performance, but they make the stepper look more like a prototype than a commercial production tool, Janssen is told. They even advise him to use black anodized parts.

IBM calls the stepper's menu and software excellent, but also far too complicated. Instead of typing in cryptic commands, the Americans want a user-friendly interface that makes sense not only to engineers, but also to the plant's operators. They even offer to help design it.

Janssen asks point-blank how IBM rates the PAS 2000 compared to competitors' machines they've evaluated. The CERCO lens turns out to score poorly. The hydraulics are a weakness, and the training that Philips gave to IBM's team was below par. But they're full of praise for the alignment system. Despite the criticism in the evaluation, the PAS 2000 scores high in throughput, reliability, and documentation. *Not bad*, Janssen thinks.

IBM stresses that Philips has to do something about the lens. The chip fab needs a larger projection field and warns Janssen that all his competitors are currently developing much better optics. Philips needs to choose a different supplier, they tell him. IBM is happy to tell him which one they prefer: Zeiss is the best, followed by Tropel, Nikon, and Canon.

All's well that ends well: that's how S&I interprets the signals Janssen's received. Everyone is in great spirits. It won't be long before IBM places an order, they decide the positive reports mean. Philips' perfectionistic engineers have been plagued by the fact the machine they've delivered to Burlington isn't finished, but apparently the Americans understand what a hellish task it is to build a stepper. Okay, the lens sucks, but IBM hasn't even demanded that they replace the oil-based hydraulics. The mood among the PAS 2000 team is good—exuberant, even. "Ten machines? Don't be ridiculous," George crows optimistically to his people. "They'll order thirty or forty!" Everyone thinks it's a slam dunk.

* * *

The perceived breakthrough with the stepper at IBM inspires Wim Troost to draft far-reaching plans. He sees an entire business unit before him, whose main activity is making machines for chip production. First off, there's his pride and joy, the EBPG, which S&I has been working on since 1976. This e-beam writer has proven its worth since then. A few units have been sold, and the expectation is that e-beam lithography will occupy a central role in future chip fabrication. Add in the PAS 2000, and Troost has the entire IC lithography landscape covered.

In addition, Troost argues that S&I should use its electron microscopes to analyze the chip process. Expertise in electron optics will also be useful in developing e-beam writers for chips.

Meanwhile, Troost has become acquainted with the wire bonders being developed by Elcoma's mechanization group. These superpowered sewing machines connect the contact pads on chips to the outside world via gold wire. Chip fabs can also make good use of S&I's automatic testers, Troost argues.

Troost is inspired. The global market for wafer steppers is slated to grow to a thousand machines in the coming years, and Philips should be able to deliver 40 percent of them at $1 million apiece, he argues. He brings up his plan time and again during the Monday morning meetings where S&I's directors present their unit's activities. But the atmosphere there isn't so friendly. The other directors don't much want to help Troost and give him no room to set up something new. "Wim, that's not a good fit for Philips," they say tersely. "We have better uses for our time."

Troost is shocked by their lack of vision and confidence. "Close the cardboard factories and shut down welding operations, fine," he responds bitterly. "But this is a great fit for our mechanization operations. These are strategic machines with a promising commercial future." It doesn't help. Even Henk Bodt, who currently directs S&I's testing and control division and will later join ASML's management team, isn't interested in the venture. No one takes Troost truly seriously.

Only De Kruiff is interested in what he has to say. S&I's technical director arranges for Troost to have fifteen minutes to present his plan to Philips' executive board. But they, too, shoot down his plan.

* * *

Meanwhile, commercial director Ab de Boer keeps working on the Dutch government. Europe is falling ever further behind the Americans and Japanese, and that opens up all kinds of opportunities to pry money loose for strategic development. De Boer practically camps out on the doorstep at the Ministry of Economic Affairs to wheedle support for his division's lithography efforts.

When he once again visits the ministry's interim director general, Jan Hillege, on August 4, 1982, he reminds the top official that Europe is lagging behind the US and Japan in semiconductor technology—and the gap is steadily growing. He tells Hillege in no uncertain terms that this isn't just about chips; integrated circuits are of strategic value for every industry that uses microelectronics. "We have a choice," De Boer says. "We can become dependent on the Americans and Japanese for this strategic technology, or we can invest in it ourselves. Steppers are a cornerstone of the European industrial strategy for responding to this threat."

De Boer tells Hillege that investing in his division's lithography efforts is a chance to cultivate new territory. The chip market will double in volume between 1980 and 1985, and that offers immense opportunities. "The global market for lithography machines will more than triple," De Boer tells Hillege. His division expects other activities such as welding to decline. Lithography promises to more than compensate for these end-of-life pursuits.

De Boer aims high. He tells Hillege there's not much point in trying to enter the lithography market with his division's limited financial resources. "S&I's management has rejected that approach, given the development speed and complexity of this market and its technology," he declares. He says the competition is "alarmingly strong." S&I can only succeed if it invests heavily.

As De Boer sees it, there are two options: Philips can proceed under its own power, or it can look for an American machinery manufacturer to set up a joint venture. Either alternative requires a substantial financial injection. He asks if the ministry will fund a quarter of the risk-bearing investments for the years 1981 through 1986: $25 million for the e-beam writer and $50 million for the PAS 2000. “Manufacturers in the US and Japan receive generous funding from their governments,” De Boer says. “In Germany, England, France, and Italy, too, the government is helping out its industry.”

De Boer points out that the US is responsible for half of global chip production. Partnering with an American maker of semiconductor production equipment will give them a solid position in the US. Such an undertaking also has the potential to penetrate the Japanese market. The joint venture can draw all its expertise from Philips’ subsidiaries CFT, S&I, Elcoma, and Natlab. “Alone, we might be able to capture a market share of 10 percent, but with an American partner 20 to 25 percent is almost guaranteed,” De Boer confidently declares.

Hillege doesn’t have to worry the joint venture will siphon off production and thus jobs. “We’re going to set up the sales team in the US, but the joint venture will build its lithography equipment and subassemblies at S&I in Eindhoven,” De Boer says. “Production will initially jump. That means machinery manufacture and thus employment can achieve the same order of magnitude we’d have without an American partner.”

A month later, De Boer sends the ministry a detailed plan including figures. The plan expects lithography personnel to grow from 117 employees in 1981 to 282 in 1986. S&I’s management predicts that growth to occur exclusively in technical support and production. They don’t expect R&D to expand. In 1981 and 1982, S&I has fifty-plus people working on development, and even believes it can make do with just forty-four R&D jobs through 1986.

S&I is investing more energy in lobbying the government than in cultivating customers. But funding doesn’t materialize, and that keeps investment in steppers at a low priority. The lithographic activities are kept on life support, but no more. Meanwhile, IBM keeps failing to place an order. Everyone sits around, passively waiting for the order to arrive. No one bothers to contact the Americans to seal this important deal.

* * *

In the early 1980s, S&I's lithography development is petering out. Nothing exciting is happening, and that sours the mood. Klaassen bikes to Natlab more and more often, instead of to his own office. The rescue mission has solidified his click with Munnig Schmidt, and even after the researcher returns to Natlab, the two continue to work together.

Klaassen is impressed by Munnig Schmidt's invention. His linear motor is now running smoothly. Its propulsion system is revolutionary, even if it looks simple. Control is a matter of applying the right amount of current to the right coils. Munnig Schmidt measures the carriage's position using an interferometer with a tiny mirror he's attached to the train of coils.

At some point Munnig Schmidt leaves to work on vacuum cleaners and electric shavers at another division. He offers Klaassen the reins of the wafer stage project at Natlab. Klaassen seizes the chance. He's young, ambitious, and all too eager to escape the depressing atmosphere at S&I. George and Beelaard turn a blind eye, but they exhort him not to say a word to upper management. Officially Klaassen works for S&I, but from then on he bikes to Natlab every day.

Klaassen starts working on a design in which three linear motors work together in an H-shaped setup, as previously concocted by Bouwer. The S&I engineer spends months at Natlab. The stage has to accelerate sufficiently, be accurate, and not vibrate too long after movement stops. Acceleration turns out to be easy. Speed is limited only by the interferometer, which measures displacement using a laser beam. Accuracy seems to be okay, but in fact they can't properly measure it. To do that they need a lens, and the system doesn't have one yet. Klaassen sees that it's critical to dampen the vibration: when he hits the brake, the table doesn't stop moving right away. "It's a cobbled-together mess that barely gets the job done, but it meets the specs," he notes in his lab journal.

All his tinkering at Natlab is done by trial and error. Henk Bartelings helps Klaassen with the control electronics, and sometimes they spend half a day adjusting volume dials to get it all working. When they finally manage to get it just right, Bartelings is pleased. "Another job well done," he says. After weeks of adjustments, Klaassen's system is finally working according to spec. He even manages to use wheels to move the motors with sufficient accuracy, so they no longer need air bearings. But Klaassen's experience at S&I has taught him they're miles away from an industrial drive system suitable for mass production. A Natlab experiment is a far cry from a commercial machine.

17. **A Brick Shithouse**

Cobilt, Perkin-Elmer, and Varian all pay visits to Eindhoven to discuss a joint venture. When the Americans don't bite, Wim Troost is told to shut down his lithography efforts.

Over the years, Wim Troost loses credibility. He isn't given the resources or the authority to invest more into his wafer steppers. Results have failed to materialize. After a while, Elcoma's chip fab starts to wonder if it's not a little risky to buy lithographic machines from S&I.

Elcoma's directors pepper production managers Kees Krijgsman and Jan Huart with questions. The delays have made them start to doubt whether S&I can handle the stepper market.

Philips' chip fabs notice that Perkin-Elmer and GCA *are* able to deliver. In the early eighties, these two companies dominate the lithography market. In 1981 Perkin-Elmer has a global installed base of 2,400 Micralign projection printers. A whopping 125 fabs and labs around the world are using the machines. GCA's star is also rising fast. In 1981 the company sells two hundred wafer steppers. It's the absolute ruler of the stepper market.

The pressure on Troost grows increasingly uncomfortable. The five steppers S&I has developed for Elcoma are child's play compared to the hundreds of machines that roll off the assembly line each year at GCA. How is S&I supposed to compete globally on price, stability, quality, maintenance, and service if it can't deliver a commercially viable machine?

To make matters worse, Troost is in a bind. Elcoma has expressed its intent to buy the five steppers, but hasn't signed on the dotted line. What's more, the chip division is going through rough times. At the start of 1981, the fab in Nijmegen lays off nearly 3,000 of its 14,700 workers. "That's all well and good, Wim, but are those orders guaranteed?" his bosses at S&I keep asking him.

Troost doesn't have the sales staff to hawk the steppers. S&I hasn't even cleared the product for external sales yet. As a result, none of Philips' sales departments around the world jump on it, and in actual fact there's no sales effort at all.

The ongoing impasse is disastrous. The likelihood that S&I can make something of its stepper business is shrinking by the day. When De Boer knocks on Wisse Dekker's door for funding, Philips' CEO doesn't give him a cent. For the umpteenth time, S&I's management concludes that their division is the black sheep of the Philips family. They've felt misunderstood for years. Their men are only good for keeping the production machinery running to make light bulbs, electric razors, and TVs. When it's time to invest, the answer is always no. Once again the top dogs won't listen to their plans, while Philips is pouring more than a billion into the Megachip project, a race to catch up in memory technology. The fact that lithography is crucial to that endeavor? That, management ignores. De Boer reads Dekker's message loud and clear: put an end to that stepper nonsense as soon as you possibly can.

Troost moves on to Dutch investors. When they refuse to help, he and De Boer fly to San Francisco to drum up funding from venture capitalists. They aren't able to strike a chord with anyone. De Boer doesn't have enough feel for the semiconductor business, and Troost lacks the verve to hook investors with his presentations.

Dekker ramps up the pressure to relieve Philips of all its "hobbies" as fast as possible. S&I's management must get rid of all noncore activities. In addition to steppers, that means electron optics, numerical control systems, welding, and nuclear analysis are up for sale. If selling's not an option, then it'll be a joint venture, Dekker commands.

Elcoma's Kees Krijgsman points Troost at suitable joint venture candidates, such as the relatively unknown Cobilt. In those days, the company is embroiled in a multiyear squabble with Perkin-Elmer over patent infringements for the Micralign projection scanners.

Everyone knows there's also a potential partner closer to home: a Dutch company that develops chip production equipment. ASM

International has already made a name for itself. In 1981, the nation's newspapers publish copious articles on the company. ASM's CEO, Arthur del Prado, has built himself a substantial reputation as a businessman in the chip market. Troost and Krijgsman list the pros and cons of joining forces with ASM. They conclude that the equipment maker is a little too small for them.

What's more, the production equipment that ASM delivers falls in a completely different category than steppers, which are much more complex and technologically more strategic. Chip manufacturers let their fab managers decide where to buy their furnaces, etchers, and evaporators, but when it's time to purchase lithography equipment, senior management is always involved. "ASM knows the industry, but it doesn't have the contacts at that level," Krijgsman tells Troost. Another black mark is that it doesn't supply to Philips' chip fab in Nijmegen. But the most important concern is ASM's limited size and financial instability.

And so ASM disappears off the radar. To Troost and Krijgsman, it's clear that Philips has a greater chance of succeeding in lithography if it joins forces with a leading American firm.

* * *

Troost discusses a potential joint venture with Cobilt. His contact at the company voices his surprise that behemoth Philips is dependent on a foreign supplier for its optics. He'll only consider Troost's proposal once he's convinced of the optics supplier's financial stability.

Herman van Heek is the one who arranges for Cobilt's man to travel to Zeiss in Oberkochen, West Germany. Van Heek has been on good terms with CERCO in Paris for years, and recently he's developed a relationship with the German optics specialists. He avoids sending Cobilt to the French supplier, because they can't show him serious mass production. Things in Paris are a mess.

Commercial director De Boer goes with them. Zeiss rolls out the red carpet for the three men. The Germans diplomatically convey to the American from Cobilt that there's a far greater chance their company will still be around in fifty years than that his will survive that long. It's a successful trip, but the subsequent talks run aground.

Then Troost starts flirting with a real gorilla: Perkin-Elmer. At the time, the company has $1 billion in revenue in analytical equipment. In the seventies the Micralign projection scanner propelled the company into the largest manufacturer of chip production equipment. The scanner is Perkin-Elmer's most successful product ever. Thanks to its installed base of a few thousand Micraligns around the world, the company has excellent customer contacts at the start of the eighties. It has a foot in the door at almost everyone on the planet who makes chips: from universities to the heavy hitters like IBM, Intel, and NEC.

With its huge market share, formidable installed base, and global sales machine, Perkin-Elmer seems like the ideal candidate to help Philips strike a blow in the lithography market. What's more, the American company is ripe for a new project, because the Micralign technology is outdated. Its comfortable market position has lulled it to sleep. It hasn't taken the stepper seriously, and isn't even developing the technology.

But there are years of life left in stepper technology. That's why GCA has become a serious threat to Perkin-Elmer. The unexpectedly high popularity of the DSW4800 steppers has put the maker of the Micralign in a tight bind, and it's desperate for technology that will usher in a new phase of growth.

Perkin-Elmer says it would like to send a large group to visit. Among the visitors is optical systems engineer Dave Markle, the man who created the Micralign. Troost wants to display his wares in the best possible light, but that's problematic. Philips' technology is scattered across Natlab, S&I, and the machine shops. At Natlab, the Silicon Repeater 2 is gathering dust, and the newest thing Troost can show Perkin-Elmer are parts in the machine shop, where five steppers are under construction. He's most worried about questions on CERCO and the optics.

Troost sweats bullets to put together a full one-week program that will convince Perkin-Elmer that Philips is the right partner. But he succeeds in keeping the Americans entertained that long with conversations at S&I and Natlab and excursions in the evenings.

Van Heek takes Dave Markle's group to a game at the PSV soccer stadium and gives six seasoned Perkin-Elmer engineers a tour of S&I. The Americans don't hide the fact they think the PAS 2000 is overengineered. The tons of granite, the damping systems: it's all way overdone in the eyes of Perkins-Elmer's crew. They also don't understand why the machine gets its alternating current from a generator that's powered by an electric motor that in turn is plugged into the regular power grid. Van Heek designed it that way in 1972, and it hasn't been changed in the intervening ten years. "It's built like a brick shithouse," they tell him. In other words: high-end technology, but unnecessarily expensive.

When the guys from Perkin-Elmer get on the plane at the end of the visit, they say they're very interested. Troost is surprised. It isn't the response he'd expected: the Americans also spoke with several members of Philips' executive board, and they were none too positive about the meeting. From their discussion with the board members, the visitors from Perkins-Elmer concluded that Philips' senior management was clueless about the chip market. "Wim, your top guys, do they know what they're talking about?" they'd asked him afterward.

In spite of all that, Perkin-Elmer sends a positive signal. "What we're really saying is yes, we want to do this joint venture," they emphasize to Troost. But Perkin-Elmer is also considering another partner. The group is traveling straight on to Liechtenstein to take a look at the state of lithography at the startup Censor.

Censor is funded by the German Ministry of Economic Affairs, the auto industry, and the electronics industry. It's just started building a stepper with an electrically powered mechanical table. Before Perkin-Elmer's men get on the plane, however, they tell Troost they aren't taking Censor very seriously. The tiny company is no real match for Philips. The trip to Liechtenstein is a formality, and they don't expect much. They promise that Perkin-Elmer will be in touch soon.

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A week later, Perkin-Elmer tells Troost that Censor is a highly interesting company, primarily thanks to the electrically powered mechanical table[13] in its stepper. The machines S&I is building have a hydraulic stage, and that's a downside. But Perkin-Elmer is doubtful of Censor's optics and the tiny company's strength. They've listed the pros and cons and all things considered, they prefer Philips, but they expect the multinational to make a quick decision. Troost is caught in Philips' web of red tape and can't say yes himself on the spot.

The Americans give him a week. That shows how serious their interest is in joining forces with the Dutch company. "Contact us within seven days. If you don't respond, we'll go with Censor," they warn. And they do. Philips isn't able to make a decision that fast, and so it loses one of the best opportunities it will be offered in those turbulent years. George de Kruiff flies to the US to try to save the situation, to no avail. The message Perkin-Elmer's senior vice president and future CEO Gaynor Kelly gives him is short and sweet: "Nope, we're not doing it."

* * *

When a subsequent attempt to set up a joint venture with Varian ends in failure, Troost is left empty-handed. His enormous network inside Philips hasn't helped him to make something of the stepper adventure. The guys at Elcoma and Natlab have done their best, but within S&I's management team he's become an outcast. Fellow business unit directors take a dim view of his opportunistic approach to doing business. They tolerate him because he brings in revenue, but in their hearts they want nothing more than to see the door swing shut behind him.

Arguments with management, conflicts with his fellow directors, his tendency to meddle in the tiniest details: all these keep Troost from rising above the corporate inversion layer—the glass ceiling above which the true leaders reside. For two decades he never rises above the level of business unit director, though in the seventies S&I is one of the company's incubators for management talent. All around him, countless colleagues at S&I do go on to reach the top.

Ab de Boer and his technical director, Bert van Mechelen, don't see Troost as an executive of the future. He's too much a man of details and engineering, instead of the big picture. The strategy he's proposing to create a semiconductor equipment division looks to them like tunnel vision from a man whose hobby has gotten out of hand.

After the disasters with Cobilt, Perkin-Elmer, and Varian, Troost has squandered pretty much all his credit with his fellow managers. "Wim, close up shop, you're burning through our money," he regularly hears. Yet in early 1983 he travels to Tokyo in an attempt to sell his stepper to Matsushita, a Japanese company that has strong ties to Philips. When by chance he runs into Bill Vogel, a fellow manager at Philips, one evening, Bill says to him, "Wim, what are you doing here? Have you got business here? Or are you still peddling your damned lithography? Can't we spend our money in better ways?" Eventually, Troost is ordered to put an end to it. "Stop losing money," De Boer says in a meeting attended by S&I's entire management team. "I don't care how you do it, but shut the project down."

After three joint venture deals have fallen through, everyone involved is demoralized. Their stepper's future seems to have evaporated. Steef Wittekoek, the man who took over from Van Heek in 1974 and has been supporting stepper development at S&I from Natlab, is also discouraged. When Philips Medical asks him to help install one of the first MRI scanners in a hospital in New York, he jumps at the chance. Back in his academic life he worked on nuclear spin resonance, and he decides to dive back into his old specialty. A month later he flies his family to America.

Part 4

The Deal

1983–1984

Arthur del Prado, date unknown Photo: ASML

18. **Arthur del Prado**

ASM International is growing like a weed, but Philips still doesn't see Arthur Del Prado's company as a worthy partner.

While Philips is struggling to find its feet in the turbulent seventies,[1] a fast-growing technology firm sixty miles to the north is oblivious to the recession. From his tree-lined neighborhood in Bilthoven, a small town just northeast of Utrecht, Arthur del Prado is growing a company focused on the budding chip machinery market.

Del Prado doesn't *do* business; he *is* business. The man eats, sleeps, and breathes Advanced Semiconductor Materials (ASM), an internationally active firm which he runs with a mix of charm, ambition, and recklessness—his willingness to take risks seems boundless. By the early eighties he already has a strong foothold in every important semiconductor market. The recession years seem unable to touch Del Prado's empire. ASM's growth explodes once it makes the switch from sales and distribution company to independent machinery manufacturer. Revenue skyrockets, by almost 50 percent a year. In 1978 the company earns $14 million; in 1983, seven times that much—unheard of at a time when Philips and the Elcoma chip fab are both laying off workers by the thousands.[2] ASM is a shining pearl in the Netherlands' bleak economic landscape, a thriving company in a promising new market whose playground is the entire world.

In those turbulent years, Del Prado embraces his success with gusto. The Volkswagen he drove to customers in the early years has long since been replaced by a private plane. ASM opens offices in Hong Kong, Japan, and the US and acquires companies in all three.

The zeitgeist is working in Del Prado's favor. Chip manufacturers are turning away from developing their own machines. Increasingly, they're looking to specialized suppliers to buy their production equipment.

But Philips is different. Del Prado is surprised by how rigidly Elcoma's engineers cling to their conviction that the best production tools are the machines they build themselves. Elcoma does order a wire bonder from ASM, but no subsequent orders follow. Eventually it starts using wire bonders developed in house.

Del Prado smells an opportunity. He knows that Elcoma makes a range of chip production equipment, and that it's working with Natlab to develop wafer steppers. In 1976, he drafts a diplomatic proposal to Elcoma's chip fab director, Jan Huart. The subtext of his letter: leave the machines to me so you can concentrate on your core activity, actual chip production.

Del Prado hammers at Philips for years, but the company won't give him the time of day. When Natlab finally knocks on ASM's door in 1983, its wafer stepper business is more dead than alive. Del Prado says yes nonetheless, fully aware that he's risking his whole company on the venture.

* * *

Arthur del Prado enters the world in 1931 in the Indonesian city of Jakarta, still known by its colonial name of Batavia back then. Both his parents are Dutch citizens; his dark-haired father was born in Paramaribo, Suriname, and is descended from Portuguese Jews. Del Prado senior is a captain with the Royal Interocean Lines shipping company. Del Prado junior is proud of his heritage, a fact of which business associates who spend enough time with him are well aware.

During the Second World War he's separated from his family and imprisoned in an internment camp in the Dutch East Indies. When the war ends he and his parents and sister move to the Netherlands, where he studies chemistry and economy. After that he leaves for Boston to attend classes at Harvard Business School.

After finishing his studies in 1958, twenty-six-year-old Arthur journeys to the American West Coast. In what will later become known as Silicon Valley, he encounters a burgeoning young industry: computer chips. Palo Alto is drenched in optimism and ambition, and once the mood works its magic on him it never lets him go.

Del Prado returns to the Netherlands with a silicon wafer in one hand and five hundred dollars in the other, as a prominent Dutch newspaper later quotes him saying. It's a great time to be entering the field. Following their American counterparts' lead, major European electronics companies such as Philips, Siemens, and Telefunken are training their gaze on the semiconductor metalloid silicon as an alternative to germanium. After Del Prado moves to Bilthoven in the early sixties, he decides he'll name his company Advanced Semiconductor Materials (ASM).[3] ASM will serve the growing European chip industry through a broad portfolio of materials and equipment.

The ambitious entrepreneur doesn't let setbacks distract him from his goal. He charges full steam ahead, using the marketing tools of the time: magazines and trade shows. In the fall of 1972, ASM mans a stand at major shows in Germany and England. In full-page ads, Del Prado positions his company as a serious player. The headline: "Over one hundred man-years of semiconductor engineering propel Advanced Semiconductor Materials Incorporated's products to the top." The "Incorporated" is a reference to ambition rather than actual status; ASM is still an LLC and not yet publicly traded.

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Del Prado funnels boundless energy into building his company. In the decade from the mid-sixties to the mid-seventies, he builds a portfolio of over thirty brands. If it's semiconductor-related, you can get it at ASM. That breadth gives the company the financial firepower to hire engineers, set up its own production and assembly, and make its first acquisitions. By the mid-seventies ASM has reached a revenue of several dozen million, and Del Prado is ready for the real work: spreading his wings and going global.

His relationship with another Dutch pioneer in the chip industry gives him a massive boost toward that goal. Sometime in 1971, Del Prado meets Richard Fierkens, the founder and owner of Fico Tooling. The family company provides Philips with equipment to package transistors. Both entrepreneurs think a partnership could be beneficial. ASM will represent Fico globally and a few years later, in 1974, it even acquires a majority interest.

Del Prado takes the newly rechristened ASM Fico to Asia, where chip manufacturers have been packaging and assembling chips since the mid-sixties in ever greater numbers. In 1975 his search for an Asian beachhead takes him to Hong Kong, where he hires Patrick Lam to lead ASM Asia. Lam is the man who, in the years that follow, will expand ASM into the world's major player in chip assembly and packaging machines, and who will take these back-end activities public in 1988 as ASM Pacific Technology.

In 1976 Del Prado opens ASM America in Phoenix, Arizona. Five years later, his company is the first non-American industrial enterprise to be listed on the NASDAQ since the Second World War. The sale of 1.1 million shares brings in $16 million for ASM. The financing round gives Del Prado additional room for expansions and acquisitions.

The NASDAQ listing puts ASM on the global map. The Dutch business community pricks up its ears. While Philips is in crisis and the economy is foundering in the Low Countries, Del Prado leaps out as an innovative international businessman achieving significant annual growth, year after year, in a new growth market. In 1983 he's named the Netherlands' businessman of the year. That same year, ASM issues another round of shares, again on the NASDAQ.

* * *

Del Prado keeps dreaming about a partnership with Philips. It still bothers him that Elcoma never answered his 1976 letter. When in 1981 a major Dutch newspaper publishes an interview with Eduard Pannenborg, one of Philips' research directors and a member of its executive board, Del Prado has another go at approaching the company.

In the interview, Pannenborg criticizes the lack of European industrial policy for microelectronics and says that Japan and the US are doing a much better job there. Del Prado starts off his new letter by buttering up the director, saying he supports his analysis.

Pannenborg's remarks about the many enterprising startups in the American chip industry strike a particular chord with Del Prado.

But then ASM's CEO strikes a critical tone. Given that analysis, he still doesn't understand why Philips is unwilling to join forces with his company. He tells Pannenborg that the electronics company lacks the pioneering spirit that can spur the Netherlands to become a second Silicon Valley. Del Prado closes his long letter with a plea to work together.

The letter appears to hit a raw nerve with Pannenborg, because no one writes back for five long months. When they do, it isn't to answer Del Prado's letter to the director, but to address a glowing article on ASM that appeared in one of the country's major newspapers in October 1981. In the piece titled "Silicon Valley Just Down the Street," the Dutch businessman gives a nod to the US, where major companies are all too eager to partner with small ones.

Del Prado doesn't name Philips in the article, but his message is clear. "In America, major industrial firms are so much more open, and eager to work with growing young companies. The way IBM or a Hewlett Packard engages with us, openly sharing their expertise—well, in Europe that's... enough said," the newspaper quotes him as saying.

Philips' article-prompted letter results in Del Prado meeting with Ab de Boer, the commercial director at S&I, where they're currently working on the stepper and the e-beam writer. Over coffee, De Boer apparently expresses his reservations about the technological expertise present at ASM, because Del Prado subsequently writes him a detailed letter listing his company's technical activities, and also notes that he's just taken over Elmont International in the US and Plating Industries in Hong Kong.[4] Del Prado says that Elmont is bursting with in-house precision technology expertise, which will be a major plus for lithography development. In the letter, he indicates he's willing to take over Philips' wafer stepper and e-beam activities. ASM can introduce the products to customers worldwide and add a service group for lithography to its corporate structure.

De Boer's response is miserly. He doesn't make time for a second meeting. He agrees with Wim Troost that ASM is a size too small. A year earlier, in 1980, the company's revenue was $37 million. Troost has calculated that just the development of a new generation of steppers will far exceed $50 million. The expertise required to make wire bonders is nothing compared to the advanced technology that lithography demands. Del Prado is underestimating lithography's complexity, Philips has decided.

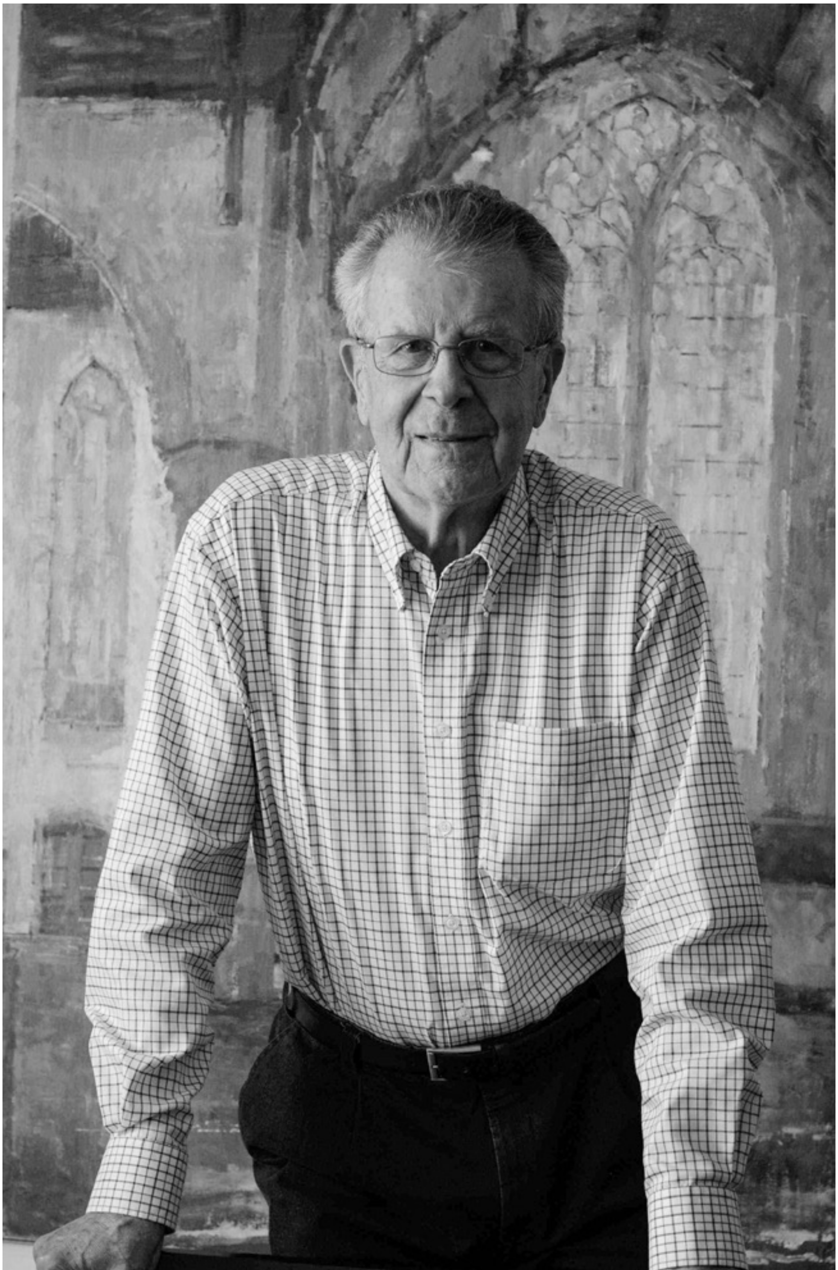
* * *

In 1982 Philips and ASM are regular visitors at the Dutch Ministry of Economic Affairs in The Hague. The glacial giant is unimpressed by the enterprising dwarf, and ASM expresses its disappointment at that in letters and conversations. Philips has passed over ASM for the development of a plasma etcher, in favor of the American company Etec. The ministry wants to promote the Netherland's plasma etching industry, and ASM hopes the ministry can help it gain Philips' ear.

ASM consistently brings up the wafer stepper in its conversations at the ministry. On October 7, 1982 there's yet another meeting in The Hague, attended by Arthur del Prado, Elcoma's Jan Huart, S&I's Ab de Boer, and the ministry's interim director general, Jan Hillege. ASM's CEO proposes that his company market Philips' wafer stepper and e-beam equipment in Japan and the US. De Boer says he thinks ASM is too small for such a large project. "Besides, we're talking with Cobilt in America," he adds.

Del Prado persists. In a detailed letter to De Boer (which he copies to the ministry), he refers to the conversation. ASM's CEO proposes that his company handle the final assembly and marketing for the steppers in America. He underscores the fact that ASM is already supplying every major chip fab in the US. He also voices doubts about Philips' negotiations with Cobilt, a machinery manufacturer that ASM formerly represented in Europe. Del Prado says Philips' concerns about ASM are misplaced, and that it would be undesirable and unfortunate if his countrymen chose an American partner. He notes that the ministry is eager to shore up the European industry, too.

In December, a delegation from S&I visits ASM's offices in Bilthoven while S&I marketeer Ger Janssen visits Tokyo, where ASM is getting its Japanese operations off the ground. But Philips continues to keep Del Prado's company at arm's length. It may be an international player, but for Philips it's the bottom line that counts: ASM is simply too small for the lithography market.



George de Kruiff in 2011

19. **Fifty-Fifty**

During their first meeting, George de Kruiff and Arthur del Prado forge a joint venture between Philips and ASM International in less than an hour.

In the spring of 1983 George de Kruiff, S&I's technical director, reads about ASM International's success in the morning paper. Thanks to its rapid growth, the company in Bilthoven is making a name for itself in the Netherlands. Two years earlier, owner Arthur del Prado made the front page when his company issued one million shares on the NASDAQ in America. Del Prado plans to issue additional shares in September 1983, this time in Amsterdam. That's when De Kruiff realizes: this man has money.

De Kruiff sees the answer to his problem. Philips' CEO, Wisse Dekker, has made it clear to S&I there's no place left for non-core activities. Electron microscopes, industrial control systems, welding operations, and lithography: De Kruiff must sell them all off. As he puts down his paper, he realizes he's just seen one very last chance to save the stepper business and keep layoffs at bay.

The lithography market is a mystery to De Kruiff, so he goes to Wim Troost, the man who spent the previous year speaking to every potential joint venture partner. Troost says he has reservations about ASM. Elcoma has never taken the furnace supplier seriously, and their equipment is in a whole different league from the strategic lithography business. "This just isn't the one," Troost tells De Kruiff. Ab de Boer, who's recently left the company, was never enthused about ASM, either. But Troost also recognizes this is the very last chance to save the activities he's poured his heart and soul into for the past several years. Philips' stepper operations are as good as finished; ASM is the last remaining lifeline.

Troost knows better than anyone how things get done at Philips, and he advises De Kruiff to take the company's top legal guy and top financial guy with him to Bilthoven. Both men have a direct line to the executive board and can instantly address any issues or questions ASM has. “That’ll keep the shit from hitting the fan later,” Troost advises. De Kruiff calls Del Prado, introduces himself, and asks if he can pay a visit to Bilthoven.

* * *

De Kruiff encounters an extremely charming, self-assured businessman at the peak of his success. Unlike De Kruiff, Del Prado is a seasoned veteran of the semiconductor industry. During the recent recession ASM kept growing, and now that the chip market is climbing out of the hole in 1983, Del Prado knows his revenue and profit numbers will be formidable. His ASM is a bright beacon of success in the bleak Netherlands, and he’s riding high on euphoria.

ASM’s CEO is initially cautious. He’s intimately familiar with the multinational’s quirks, but De Kruiff barely even knows what ASM does. S&I’s technical director is wholly unaware of the painful history between the two companies. When he steps into Del Prado’s office at the start of 1983, it’s the first time the two towering men have laid eyes on one another.

De Kruiff comes right to the point, and he’s surprisingly open about his problem. He’s come to ASM for help because his executive board isn’t interested in pumping any more money into the stepper project. His company is bleeding money, and it has other priorities.

That notwithstanding, Philips is a potentially huge customer. Wisse Dekker has decided to invest $700 million—$1.8 billion in 2018 dollars—in the Megachip project, intended to catch Philips up to the competition in memory technology. Lithography is vital to that effort. If ASM wants to get into the stepper business, it can hitch its wagon to the Megachip project and get off to a flying start, De Kruiff suggests. “We’re looking for a company that knows the market and is strong in sales,” he says, stroking Del Prado’s ego.

De Kruiff says the chip fabs at Valvo in Hamburg and Elcoma in Nijmegen will each receive two machines shortly, but only one machine has been sold to an external customer. That customer, IBM, is very satisfied with the machine, he lies. But Philips has never aspired to sell steppers, and the executive board's lack of commitment has hamstrung the project for years. "But Natlab's developed technology that makes our machines superior to the competition," De Kruiff confides.

He then asks Del Prado point-blank whether he's interested in working together. De Kruiff lists off all the options. "ASM can take it all over, but a joint venture is also a possibility. You're at the heart of the semiconductor market, so in any case we'd like ASM to take the lead on these activities."

* * *

For Del Prado, the situation is clear. After years of abrasive talks with Philips heavyweights, the electronics conglomerate has come crawling to ASM's door. He's finally getting the recognition he's been seeking for years. Del Prado doesn't have to think long. The contours of a dream company instantly take shape in his mind: a powerhouse that supplies chip fabs with all their machines, with the wafer stepper as its flagship. No company in the world offers such a complete package.

Del Prado listens attentively as De Kruiff gives his pitch. Then ASM's CEO says, "Excuse me for a moment." He walks out of the room to consult with his team. Nearly an hour passes before he comes back. He walks in, sits down, and says, "Let's do it."

All in all, the meeting has lasted just over an hour and the two men have spoken with each other for less than fifteen minutes. The stepper business is in line with Del Prado's ambitions. He makes machines for nearly every facet of the chip production process. But lithography, the most strategic of them all, is his gaping blank spot.

By this point, Del Prado is intimately familiar with Philips' foibles and sensitive spots, and he says nothing about his endless talks with the multinational at the Ministry of Economic Affairs. On the way back to Eindhoven, De Kruiff says to Troost, "It was like my words came from God's mouth straight to his ear. Unbelievable! It was our first meeting ever, he was gone most of the time, and his answer was an immediate yes." De Kruiff is relieved, but also astonished.

Troost wisely keeps quiet. He's watched the situation unfold with a mix of amazement and admiration. ASM is going to save his baby, but he knows better than anyone how hard it will be to get the lithography business and the stepper's complex development back on track. The cost will be enormous. In September of that same year, he makes a new estimate of the development costs for optical lithography: over $42 million. Troost realizes all too well that Del Prado doesn't know what he's agreed to. He knows ASM doesn't have the experience, the sales force, or the resources to do the job. But he's filled with admiration for the ease with which Del Prado agreed to De Kruiff's proposal.

* * *

At the end of June 1983 Philips' talks with ASM International intensify. A new name for the joint venture pops up for the first time: ASM Lithographic Systems, at that point still being abbreviated as ALS.[5] Someone's also suggested they split the shares. Philips and MIP, a state-owned private equity fund, will each get 30 percent; as the project lead, ASM will receive 40 percent.

Del Prado knows the venture will be highly dependent on Natlab's technological expertise for the machines' development. ASM doesn't have that kind of expertise in house. In the months that follow, ASM's CEO declares access to the research lab non-negotiable. "If we close this deal, we're going to need Natlab," he tells De Kruiff.

* * *

Del Prado and De Kruiff like each other. Their first meeting in Bilthoven lays the foundation for a close relationship. The highly charming businessman of Jewish-Portuguese descent gets along famously with the somewhat aristocratic Philips manager. They soon develop a friendship.

But the bureaucratic behemoth that is Philips doesn't give De Kruiff much wiggle room. If the joint venture is going to need Natlab's support for research, there's only one option, he tells Del Prado. The only way to do it is to give Philips a controlling interest. What's more, the lithography R&D won't come for free: the joint venture will have to pay for every hour. De Kruiff knows that access to the electronics multinational's crown jewels is something special. In those days Natlab is a worldwide legend, but Philips' technology incubator is strictly off limits to outsiders.

Del Prado reminds De Kruiff of his initial offer. "If Philips wants us to run the show, it's only logical that *we* get more than half the shares," he says. But De Kruiff doesn't budge. He can only grant access to Natlab's services if Philips gets at least 50 percent of the new company's shares.

But a fifty-fifty split still allows ASM to take a leading role, De Kruiff suggests. "I propose we make you the executive director," he smiles. "You know the business; you'll guide the company, you'll be in the driver's seat." De Kruiff will be the venture's chairman of the board, with the special task of ensuring a good relationship with Natlab.

In the end, ASM and Philips agree to split the shares evenly.[6] Del Prado makes one last attempt to gain access to Natlab's R&D for his other activities, but Philips firmly refuses. Natlab is still fully off limits to outsiders.

* * *

On September 8, 1983 at three o'clock in the afternoon, "Philips (Scientific and Industrial Equipment) and Advanced Semiconductor Materials International NV (ASM International) in Bilthoven" announce they are launching a joint venture to develop, manufacture, and market advanced lithographic equipment. "The new company will be located in Eindhoven and will initially employ roughly fifty workers, most of whom are currently working on lithography at Philips. That number is expected to grow," the press release notes. The real negotiations have yet to begin.

20. **The Contract from Hell**

Philips' bean counters saddle the joint venture with a heavy burden.

ASM's memorandum of understanding for its joint venture with Philips enhances Arthur del Prado's sense of euphoria. He's used to doubling his revenue every two years and is raring to start selling the stepper. And the market is clamoring for equipment. Competitors GCA and Nikon deliver hundreds of wafer steppers each year. The semiconductor industry is booming, and analysts are adjusting their forecasts upward. Soon there will be demand for a thousand litho machines a year.

Del Prado's hands are starting to tingle. He's hearing initial rumors of weaknesses at market leader GCA, and he's under the impression S&I has a machine that's ready to ship. He has no idea of the problems and is eager to show Philips what it means to sell a product. In the fall of 1983, he hires Willem de Leeuw as his CTO. De Leeuw is leaving airplane manufacturer Fokker and has no experience in semiconductors, let alone chip lithography. But from the start Del Prado tasks him with managing the stepper business in Eindhoven. "ASM is ready," De Leeuw tells Wim Troost. "Our sales divisions in Japan and Phoenix are raring to go." He urges Troost to get things moving at Philips.

* * *

It's a completely different world in Eindhoven. The global recession has depressed Philips' revenue, and under Wisse Dekker's command the company is busy cleaning house. Dekker has already decided to evict the non-core activities, such as lithography. Now he wants to drain the bureaucratic swamp by limiting the national divisions' power.

The internal conflict during Dekker's reorganization puts severe strain on Troost. He barely has any attention to spare for the joint venture with ASM. He even drops the ball in places—despite his addiction to total control. But in April 1983 Jan van der Ster, the new director of S&I's Dutch division, manages to push something through without consulting his boss. While Troost is in Japan trying to sell steppers to Matsushita, Van der Ster hires someone to run the stepper project and lighten Troost's load. Head of stepper development Ronald Beelaard will also report to the newcomer, whose name is Jacques de Vos.

* * *

In the fall of 1983 Del Prado dials up the pressure. Stepper production has to increase. At the start of June, S&I mapped out the entire stepper pipeline in a business plan for ASM Lithographic Systems, without consulting ASM. Nor does ASM have a say in S&I's revised plan.

When De Leeuw comes on at ASM and reads through the documents, he concludes that S&I can only deliver ten steppers in 1984—not nearly enough, in his view. Del Prado tells him to step up production. Troost blinks when he hears the order, but De Leeuw is insistent. It will take at least six months to get all the contracts for the joint venture in place. "If we don't move forward during that time, we might as well not even begin," De Leeuw tells Troost. ASM's new CTO wants Philips to go ahead and ramp up its materials orders so it can increase production. He makes it clear that ASM is targeting an aggressive growth scenario of forty machines.

Troost is skeptical. He knows from experience that their lens supplier, CERCO, is unreliable. He also knows that Philips' machine factory, which supplies the mechanical parts, is notoriously slow and never delivers on its promises. And he knows the market isn't eager to embrace hydraulic machines, even if not everyone in Eindhoven has gotten the memo.

De Leeuw isn't interested in Troost's objections and stands his ground. "No wonder everything moves so slowly around here," he tells the S&I director. "You just need to start screwing the things together." Troost takes his reservations to his boss, but De Kruiff washes his hands of the matter. “Wim, don’t get involved,” he commands. “They’re the commercial guys. They’re running the show.” Nonetheless, the stepper team at Philips sticks to its projection of ten PAS 2000 machines[7] in 1983.

Troost continues to meddle in the joint venture—he’s not someone who can stand on the sidelines and watch. He’s fought tooth and nail for his steppers throughout the turbulent years just past. Now he’s suddenly dealing with an outsider who’s also taking the helm away from him. Troost still questions the wisdom of the deal with ASM. *Guys, this is not the one*, he often thinks to himself. But the man who kept the steppers alive for years also knows that ASM is his last lifeline. Troost is realistic enough to realize that ASM has a point in demanding higher production, and that sales isn’t one of Philips’ stronger points. S&I’s sluggish organization and inability to make decisions is why the project has labored in the margins for so long.

Troost discusses his doubts once again with De Kruiff. ASM is moving too fast, and S&I hasn’t got its act together. Once again, De Kruiff’s response is resolute. He insists that Troost needs to stop interfering. And eventually, Troost does throw in the towel. Deep down he knows ASM is right when it says the operation needs to move faster. But he also knows the wheels just don’t turn that fast at Philips. He realizes the long lead times mean there will be plenty of opportunities to call off the venture, in part or in whole. To colleagues he says that experience is the best teacher. If the orders don’t materialize, ASM can always correct its course.

* * *

De Vos, the new head of the stepper project, has an unbiased view of the situation at S&I, thanks to his lack of history with the division. His discussions with the lithography policy team about the stepper’s development are intense. He thinks ASM’s ambitions are too optimistic, and the objectives in the business plan drafted at the end of July are unrealistic. After another draining meeting with the litho policy team on October 13, 1983, De Vos reiterates his standpoint in an internal memo. His wording is diplomatic, but his message is clear: De Leeuw is insane to expect forty machines. It's madness to drastically ramp up production at this early point.

There have been major setbacks "regarding the lens and the forecast in the current development and projection plan for the PAS 2000," he writes. His engineers simply haven't got the technology working yet. He believes even the best-case scenario will encounter delays. There's a shortage of staff, and the new people he's hiring will need six months to get up to speed.

In his internal memo, De Vos also paints a shocking picture of the situation at optics supplier CERCO. Philips employees have just returned from meetings in Paris to inspect the latest batch of sixteen lenses. Three of the lenses passed muster, but only one of them meets the requirements that IBM posited a year earlier. Eight lenses can be repaired, but of those only three will be able to meet Big Blue's high bar.

From those facts, De Vos draws a clear conclusion: not a single PAS 2000 will be completed in 1983, and in 1984 there will be at most nine. The joint venture's plan to set up a factory in 1983 to produce forty machines a year is divorced from reality. De Vos diplomatically calls this ambition "in disharmony with the uncertainties in the development division." He also criticizes ASM's optimism about the new generation of machines. He says it isn't feasible to launch a new system for the next generation of chips[8] by 1985.

De Vos knows his memo won't make him any friends. So he adds a personal note at the bottom: "These conclusions and recommendations are not intended to crush the joint venture. On the contrary. But we must realistically acknowledge the current state of affairs in our lithography efforts." He also notes that his staff isn't chomping at the bit to work with ASM: "The only argument I could make to alleviate the growing concern for the future among the lithography staff was the following: we won't pursue a joint venture we don't believe in."

* * *

Troost still has his doubts, but he hews to the official plan: ASM is in charge and he'll work with De Leeuw on plans to increase production. At some point an excited Arthur Del Prado calls him from Israel. ASM's CEO is spending a day with the army there and proudly phones Troost over a wireless connection—extraordinary in those days. "These gentlemen will soon need steppers, too; make sure you have a prototype to show them," Del Prado bellows above the roar of a nearby tank. In that instant Troost nearly loses the will to live. He knows the Israelis have top-notch technology, but they have very little in the way of semiconductor production infrastructure. It's yet more evidence for him that Del Prado knows nothing about the lithography market.

At last, at the end of 1983, S&I officially decides to pursue a more aggressive course. Production manager Joop van Kessel grabs the parts list for the ten machines and corrects the numbers by hand. He increases the orders for PAS 2000 production—not to ASM's desired forty machines, but to twenty. He builds an escape route into the orders: the option to cancel them. The most volatile factor is CERCO. Before Christmas, two employees will travel to Paris to ask the unreliable lens maker if it can truly supply twenty lenses.

On a separate sheet of paper, Van Kessel sketches the critical path by hand: everything must be received within ten months. That leaves six weeks for initial assembly, and another six weeks to build the optical column. After that come two months of testing and adjustments, leaving three months for final testing and fine-tuning.

Now that all the i's are dotted and the t's crossed, Troost signs a contract at the end of 1983 in which he and De Leeuw agree that Philips will go ahead and order parts to manufacture twenty steppers—though it leaves a sour taste in his mouth. Philips' costs will be reimbursed in full by the new fifty-fifty joint venture company. The revenue for machines sold will go to the joint venture as well. "Both parties agree that orders and investments must be made now on behalf of the joint venture, if the agreed schedule is to be met," it says in the contract.

* * *

But the discussion festers on. In January 1984 things come to a head. De Vos thinks they should end their several-year relationship with CERCO, but his colleagues bitterly disagree. They have to stop getting their lenses from Paris, he believes. In early 1984 he sounds the alarm about CERCO in a letter to De Kruiff: "Others would prefer to risk a fiasco—for the third time—by working with this firm, in disharmony with the certainty the production division deserves to be given."

De Vos's analysis is sound; CERCO's performance is dismal—and has been for years. But at that exact moment Philips doesn't have much choice. The specialized lenses are crucial for its steppers, but there are only a couple of places in the world to get them. Troost, Beelaard, and Van Kessel aren't ready to end a relationship that dates all the way back to the sixties. They're working feverishly with De Kruiff to find another lens supplier, and are in talks with Zeiss, among others. But Troost doesn't want to sever contact with CERCO yet. He can't: he needs dozens of lenses for the machines De Leeuw's insisting on.

De Vos's advice to management leads to intense run-ins. His problem is that he's right, but his style is bull-in-a-china-shop. What's more, his boss isn't supporting him. Troost has signed a contract with ASM that says he has to manufacture more steppers. De Vos also clashes with the production department, which is eager to see the activities intensify.

De Vos becomes isolated within S&I, an organization where everything revolves around agreement and maintaining good relationships. He isn't capable of packaging his opinions in the diplomacy required to get things done at Philips. The tension between him and his subordinate Beelaard escalates. Newcomer De Vos sees to it that the man who's been the linchpin of e-beam and stepper development for years is transferred to a different Philips division.

Troost just lets it all unfold. But when Van der Ster hears how De Vos is upending things and moreover making the mistake of throwing crucial expertise out the window in firing Beelaard, the division director comes down hard. He fires De Vos on the spot—a rarity at Philips. Troost doesn't get involved. He's about to retire, and avoiding confrontation.

* * *

When the plans for the joint venture become known at Philips, everyone and his brother gets involved. Harm Mooijweer, one of Natlab's section directors, also gets wind of the venture. In an August 1983 memo, he warns De Kruiff and Troost that they need to keep a close eye on things. Mooijweer estimates Natlab's total cost over the past ten years for the stepper research effort to be $6.7 million. "Academics with assistants and expensive shop support," he explains.

Mooijweer underscores the need to play it safe in calculating what the venture should pay for Natlab's future R&D. "Experience teaches that spinoffs rarely earn much in their first years," he writes. He therefore advises them to charge an annual fee of $700,000 instead of a percentage of revenue.

Troost is conflicted. His heart belongs to the stepper, but he's also duty-bound to protect his employer's interests. In those days he's responsible for finances, two thousand employees, and the factories at S&I. That means he has to safeguard inventory and goods and charge outsiders for every single widget. On the other hand, Troost has to protect the interests of ASM Lithographic Systems, a company he views as his brainchild and on whose board of directors he sits. The conflict eats at him (appendix 9).

* * *

At some point Philips' participation committee calls Troost to account. The group's twelve wise men safeguard the multinational's interests during spinoffs and joint ventures. They stick their noses into patents, trademarks, research, logistics, legal matters, everything. They give Troost hell about the proposed name. ASM Lithographic Systems has the acronym ALS, an incurable disease that is fatal within a few years.[9]

If there's one thing Philips' bureaucrats are good at, it's defending the multinational's assets. S&I's financial department drafts a meticulous list of everything the joint venture must pay for (appendix 8). They want to squeeze as much money as they can out of the deal with ASM.

The list leaves a sour taste in Troost's mouth. He thinks the costs Philips is saddling the new lithography company with are an abomination. The multinational has fixed rules that govern its calculations, and as the head of S&I's factory he must adhere to them. But he also wants the joint venture to succeed. He knows the $2.1 million each of the partners must cough up is far from sufficient—by his own calculation, just the development of a new generation of machines will cost ten times that amount.

Troost adds it all up and concludes that ASM is the only partner who will actually be investing money in the joint venture. Philips won't be putting in cash, just dated inventory, materials, and modules, hours worked, and seventeen rickety PAS 2000 steppers. It's so hard for him to swallow that he hints to Del Prado he's worried about the joint venture's financial starting point. ASM's CEO doesn't pick up on Troost's hint. He's never taken Troost seriously, and besides, he's caught up in his enthusiasm.

Troost doesn't hide the fact he thinks the joint venture setup is no way to hit the ground running. He believes the contract Philips' lawyers have drafted is unconscionable. "This new company will be too broke to buy coffee," he tells his colleagues. Yet he manages to do some good. He ensures that S&I will take on a large chunk of the costs, including the parts and materials that have been ordered for the twenty steppers.

The final contract dated March 9, 1984 (appendix 9) also mentions the assumption of Natlab technology. The new firm will have access to everything it needs to further develop the stepper, albeit for a price. On top of that, the annual research fee will cost ASM Lithographic Systems 1.5 percent of its revenue.

In those final months, Troost wages a fierce war with Philips' works council over the transfer of forty-seven people to the joint venture—a list of names he drew up with his department heads. Almost no one wants to embark on a new adventure, and the works

From left to right, Willem de Leeuw and Paul van den Hoek (ASM International) and George de Kruiff and Wim Troost (Philips) sign the contract to launch a joint venture in chip lithography.

council demands an absolute guarantee that the employees have the option to return to Philips' safe nest and its generous pension plan. "At the end of a year it'll be a success, and there will be no reason to go back—you'll be even better off there than at Philips," Troost encourages the transferees, reminding them of the ongoing reorgs and staff reassignments at S&I.

Agreement is reached just days before the joint venture contract is scheduled to be signed. The works council hasn't had to make many concessions. The return-to-work guarantee for the forty-seven employees stays, but for four years instead of the desired five. Troost has become joined at the hip with the company's lithography efforts, but management passes him over in selecting the joint venture's CEO. He's been the laughingstock of S&I for years, and the De Vos affair revealed that he won't intervene when he needs to. Management has lost all confidence in him.

Part 5

A Leveraged Die-Out
1984

Gjalt Smit, precise date unknown; probably the early eighties.

21. **Gjalt Smit**

Gjalt Smit, airplane builder, cosmopolitan, lover of espresso and Italian cuisine, is urged by headhunters to lead an imminent joint venture between ASM and Philips.

When a newly graduated Gjalt Smit joins Philips in 1969, he finds himself in a bureaucratic juggernaut. The company has grown drastically since the end of the war. Management's never learned how to be frugal or efficient.

As is the custom at Philips, Smit's PhD automatically grants him membership in the company's Society of Young Academics. Over drinks he exchanges his first experiences with other university graduates, most of them fresh out of school. They express their amazement at the company's conservatism and the infighting among Philips divisions. Fifteen inspired twenty-somethings come up with the idea to chronicle several abuses at the multinational. They plan to report their findings to the executive board.

Smit is at the heart of the group. The would-be Don Quixotes throw themselves into the project, writing a proposal to the executive team at every industrial division and offering to come in and discuss the problem. Philips has no desire to offend talented young employees, and after some false starts Smit and two others are granted an audience with CEO Henk van Riemsdijk. He skillfully kills the initiative by never following through on his commitments.

The brief adventure is typical of Smit. He's full of bravado, unimpressed by authority, and definitely not afraid to stick his neck out. Audacious is perhaps the best way to describe him. And cosmopolitan. By the time he joins Philips in 1969, he's already spent significant time in the US and Italy.

Smit earned his doctorate in astrophysics, but he's not your typical science nerd. When push comes to shove, he's more interested in worldly issues. He isn't religious, but theology fascinates him. He speaks scornfully of the way scientists bury themselves in their work. It's no fluke that fifteen years later, when he's hired to lead a group of disillusioned Philips employees, this sometime rebel sparks a cultural revolution that lays the foundation for a sense of team spirit that will enable ASML to conquer the world.

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Gjalt Smit is born in 1938 in the northeastern city of Groningen, into a family of schoolteachers. When he's eleven the family moves to nearby Hoogeveen, where his father will teach French at the local high school. Young Gjalt is crazy about airplanes. He builds model helicopters in his free time, and he and his math teacher found the Hoogeveen Aviation Club.

Smit ekes his way through high school, even though his heart is set on studying aeronautical engineering at the Delft University of Technology. At the end of fall term in his senior year, he's still failing both physics and math. A few weeks later, the principal announces that the school's science teachers have unexpectedly been let go. He says the students are free to come and go as they please, and that students from the university in Groningen are available to answer their questions.

That does wonders. Smit is freed from the straitjacket of regular school routine and able to manage his time as he likes. The unexpected freedom is his salvation. He reads through the final exam requirements, sets up a systematic plan of study, and ends the year as class salutatorian. He even improves his illegible handwriting.

When he arrives at the university in Delft, an immense freedom overtakes him. Mom and Dad are far away, and he can do as he pleases. He's seized by motivation and likes to say that his academic career is "purring like an engine." Aeronautical engineering is perfect for him. In those days it's a highly multidisciplinary program, focused on systems thinking.

But technology isn't all that appeals to him; Smit is also interested in philosophical questions and actively enjoys the varied lectures offered by the university's Studium Generale division. He's fascinated by philosophy and the phenomenon of religion.

He founds a club for students in Delft and Leiden to discuss the philosophical import of quantum mechanics and the theory of relativity. Sitting on a comfortable leather couch with a good drink, discussing God and whether He exists: Smit is in seventh heaven. At some point he invites a local pastor to join them, and he also invites Henk van de Hulst, an astronomer at the university in Leiden who will later become Smit's doctoral advisor.

Smit's master's project is in magnetohydrodynamics, and as graduation draws closer Henk van der Maas, head of the aeronautical engineering department at TU Delft, asks Smit if he would like to travel to the US on a NASA fellowship for promising students. As is his custom, Van der Maas couches his question as a command: "Smit, you're going to America!"

By then, Smit's already had it with research. He doesn't see science as his calling—it's too far removed from daily reality, and too monotonous. But an offer to visit the US, well, it's an offer he can't refuse. Besides, he's curious. So he nods obediently and says, "Thank you, professor."

The NASA fellowship offers him Princeton or the University of Maryland. He chooses the latter; he suspects he'd look like a dodo amid the scientific brilliance at Princeton. He feels more like an engineer than a physicist.

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When twenty-five-year-old Smit steps off the passenger ship *Statendam* at New York Harbor on August 29, 1963, he can't travel straight on to Washington. The capital city is on lockdown because someone named Martin Luther King is giving a speech there. Kennedy's America is undergoing a transformation, and the country is filled with optimism. When the president is murdered three months later, Smit is there to see close up how his adopted countrymen react.

In 1963 the US is the center of the world. The country warmly welcomes foreigners. Washington is home to a highly educated elite, with a vast smorgasbord of cultural events. A year later, Smit even shakes President Johnson's hand at a White House reception welcoming newly arrived foreign scientists. The young Dutchman is deeply impressed the president has taken the time for something so relatively minor.

Smit ultimately spends two years in the US working on issues in plasma physics for nuclear fusion and space exploration. The young agnostic knows the church plays a crucial role in American networking. He's interested in religion, and he was raised on the Bible both at home and at school. In the Presbyterian circles in which he moves in the US, the main thing isn't so much theology or belief; it's social relationships. On his first Sunday visit to church in Washington, he manages to get his Dutch girlfriend a job during the mid-service coffee break; now she can come to the US, too. They marry and have their first child in America.

He doesn't enjoy his research, but his surroundings fascinate him. Smit's fellowship is extended by a year. He's settled into American life well, and he and his wife and baby travel the country, staying with welcoming families he's met through the church everywhere they go.

As his inevitable return to Europe inches closer, Smit writes to Van de Hulst, the professor in his philosophy club, to ask what his employment options are. Van de Hulst is the chair of the advisory council for the European Space Research Organization (now the European Space Agency), and his handwritten response reveals that ESRO is setting up a new center for earth observation, ESRIN, just outside Rome. He suggests Smit contact its director-to-be.

And so in 1965 Smit becomes ESRIN's first employee. His years in Rome are some of the best of his life. Not much science gets done in his first six months. He opens a bank account and buys the wastebaskets and desks for ESRIN's first building, a derelict bishop's palace outside the town of Frascati. He spends the rest of his time drinking Italian espresso and eating exquisite meals. To a hedonist like Smit, it feels like finding home.

When Smit's German manager finally shows up for duty, he gives Smit a dissertation topic. Smit asks Van de Hulst, one of the founders of radio astronomy, to be his advisor. At the start of

1969 he turns in his thesis, a razor-thin booklet of seventy pages that mathematically analyzes non-linear solar wind flows in the Earth's magnetic field. His research confirms and explains recent measurements taken by NASA's first satellites.

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But the longer he does scientific research, the less Smit enjoys it. It feels irrelevant to him. When Van de Hulst invites him to come work at the university in Leiden, Smit doesn't want to. Giving lectures in rainy Holland, when he's gotten used to the Italian sun? It sounds awful. He's happy as a clam right here in Rome.

Smit contacts Philips in Milan for a potential sales job in Italy. The multinational has one for him. At the end of the sixties Philips is a growing company, with several hundred thousand employees outside the Netherlands. The Italian office tells him the company wants him in Eindhoven for the first two years, for training. That's a setback, but at least he can return to the Mediterranean afterward.

In Eindhoven he interviews at the Products for Industrial Applications division, PIT.[1] Wim Troost proudly shows him a minicomputer developed by his own PIT subdivision, Industrial Data Systems.

Troost is in every regard Smit's opposite. They get off on the wrong foot right away. When Smit cockily struts into Troost's office, the industry veteran is unimpressed. *Yet another snot-nosed kid looking to race up the corporate ladder*, he thinks. Troost himself is an unobtrusively dedicated workhorse, a Philips man in heart and soul. He's never asked for a promotion and it makes the hair stand up on his neck when candidates start talking about career prospects in their very first interview.

But Smit is hired. Philips promises the passable speaker of Italian that he can head south again in a couple of years. Smit learns to work with process computers and is even tasked with training other Philips departments to use them, which means he learns all there is to know about the latest in information technology. The company is soon sending him to provide support in Italy on a regular basis.

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Back in the sunny south, Smit is put in charge of the local IDS group. Among other things, he helps automate a cement factory. For Smit, Italy is paradise. He waxes lyrical about espresso and Italian dining, dismissive of the Dutch lack of *savoir vivre*. He complains about the lack of dinner invitations when he visits Eindhoven. When Smit hosts Italian visitors in the Netherlands, he rolls out the red carpet for them. He takes one group with him to Amsterdam to see the waterworks project S&I has automated. He always fetes his visitors lavishly and puts them up at the Pulitzer hotel.

Above all, Smit admires his Italian boss, Armando Cervi—and not just his smart suit, handsome ties, and radiant wife. Cervi's path through life impresses Smit. The Italian studied physics, attended the conservatory, and took over the family's dent removal company when his father died. Only later did he become Philips' top man in Italy. Cervi is also a shrewd politician, someone who knows exactly how to survive in a corrupt society. But the thing Smit likes best is the eloquent Cervi's occasional foul language. Every now and then the Italian barks that for this or that job he needs a guy *con coglioni quadrati*, with square balls. Smit thinks it's fabulous.

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At the start of the seventies, Smit shares his list of project prospects in Italy with Joop van Kessel. Van Kessel is Troost's golden boy. He provides technical support to the sales teams in the national divisions around Europe and he has a good feel for sales himself. The young engineer has risen to become the head of S&I's industrial projects department.

In the years leading up to that promotion, Van Kessel worked on the front lines himself, carrying out large-scale projects. He was part of the team that automated the Netherlands' first nuclear reactor and he created the process control system for three natural gas compressor stations around the country. Van Kessel was born for this kind of hands-on work. When Troost tapped him to lead the industrial projects department, he accepted the promotion reluctantly; he'd rather be working outdoors, in the fresh air.

Philips is trying to gain a foothold in several countries, and Van Kessel has an excellent feel for making quotations. He knows better than anyone how to estimate the time and expense a project will incur. Mistakes mean heavy losses, so Troost prefers to put his experienced man on the job. And so Van Kessel and his project leaders crisscross their way through Europe to help the national divisions' sales teams properly assess the value of customers' requests. When local management wants to talk, Troost goes along with them.

This work is how Van Kessel meets Smit, who's responsible for IDS in Italy under the local S&I director there, Cervi. By the time they meet, Smit has years of experience in the Mediterranean country. He's turning heads at the *compagnia*. The PhD-slash-engineer speaks pretty good Italian, moves easily among his colleagues, and is accepted by most of their customers—not always a given in southern Europe.

Van Kessel approves of Smit. He's professional and good at his job. They joke together about Philips' inflexibility and complain about the multinational's compulsory rules for calculating costs—the two of them always manage to find a couple of loopholes to keep them from missing the boat with a quote that's too high. Smit views Van Kessel as competent, someone who knows what S&I can and can't do and how to plan and calculate industrial projects.

The two see each other regularly in Italy, and they also visit each other at home. Van Kessel is a welcome guest at Smit's apartment on a cliff overlooking Lake Como. There he meets his colleague's two daughters and gets help from Smit's wife writing quotes in English, which she teaches in Italy.

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Salesman Smit and engineer Van Kessel learn the hard way how to peddle technology in the south. When Cervi tells Smit that food conglomerate Motta wants to build a new ice cream factory, the two make a salivating beeline for the company. Smit knows that Motta is still using analog control systems in its factories, and he and Van Kessel discuss how to best sell S&I's gadgets and Philips' P800 computers to the company. Smit whips together a good pitch, and on the plane he does a dry run for Van Kessel.

When they arrive at Motta, they're taken to a meeting room to wait. After a while two gentlemen come in dressed to the nines: sharp suits, striking ties, gleaming shoes. Even a blind man could see that Dutchmen are on one side of the table and Italians on the other. Smit starts off in English, but after three sentences the Italians ask him if anyone speaks their language. "Okay," Smit answers, "we can continue in Italian." He launches into an impassioned speech on Philips' system and the service the Dutch organization delivers. After ten minutes the men from Motta look at each other and say, "Mr. Smit, we're not sure you've understood what we're looking for. Can you tell us how your system will help us make better ice cream more cheaply?" Five minutes later, the pair are back out on the street.

Later, a now wiser Smit hears that several hospitals are interested in automating their clinical laboratories. He visits university clinics from Milan to Palermo to learn about their issues. When he's given the chance to draw up a quote for the university clinic in Genoa, he outdoes even IBM and Honeywell. The Americans fill their offers with descriptions of their computer technology, but Smit takes a different tack. He doesn't want to talk about computers, because Philips' systems are new and unproven, and they have their limitations.

Thanks to his lab visits and conversations with the people who work there, Smit knows where the problems lie—he's heard all about them over many long dinners. In his quote he describes the operational issues that plague the doctors and nursing staff, and how he plans to solve them. He doesn't mention the tool he'll use—the computer—until the last of the offer's thirty pages, and then only in passing. His tactic wins him the contract.

A euphoric Smit calls Van Kessel. But when he steps off Philips' company plane in Eindhoven a few weeks later, a crisis awaits him. "We have a massive problem," Troost tells him. Philips Medical

Systems doesn't want IDS to handle the project. The healthcare industry is its domain and Smit's group should keep its hands off—never mind that the Genoa project is about automating a lab and Philips Medical has no expertise there at the time. Troost wants to avoid an all-out war and orders Smit to step away from the half-a-million-dollar contract.

That setback marks the beginning of Smit's departure from Philips. He's had doubts about the company for some time now. The people there are more focused on themselves than on the market and on customers. He sees no opportunity to rise higher in Philips' Italian division, where Cervi has been replaced by an Italian with no love for Dutch spies. A year later Smit decides to leave.

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Smit returns to the Netherlands. He stays in information technology, first as the head of Holec Control Systems, a new automation house, and then as the sales manager for telecom behemoth ITT's Dutch office. ITT is having a rough time in the Netherlands when Smit joins. The company used to work with Philips to supply PTT, the state-owned Dutch postal and telephony service, with switchboards, but ITT's suspected involvement in the 1973 Pinochet coup in Chile has ended the relationship. Now the American company has to find a way to get back in PTT's good graces so it can sell them the next generation of computer-controlled switchboards.

ITT is a welcome training ground for Smit. He's part of an inspiring executive team along with Ton Willekens, who will later manage logistics at ASML, and Ben Verwaayen, who will later become CEO at British Telecom and Alcatel-Lucent. He also learns the meaning of *management control*: ITT develops strategies and operational plans with concretely measurable goals, which are regularly reviewed. It's a phenomenon Smit never encountered at Philips. The Dutch multinational has no visible forecasting mechanism. There, you're lucky to hear about financial results a year after the fact.

Smit's commercial role at ITT consists of intensely lobbying PTT and the Dutch government at every level. For his customers, Smit organizes trips to the US and to ITT's production sites in Europe. He invites PTT representatives to his house for dinner and takes government officials to the best restaurants in The Hague—often twice a day. ITT is like a soccer team: everyone knows who needs what kind of coverage, from chauffeur to CEO. It's an American sales tactic that ASML will also go on to use in its relationships with chip manufacturers.

It takes ITT four long years to worm its way back in at PTT. At last the company succeeds in landing a huge order—shared with Ericsson and Philips—for digital switchboards. But by 1983 it's obvious to Smit the company's telecom operations are spiraling downward. The end is nigh.

So when headhunters approach Smit late that year to ask if he'd like to lead a new joint venture that ASM International and Philips are planning, the timing is exceptional.

22. **Hoodwinked**

Philips employees describe Arthur del Prado as a greedy businessman. Gjalt Smit's colleagues at ITT tell him he's being played.

When Gjalt Smit meets Arthur del Prado at the end of 1983, there's an instant click. Smit impresses ASM's CEO. Del Prado sees a man of many talents, a sharp scientist who also has a feel for marketing and sales. Smit's master's in magnetohydrodynamics followed by a doctorate in astronomical plasma physics demonstrate his ability to go deep. His roots in aeronautical engineering and his experience at Philips and Holec make him a systems thinker.

But what most appeals to Del Prado is Smit's feel for business. The now forty-five-year-old polymath scored sales successes for Philips in Italy and raked in million-dollar orders for ITT after a multiyear charm offensive.

Del Prado smiles at Smit's skilled presentation. The interviewee is eager to show he's a man of the world. He regales Del Prado with self-assured tales of his time in Italy and America. Smit's crazy about the US, though his years in Italy make him turn up his nose at American coffee. Yes, he's an engineer with a PhD, but he's quick to sneer at the way scientists focus solely on the numbers. He downplays his doctorate, saying he just happened into it; he was good at science and math, but he doesn't give a fig for research. Smit's ambitions lie on a higher level: management, strategy, charting a course, winning.

When Del Prado says the joint venture is with S&I, Smit hesitates. He's on full guard when Troost's name comes up. He knows his former boss's strengths and weaknesses—above all, Troost personifies rigid, inflexible Philips to Smit. There's a reason he ran screaming from S&I.

How to tell Del Prado that? Smit starts off diplomatically. "Of course, Philips isn't a company of entrepreneurs. I have great respect for the technology, and I'm grateful for the things I learned there." Then he boldly adds, "But in terms of business and marketing, it's a mess there."

It's music to Del Prado's ears. ASM spent years trying to penetrate the perplexing electronics conglomerate. Del Prado tried using charm, sent hostile letters, called on the Ministry of Economic Affairs for help. But despite ASM's successes, those arrogant Philips executives never gave him the time of day, until George de Kruiff showed up and reached out to him.

ASM's CEO reassures his visitor. "Have no fear. Philips won't be in charge of the endeavor; we will." Smit senses he's struck the right chord and toots his own horn even louder. "I didn't discover how financial controlling works until I joined ITT." In the same breath he adds a comparison with his gliding hobby. "As a pilot, you need measurements and instruments to chart your course. You have to understand everything so you know which way to fly. What I learned at ITT was an eye-opener. Everything was so much more transparent there. Everyone could see my weak points at a glance."

Smit notes Del Prado's nodding response and takes it as permission to gossip further about his former employer. "At Philips you've got accounting, but no control. They don't even have a profit and loss statement, like the Americans do. In my time at Philips, I never once saw anyone map out where the money went or discuss financial performance."

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It's clear to Del Prado. This is no stodgy engineer, but a man with a feel for sales and financial policy. Someone you can conquer the world with. Smit, in turn, is impressed by Del Prado. As always, ASM's founder is displaying his most charming side. His company is a budding multinational with offices in France, Hong Kong, Japan, and the US. He's just raised several million in funding for the second time, on the Amsterdam exchange. And in the fall of 1983 he won the NCD prize for business excellence. Del Prado's vision also appeals to Smit. ASM already has an impressive portfolio of equipment for the semiconductor industry, and the deal with

Philips will turn the company into a one-stop shop, a technology supplier where chip manufacturers can purchase pretty much all their machinery in one fell swoop.

Smit also likes the technology agreement with Philips. Natlab's reputation is at its peak in those days. It's the birthplace of multiple inventions for radio and television, and the compact disc is enjoying its first success. If this bastion of cutting-edge research is playing on ASM Lithographic Systems' team, then Del Prado has hit the major leagues, Smit realizes.

It's Smit's first interview for the top position at an independent company. Del Prado charms him completely. "Smit, you're asking the right questions, and you understand the business equations in this industry," ASM's leader says. Smit is flattered. He knows these kinds of endeavors are in it for the long haul, but running his own shop is an appealing idea. He doesn't know the first thing about lithography, but he'll learn. He gets into his bordeaux red Opel Senator after the interview and drives out of Bilthoven in high spirits.

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A few weeks later Smit drives to Philips to meet De Kruiff, S&I's technical director, and talk with his old boss, Troost. When he steps into his former employer's office after eight years away, his feelings are mixed. On one hand, it feels suffocating. Time seems to have stood still there. The same people, the same wooden desks, the same stale smell. No progress, no ambition to match JFK's "We choose to go to the moon *because* it is hard!"

On the other hand, it has an oddly pleasant feel of homecoming. Philips is like an old familiar song. Smit may rail about the stupid company that made him give up a hard-won contract to outfit Italian hospitals, but he also had good times there, and he learned a hell of a lot.

After he meets with De Kruiff, his reunion with his former boss is icy. Flamboyant Smit and diligent workhorse Troost have completely different personalities. Smit puts on a careful performance; he doesn't want to seem too enthusiastic.

Across from him sits a man who spent nearly ten years fighting to keep the stepper project going, who gave his heart and soul to keep it alive. A man who is being passed over for the CEO position that job-hopping Smit is here to discuss.

But deeply loyal Troost has been ordered by De Kruiff not to involve himself with the joint venture—De Kruiff keeps hammering on the fact that Del Prado is in the driver's seat. Troost also knows that his former employee is the only candidate for the position, so he does his best to sell him on the promise of the steppers. "It will be an enormous challenge to pry the project loose from Philips and give it its own momentum," he says wearily.

The two men bond the way Philips colleagues always bond: over stories about how sluggish the company is, its internal politics and stifling bureaucracy. Troost notes that Smit has changed. He still likes to carry a conversation and add his own twist to his former manager's words, but he's matured—significantly.

After he leaves Troost, Smit returns to De Kruiff to shake on it. De Kruiff says they're going to be neighbors; the joint venture will start off in the TQ complex on Philips' industrial campus. But when Smit hears that he'll be working in the same buildings where Troost roams the halls, he can't suppress a cri de coeur: "One thing, Mr. De Kruiff: the door between me and Wim Troost, it needs to be locked."

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Smit has no inkling yet that the mood among the stepper team in the gray TQ bunkers is negative, to say the least.

In February 1984, S&I's union members publish a critical newsletter. Philips doesn't have many union workers, but the ones it does have tend to be radical. There's no doubt whose side the newsletter's authors stand on. The front page sports a caricature of a tubby Del Prado hypnotizing a Philips employee: "You're raring to go! You're raring to go! You're delighted to be part of the joint venture with ASMI."

* * *

The engineers and developers who work full time on the stepper understand the reason for the joint venture setup. It's only a bitter pill to swallow for a small group of people who spend just part of their time on lithography, yet must transfer along with the rest. Most of them come from production and logistics. The union newsletter provides these employees the space to vent their frustration anonymously.

Their main irritation is that management isn't keeping them informed. That makes them suspicious. The information they do have about the adventure doesn't excite any of them. "Given the nature of the company, you can almost guarantee it'll be hard to change jobs," says one anonymous interviewee. "It'll be a small company, so prospects will be limited. [...] One of the conditions really needs to be that there will be a second generation of equipment after 1990. Because as you can imagine, after six or so years the PAS 2000 will have lost all its value in the market. Without a second machine, there won't be much you can do in the way of career planning."

But the grumblers are also resigned. S&I's employees know the unions haven't yet put their stamp of approval on the joint venture, but they also know that protests accomplish little. "What can you do about it?" an anonymous interviewee says. "Philips will do what it does. You're looking at a fait accompli. If you fight back, there's a chance you'll only make things worse. [...] Among the current issues is the major question of whether we're on the right road. We need a good machine and a well-run company. The way things stand now, we have our doubts!"

But amid the criticism and resignation there's also room for humor. At the back of the newsletter, the editors give a hilarious sendup of the stepper's history: a "machine made of aluminum, brick, and glass, swimming in oil and operated by an electronic operator." The piece regales the reader with a heroic tale of rescue, in which the brilliant Dr. S. Wholewheatcake—a reference to Steef Wittekoek at Natlab, whose last name literally translates to "white cake"—manages to save S&I's failed project in the blink of an eye.

But once Wholewheatcake's team leaves the scene, S&I's employees manage to turn the "minor errors left behind by wise men" into real problems. "To solve these problems, people stopped attending meetings, and fewer wise men gathered to discuss them. But major problems only became majorder and more numerous. They even began leading lives of their own, with their own names. The factory [...] began to resemble the El Sleezo Cafe from *The Muppet Movie*."

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Smit's first warning signs don't come from people he knows at Philips—he isn't allowed to talk with them at the time—but from his ITT colleagues in The Hague. They cast serious doubts on his intended career move. "Okay, fine, you're leaving ITT, but do you know what you're doing, Gjalt?" they ask him point-blank. His colleagues are well aware of what's going on in the semiconductor industry thanks to their contacts at subsidiaries Bell Telephone in Antwerp and ITT in Brussels, two groups that are both dependent on advanced chips for the new telephone system. Smit also gets wind of what renowned analysts are saying: the joint venture between ASM and Philips is destined to end in failure.

But it's too late. Smit has given notice at his comfortable job in The Hague. His wife and two daughters are glad: in those days they live an hour away in Breda, and now he'll be working closer to home. But the ITT rumors keep running through his head. "Those guys aren't idiots," he says, by way of explaining his worries to Del Prado.

ASM's CEO reassures him. "Gjalt, we've got a whole team in America that's going to support you, too. IBM is frigging *excited* about the machine, and Philips has copies in Nijmegen and Hamburg." Del Prado's message: if Smit takes care of delivering the machines, then ASM will take care of getting orders through its global network.

In any case, Smit has waved farewell to ITT. He watches with some degree of dread as April 1, 1984 approaches: the date on which his uncertain adventure begins.

23. **The Reunion**

Gjalt Smit is handed a demoralized team that's convinced Philips has rigged up a special gallows to rid itself of them.

In the spring of 1984, forty-seven Philips employees have little to look forward to. They've been selected by Wim Troost to move to the company's new joint venture, ASM Lithographic Systems, on April 1. It's a dispirited group that's been saddled with a single employee from ASM International, seventeen unsellable machines, and a terrible image. Meanwhile, market leader GCA has hundreds of steppers on the market and runner-up Nikon is quickly gaining ground. ASML's market share? Zero percent.

Renowned market analyst Rick Ruddell proclaims the joint venture between ASM and Philips dead in the water. Ruddell is an expert on the lithography market. In the mid-seventies he tracked the rise of Perkin-Elmer, and he watched as in the early eighties the market leader came under pressure from GCA, which brought the first commercial wafer stepper to market in 1978. In 1981 semiconductor companies bought as many steppers from GCA as they did projection aligners from Perkin-Elmer and Canon.[2]

In the seventies Ruddell wrote admiringly about Natlab and the highly advanced stepper it developed in late 1973. He praised the pioneering Dutch spirit. But his enthusiasm vanished in the early eighties as GCA scored customer after customer and S&I just didn't seem to grasp the game.

Ruddell visited Eindhoven, but as the years passed, S&I's vision and plans grew fuzzier. As the American analyst became increasingly negative about the Dutch multinational, he praised Japan's up-and-coming Canon and Nikon. He published his conclusions in lengthy reports, well substantiated with statistics and analyses. In the early eighties he ripped the activities in Eindhoven to shreds. Ruddell kept repeating the same humiliating message: Philips doesn't know what it wants to do with its steppers.

In the Ruddell & Associates report for 1983, the Dutch company was a laughingstock. "Since Philips chose not to respond to our questionnaire, we shall attempt to provide what information that we have," Ruddell wrote, referring to the first reports of a joint venture with ASM. He instantly put his finger on the problem: "Philips has never been able to 'get off the dime' and give this system the sales support that it deserved." Then he got vicious: "Imagine, one of the largest corporations in the world was unable to take even the first steps that [Liechtenstein's fledgling stepper manufacturer] Censor has accomplished. And the irony of it is that until very recently, Philips probably had the finest stepper in the world."

Ruddell wryly concluded that it was no surprise, then, the Dutch company wasn't able to "get their act together and come up with some response" to his survey and repeated phone calls. Then he hung Philips out to dry. He listed every question he asked the company. Beneath nearly all thirty-one of them was written "No comment."

Ruddell's observation was painful, but he was right. After Troost issued his 1979 edict to build a stepper with a hydraulic table, S&I's engineers stubbornly kept working on an unsellable concept. S&I didn't look outward, at competitors and customers, but poured all its energy into completing a machine no one was interested in having.

In 1982 S&I did deliver the technology to IBM, but no orders followed. Subsequent attempts to create joint ventures with Cobilt, Perkin-Elmer, and Varian ran aground. And all that while, Philips wasn't investing in optical lithography. It wasn't freeing up money for a sales division. For nearly two years, development at S&I was at an effective standstill.

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The engineers that Philips has transferred to the joint venture are all too aware of their position. They're the joke of the lithography market. No one is betting even a penny on their resurrection. No wonder ASML's employees view their new home as a leveraged die-out, a play on the term *leveraged buyout*: a spinoff created for the purpose of going bankrupt. It's how Philips has decided to shed its unnecessary baggage, they're all steadfastly convinced.

But then Troost organizes a meet-and-greet with Del Prado and Smit in the Bilderberg hotel. For Smit it's a veritable reunion. He encounters former colleagues such as Joop van Kessel and Ger Janssen, people with whom he got along well eight years ago in his time at S&I. A few years back he even tried to convince Van Kessel to come work for him.

When Smit climbs onto the podium and, full of fire and passion, tells the group he plans to conquer the world with their wafer stepper, his words are met with disbelief and skepticism. Then Van Kessel takes the stage. He knows Smit made quite a career for himself at ITT, and he knows the man from the time they did business for S&I together in Italy. Van Kessel knows that Smit's extremely talented. "You can trust Gjalt Smit," Van Kessel tells his peers. The mood after the meeting is more positive. Troost and the HR employee in attendance clap Van Kessel on the back. "Great work, Joop. You've done these people a huge favor."

Smit is also glad of Van Kessel's presence. They go way back. Smit knows this natural skeptic is a go-getter with a good feel for sales and an ability to lead others. Van Kessel will soon grow into Smit's most vital pillar of support.

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After the meeting, Smit immediately contacts Van Kessel. He wants to know what's really going on. Van Kessel calls Richard George and Ger Janssen to join them, and the three men tell Smit a tale that confirms the rumors he heard at ITT. "Gjalt, not to burst your bubble, but we think you're crazy to come back here. You've agreed to run a hot mess. The staff don't want to be here; it's a catastrophe waiting to happen. The steppers are a bottomless pit. Philips just wants to be rid of them. This gig is dead in the water."

With just a few weeks left before the joint venture officially launches, its new CEO's understanding of the situation is growing sharper. He's not enthused. Stepper development was on hold for years at S&I. There's a PAS 2000 gathering dust at IBM in Burlington; Philips has two more in Nijmegen and Hamburg. And that's it: no more have been sold. There are ten machinery manufacturers in the world focused on chip lithography. Philips ranks dead bottom on the list.

Cees Doesburg, Richard George, Herman van Heek, and Joop van Kessel are the stepper team's point men. Even before he officially starts work on April 1, Smit holds long talks with them—often deep into the night. They talk about their colleagues' resigned attitude, about customers, about competitors and missed opportunities. The conversation often turns emotional. Their new CEO turns out to have no clue about the semiconductor industry, which only heightens their belief that Smit's been hoodwinked. Janssen is always there with them, too. He's well versed in the lithography market and wrote business plan after business plan at S&I.

Smit says that De Kruiff, Del Prado, and Troost all promise they're going to pour money into the steppers, but no one believes him. "Gjalt, with all due respect, we've asked for money a hundred times over the last several years. Wim Troost was never able to get us even a cent. We've written many a business plan, and every one has been rejected."

It will take a lot of money to breathe new life into stepper development, they know. What's more, the entire industry is on the eve of a leap in technology. They don't even have customers for the PAS 2000, and they should really already be working on the next-generation stepper.

At the time there are seventeen PAS 2000 steppers, most of them still being assembled. George, Van Kessel, and Janssen are pessimistic about them. Van Kessel has managed to keep a lid on overproduction by making sure they only ordered parts for twenty PAS 2000 machines, not forty. Customers aren't lining up to buy systems with oil-based positioning tables, though there's still some hope that chip manufacturers will want to try out their superior alignment technology with an eye to buying a future stepper with a different drive system. Against their better judgment, everyone's clinging to that superior, but unsellable, technology.

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When the company launches, sixteen PAS 2000 wafer steppers are under construction and one PAS 2000 demo machine is standing on the S&I factory floor where ASML is temporarily located. These machines and other inventory are valued at $1.8 million on opening day. As agreed, Philips deducts this amount from the $2.1 million each founding partner has promised to invest in the joint venture. The company transfers three hundred thousand dollars to ASML's bank account on April 1, 1984. ASM transfers $2.1 million a few days later.

24. **The Deadline**

ASML has to deliver a machine for a new chip generation within two years. Gjalt Smit discovers he needs a mountain of cash to finance his race to catch up.

During the long talks Gjalt Smit has with his new team, their technical pride surfaces. Richard George in particular speaks animatedly about how superior the technology developed at Natlab is. The lab even has a solution ready and waiting for the outdated oil-based tables, he says. "And Gjalt, it's a sublime solution," he earnestly tells his soon-to-be boss. "It's something our competitors can only dream of." George describes Natlab's electric table, with which ASML in theory has a superior and extremely precise wafer stage at its disposal.

The more fragments and snippets of information he hears, the faster the fog around Smit begins to clear. Slowly but surely, he realizes that Philips' lithographic technology contains many elements that are still far ahead of their time. Particularly the alignment system to precisely overlay chip patterns is superior. The electric positioning table is another unique potential selling point, a feature the competition doesn't have.

In his discussions, Smit notices his people have mixed feelings about Natlab. On one hand, they admire the researchers' intellect bordering on genius. On the other, they think the researchers are arrogant. But Smit instantly kills the complaints and doubts about the partnership. "Are you crazy?" he says. "We desperately need Natlab."

The conversation about Natlab triggers Richard George to mention Steef Wittekoek: "Gjalt, there's a guy in the States we need to have." He tells Smit that Wittekoek was the heart of Philips' stepper development for years. After Wittekoek took the project over from Van Heek in 1974, he built a second version of the wafer stepper, the Silicon Repeater 2, and he and Ad Bouwer added a new invention: the H-stage.

Wittekoek advised the S&I team from Natlab, but didn't see a future in the project once the deal between Philips and Perkin-Elmer ran aground. He left to work for Philips Medical in the US. George suggests he give Wittekoek a call. "Do you know him personally?" Smit asks. "Yes? Then hop on a plane. Go to New York."

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ASML wants to conquer the world, and you can only do that with a revolutionary machine, one that leaves the competition far behind. Only with a spectacular product can the Dutch company make a place for itself in a market where it currently has no share. But there's a problem. Semiconductor manufacturers want to be able to test machines for the next generation of chips within two years. ASML's nine competitors are already working on that goal. They're planning to demonstrate their new lithographic equipment at SEMICON West 1986 in Silicon Valley. Companies that have nothing to show will be minor players at best, everyone is convinced.

There's nothing for it. ASML has to show what it can do. And not just that: in a market with established players, it has to come up with something better. But developing a complex machine and having it ready for mass production within two years is all but impossible. Yet they have no choice.

All the stories Smit's hearing from his technical team members convince him that ASML's positioning and displacement technologies are superior. If they can also deliver the optics, they can create a world-class machine. A device that far outstrips its predecessor, yet will carry on its name—because the management team is clear about that. There are only a few PAS 2000s at chip fabs, but the brand is so well known by now they want to capitalize on it, despite the P for Philips. Their new product will bear the name PAS 2500.

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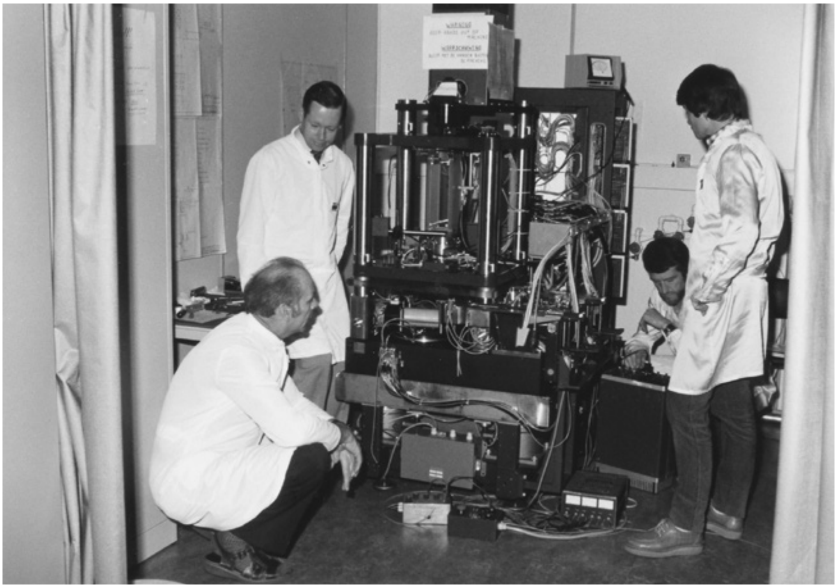
The intense discussions ignite hope and a fighting spirit. In the venture's first month, George draws the sketches for ASML's initial



The PAS 2000 under construction in S&I building TQ2 on Philips' industrial campus in Eindhoven. The plastic curtains at the left and right keep as much dust as possible out of the assembly area.

machine. His task is clear: make sure we have a device within two years. At S&I the tenacious go-getter had just a dozen engineers at his disposal to make something of the PAS 2000, to no avail. He's learned a great deal from his mistakes and is eager to do it right this time around.

The time constraint ASML is operating under in 1984 is in stark contrast to the way Philips traditionally builds machines. At the multinational they always take plenty of time to create the production technology for, say, light bulbs or television sets. First there's development, then they make prototypes, and once prototype production is where they want it, they build extremely robust machines capable of churning out bulbs and TVs day in, day out. At Philips, a new generation of machines can take ten years to create.

ASML doesn't have anything like that kind of time. George realizes they're going to have to break with traditional development culture. The solution he devises is to chop the machine up into chunks. Specialized teams will develop each chunk, each system module, in parallel. That will take them eighteen months. Then they'll put the whole thing together. Each piece will have to slot in and communicate with the others perfectly.

George sits at his drawing table and sketches the separate modules and subsystems. For each part he defines a project and assigns engineers to it: ten to fifteen per subsystem. The individual parts need to be reasonably independent; they have to be able to be separately operated and tested. But by now George is intimately aware that all those separate machine parts will have to work together perfectly at the end. To accomplish that, he defines three layout projects: one for the mechanics, one for the electronics, and a third for the software.[3] George's experience has taught him that the real pain comes at the end, during what's called the integration phase. Major mistakes don't surface until the machine is being put together and all the modules and subsystems have to talk to one another.

In the traditional approach, all the subsystems go through testing one by one. Otherwise errors are almost impossible to track down, making integration too complex and thus even more time-consuming: every time the testers run across a problem, everything shuts down. It takes the engineers hours and sometimes even days to find a solution. All that time, the other system parts are waiting for their turn to go through testing.

Testing and integrating each of the five system parts will take at least half a year. "So if we have to test and integrate everything in series, it'll take us at least four years, and we won't be able to present the PAS 2500 at SEMICON West 1986," George tells Smit. "Gjalt, there's only one solution. We build not one, but five prototypes at the same time. We can do testing on each one. We'll work with five teams in parallel to get rid of the errors and shorten the testing and integration phase from two and half years to six months."

The idea is simple, but very expensive. Five machines will cost millions in parts. But that's nothing compared to the expense in salaries. George says that at the peak, they'll need 250 engineers running in their race to catch up. But materials and manpower aren't even the only problems. The new generation of machines also needs an extremely clean development and production environment. ASML will have to construct a new building with cleanrooms in record time.

The first PAS 2500s will be prototypes, but there won't be any time left to build mature machines. The test steppers will have to be good enough, and sellable. After all, chip manufacturers will want to try out the PAS 2500 in 1986 in their test production. Only after that will they decide to buy large series of machines for mass production. But ASML will already need to have a factory ready where it can put together dozens of machines at a time. "Just the cleanrooms for mass production are going to cost us twenty million," estimates Van Kessel, the man who will keep an eye on cost.

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Thanks to his talks with George and Van Kessel in particular, by the time the joint venture launches Smit has a good picture of what will happen in the coming years. He doesn't have to worry about the stepper's superior technology; that's in good shape. After all the failures at Philips, he now has to make sure the machine becomes a commercial success. That his engineers don't make the same mistakes, but become a little more worldly, start listening to customers and understanding what they want. That they make it to production. That they set up a well-oiled sales and marketing machine. Surrounded as he is by bright engineers, Smit knows he needs to create a flat organization with a culture of empowerment: no hierarchy, but people who take the initiative themselves. One of the first things Smit and Van Kessel do is set up an information infrastructure to make sure everything runs smoothly. ASML needs an advanced logistics system for production. His experience at ITT has taught Smit that that's an enormous task. So he mentions it to Van Kessel before the joint venture even launches.

Van Kessel's going to head up production, but Smit knows his experience is mostly in automation projects, not production processes. ”I know what you’ve done at Philips, and soon you’ll be managing operations, but wouldn’t it be a good idea to get a production guy to help you out?” Smit asks his soon-to-be head of manufacturing. Van Kessel thinks it’s a great idea and answers with a resounding yes.

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And so, in the first months of 1984, Will Bertrand at the Eindhoven University of Technology receives a phone call from Smit. It’s just luck that ASML’s future CEO is calling him—but not entirely. A former ITT colleague told Smit that Bertrand did some amazing things in Elcoma’s semiconductor fab when he was doing his doctoral research. The young engineer designed a production management system with shorter throughput times and greater reliability, which increased chip yield by 12 percent. He’s exactly what Smit’s looking for: someone with a scientific background, but also practical experience.

A few minutes into the call, Bertrand hears why Smit isn’t knocking on mother Philips’ door. That would be the obvious choice; the electronics company is filled with production experts. “Above all, I have to make sure this doesn’t become a Philips company,” Smit says point-blank. “If we adopt that bureaucratic culture here, we’re dead before we get started.” He can’t do without Philips, but he wants to limit the parent company’s involvement to an absolute minimum.

Smit’s pitch intrigues Bertrand. He’s earned his PhD, but science for science’s sake isn’t his thing. He wants his work to have real-world consequences. Smit’s request is an ideal opportunity to leave the academic world behind.

For Van Kessel, Bertrand’s arrival is a breath of fresh air. Now he has a top logistics expert as his right-hand man, and that has a calming effect. Just Bertrand’s presence forces Van Kessel to sit down with him from time to time and go over the state of affairs. How will they involve the engineers in their planning? What does an efficient assembly plant look like? How will they set up purchasing and sales? While Van Kessel's ideas bounce off in every direction, Bertrand provides balance. "Ho there, Joop, slow down. What's the main thing?" he asks, and then they draw another flow chart to get their thoughts on the same page.

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In ASML's first months, it's still completely unclear how the machinery manufacturer is going to set up its production process. They've agreed with Philips that the joint venture will be fully separate from its parent company, from salaries to logistics and production. Smit has contacts at German manufacturers, and he asks Van Kessel and Bertrand to go talk with them for inspiration. There they encounter the phenomenon of *Fertigungstiefe:* the holy conviction among machinery manufacturers that you're better off having full control over everything.

ASML's management team considers taking that approach. That the company will buy its optics elsewhere is not up for discussion, but if it's going to build hundreds of machines per year, there's a lot to be said for doing its own metalworking. But after discussing it with Philips, Smit and Van Kessel conclude they shouldn't make anything themselves.

And so ASML decides right in its very first months to become a company that only does development and assembly. That's unheard of in those days. When Bertrand mentions it to their German contacts, they ask him if he's gone completely mad. In Germany, farming everything out is synonymous with handing other people the keys. "You're asking for trouble; you'll lose all control that way," they tell Bertrand.

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Bertrand hears ASML's engineers talking about the development speed they're going to need. He concludes that a classical system for material requirements planning (MRP) won't get them there. An MRP system assumes stable parts lists. "But development tells me the product structure isn't stable," Bertrand says to Van Kessel. "If it changes from one quarter to the next, then we're talking about projects." But at ASML they aren't dealing with pure projects, either. Each generation of wafer steppers is similar to the previous one, even with some major changes such as the move from a hydraulic stage to an electric wafer table. Bertrand needs to find a hybrid system.

As a logistics expert, he knows how to manage the production of complex machines. Inventory, material requirements, buying in phases, that kind of thing. Those are standard processes that are no different for a wafer stepper than for an electron microscope. His primary task is to schedule it all efficiently, so they don't need a gigantic team to get all the materials they need. At the same time, the system has to be able to handle a changing product structure. Bertrand's challenge is to build an MRP system that can manage the dynamism of his bill of materials.

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R&D is turbulent at ASML. Every day there are small changes, often minimal improvements or adjustments. The engineers make them without anyone else's input. Sometimes the changes are substantial. In moving from a hydraulic motor to an electric one, the supply chain completely changes. That means signing contracts with all their new suppliers and recording those agreements in their logistics system.

It takes Bertrand four months, but he finally has a solution: he decides to involve the developers early in the process and let them decide on the components. The R&D guys will have to keep track of all that they do: every adjustment, every screw and nut, it all has to be neatly recorded in folders in the logistics system, well before the final result is there.

The idea sounds simple, but Philips never once came up with it in the preceding decades—Natlab, which thinks up the company's new marvels, is completely divorced from industry. The salient characteristic of its research is anarchy. Thinking up smart ideas is what matters. The lab keeps well away from strict regimes to ensure that inventions are quickly and efficiently converted into reliable products.

Bertrand decides that from now on, the tech guys have to document the components and subparts they develop. What's more, they have to release that information well in advance. They have to provide a useful indication before the complete drawings and parts lists are finished. That way ASML can say to its suppliers: this is what we're building; we don't know exactly what it's going to look like, but the part will be made of Zerodur or high-alloy steel and it will have these and these characteristics.

The early release of development information will turbocharge ASML and its suppliers. Everyone will know what's going on earlier and be able to prepare for it. Suppliers can go ahead and order materials and schedule manpower.

The idea to signal the supply chain early has another big advantage. Given a deadline, the entire schedule for component delivery can be calculated backward, from milling machine to drawing board. If a machiner or electronics manufacturer receives basic information about his task's materials and complexity, he can indicate how much time he'll need to manufacture the system or circuit board.

The biggest advantage is that this approach gives ASML's developers the opportunity to set priorities. R&D knows from experience which parts they'll have to wait a longer or shorter time for, but at Philips that was never translated into visible urgencies. Bertrand wants a system that translates suppliers' indications into urgencies that help developers prioritize. Suddenly there's a way to tell the R&D department which drawings have to be ready when, to create breathing room in the production process and get everything done on time. Bertrand's system is completely new.

But there's a problem. The discipline to document isn't second nature to developers and inventors. Yet they have to do it, or the whole schedule will fall apart. Smit knows his idiosyncratic researchers won't welcome Bertrand's plan. Suddenly they're going to have to spend hours of their precious time each day on administrative tasks. At the end of 1984 Van Kessel and Bertrand select XBMS,[4] a logistics system from Xerox that the American company also uses at its photocopier plant in the Netherlands. It will cost millions to license the software, but Smit simply wants the best of the best and instantly agrees. When he presents his choice of XBMS to Del Prado, ASM's CEO asks why it all has to be so expensive. "Logistics is just back-of-the-napkin stuff," he sniffs. Smit concludes that this, at any rate, is a chip industry business equation his shareholder doesn't understand.

Soon thereafter, Smit gathers his engineers together. He knows there's a real danger everyone will create his own individual recordkeeping system. He's all for creativity, but he knows from his time at ITT that in production and logistics everything must be set up perfectly, especially a system that has to guide a river of ten thousand parts safely to the sea.

Smit tells everyone how important it is they use XBMS for its many advantages. "You're all going to use XBMS. From now on, it's required," he says. "I know you don't think you need it, but it will helps us to implement changes fast, inform suppliers fast, and reach the market fast." He hires a full-time employee to watch over the entry of information into XBMS.

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In bringing Bertrand on board, Smit injects an element into ASML's corporate culture to which the company will continually return: the hiring of external experts in any area where it lacks experience. Smit consistently selects consultants of the very highest caliber; he couldn't care less what they cost. It's a cultural element that will come to form an inseparable part of the company—and it's what will enable ASML to grow into a world-class business known for superior quality.

25. **A Hundred Million Dollars**

At the SEMICON West machinery trade show, American chip manufacturers assert that ASML would be well advised to stop. But Gjalt Smit still sees an opportunity—albeit one with a hefty price tag.

Gjalt Smit patiently listens as Richard George and Joop van Kessel fling six-figure numbers across the table. Development and production, startup investments in materials, buildings, logistics, and an army of engineers. All together, it will easily cost tens of millions per year. "ASM and Philips will never pay that," George and Van Kessel predict.

Smit can see that their numbers are realistic. The calculations all add up. He also knows that working in parallel is the only way to get operational machines and prepare ASML for mass production within two years. They can't avoid setting up advanced logistics and a new cleanroom, either. They're all absolute necessities. Smit doesn't panic; he's used to figures like these. At Holec and ITT he dealt with much larger investments.

At ASML, Smit's task and mission is to ensure that all the pieces fit together so they can reach their goal. Money is just one of the pillars holding up the company, and he's hired Gerard Verdonschot as CFO to solve that puzzle.

It's clear as day that ASML's race to catch up is going to cost mountains of dough. Smit and his people estimate a rough total of $100 million. Now the CEO needs to present it to his board as soon as he possibly can.

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In his first chaotic month, Smit wants to throw himself fully into planning, but he barely has any time to focus on strategy. He's swamped with side issues. He has to whip their recordkeeping and human resources into shape using quick-and-dirty solutions, talk to the unions, arrange social security and pension plans, find space for everyone to work. And ASML needs to start hiring like crazy. To get development up and running, they'll need dozens of people, fast.

Despite the mountains of work, Smit frees up time for the things he considers his top priority. First of all, he hits the road to arrange the oh-so-vital optics. To do that, he and Natlab's management visit Zeiss in Oberkochen, West Germany.

He also takes a look around Elcoma's chip fab in Nijmegen and Valvo's in Hamburg. These Philips sites are currently experimenting with the company's oil-based steppers. There are no friends for Smit there. Both fabs have bought the machines at gunpoint. Smit's impression is that they barely use them.[5] At any rate, the Philips employees he talks with don't strike him as the promising customers Del Prado made them out to be.

Smit begins to realize that ASM doesn't know how much resistance chip manufacturers have to using oil. Neither Del Prado nor his technical right-hand man, Willem de Leeuw, understands that. After barely a month on the job, Smit can only draw one conclusion: the assumptions on which the joint venture partners based their commercial optimism are false. But he also knows that ultimately, it's customers who will determine ASML's fate. To reach them, he books a flight to the US in late May 1984. He'll attend SEMICON West in San Mateo, California and visit chip manufacturers in Silicon Valley while he's there.

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Smit combines his California trip with a stop in New York to speak with Steef Wittekoek. Wittekoek has already been visited by George, and during that meeting he expressed a desire to become ASML's head of development. That puts Smit in a bit of a pickle, because his management team has told him Wittekoek isn't suited to be a manager. What's more, he's headhunted Nico Hermans away from Xerox; Hermans has already accepted the position.

Smit meets Wittekoek in the lobby of the Hilton hotel in Tarrytown, New York. ASML's CEO describes his mission. "We're going to take first place," he tells Wittekoek. "It doesn't matter what it costs; we're going for the gold, and that takes brainpower and a lot of guts." Smit's bravado sounds overly ambitious to Wittekoek. He was there to see S&I fumble and eventually fail. But the new CEO's eagerness appeals to him.

Then he's told he can't run development. "Steef, I'd love to have you on board as our free safety," Smit diplomatically says. "You'll have multiple roles. First, a role as chief technology officer. I want you to keep a critical eye on our development. That also means you'll be the technical face of the company, accompanying me on customer visits to explain our technology. ASML isn't on the map yet, but everyone knows you from the tech conferences where you represented Philips. You'll also be involved in PR and marketing, and in addition I'd like you to handle our patents."

Smit's passion impresses Wittekoek. The dignified researcher is also delighted with a role as ambassador for the Dutch stepper maker. Smit gives him a title he first encountered at ITT: executive scientist, the company's scientific and technological guru—in short, someone with prestige. "As our executive scientist, you'll meet with our customers' senior management," Smit tells him. "You'll report directly to me and you'll be part of our executive team." That does the trick: Wittekoek is sold. "This is the man I've always hoped for," he tells his wife when he gets home.

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A day later, Smit gets pummeled in San Mateo at the world's leading chip machinery show. Everywhere he mentions that Philips' stepper project has risen from the ashes, he gets the same bitter message: don't bother, stop now. The Americans tell Smit they aren't interested in a European stepper supplier. Philips is a great company, but it doesn't understand a thing about making chips. Yeah, that novel stepper they made, that was pretty neat, but now? Total history. "Mr. Smit, I'm sorry to have to say this, but the race has been run," they all tell him. "These days we can buy a stepper from everyone."

If Smit had any doubts about that last remark, the show floor at SEMICON West 1984 removes them. Market leaders GCA and

Nikon aren't the only ones wooing wealthy customers. A whole new generation of lithography companies is there in San Mateo. Ultratech, TRE, Optimetrix, Censor, and Canon: they're all vying for chip manufacturers' favor.

Smit also absorbs the latest figures and rumors. According to analysts, GCA now has four hundred machines in the market; Nikon and Ultratech are close behind, with two hundred and one hundred machines, respectively. Even Censor, the stepper startup from Liechtenstein that's just been acquired by Perkin-Elmer, has already sold dozens of wafer steppers. The same is true of TRE. Canon hasn't released any numbers. He does hear that another Japanese company, Hitachi, is looking to enter the lithography machine market.

The American chip makers don't spare Smit's feelings. "GCA and Nikon already have a huge installed base, and soon the newcomers will have one, too," they tell him. A company's installed base—the number of machines in operation at customers' factories—is a key concept. GCA and Nikon are already in the hundreds.

An installed base gives lithography suppliers experience and expertise, because the steppers are accompanied by hordes of service engineers. The complex machines go down at the drop of a pin, and chip fabs want to keep that costly downtime to an absolute minimum. Support is essential. At its peak, GCA alone has hundreds of service engineers out in the field. ASML has no machines in the market, no service department, and thus no oh-so-crucial practical experience in chip production.

Time and again, potential customers rub this bitter fact in Smit's face when he asks them what he can do to pique their interest. "Come back once you've sold twenty. Then we'll talk."

Via Elcoma, Smit comes into contact with Jim Morgan, the CEO of Applied Materials—ASM's arch enemy. In those days, Applied is the same size as Del Prado's company. Elcoma buys its equipment from Morgan instead of its countryman. Morgan thinks it's foolish of ASM to enter this market. "How do you plan to get a foot in the door in an industry where two established companies have divvied up the market between them?" the flabbergasted CEO asks Smit.

Smit doesn't defend himself; he just keeps asking questions. What does Morgan think of Del Prado's strategy of positioning himself as a supplier of complete solutions? "I wouldn't do it," Morgan answers. "Lithography is nothing like process equipment."

Morgan's strategy is to specialize, focusing on what's called front-end equipment: machines for deposition, etching, epitaxial crystal growth, that kind of thing. "Those processes make sense together," he explains. Lithography isn't his thing. "Lithography isn't a process; it's a mechanical-optical manipulation. I can connect the dots between chemical deposition and sputtering: those processes draw on some of the same disciplines. But lithographic technology is a whole different thing. And as far as I can tell, it's also a pretty expensive hobby."

Applied's CEO argues that lithography is also far more strategic for chip manufacturers. Miniaturization directly affects costs, yields, and performance. "That's why lithography is a decision that chip manufacturers make at the executive board level," he tells Smit. "They leave decisions about sputtering and etching equipment to the fabs." Morgan also thinks chip manufacturers don't want to buy everything from one supplier. "That would make them far too dependent."

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Smit returns to Holland with a heavy heart. His picture of gloom and doom is complete. But when he reviews all he's learned during the flight home, he sees the first rays of light flickering at the end of the tunnel. The negative voices running through his head start to make way for the positive SEMICON West buzz. The semiconductor industry is vibrant and thriving. Chips are changing the world.

This industry is on the verge of leaping another hurdle, one that creates opportunities for machinery manufacturers. At the show in San Mateo, everyone was wondering how they'll make the next generation of machines in order to keep Moore's law alive—how to take the step from large scale integration (LSI) to very large scale integration (VLSI). It's clear that chip details will shrink to less than one-thousandth of a millimeter in the coming years, and that lithography machines will no longer work on four-inch silicon wafers but on six-inch ones. This transition will happen in the next two years.

VLSI requires a completely new lithography generation, machines that can image 0.7-micron details onto chips and make it possible to achieve even tighter microelectronics integration. If SEMICON West has made one thing clear to Smit, it's that no one has a lithographic solution yet for that kind of chip.

He lets it sink in for a few days, and then he's sure. A brave new world opens up before him. The team around him is demoralized as ever in Philips' bleak and dreary building in Eindhoven, but every day Smit grows more convinced there's a way to escape this black hole. And more than that: if ASML succeeds in delivering the best stepper for the VLSI generation of chips, it will have the semiconductor industry at its feet.

In San Mateo Smit didn't see a single lithography supplier who already has a VLSI-ready machine.[6] GCA and Nikon still haven't made any official announcements. The current steppers being made by the Americans and the Japanese definitely fall short of the step to VLSI. Lithographic equipment will have to drastically improve in pretty much every aspect: the optics, alignment, and positioning. The machines made by Canon, GCA, Nikon, and Perkin-Elmer still use lead screws to move the table. That doesn't give them the positioning precision required to image details less than a micron in size. And that's exactly where ASML's technology is superior.

The realization excites and intrigues Smit. As an aviation fanatic, he tracked that industry's move to consolidate. While he was still in college, the world had fifty airplane motor manufacturers; after he completed his PhD, only a handful were left. During his time at ITT he also witnessed a technology shift in the telecom industry.[7] He knows that a new player in an established market doesn't stand a chance, unless that newcomer can achieve a technological breakthrough.

If everything putters on as business as usual, ASML can't possibly beat GCA and Nikon. But Smit knows the move from LSI to VLSI creates an opportunity. This paradigm shift can completely upend the established order. This is the chip industry, where everything changes in the blink of an eye. For the coming generation of VLSI chips, machinery manufacturers are going to have to develop brand new lithographic technology. Every single one of them.

In a few days' time, Smit's glum mood flips to a nearly manic positivity. *This is the moment*, he thinks. *We're right in the middle of it*. Slowly but surely, it all falls into place. His intense conversations with customers at SEMICON West have sharpened his understanding. From that moment on, there are only two choices: ASML closes its doors before it's even opened them, or it bets all it has on delivering a sublime VLSI stepper two years from now that will let the company conquer the market. It's now or never.

* * *

Smit is now faced with the nearly impossible task of winning over his shareholders and readying ASML for a supremely bold operation. He estimates they'll need a hundred million dollars. That's what ASM and Philips will have to invest in the coming years to become the market leader in chip lithography. If that isn't the two parent companies' ambition, then the whole adventure should stop today. Now he just needs to figure out how to break the news to his board of directors.

It's unlikely the joint venture partners will sign on to his plan. ASM has just pumped in a major infusion of cash; Philips is constantly reorganizing. But Smit knows his story is convincing. And he can also hold out a juicy carrot for his shareholders. The analysts are unanimous that the semiconductor industry will grow rapidly in the near future, and as a result the market for VLSI machinery will be bursting at the seams in a few years. His conversation with the board will be intense, so everything's riding on a good pitch and excellent preparation.

In June Smit hunkers down for a few days with George, Van Kessel, and Ger Janssen to whip up a plan of attack. He starts with the original business plan for the joint venture, written by ASM and Philips in the summer of 1983. With his visit to SEMICON West fresh in his mind, Smit concludes with some disdain that his shareholders had no idea what they were talking about.

A year earlier, ASM and Philips put down on paper that the venture should gradually grow to an annual output of seventy-five to a hundred steppers sold. That would generate an annual revenue of $95 to $105 million in 1988. That's not nearly aggressive enough, Smit concludes. If the analysts' prognoses are right, then ASML will still be fighting a rearguard action with those numbers. Aiming for a spot at the back of the litho pack means eventually giving up, Smit tells his team. "In that case, we might as well give up now."

Smit's envisioning an entirely different scenario. He knows he'll have to invest heavily to develop a new machine. At the same time, the company will have to be gearing up for mass production.

It's a puzzle to Smit why the initial business plan is partially based on the old PAS 2000 machine, when it's obvious that oil-driven systems are unacceptable in chip fabs. At S&I they didn't even try to replace the hydraulics with electromechanical technology. It's one of the reasons why ASML is so far behind now.

But in the summer of 1984 there's not a cloud in sight. That makes even Smit and his management team hopeful that chip manufacturers will want to buy their PAS 2000 machines to try out the superior alignment technology. Besides, the Dutch company doesn't have anything else to offer.

ASM and Philips have closed a strategic deal regarding access to Natlab's lithographic expertise. But strangely enough the electric wafer table isn't part of that deal. The new stage displaces the silicon wafers at high speed and also positions them very precisely. That alignment technology makes the table one of Natlab's crown jewels. But the partnership agreement[8] says that ASML will have to negotiate for that itself later with Philips.

By now it's obvious the part is crucial for the company. To discuss the issue, Smit makes an appointment with Kees Bulthuis, one of Natlab's section directors at the time. They agree that ASML can take over the technology for $930,000.[9] There's just one small problem: Smit doesn't have a cent. "Okay," Bulthuis says, "you can pay for it later."

26. **From Paris to Oberkochen**

CERCO can't meet the increasingly stringent requirements for the stepper's optics, but Zeiss isn't interested in helping.

To make VLSI chips, they need new lenses that can produce sharp images of even smaller details. And they have to project those details onto a greater field of view, so the industry can make larger chips and increase its productivity. That kind of optics doesn't exist yet.

Canon and Nikon have the luxury of making their own lenses. Even GCA has crucial optics expertise in house with its acquisition of Tropel. ASML has inherited a great deal of technology from Philips, but it can't make its own optics; the fledgling machinery manufacturer must look to others for that. Unfortunately, their French supplier CERCO makes Gjalt Smit feel like an airplane manufacturer who can't get his hands on good engines.

* * *

Designing and manufacturing optics is as much an art as it is a science. In addition to ingenious thinking and precise calculation, it requires seasoned craftsmen with ten years' experience and the hands of an angel to grind and polish the lenses. Natlab's machine shops don't have that kind of skill. After the Second World War the lab's technical support services mastered a whole host of disciplines, but optics is in a class by itself. In addition to a glass blower and mechanical shops, Natlab does have an optical shop and even a very good grinder, but it's not the door to knock on for something as finicky as a microscope lens. That's where CERCO comes in.

The relationship between Philips and the tiny French optics specialist is a good one—and long. For years Natlab's researchers and S&I's engineers have gladly traveled to Paris to discuss their needs. The ambience is always friendly.

At the end of the seventies, CERCO pulls off a monster feat: the design and production of the Super Tulipe optics for the PAS 2000.

The lens is capable of making images using two spectral lines from a mercury vapor lamp.[10]

But in the early eighties, Natlab's engineers gradually discover that their requirements are growing beyond CERCO's capacity. The French specialists are teetering at the edge of their abilities, yet eagerly overcommit to complex projects. With a lot of blood, sweat, and tears they often succeed in creating a new lens, but when Philips then orders five identical copies, they're unable to reproduce their work. The more Natlab asks for, the more often CERCO comes up short.

* * *

And so in 1983 Herman van Heek travels to Paris to talk about an advanced lens. He takes Joseph Braat with him, one of Philips' top optical specialists. The lens will be the workhorse of Philips' and Siemens' joint Megachip project. CERCO embraces the order with enthusiasm. The company will design and manufacture the lens, which will be named Crocus. But when Braat inspects the initial design a month later, he concludes that it's so complex the optics are impossible to make. He travels to Paris with a heavy heart to warn CERCO's CEO—but Hugues decides to make the lens anyway.

When CERCO sends the first Crocus lens in a series of five to Philips a few months later, Braat's worries are confirmed. The optics don't meet the requirements.[11] CERCO can't get it right, and this debacle is the beginning of the end of Philips' relationship with the French optics house.

As it happens, just around then Braat runs across an article by renowned optics expert Erhard Glatzel at Zeiss. In the article, Glatzel describes how to design a stepper lens in a way you can actually manufacture. In an optical column with dozens of individual lens elements, errors always creep in. Glatzel shows how to maximize the chance of achieving a working optical system despite all the unavoidable errors. That expertise is the reason why in those days Zeiss is able to make advanced optics with decent reliability for Hasselblad's cameras. The German company even delivers hundreds of g-line stepper lenses to GCA. Braat and Van Heek also know the stories making the rounds: when you order a part from Zeiss, you can be sure you'll get ten or twenty units that meet the stated specifications precisely.

After Braat reads Glatzel's article, he takes the information straight to Richard George. George is surprised that Zeiss would share that data. "We need to take this to Paris!" he shouts. Zeiss's expertise is the final lifeline to which George and Van Heek cling. They go to CERCO and play it safe: they ask Hugues to make a simpler lens, one that works with a single wavelength (the g-line) and designed to Glatzel's instructions. CERCO's CEO can feel the pressure. He has no choice but to lay all his cards on the table. In the past he's been able to sweep his optical secrets under the rug, but now he's under the microscope and has to openly discuss every detail of what will become the Dahlia lens.

George and Van Heek micromanage the endeavor: for six long months, they fly to Paris every two weeks. At last the Dahlia goes into production. In 1985 the lens will—for lack of a better choice—be used in the PAS 2400, ASML's first stepper with an electric wafer table.

* * *

By now Philips is all too aware that it can't let its fate depend on CERCO. The company finally severs its ties. To Braat, it feels like betrayal. But there's no way around it. In early 1984, the joint venture between ASM and Philips is being hammered out, and they need a reliable supplier who can deliver large series of advanced lenses. So at the start of the year, Braat and Van Heek travel to Oberkochen to ask Zeiss if it will make optics for them, too.

Van Heek is enthusiastic. By this point he's in charge of the optics for the PAS 2000 stepper at S&I. He singlehandedly developed its very first version—the Silicon Repeater 1—at Natlab ten years earlier. The joint venture with ASM finally brings his machine's commercial launch into view. When he and Braat fly to Zeiss, an ambitious wish list is tucked in his jacket pocket. He wants custom optics. First off, he wants a wide lens aperture to image larger chips at higher quality. Add to that a set of special prisms and lenses so they can build in ASML's unique through-the-lens alignment technology.

At Natlab, Braat is working on a third version of the Silicon Repeater. The machine will ensure that the Megachip project has lithographic equipment, should third-party suppliers fail to deliver on time. At the request of his group head, Ad Huijser, Braat's designed an i-line objective to get a feel for the complexity of the optics. That means Braat is intimately familiar with the narrow tolerances in a lens like that. Braat and Van Heek also know that Zeiss is working on i-line optics, and they predict the company's engineers will be eager to discuss the problem.

In Oberkochen Van Heek and Braat meet Gerhard Ittner, head of Zeiss's R&D lab. The physicist has worked for the company since 1970 and was there to see how its low-end line of photographic objectives was trounced by the Japanese competition. German camera manufacturers stopped placing orders, which gave Zeiss the space to supply GCA with optics for photorepeaters and, later, steppers. That work was also a good fit for Hasselblad's high-end objectives. And so chip lithography saved Zeiss.

When Van Heek and Braat arrive, Ittner is swamped with work. GCA in particular is claiming much of Zeiss's production capacity for its popular steppers. In addition, Zeiss has made agreements with two other stepper manufacturers, Censor and Hitachi. Ittner isn't really interested in even more work. Zeiss can't expand its production capacity in the short term; it takes years before craftsmen have the experience required to polish lithographic lenses. There's a reason why Zeiss's employees are known as the folk with the golden fingers. Van Heek asks about an optical system that can handle two wavelengths, but Ittner's answer is instant: "Absolutely not. Way too tricky."

Ittner doesn't let it show, but he's on the fence. Things are getting tenser with his American customer GCA, and ASML might offer new opportunities. Zeiss is currently embroiled in heated discussions with GCA over the quality of the lenses. Chip manufacturers are having problems with GCA's stepper, and the partners are blaming one another. Zeiss says GCA's machine design is outdated. The American company needs to change its systems to take full advantage of the latest lenses. GCA blames Zeiss for sending it lenses that degrade in quality once they're delivered.

* * *

Van Heek attempts to turn the conversation in a new direction. "We want to get our numerical aperture up to 0.30, and even higher if we can, to 0.32 or 0.34," he tries. But Ittner isn't buying. "That's not how it works around here. We can offer you 0.28, and that's it." Ittner then rattles off several standard lenses in stock. Philips can buy those, but this station doesn't play requests. He does say that Zeiss is working on a new generation of i-line lenses. The company plans to sell them as a standard lens for chip lithography. They already have three customers lined up, and Ittner expects the new lens column to be ready in six months.

When Braat offers to show him Natlab's i-line design, Ittner politely declines the gesture. The two men from Philips get the picture: the guys in Oberkochen think they're better than everyone else. All things considered, Ittner doesn't have much to offer Braat and Van Heek. The R&D manager's attitude seems very formal and distant to them—like they've been granted an audience and should be happy he's even talking to them. Zeiss isn't interested in custom orders, not even from Philips. Building in complex tailor-made extras is out of the question.

After Van Heek and Braat have talked at length with Ittner, he announces the arrival of *Herr Doktor* Glatzel, head of the company's math department. At the time, Glatzel is a global optics rock star. The wide-angle lens he designed for Hasselblad's camera that went to the moon earned him an Apollo Achievement Award from NASA. He's famous for designing the photographic objectives[12] that give Zeiss's Contarex cameras their renowned quality.

Within Zeiss's corporate hierarchy, Herr Doktor Glatzel is untouchable. In those days every optics company has a math department, where brilliant mathematicians and physicists make their own lens calculations. In the fifties and sixties they do it by hand; later, using the first computers and supercomputers. At highly stratified Zeiss, the mathematicians stand alone at the top. They work silently in spacious offices down long halls, bent over their optical matrices like monks. To help them recharge after four hours of mental exertion, they may take longer lunches than their colleagues. At the peak of that mathematical pyramid stands Glatzel, alone at the very top.

The aura of unassailability surrounding this man, dressed in a smart three-piece suit of gray, doesn't escape Van Heek and Braat. Ittner receives Zeiss's chief optical designer with a regard that borders on reverence. Then comes a ritual that makes the two visitors' jaws drop. Ittner presents all their questions to Glatzel anew. "What do you think of this question, Herr Doktor?" Glatzel answers each time in short, decisive sentences. "We won't do that. That can't be done." There's no room for discussion. If something's impossible, then it's impossible. Glatzel repeats what Ittner told them earlier: the company will not make a custom lens for Philips.

To colleagues who know him personally, the chain-smoking Glatzel is a mild, almost timid person. But in the company's rigid hierarchy the man has been elevated on a pedestal so high that he towers above the rest like a general. The reticent mathematician has morphed into a gorilla you don't argue with, into an arrogant presence who leaves no room for dissenting opinions. In thirty minutes' time, Van Heek and Braat have been exposed to the whole pecking order at Zeiss, ending in an elite corps of socially intractable mathematicians who are always, by definition, right.

Van Heek and Braat leave Oberkochen disillusioned. But though they can't feel it yet, they've planted the seed for a relationship that will slowly but surely grow.[13]

* * *

Meanwhile, back in Paris CERCO just can't get the hang of mass production. In the fall of 1984 Smit goes to check on things himself, taking Van Heek with him. As soon as ASML's CEO stands eye to eye with Monsieur Hugues and shakes his hand, he knows: this isn't going to work.

During his studies, Smit worked for a time at Sud Aviation in Toulouse, where the French airplane manufacturer built the Caravelle. As he walks the production floor at CERCO, he smells the same stale situation. He sees a typical company from a country of engineers, where large corporations never accomplish anything because they're addicted to a vicious drug: the French government's bounteous subsidies.

Smit realizes Hugues isn't going to be able to deliver. CERCO's CEO is happy to work on creating lenses with the new specifications, but he'll need money to do it. After a businesslike conversation, Smit and Van Heek enjoy an excellent lunch at a café on the Place de la Bataille de Stalingrad. For Smit, it's the last meal he'll eat with CERCO. He's not interested in opening his wallet for someone who makes him uneasy. "Ah, CERCO," Smit says to Van Heek on the way home. "Lovely people, wonderful for dining and discussing Debussy and Rousseau, but poor value for our money."

Smit has little trouble convincing his management team to end its relationship with the French company. For the PAS 2500, ASML will be at Zeiss's mercy, even if the German company was rigid and inflexible during initial talks. Zeiss has the expertise and the production capacity. It sells hundreds of lenses each year to market leader GCA. If they can't make the lenses Smit needs in Oberkochen, nobody can.

If Zeiss will supply them with lenses, then the race can begin for real. The combination of superior German optics and superior Dutch alignment will make ASML invincible in overlay precision, Smit predicts. He doesn't see anything on the market that can match what ASML has the potential to offer. Their chance of success is slim, he knows, but it's a chance. They don't have much time to seize it. In just two short years they have to have a new machine available that chip manufacturers can use for their first experiments with VLSI production.

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The relationship between ASML and Zeiss finally materializes, and their mutual dependence will gradually increase until neither can survive without the other. But even though deep friendships will eventually develop between the two companies, the relationship will remain a love-hate affair for quite some time, a marriage of convenience in which the partners are sometimes at each others' throats, even if they pretend to be a dream couple to the outside world.

The rigid German hierarchy does more than just clash horribly with the direct way Dutch engineers engage with each other. It also blocks innovation at Zeiss. The company's authoritarian optics experts have a deeply entrenched habit of tossing their lens designs down to the production department like manna from heaven, and it causes constant tension. The strictly one-way traffic and the cultural divide between brains and brawn lead to ever more errors. This mid-eighties lack of collaboration between Zeiss's physicists, mathematicians, and craftsmen will grow to haunt the company as the years progress.

But on the technical level, in research and development, the Dutch and the Germans are quick to click. The bond between the two companies will become very tight, and it will lay the foundation for total domination of the chip lithography market. But now, in the mid-eighties, all that is fifteen years in the future.

27. **The Company from Hell**

Jaded Philips engineers demoralize two new hires. The newcomers threaten to leave, but decide to stay after all when they're given challenging assignments.

At S&I's TQ complex, the mood among ASML's employees continues to deteriorate. The people from Philips keep complaining about their forced move to the joint venture, and that ruins the ambience for two young engineers: Martin van den Brink and Frits van Hout. All day long, they have to listen to how badly all of it sucks.

Van den Brink studied physics; he did his master's thesis on district heating at the University of Twente. At the end of 1983 he applies to Philips, and HR introduces him to S&I. Van den Brink knows what he wants. When George de Kruiff offers him a testing and measurement position at S&I based on his software expertise, Van den Brink takes a look around and instantly decides it's not for him. He walks into Troost's office to thank him for his time. "I'm done here; this isn't the place for me." Then Troost pulls out a brochure for the PAS 2000. It piques Van den Brink's interest.

When Van den Brink starts at S&I on March 1, 1984, he meets his bosses for the first time: Richard George and Herman van Heek. They haven't seen their new employee before today, because they were busy. George and Van Heek cast a critical eye on the young engineer's résumé. Van den Brink worked his way through community college before making it to the technical university, so he's clearly persistent. But then they see the district heating project: not exactly a plus for someone who needs to work in a development team squarely centered on optics. But George and Van Heek can't undo what's been done; Van den Brink already has an official contract.

Frits van Hout also signs up with the new joint venture in those first months. After three years of physics and math at Oxford and three completing his masters at ETH in Zurich, he's back in the

Netherlands. He's set his sights on Fokker, Philips, and Volker Stevin. The airplane manufacturer is in the middle of developing the Fokker 50 and Fokker 100, but the twenty-four-year-old engineer is most fascinated by the success of Philips' compact disc.

Van Hout is surprised that Philips' HR responds to his open application within a week. They invite him to come interview in February. When he does, they give him two options: Elcoma, or "a department at S&I that might get spun off." HR sets up a whole day of meetings at all the industrial divisions, and so Van Hout visits De Kruiff, Van Heek, and Troost one after another. That last meeting is a little uncomfortable, until Van Hout spies a cryostat in a display case. He recognizes the device; he spent years researching low temperatures in Zurich. He comments on it, and the ice is broken.

Van Hout almost instantly receives a letter: he's been hired to work at "a yet to be named company that is currently still part of S&I." He's astonished. It's tough economic times in the Netherlands, yet he's been hired right out of the gate. He can start on Tuesday, May 1. But when Van Hout calls HR the preceding Friday to ask where he's supposed to go, they don't know. "That's an independent company now," they tell him. He eventually learns he should report to the TQ complex on the Philips industrial campus, but his boss Van Heek is nowhere to be found. Van Hout does meet twenty new colleagues, but no one knows what to do with him. They're all surprised by his arrival. And curious: what Philips division did he transfer from? He didn't come from Philips? From ASM International, then? When Van Hout tells them about his application, they're all struck speechless. "What did you say? You joined out of your own free will?"

* * *

Three months later, both Van den Brink and Van Hout are enormously frustrated. The young engineers spend many hours together. There's plenty of time to talk; there's barely anything for them to do. They're soon on the same wavelength, and they share an opinion of their new employer. They absolutely, definitely need to leave

ASML as fast as they can. The mood is terrible, the company isn't serious, and it's boring there. "In short, this is the company from hell," Van den Brink says. "Yeah, it's just crap," Van Hout replies. "Nothing happens, everybody's just farting around." At the start of August 1984, they make a pact: it's time to go. Van den Brink is averse to diplomacy and politics. He's allergic to complaining and tells it like it is. When he goes to Van Heek, he says straight up, "I'm leaving." Van Heek asks why. Van den Brink answers just as directly: "Nothing happens here. There's fuck-all to do and we're not allowed to start anything. Those old Philips guys complain every single minute about what will be left of their pension and whether they'll get a gold watch if they stay for twenty-five years. I'm surrounded by people who couldn't care less what happens to this company." Van Heek argues that right now ASML is busy hiring a large number of people. But the young engineer doesn't budge. "This is never going to take off; all people do here is moan."

Van den Brink's words shock Van Heek. He knows his young colleague is right, but the conversations he's had with Smit and the management team in recent months have gotten him believing in the business again. What's more, he's seen that Van den Brink is a talented engineer. Van den Brink is responsible for the alignment system and he checks the CERCO lenses when they come in. In his first months he mastered the required knowledge of optics in no time. He's also ambitious and highly driven, exactly the spirit that ASML needs.

"Come, let's talk," Van Heek says to Van den Brink, and they walk to a bench in the park between the S&I buildings and the railroad tracks. "So what will you do next?" Van Heek asks. "I'm just leaving," Van den Brink answers. Then Van Heek makes a suggestion. They're going to build a whole new stepper, and there are several system parts whose design will be extremely challenging. Would he be interested in doing the lens projection and alignment system? Van den Brink doesn't hesitate. "I'd love to do alignment—and reticle handling." The challenge facing the lens and the alignment system is part of a single whole and the young engineer is so eager that he's signing up for not one, but two parts of the system. It's characteristic of Van den Brink, an ambitious engineer with a tendency to pile much too much onto his plate.

In his first months at ASML, Van den Brink has immersed himself in the stepper's optical issues, and by now he knows exactly where the sore points lie. The Natlab-created and patented alignment system is by far the best of the top technologies that set ASML apart from its competitors. On that front, Van den Brink has a wish. "I want to spend one day each week at Natlab," he tells Van Heek. "Because there's not a soul here who knows how the stepper works."

ASML's young engineer knows that all the knowledge he needs is just a twenty-minute bike ride away, at Philips. All the greats are there: Ad Bouwer, the man who built the stepper; Gijs Bouwhuis, the optics guru who invented through-the-lens alignment in the early seventies; Joseph Braat, the optical designer; and Jan van der Werf, who's working on alignment. What's more, Ad Huijser's optics group at Natlab is working on its own stepper—completely separate from the work at ASML. Their Silicon Repeater 3 will be a backup. Lithography is crucial for the money-guzzling Megachip project, and apparently Philips doesn't have enough confidence in external suppliers.

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Van Heek doesn't waste a second when he hears what Van den Brink wants. The young engineer will work on both alignment and reticle handling, and he has permission to spend one day a week at Natlab. "Oh, next week I'll be going to Oberkochen to talk with Zeiss about what we need," Van Heek adds. "Want to come with me?"

Van Heek doesn't forget his other young team member. Perhaps Frits van Hout would like to be the project manager for the PAS 2000? He may be taking the lead on a stepper that's on its last legs, but his new role gives him a seat on the development committee,[14] ASML's most important advisory body for its systems engineering. Not a bad position for a young engineer in the first year of his career. And it doesn't take him long to say yes.

28. **The Japanese**

At the start of the eighties, Japanese chip makers and machinery manufacturers are invincible. GCA is losing ground fast.

At the time ASML is getting started, the American chip industry is in shock. Japanese manufacturers are crushing their US competitors. Their products are far more reliable. The Americans don't have an answer to the quality the Asians deliver. The computer industry needs enormous quantities of memory chips, and the Japanese are producing them in abundance—robust chips, and practically error-free. In his reports, analyst Rick Ruddell describes the positive influence that Nikon's steppers and Canon's projection scanners are having on the Japanese chip industry. And in 1984, with NEC leading the charge, Japan already has 40 percent of the global chip market. Two years later, their 256-kilobit DRAMs will help them conquer a whopping 90 percent of this market.

What a difference from the preceding decades. In the sixties and early seventies, the Americans consider themselves the absolute winners in the chip market. It's their birthright. Bell Labs invents the transistor, Intel and Texas Instruments create the integrated circuit soon after, and in the early seventies Intel develops the microprocessor. DRAMs and non-volatile memories are also American inventions. In short, the chip industry *is* America.

But the Japanese are slowly gaining ground. In 1979, the country's Ministry of International Trade and Industry (MITI) celebrates "the first year of technological independence," an initial triumph in a systematic campaign to make Japan a global industrial leader. The Japanese begin the seventies making electronics for wristwatches and pocket calculators; they end them at the heart of the semiconductor industry, DRAMs. Cor van der Klugt, who as the board member responsible for Philips' consumer electronics division is acutely feeling the consequences of Japanese determination, cries out that with every branch of the industry Japan steals from the West, it's preparing the fall of the next.

The Americans can't match the leap in quality the Japanese are making in the seventies. In 1979, one of Hewlett-Packard's managers explains the state of affairs at an industry conference.[15] On the overhead projector he lists the chips that HP buys for its computers, instruments, and calculators. They number in the hundreds of thousands. Most of them come from American IC manufacturers, but HP buys a few of them from major Japanese companies like Fujitsu, Hitachi, Mitsubishi, NEC, and Toshiba.

The audience pricks up its ears when the presenter starts talking about quality. He says that HP has to send back at least 5 percent of American chips. That rarely happens with Japanese components. What's more, Japanese orders are always on time, and spare parts are always available. American chips usually arrive too late, and replacement parts are often just as unreliable. The HP manager says his compatriots make him uncomfortable: he's lucky to even *get* spare parts in the first place.

Complaints about quality aren't new at the end of the seventies, but 1979 is the first time HP has voiced its complaints in public. The real shock for American chip makers are the Japanese figures the manager quotes. They're almost too good to be true. But in the weeks that follow, several large American companies confirm the information HP has revealed. The Japanese are doing the impossible, and it looks like they're going to keep doing it until they control the entire chip industry.

The Japanese first prove they're running a tight ship in 1978. That year, IBM demonstrates its technological superiority by proudly presenting the first 64-kilobit DRAM chip to the world. But it's Hitachi, NEC, and Toshiba who gobble up the DRAM market. The force with which the Japanese flood the world with their memory chips strikes a fierce blow to American confidence.

In a 1987 report, market researcher Jay Stowsky calls it the "long march" of the Japanese. He summarizes numerous factors that underlie the country's success. A close working relationship with machinery manufacturers is one of them, but Hitachi, NEC, and Toshiba also opt for a simpler chip design strategy and succeed in manufacturing memory chips using older technology. American chip makers prefer more advanced technology, but that road is bumpier.

The Japanese are acutely aware that chip production technology is highly strategic. Knowledge of lithography is particularly crucial to stay ahead in information-intensive markets such as telecom and computers. Japanese giants Canon and Nikon are already pursuing chip lithography in the seventies. They have the optical technology in house, and both companies are strongly vertically integrated—and amply financed. Nikon began in 1917 as a merger of three Japanese optics companies and specializes in cameras, microscopes, binoculars, and optical instruments. Canon was founded in 1937 as Precision Optical Instruments Laboratory and has been a camera maker from the start. After the Second World War it joined forces with the national television broadcaster, NHK, to build a television camera, which saw the light of day in 1958. The multinational then expanded its focus to copy machines, calculators, and computers.

While chip manufacturers are swamping GCA with wafer stepper orders in the late seventies, Canon and Nikon are putting on their running shoes. The MITI leads the Japanese semiconductor industry's charge to quash American dominance with a VLSI project. In *keiretsu*—groups of affiliated firms—the companies work closely with chip makers to perfect their machines. Canon and Nikon even work side by side, because they aren't yet competitors in this market. At that time Canon is developing not steppers but one-to-one projection scanners, like Perkin-Elmer.

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When Japan starts preparing to mass-produce 64-kilobit DRAMs at the start of the eighties, Canon and Nikon see formidable opportunities opening up. If they serve their compatriots well, they'll have a guaranteed outlet for their wares: Japanese chip makers have been burned by relying on American machinery manufacturers. In the late seventies, American companies couldn't keep up with demand and prioritized their US customers. Even lithography company GCA left its Japanese customers out in the cold. The Japanese are determined not to let that happen again.

In 1981 the semiconductor industry is headed for a recession, but Japan is celebrating victory when Nikon launches its first steppers at home that year. It's the first step in a frontal attack on GCA's lucrative market. GCA's customers NEC and Toshiba switch in a flash to Nikon, which quickly ramps up production. The Japanese lithography company also delivers top-notch quality. It not only has a better handle on the mechanics and system architecture than GCA, but also sports a higher-resolution lens. All in all, the Japanese systems are better and more reliable.

Despite the recession, GCA still feels invincible in 1982. Its figures speak for themselves: it absolutely dominates the market. That year, it has a market share of 95 percent in Japan. In the rest of the world, it supplies 100 percent of steppers. Ten-million-dollar orders for a series of wafer steppers to equip an entire fab are business as usual for the company.

During the recession in 1981 and 1982, Japanese chip manufacturers hit hard in the market. They keep ruthlessly investing in production, supported by the country's major financial institutions. While their American competitors are putting on the brakes, they're focusing on automation and lowering production costs.

That's how Japanese chip makers succeed in conquering a whopping 70 percent of the global market for 64-kilobit DRAMs in 1981. In 1982, Motorola and Texas Instruments are the only serious American players left in DRAM chips. The high quality of Japanese memories also generates a shift in the stepper market.

Canon and Nikon have access to huge cash flows and abundant opportunities to further perfect their technology with customer help. The market for 64-kilobit memories provides a healthy foundation for everything else: the highly vertically integrated Japanese technology titans also use the chips in their own computers and equipment, and they sell the components to sister companies within their own *keiretsu*.

Compared to Canon and Nikon, GCA is at a significant disadvantage. It doesn't have an intimate relationship with customers. American chip makers distrust their machinery suppliers and don't want to share the details of their production technology—afraid as they are that the information will make it to the competitor. They'd rather service the machines in their fabs themselves than get suppliers involved. As a result, machinery manufacturers have a harder time refining their technology and they're on their own in charting an R&D road map. In contrast, machinery developers in Japan work closely with process operators and chip fabs. They learn from each other.

GCA isn't used to competition and is slow to respond. It doesn't do any manufacturing in Japan, and even its entire service department in Asia is staffed by Americans. In 1983, GCA's share of the Japanese stepper market drops to 45 percent. The company hastily tries to improve its local service by creating a fifty-fifty joint venture with Sumitoma. The two companies set up a new distribution system, hire Japanese engineers, and start buying subassemblies from Japanese suppliers with the goal of putting together complete systems. It doesn't accomplish much. While GCA is busy defending its market share in Japan, Nikon sets up shop in Silicon Valley in 1982. Just as in Japan, Nikon Precision USA sets up a solid service network before it starts selling steppers in bulk.

The Japanese may be scaling up during the crisis, but the semiconductor recession in the US hits GCA hard. In the American market, the company's revenue drops by 50 percent in 1981 and 1982. People are already talking about Nikon's steppers, and many American process engineers are eager to get a taste of the new Japanese machines. But their managers don't give them much chance to do so while the chip industry is climbing out of the hole in 1983. Machine operators are scarce in American chip fabs, and most of them have been trained to use GCA's steppers.

This intense production pressure and lack of time mean American chip makers don't want to switch to a new lithography supplier. Their existing equipment—that magical installed base—casts the deciding vote in buying new systems. Large customers like ATT and AMD are still buying in the US, and that helps GCA get back on its feet in 1983.

Profiting from a reviving market, GCA earns a top revenue of more than $200 million in steppers in 1984. That makes it the world's largest supplier of semiconductor machines. But this is its last year of glory. The Japanese are relentless. By the end of 1984, the Japanese stepper market is bigger than the American one. Of the eleven hundred wafer steppers sold—most of them made by GCA and Nikon—six hundred go to wafer fabs in Japan. That year Japanese chip manufacturers buy more steppers than the rest of the world put together, and they mostly buy them from their compatriots.

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ASML hasn't noticed yet, but in 1984 GCA is a rattling, faltering machine. A new recession is looming, and it will soon drive the machinery manufacturer to the brink of the abyss. Nikon is ready in every respect to take over GCA's role. The Japanese company excels in precision technology and in-house optics. Their lenses trump even those of Zeiss, which GCA uses in its steppers. The German company's problems are growing.

With steady dedication, Nikon conquers the lithography market step by step. Right behind it is Canon, which has shifted its focus from scanners to steppers. The diligence with which the two Japanese machinery manufacturers operate and the strength they develop has a devastating effect on GCA. This is the climate in which ASML opens for business: the Americans in shock, the Japanese tasting victory.

29. **The First Drawings**

Gjalt Smit presents a sky-high price tag to the board. It's their choice: pay up, or close up shop.

A hundred million dollars. That figure buzzes through Gjalt Smit's mind. How on earth is he going to explain to his board of directors that that's what they need to invest to conquer the lithography market?

Before he presents his business plan to the shareholders, Smit combs through it inch by inch with Richard George, Joop van Kessel, and Ger Janssen. The plan seems very ambitious to them. The three men's jaws drop as they read it. They think Smit's a megalomaniac, but his argument holds water. In theory it's realistic; it's just going to cost a pretty penny. "Gjalt, you'll never push this through," Van Kessel and George declare.

For eight days in a row, Smit rehearses his speech to the board in his head. A hundred million: it's a lot. There's a recession on in the Netherlands; Philips is retreating to its core activities. But the chip market has the wind in its sails. Analysts predict formidable growth in the coming years.

The whole endeavor will only succeed if ASML bets on growth. In that regard, Smit's plans are miles away from the assumptions ASM and Philips made a few years ago when they decided to partner. In his eyes, the business plan the two companies wrote in 1983 is just the scribblings of amateurs. He's only been surveying the field for a few months, but he's convinced of his strategy, despite its hefty price tag.

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When the moment arrives, Smit gives an impassioned speech to his board. The four directors have little trouble with the technical challenges in his argument. The technology is ready to go; it's primarily a question of organization combined with discipline, flexibility, and creativity. They've got something no one in the industry can beat, not even champions GCA and Nikon. Then Smit comes to his crucial message. He has to convince his shareholders that market domination won't come cheap.

Smit feels like a flutist who has to drag the whole orchestra in his direction. The tune he's playing is completely different from what George de Kruiff, Willem de Leeuw, Arthur del Prado, and Wim Troost are used to hearing. Troost is a lithography diehard; Del Prado has years of experience in chip equipment. Now he has to convince these men that their business plan is just paper with ink on it, and that he's envisioning a completely different strategy, requiring much higher investments.

He explains what he heard at SEMICON West. How dire ASML's position is. American chip makers have given him no hope for a single order. They aren't holding out even the slightest of lifelines. But he's careful to paint a scenario in which the Dutch joint venture can emerge victorious after all. Smit sketches the contours of a market that will become increasingly capital-intensive in the coming years. "I've seen it in telecommunications and in aviation," he says. "The R&D investments for a new generation of equipment are ten times those for the previous generation. Things are no different in our market." Just as in telecom and aviation, he predicts a shakeout in chip lithography. Under these circumstances, only a very aggressive, innovative, and focused strategy has a chance of success.

"To keep capital-intensive development going, you need a large market," Smit tells the four men. "Right now, ten or so players are jostling for position. None of them will last over the long term unless they score the biggest customers." Just as in telecom and aviation, only a few large players will be left standing in lithography; only the companies with massive technological and financial firepower will make it. "And often they need significant government support to boot," Smit says.

It's already a fact in aviation, and it's happening right now in telecom, Smit explains. Soon it will be the stepper market's turn: vicious competition and exorbitant development costs will induce a round of consolidation. "Victims will fall. Only a few will remain. So we'll have to go for a spot in the top three at least," Smit reasons. "And if we go for the top three, there's only one way to get there: investing to reach the absolute top. We have to go for the gold. Number three isn't enough. We have to aim for first place. Our only chance to win is with an aggressive, innovative, and focused strategy. The inevitable shakeout underscores how crucial that is. If we're lucky, we'll end up on top; if we're less successful, we'll end up in third place; and if we're unlucky, we'll come out in sixth. But if we decide we're satisfied with being number three or number six in advance, then we might as well stop now. We have to aim for the top. We don't have any real alternative. It's our only chance of surviving, and it's doable."

That means performing on all fronts, Smit barrels on. ASML needs to excel not only in terms of technology, but also in logistics, production, and service. "And we need a winner's mindset," he adds. "We need a culture of people who want to fight to win together." It comes down to flawless execution and ample investment. Yes, it's going to cost, but if they succeed, ASML can look forward to a killer position in the market.

Smit cautiously suggests what kind of money they'll need to invest. "Our first estimates indicate that we may need as much as one hundred million dollars." He phrases it carefully, diplomatically. "Gentlemen, this is a rough estimate. I haven't worked out the details. It might be less, maybe fifty million. But this is the order of magnitude you should be thinking of."

He tells the board they don't have to decide now; he'll work it all out in detail first. That comment injects some calm into the meeting. Smit then encourages his board of directors through another analogy from his favorite subject, aviation. "The heavier an airplane's load, the more fuel it needs to reach a cruising altitude. We have to go full throttle, or we'll crash. If we aren't willing to burn kerosene, we're better off canceling the flight."

Then Smit holds out a carrot for the joint venture partners: "If we train to win the gold medal, and we reach a top position, the fruits of that effort will be there waiting for us, too."

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The figures Smit cites are a shock to Del Prado. The requested investment is almost as large as his company's annual revenue. ASM is turning a profit at that time, but Del Prado knows that Smit's reach sometimes far exceeds his grasp. Nevertheless, Smit's analysis and conclusion do intrigue him. The idea of reaching global number one is music to his ears, and the opportunities lying before them speak to his businessman's heart. He knows that to win the highest prize, you have to pay the highest price.

De Kruiff and Troost are less shocked by the hefty figure. They understand the complexity involved. At behemoth Philips they were used to these kinds of investments. Without an assembly line costing a few hundred million, you can't mass-produce TVs or light bulbs. Troost also knows perfectly well that Smit's calculations are sound, though he doesn't say a word. Two years earlier he himself estimated the development costs for the PAS 2000 at $50 million, when S&I begged the Ministry of Economic Affairs for financial support.

But just like Del Prado and his technical right hand, De Leeuw, De Kruiff and Troost don't instantly say yes. The two men from Philips aren't authorized to sign off on amounts this big. They'll have to take it to their own board of directors. What's more, De Kruiff knows Philips is a political minefield. Elcoma, the product division responsible for the company's chip activities, still hasn't officially committed to buying ASML's steppers.

Smit doesn't get a yes during his presentation, but he doesn't get a no, either. Del Prado loves the idea of aiming for the top, but flinches at the size of the investment. "That's great, Gjalt," he says, "but you'll have to find the financing for it yourself." He says that ASM and Philips can help out, but shelling out a hundred million is out of the question. The partners do decide to increase their stake by $1.5 million each.

Smit interprets the outcome as positive. The tentative answer is yes, and he gets an extra $3 million. The situation is still nebulous; the estimated expenses will gradually come due, and the influx of cash means there's no acute need for money. In the absence of a definite no, ASML can push on. His board of directors wants him to go hunting for money himself and work out his plans in greater detail. For now, he has a green light.

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After the meeting, Troost suggests to Smit they pay an immediate visit to the head of Elcoma's chip fab in Nijmegen, Henk Kerkmeester. They enthusiastically tell him about ASML's plans for the PAS 2500. But the fab manager's response is bristly. Isn't the reason clear? Troost, the man, represents a history of struggle between Elcoma and S&I, and that clouds Kerkmeester's judgment. The fab manager is needling them. Didn't Elcoma make it clear in the preceding years that it has no desire for an oil-based machine? By the way, no one at Elcoma was asked to weigh in on the joint venture.

Kerkmeester also makes it clear Elcoma has no interest in a relationship with ASM. It buys its furnaces from Applied Materials in the US. Kerkmeester sees the joint venture as a move by Philips to get rid of its stepper operations. He refuses to make a single promise. "Pretty stories don't get me anywhere," he growls. "Come back when your new machine is ready." Troost slams the door behind him.

When Smit visits Valvo's chip fab in Hamburg a few weeks later, he's told the same thing. The German site only bought the PAS 2000 under duress. It's using the stepper, but there are problems. Smit hears a whole lot of no and concludes the German fab doesn't really listen to its Dutch bosses. It's a familiar phenomenon. In the time he worked in Italy for S&I, he too regularly ignored his Dutch colleagues.

It's the summer of 1984, and Smit's standing there empty-handed. The American companies have all shouted no, and even the parent company's chip division has turned up its nose at ASML's technology.

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It isn't Smit's only problem. He also needs to pep up the jaded gang of employees who came from Philips. What's more, the team that came from S&I needs to join forces with the guys at Natlab. To successfully develop the stepper, they'll have to work closely and smoothly with Philips' research division. That's where the linear motor was born, but most of all, that's where the optical specialists work who are vital to ASML's survival.

As a Natlab fan, De Kruiff has always maintained a good relationship with the research center. Shortly after ASML launches, he introduces Smit to Kees Bulthuis, one of Natlab's section directors, and Marino Carasso. Carasso is the section director responsible for stepper development. He and Smit are aware of the love-hate relationship between Natlab and S&I. If ASML is going to succeed, then that acrimony will have to end, they decide. Carasso and Smit plan a meeting at ASML.

Ten Natlab researchers show up to learn about ASML's plans, joining a dozen ASML employees of whom most have come from S&I. The two teams are as friendly as two opposing armies. Smit tells them the story. The existing stepper is unsellable, and they're going to have to work damned hard to capture a share of the market. He shows them the incredibly challenging project that lies before them, and tells them the accompanying requirements are nearly impossible. What's more, there's hardly any time.

Carasso and Smit address the group together. "Okay, folks," Smit says. "We're facing an amazing challenge. We know there's been friction in the past, all of it for a reason. But now it's time to bury the hatchet, because all the old arguments are water under the bridge. They won't help us now. We've got a fantastic project and this is a war we want to win. So let's rock this party. Every man in this room is kickass. Maybe a little ornery, too, which means it's not always easy to get along. But we don't have time for friction now. We've got to be a dream team. Seeing where the ball needs to go, who we can pass it to, moving like one mind to reach the goal together. Everyone here already does his very best, but now it's time to do our best together. So if there's a problem, open your mouth. Marino and I are good friends, and we expect you all to become friends, too."

30. **The Cartoon Presentation**

Gjalt Smit wins over his employees with a humorous presentation. They're really going to get the chance to show the world their technology after all.

How can I break the vicious circle of negativity? Gjalt Smit's been asking himself that question since he was first confronted with the ex-Philips crew's reluctance. He knows his fifty-member team is bursting with talent and experience, but after years at Philips all their spunk is gone. But he has no use for a washed-out team in his campaign to conquer the market. He needs guys *con coglioni quadrati*, motivated men who run harder and perform way better than they ever did at mother Philips.

At ITT, Smit saw what a positive company culture can accomplish. In his years at Philips, he saw just the opposite: bureaucracy, a laissez-faire culture where no one takes responsibility, the devastating effects of internal friction and management's empty promises. He's developed a serious allergy to that kind of environment, and for his entire tenure at ASML, that revulsion will be the driving force behind the company culture he works to create. For Smit, it's one of the fundamental business equations: one of the requirements for success, and a crucial factor in breaking through the current negative climate.

After he's sketched the first outlines of ASML's strategy for his board of directors, Smit is bursting with energy. They didn't instantly torpedo his plans! Now it's time to cheer up his employees. Though his picture of where they're headed is still fuzzy in places, he wants to communicate a positive message a.s.a.p. He calls ITT and asks Ben Verwaayen's secretary for advice. She refers him to a professor in Amsterdam who draws cartoons in his free time. He calls the man up and explains his plan. "Can you turn this whole story into spot-on cartoons for me?"

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When ASML's employees arrive at the Philips Recreation Center in June 1984,[16] the mood is dismal. For months they've been complaining. Smit's slight build hardly inspires confidence. He pushes up his glasses and turns on the overhead projector. He's barely said a word before the first smiles appear. His presentation turns out to be a slide show of funny cartoons. *Wow*, thinks Frans Klaassen, who's come to ASML from Philips. Just the fact that Smit's turned the whole story into drawings impresses the thirty-year-old developer. *Here's someone who's put some thought into his presentation*. That's an experience Klaassen never had at Philips.

Smit lays out the situation in a clear voice. He sounds decisive and determined. And not just that. He's also brimming with positivity. Since his trip to San Mateo, he knows ASML has a chance: a chance to leap from the underdog position to the center of the world stage. He's been floating on enthusiasm for weeks.

Smit explains it all in plain, intelligible terms. He hasn't been able to dive into the material in detail over the past few months, but several points have come to his attention, he tells his audience. "You guys have a good stepper," he says, showing a slide caricaturing the stepper as a child's scooter. "The concept is solid, with a great alignment system. Your stepper is basically fine."

After he's covered all the technology, Smit tells them what still needs to be done. From his talks with George and Van Kessel, he's picked up everything that's still wrong with the machine. One by one, he walks through the problems and possible solutions. Then he says, "Of course, this will all cost money. We need to invest in development, production, marketing, service, and a whole lot more. We'll need people for all that, and we're going to hire them." His listeners can't believe what they're hearing. Here's a guy saying he wants to invest, saying he's even going to bring in more people.

But Smit isn't finished yet. He shows a slide of a podium with the numbers 1, 2, and 3. "Gentlemen, we're going for the gold medal," he declares. "We're going for first place in the market." Again his audience is astonished. Smit explains what he means. "You can't say, I'm going to train for silver and see if I can make it all the way to gold. No. The people who win silver at the Olympic Games have trained for gold. And if you go for the gold, you're lucky if you win gold and less lucky if you win silver. And if you're unlucky, you end up number six. But in the chip lithography market, there isn't even room for six contenders."

Then Smit shows them that ASML is languishing at the bottom of the list of the ten largest players—before telling his team not to let that scare them off the field. He tells his people that in a few years, the industry will start production on a new generation of chips. They already know that, but Smit also tells them something new. He predicts it will induce a shakeout in the industry. Of those ten players, large and small, renowned and less well known, including ASML, only three or four will be left. His words are impassioned: "This is our only chance, and we have to seize it with all we've got."

Smit even manages to portray underdog ASML as the technological winner. "We may be at the bottom," he says, "but that's just an optical illusion. The analyst Rick Ruddell put the others above us because they're farther along in terms of installed base and sales, not because their technology is better. At least five of those companies are a complete joke." It's music to his audience of engineers.

Smit actually has no clue what kind of technology his competitors have, but he knows it works wonders when a coach tells his players they're much better than their opponents. "Guys, we may not yet have a product on the market, but we're going to win this one."

31. **The First Want Ad**

ASML advertises its first job openings. Gjalt Smit makes unauthorized use of the Philips logo.

Once the blueprint for the PAS 2500 is ready at the end of April 1984, Gjalt Smit, Richard George, and Joop van Kessel turn to the task of attracting new personnel. Where in heaven's name will they find hundreds of engineers to develop and manufacture a new machine within two years? Smit suggests they get started right away. He wants to look beyond the Netherlands. "The Dutch manufacturing industry has all but vanished," he tells George and Van Kessel. "This country has dismantled an entire industry. The Netherlands isn't suited to manufacturing. It's a land of traders. The process industry is important, but we don't have a high-tech manufacturing culture here."

ASML needs dozens of people in all kinds of disciplines pronto. Software, electronics, mechanics, optics, measurement and control technology, you name it. Guys who know what precision is, how to develop systems and fit all those parts together very precisely. Men *con coglioni quadrati*, Smit winks at Van Kessel.

Smit suggests they look for engineers in Baden-Württemberg, near Stuttgart, where Germany's high-tech machinery manufacturing is concentrated. Three hundred miles away? "That's a long way to go," George and Van Kessel say. Both have more experience with their native technical industry. At the start of 1984, the Netherlands is in a recession, and the pair suggest this might be a good time to look for people at home.

But the most experienced engineers are at Philips, Fokker, and a few small companies such as Old Delft and Enraf Nonius. ASML has promised Philips it won't hire people away. But, Smit counters, if engineers apply to a want ad of their own free will, there's not much Philips can do about it, right? And while they're on the subject: ASML can even cast itself in the ad as a new Philips activity.

Smit asks ten colleagues to be available from six to ten p.m. on four evenings in May to answer applicant's questions by phone. That way, the telephone team can make first-round eliminations. Smit also decides to use Philips' logo in the ad, though he knows he isn't allowed to. The fact that applicants address their letters to ASML "c/o Philips Incorporated" completes the picture of an established employer.

On May 11, 1984 the weekly recruiting paper *Intermediair* publishes the first want ad ever run by the company still going by ASM Lithographic Systems (ALS) at that time. The company cheerfully describes itself as a "joint venture between ASM International and the Science & Industry division of Philips Incorporated." ASML says it's capitalizing on "Philips' research and expertise and ASM's global marketing experience." It also presents its product: "The wafer stepper, the heart of chip manufacture, uses extremely advanced technology to optically etch patterns into silicon wafers at high speed and with flawless precision. A device unique in the world, the result of ten years of Philips research." The company is offering a challenge for educated engineers in a variety of disciplines who want to work at "the cutting edge of global excellence."

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"This one looks good," says Wim Hendriksen, who's working as a software engineer at Philips Medical in the nearby town of Best. He reads out loud to his wife from the want ad: "ALS is a quintessential high-technology company with plans to conquer the global industry in the near future. The company embraces modern social norms, with a healthy, even balance between improvisation and discipline."

Hendriksen has no idea what a wafer stepper is, but the technical challenge is significant and that appeals to him. He reads that the job involves "a mix of modern technologies such as software, electronics, mechanics, optics, and measurement and control technology." ASML is looking for experts who know their way around these disciplines and want to work as a team to reach the absolute top, the ad proclaims. "Professionals with a pioneer's mindset who realize that getting in on the ground floor of this unique joint venture offers massive career opportunities." That enterprising spirit appeals to Hendriksen. He's sold: "I'm going to do this."

Hendriksen also reads that ASML intends to grow to several hundred employees in the next few years, with revenue of several hundred million. He's someone who likes to recast things in clear, understandable numbers for those around him. "That means roughly half a million in revenue per employee," he tells his wife. "I don't think Medical achieves that."

A letter is not required, the ad says. Interested applicants can call after office hours, between six and ten p.m.—unusual in those days. The next evening, Hendriksen gets Richard George on the line. The two immediately plan a meeting. The *Intermediair* ad doesn't specifically say that working at ASML means a job guaranteed by Philips, but people who want to read that into it, can. The logos for both ASM and Philips are prominently visible. It earns Smit a scolding from mother Philips, but he pretends he didn't know it wasn't okay and promises it will never happen again.

And ASML accomplishes its goal. The ad generates some three hundred applicants. Smit and his management team are astonished at the talent that's there for the taking in Holland. The poor economic situation turns out to have left plenty of engineers available. They hire almost a hundred. Smit decides that all of them first need two weeks of training to acquaint themselves with the stepper and asks Heico Frima—the sole employee who came over from ASM—to put together an introductory course.

Part 6

The Deadline
1984–1986

32. The Business Plan

ASML's first business plan is a political document. Gjalt Smit pulls out all the stops to secure funding: little white lies, narrowly interpreted figures, unrealistic goals. But he has a clear vision.

Based on selective predictions for the chip market plus information from Richard George, Joop van Kessel, Ger Janssen, and CFO Gerard Verdonschot, Gjalt Smit puts together a very ambitious business plan[1] in the summer of 1984. Chips are booming, and demand for the machines to make them far outstrips supply. ASML's team cites analysts who say the situation will remain rosy for the foreseeable future, and whose reports are filled with encouraging figures.

ASML's management team gets its figures from reports by Rick Ruddell, Dataquest, and the trade journal *Electronics*. The predictions vary somewhat across all those sources, but Smit distills them down to the most positive scenario and projects a straight line into the future, to global sales of twelve to eighteen hundred wafer steppers in 1988, with a total value of $840 million to $1.26 billion.

The arguments and figures in the plan are narrowly interpreted market conditions and little white lies. Smit and his team need money—lots of it. The business plan they send to ASML's shareholders and management team on August 6, 1984 is thus a highly political document. The overarching theme is one of princely rewards over time. That picture must entice the shareholders to dig deep into their pockets.

To anyone who knows where ASML really stands and has some understanding of the semiconductor market, the business plan is completely absurd. For example, in the document Smit says the company will deliver a new machine for the next generation of chips in a mere eighteen months, on January 1, 1986. A machine that chip manufacturers can use for their first VLSI production tests. Smit even writes that he plans to develop and build ten to fifteen at a time. That would be quite the accomplishment. In those days, just the lead time for production—never mind development—of such complex machines is at least eighteen months.

George consistently tells the management team that Smit's ambitions are wholly unrealistic. Smit claims that ASML will sell sixty to seventy steppers in 1986 so the company will reach its goal: to make a profit in that same year. "That means we'll have to mass-produce them and sell them within two years," George tells Smit. "That's never going to happen."

George has additional criticisms. Smit claims the company needs to quickly grow to eighty developers in 1985, then projects the R&D team's size to remain constant in the years that follow. "That's a gross underestimate," the hot-tempered George bellows at Smit.

But ASML's CEO has a higher purpose. He has to show that the whole project is not a lost cause, and that speed is of the essence. ASML is battling nine other players in the race for next-generation VLSI machines. The time frame is just two short years. To make his strategy a reality, Smit needs one hundred million dollars. He knows all too well that this amount is completely unacceptable to his shareholders, so he pitches fifty million instead.

That's also why Smit deliberately keeps the business plan's R&D staffing estimate low. In actuality he'll ignore the numbers and rush full speed ahead. Within a few months, he'll have hired more than a hundred developers, and ASML will continue to solicit engineers in 1985.

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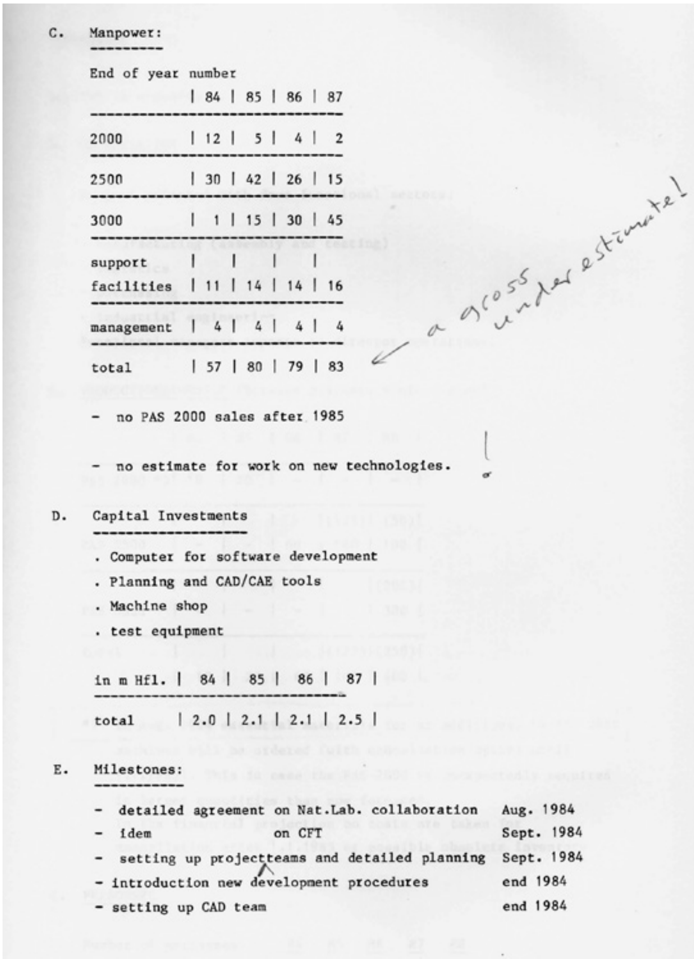
What are the barely-four-month-old company's ambitions? In the business plan it says that by the end of 1988, the company should be among the top three global suppliers of optical wafer steppers. In 1986 the company should be turning a profit, and three years later, in 1989, it plans to have paid off all its debt. On its way to the top, ASML will first have to traverse a deep valley, Smit writes. At the end of 1985, its cumulative loss will run to twenty million dol-



C. Manpower:

End of year number

	84	85	86	87
2000	12	5	4	2
2500	30	42	26	15
3000	1	15	30	45
support facilities	11	14	14	16
management	4	4	4	4
total	57	80	79	83

a gross underestimate!

- no PAS 2000 sales after 1985
- no estimate for work on new technologies.

D. Capital Investments

. Computer for software development
. Planning and CAD/CAE tools
. Machine shop
. test equipment

in m Hfl.	84	85	86	87
total	2.0	2.1	2.1	2.5

E. Milestones:

- detailed agreement on Nat.Lab. collaboration Aug. 1984
- idem on CFT Sept. 1984
- setting up projectteams and detailed planning Sept. 1984
- introduction new development procedures end 1984
- setting up CAD team end 1984

In ASML's August 1984 business plan, Gjalt Smit keeps his personnel estimates as low as he can in order to secure a green light for his investment plans. Richard George, who's responsible for the PAS 2500's systems development, is looking through a different pair of glasses. "A gross underestimate!" he writes in the margins of his copy of the business plan.

George's vision will turn out to be 20/20. In late 1987, the number of engineers involved in R&D and production will be nearly four times Smit's 1984 estimate: not 62, but 218. The remaining staff (administrative, sales, and marketing) will have swollen to 162 employees, eight times Smit's original estimate.

lars. “Negotiations with potential suppliers of these funds are already underway,” he writes about the required fifty million dollars.

“We are facing a complex and ambitious task,” Smit writes in the business plan’s closing summary. “Not least because much time has been lost. The market is there. The product we are offering is proven and competitive. The challenge is to make sufficient numbers in a short time, and to capture the required market share.”

ASML has all the key technologies in house. Successfully bringing them to market is a question of organization, Smit writes. If it works, he emphasizes for the dozenth time, the rewards will be immense. “Will we succeed in hiring the human capital we need and setting up a high-tech company with a revenue of half a million dollars per employee? There is no viable alternative to this plan,” he resolutely ends.

Smit’s business plan is brimming with optimism on all fronts. He’s still aiming to sell dozens of the old oil-based PAS 2000 machines. In truth he knows that’s highly unlikely. He’s hearing on all sides that chip makers aren’t interested in machines that are literally dripping with oil. And not only that: the oil system’s generator is bigger than the stepper itself and makes so much racket it needs custom housing to meet noise requirements. But apparently there’s still a hope that ASML can foist its inventory on companies that want to try out the superior alignment system.

In fact, ASML’s employees in building TQ3 on Philips’ industrial campus are still busy at work on the oil-based steppers. Parts are streaming in, bought at parent ASM’s insistence in the period when the joint venture was first being set up.

In August 1984, ASML still doesn’t have a plan for leaving the hydraulics behind. In fact, the machinery manufacturer plans to order parts for another ten PAS 2000 machines that same month.[2] “In case we unexpectedly need more PAS 2000s than we now predict,” the business plan reads.

Smit is greatly exaggerating the PAS 2000’s competitive position. For example, the business plan says the system is reliable and has proven itself in a production environment. The oil-based stepper supposedly beats out the machines built by GCA, Nikon, Perkin-Elmer Censor, and Ultratech in production yield and throughput. Its yield is better than everything else on the market, and only Ultratech's projection aligners are better than the PAS 2000 in terms of throughput.

Yet a short glance at the stepper's weak points puts the lie to rest. Despite the assumption that a good number of PAS 2000s will be sold, the business plan clearly states that a handful of essential requirements such as an electric table, the ability to handle six-inch wafers, and a lens with a larger field of view make the current design nonviable. "The PAS 2000's basic features are unparalleled, but these fundamental disadvantages make the machine unsellable in large quantities." The plan is also honest about servicing and customer commitment. On these points, the PAS 2000 scores markedly lower than the competition.

In August 1984, ASML is still optimistic that customers will want to try out the PAS 2000. In any case, the disadvantages don't keep Smit from predicting the sale of another four oil-based steppers that year—with just four months left to go. For 1985, his goal is twenty. He's based these predictions on the assumption that chip manufacturing machinery is still a seller's market: chip makers will buy whatever they can get.

The business plan is still using Philips' logic to some degree: the alignment is superior enough that chip manufacturers will want to try out the PAS 2000 for test production in a technology-driven market that's clamoring for manufacturing tools. They'll buy them with an eye to purchasing "highly competitive PAS 2500 machines in early 1986" with an electric wafer table, and thus without the oil.

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The business plan also makes it clear that ASML is facing a number of significant obstacles to meeting potential customer's needs. It's clear that lithography has matured into a strategic technology. Chip manufacturers know they'll be bound to a stepper supplier for a long time, and that makes stability and endurance important.

Their choice is also highly technology-driven, and they want their machinery manufacturers to have already gained practical experience working with the big names.

In truth, ASML can barely meet these requirements. With a profitable ASM and behemoth Philips on its side, the company can demonstrate that it's reasonably financially stable. In addition, it currently has a strong technological ace in the hole: the alignment that enables a precise overlay. But because that technology is packaged in an oil-driven machine, the whole thing is in fact unsellable.

Smit turns to a heavy marketing campaign for the solution. At the end of 1984 he wants to advertise ASML's unequalled overlay in the trade press. Then, in the first half of 1985, he wants to launch a second campaign in the business press that emphasizes ASML's commitment to the long term. He also wants to invest heavily in service and support.

Together, the two marketing campaigns and the sale of PAS 2000 steppers as test machines should generate orders for the PAS 2500 in the second half of 1985. It's a prediction drenched in optimism. ASML even wants to set up development and production in the US and Japan—90 percent of the market is there, after all. They'll set up a demo lab in Phoenix in 1984, a sales office in 1985, and in 1986 a production facility, plus a second demo lab in Silicon Valley. Smit plans to do the same in Japan in 1988. Should production exceed three hundred machines per year before that time, ASML will accelerate its international expansion.

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The hype surrounding the semiconductor market works in Smit's favor. A few months later all hell will break loose, and that recession will have the chip industry in its grip for three years. But in August of 1984, there's no sign of the trouble to come. ASML's business plan breezily assumes the market growth for wafer steppers will continue in a straight line for four more years.

That's not to say there's no trouble at all. Smit and his management team do see a few clouds on the horizon. They write that lithography suppliers will continue to enjoy a seller's market in 1984 and 1985, but after that competition will increase, leading to pricing pressure and ultimately a shakeout. Of ASML's nine competitors, only five will be left in the end, they predict.

This argument, too, is fully fixed on the need for serious funding. Smit emphasizes that it's wasted energy to go halfway; if they do, ASML will certainly fall by the wayside within a few years. If the market keeps growing linearly, ASML's best-case scenario is to sell 400 steppers in 1988. If things are less rosy, they'll still sell 250. That will give ASML a quarter of the market. The Dutch company plans to sell most of its steppers in the US, the rest in Japan and Europe.

At that time, Japan already has 45 percent of the chip market—the same as the United States.

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Despite all the politics, rose-colored figures, and wildly unrealistic goals, ASML's very first business plan is visionary. Smit describes the strategic options for pricing and product differentiation and comes to the conclusion that his company needs to focus on the lowest cost per manufactured, viable chip. In other words: the machines can be expensive as long as they spit out inexpensive chips. Even in his first business plan, Smit views cost of ownership as the best way for the company to hold its own later, against bargain-basement suppliers and competitors looking to dump old inventory.

Because simply put, a wafer stepper is nothing less than a money-printing machine. It doesn't much matter what the machine costs, as long as it's fast. The company that can deliver a machine that prints money faster than the competitors' can charge more for it. Its price plays a minor role in the sales process. "This is how we ensure a high return on our high investments," Smit argues.

The industry transition from projection aligners to wafer steppers, which is happening as Smit writes, underscores the value of a cost-of-ownership strategy. Steppers are significantly more expensive than aligners, and their productivity is much lower to boot, thanks to the slower exposure process. But stepper lithography's extreme precision produces appreciably more viable chips and makes it possible to print smaller details. As a result, the same chip fits onto a smaller piece of silicon, which significantly lowers its cost.

Cost of ownership will grow to become the core of ASML's sales and marketing strategy. In the nineties, future CEO Willem Maris will take to calling it "value of ownership." Technologically speaking, the electric wafer stage will be the cornerstone of the high throughput ASML's steppers achieve. But at the time Smit's presenting his business plan, that Natlab technology has yet to mature into a practical component.

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The collected knowledge in ASML's business plan provides a pretty good window onto the lithographic playing field. It reveals that GCA is already under pressure, and correctly predicts that this American lithography supplier will lose market share—even if the Dutch aren't quite clear on the whole story. According to ASML's plan, the market leader has excellent sales and service, but in fact by the summer of 1984 GCA's service is rotten to the core. The document correctly notes that GCA's stepper isn't very advanced, though there are ways to improve it.

At that time, Canon and Perkin-Elmer are the high-growth players. Both companies supply primarily aligners. Their market shares in steppers are just 1 and 5 percent, respectively; however, analysts predict they'll grow to 15 and 23 percent in the next four years. The assumptions for Perkin-Elmer are based primarily on the company's reputation. It's dominated the projection aligner market for years.

Analysts predict that Perkin-Elmer's strong, professional sales organization in the US and Europe will spur heavy growth in the company's stepper activities, obtained through the purchase of Censor. "Could become the market leader," ASML's business plan briefly notes about its American competitor. The predictions for Canon largely anticipate actual developments in the years that follow, but Perkin-Elmer will pull out of the market a few years later when Censor's steppers suffer from poor technical performance.

All in all, the business plan is a giant exercise in positive thinking. Smit writes that not a single supplier has an established position "with the limited exception of GCA and Nikon." The word "limited" reveals that Smit doesn't yet realize how strong Nikon is. His assumptions are based on the poor reputation the company's first stepper generations have. Nikon's early models are based largely on GCA's machines, which constantly need an operator to adjust settings and keep the stepper running. Europe apparently shares America's ignorance of how good Nikon's newer machines are. That's part of the reason why Smit thinks he has a two-year time frame before he needs to be selling in volume.

Thanks to his visits to Elcoma in Nijmegen and Valvo in Hamburg, Smit knows quite well what chip makers think about strategic lithography technology and how hard it is to gain a foothold in that market. His trip to SEMICON West only reinforced that message. GCA, the first to enter the market, has captured a significant share since 1978, and in recent years Nikon has been an up-and-coming powerhouse. None of that keeps Smit from aiming improbably high.

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The business plan also reflects the reigning expectations about progress in chip technology in the early eighties. It's clear that the one-to-one scanners and projection aligners sold by Perkin-Elmer and Ultratech are past their peak. They're hitting their limits now that wafers are getting bigger. The business plan declares that the market for projection scanners reached its peak in 1983 and 1984, a claim that rapidly becomes reality in the years that follow.

In full agreement with the assumptions of the time, the business plan predicts that optical technologies will hit their expiration date within ten years. Everyone seems to agree that the wavelengths of the available light sources are the limiting factor in imaging onto chips. Just as for projection aligners, optical step-and-repeat reduction has a limited lifespan, the plan says.

In fact, one of ASML's top three objectives is to mature into a recognized supplier of "other lithographic equipment" for volume production by the end of the eighties. The statement clearly shows how uncertain the industry still is at the time regarding optical methods for manufacturing chips. That's why the company's ambitions for developing electron-beam optics and possibly x-ray lithography are its number-two priority: below the desired top-three market position, but above turning a profit and paying off all debt.

At that time most of the industry's confidence is in e-beam lithography, but one-to-one imaging using x-rays is also the subject of much attention. For example, in the eighties Nikon is still working full tilt on synchrotrons to generate the parallel x-rays required for IC manufacture. "If your company doesn't have an active x-ray development program, create one," Rick Ruddell writes in his 1985 report on the lithography market. ASML's business plan adheres to that logic. "There are signs of increasing interest in e-beam technologies for wafer processing equipment, which makes them crucial for continuity in the late eighties," Smit writes. There are doubts about x-ray imaging, but Smit notes Nikon's efforts and also reports that Perkin-Elmer is working on the technology.

In short: ASML's business plan demonstrates that in 1984, it's completely unclear that optical technology will have such staying power. The plan predicts that optical technology will reach its peak in 1990, and that new techniques such as e-beam and x-ray imaging will overtake it sometime in 1994. By 2000 step-and-repeat imaging will have run its course, asserts the document that underpins ASML's future steady advance.

The business plan also nicely sums up the technological state of the art. In 1984, the most advanced chip processes produce chips with details from 1 to 1.5 microns, and the steppers in use have an overlay precision of 0.35 microns. In 1988 chip details will be 0.8 microns and overlay accuracy 0.2 microns. In those four years, the imaging field will grow from 14 to 18 millimeters on a side. The nascent MOS technology in particular requires larger exposure fields. The major players will soon be making their ICs on eight-inch wafers, too.

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ASML's first business plan also addresses its strategy of farming out as much as it can. The joint venture aims to produce more than three hundred machines within four years. The company plans to assemble them at its new location in Veldhoven, a few miles south of Eindhoven. It isn't feasible to manufacture everything themselves, so outsourcing as much as possible is one of the company's key strategies. And not just individual parts: the company plans to farm out complete subassemblies, too. The business plan diplomatically notes that ASML is looking to make "special arrangements" with Philips' machine factories in nearby Acht. In truth, however, that's no longer an option for Smit and his head of production, Van Kessel. They're familiar with the notoriously poor reputation that part of Philips has for failing to meet deadlines.

Smit doesn't expect Dutch toolmakers to be able to meet the extremely narrow tolerances in lithography and suggests they look for suppliers in Baden-Württemberg, a state in southwest Germany that's home to many high-tech companies, including optics specialist Zeiss. But to his utter surprise, Van Kessel soon announces he may have found the perfect match just around the corner. Large machiners turn up their noses at risky customers like tiny ASML, but two small specialists, G. van der Leegte[3] and Nedinsco, are interested.

In those days, most machine factories do a lot of coarse lathing and milling, but ASML is one level up. G. van der Leegte is a toolmaker by origin, used to making one-off pieces or small runs with extreme precision. The company has specialized techniques such as wire erosion and die sinking in house to make finely detailed mechanical parts such as coining presses and injection moulds. That makes G. van der Leegte more expensive, but it's exactly what ASML is looking for.

Small companies like G. van der Leegte live off the crumbs that fall from titan Philips' table. The behemoth does everything itself, but the machine factory in Acht is infamous for its unreliability. The division never meets its deadlines, and so Philips' business units often turn to an external machiner. The requirements ASML is posing are quite a challenge for G. van der Leegte, but the company is eager to master that level of precision and the owner, Gerard van der Leegte, is prepared to invest in that effort.

Small suppliers like these can live just fine off ASML's volumes in the second half of the eighties. As Philips falls further into decay, these suppliers grow in lockstep with ASML. And so the seed of ASML's famed outsourcing ecosystem is planted in those years.

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Smit and his management team want to accelerate development. Based on market estimates, the R&D department needs to deliver a prototype PAS 2500 stepper by January 1, 1986. Six months later, the machine must be ready for mass production. ASML puts the stepper generation after that in its road map for two years later. In January 1988, R&D must be complete on a stepper that can image 0.7-micron details[4] onto an eighteen-millimeter-square field.

That R&D effort will be immense. To shorten development time, ASML wants to hire even more new people a.s.a.p. Outsourcing is also the mantra for development. Natlab and the CFT are among the suppliers that will focus on designing the electric wafer table and improving the alignment system (appendix 10).

Meanwhile, Smit is talking with the NMB bank and the Ministry of Economic Affairs to secure financing and credit, rose-colored business plan firmly in hand.

33. **Landmark**

ASML wants to move its offices to Veldhoven, at a site that's visible from the A2 freeway. The neighboring cities of Eindhoven and Son try to block the move.

In the summer of 1984, portable buildings are hastily erected on Philips' industrial campus to house ASML's management team and its finance, marketing, and HR departments. There, Gjalt Smit and Joop van Kessel pore over the plans for a new location. Smit's set his sights on an imposing building that exudes a high-tech vibe. Everyone in the greater Eindhoven region will know ASML exists. He wants a landmark, a striking visual reference point that no one can ignore. Amid the dank Dutch landscape, Smit wants to build a headquarters that feels like Silicon Valley.

They're in a hurry. Mass production is slated to start in August 1985. This won't be just any plant. It will need to have superclean labs and assembly areas rated for different chemical classes plus sealed spaces for machine testing and integration. That last group in particular must be insulated against vibrations, so the building will need a special foundation.

ASML's CEO has a few more personal wishes. His family has since moved to a town about thirty miles away, and he tells Van Kessel he wants to be able to bike from the train station to work. ASML's head of production suggests the town of Veldhoven; Smit is partial to the vacant lot near Philips Medical in the town of Best.

After Smit and Van Kessel present their ideas to Philips' architectural department, they're proffered a dreary building of the kind built everywhere in Eindhoven after the war. The bureaucracy-drenched firm doesn't want to set a deadline, either. Smit walks out and doesn't look back.

A short while later, architect Robert van Aken designs him a striking building. Van Kessel sends the drawings to city hall in both Veldhoven and Best, asking each town if it would welcome ASML's

The Het Akkereind site in Veldhoven where ASML's first plant will later be built. As luck would have it, this photo was taken by Anne-Marie van Heek-Volbeda, the wife of Herman van Heek, who built Philips' Silicon Repeater 1 in the 1970s.

eye-catching factory. Oh, by the way, within four years the plant will employ more than three hundred people, two-thirds of them with university degrees. It's a highly attractive proposal in a country plagued by unemployment. The mayor of Best calls Van Kessel that same evening. Would Mr. Smit like to come to his house for dinner?

Three miles away, Veldhoven's mayor and city council weigh their chances. ASML has its eye on a collection of fields right beside the freeway, named Het Akkereind. The company's interest dovetails with a request the city sent to the provincial council a year earlier. Veldhoven wants to rezone Het Akkereind from non-urban to urban. The city has recreational facilities in mind, but the rezoning would also permit clean industrial use.

Veldhoven's leaders respond quickly. Councilman Johan Stevens sets a meeting with Smit and immediately calls the local press, which he triumphantly receives at city hall the next day. He has big news: he's in talks with ASML, which will create three hundred jobs in Veldhoven within three years. There are still a few kinks to iron out, but they're just peanuts.

On August 22, the front-page headline of the major regional paper reads "Veldhoven May Win Bid for Joint ASM–Philips Factory." With the subhead "300 new jobs in 1988" the paper can finally report some good news in a time when unemployment rates are breaking records.[5] "Construction is expected to start on November 1," the paper writes. "The complex will include a 35,000 square foot factory and 25,000 square feet of office space."

Councilman Stevens plays his hand well. He uses the interview with the paper to portray Veldhoven's future residents as global players and says ASML will ride the wave of explosive growth in the chip industry. In 1988, American and Japanese chip manufacturers will spend one billion dollars on wafer steppers, many of them from ASML, the paper quotes Stevens as saying.

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The councilman neatly summarizes the advantages Veldhoven has to offer. They're a perfect fit for the wish list ASML has given him: Het Akkereind is close to the freeway exit, "which is important, considering the company's international contacts," and will serve nicely to showcase the company given its high-visibility location. The paper describes with visible relish how Stevens' small town contrasts with its city-sized neighbor. "For that matter, it's a well-known fact that industrial land is appreciably cheaper in Veldhoven than in, say, Eindhoven," the journalist notes.

Stevens also plays it smart outside the public arena. He takes Smit to the province capital, Den Bosch, where ASML's CEO can tell his impassioned story to Dries van Agt, the country's former prime minister and now the Queen's Commissioner for the province. Soon afterward, the province greenlights the project. "ASML May Move to Het Akkereind in Veldhoven," the regional paper reports, accompanied by a picturesque artist's impression that architect Robert van Aken has commissioned for the future building. "ASM Lithography Incorporated doesn't belong at your everyday industrial site," the paper writes. "But Veldhoven's Akkereind South location clearly meets all the needs of a company like this one."

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And so ASML selects Veldhoven. The mayor of nearby Best gallantly accepts his defeat, but the city leaders in Eindhoven and Son, where many industrial parks stand empty, are not amused. When they learn that ASML has chosen a site zoned for recreation, they take their frustration to the Dutch Supreme Court. Smit is furious when he hears the two cities and the Ekkersrijt industrial park are trying to block the province's decision.

ASML is on a tight schedule, but it can't start construction until the matter's settled. They must break ground by November 1, but the case won't appear before the court until several days later. "What assholes," Smit bellows at Van Kessel. "The government is supposed to help you and support you, but they're working against us. We're going to start construction, whatever they may say. They can blow my head off if they don't like it."

In the days that follow, Smit calls one of the Supreme Court justices. He knows the man from his time at ITT; they were both members of an advisory group, along with several prominent government officials. "Stop, stop," the magistrate responds. "Don't say another word; this may end up on my desk." But Smit just wants the judge to tell him who the most capable lawyer is for this kind of thing. The justice gives him the phone number of a professor in Amsterdam, an authority on spatial planning.

An aggrieved Smit doesn't let the building permit sit idle, even though the Supreme Court may still invalidate it. On October 12, the first bulldozers rumble across Het Akkereind to lay down an access road. The contractor, IBC, suggests they wait on driving piles for the foundation until the Supreme Court has made its decision, but an incensed Smit won't hear of it. "I want you to drive those piles now! No waiting for trial!"

The regional paper gives Smit an opportunity to explain that he has good arguments for not choosing a regular industrial park. "Compared to our dust-free laboratories, a hospital operating room is a garbage belt." The Veldhoven location is only logical, he says, given its proximity to Natlab and to mother Philips' machine factories.

Though the whole affair has brought Smit to a boiling point, in public ASML's CEO takes a diplomatic tone. "Obviously we didn't make any threats during negotiations," he says in the paper, referring to his discussions with the four cities. "I did tell them it was now or never. Any delay would be catastrophic. We want to break ground in November, and we could have opted to build in the US or Japan. In the end, that's where our major customers are. Our current market share is zero, and we absolutely must grow to 20 percent in the next few years."

ASML has public opinion on its side. Every week, the regional paper gleefully throws oil on the fire. One such move is an article titled "Townships' Battle over ASML Is Tasteless," in which the regional trade union rants about local political parties. "The political game is more important to them than their constituents' employment." The regional employment agency also denounces the parties' behavior.

Even before the Supreme Court hears the case, the regional paper reserves a full page to sum up the situation to date. "Wafer Stepper Takes the World by Storm" is splashed across the top. Beneath it is a large photo of Het Akkereind with a pile driver at work. "No one expects construction on ASML's new headquarters in Veldhoven to be stopped," reads the subhead. In one of the articles, Van Kessel is granted space to proudly explain what exactly ASM Lithography does.

And his colleagues? They've begun to beam with pride. Their tiny company—barely a hundred employees at that time—has spent months in the spotlight. Not even a year old, and ASML is already turning heads.

Smit and Van Kessel work with their attorney to prepare the case down to the last detail. On the day of the hearing, they bring along photos and a scale model of the proposed building. The presiding judge is impressed. What's more, he turns out to be the kind of judge who detests legal hairsplitting and looks to see what's genuinely fair. ASML may keep its permit to build.

34. **Back to Elcoma**

George de Kruiff takes Gjalt Smit with him to Elcoma. There they meet Kees Krijgsman and Willem Maris, who promise to buy ASML's technology—as long as it's ready on time.

Gjalt Smit's ambitious plans quickly race through the old boy network at Philips. When Ferdinand Rauwenhoff, the head of Philips' Dutch division, hears about it, he enthusiastically says to George de Kruiff, S&I's technical director and a member of ASML's board, "At last we've got another guy at Philips who's making things happen, someone who's saying 'Let's go to the moon'!"

De Kruiff is also excited by the young company's ambition, but he's wrestling with a significant problem. He may be the chairman of ASML's supervisory board, but he's dependent on Philips' executive board to double the joint venture's capital. Smit's asking for a hefty investment. ASM and Philips have already raised their outlay by $3 million, but that still doesn't get them there.

De Kruiff knows Elcoma is the key. If he can get the fab's management excited about ASML's steppers, that would send a positive signal to Philips' executives. And so, soon after Smit presents his business plan to the supervisory board, De Kruiff suggests they visit Kees Krijgsman, who's in charge of Elcoma's chip activities.

Smit doesn't expect much to come of it. He visited Elcoma a few months earlier with Wim Troost, and the coffee they shared with Henk Kerkmeester left a bitter taste in his mouth. But they need money. They absolutely have to win over Philips' chip fabs, he knows, and not just for the additional capital. *Not* supplying its majority shareholder would completely discredit ASML in the eyes of other chip manufacturers. What's more, a customer just down the road would be ideal for operational troubleshooting on the first machines.

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Willem Maris, the man who will become ASML's CEO five years later, and Kees Krijgsman jointly run one of Philips' most ambitious projects in those years: the Megachip project. Working with Siemens, the company is racing to close the sizeable distance with their Far East competitors in chip technology. Philips and Siemens want to develop highly advanced production for memory chips that can store one million bits—hence the name Megachip. This unholy alliance is a massive effort, with a budget to match. While Philips is cutting back wherever it can in those days, Krijgsman has a virtually blank check: he's been authorized to spend up to $700 million. At Natlab, development on the megabit memory chip is in full swing. A test fab has been erected where Philips' researchers have access to the most advanced equipment in order to put Europe back on the chip map. Natlab's even developing a couple of steppers for the project, as a backup.

The schedule is tight, and it applies to the project's machinery suppliers, too. On April 1, 1986 Philips wants to receive systems for use in producing megabit memories from several companies. It will decide which system to buy three months later. "Then we'll decide which machines we'll use for mass production," Krijgsman tells De Kruiff and Smit.

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Smit unveils his plans: ASML can meet the April 1 deadline, because its internal deadline for the PAS 2500 is January 1, 1986. By now he's given his pitch multiple times, and it flows like wine. Krijgsman is impressed. Elcoma's director is frank about his requirements. He wants to receive the first PAS 2500 on April 1, 1986 and not a day later. "Otherwise it'll be Nikon," he warns.

If ASML meets the requirements, and Elcoma approves the machines, then Krijgsman will buy PAS 2500 steppers for the Megachip project. Smit is astonished. He knows Krijgsman wasn't forged in Philips' culture—he came to the project from Honeywell—but still he's surprised by Krijgsman's constructive attitude. But the requirements are aggressive. ASML has just eighteen months left to develop and produce a machine. From that moment on, a razor-sharp deadline is in effect.

The meeting with Krijgsman and Maris is a milestone for ASML. While Elcoma's fab managers in Nijmegen have advised their bosses not to do business with ASML, the Megachip duo express their support for Smit. He has the audacity to bring up the old oil-based stepper while he's at it, but Krijgsman and Maris are resolute. The CERCO lens's limited field of view makes the machine unsuitable for their plans.

Krijgsman doesn't just lend Smit his support; he also makes him an extraordinary offer. He invites ASML's CEO to attend the monthly meetings in which he and Maris discuss progress on the Megachip project, along with Kees Bulthuis and Marino Carasso from Natlab and Roel Kramer from the Megachip test fab. "That will help you get a handle on our requirements for lithographic equipment," Krijgsman says. Smit is speechless. He has to restrain himself from leaping out of his chair and whooping for joy. From now on, he's welcome at the meetings in which Elcoma and Natlab discuss their technology policy! ASML's CEO can't help thinking about the love-hate relationship he's always had with Philips. He can't curse them enough for all the rotten moves they pulled internally and all the opportunities they've missed—but Philips can also be an answer to prayers.

Smit is now experiencing the particular depth of support the Philips establishment has for its spinoff activities, and it's an experience he'll go on to have several times more while he's at ASML. When the joint venture's problems play out beyond the thick walls of the Philips fortress, the company's managers are often ready to help. ASML already received Natlab's help with the electric table earlier; and now, at last, Elcoma is sending a positive signal—even if it's a conditional one.

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"Wow, Gjalt, now *that* was a good conversation!" A delighted De Kruiff claps Smit on the back as they leave Elcoma's office in Eindhoven. “What a constructive guy, that Krijgsman,” he adds with relief. De Kruiff knows it will no longer be hard to get extra funding for ASML.

For Smit, too, it’s a breakthrough. His relationship with Elcoma is suddenly looking much rosier. It’s clear to him that Krijgsman is sticking out his neck for ASML. That will convince the supervisory board to endorse his business plan.

But the shareholders cap their funding at $7.5 million. They make it clear that ASML will have to find the rest elsewhere.

ASM, Elcoma, and Philips: from that moment on, everyone is chained to the ASML project. The company has to succeed, even if all those involved can’t yet fathom all the consequences. It will be the financial consequences in particular that later provoke unavoidable confrontations between Smit and Del Prado, but tonight, those consequences are just a distant future worry for ASML’s CEO.

35. **Victoria Veste**

New employees start off with an introductory training where Gjalt Smit drives home an insistent message: ASML is nothing like Philips in any way whatsoever.

In early September 1984, on a dreary Tuesday morning, Wim Hendriksen walks into the Victoria Veste roadhouse, across the street from Eindhoven Central Station. He's there for the one-week introductory course that he and twenty other new ASML employees will be taking. Just like Hendriksen, most of the others have only been on the job for a few days. Many of them have come straight from Philips. Gjalt Smit makes clever use of the fact in his kickoff speech. "I spent seven years of my life working for the S&I division, and I ran away screaming," he says. "Way too much red tape. It was inevitable the stepper project would fail there."

But Smit soon gives his monologue a positive spin. Though Philips wasn't able to deliver, the industry was initially enthusiastic about the company's lithographic technology. "And ASML will deliver," he says.

Smit then tells his other shareholder's success story. ASM International knows the chip market inside and out. The machinery manufacturer is successful, growing fast, and turning a profit. Smit points to the recent banner years of 1982 and 1983, when the technology company saw its revenue jump from $52 million to $77 million. "In 1984, ASM expects to earn a whopping $106 million. That means it's growing faster than the market," Smit tells his new recruits. "The company has a great track record over its sixteen-year history, and in addition to two locations in the Netherlands, it has offices in Phoenix, Hong Kong, and Tokyo."

ASML's CEO tells his audience the company is going for the gold. "We still have a long row to hoe," he says, "because the PAS machines have lost their jump on the competition." Nonetheless, ASML can take the bull by the horns: "The PAS is a Mercedes with today's mechanics and yesterday's body. It's solid inside, the throughput and precision are fine, but everything around them is falling apart." Fortunately, ASML has everything it needs to get there. "We're as small and nimble as a startup, with the technological history of a longtime heavyweight."

Smit tutors his audience in the quirks of the chip lithography market. Het tells them these are complex machines. There won't be any new competitors; the hurdles are too high for that. "Our competitors Perkin-Elmer in the US and Nikon in Japan haven't yet definitively established their positions," Smit says. "Our goal is to capture a quarter of the market in 1988. At that point five of our nine competitors will be left."

Then he tells them the numbers. "We'll move from twenty to three hundred steppers in 1988, with a revenue of $156 million. Our road map is ambitious, but realistic." To build speed, ASML is going to farm out as much as it can. The company will only develop the most crucial expertise in house, and that's what the new engineers are for. They will shape the heart of the machine. "We're going to earn half a million in revenue per employee," Smit tells them.

ASML's market is in the US, and Smit wants to set up shop there as soon as he can. The Veldhoven site must also follow the American model. "Europe leads in technology, but commercially it's a disaster," Smit says. "That means we need to visit the US as often as we can. We have no use for people who think and think and conduct studies; we want people who *act*. We want our company to have a Silicon Valley mindset."

Next, a few veterans explain various technical aspects of the wafer stepper. One of them is Martin van den Brink. He's been at ASML for barely six months, but he rattles off the details of the alignment system like he's never done anything else.

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After a few days at the Victoria Veste, Wim Hendriksen is certain. He signed up to work for a Philips subsidiary, but his young employer is going to rigorously abandon its mother company's tepid approach.

This is a company that believes in all or nothing, he concludes. Hendriksen feels like he's stepped onto a roller coaster, and the sensation dizzies him. Half a million dollars in revenue per employee and a play for global market leadership: ASML won't settle for less.

It's an ambition that continues to intrigue Hendriksen. *If it works*, he thinks, *that's great*. If it doesn't work, the company will fall on its face, hard. He will save the designs he draws for decades. They comprise his bible and his compass; a clear goal, *that's* where he's headed.

* * *

The hiring campaign generates a steady stream of new employees in the fall of 1984. Among them are many refugees from stodgy Philips. They find themselves in a company where opposing their former employer has been elevated to an art.

That fall, the young engineers Martin van den Brink and Frits van Hout are witness to an amazing transformation. The influx of fresh blood flips the company's mood around in just a few short months. The complaining dies out in the old factory as many of the former Philips brigade start to get excited about the future. Others make use of exemption rules to return to mother Philips—Smit doesn't stop them. The lunchroom moaning disappears. Engineers joke and laugh as they wolf down their sandwiches.

New employees like Hendriksen feel none of the sour climate that permeated building TQ3 just a few months earlier. Some of their colleagues are born complainers, but he and his fellow newbies just waltz right over them. Now and then he sees pale figures shuffling over the hallway tiles: Philips employees from other parts of the TQ labyrinth. Hendriksen and his colleagues have no idea who these zombies are. For his part, when it's time to eat he grabs a quick sandwich and then it's back to work. No one spends time dawdling in the break room.

36. **Anthill**

ASML is still a chaotic mess. The newly appointed service engineer Jos Vreeker discovers that with zero machines at customers, there's not much to service at this point.

On a Friday afternoon in October, Martin van den Brink walks to the front of one of the cramped makeshift meeting rooms in building TQ3. Barely a year out of school himself, Van den Brink stops beside the flip chart and faces the dozen or so engineers who have gathered. "Gentlemen," he says, "the stepper we currently have sucks. We're going to design a new one. What will it be?"

Jos Vreeker nearly falls off his chair when he hears that. That Friday afternoon, he finally truly realizes where his new employer stands. For four years, he traveled through Europe servicing Perkin-Elmer's Micralign projection aligners, the very successful chip scanners that every lab and fab in the world has at least one of. Now he's discovered he's signed on with a firm that doesn't currently have any new machines to sell.

Vreeker is used to servicing top-quality products for a tightly run, disciplined, hierarchical company, but at ASML there's barely anything to service. When he sees the old PAS 2000 steppers on the assembly floor, he's shocked. *Real shoestring work*, he thinks, and he wonders how they'll ever get the machines working.

Before ASML moves to Veldhoven, its management team, office staff, and HR department have to make do in a few cramped portable buildings erected near building TQ3, where the company is developing the stepper.

When Vreeker travels to Philips' sites to service their PAS 2000s in the months that follow, he's struck by how dismissive the stepper operators are about ASML's technology.

During the introductory training, he learned how insanely precise the machines are: how perfectly their superior alignment system and H-stage are able to overlay chip patterns. But when he mentions in one of the chip fabs that ASML's systems achieve an overlay of 125 nanometers, people just shrug. That's nice, but way more than they need. "That kind of alignment system is absurd," he keeps being told. Why would they need a machine with a 0.125-micron overlay when they can't image details smaller than a micron? The idea that optical lithography will soon bump up against its limits is still widespread in the mid-eighties.

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Vreeker isn't the only one who's surprised. *This is a disaster zone*, is the first thing Fia Loozen thinks when she walks into the barracks at the end of November. In the days that follow, the executive assistant discovers that her office is as well trafficked as Grand Central Station. A large cabinet beside her desk is filled with office supplies, soda, beer, cookies, and candy. Beside it stands a fridge, and on top of that the coffee machine. Engineers waltz in every other minute to grab a snack and make coffee. The brand-new secretary is supposed to work amid all that chaos? Loozen is not amused.

Three months earlier, the Amsterdam native sent an application to ASML after seeing an ad in the *Intermediair*. She previously worked for a travel agency in Italy and has years of experience at Gillette and Henkel. For the past three years she's been working at the employment agency in Uden, twenty miles north of Eindhoven. It's not her thing, she's decided; she wants a job that provides a challenge again.

Gjalt Smit himself invites her to his apartment in Eindhoven for an interview—a habit of his in those days. ASML is cramped for space in the portable buildings that serve as the company's temporary home at S&I's complex. He also invited his head of development, Nico Hermans, and his CTO, Gerard Verdonschot, to his home a few months earlier. Smit sees it as a benefit. Philips' oppressive stench is absent from his private domain; it feels more like a startup there than in the factory that reeks of oil.

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Loozen's fingers start to itch as she listens to Smit's impassioned speech. As the CEO pours tea, he tells her ASML is going to conquer the world. *That's the kind of company I want to pour my energy into*, she thinks. But once she starts work, her new surroundings are difficult to stomach. The brand-new Decwriter is pretty much the only thing that impresses her in the initial months. She's used electric IBM typewriters before, but now she doesn't have to use whiteout anymore. Everything else is a mess. The makeshift offices, yes; but mainly, the way her colleagues interact. In the barracks and on the factory floor, it's chaos. When she looks around, she sees an anthill: everyone's busy, but doing what? She has no idea. Her HR colleague is consumed with finding new hires and has papered the floor of her office with folders. Apparently they're all busy doing important things, but Loozen can't discern any structure to it. The place is fun, though; the atmosphere is informal and people make jokes.

It looks like a disaster zone. No, it *is* a disaster zone, and that's not Loozen's thing. Her first move is to kick the coffee machine out of her office. All the communal snacks and supplies move to the end of the hall, beside the restrooms. Her colleagues think it's lame, but Loozen needs order so she can work. She's not there for the coffee.

37. **Hotel Victoria**

Gjalt Smit turns ASML's first offsite retreat on its head, demanding a new machine even sooner. Within a day, his team drafts the company's first product road map.

In mid-November 1984, ASML's managers and senior engineers board a bus headed north. The twenty of them will spend the next two days in Hotel Victoria at the edge of De Hoge Veluwe National Park, engaged in a mix of team building and training. They're preparing for an intense bout of catch-up; development must move faster. Their new machine must be ready to launch in record time.

The goal is clear. Elcoma wants to receive the PAS 2500 stepper on April 1, 1986, and a few months later ASML wants to demo the machine at SEMICON West. That means they have a year to design and manufacture a new system that can handle the generation of chips that fabs will be starting to test in 1986. Gjalt Smit has given them a deadline of January 1, 1986. In a letter to the PAS 2500 project team, he says that delivery on that date is "an absolute requirement." He ends the letter with: "GOAL: on 1/1/1986 A PAS 2500 we can SELL, not progress on THE ULTIMATE PAS 2500." In the parkside hotel, ASML's leaders discuss how to make that happen.

Around two p.m. the team building program starts. Two trainers, both from Philips, start off with a standard course on how to move from idea to completed machine faster. At Philips, that process typically takes nine to twelve years, and the company has come up with a method to reduce that time to roughly seven years. ASML's people sigh. They've got a little bit more than one.

Smit blows in around ten p.m. He arrived at Schiphol Airport an hour earlier, after a trip to America where he once again spoke with customers. They told him the technology ASML wants to use in the PAS 2500 is far too ambitious. The biggest mismatch is the light source. ASML's engineering team wants to use the mercury i-line, but the chip industry isn't working with this wavelength yet. It's clear to Smit that chip manufacturers want to play it safe. For now, the entire industry wants to keep using the g-line wavelength emitted by the same mercury vapor lamps.

That same evening, the CEO calls his management team together. Smit tells them in no uncertain terms that if ASML keeps pursuing the i-line, it may be the technological frontrunner, but it will have a machine no one will buy. The whole industry has set up its infrastructure and available materials based on the g-line.

Smit has another announcement. During his trip to the US, he became convinced that ASML truly cannot sell the PAS 2000 as a test machine. Oil is simply taboo. What's more, the first signs of a recession are visible. Chip makers are growing cautious.

Smit's conclusion: they need a machine without oil, stat—preferably next year. Customers have again pointed out ASML's lack of an installed base, and so he wants a machine customers can start experimenting with as soon as possible. Waiting for the PAS 2500 is not an option.

To make the step to machines ready for sale as fast as they can, he wants to be able to demo a stepper at SEMICON West *1985*. Richard George, Nico Hermans, and Joop van Kessel scratch their heads. *How on earth will we make that happen?* Smit's asking the all but impossible. He wants a completed machine in just over six months' time.

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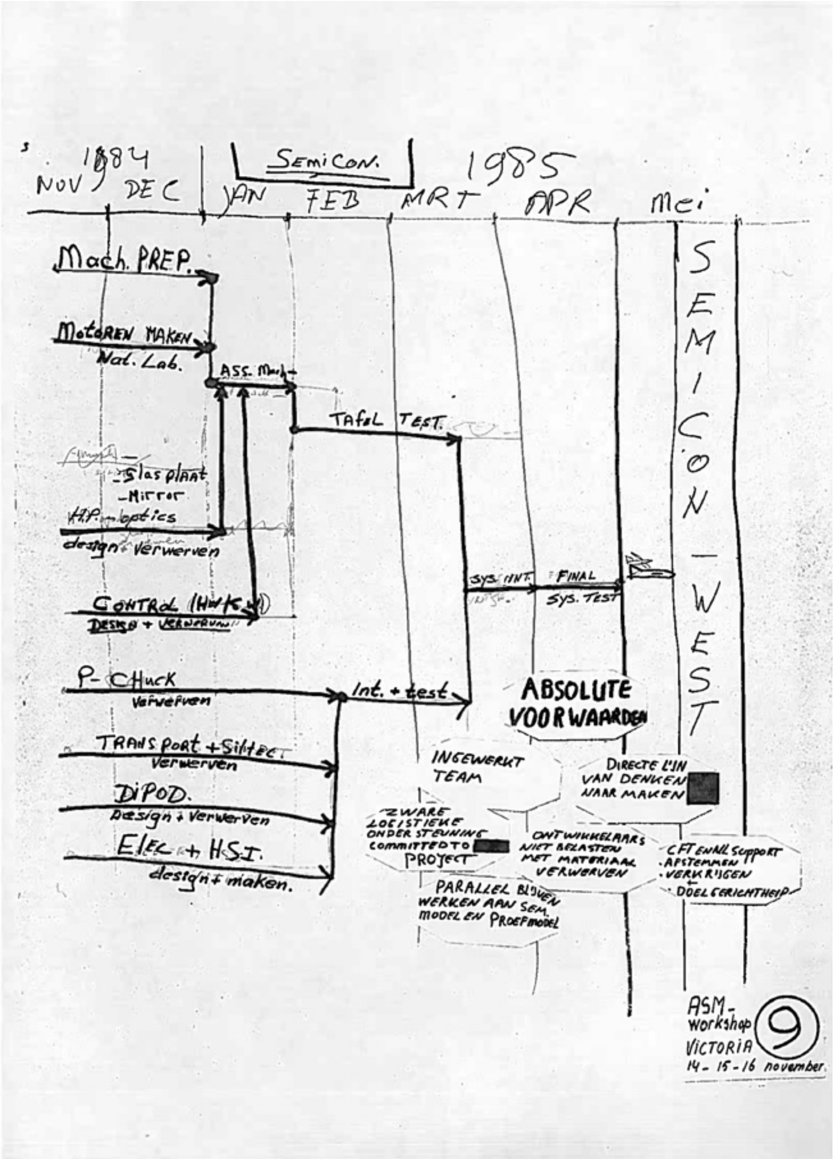
At breakfast, the rest of the team catches wind of the first rumors, and soon the room is buzzing: Smit wants to turn it all upside down. When the training sessions resume, Philips' trainers are nonplussed. They didn't realize on the first day that the company's entire management team is there, and they fall off their chairs when the CEO himself walks up to the front of the room and rewrites their entire schedule. They slink forlornly to the back of the room and listen along with the rest.

Smit outlines the situation. He's set his sights on the US, but how in god's name is he supposed to convince an American fab

Sketches that were made during the offsite retreat at the Hotel Victoria in Hoenderloo, the Netherlands. The retreat marked the first definitive acknowledgement that the oil-based PAS 2000 would be abandoned. Among other things, the page pictured includes the decision to stop ordering parts for that machine.



The road map to convert the PAS 2000 into a machine with an electric table for SEMICON West 1985.

manager to buy a machine from some tiny company in Holland? "We have absolutely zero presence in the American market," he says. "We have no installed base, no service division, no applications lab, and no experience." The original plan to use the PAS 2000 to generate interest in the PAS 2500 is doomed to fail. "Waiting for the PAS 2500 is just too big a risk." Elcoma has committed to buying the PAS 2500 steppers in 1986, but that won't win them any American customers that year. They need US references as soon as possible. They have to show people they've got staying power. To radiate commitment. His guys need to make that happen, well before ASML introduces the PAS 2500.

Smit keeps hammering on his point: he must and will have a machine sooner. "Otherwise we'll go bankrupt, pure and simple," he says, "and that's out of the question. We can forget the PAS 2000, so: what are we going to do?"

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Smit refuses to budge on the deadline. He wants to demonstrate a g-line stepper at SEMICON West the next spring. Without compromising development on the PAS 2500—because after a first machine in 1985, ASML must push forward with a system for the VLSI generation of chips. "How will we have a working g-line machine seven months from now?" he asks. "I want a plan by the end of the day."

The mood is one of hectic energy. Groups break off into separate rooms to work on specific details. Every ninety minutes, the teams regroup in the main room to coordinate. That day, miles of paper are filled with ideas and sketches. Philips' trainers are asked to coordinate things, but within a few hours they've been effectively banished to the sidelines.

As the day wears on, it becomes clear to everyone that there's no way to design the PAS 2500 any faster. Development and production simply don't fit in the space of nine months, even working in parallel—any more than using nine women will grow a baby in thirty days.

But the group does come up with a solution. It's possible to develop Natlab's electric table in the allotted time. They'll put it into the old PAS 2000, instead of a hydraulic stage. There are still several of those machines in stock, so that's no problem. If they're able to get the linear motors working in the PAS 2000, then at any rate they'll have something to demo. The only drawback is that CERCO's existing g-line optics can only expose a ten-by-ten-millimeter field, and the industry is already asking for fourteen by fourteen.

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By the time the engineers leave Hotel Victoria, the wads of paper are stacked waist-high. But ASML has a plan now, and a clear goal. In the coming months they'll make a transitional machine to penetrate the American market. They've christened this in-between stepper the PAS 2400.[6] Evert Polak, an aeronautical engineer who's transferred to ASML from Philips S&I, is tasked with leading development. Richard George's team will continue working on the PAS 2500.

Smit does something Philips never did when it was developing the stepper: he listens to customers. Their wish is his command. Smit doesn't rely on what his engineers bring back from technical conferences or pull out of the scientific literature. He asks customers what they need himself. He hands the conclusions from his analyses to his engineering staff as hard specifications. In essence, Smit's done the very first product marketing, and with new plans for the PAS 2400 and PAS 2500, ASML's first product road map is born.

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Smit's choices also upend the company's optics development. ASML has spent months begging Zeiss for a custom i-line lens, to no avail. Now suddenly they're off on a different tack. Smit decides to use one of Zeiss's standard g-line lenses. ASML will have to adapt the alignment system in order to build the lens into the PAS 2500. [7]

At the time, Smit doesn't know that the lens used by GCA[8] is starting to gain an abysmal reputation in the chip industry. The pressure to deliver is so high that the American stepper supplier doesn't take the time to quality-check all the hundreds of lenses Zeiss sends it. GCA's engineers also don't realize that the lens columns Zeiss sends them are beset by a vicious problem: drift. At first everything's fine, but after a while the imaging quality degrades—with deleterious effects. Chip makers' downtime goes up.

Because GCA has no idea what's causing the problem, it doesn't notify Zeiss. When, during his first meeting with Zeiss in 1984, Martin van den Brink suggests they conduct extensive testing when the lenses leave the factory in Oberkochen, the Germans don't want to hear of it. They consider final quality audits a waste of time, seeing as they've delivered hundreds of g-line lenses to GCA and not a single one has ever been returned.

The lens issue will turn into one of Zeiss's greatest debacles. It will be a major contributor to GCA's demise and will severely damage the lens maker's reputation. Zeiss's optics are no match for the high-quality lenses that Nikon and especially Canon are using in those days. ASML will also be caught up in the damage done to Zeiss's image, but in 1984 the Dutch company is not yet aware of the situation's severity.

In the years that follow, GCA will have to replace its customers' g-line lenses by the truckload. ASML may barely be selling wafer steppers by that point, but it will insist that Zeiss conduct final quality audits.

When they investigate, they will discover a fundamental problem. Zeiss glues the glass lens into the metal mount using a flexible sealant. That's necessary to allow for the difference in thermal expansion between the two materials, but the sealant is sensitive to moisture and temperature, which creates drift. The problem is so acute that Hans Letsche, Zeiss's head of semiconductor lenses, and his right-hand man Bernhard Kammerer have no other option than to cooperate with ASML to solve this problem.

As a result, in the mid-nineties Chris Velzel and Rien Koster at the CFT will think up a solution in the form of a hinged mount and a glass-to-metal bonding. They use an extremely thin layer of glue that cannot affect the position of the glass lens relative to the metal mounts as it shrinks and expands.[9]

This forced partnership is a breakthrough, considering that Zeiss had previously avoided any form of collaboration with the Dutch stepper maker. The partners will go on to collaborate several more times, which will make the ASML-Zeiss combination stronger and stronger.

38. **The American Market**

Gjalt Smit confronts his engineers with video footage in which customers express their disdain for ASML.

In the fall of 1984, Gjalt Smit asks a marketing firm in Silicon Valley to conduct roundtable discussions with lithography experts from the major chip manufacturers. In these focus group sessions they discuss the factors for lithographic success. The participants know they're being recorded on video, but not that ASML is behind the sessions. What do the experts expect from suppliers, and by the way, what do they think of newcomer ASML?

Their blunt comments make it clear that absolutely no one is interested in a European supplier. The chip industry lives in the US and Japan. The Americans paint the Dutch engineers as residents of the Old World, a continent known for its risk-averse and conservative attitudes.

When Smit confronts his team with the video, it's a painful but valuable shock. They realize there's a lot of work to be done to remove American skepticism. Superior machine performance is a basic requirement. The Americans say they're primarily looking for lithography firms with staying power, financial resources, and a willingness to invest in local service. They should also have a clear road map for the future.

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In the August 1984 business plan, Smit focuses on both the Americans and the Japanese. "To build credibility with customers, we need to set up production in the US and Japan, as quickly as we can afford to," he writes. ASML has already rented a building in Phoenix that will serve as an applications lab. In 1986 Smit wants demo spaces in Silicon Valley, and soon after in Japan.

After seeing the video, Smit changes tack. He realizes there's no point in chasing after Japan; America is more than enough of a challenge. And so Japan disappears off his radar. He's betting everything on the US, even if ASML's opportunities are limited there.

ASML can forget about major players like Intel, Motorola, and Texas Instruments. They're at war with their Japanese competitors Hitachi, NEC, and Toshiba. The Americans' reputation has been tarnished. They're obsessed by just one thing: beating their Asian competitors. To do that, they have to equal the quality, reliability, and service provided by the pinnacle of manufacturing excellence: Japan. The American giants are buying their steppers from Canon and Nikon, in order to set up their fabs just like their opponents.

This need to achieve higher quality signals the beginning of the end for GCA. The company that launched the first commercial stepper in 1978 can't match Japanese quality, and it's quickly losing ground. Never before has GCA experienced anything like the fierce competition now coming from Canon and Nikon.

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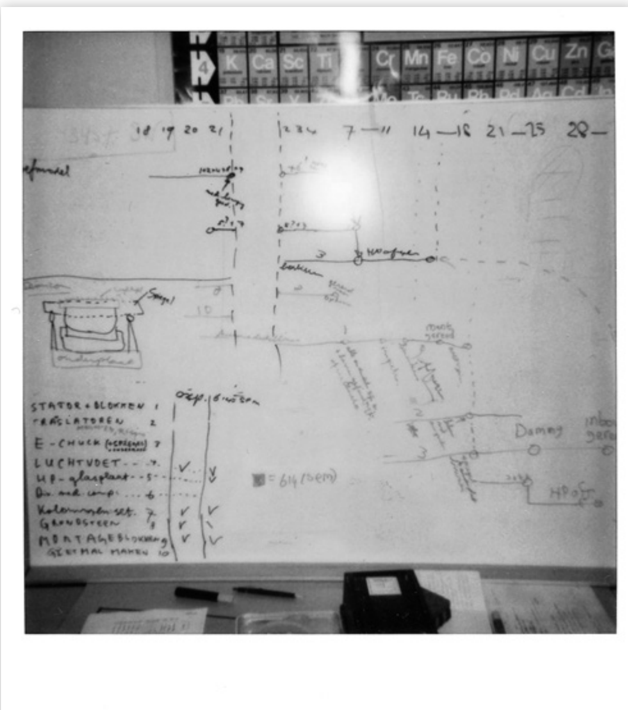
That means the bar is insanely high for ASML. The PAS 2500 has a real chance of success, but only the highest professionalism will convince American customers. Smit realizes he doesn't have a chance at Intel, Motorola, and Texas Instruments. His only option is to go after the second tier: companies like AMD, Cypress, and MMI.

Smit reasons that AMD's primary competitor is Intel, not the Japanese. That means the company might potentially be interested in machines that will help it beat out its rival in Santa Clara. The same is true for Cypress. Both companies are looking for ways to outdo their larger US competitors. And that's what Smit is offering with ASML's steppers.

39. **If Something's Supposed to Come in on Friday, It Isn't Coming at All**

Frans Klaassen is tapped to develop the wafer table control system at ASML. The pressure is enormous. The company's future depends on him.

Before the team traipsed off to Hotel Victoria, Klaassen's horizon was still safely in the distance. The electric table he was working on needed to be ready at the start of 1986. Only then would they ship the PAS 2500. But the impromptu session at the retreat shrinks his available time by half a year. Smit wants to demo the PAS 2400 with an electric table at SEMICON West in late May, and that means Klaassen has six months to get it all working.



The Polaroid photo Evert Polak took in late 1984 to record the development road map for the electric stage.

When Klaassen lets himself think about it, his head feels like it might explode. He's finding problem after problem and he can't get a handle on what he needs to do. How will they make the new motors in the factory? Will they work well with the lenses? ASML is setting aside a technologically perfect oil-based system for an alternative no one can say for sure will work.

The truth of the matter is that ASML simply doesn't have another option. Customers don't want oil-based machines. Period. The only thing they can do is perfect Natlab's electric table (appendix 11). In so doing, the company follows a path it will often tread in the years to come: risking its future by betting everything on an immature and unproven technology.

The future of the now one-hundred-employee company depends entirely on Klaassen. That's how it feels, that's how it is, and that's why he's sweating bullets. He's the most well versed of them in the new drive technology. "They say they want to get rid of the oil, but my thing is only half finished," he tells colleagues. "That's a pretty drastic decision."

Klaassen expresses his concerns to Evert Polak, the project leader for the PAS 2400. At his request, Klaassen explains everything to him: what still needs to happen, what's critical, where the problems are. Klaassen's throat starts to close up. "It's never going to work," he cries as he looks at his growing list. But Polak is calm. "Frans," he says, "we're all in the same boat here. Let's just get started, and solve each issue one by one." Slowly but surely, Klaassen gets the message: complaining won't help. All they can do is press forward.

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Klaassen bikes over to Natlab to pick up his old drawings, then gets down to work. He has to redesign the table from scratch, because it has to fit into the PAS 2000's frame. He rips off the 2000's hydraulic stage; the oil pump and generators can go, too. The machine instantly drops half its weight.

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The project is massive. During the PAS 2400 team's first meeting, Polak draws the entire schedule on a whiteboard. Stators, e-chucks, flat-pad air bearings, glass slides, base stones—all the mechanics are plotted on a timeline for Klaassen and his designers to use. There's a road map for the control electronics and software, too. At the end of the meeting the whole schedule is on the whiteboard, week by week. Polak documents it with a Polaroid camera and hands the photo to Klaassen. It gives them all a shared sense of urgency.

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Klaassen demonstrated the principle of the electric wafer stage at Natlab, but now he and his team are facing a whole new challenge. They have to develop a system that will do its job day in, day out, at high speed and high precision. The stage contains a few critical components, such as a stator, the part of a linear motor that contains the electric coils, and a few glass parts that require extreme accuracy. Even the granite base is critical. It must be perfectly flat, because it's part of an air bearing with a gap of just ten microns.

The linear motor is a completely new concept. Electric motors have been around for more than a century, but not a drive system that works like a loudspeaker: an electromagnet that makes a permanent magnet move. Philips has plenty of expertise in winding coils for conventional electric motors, from electric shavers to heavy-duty engines. But nowhere in the world is there an industrial production line for linear motors.

The core of the linear motor is made of laminations: thin sheets of electrical steel glued into a stack. The glue or resin has to bind the strips together, while simultaneously insulating them electrically from each other. Then comes the copper wire. Each segment of the motor must be painstakingly wound very precisely, then slid over the core. All in all, it's a very delicate job.

A year earlier, Natlab's shop made one for Klaassen by hand. That manual craftwork took a month back then.

Now Klaassen has to find a factory that will mass-produce his stators. If all goes well, ASML will need fifty to a hundred of them in a few years, and there's no way to make that many by hand. What's more, production must be predictable and the only way to achieve that is mechanically, in a reliable manufacturing process.

Klaassen and his designers head east, to Philips' motor coil plant in Almelo. But the factory isn't interested in making those complicated things Natlab's thought up. By the way, what's all this about a joint venture between ASM and Philips? No one in Almelo has heard of it. "What you're asking for, that can't be done," they tell Klaassen. "We'd have to wind and solder it in the space of a few seconds, and that's impossible." Philips is used to much greater production runs. Tens of thousands, not dozens.

The team persists. The Polaroid photo of their aggressive schedule has been burned into Klaassen's brain, pixel by pixel. He inquires at machine factories external to Philips, but there the name ASML carries no weight at all. The manufacturing companies Klaassen tries to interest in the job are unenthused. Once he tells them it's for fifty units a year and tells them how fast he needs them, the conversation is over. Klaassen feels like a pariah.

* * *

But his work also has its blessings. When he needs help from higher up, it's instantly forthcoming. In that regard, this is the best job he's had. He just has to snap his fingers and Richard George, Nico Hermans, and even Gjalt Smit are ready to do whatever it takes so he can move forward. And if that doesn't work, there's always Wim Troost. The former S&I business unit director is always willing to make the rounds of his vast network at Philips: would they please help out his baby ASML?

Slowly but surely, Philips' factory in Almelo begins to realize the people asking for the stators are an undauntable group, determined to make their machine a success. People who dig in and hang on and never let go. Klaassen and his designers finally meet with some of the plant's engineers who are prepared to listen and help them fabricate the crucial coils.

At that time, the diminutive dwarf ASML must still rely heavily on the bureaucratic behemoth Philips. It's a lazy, ornery, uncooperative beast, but it's sitting on a technological treasure trove. No other company is able to make the advanced parts the tiny stepper manufacturer is asking for. What's more, there are enough people in crucial positions at the multinational who want to help one of Philips' offspring progress.

ASML's people are constantly knocking on the door at Philips' other machine factories, too. Everywhere they go, they have to fight to get the parts on time and to the required specifications. Everywhere they go, people tell them Philips can't make what they want. It's too complex. But with enough pushing and pulling, they almost always get their way. ASML doesn't have any other option. Polak's simple Polaroid photo says it all. They simply must get their parts. On time.

Sometimes they're lucky. For extremely flat mirrors and several precision glass parts, they just have to cross the street to Philips' glass factory. A gift from the gods, because these are extremely difficult pieces, parts ASML can't possibly get by just sending over a drawing. ASML's designers often spend hours talking with their colleagues at Philips, puzzling out how on earth they're going to even make the things at all.

* * *

But it's Klaassen who's squarely the center of attention in November and December of 1984. Aside from the optics, the wafer stage project is the most critical part, and at that time it's the one causing the most concern. ASML stands or falls on the success of Klaassen's efforts. Even Smit drops by his office each day to see how things are going. Klaassen can almost taste the pressure. All the time. Everyone knows the deadline is sacred.

Despite the stress, Klaassen is having the time of his life. The young engineer gets anything he wants. When he hits a roadblock, he just has to whistle, and George and Hermans make sure he can keep moving forward. The ordered parts start streaming in. When

Klaassen needs another designer, he gets one right away. And there's moral support, too. "Frans, there's a case of beer with your name on it if you get that thing working by Christmas," Hermans and Smit call out at some point that fall.

* * *

Convincing Philips' production plants to help them may be a nightmare, but getting the parts they make back on time is an even greater challenge. Klaassen is waiting on countless critical components. If he doesn't have even one of them, he can't move forward.

To keep parts delivery under control, Henk van Engelen steps in to assist. Van Engelen helps Klaassen navigate the innards of the bureaucratic beast. Sometimes there are three warehouses between production and delivery. Parts from other countries first have to go through customs, then to a warehouse in nearby Acht, then to one of S&I's distribution centers. Pencil pushers at each little island are there to check the parts off their lists. "It may be up for delivery sometime next week," they yawn. But Klaassen is young and impatient. He just cannot understand why something that arrived at the airport today can't be on his desk tomorrow. Why it always seems to take two weeks.

If Klaassen calls about parts on Friday afternoon, the desk jockeys at Philips say, "We can't get that out before the weekend; it's nearly five o'clock." Can't they stay late? No, Philips employees never do that. Klaassen asks what it would take to get them to stay late anyway. Wonder of wonders, there is a way: a little cash, a few beers, a bottle or two of wine. Klaassen and Van Engelen make arrangements with Hermans, and from that point on, the trunk of Van Engelen's car is always full of beer and wine to help extract the ordered parts from the clutch of Philips' red tape. Now and then they pay for the overtime in cold, hard cash.

Sometimes Klaassen and Van Engelen are told that parts have gotten stuck in one warehouse or another. After a while, they figure out how to solve that one, too. Van Engelen gets in his car and drives right over. The two develop feelers for the vagaries and moods of the beast that is Philips. When employees tell them that parts will be arriving on Friday, they know the real score. Klaassen even has a catchphrase for it: "If something's supposed to come in on Friday, it isn't coming at all."

* * *

The mechanics aren't Klaassen's only concern. The stepper also needs electronics, to control it and supply the power that feeds the linear motor. Jacques Stals is in charge of designing the electronics. To be able to manufacture the printed circuit boards, the young engineer has to make sure he has all the parts in house. Cables, plugs, components: S&I's circuit board factory can't make the PCBs until everything's complete. If even one small part is missing, they can't start assembling the electronics.

By now Klaassen's been around the block a few times. How often have S&I employees told him his stuff is "somewhere in the warehouse"? They can see it's come in on their monitor, but they have no idea where it is. "Jacques," Klaassen says to his colleague Stals, "I've had it with that warehouse. It hasn't come in until it's here beside your desk." He orders Stals to check everything twice. He can't cross it off the list until it's sitting in his office.

It works like a charm. The warehouse employees soon realize the nagging will continue until the parts are in Stals' office. If they aren't there, Klaassen will keep shouting at them. Countless cables, plugs, and boxes of parts start piling up beside Stals' desk.

* * *

The days and weeks rush past. The tiny, enterprising dwarf may be dependent on Philips, but it's managed to work the beast well enough that a highly advanced positioning system is starting to take shape. A smoothly moving system in two directions, using interferometers and advanced electronics to position both wafer and lens down to a fraction of a micron.

As 1984 draws to a close, in the dark weeks before Christmas, Klaassen is staring at his system when Nico Hermans bursts in.

Frans Klaassen in 2013 with part of the electric motor as it looked in 1984.

“So should I buy that case of beer?” the head of development asks. “Will we have it working by Christmas?” Klaassen’s just uncovered another problem. The power transistors that supply the motors keep blowing out. “If you want to see it move, I can show you, but only once. It’ll blow the amplifiers,” a dejected Klaassen tells Hermans. But Hermans’ response is enthusiastic. “That’s fantastic!” he says. “Show me!”

A few days later, Hermans puts a case of beer on ice and gathers everyone together for the demo. Klaassen turns on his machine. The wafer stage takes a single step and then the amplifiers blow—bam!—and it stops moving. Amid loud cheering and whooping they open the bottles of beer. A huge smile spreads across Klaassen’s face.

40. **Hurry, Hurry, the Future's Nipping at Your Heels**

The PAS 2500 encounters delays. Gjalt Smit doesn't want to hear the bad news.

It's cold and windy when twenty-four ASML employees board a bus in Eindhoven on March 11, 1985. They're headed to Weil am Rhein in West Germany; a day later, they'll leave for SEMICON Europe in Zurich. Gjalt Smit is among the passengers—a gesture his employees appreciate. The CEO is the only member of the ASML team that's attended a SEMICON show before. He thinks the European chip machinery show is the ideal opportunity for his engineers to observe the competition close up.

Wim Hendriksen is also on the bus. The man who's responsible for the stepper's software has been itching to say something for months. He's the last one in the chain of machine development and production. Software developers can't truly test their code until the whole system has been assembled. The PAS 2500 has to be up and running on January 1, 1986, but no matter how Hendriksen crunches the numbers, he comes out three or four months later. "We can forget about January," he tells his immediate boss, Cees Doesburg, but Doesburg ignores him and just repeats the management team's mantra: we will not accept delays. Richard George has made no secret of the fact the schedule is unrealistic, but Nico Hermans and Gjalt Smit just don't want to hear it.

But Hendriksen just has to get it off his chest. When Smit sits down beside him on the way to Switzerland, Hendriksen tells him the bad news. He can't keep it to himself; that's just the way he is. Hendriksen explains that it's completely impossible to deliver a PAS 2500 on January 1, 1986. "You can forget it. It just isn't possible," he tells Smit. "Then we can close up shop," the CEO snarls, without asking Hendriksen for details.

Hendriksen's claim has hit a raw nerve. Smit isn't open to hearing bad news. Hermans, the ASML executive in charge of the project, hasn't indicated there's a problem, and though Smit regularly makes the rounds of the company and should know where things stand, he's closed himself off to the idea. The incident en route to Zurich doesn't change that. Hendriksen feels like an obstructionist and a cynic. He remembers the advice his previous boss always gave him: "Never fight a battle you can't win." Hendriksen drops the matter, and no one else on the bus to Germany spares a thought for the coming crisis. "Well, I tried," he writes that night in his journal.

* * *

The cadre of ASML engineers has been tasked with an unusual mission. Eaton-Optimetrix, GCA, Nikon, Ultratech, and Censor—now part of Perkin-Elmer—all have booths on the SEMICON Zurich floor. Canon is absent. All of them are gearing up for the VLSI generation. The Dutch team must find out how far the competition has gotten.

First off, they have to ferret out how the competition has tackled machine design. To do that, each of them has been assigned a specific subsystem. They have to uncover how each company stands: light source, reticle handler, lens, alignment, stages, wafer handler, and electronics. In addition, each of them has been given a special task, such as "find out everything about GCA."

It's not so easy to get hold of the information. GCA and Nikon are carefully shielding their technology. Each company has installed its stepper and a wafer track in its own yellow room, attracting huge interest. With cameras inside and monitors outside, visitors can see how it all works. Only customers may enter the yellow room. But often, the Dutch engineers can find out what they need to know by hanging around until a customer shows up for a demo, and listening in as the vendor explains the salient details.

In the weeks that follow, Frits van Hout compiles a trip report[10] containing all their findings. He writes that every litho company has a mechanical wafer stage using lead screws or ball screws combined with ordinary electric motors—much less accurate than ASML's linear motors. All the machines can process wafers five to six inches in diameter. Much of the desired information remains elusive. They've learned almost nothing about lenses and light sources.

* * *

Smit does achieve his goal: SEMICON makes a deep impression on his engineers. They've witnessed four competitors with complete, deliverable machines. From what they've seen, they can draw the reassuring conclusion that no one has a system that's ready for VLSI chips yet. But it's also crystal clear the competition isn't sitting still. They need to hurry. After Zurich, no one remembers Hendriksen's painful comments. When he stumbles exhausted into his hotel room in Weil am Rein at the end of the week, he adds just one sentence to his journal: "Hurry, hurry, the future's nipping at your heels." The next day they all get back on the bus. All except Smit. He disappoints his team by taking a flight home.

41. **We Can Win This**

Off to SEMICON West—knees weak, mouth dry.

In the spring of 1985 the PAS 2400 is ready, and now it's time to show it to the world. Against his better judgment, Gjalt Smit tries to get Philips' Megachip project to buy the machine. He attempts to win Roel Kramer over, but the man who's responsible for setting up the Megachip test factory soon tires of the sales pitch: "Gjalt, we'll decide for ourselves what we need."

But Philips isn't Smit's major challenge, anyway. The major challenge is getting a foot in the door in the US, the birthplace of the semiconductor industry and still the source of nearly half the world's chips. When Smit reviews the videos from the focus group sessions, it's clear to him that even the second-tier chip makers aren't looking to work with an insignificant European litho company.

To break past that, Smit wants to supercharge ASML's image. He sees part of the key in clever marketing. The advantages of European technology must be drummed into the American mind. Smit knows he'll have to play the game American style: with spectacle, bluster, and bluff. He gets rid of the media agency that parent ASM uses. They make sleep-inducing ads with boring photos. Not distinctive enough for Smit.

One of ASML's salespeople in Phoenix points him toward a creative agency in Los Angeles. Smit calls the owner, Chuck Roberts, who's intrigued by the challenge. ASML's CEO flies to LA for an intense round of talks. The two men agree on the message: they have to tell the story of ingenious Dutch engineers who've crafted a superior machine. Hombres with commitment and staying power. "*Con coglioni quadrati!*" Smit grins.

Smit and Roberts opt for an aggressive ad campaign. They want to make a spectacular splash at SEMICON West 1985. There, at the premier platform for chip machines, ASML's very first stepper will be in the spotlight. From May 21 to 23 in San Mateo, a thousand suppliers will present their machines to forty-five thousand visitors from across the world. Attention guaranteed. ASML reserves a whopping ten full pages in the SEMICON West exhibition catalog.

To Dutch sensibilities, the ad campaign is audacious. Tiny, unassuming ASML is making a full frontal attack on the establishment. "ASM Lithography presents some wafer stepper numbers GCA and Nikon would like to ignore," the headline screams. Across several pages, ASML compares the features of its PAS 2000 stepper to the market leaders' numbers. The Dutch machine is significantly faster and thus delivers 10 to 20 percent greater yield. Its precision—a major competitive factor—is also much higher. The ad wisely omits comparisons on the optics—its CERCO lens can't compete.

* * *

Even before ASML demos the PAS 2400 at SEMICON West, it gets a big shot in the arm in early May. The Ministry of Economic Affairs is granting the company a $7.8 million credit. The national media take notice. Smit seizes on the chance to showcase ASML and its latest PAS 2400 machine.

His strategy is bold, to put it mildly. ASML is barely a year old, has sold hardly any steppers, and is still camping out in makeshift trailers on Philips' industrial campus, but Smit doesn't hesitate to paint his company as the future market leader. "Within five years, the company [...] intends to be the world's largest supplier of lithographic systems for the IC industry," Smit tells a leading national newspaper.[11] The paper then shares the specifics of that ambition: "CEO Gjalt Smit is targeting a revenue of $150 million in 1989."

The paper refers to the company's aggressive ad campaign for SEMICON West. "It takes pluck for the new kid on the block to confront the lion in its own den: for a small young company to launch a full frontal attack on its two largest competitors." Smit eagerly stokes the fire: "You can only do that when you're sure of yourself. When you're absolutely certain you have something special to offer. Otherwise you'll fall flat on your face."

Nico Hermans also brags with the best of them in the article. “It may sound arrogant,” the head of development tells the reporter, “but we’re going to leave the competition in the dust. We’re simply in a higher league.”

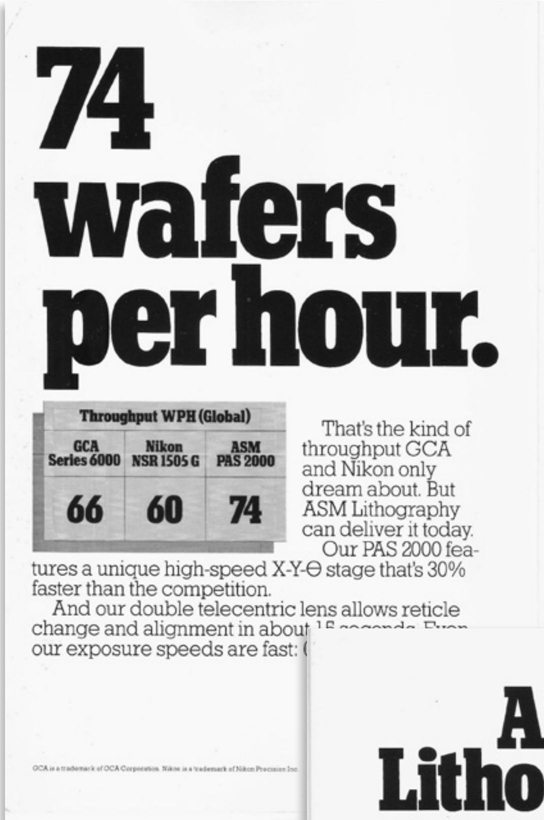
* * *

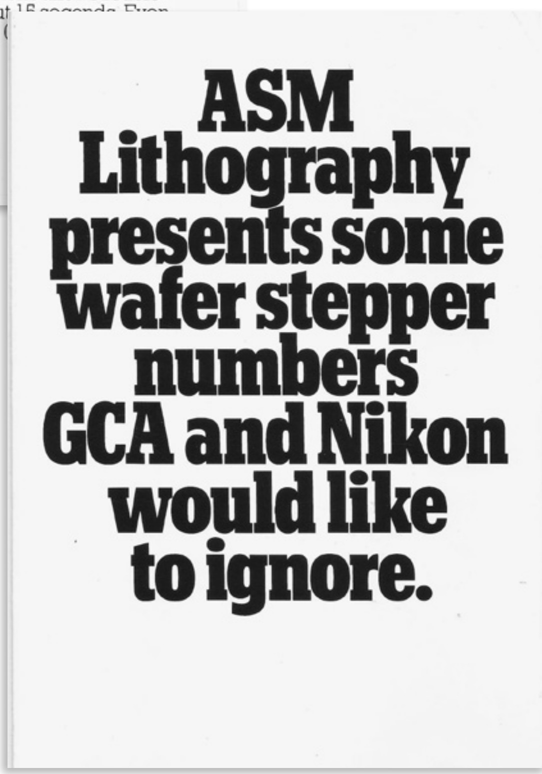
The man who’s spent months working on the electric wafer table and who’ll demo the PAS 2400 at SEMICON West in May is less confident. Knees weak, mouth dry, Frans Klaassen flies to Silicon Valley, terrified he’s going to crash and burn in front of the whole world. The entire journey flashes through his mind: what a disaster if his beautiful stage doesn’t move, or if some other part flakes out on him.

The nerves don’t really hit until he sees ASM International’s booth at the show. Intoxicated by record revenue numbers and perceived market growth, Arthur del Prado reserved a place of honor at the global chip machine expo back in 1984. A year earlier, Philips occupied a low-rent spot off to the side of the show. Now ASML is part of mother ASM’s booth, in the show’s most expensive square footage, prominently located in the central pavilion, beside the Japanese giants Canon and Nikon.

But Klaassen’s terror soon dissipates when he sees their competitors’ machines. The steppers familiar to him from snazzy brochures are on the fritz for most of the show. Engineers are constantly working on them—and the housing is frequently off while they tinker. Klaassen takes advantage of those moments to sneak a look at the stepper’s interior. ASML’s veteran engineer instantly sees that the machines are just prototypes.

The PAS 2400 is almost constantly operational, and its occasional down moments are no disaster. Now that Klaassen can judge the competition on its technical merits, his confidence grows. He realizes there’s a lot of potential in ASML’s technology. “We can win this,” he enthusiastically tells his colleagues.





On the eve of SEMICON West 1985, ASML wages a full frontal attack on market leaders GCA and Nikon. The ad campaign emphasizes the PAS 2000's strong points, but wisely stays mum about its weak optics. (The PAS 2000 in question is the PAS 2000B machine with electric wafer stage, internally known as the PAS 2400.)

0.125 overlay accuracy.

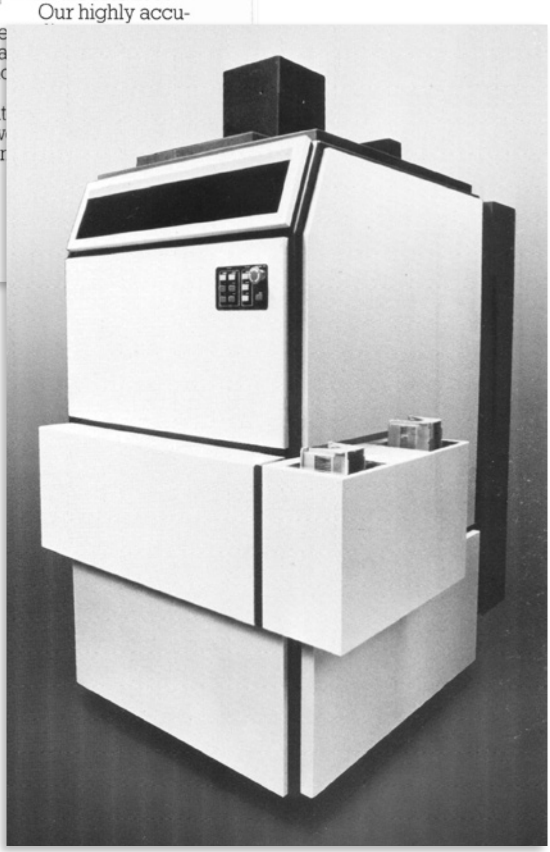
Overlay Accuracy (Global)			
GCA Series 6000	$\bar{x}$	$\pm$ 0.25 μm	2 Sigma*
Nikon NSR 1505 G	$\bar{x}$	$\pm$ 0.25 μm	2 Sigma*
ASM PAS 2000	$\bar{x}$	$\pm$ 0.125 μm	3 Sigma**

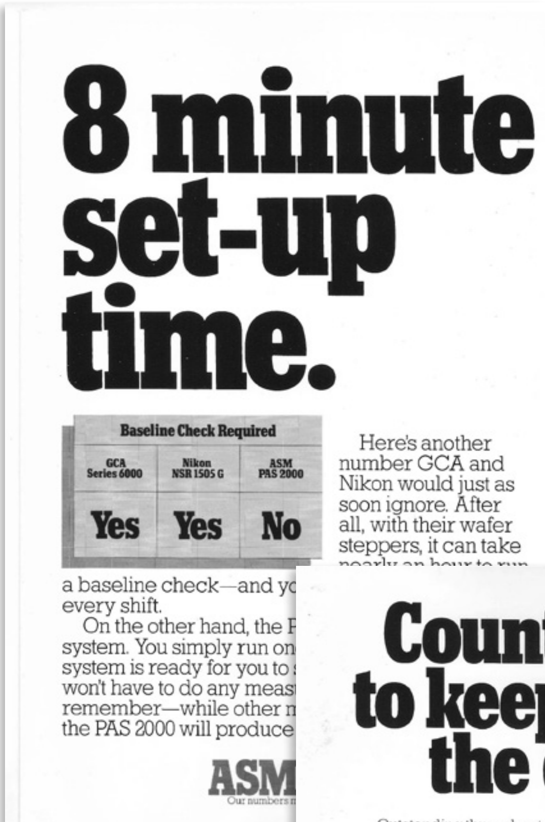
GCA and Nikon can't even come close to alignment like this. But that's exactly what you get with the PAS 2000.

Our highly accu-

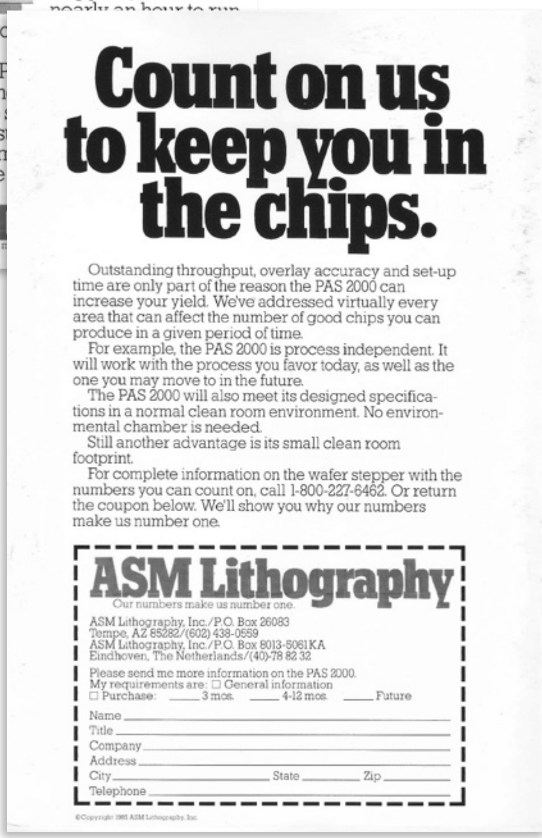
rate, automatic through-the-le
and unparalleled mechanica
improve the stepper resolutic
fab line.

And since the PAS 2000 aut
layers to the zero layer, you w
putting additional markers or





8 minute set-up time.
Baseline Check Required
GCA Series 6000
Nikon NSR 1505 G
ASM PAS 2000
Yes
Yes
No
Here's another number GCA and Nikon would just as soon ignore. After all, with their wafer steppers, it can take
a baseline check—and yo
every shift.
On the other hand, the P
system. You simply run on
system is ready for you to
won't have to do any meas
remember—while other m
the PAS 2000 will produce
ASM



Count on us to keep you in the chips.
Outstanding throughput, overlay accuracy and set-up time are only part of the reason the PAS 2000 can increase your yield. We've addressed virtually every area that can affect the number of good chips you can produce in a given period of time.
For example, the PAS 2000 is process independent. It will work with the process you favor today, as well as the one you may move to in the future.
The PAS 2000 will also meet its designed specifications in a normal clean room environment. No environmental chamber is needed.
Still another advantage is its small clean room footprint.
For complete information on the wafer stepper with the numbers you can count on, call 1-800-227-6462. Or return the coupon below. We'll show you why our numbers make us number one.
ASM Lithography
Our numbers make us number one.
ASM Lithography, Inc./P.O. Box 26083
Tempe, AZ 85282/(602) 438-0559
ASM Lithography, Inc./P.O. Box 8013-5061KA
Eindhoven, The Netherlands/(40)-78 82 32
Please send me more information on the PAS 2000.
My requirements are: ☐ General information
☐ Purchase: ____ 3 mos. ____ 4-12 mos. ____ Future
Name
Title
Company
Address
City State Zip
Telephone

42. **We Hear You, Jerry**

Gjalt Smit jumps on the Concorde for a quick brainstorming session with his American marketing guy. Chip maker AMD gives him a cool reception.

Chuck Roberts, the man Gjalt Smit's hired for ASML's US marketing, has strong opinions. He knows why most ads don't work: without exception, they display boring photos of tools or machines. "That kind of product ad is fine for cars, airplanes, and watches, but it doesn't get the message across for chip machines," Roberts tells Smit. The American is teaching ASML's CEO a simple marketing lesson. It's basic psychology: people aren't interested in photos of others; they're interested in photos of themselves. The professional market is no exception, Roberts says. "So if your top priority is to win AMD over," he tells Smit, "then we need to make an ad specifically for them."

Shortly thereafter, Roberts spots a unique opportunity. At the SEMI Southwest spring banquet, Jerry Sanders bemoans American chip machinery manufacturers' quality and service. Their systems are so crappy that Sanders has been forced to buy equipment in Japan, and AMD's CEO hates that. His message is clear, and everyone understands his revulsion. His countrymen view Japan as a ruthless arch enemy, thanks to the country's economic success in chips, cars, and computers. Roberts reads Sanders' scathing comments and instantly picks up the phone. "Smit, Sanders is trashing GCA and Perkin-Elmer because he's not satisfied with their machines. They're forcing him to buy in Japan, but he'd rather not. This is our chance!" Smit is instantly on board. He has Roberts reserve space in the *Electronic News* and *Semiconductor International* trade journals and asks his ad man to fly to New York the next day. Smit hops on a plane to Paris the next morning. At Charles de Gaulle Airport he boards the eleven a.m. Concorde to New York—Smit's not one to worry about a few extra dollars in an emergency.

The supersonic flight will save him four hours; he can meet with Roberts at the JFK Airport Hilton at eleven a.m. Eastern time and fly back home that same evening.

The result is a striking ad that directly addresses AMD's CEO. The headline is in big, bolded letters: "We hear you, Jerry." Beneath that: "ASM Lithography accepts Jerry Sanders' reliability challenge with a 90% uptime guarantee for wafer steppers. That's nearly twice what the industry delivers now. [...] Jerry, you don't even have to worry about the San Andreas fault acting up. These machines are that solid."

* * *

A month later, Smit and Steef Wittekoek visit AMD. They have no idea whether their "We hear you, Jerry" ad has worked, but their sales engineer in California, Tom Kandris, has been able to arrange a meeting with Colin Knight, the man at AMD who selects its production technology.

As they wait in the AMD lobby in Sunnyvale, they're given unpleasant news. The engineering manager, a burly Polish woman, apologizes. We're sorry, but upon further reflection, AMD isn't interested in meeting with ASML. When Smit and Wittekoek ask why, they hear the same reservations they heard from Megachip manager Kramer about the PAS 2400: the CERCO lens's small field of view is unacceptable. And anyway, the woman says, we don't even have a meeting room available.

Kandris, a handsome man of Greek descent with waving chestnut locks, turns on all his charm to convince the woman to set up a meeting after all. His CEO and executive scientist have flown all the way from Europe for this meeting! Well, then, okay. If the gentlemen would please take a seat.

After a long wait, the engineering manager comes back. Mr. Knight's schedule is full. They have half an hour to make their point to a group of young engineers. After a short introduction by Smit, Wittekoek explains the concepts behind ASML's lithographic system to AMD's engineers. Their questions are razor sharp.

Smit takes issue with their demeaning attitude toward Wittekoek. “These little worker bees were apparently ordered to pick us off,” he later says to Wittekoek.

But Wittekoek doesn’t so much as frown. He remains pleasant, even when the questions are condescending. He pays the engineers friendly compliments. What fascinating questions and topics his young audience is raising! ASML’s executive scientist patiently addresses them all. The mood in the room flips, and the conversation turns lively. After two hours, Knight suddenly sticks his head in. Smit and Wittekoek see their chance and ask him to come in and join them.

The meeting stretches on, until around one o’clock Smit asks Knight if he’s getting hungry for lunch. Knight says yes. During the meal, the American confirms he’s interested in a non-Japanese lithography supplier. The conversation is friendly, but it’s also clear ASML isn’t in a position to help AMD at the moment. The American chip maker has no need for the PAS 2400. The PAS 2500 won’t be ready for another year. Then Smit says, “Colin, what would you say if we gave you a PAS 2400 to use, free of charge? Then you can test out our superior alignment and stage. That’ll give you a good feel for what’s in the PAS 2500.” Knight likes the idea.

43. **AMD**

With a lot of blood, sweat, and tears, ASML delivers an evaluation stepper to AMD and eventually wins the race.

In the summer of 1985, the harsh reality becomes apparent to ASML. Things were already going downhill at the end of 1984; now the entire semiconductor industry has come crashing to a halt. Potential lithography customers are few and far between. The Japanese market is an invincible fortress, and the major American companies that are still buying are looking to Nikon for their lithography equipment.

Gjalt Smit starts having his first doubts. The chip industry is in truly stormy weather. ASML hasn't received a single order from serious chip manufacturers. Even Philips is refusing to commit. Rock bottom is still a long way off.

At ITT Smit learned to operate according to budget—no matter what happens. Now ASML is feeling the squeeze to reduce costs, but at the same time the CEO knows his company will die if he starts scrimping on strategic investments. If he cuts the development budget, the first victim will be the PAS 2500. Cutting corners there is the same as saying goodbye to the future.

"Should we step on the brakes?" Smit asks his CFO, Gerard Verdonschot, multiple times. But Verdonschot is resolute. "Gjalt, we can cut costs, but our shareholders won't feel the effect now. If we cut costs and that makes us miss deadlines, they're guaranteed to feel the negative consequences. Let's keep to our current road."

When ASML moves to its new building in Veldhoven in the summer of 1985, Smit decides not to tempt fate; there will be no celebratory bash.

Meanwhile, parent company ASM International is having a harder and harder time. The company shot up like a rocket for years, but in 1985 it turns a loss for the first time: $5.8 million on a revenue of $105 million. While the founding partner is bleeding, its offspring keeps guzzling money unabated. It's the opening act of a Greek tragedy in which parent and child are each trapped in their own roles. Their interests and objectives start to diverge, and friction begins to build.

* * *

In the fall of 1985 Smit receives a phone call. It's Arthur del Prado. ASM's CEO excitedly says he's found a customer for five PAS 2000 machines. "That's fantastic," Smit says. But he's shocked to hear the customer is in Bulgaria. Smit's suspected for some time that Del Prado is looking for customers outside the mainstream. In those days, doing chip-technology business with Eastern Bloc countries is profitable. Customers behind the Iron Curtain will gladly pay double the price. It's an El Dorado for tech salespeople, but a problem for someone who wants to safeguard his chances of exporting to the US.

The Cold War is on, you see, and the US has put strict embargos on trade with Eastern Bloc countries. The Netherlands is also party to these COCOM rules. Smit tells Del Prado he thinks it's a risky move. When he was an executive at ITT, his American former employer, deals like this required his personal guarantee and his signature on reams of documents filled with ethical regulations. His knee-jerk reaction is to demur. But Smit doesn't instantly say no to his most important shareholder. He'll ask fellow board member George de Kruiff to sound out the deal at Philips.

Smit doesn't have to wait long for an answer from Philips' management. The Dutch multinational has significant military interests in the US and commands ASML to walk away, fast.

These kinds of incidents, and the way Smit spends money like water, don't help his relationship with Del Prado. His costly strategy is bleeding ASM dry, but he doesn't see any other way.

* * *

Yet there are also bright spots. In addition to Philips' commitment to buy PAS 2500 machines for the Megachip project, Elcoma in

Assembly in the new cleanrooms in ASML's first building in Veldhoven. Identified in this photo: Victor van Bunder (left, with beard), Toon van den Kerkhof (left, in the foreground).

Nijmegen also wants to buy ten to fifteen steppers in late 1986: some of them from ASML, some from GCA. Elcoma places its order in June 1985. By the end of 1986 it wants to be in possession of full-fledged PAS 2500s. ASML may supply a PAS 2400 for evaluation.

In the months that follow, the semiconductor recession deepens. AMD also sends bad news. The visit by Smit and Wittekoek has generated interest in Sunnyvale, but Jerry Sanders' company doesn't need new machines in the short term.

Strangely enough, the market slowdown works in ASML's favor. The Dutch company can't deliver machines now, anyway. The crisis affords ASML some temporal breathing room.

But the chip market is cyclical, and AMD knows that better than anyone. To be ready for the next upturn, it invites four lithography manufacturers[12] to deliver steppers for its pilot plant in Austin, Texas. AMD wants to start producing the new generation of VLSI chips in the small Southern town nine months later, so it's subjecting new lithography machines to a thorough selection procedure.

Sanders' company keeps nagging: when can ASML deliver its first PAS 2500?

There's no way in the world ASML can have a PAS 2500 machine ready by the summer or even the fall of 1985. The company has no choice but to stick with Smit's original offer and send over a PAS 2400. Smit takes a flight to San Jose to deliver the message to AMD's executive staff. When he lands, he drives straight to the nearest Marriott hotel, where his account managers meet him with sour faces. "AMD's already let us know we're out of the running. The PAS 2400 just isn't acceptable to them. Sorry, Gjalt; they're not interested in meeting."

After this slap in the face, the four men move on to other topics. Smit vents his frustration by roundly cursing the weak American coffee. When he settles down, his American employees tell him AMD is having trouble convincing its engineers in California to move from balmy Silicon Valley to scorching Austin—at the time, Austin is just a tiny town on the edge of the Texas desert.

Smit once again sees an opportunity. He suggests they fax AMD's management with an offer to deliver the PAS 2400 to Austin. He also offers to help them find engineers who would welcome a move to Texas. In addition, he offers them preferred early delivery of one of the first PAS 2500 machines—Smit's hedging here just a little; the very first machine has been promised to Philips.

Smit's bluffing. He knows full well that no American engineer is eager to move to sweltering Texas. But a few weeks later, he gets an answer. AMD accepts the PAS 2400 for its testing procedure. There is one condition: they want to receive the machine within the next few weeks.

At the time, Smit doesn't know that ASML is being offered Perkin-Elmer's spot; the company has thrown in the towel and is ceasing development on its Censor steppers. GCA is having an increasingly tough time as well. Canon and Nikon deliver better machines, but Jerry Sanders breaks out in hives when he imagines being dependent on the Japanese. AMD doesn't address ASML's offer to help find engineers for Austin—to Smit's immense relief. In July 1985 there are three requests for PAS 2400s noted in ASML's books: from AMD, Cypress, and National Semiconductor.

* * *

ASML makes AMD its top priority. The company decides to send the first PAS 2400 to the pilot plant in Texas. After a race against the clock, the stepper arrives in Austin accompanied by a small team led by Rein Meyer. There they discover that two engineers from Nikon have been there for two weeks already, trying to get their machine working. When Meyer and his crew get the PAS 2400 up and running within a day, it's a psychological victory.

But in the days that follow, a serious problem is discovered. The PAS 2400 is ASML's first machine with a linear motor, and it turns out the heat generated by intensive use warps the machine. That torpedoes all ASML's claims of superior precision. Meyer succeeds in postponing the acceptance tests—he has to conduct them in the presence of AMD's engineers. Meanwhile, his colleagues back in Veldhoven are working day and night to solve the problem. They finally come up with a tricky patch that only developer Jan van Duivenvoorde is capable of implementing. It's a temporary fix, but it buys the team time to come up with a permanent solution. Smit and his management team decide to take the gamble and send Van Duivenvoorde—who doesn't speak a word of English—to Austin to work his magic.

Meyer is left wondering how to smuggle Van Duivenvoorde inside. He decides to chance it at night; his access pass is valid twenty-four hours a day. He picks his colleague up at the airport and drives straight to AMD's pilot plant, where they patch the machine. The next day AMD runs its tests on the stage. Meyer celebrates their success; Van Duivenvoorde is already on the plane back to Holland.

In October 1985, Smit calls his whole team together and lets them know that PAS 2400s are up and running at Philips in Nijmegen, in Hamburg, and at Natlab. He proudly reports that the machine at AMD was working within two days. The Americans are also evaluating a Nikon. "It's been there for a week and still isn't working. And another competitor has already dropped out," the CEO crows, adding that customers are generally dissatisfied with their competitors' machines.

Smit thinks back to his cartoon presentation. The shakeout he predicted has since begun. The top three are fairly obvious: Nikon, Canon, and GCA. Standing before his team, Smit sketches a much more realistic view of his company's viability than the one he gave customers a few months earlier. After the top three come two shaky maybes, he says. One of them is ASML.

GCA is also about to fall. The former market leader can't compete with Japanese quality. What's more, its management has manufactured far too many machines, despite warnings from the sales division. In the ever-deepening recession, GCA can't sell them. A little more than a week after the meeting at ASML, news surfaces of liquidity problems at GCA. The company's stock plummets in the first week of November 1985, from $35 to $7.

A few months later, AMD lets ASML know it's won the race, though there are a few issues: the CERCO lens is performing under par, and the machine generates too much dust. But despite the win, no order is forthcoming.

* * *

In the fall of 1985, Verdonschot walks into Smit's office. The CFO suspects ASML's engineers are working on bells and whistles the PAS 2500 doesn't need. With the deadline looming, they're wasting time on a hobby.

Verdonschot often spies on his engineers. His impromptu chats with whomever he runs into in the hall irritate Nico Hermans, the head of development. This time, he's observed that the designers are outfitting the PAS 2500 to use larger masks: six-inch reticles instead of the five-inch industry standard.

* * *

Smit is instantly on alert, because no one's discussed this with him. He knows a grave danger lurks in engineers who think up nifty things in comfortable isolation, without knowing exactly what customers are dealing with. As a small company, ASML is taking an unconscionable risk if it deviates from the industry standard. The Dutch machinery manufacturer already has enough trouble appearing credible.

A few days later, while Smit's in Silicon Valley, he feels out the situation at LSI Logic. "By the way," he asks the fab manager, "what do you think of six-inch reticles? Are they the next big thing?" The answer is unequivocal: "Are you insane? What do you think it would cost to convert our mask library from five-inch to six-inch reticles?" The man shakes his head. "Six inches means a lot of plate, sir," he adds, referring to the expensive chrome film that coats the masks.

Smit's observations are correct. In late 1984, the R&D department had unanimously decided to ready the PAS 2500 for six-inch masks. But what the CEO and his financial right-hand man don't know is that his engineers already know the score. Earlier that same fall, Martin van den Brink travels to California to take in the latest technical requirements—the PAS 2500 will be shipping just a few months later, in early 1986. To his dismay, he hears at an industry conference and his visits to mask shops[13] that everyone's using five-inch masks. Van den Brink instantly realizes: our six-inch plan is a showstopper. The about-face he has to announce back in Veldhoven is so drastic that he fears for his job.

Back in Veldhoven, Smit and his team quickly agree they've been flirting with disaster. The engineers see that their boss intimately understands the dynamics of the market. They feel supported. Smit asks his people to list out all the PAS 2500 specifications once more, and to drop everything that isn't absolutely vital right now. Time's running out. It's back to basics: the only thing that counts is hitting the basic requirements to meet the deadline.

His engineers hastily gather to discuss the timetable.[14] The system to automatically feed in six-inch masks is instantly killed. An alternative five-inch system can't be made in the space of a few months. In four weeks they whip together a manual mask handler for the PAS 2500. In that same meeting, the engineers set new deadlines for the five machines under construction. The stepper for Natlab is under the most pressure; it has to ship on March 1, 1986. A demo machine for SEMICON West in San Mateo is next in line, two months later.

But no one at ASML is sure they've got it right. Not even Smit. And so he flies his entire American sales team over to coordinate with the PAS 2500 development team. Smit has a natural mistrust of engineers, and he wants to be sure development and sales are on exactly the same page.

The conversations with the seven Americans offer direction, but they don't provide 100 percent clarity. For example, the sales staff say that a number of chip manufacturers are, in fact, considering six-inch masks. They expect the transition to occur in eighteen months to two years. During their pitches to customers, the sales team has also mentioned that Zeiss i-line lenses will be available. And there is indeed interest in those.

Two weeks later the optics question is resolved, when it becomes clear Zeiss is having problems manufacturing the i-line lenses. It was already obvious that most chip makers want to stick with the tried and true g-line option. Philips is sending out the same signal, and that helps them focus. ASML decides to target Zeiss's g-line lens that GCA and Hitachi are already using.[15] They'll postpone the i-line for now. Besides, customers aren't ready for them yet.

These are months filled with confusion, but there's also a bright spot. Competitor GCA is in trouble, and the news reaches Veldhoven that Zeiss has more attention to spare for its Dutch customer.

ASML will outfit its stepper to use SMIF boxes, cassettes used to transport silicon wafers in the chip fab. Smit can live with that. It's just an optional feature in ASML's machines, and that aspect has marketing value. It will later turn out to be one of the PAS 2500's sexier features.

44. **Smit's Sounding Board**

Gjalt Smit is missing structure at his company, so he turns to a consultant. His employees' experience is quite different. Increasingly, their boss serves only to disrupt their work.

After ASML's moved to its new home in Veldhoven in August and September of 1985, the time pressure mounts and problems start to pile up. The schedule for the PAS 2500 is in serious danger. Gjalt Smit sees driven employees, but also increasing frustration. He knows he can't ignore it. One day he walks into Pim Kan's office. Smit knows Kan from Holec, and hired him to handle ASML's HR affairs after summarily dismissing the first head of HR who came over from Philips. Kan says employees have been complaining about a lack of clarity. "They're dissatisfied. They feel like the size of their salaries has been chosen at random. There's no clear information about performance reviews, pay raises, and opportunities for promotion."

Kan's evaluation matches Smit's assessment. In a year's time, ASML has hired an additional few hundred people. The original fifty employees from Philips have to train their new colleagues—while in parallel they're building the PAS 2400 and PAS 2500 in record time.

Everyone has the freedom to do whatever's good for the company, but to Smit his crew is looking more and more like a disorganized mob. There's no infrastructure surrounding his people. They do have an organogram, but that piece of paper doesn't mean much. Real structure is missing. Stability is missing. Smit appoints all kinds of group managers, but they're new, too, and often know little about running a team. In short: he sees chaos.

Smit tells Kan that he's looking for structure. He's missing a framework of job descriptions and the compensation to fit them. He wants to hire an American consulting firm to figure it out: "We're fighting this war American style, after all." His HR guy suggests he go to Hay: "They specialize in that kind of thing."

* * *

Not long after, Jos Bomers gets a phone call from a colleague. Bomers is a senior consultant with the Hay Group. Organizational design and culture is his thing. A few years back, Philips' CEO, Wisse Dekker, hired him to evaluate the company's top four hundred managers, and that's when he met people like George de Kruiff and Wim Troost. In the early eighties, they told him about their problem child, the stepper project, in great detail.

Bomer's colleague gives it to him straight. He's been visited by one Gjalt Smit from ASML. He listened to Smit's story, but he can't make heads or tails of it. "I can't figure the man out," he tells Bomers. "He talks and talks and talks. I can't wrap my head around it. I don't understand what the situation is there. Can you take the gig over?"

Bomers meets Smit in a Chinese restaurant in downtown Eindhoven. He discovers his colleague wasn't exaggerating. Smit is a verbal waterfall. ASML's CEO has entered a period in which he's truly worried about his company for the first time.

But Gjalt Smit is still Gjalt Smit, and he describes with fervor the opportunities his company is facing. It's clear he's worried about his employees' motivation, about his team which is three-fourths headstrong engineers. In the hours the two spend talking, Bomers asks a few questions, but there's not much silence for him to fill. At the end of the conversation they both conclude they've made no progress at all. They plan another meeting.

A week later the saga continues, again at the Chinese restaurant. Again, Smit's a waterfall of words and his companion is quiet as a mouse. After Bomers has spent ninety minutes listening to Smit's ideas and stories about his management team, the consultant decides to intervene. He realizes it's time to make an impact. If the meeting ends the way it did last week, once again they'll have accomplished nothing. "Gjalt," Bomers says, "you talk a whole lot. I understand a lot of what you've said, but there's a lot I don't understand, too." Then he cuts to the chase. "I don't think you're very good at listening."

Smit is instantly alert. He sits up straight, but Bomers isn't finished yet. "Gjalt, I think you've already lost your organization." His next words are harsh. "The way I hear you talking about your management, you've lost them. Now. They no longer understand you. I'm not a hundred percent sure, but I'm pretty damned close."

Smit is stunned. "Why do you say that?" he asks. Bomers explains. He's listened attentively during their two meetings. "The salary system isn't your first priority. That will come later. Your company is small, it's growing fast, everything's in motion." Smit instantly understands, and he's immediately intrigued. Then Bomers says, "Do you know what the key people in your team think about the joint? About *you*? About management? It's time you found out."

Bomers has made his point. He proposes they take stock of the situation and describes his method. Within a week, ASML's CEO can know exactly what's going on at his company. But to do that, he has to cooperate 100 percent. The consultant describes the procedure, the surveys. He says it will only work if Smit tells his people exactly *why* he's doing it. "You also have to tell them you're going to *do* something with the information."

Smit instinctively knows a good idea when he sees one. As he listens and acknowledges the value in Bomer's plan, he doesn't have to think for long. He responds with a short "okay, *okay*" and hires the Hay consultant to make it happen. Bomers rarely encounters leadership that potently agile. He's astonished. Smit's response is a revelation. He's spent hours listening to the man's cascade of words and when he finally intervenes, it takes two seconds to reach the same wavelength. Minutes later, the project is his.

* * *

Smit sees it from a different perspective. Bomer's proposal galvanizes him. Not because he agrees with the consultant's assessment that he's lost touch with his people; on the contrary: Smit is passionately convinced he has a deep connection with his team. Philips' dusty mothball stench is gone, but the company is lacking structure and he's worried his people might not make it.

ASML is building a battleship, while the war is already underway. The boat isn't finished yet, but meanwhile the cannons are booming and blood is flowing. Provisioning is spotty, sailors are running madly back and forth, and though the captain's shouting out orders, his men don't understand how to turn Smit's battle plans, changes of course, and strategy into action.

Smit doesn't just want his team to make a robust stepper. He also wants his company to be a unified whole. Marketing, development, operations, and logistics: it all has to work as a single, well-oiled machine. That's why Smit detests people who think it's all about the technology. Forget the technology, he tells them; it's the whole thing together. It's not about the piano or the violin, but about the symphony. It's not about Michael Jordan, it's about the Chicago Bulls as a whole. Smit's only question is, how do I inject more oomph into *my* Bulls?

It's not a simple question, because Smit is immersed in an almost surrealistic environment. All around him, engineers are slaving away in a nerve-wracking race to build world-class technology, all so they can meet an absurdly unrealistic deadline. But that deadline is ASML's only chance to survive. The CEO ignores any opposing voice. If the delivery of the PAS 2500 is endangered, his company will fall apart. Of that he's acutely aware.

* * *

Smit is both an aeronautical engineer and a theoretical physicist, and he sees connections other people miss. He's extraordinarily passionate about communicating his vision to his people. Not everyone is open to listening; most of them have plenty else to worry about. They're much too busy building steppers.

ASML's army of engineers doesn't have time for psychological mumbo jumbo. The salary system sucks, period, and they're vocal about it to PR guy Kan. But other than that, they're busy building their machines. The company's financial situation doesn't worry them at all, because Smit and Gerard Verdonschot keep that information carefully under wraps—though some of them do notice that ASML's CFO does a lot of pacing back and forth in his office.

Smit's view of ASML is, in fact, at right angles to the company's state of mind. The guys in the cleanroom don't sense any disarray or chaos. The new hires are injecting enthusiasm into the company, and the Philips contingent greatly enjoy watching their young colleagues master the ropes. The R&D department has rapidly evolved into an unstoppable tank on a sacred mission: winning the lithography war. The deadline is clear and their goal is challenging and intriguing: they're going for first place, for the gold medal.

But his people do experience another problem. They barely see their boss, and when they do see him, he's often a thorn in their sides. They're working together at breakneck speed to get things done, and he blows in like an unguided missile shouting orders left and right that interfere with their work. Turn left; no, wait, turn right.

Smit isn't concerned with his team's frustrations; he has a higher purpose. He instinctively senses that his company is primarily focused on itself, and not at all on customers. All those busy bees in their dust-free lab coats have no idea what the world is like outside. They're safely tucked away in their cleanrooms, having a grand time thinking up ideas. Smit is doing exactly the opposite. He isn't looking at what they *can* do, but what they *need* to do. For him, everything revolves around gaining momentum in the market. And he knows no mercy. His guys have to meet the stated deadline. They have to reach the point at which customers are prepared to buy from ASML.

Smit's decrees have a significant impact on the R&D department. Several of his interventions are desperately necessary, such as settling on a light source and a mask size. But the engineers can't fathom some of his orders. Often, Smit's twists and turns leave them reeling. Lithography veteran Herman van Heek takes it all with his usual grain of salt, and coins a new nickname for Smit: Supreme Commander-in-Chief.

* * *

Meanwhile, the relationship between Smit and Bomers is intensifying. ASML's CEO considers Hay's consultant someone he can safely confide in. Bomers admires his intellectual client, a gifted man who combines technical insight with social prowess. Someone who knows that world-class technology without a motivated team is about as valuable as a box of scrap metal.

Bomers sets the ball rolling with interviews, and in the process he gets to know ASML's top twenty men. Martin van de Brink, Richard George, Nico Hermans, Evert Polak, Steef Wittekoek: the whole top layer and the next one down provide anonymized feedback. After just over a week, the outcome is clear. People appreciate their freedom and the constructive atmosphere, but everyone is worried.

Some have questions about their mission. They're doubtful. Is this really going to work? There aren't any customers and no machines are ready. ASML is like the Wild West. It's unclear who's responsible for exactly what. Their boss runs around like a madman, and he spends money like it's going out of style—on every front. They know Gjalt Smit; they hear what he says. But is he right? He's never made them any promises. They see a company that's spending money like water without a source of new funds. The top guys worry they'll soon be told the show is over. Money's gone, end of the road.

Smit calls his top twenty people together at an evening meeting to show them the results of Hay's corporate culture survey. The men agree completely with the analysis. The report compliments Smit on some points; on others, the outcome is confronting. He can pump people up, he can tell a good story, and he's great at growing the company, but his strategy is unclear to his team.

Smit's people report that they hear him saying ASML is going for market domination, but they still have to create the machines that will make it happen. Has he lost his mind? It all sounds great, but for the team, Smit's story doesn't hold water. Everything has to happen simultaneously: development, marketing, hiring good people, a new building, finding investors. For an adventure like that, you need a team that knows exactly how and why it needs to make something happen. That knows what the goal is. But the current team can't translate Smit's vision into a clear focus and priorities it can run with.

* * *

Bomers' survey hits Smit's reset button. The CEO knows ASML has fantastic technology on its hands, that a winning strategy is possible. He's even convinced a gold medal is in their future. He tells his team that time and again, but Bomers has shown him that isn't enough. Everyone enjoys working at ASML and appreciates the freedom the company gives them, but there's a lack of structure. With Bomers' help, Smit concludes there needs to be more law and order. His people will have to give up some of their freedom.

The cultural survey has a cathartic effect on the team. Its frankness motivates them. People see that Smit's acknowledging their issues. The ice has been broken. Patience develops: people understand he can't fix everything at once.

Smit and his management team then ask Hay to write a proposal to establish a business process organization, including a good performance review and compensation system. It will be a lengthy project that changes the organization at both its Veldhoven and Phoenix offices. Once again, ASML will grow stronger by bringing in outside wisdom.

* * *

In the years that follow, Bomers becomes Smit's sounding board, his major confidant outside the company. The consultant is a pleasant man with experience and insight. Over the course of several years they visit every restaurant in Eindhoven. Smit's found the psychologist he needs. He can vent to Bomers, collect his thoughts as he gets things off his chest. Finally someone in whom he can freely confide his doubts, pain, and anger without consequences. Someone he can tell about the worries he can't share with his employees or board.

Though Bomers is only watching the company from the sidelines, after several months he begins to have his own doubts. ASML's stepper development is an insatiable monster. Until that monster bears a child, the company has nothing to sell, yet its hunger cannot be sated. The consultant is no engineer, but when he looks at ASML he sees endless rivers of money vanishing into bottomless pits.

Bomers looks on aghast. During their meetings he tells Smit several times, “That’s all very well, but it all costs an incredible amount of money. Hay’s services cost even more money. GCA and Nikon are serving an established market. You don’t even have a product, and you’re investing like a madman. Where does that confidence come from? You must be supremely convinced that your technology is dynamite. Gjalt, it’s not my place to interfere, I’m not an engineer, but if you’re wrong about that, then you’ll go down, hard.” Smit’s response to these kinds of arguments is always breezy: “Yeah, yeah, I know.”

His plan is solid. That’s the anchor Smit clings to. He’s looking at a giant puzzle, and in theory ASML can fit all the pieces together. But in practice, Smit’s not at all sure of himself. Yet he’s not the kind of man to wallow in worry. He’s a theoretical physicist who’s convinced his idea works. That is the basis for his self-confidence, and that’s what guides his search for solutions.

But in his talks with Bomers, Smit does express his reservations. He doesn’t say a word about them at ASML, but he doesn’t have to keep up appearances with a consultant. He’s especially unsure of the supervisory board. “See,” Smit says, “I’m taking an obviously gigantic risk. Del Prado is watching me like a hawk. And even worse, the market is against us.” Bomers nods.

* * *

Often they talk about the company’s management, about how Smit handles things. Bomers sees him filling an essential role. The engineers can hold their own, but certainly in the initial years they need guidance. Someone who can shape the business, who has the courage to invest and will go for it full throttle. That describes Gjalt Smit to a tee.

Bomers maintains a relationship with ASML for many years, even after Smit’s time. Through the years he watches a rare dynamic arise in the team, giving rise to a flourishing company culture.

45. **Emergency Meeting**

ASML is going to miss the deadline for its very first machine. When Gjalt Smit realizes, the place explodes.

In June 1985, Richard George asks Frits van Hout to finalize the schedule for the PAS 2500. Soon after the young engineer gets started, he understands why he's been made the project controller. The existing schedule has been slapped together: a rough estimate, improvised on the fly.

Van Hout's going to change that. He visits each of the project leaders for the five PAS 2500 development machines, grills them on the situation, and feeds everything into a scheduling program. The job runs over the weekend on a VAX minicomputer. On Monday morning Van Hout prints out the result, then tapes the pages together on the floor into twenty-foot strips, and literally walks through them. He has a simple anchor point: the sacred deadline.

If you miss the boat in the chip market, you're dead in the water before you even set sail. And so there's no play in Van Hout's schedule. Not one hour. ASML's continued existence is at stake. It's all or nothing. In 1985 the company will complete a machine with a new motor. But by early 1986, it has to have a stepper with a new lens. Moore's law tolerates no delay (appendix 7). If they don't succeed, then it's game over.

It's the only chance ASML will ever get: delivering a stepper for the coming generation of VLSI chips. One that's on time and so appealing that semiconductor manufacturers can't ignore it. Philips is the first in line for a PAS 2500 for its money-guzzling race to catch up. But lithography is so crucial for its Megachip project that the Dutch electronics conglomerate has also placed orders at other lithography companies. Natlab's even secretly working on its own stepper,[16] in case external suppliers fail to come through.

CEO Gjalt Smit is clinging ferociously to January 1, 1986, the deadline he posed eighteen months earlier. That should give ASML enough time to ship a working stepper to Philips in April and another one to SEMICON West 1986 a month later. When Van Hout types in the hard deadline and sees what the program spits out, it's all negative numbers. If he can believe the schedules the five project leaders have given him, they'll come up days—weeks—no, *months* too short.

In early November 1985, Van Hout and his fellow developers conclude that in the very best case, they'll be able to deliver two of the five machines a month after Smit's deadline. So he enters February 1, 1986 as the final date in his scheduling system.

In November and December 1985, Van Hout watches as the PAS 2500's development falls further and further behind. He could put it into hard numbers, but the developers can already smell disaster a mile away. They know that working longer days is the only option.

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The time crunch Van Hout is seeing will evolve into a household word: *negative slack*.[17] It's a recurring factor in the high-octane race to deliver a new machine every three years for the next generation of chips. Every time the deadlines get sharper, engineers are compelled to do more in less time. The result is chronic overtime. Burning the midnight oil is more the rule than the exception. And so it goes with the PAS 2500.

For decades to come, "negative slack" will be synonymous at ASML with stress, arguments, insane overtime, and burnouts—but the rigorous preservation of deadlines also lays the foundation for camaraderie and an unparalleled formula for success.

In the first week of the new year, Smit knocks on Van Hout's door. Richard George and Nico Hermans are both on vacation, and the CEO needs to report to the supervisory board. So he asks Van Hout: is the PAS 2500 on schedule? Obviously they haven't met the January 1 deadline. Van Hout explains that he's not even sure they'll make March 1. "It's incredibly tight," he says. "It can easily become later." Van Hout has been worried about the schedule for some time now, but he doesn't know that Hermans, the head of development, hasn't kept the CEO in the loop. "Are we going to make it?" Smit insists. "It's going to be really tough," Van Hout hesitantly answers.

Smit explodes. Hermans has consistently told him everything's running smoothly, but the information Van Hout is giving him is a terrible wake-up call. The tale of Smit's outburst quickly reaches the factory floor. Everyone knows how dire the situation is. Van Hout has talked freely about it with colleagues. "Frits van Hout no longer believes in the schedule, either," Wim Hendriksen notes in his journal on January 9. The rumors fly through the company. The project managers drop all pretense, too. No one has anywhere left to hide. Besides, everyone can see with his own eyes the machine isn't finished: the exposure column containing the mercury vapor lamp hasn't been mounted yet. Hendriksen is vindicated. He saw the crisis approaching nine months ago. Everything's getting out of hand. "Management discovers that PAS 2500 development is *not* running according to plan!" he notes in his journal.

* * *

Smit calls George and Hermans to task. "The gentlemen held an emergency meeting today," Hendriksen writes on January 10. The CEO phones Willem Maris, who stuck out his neck for ASML a year ago at Elcoma. But Maris doesn't cut him even a tiny bit of slack; the Megachip project can't afford it. The following Monday, Smit calls another meeting to discuss the delays. This time the meeting is larger, with a total of twenty crucial people. Smit takes a hard line. He demands a working machine in March.

Absolutely effing impossible, thinks George, who's there as the project leader for the PAS 2500. He realized months ago that he'd badly underestimated the testing phase. He knows he should have sounded the alarm earlier and asked for more manpower. Hermans, head of development and George's boss, knew it too, but he failed to inform Smit, either.

During the meeting, George goes at it hard. The Englishman isn't known for diplomacy, and he's living up to his reputation. "You're fucking insane," he screams at Smit. "That machine won't be ready until May. If you think it'll be finished in March, then one of us is ready for the loony bin."

Smit now has a problem. Hermans has committed a mortal sin by not telling him about the delays right away. George's public expression of his doubts about the project's viability also bother Smit. Even if the Englishman is completely right, psychologically speaking he's disadvantaged his team. Smit's afraid George will undermine his people's motivation. For the CEO, the deadline is sacred. *It has to happen, no dicking around*, he thinks. He needs to remove George from the project; an idiot could see that. If one player says the team's going to lose during the halftime break, the coach has to bench him. If you start doubting your victory, you're certain to lose.

Smit knows he also needs to intervene in development. What should he do with Hermans? He feels out both Joop van Kessel and Willem de Leeuw at ASM. His CFO, Gerard Verdonschot, advises him to can Hermans—the two don't get along very well.

Smit meets with his sounding board, Jos Bomers. Hay's consultant also has regular talks with the rest of the management team. As a result, he knows both George and Hermans fairly well.

"What should I do? Fire Nico?" Smit asks his confidant. "It would be premature to fire Hermans," Bomers counsels. "It's clear why Verdonschot wants you to, but look before you leap! If you kick Nico out, you'll lose someone who's been involved with your R&D from the start. He knows the other guys well. He butts heads with some of them, such as Gerard, but I wouldn't do it. Do something novel. You don't have anyone heading up HR and general affairs. Let Nico run those; then you won't have to go out and find someone."

Bomers is used to talking to people in high places, but no one is like Gjalt Smit. When ASML's CEO hears something that makes sense, he can turn on a dime. It amazes Bomers every time it happens. He's never encountered anything like it in circles where the egos are huge and the testosterone can reach explosive levels. Today, too, all Bomers has to do is present a few clear arguments.

He's barely finished speaking before Smit is convinced. He instantly understands that putting Hermans in charge of HR and general affairs is the best solution.

Smit calls the development staff together. He says Hermans is being moved to a new position and then announces that Evert Polak, the project manager for the PAS 2400, will be taking over as head of development. Hermans is congratulated by someone who doesn't realize he's been shunted aside and thinks he's been promoted to general manager.

After the meeting, Polak asks Van Hout what he thinks. "I saw you shaking your head," Polak tells his young colleague. Van Hout isn't used to people being shoved summarily aside and doesn't think his boss deserves it. "Smit's pretty quick to get rid of people without understanding what's going on," he observes.

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After he's moved Hermans to another position, Smit's ready to tackle George. He has no need for people who openly question the company's goals. He knows the Englishman's explosive character and selects neutral territory to deliver his message: the same Chinese restaurant where he first met Bomers. "Richard, you've put enormous effort into getting us this far," he diplomatically begins. Then he cuts to the chase. "But you can't finish the PAS 2500 project." Smit asks George to go to America and help with product marketing. Immediately. His family may go with him.

In transferring George, Smit kills two birds with one stone. The sales and service team he's putting together in the US isn't familiar enough with the stepper. George knows the machine inside and out, he's customer friendly, and as a native English speaker, he's an excellent fit for American customers.

George takes it badly. He can't see his project through to the end, and he has the feeling he's being exiled. Smit's plan to choose a setting where the meeting can't get out of hand fails. George is livid and makes no secret of it. He jumps up and storms out of the restaurant.

It's inconceivable to George that he can't be there for the birth of his baby, the PAS 2500. The only way he can still exercise any influence is through Polak. He invites his new boss out for dinner. The two engineers discuss recent developments over Chinese food. George says that to be honest, he doesn't aspire to develop a third stepper; setting up product marketing in the US sounds like fun to him. But he is worried. "You can't do this alone," he tells Polak. "Make sure that Martin and Frits take over my duties." He explains that Martin van den Brink is by far the best systems engineer and technical manager in the PAS 2500 team, and that his right-hand man, Van Hout, has the most insight into the organizational side of things as the project controller.

To everyone's amazement, a few days later Polak puts Van Hout in charge of the PAS 2500. In the R&D team, comprised largely of seasoned engineers, a young colleague with barely eighteen months' experience will be calling the shots on a machine that will determine the company's fate. Polak asks Van Hout to work with Van den Brink. "Meet with Martin and divide things up as you see fit; you're the boss." From that moment on, Van Hout is the project manager and Van den Brink is the head of systems engineering for the PAS 2500. It's a bold move. Polak himself isn't completely at ease with it.

* * *

And so Polak blows a fresh wind through the not-yet-two-year-old company's R&D. The engineer comes from S&I's stable, where he earned his spurs in aerospace projects. He isn't part of the first group that transferred to the joint venture; he applied to ASML on his own, attracted by the challenges facing the young high-tech company. When Frans Klaassen is struggling to get the electric wafer table working, Polak serves as his coach.

From 1986 on, he employs his gift for motivating others as the company's head of development. Polak immediately puts two young kids on ASML's most important project and more or less says to them: make sure it turns out well. The young duo are surprised to be given so much responsibility, but it also boosts their self-confidence. They spread their wings and fly. Polak is a man of few words, but he exudes calm. One striking example is the moment in which, years later, he hosts a delegation from Zeiss. The Germans have come with their tails between their legs to confess that their optics are in deep shit. The design flaws in a huge set of lenses are so severe the lenses will have to be replaced, a job that will take months to complete. When Zeiss's people have finished talking, all eyes are trained on Polak. Everyone's feeling discouraged, and everyone expects him to give Zeiss an earful. Calm as a millpond, Polak simply says, "What can we do to help you?"

Polak is also a control freak and he likes a systematic approach. He learned that working on space technology, where everything is decided in detail. He teaches valuable lessons to the boisterous young newcomers eager to change everything. "Don't start walking if you don't know where you should go," he tells Van Hout and Van den Brink when they can't tell him exactly how they want to tackle the problem. "Slow down and think it through." Polak knows how challenging the stepper's development is and encourages his team to persevere: "Don't give up when it gets tough. You can make anything happen if you want it badly enough."

When Smit hears that Polak has put two wet-behind-the-ears bouncing balls in charge of ASML's most important project, his response is less than enthusiastic. "For god's sake, hire a real leader," he tells Polak. Polak does what his boss tells him. The young engineers are told they'll soon have someone above them.

But the decisions Polak makes after Smit's hard-handed reorg miraculously hit the mark. By this point Van Hout and Van den Brink have eighteen months' experience with complex systems, and the longer they work, the more excited they are about what they do. They're unstoppable.

For three years, under Smit and his successor, various candidates are interviewed to take over the project from the two young engineers. Program managers from renowned technology companies apply, among them a project manager for the Fokker 100. But things are insanely hectic and none of the newly hired technical managers are able to surpass the duo they're supposed to lead. They move on to other positions at ASML, and in one case a former Philips manager cuts his losses and leaves soon after he's joined. After three years Van Hout and Van den Brink have proven themselves, and they're fully accepted in their role.

46. **Not Wild About Wild**

Gjalt Smit has the gall to go around Zeiss and order lenses from additional optics firms. Valuable time is lost.

At the end of 1985, when ASML is up to its neck developing the first PAS 2500 steppers with a g-line lens, negotiations with Zeiss for i-line optics are already in full swing. The German company has spent several fantastic years supplying market leader GCA, but the American company is in dire straits. Accordingly, Gjalt Smit expects that Zeiss is ready to welcome other customers. Smit travels to Oberkochen several times, but the story is the same every visit: Zeiss doesn't want an exclusive relationship; it's keeping all its options open.

Zeiss has that luxury: ASET,[18] Hitachi, and Perkin-Elmer Censor are all clamoring for optics. GCA hasn't gone completely belly-up yet. The company is furiously trying to claw its way back with improved steppers. Its Tropel division now provides it with in-house lens production, but Tropel's operations are small. For large quantities, the American lithography manufacturer still relies on Zeiss. For the time being, ASML is just one of many suitors. There's still a long way to go before the Dutch and German firms will cement their exclusive "two companies, one business" relationship.[19]

After a few awkward meetings, Smit visits Zeiss again in early 1986 to talk with the executive board. He encounters a recalcitrant crew. The Germans don't want to make any special agreements. From Zeiss's standpoint, that's not so strange. The company is going through a critical and uncertain period: the losses are piling up at its major customer, GCA, but there's a chance the lithography company will revive after some CPR from the US government. ASML hasn't even remotely proven itself. Zeiss is full of doubts about the Dutch company. The Germans don't want to yoke themselves to a small, weak partner.

The meeting forms a turning point for Smit. ASML's CEO has completely had it with reluctant Zeiss. "This is a lost cause," he tells his development team. “We’ll never get anywhere with the black suits on the top floor of the Zeiss tower.” In the weeks that follow, he discusses his dramatic conclusion with the management team: they’re going to approach other optics specialists after all.

Smit’s drive to keep things moving can’t be restrained and borders on blind ambition. Conversations with customers are his compass. His decrees regarding the light source and mask size seem simple, but turn out to be essential. And so ASML’s product marketing slowly begins to take shape. When the self-confident and ambitious CEO gets an idea in his head, there’s no talking him out of it.

Smit careens in every direction. It drives his engineers crazy, but they also know once the Supreme Commander-in-Chief has set his sights on a thing, there’s no escaping it. In the months after Smit’s visit to Zeiss, ASML maps out all the alternatives. Smit requests they contact Olympus and Wild Heerbrugg in addition to Zeiss.

His decision seems obvious. If Zeiss won’t be their exclusive supplier, then ASML’s going to buy its wares from other optics suppliers. Logical and simple. But that choice has far-reaching consequences. It involves complex parts that can only be developed through intense collaboration.

ASML now has to pour time and money into multiple supply paths. That means multiple design paths, production at different suppliers, and complex integration phases side by side. It means multiple optics designs and suppliers all simultaneously performing the same trick and all wanting to earn a healthy margin to survive. It means, effectively, more expensive lenses.

In ASML’s present state, this exercise is insanely daring. In 1986 there’s not a single major customer in sight, while the joint venture is burning through millions every month.

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While ASML is wrestling with its lens problems, over the course of 1986 the company gradually starts to realize the PAS 2500 stepper doesn’t meet the needs of chip makers in the US. Development setbacks mean the machine isn't ready yet. At the same time, the American market is rapidly changing. The country's semiconductor manufacturers have lost the battle for the memory chip market to the Japanese. The US industry is shifting more and more to an area where it can make a mark: the market for application-specific chips. These application-specific ICs, or ASICs, pose entirely different requirements on lithography. While wafer steppers in Japanese fabs are busy stamping out identical memory chips all day, American fabs need steppers that can constantly change settings to expose a wide variety of chips. ASML has no choice. The US is its top priority, and so the company soon comes up with the idea to capitalize on this development with a new type of stepper that's almost entirely automated.

The PAS 3000, the successor to the PAS 2500, was already part of ASML's first business plan, but now the machine will be tweaked specifically for the ASIC market. "Where there are highly divergent requirements regarding logistical support for IC fabs," ASML's R&D department writes in a detailed road map document[20] for the PAS 2500 and PAS 3000. "To that end, the PAS 3000 will be highly automated, which will enable integration with factory control systems."

The goals for the new machine are ambitious. They already knew this stepper would have to make chips with 0.7-micron details, but ASML also wants to be able to deliver versions for older chip processes, with g-line and h-line lenses. With these requirements in mind, the company asks Zeiss, Olympus, and Wild to develop appropriate lens versions.

All together, ASML initially selects two suppliers for each lens type so it can compare different manufacturers' performance. Olympus soon bites the dust. It's evident in the very first meetings with the Japanese company that the language barrier is immense. In the engineering meetings, all communication goes through interpreters.[21] ASML undertakes a serious project with Wild Heerbrugg, in which both companies invest in the development costs for ten prototypes.

In March 1986, Zeiss starts designing a strategically important i-line lens for the 0.7-micron chip generation, at Philips' and Siemens' request. ASML may use the lens, christened Europa, in its newest model PAS 2500/40. It's intended to be the optical engine driving Philips' and Siemens' heavily subsidized Megachip race to catch up. Megachip will need its first steppers with a Europa lens in 1987. For the initial scale-up to mass production, in early 1988, nine Europa lenses are scheduled. In those years, ASML's R&D department is a pressure cooker. Wild Heerbrugg's project leader can't take it any longer, and the baton passes to Herman van Heek. But Natlab's pioneer soon flees the frantic pace himself, moving to Philips' CFT to continue his career. Contact with the Swiss optics company is dumped on Van den Brink's plate: "Martin, you need to handle Wild." The ornery engineer hates the idea. "Wild won't amount to anything," he grumbles. With just two years of industry experience, the young physicist isn't eager to manage a supplier. "Still, you have to do it," Van Heek answers. "The decision comes from higher up."

It's a step made in desperation. CEO Smit and head of development Evert Polak still think Van den Brink and Frits van Hout have to bear far too much responsibility, but they don't have any other choice. The young pair of engineers is eager, but this isn't a task that appeals to them. They hold long conversations about it. Van Hout: "Everyone agrees we're never going to make it." Van den Brink: "When Gjalt decides on something, there's no arguing."

In September 1986, Van Hout and Van den Brink summarize the situation. In their report, titled "Lens Development at ASML,"[22] they describe all the active projects for their boss, Polak. Wild Heerbrugg in Switzerland has built a reputation as a supplier of high-quality optical systems for cartography and space travel. In theory, the company appears to be an excellent alternative.

Van den Brink thinks it's madness, but the diplomatic Van Hout politely presents the management team's view in his report to Polak. "The projection lens may be viewed as the most critical element," he writes. "It is [...] advisable to look for multiple suppliers and multiple lens types, so that ASML will be less at the mercy of projection lens problems."

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Van den Brink decides to go to Switzerland to review the project's progress and introduce himself as the new project leader. He asks Joseph Braat to accompany him as the optics expert. By this time, the Natlab researcher has made a name for himself in optics. In the seventies the young engineer worked for Gijs Bouwhuis, who was Natlab's optical conscience in those days.

Van den Brink and Braat want to see with their own eyes how production is coming along. When they announce their presence at eight-thirty in the morning, they're received by Wild's CEO, Herr Doktor Schwarzmüller, surrounded by a horde of salesmen and lawyers. It's clear Schwarzmüller is out to intimidate.

Showy on the outside, vacant on the inside: the precise recipe for making twenty-nine-year-old Van den Brink bristle. "So, Herr Van den Brink, you are the project's leader?" Schwarzmüller begins his monologue. "Then I would like to inform you we are stopping the project as of today, because the contract has not been signed. If you do not sign before you leave, we will pull the plug."

Schwarzmüller's talking about a contract worth millions. Van den Brink thinks the whole project with Wild is a mistake, but he knows that his boss Smit expects him to do it. He can feel the weight of the responsibility. It's early 1987, the project with Wild is wildly expensive, and he knows all too well that ASML doesn't have a cent to its name. The way Schwarzmüller's pressuring him to sign raises his hackles. Braat also has strong reservations. Van den Brink stands up, brusquely says, "I never sign contracts. We're done here," and makes a move to leave.

It all takes less than a second, but it's enough time for Van den Brink to enjoy the surprise on Schwarzmüller's face. Then he turns around and says, "Hang on, before I walk away, I want to make sure the home front is with me on this. Give me five minutes." A few minutes later he's on the phone with Smit. "Gjalt, I'm here with Schwarzmüller at Wild and he's got a knife at my throat. He wants me to sign the contract right this second. I don't care about them putting me under pressure, but this is my first meeting. As far as I'm concerned, they can go fuck themselves. I'm not in the mood for this."

Smit says he doesn't want to end the relationship with Wild. "Okay," Van den Brink answers. "But there's a problem in the contract. The depth of focus isn't well defined. If the focal plane is even a tiny bit warped, we won't have any depth of field at all. That's something Wild's having trouble with, and it isn't specified." Van den Brink and Braat know this is a weak point in Wild's lens design.

Van den Brink proposes the following to Smit: "If the depth of focus is right in the contract, we're covered. I suggest I go back and adjust the contract. If they won't accept it, I'll walk away." Smit agrees.

Van den Brink walks back into the meeting room. He writes down a mathematical formula and says to Schwarzmüller, "I'll sign the contract once you add this formula to it." Wild's CEO agrees, and invites his guests to celebrate the signing of the contract with an extended lunch at a nearby castle.

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After its experiences with CERCO, ASML asks Joseph Braat at Natlab to calculate tolerances for the Wild lens. For multiple reasons, he's the right person to tackle the optical issues in stepper lenses. During his studies at the French Optics Institute in Orsay, he became acquainted with the computer, a device that's a perfect fit for the mathematical world of optics. He uses that knowledge in Piet Kramer's optics group at Natlab, when he encounters mini-optics for the video long-play disc, the forerunner of the compact disc.

Braat decides to write his own program for the video player's aspherical optics. His code initially covers five hundred punch cards and is limited to reproducing and comparing the results from suppliers like CERCO. Braat and his software program are soon common knowledge at the lab. Optical computer tools are already available in the late seventies, but they don't target aspherical lenses. A steady stream of colleagues drops by Braat's desk: could he run their problems through his code, too? And so his optical program grows to cover forty thousand punch cards by the end of the seventies. In the early eighties, he uses it to effortlessly design complex lenses for steppers and to analyze and optimize existing designs.

To calculate the tolerances, Braat asks Wild's chief mathematician, Klaus Hlidebrand, for the lens recipe. He feeds the numbers into his simulation program and quickly discovers the Swiss company's design is unreliable. Their tolerances are three times smaller than acceptable. Tolerances are the maximum allowable deviations for things such as the index of refraction, mutual distances, and centering the lens elements. The smaller the tolerances, the less leeway they'll have in production. Errors will be quicker to creep in during fabrication, and it will be harder to make a lens that meets the specifications.

Braat takes Van den Brink and flies back to Heerbrugg to tell Hildebrand about his concerns. Wild's mathematician is not impressed and reminds them of his years of experience. Van den Brink can tell the haughty Swissman thinks Braat is just a snot-nosed kid. He waves away Braat's warnings about production difficulties. "We're the global leader in cartography, and those tolerances are absolutely no problem for us," he says. "Our plant has no trouble with them."

Just as at Zeiss, the mathematical department at Wild Heerbrugg is the center of the universe, and a supreme being handles all matters optical. Like Erhard Glatzel at Zeiss, Herr Doktor Hildebrand is one of the world's most brilliant optics experts. From the way he wears his suit to the awed respect his colleagues show him: when Van den Brink is at Wild, he might just as well be at Zeiss.

Braat has less trouble with the situation. By this point he knows Hildebrand from conferences. Braat considers him an extremely pleasant person, but also someone who at sixty-five years of age has gotten stuck in his ideas. The only thing that surprises the Natlabber is that Hildebrand's closest colleague is surprisingly submissive toward his boss, even though he's only ten years younger. That employee knows Braat is right. He cautiously supports the point the Dutchman has made that lithographic lenses must be designed based on wavefront aberrations and not ray aberrations to reach an optimal result, but Hildebrand ignores the comments.

Braat also brings up another problem. The imaging quality of the Wild lens is good, but it falls outside the specifications for distortion. Later, Braat's software program reveals that the optics Hildebrand has designed have a curved image plane. The curvature is minimal, but the lack of sufficient depth of field makes it hard to form a good image in the flat plane. Braat informs Wild, but Hildebrand refuses to budge on that, too. "Well, then, my dear Herr Braat, I suggest you double-check your program. We've been calculating distortion for a very long time and we've never had a problem."

Meanwhile, Braat has made his own detailed lens design. He's based it on the "relaxed" design method promulgated by Glatzel, which produces a lens with broad production tolerances. Natlab's optics expert is pretty sure it's a good design, and he asks Hildebrand to calculate the aberrations for it. During his next visit, the Swissman somewhat dismissively notes that it takes time for one to gain sufficient experience in optical design. He says Braat's lens design doesn't meet all the aberration requirements.

In those days, every self-respecting optical engineer writes his own calculation software, just like Braat. The optics field is transitioning from manual calculation to the use of computer tools, and the commercially available solutions aren't yet good enough to use for lithographic optics.

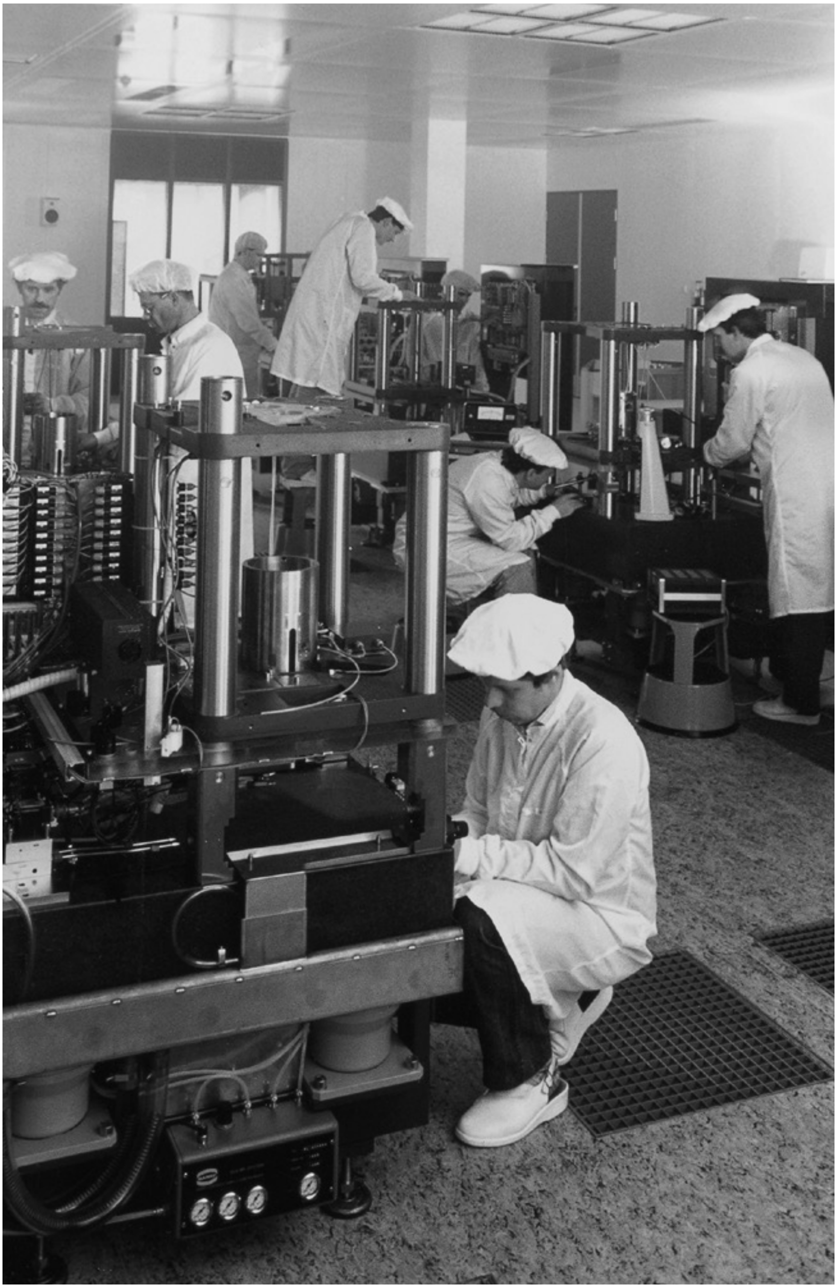
Braat checks every detail, but at the end of the day it turns out it's Hildebrand's software that's made an error—because it uses ray aberrations in its calculations. Braat explains to the Swissman that that's sufficient for cartographic lenses, which can tolerate three times the aberration of lithographic lenses; but lithography requires much higher precision and the way to achieve that is to use wavefront aberrations in your calculations. Wild has never noticed the problem because the production tolerances for cartographic lenses cause errors just as large as the aberrations arising from calculation error. Hildebrand has no choice but to gallantly admit his error. He adjusts his lithographic software to use wavefront aberrations and promises to start lens production. But the design being used is in theory still Wild's, with its very tiny mechanical and optical tolerances during production and an accompanying large sensitivity to external changes.

Almost a year later, Wild contacts ASML again. There's a problem. The focal plane of their lens appears to be sensitive to air pressure. Depending on the weather the image plane is displaced too much and is too curved to achieve a sharp image on a single surface across the whole field of view. Within the specified weather conditions the lens turns out not to meet ASML's specs. They try to fix the problem with a helium filling, but Wild can't keep the lens from leaking helium. Thanks to Van den Brink's addition to the contract, ASML can walk away for a reasonable price. It means the end of the relationship with Wild Heerbrugg.

Part 7

The Big Spender

1986–1987



Assembling PAS 2400 steppers for MMI in ASML's new building in Veldhoven.

47. **Euphoria**

In early 1986 the first rays of light appear at the end of the tunnel. ASML wins its first customer and finally achieves its coveted installed base. The end of the crisis also seems to be on the horizon.

At the start of 1986, ASML's American sales team manages to singlehandedly sell the PAS 2400 to Monolithic Memories (MMI), a small chip manufacturer. The presence of local support convinces the company to put its trust in ASML. There's a stepper at ASML's lab in Phoenix, and the three sales engineers there have been joined by two service engineers, both of them former GCA employees.

MMI manufactures relatively small chips and thus its lithography requirements are less stringent. The PAS 2400's smaller exposure field is no problem, which means the company can take advantage of several positive PAS 2400 features, including its high throughput, high precision, and extreme reliability. The electric table proves its value at MMI, making this customer a vital one in helping ASML survive a crucial phase in its existence. From then on, the machinery manufacturer is no longer a paper tiger, but a serious newcomer with an honest-to-goodness installed base.

In reality, the PAS 2400 is just a slapdash solution. It's a PAS 2000 whose hydraulic table has been replaced by a clean electric version. At MMI the 2400 works as it should. In fact, the tiny chip manufacturer is so pleased that George Kern, MMI's head of production, lets ASML use his photo in the ads it runs in early 1986. In the ad, Kern says the Dutch steppers greatly increase the number of viable chips: "Overlay accuracy and yields both exceeded our previous steppers' by half." His yield has risen by a third thanks to the PAS 2400's higher throughput and reliability. "As important [...] was uptime—over 90 percent," Kern gushes, then adds that he's bought another four of the machines.

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The mood at ASML is euphoric. They've landed a customer, and the deadline for the PAS 2500 has been pushed back a few months, giving the company's developers a little breathing room. It's still tight, but the engineers know they're going to make it—albeit with daily crisis meetings and a lot of blood, sweat, and tears. There's no longer any doubt they'll deliver machines for the Megachip project in April and for SEMICON West in May. Overtime is the order of the day, for months on end. The team experiences the pleasant stress of a finish line that's in sight and the knowledge they're going to cross it.

It's usually Evert Polak who sticks his head in the door around six p.m. and asks if they've already eaten. Half an hour later the smell of Chinese takeout suffuses the brand-new building—ASML's relocation is a godsend for the restaurant down the street. There's no daily rhythm to speak of, just backbreaking work that runs straight through the evenings and weekends. The last employees often straggle out the door in the wee hours of the night.

For those who live further away, ASML has rented a house in Veldhoven. Engineers from the north and the east can sleep there after another late night. They all keep sleeping bags in the trunks of their cars, in case all the beds are taken and they have to claim a few square feet on the office floor. Recent arrivals from the US spend their first few months in the rental house, too.

By this point ASML has more than three hundred employees, a handful of PAS 2400 steppers up and running at customers, and the distant but growing glimmer of its first victory. It's a real company. The engineers have no doubt: they're building a machine that's going to conquer the world. After two years of blood, sweat, and tears they're finally going to have a working product, a stepper the market's been waiting for. At last they're going to make their name in the industry. At last their vision—a place on the winners' podium in chip lithography—is no longer a dream, but tangible reality.

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The PAS 2500's approaching finish line isn't the only cause for optimism. Suddenly everything seems to be going their way, and the clouds have made way for sunny skies of blue. The first sign of this reversal of fortune came a few months earlier, when competitor GCA's share price plummeted. The former market leader is in big trouble. Several of its employees have even jumped ship for ASML.

In late February, Gjalt Smit announces the triumphant news that he's managed to interest Ken Pynn, GCA's service manager, in working for ASML. When Pynn arrives in Veldhoven, Smit and his team finally learn just how serious the problems are at their competitor. In early May 1986, Smit summarizes the problem for his management team: GCA's technological innovation was too slow and the company didn't pay enough attention to creating a professional infrastructure. Everyone knows GCA is as good as dead, and that means ASML is looking at an opportunity.

GCA isn't the only one wrestling with lithography. Perkin-Elmer has lost much of its credibility after Censor's poor performance, and the company has shut down its European stepper operations.

Another bright spot for ASML: the first signs of recovery arise in the spring of 1986. At least, they seem to. "Unexpected positive changes in the business environment and our competitive position [...] (among which the 'near bankruptcy' of market leader GCA) call for an adjustment of our strategies and plans," Smit writes in his operating plan for 1986 in early May.[1] He detects a sense of optimism among customers. In a few weeks ASML will ship the first PAS 2500 to Natlab, but the machine has already attracted the full attention of American chip manufacturers. Cypress is interested, AMD has signed a letter of intent to buy two PAS 2500s, and VTI wants two as well. Smit expects MMI to order another two PAS 2400s. All these orders should materialize within three months, he believes.

In addition, China has ordered one of the old oil-based PAS 2000 steppers, and other Far Eastern countries have demonstrated interest. Smit feels the urgency of the next step: he needs to get his company ready for the growth spurt that will follow. "In particular, more rapidly maturing opportunities for 1987 force us to try to establish a dominant position on the US market during 1987 instead of 1988 as previously projected," he writes in the operating plan.

Smit describes the opportunity that's opened up: chip manufacturers who are ready to start producing VLSI chips are increasingly interested in non-Japanese brands. His company has a new product in the pipeline that has given customer trust a significant boost, he writes in the operating plan. That product is the Europa lens, of which Zeiss will make nine. The lens has a large projection field and will be able to image chips with details smaller than a micron. The Europa lens will be used in the nine PAS 2500 machines that Philips and Siemens need in early 1987 for their Megachip project. The major VLSI fabs are showing "increasingly serious interest [...] in the non-Japanese PAS 2500," Smit writes. "Indeed, most customers see it on paper as by far the best machine for one micron and beyond." Nonetheless, Smit's operating plan also contains a negative point: ASML was supposed to ship four PAS 2500s to Elcoma every month for five months starting in August, but the Philips division has delayed its order for the twenty machines to the following year.

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ASML has a machine that shines, its primary competitor is down for the count, and the market environment is favorable. Smit can taste approaching victory and wants to step on the gas. He wants to ramp up to high-volume production, and proposes to his management team that the company target 125 machines in 1987 and 250 in 1988. To that end, he wants to produce 40 steppers in 1986.

Smit is still assuming that the global market for steppers hit its low point the year before at just under 500 machines. The expectation is that more will be sold in 1986. In fact, only 250 machines were sold around the world in 1985, and despite the apparent signs of recovery in the spring of 1986, only 125 to 150 steppers will pass through the factory gates that year. But ASML's CEO doesn't know all that yet. He sees growing indications that orders will be substantial in 1987, he optimistically writes in his plan in May. His boundless ambition shines through again: "We expect that each machine shipped by us this year will carry a 'multiplier factor' of five to ten for 1987 shipments." Smit hasn't yet made plans to expand the plant, but it's clear he thinks the existing production space is insufficient. The company will need to expand significantly by the end of 1987, when it will be making the new stepper that Philips and Siemens will use in their Megachip production lines.

According to Smit, streamlined high-volume mass production is "the first and absolute prerequisite" to establish a dominant position on the US market. Without high-volume production, ASML doesn't stand a chance of capitalizing on the opportunities now arising as the chip market recovers. "More concentrated efforts are necessary to realize controlled series production of the PAS 2500 in 1986," he writes to his management team.

To achieve professional-quality production, the organization will have to grow substantially, in both engineering and production. Smit realizes that means they need to invest heavily again in 1986—far more heavily than projected. He doesn't care. His eye is on the gold medal, and if that means burning through millions, so be it. He's a leader on a mission, impassioned and unstoppable, but his unbridled energy is in stark contrast to ASML's empty wallet and its technological state of the union. The PAS 2500 will ship to Natlab in a few weeks for the Megachip project, but it's a prototype that still needs a great deal of work. "Basic development has hardly been completed," Smit writes. There's a laundry list of specifications the machine doesn't yet meet. It's clear that several parts need to go back to the drawing board before ASML can farm out their mass production and start assembling its machines in bulk.

In fact, it's a wonder the PAS 2500 is finally ready for Natlab at all. The machine has been developed by a team consisting largely of engineers who had never even heard of lithography two years earlier.

* * *

In his euphoria, Smit thinks he's found the right arguments to make shareholders and investors reach into their pockets. He can show them why ASML needs the money. He's discussed it at length with his management team, immediately recording his conclusions and the reasons why. The resulting plan says that ASML can still produce and ship forty machines that very year, corresponding to a revenue of $28.5 million.

Smit calculates a 1986 bottom line of $5.8 million in the red, but he also dangles the reward: $6.1 million net profit in 1987. All the rosy numbers still don't make ASML rich in 1987, because that year the company has to pay back an $8.1 million loan from the Dutch Ministry of Economic Affairs. To nip unwarranted optimism in the bud, he uses "the conservative P&L assumption of sales of 100" machines in 1987, rather than the 135 machines he's convinced ASML will deliver. Those hundred steppers should generate revenue of $96 million in 1987—not including Japan, he notes. The mood in Veldhoven is apparently so upbeat that selling machines there is once again an option.

* * *

ASML doesn't realize it at the time, but the semiconductor recession will deepen over the course of 1986. That year the company will ultimately sell not forty machines, but twelve. And most of those will be sold at cut-rate prices, because their competitors are barely treading water and are dumping their inventory.

But Smit is still in the grip of euphoria when he pens his operational plan in May. He physically underlines the keywords in his battle cry to management: "Can ASM Lithography implement the above all organizational measures needed to deliver a reliable product in quantity together with the intensive professional support required: in other words, can it MANAGE and CONTROL the extremely rapid growth and change it is faced with, where others seem to have so clearly failed!"

48. **America's Toughest Boss**

ASML breaks onto the international stage when it delivers a VLSI stepper to Cypress. The fearsome analyst Rick Ruddell actually squeezes approving words from his pen.

On May 7, 1986 the first PAS 2500[2] finally leaves the cleanroom in Veldhoven. It's a formidable accomplishment for ASML's engineers, even if it's a few months late. The first PAS 2500's destination is San Mateo, California, where from May 21 to 23 it will grace the showroom floor at SEMICON West, the world's premier chip machinery trade show. A second PAS 2500 stepper is ready to ship to Philips' and Siemens' Megachip project.

In San Mateo, ASML's display is a full-fledged lithography island: a production unit that combines the PAS 2500 with a wafer track. The second device applies a thin layer of photoresist to the silicon wafers before they enter the stepper. It's the first time ASML's engineers have connected a wafer track to their PAS 2500.[3]

On its very first day, the PAS 2500 exposes five hundred wafers. Software engineer Ben Slaghekke calls his boss, Wim Hendriksen, every day to give him an update, and reports that the crowd is buzzing at ASML's booth. A day later, Slaghekke makes the rounds of the competition with a short survey. His first question: what's the best lithography machine? They all answer: ours. Next question: what's the second-best machine? They all answer: ASML's.

It all looks very slick. The wafers glide from the wafer track to the stepper, which then automatically exposes them and transfers them to a box. The secret behind this miracle of automation is hidden behind a handful of panels. There, a camera system shows Rein Meyer what's happening inside the PAS 2500, and he types just the right commands into a bank of terminals and keyboards to make everything run smoothly. The operator isn't allowed to leave his cage all day; his contact with the outside world is limited to colleagues who bring him sandwiches and cans of Coke.

The only glitch comes on the final day: the wafer track stalls. That evening Hendriksen writes in his journal, "SVG is mad: their track was down, not good for customers." A month after SEMICON West, ASML's employee newsletter proudly boasts of the impressive PAS 2500 feat, "We plugged it in and… it worked."

* * *

While Meyer is climbing into his sweatbox on the final day of SEMICON West, his colleagues back in Veldhoven are readying a second PAS 2500 for its journey to the Megachip pilot plant on Philips' Natlab campus. A forklift slides the machine onto a standard pallet in a box truck that's been hosed clean. The truck's climate control is sufficient for the task at hand—the day before, it transported a shipment of lettuce.

Jos Vreeker has the honor of caring for the machine in the coming months. Vreeker, hired as a technical support engineer, has spent the last eighteen months as a jack of all trades. He orders parts, goes to pick up instruments, writes machine documentation, that kind of thing. Now that the stepper's finished, he can finally do what he was hired for.

As Vreeker nervously watches the forklift slowly ease ASML's first customer order into the truck, he spies impending disaster. The balloon that serves as a makeshift clamp for one of the components is losing air. Vreeker jumps into the truck to blow the balloon back up. His colleagues howl with laughter: it looks like he's giving the machine mouth-to-mouth resuscitation. At last the truck can depart—at a careful crawl—for Natlab. No one's informed the police; the team stops traffic at intersections themselves, while the vehicle inches down the Eindhoven beltway.

* * *

In the weeks and months that follow, Vreeker bumps up hard against the PAS 2500's limitations. The internal company newsletter[4] from that time crows about marvelously advanced technology. And it's true, at least in part. The machine does a perfect job of exposing the silicon wafers.

But everything else about it is a mess. The first PAS 2500 has three different terminals, which control three different components. Nothing is automated. Operators who want to expose a wafer have to do what Meyer did at SEMICON West: enter the commands for every step by hand. Vreeker discovers the machine is devoid of electromagnetic shielding when he turns on the 350-watt mercury vapor lamp. The electromagnetic pulse it emits is large enough to shut down the TRE stepper beside it every time.

In truth, the PAS 2500 is still under development—not in ASML's cleanroom, but in Philips' Megachip pilot plant. For three months, ASML's engineers travel to the plant to work on their machine. It's a valuable experience. The machines they install at Elcoma and other customers in the months thereafter are up and running much, much faster.

* * *

Several companies request a quote from ASML at SEMICON West, but Cypress's enthusiasm stands out above the rest. CEO Thurman John "TJ" Rogers pays the booth a personal visit to see the PAS 2500 in action. Rogers is an engineer to the core. He led AMD's R&D department, then started his own chip company a few years back. He instantly perceives the machine's advantages. This is the technology that might just let him give his former employer a real run for its money. He decides pretty much on the spot to buy ASML's machines. Soon thereafter, Smit flies to Silicon Valley to hammer out the deal. He's done his homework. His American team sent him reams of articles on Cypress, one of the dozens of West Coast startups that populate the eighties. After the blow the Japanese have dealt to American companies with their superior production, these startups are the US semiconductor industry's new hope.

These newcomers are heralded as the third wave, after the birth of the chip industry in the fifties and the second wave in the sixties. And for good reason. In addition to Cypress, the third wave includes companies like Linear Technology, LSI Logic, Maxim, and Sierra. All of them are focused on niche markets. They make application-oriented chips in small runs, which sometimes go on to have broader success. Their customers are titans like Hewlett-Packard, Digital Equipment, and Data General. These companies eagerly buy the startups' chips to improve features in their instruments and devices while simultaneously making them cheaper.

Cypress is modeled after AMD. In interviews, Rogers loudly expresses his admiration for his former boss, Jerry Sanders. "Jerry isn't blurred by an engineer's vision," he tells the trade press. "Jerry doesn't make chips to see if they work; he does it to make money. If you keep that in mind all the time and move fast enough, you can stay out of the way of the Japanese steamroller."[5]

Rogers' management style is confrontational. Within a few years he's developed a reputation as the General Patton of the semiconductor industry. The CEO likes to rule with an iron fist and is proud of it. At Cypress, candidates run a gauntlet of ten interviews before they're hired. Seven years later, Fortune will crown him one of America's toughest bosses.[6]

Rogers founds Cypress in 1983 at the age of thirty-four, and within two years he's raised $42 million in venture capital. When he encounters ASML at SEMICON West in May of 1986, Cypress is just weeks away from its NASDAQ IPO, which will raise $73 million for the company.

Smit knows he's dealing with an alpha male, so he caters to the Cypress CEO's ego. When the two men first meet, Smit mentions he's curious to know more about TJ's management style. How does he run his successful company? Smit would love to hear a few tips. In fact, Rogers' management-by-terror approach disgusts Smit, but why not butter up this eight-hundred-pound gorilla? During their conversation, Rogers turns out to have quite a few demands. "You guys have the best machine on earth," he starts out, only to instantly switch into cowboy style: "But if I fall flat on my face, I want to make damned sure you fall with me. So you're going to buy a share of my company."[7] Smit pretends to be enthused, but silently he's wondering where in heaven's name he's supposed to get the money

In May 1986 ASML demos its first full-fledged wafer stepper, the PAS 2500/10, at SEMICON West in San Mateo, California.

for that. ASML has been bleeding for two years, and now a startup is asking him to stick a few million dollars into an uncertain future.

Back home in Holland, ASML's CFO, Gerard Verdonschot, asks the NMB bank if it would be willing to lend ASML a few million. The major problem is that as the CEO of a company turning a loss, Smit can't justify purchasing shares in another company. But NMB director Ide van der Boor fixes it for him. He buys shares in Cypress on ASML's behalf and holds them in escrow at his bank.

And so Van der Boor keeps the deal hidden from ASML's board—for which Smit is grateful. In these hard times, he's not eager to get down on his knees and beg his shareholders for money again. Just over a year later, he'll wipe the slate clean. Shortly before he leaves ASML, he gives the order to sell the Cypress shares—at a small profit, even.

* * *

On August 8, 1986 Queen's Commissioner Dries van Agt visits ASML's cleanrooms in Veldhoven. From left to right: Wim Troost, Dries Van Agt's secretary, Dries van Agt, Gjalt Smit, Joop van Kessel, Harry Daniëls, and George de Kruiff.

On June 20, 1986, a month after SEMICON West, Joop van Kessel gives ASML's production staff a pep talk. The company expects machine orders totaling $25 million to come in before Christmas, so it's time to roll up their sleeves. For the rest of the year, the company has to deliver a stepper every week to meet demand.

Cypress is first in line. The company wants to receive two PAS 2500s in the fall. These will be the first two full-fledged machines ASML has delivered. All the changes that came out of the prototype phase have been incorporated. Production is now a race against the clock. The first two PAS 2500s have to be ready for testing on August 15, followed by two batches of four machines, and then a batch of eight.

* * *

If there's one thing Smit's good at, it's stakeholder management. He lavishes attention on people he knows ASML needs. Market analyst Rick Ruddell is no exception. ASML's CEO listens to Ruddell's criticisms and manages to convince him the Dutch machinery manufacturer is not your average old-style European company. He also asks Ruddell if he knows any American experts who'd like to work for ASML. Among other things, that leads to the hiring of several good people away from competitor GCA.

From earlier encounters with Ruddell, Smit knows the American is a fan of classical music. When the analyst announces he'd like to visit ASML for a second time, the CEO invites him to a performance at the Royal Concert Hall in Amsterdam, accompanied by their wives.

Once he arrives in Holland, Ruddell also visits ASML's futuristic campus in Veldhoven. That helps to convince the analyst the young Dutch stepper manufacturer is an up-and-coming force in lithography. "We expect ASML to be very successful," he writes in his 1986 industry report.[8]

Ruddell does see some points for improvement. He believes the Zeiss lens in the PAS 2500 is inferior to Canon's optics. The German lens exposes a fourteen-by-fourteen-millimeter field, and that's on the small side.

But ASML's alignment system is "by far the best," Ruddell writes. "And the positioning and alignment of the wafer stage are also much better than the competition." All in all, the analyst expects ASML and Canon to duke it out regarding overlay. The Japanese lenses are superior, but the Dutch compensate for their optical deficiency through better alignment.

Ruddell writes that during his visit to Veldhoven, he's become convinced that ASML "really exists" and is capable of producing 100 to 125 systems a year. "We are very impressed by their management and the engineering team," he writes. He doesn't forget to underscore that parent Philips was the first to build a wafer stepper, and he compliments the company on its wooing of GCA employees, to which he himself contributed: "ASML has wisely balanced its reputation for high technical quality with seasoned American veterans in marketing, sales, and service."

The analyst notes Philips' financial stability and concludes that the electronics manufacturer's "higher levels" of management have a long-term commitment. The Ruddell & Associates report also notes that ASML will replace the first ten systems bought by customers free of charge, should it be necessary. The American analyst praises the principle behind the move: the Dutch company doesn't want to make its customers pay for its own education. "Hooray for ASML!" he writes.

This positive review by one of the industry's leading analysts is a shot in the arm. Ruddell positively gushes about Smit: "My worries about the slow response times and extremely conservative approach that characterize European companies have been unfounded so far. By European standards, Gjalt Smit is a wild man. By Silicon Valley standards, he's someone with an enduring entrepreneurial spirit and the determination to commit himself completely which is required for success."

49. **Temptation Strikes Del Prado Once Again**

GCA, lithography's Goliath, has fallen to its knees, spent. ASML is handed the American market on a silver platter.

On a lovely late summer evening in 1986, a limousine drives onto the campus of ASML's brand spanking new site in Veldhoven. From the car emerge Arthur del Prado and Richard Rifenburgh. Rifenburgh is an American investor hired in May of that year by GCA to help the machinery manufacturer right its sinking ship. The company is on the edge of bankruptcy, and the new executive is trying to salvage what he can.

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For years, GCA was America's pride in chip technology. But in early 1986 CEO Milton Greenberg leaves, and with him the entire board of directors. Vision, strategy, operations, execution: GCA's management has made a mess of them all. ASML already saw the writing on the wall back in November 1985, when GCA's share price plummeted from thirty-five to seven dollars.

After Greenberg's fall the Mellon Bank, one of GCA's largest investors, installs Rifenburgh at the company. Rifenburgh doesn't have a background in chips, but he's earned his spurs in energy, computers, construction, and lead crystal production. He comes down hard, putting a thousand people out of work and dismantling all non-core activities.

Natural-born businessman Del Prado is steadily expanding his rapidly growing empire, and when he sees his American competitor in trouble, he smells opportunity. Mergers and acquisitions are his lifeblood. He's just completed a highly successful move: in 1982 he strikes gold by opening an office in Tokyo. Four years later, the branch has over a hundred employees working in production and service. With a Japanese office staffed by Japanese employees, ASM is able to ride the wave of early-eighties success gracing this

Asian country where chip manufacturers are still investing aggressively despite the global recession.

True, in 1986 his Dutch lithography joint venture is bleeding, but ASM's CEO can't let such an exceptional catch pass him by: a company that has access to the majority of the world's chip makers. So he informs George de Kruiff at Philips and immediately sends an ASM America representative to GCA.

Rifenburgh is surprised to hear that ASM and Philips want to explore the potential acquisition of GCA.[9] The bid takes him to Holland. Ever the charmer, Del Prado rolls out the red carpet for Rifenburgh, and on the summer evening in question the two men visit the ASML campus, where Smit conducts a tour. In the days that follow, they plan a meeting in Bilthoven with people from ASM and ASML. There's even a member of Philips' executive board present.[10] Both sides give presentations. Rifenburgh and his financial right-hand man, Philip Ablove, are treated with respect, but the team from ASML are silently celebrating the Americans' visit as a psychological victory. The Dutch company doesn't have a cent to its name, yet the former market leader is on its knees before them, an opponent who seemed unbeatable just a few short years before.

Rifenburgh lays his cards on the table. GCA has lost significant market share in Japan, but the machinery manufacturer remains strong in the US. During the upswing in 1983 and 1984, the company benefited from its installed base: chip manufacturers clung to the lithography machines from their American supplier. In Japan GCA's market share may have shrunk to just a third of its former size, but a man like Del Prado, with experience and employees in the Far East, won't have much trouble breathing new life into that.

Then Rifenburgh makes an offer. He's calculated what it will cost to revive GCA. For \$50 to \$70 million, ASM and Philips can acquire a controlling interest in the company. That sum is more than a quarter of the American company's stepper revenue in its best year, 1984.[11] Del Prado won't capture his prey cheap, but the possibility of an acquisition remains tantalizing: his lithography subsidiary has just gotten its technology in shape and now it's being offered the market on a silver platter.

* * *

Philips has no interest in being the only one to open its wallet. The electronics titan is knee-deep in reorgs, one after another, and its money-guzzling Megachip project is falling behind. The partners contact the NMB bank and ask for $22.5 million. Del Prado expects he can absorb GCA for $30 million in September.

The M&A game fascinates Smit, too, though he's watching it from the sidelines. After the meeting in Bilthoven between GCA, ASM, and Philips, he walks into Ken Pynn's office. ASML's general manager is intimately familiar with his former employer; he led GCA's global service division for years. Smit asks him to write it all down: what's good, what's bad, and what's rotten about GCA. Pynn reckons that patents drive most of the value in GCA and its optics division, Tropel. At that time, the relationship between ASML and Zeiss hasn't yet crystallized, so GCA's optical technology is a major plus. "ASML and GCA are actually pretty complementary," Pynn declares. GCA has in-house optics, ASML has an elegant wafer stage. At Smit's request, Pynn estimates GCA's worth at $40 million.

When Smit broaches the subject with De Kruiff, the two are on the same wavelength. Both men would rather avoid a new war. GCA's call is a siren song. The purchase of an ailing company is strategically unwise. ASML is barely standing on its own two feet; it's still building its own foundation and a new offensive on a second front will crush it. What's more, the chip market's expected recovery keeps failing to materialize. Despite promises, AMD and Philips haven't yet placed definitive orders.

Rifenburgh may have thoroughly reorganized the company, but buying GCA means another massive reorg. That will cause guaranteed pain on both sides of the Atlantic. If the recession persists, Smit definitely won't be able to protect the team in Veldhoven. What's more, GCA's Tropel subsidiary is a gamble. The optics division has fallen far short of meeting the American stepper maker's needs. As a result, Zeiss has continued to be the company's major supplier. All in all, the acquisition is far too great a risk.

Del Prado remains eager, even under heavy pressure. In the fall days of 1986, it's patently clear ASM will suffer a record loss that year. Add to that the losses ASM and Philips are paying on behalf of their lithography venture.[12] Del Prado loses control of the acquisition process. GCA soon has a second suitor, a consortium named the Halloway Group. ASM's CEO can't close a contract with the NMB bank fast enough to finance the acquisition. At the end of November, Del Prado throws in the towel.

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Smit is relieved by the turn of affairs. If the acquisition had gone through, he'd have had to manage it. But the whole business keeps fascinating him. GCA would have given ASML direct access to the US market. The lack of this kind of insider position has bothered him for years. American firms still aren't placing large orders. He needs a proverbial crowbar to break into the US. That gives him the idea to contact machinery manufacturer Ultratech.

Ultratech's CEO is interested, and he thinks a partnership is a good idea. The two companies aren't direct competitors. ASML makes high-end machines, steppers for the tiniest details. Ultratech serves the low end with one-to-one scanners, just like Perkin-Elmer and Canon. The American machinery manufacturer has achieved a solid market position because its devices are fast. Even Philips is using Ultratech's scanners as its primary workhorse in the Megachip project.

But when Smit introduces De Kruiff to the CEO of Ultratech's parent company, General Signal, the two don't hit it off. The conversation dies after a single meeting.

50. **The Sun Sets on GCA**

GCA succumbs to an avalanche of poor choices and a lack of focus. Bad lenses from Zeiss deal the lithography giant its final blow.

In the months after Richard Rifenburgh's visit to ASML, things rapidly deteriorate for GCA. In January 1987 US defense personnel sound the alarm in the *New York Times*:[13] critical technology is in danger of vanishing. Chip manufacturers, the Pentagon, and the CIA are worried. "It is a technology that GCA pioneered in the late 1970s and one that, until just a few years ago, lay at the core of American dominance in the chip field," the article reads.

GCA's plight hits a raw nerve. The US is embroiled in a cold war with Russia. The loss of strategic technology is a very sore point with the US military. It was the country's navy, air force, and army who laid the groundwork for American hegemony in chips through billion-dollar investments in the fifties and sixties. They not only awarded contracts to major technology companies but also financed small startups, thereby paving the way for Silicon Valley, a stretch of California farmland that would evolve into the global epicenter for information technology. Attack American chip technology, and you're attacking America.

In recent years, the country's semiconductor industry has already suffered heavy damage from its Japanese competition. Companies like Hitachi, NEC, and Toshiba have almost entirely captured the market for memory chips. Now it seems to be the chip machinery market's turn. "Many say the nation is facing the prospect of heavy dependence on its international competitors for the machines that make leading-edge semiconductor production possible," the *New York Times* reports. "Its customers say GCA has lost tremendous ground to Nikon, Canon, and the ASM division of Phillips—meaning that the center of development of state-of-the art technology for manufacturing semiconductors has, in just a few years, moved overseas."

The company with the best lithography can manufacture the fastest chips, the best computers, and the most effective weapons. "It's very, very critical," says Donald Latham, who oversees the Pentagon's electronics purchasing, about lithography.[14] "This type of equipment is the key to producing finer and finer resolution semiconductor devices. It's simply something we can't lose, or we will find ourselves completely dependent on overseas manufacturers to make our most sensitive stuff." In short, the loss of GCA threatens national security. The *Times* notes that the military is "perhaps reaching for the overdramatic," but the thrust of the article is nonetheless bleak: once again, Japan is threatening to consume an entire industry.

* * *

GCA's situation is hopeless. The company is in massive debt to banks and its suppliers. In the preceding two years it lost over $100 million. Major talents have left—some of them to join ASML. GCA's filings with the SEC in early 1987 value the company at *negative* $12 million. Its share price, $40 in 1984, now hovers around $2, and the NYSE is threatening to delist the company.

In the *Times* article, Jim Owens, National Semiconductor's vice president of technology, emphasizes that the US is in danger of losing one of its base industries. "The question that we always have in the back of our minds is: 'Are they giving us the best they have, or are they holding back to gain a competitive advantage?'" To Owens, at least, it's clear he has little choice left when it comes to steppers.

The sentiment in America is understandable, but at least part of it is crocodile tears. During their heyday in the late seventies, American chip machinery manufacturers—GCA in particular—couldn't keep up with demand, and they prioritized American customers. Japanese semiconductor companies had to wait. That's part of why the Asian country's industry decided to build its own machines and sever its dependence on the Yanks.

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How did it come to this? Why, in the early eighties, does the United States relinquish control of its most critical technology market? Many researchers and analysts will ask that question in the second half of the decade as they work to explain the American chip industry's weaknesses and the roots of Japan's success. In April 1987, a Harvard doctoral candidate named Rebecca Henderson immerses herself in the history of lithography and in GCA's downfall in particular. She combs through the trade press, but it's her conversations with some seventy engineers, marketing managers, and users of photolithographic equipment that deliver a treasure trove of data on this complex industry. Her dissertation[15] and other publications provide a valuable window onto the early history of chip lithography.

* * *

In the early seventies, when Burt Wheeler, Griff Resor, Bill Tobey, Howard Lovering, and a handful of other engineers at GCA's David Mann division are developing their DSW4800 stepper, it's clear sailing. They work well together and have years of experience in optics, precision technology, and chip pattern imaging. Short lines of communication and extreme dedication enable them to build a working stepper in less than three years. It's a formidable achievement.

The DSW4800, which launches in 1978, isn't perfect, but it's good enough for its era. In no time the company is struggling to keep up with demand. The stepper paves the way for an unparalleled success. In 1981 the Mann division's revenue is $110 million, eight times what it earned in 1978. The number of engineers grows in that time from ten to more than two hundred.

But the machine's incredible success pits the company against enormous challenges. It's a three-pronged offensive, Rebecca Henderson writes. GCA has to manage a very rapidly growing business, provide service to its customers, and refine its steppers all at the same time. Its rapidly growing customer base is filled with demanding chip manufacturers, all clamoring for improvements and new features. Faster machines, better yields, higher resolution: they want it all, and they want it now. Automatic alignment, improved optics, and automatic reticle changing top the list of demands.

In those early years, it's a huge problem to move wafers between different lithographic machines during production. But customers are asking for it. They start fabrication on the most advanced machines, which can print the smallest details. They want to do the subsequent steps on an older machine using a coarser process. That saves money. In the beginning, it's a hassle to move wafers between steppers and scanners.

Wafer positioning is so sensitive that it's not even possible to switch wafers between steppers of the same type in the early years. There's too much variation in the optics for that. The lenses come from the same workshop, but their manufacturers don't have a good enough handle on the production process. Layers exposed by different steppers don't have a precise enough overlay. The resulting defects mean the chips don't work. In those first years, one stepper has to image all of a wafer's layers.

GCA partners with Zeiss pretty much from the start. The German specialist learns fast and refines its optics. A few years later, it's already making larger fields and numerical apertures available. GCA makes a smart move in enabling chip manufacturers to mount the new lenses in their existing machines. The light source also improves.

But GCA also has its troubles. It's wrestling with automatic alignment,[16] the ability to optically line up the next chip pattern over the previous one. The measurement method the David Mann division uses is sensitive to the chemical processes the chip fabs employ.

GCA is also facing enormous internal obstacles. To satisfy its customers, the company decides to make all its new machines compatible with the original DSW4800 steppers. That shackles the development team to this very first design. They don't get the chance to create a whole new architecture that improves the entire system. For years, all GCA's engineers can do is build on top of the choices that were made for the DSW4800.

For the first few years, these are luxury problems. GCA can't meet demand. It doesn't manage to establish an efficient assembly line. There are problems with inventory control, and the machines' quality steadily drops. The Americans don't take the time to put their house in order. Despite this chaos, the total number of GCA steppers on the market explodes.

There may only be a couple of product lines, but that doesn't mean service and maintenance are simple. Chip makers all have their own wish lists, and GCA's engineers and service technicians are kept busy refining every single machine installed at a customer. They add all kinds of bells and whistles and lose sight of the bigger picture. Add in customers' reluctance to talk openly about their processes and applications, and GCA's developers have to fumble in the dark hoping to get the details right. Bottom line, GCA isn't able to improve its machines to any real degree.

In the early eighties, many customers are worried about throughput. GCA claims its steppers can expose forty to fifty wafers an hour, but in practice the maximum is just fifteen to twenty. The source of the problem is GCA's fragmented engineering. Standard interfaces have been defined between the various components, such as the light source and the reticle changer. Each developer works on his own subsystem in isolation, never looking past the edge of his own module.

When customers come knocking with problems, complaints, and needs, GCA's engineers respond in the same fragmented way. They try to solve the problem within their own island of expertise. No one looks at ways to improve interaction between system components or the reliability of the system as a whole.

The isolated subsystem refinements do produce improvement. For example, the developers manage to appreciably increase the energy of the light source. But other teams' efforts often negate what's been achieved. In 1981, GCA has nineteen independent development teams working on the wafer stepper.

GCA's machines are not unified systems; they're haphazard collections of system modules. As a result, the steppers go down at the drop of a hat. "It might have been more effective to have put engineering resources into improving the overall reliability of the system instead," Henderson concludes several years later.[17] The constraints facing the company and its rapid growth kept the project teams from being able to consider cross-component redesign, she believes.

At the end of the eighties, Henderson sums up GCA's major problems. The company's rapid growth, the many customer complaints, and a lack of focus keep senior management from effectively guiding product development. Meanwhile, a river of complaints and requests keep flooding the development team. Engineers race from one customer to another instead of focusing on substantial improvements and new generations of machines.

GCA's developers also lack a sufficient understanding of chip fabrication processes and it's very hard for them to decide which applications have priority. They don't truly understand the market: they can't manage to distill clear long-term goals from the constant stream of customer complaints and requirements.

Drunk on the success of the company's stepper, GCA's senior management ices the proverbial cake with a monumental mistake. In 1980, the company decides to pursue other machines for the chip industry. It doesn't want to serve just the lithography market; it wants to serve other niches, too.

In the mid-seventies GCA acquired a company that makes wafer handlers. At the start of the eighties, it wants to diversify into bonders, ion implantation, and etching equipment. The company's management decides to throw itself into delivering complete chip fabrication lines.

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The company's diversification strategy soon takes it toll. In 1981, there are forty other R&D projects in addition to the nineteen for lithography. The stepper brings in 80 percent of revenue and over 100 percent of profit, but only a third of the company's R&D budget goes to lithography. "The other lines of equipment took both cash and top management time," Henderson writes. GCA fragments even further, and the sales and marketing departments increasingly complain that engineering won't listen to what customers need.

Engineering accuses sales of failing to prioritize customer requests and of demanding unreasonable delivery dates. Frustrations mount. When a customer's machine goes down, the developers point a finger at manufacturing and service. They in turn point the finger at R&D.

Though its best years are still to come, in 1981 GCA is already struggling to manage a nearly unmanageable organization. Then senior management makes another mistake. Eager to ensure GCA doesn't miss the next step in lithographic technology, it decides to pursue e-beam writing. In those days, the whole world still assumes optics will be old hat by the end of the nineties. A new generation of machines based on electrons or x-rays will be needed to make sure the chip industry can keep meeting Moore's famous law.

In the early eighties, GCA invests $35 million in the development of e-beam systems and $75 to $100 million in factory automation technology. Senior management hopes this will enable the company to build on its stepper success and sustain its growth. But the many problems that follow absorb all of management's attention. Because the company's stepper development is fragmented and unable to improve the system as a whole, customers overwhelm the company with questions and complaints. The executive team spends much of its time traveling to customers to quell their concerns. They also have to manage the company's growth and carry out their ambitious plans to diversify. There's no time for reflection.

The service department can't keep up with the company's rapid growth, either. For years everything goes well. It's a skilled group of experienced service engineers. Most of them have worked in the company's own factory, doing integration and testing. But eventually the company's rapid growth hobbles the service department, too. Soon service engineers are spending the majority of their time solving customer problems instead of installing and servicing machines.

In the early eighties, Ken Pynn is in charge of growing GCA's service network in the US and training its foreign support crew. He manages two hundred service engineers and district managers around the world, and it's soon clear to him that hiring and training staff plus keeping the documentation up to date is a hopeless task.

The problems start in engineering. There are teams for automatic reticle handling, optics, stages, and software development. They communicate the refinements they make and the problems they solve through field change orders, or FCOs. That results in a steady stream of hundreds of FCOs fired at the company's overworked service teams, which must reproduce all those changes on site in customers' factories.

Engineering fires off the FCOs and doesn't look back. They're poorly documented, and sometimes the parts are unavailable. To make matters worse, Pynn can't get all his people trained. "We're spending way too much time hammering round pegs into square holes," he complains to his manager.[18] Pynn's people are up to their necks in FCOs and can't possibly keep the mean time between failures low or guarantee uptime. The result is disastrous. GCA's reputation is gradually reduced to tatters.

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The g-line lens[19] Zeiss makes in the mid-eighties is the final nail in GCA's coffin. The optics exhibit drift: at first everything's fine, but after a while the image quality degrades. GCA is in such a hurry to deliver steppers to its customers that it doesn't check the lenses before they're mounted in the machines. It ships hundreds of steppers with faulty lenses. Zeiss is unaware of the problem for years. Fewer than 10 percent of the lenses are sent back for repairs.

The main problem is that GCA's steppers aren't able to automatically correct for this kind of error. The engineers don't know exactly where the problems lie.

But their Japanese competitors do manage to improve their steppers' focusing systems. What's more, they develop extremely good g-line objectives with a larger numerical aperture. That combination enables their systems to image the micropatterns more sharply onto the razor-thin layer of photoresist.

Chip manufacturers welcome developments like these with open arms, because it means they can image smaller features in their existing plants. All they have to do is change out their wafer steppers. Thanks to Canon's and Nikon's innovations, they don't need to create a whole new infrastructure. Using Japanese steppers, they can make better chips and save money doing it.

It's a law of nature that will repeat itself many times. Over and over again, the chip industry manages to extend the lifespan of existing technology and thereby delay the need for new, more expensive technologies. In the mid-eighties, it causes a shift to g-line technology at the expense of i-line.

When the industry catches wind of GCA's problems with Zeiss's g-line lenses, both companies' reputations suffer massive damage. The problem will also taint ASML in the second half of the decade, because the Dutch company is using the same lens in its PAS 2500. Only in early 1987 will the problem be solved, when the Germans introduce a better gluing procedure.

51. **Japanese Reliability**

Nikon races past a self-absorbed GCA, which has no idea how technologically superior the Japanese machines are.

While GCA is in its death throes, Nikon is steadily preparing its advance. A handful of new American lithography companies is also in the race, but the Japanese optics specialist has a higher purpose. Since 1980, Nikon has worked with giants like NEC and Toshiba in a consortium designed to demolish Japan's technological dependence on the United States.

The VLSI chip consortium, which receives support from the Japanese government, provides a massive boost to Nikon's R&D. It enables the company to rapidly deliver its first commercial lithography machine. When this SR-1 stepper[20] hits the market in 1981, it's soon obvious that much of its technology has come directly from GCA. The American company quickly dismisses the SR-1 as a knockoff of its own machine. Everything about it is the same, from the frame to the wafer stage to the optical alignment.

Major chip manufacturers who buy Nikon's machines often install them beside the ones from GCA. Operators can't ignore the similarity: the two machines look exactly alike. In the chip industry, everyone says Nikon's wafer steppers are Chinese copies of GCA's machines.

In the early eighties, under Ken Pynn's leadership, GCA's service team discovers exactly how that copy got made. NEC asks Pynn to come troubleshoot a GCA stepper that's stopped working. It turns out the machine has been taken apart. But the Japanese made mistakes when they put it back together, and now NEC's people can't get the stepper to work again. Pynn investigates and learns from Japanese colleagues that NEC gave Nikon access to its GCA machine.

But Nikon doesn't stop at a simple copy. After American chip manufacturers buy the Japanese machines, they experience much better customer service. A joke about the disparity soon starts making the rounds. It goes like this: when you buy a stepper from GCA, it comes with a note saying “Best of luck with our best machine.” When you buy a stepper from Nikon, it comes with a second package containing five service engineers.

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While GCA’s engineers are wasting time embroidering on an old design, the Japanese are busy making new machines that are increasingly reliable. GCA’s steppers require the constant attention of an operator; Nikon’s machines can run for hours without touching a single dial. And not only that. The Japanese machines are also much cheaper.

In the early eighties, GCA’s attention is mostly on itself. The company is an arrogant superpower, where the money just keeps gushing in and management is frantically seeking out new opportunities. It barely even notices its emerging competition. It’s fixated on the machinery markets it plans to diversify into. A few years later, Rebecca Henderson concludes that GCA had trouble understanding even relatively simple facets of Nikon’s success. From the conversations she has with GCA’s former employees and customers, she learns that the company’s management simply ignored warnings. She notes one occasion when American customers passed the company confidential internal reports comparing GCA’s and Nikon’s steppers. The move was clearly intended to give GCA a chance to redeem itself.

Alas, to no avail. GCA’s management tosses the intel aside and clings to the illusion that Japanese customers are the primary source of Nikon’s success, patriotically choosing their countrymen over foreign suppliers. GCA’s executive board simply can’t believe Nikon’s machine is superior. As sale after important sale is lost, GCA blames its own sales and service organizations.

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In the bounteous years of 1983 and 1984, GCA HQ in Bedford, Massachusetts makes one mistake after another. It underestimates the investments required for the coming generation of VLSI machines and keeps betting on diversification. Management wants to leverage the company's existing expertise in other markets. It wants to sell its robotic and handling systems for chips to customers in the automotive and aviation industries.

Meanwhile, GCA is rushing to withdraw from other sectors. Just a few years after the company decided to diversify into bonders, ion implantation, and etching equipment, it cancels those projects. It also stops development on its e-beam writer.

All that while, Nikon is unstoppable. In 1984 the company sells as many steppers as GCA, and in 1985 it even surpasses its American rival. By then Nikon has 65 percent of the Japanese market and is also selling well in the US.

Meanwhile, GCA's development group is losing all semblance of cohesion. There are sixty engineers working on the stepper in 1981; two years later, they number two hundred. New engineers are assigned to specific disciplines and subsystems. They don't get the chance to learn how the system works in its entirety, which means there's no opportunity to make integral improvements.

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The fact is, Nikon's machines are simply far more reliable than GCA's. The mechanical design is superior and the Japanese are much more skilled at the mass production and assembly of optical and mechanical components.

Nikon's engineers are given the opportunity to build their stepper from the ground up. That means they have a much better grasp of the factors responsible for the stepper's instability. Take the drift that plagues GCA's machines. The Americans accept it as a necessary evil; steppers are highly complex machines, so it's no wonder you have to constantly tweak them all day. But Nikon's engineers uncover one of the root causes: variations in barometric pressure throughout the day.

Herman van Heek recognized this phenomenon ten years earlier when he was building the Silicon Repeater 1 at Natlab. That shows just how amazingly advanced Philips' technology was even then. The problems with drift get out of hand at GCA in the early eighties because the American engineers have lost the forest for the trees. There are too many problems clamoring to be solved at the same time.

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While GCA is dependent on Zeiss for the bulk of its lenses, the Japanese design and produce their own. Nikon has a good grasp of the interplay between the stepper's mechanics and optics, and that has a huge impact on the machine's performance. In the early eighties, chip manufacturers see the quality of Nikon's optics rise. The Japanese company is thorough and disciplined, and that means it's better at making lenses than Zeiss.

In those days, Nikon excels in managing the lens production process. That means the company delivers reliably high quality. Access to advanced optical glass production plays an important role there. Canon also has access to excellent glass production, materials, and instruments, and a few years later its optics are also superior.

By the mid-eighties Zeiss can't compete. Its highly unreliable lenses give GCA's steppers a bad reputation. ASML isn't aware of the issue at first, but it will bump up hard against that fact in the second half of the decade.

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GCA issues a few last shudders from its deathbed. In 1985 it announces the low-end DSW5000, a stepper for two- to three-micron process applications. But by that time American semiconductor manufacturers have their eyes trained on the VLSI generation of chips, which require a resolution of 0.7 microns. The only suitable market for the DSW5000 is Japan, but GCA's share there has dropped by more than two-thirds.

The company's poor reputation, internal chaos, and directionless engineering spur an exodus of talented employees. A disillusioned Bill Tobey leaves the company in 1983. As GCA's marketing manager in the sixties, he was one of the forces behind the success of the company's photorepeaters. He can't get over how bizarre it is to see management give everything away in the early eighties.

At the same time, it's an example of how unforgiving the semiconductor market is. It's not enough to be alert. You have to be paranoid to survive. Though the game seems simple enough to play, competitors keep overtaking you left and right in the chip market. GCA hasn't failed to understand the market; it's failed to turn known requirements into better machines and better service.

The attention of GCA's management is no longer focused on its core business, steppers. In 1983 the company spends a quarter of its $38 million R&D budget on its Industrial Systems division, which is responsible for developing tougher robotics and control systems for the automotive and aerospace industries—but that division only brings in 7 percent of total revenue.

GCA underestimates the chip crisis that sets in in late 1984. The company does earn record revenue that year, of $309 million. Senior management feels invincible. The sales team warns that chip makers' interest has started to dry up. But GCA's management doesn't listen. Instead of adapting production to match demand, the board stubbornly keeps insisting it will sell five to six hundred machines in 1985.

In the end, it only sells a hundred. Later, GCA will have to write off the rest—at a per-unit price tag of $1 million—as unsellable inventory. Its stepper revenue plummets from $201 million at its peak in 1984 to $118 million in 1985. The company turns a loss of $145 million that year. In 1986 GCA is on the edge of the abyss, with a total debt of $110 million. The company manages to sell $71 million in steppers that year, reducing its loss to $25 million, but the end is nigh.

At the start of 1986 GCA cancels its low-end 5000 model and bets everything on the high-end 8000. It's a last attempt to keep up with Canon, Censor, and Nikon. But it's too late. Its money exhausted, GCA starts paying Zeiss in shares for its lenses, but eventually the Germans stop delivering.[21] In March 1986 the Mellon Bank, one of GCA's largest creditors, installs Richard Rifenburgh at the helm to straighten things out. Rifenburgh sells off the analytic instrumentation and robotics divisions and cuts employees back by two-thirds.

GCA's sales director, Bill Tobey, will later tell analysts the company shot itself in the foot: "Absolute arrogance on the part of our technical people, especially engineering. They thought that no one could possibly equal their engineering feats. We just blew it!"[22] Slowly but surely, the Americans begin to realize that the Japanese have a completely different approach. Their methods impress Richard Elkus. As the cofounder of Prometrix, a supplier to both GCA and Sumitomo, he's privy to a rare peek behind the Japanese curtain. He's impressed by the deep relationship Canon and Nikon have with their customers. He also sees that the entire Japanese industry is united in a mutual mission to make its IT and electronics sector successful, and to do that it's collaborating closely with the country's ministry for international trade.

Elkus notes a strong sense of "we're all in this together" among the Japanese. They're all devoted to the nation and willing to make sacrifices to achieve success. "On the list of priorities, profit was at the bottom," he later writes in his book *Winner Take All*.[23] "The obvious sentiment in Japan was that the semiconductor equipment industry was strategically essential to the economic and political success of the country."

52. **Boulevard of Broken Dreams**

The recession continues and ASML's most important potential customers delay their orders. It's starting to look like game over.

In the late summer days of 1986 ASML is—by the skin of its teeth—on solid technical footing. It has a real, live stepper. The machine has plenty of problems, but it works, and it contains lithographic technology that will keep chip manufacturers happy for the next several years.

After he receives Natlab's evaluation report, Steef Wittekoek congratulates the PAS 2500 team. Sure, there are a quite a few negatives, but all things considered ASML's engineers can be proud of a successful endeavor. The most important numbers are within the agreed specifications. The team has accomplished something huge here. They built a stepper for the new generation of VLSI chips in record time. The whole world can see that ASML's engineers are A-number-one.

Above all, Wittekoek is relieved. Philips has a laundry list of comments and complaints, but the specs ASML doesn't yet meet aren't showstoppers. ASML's executive scientist does emphasize that the throughput of forty-two four-inch wafers per hour is on the low side: "We've got a long way to go there."

In terms of technology ASML stands out, no doubt about that. The lithography company benefits from Natlab's experience and expertise, plus a river of technological innovations. The combination of a research team at Philips and a dedicated product development team at ASML looks like a recipe for success. The precision with which ASML's machines can overlay successive exposures is the best in the world. It produces chips with tiny details and little waste.

Initial customer reports are also positive. The predecessor to the PAS 2500, the PAS 2400, is busy making chips at MMI. That machine proves that ASML's technology is reliable. The device rarely malfunctions. Meanwhile Cypress has been persuaded to buy the PAS 2500 and even AMD looks like it will be giving the green light to buy.

The delivery of a working PAS 2500 stepper has given ASML's engineers a major boost in confidence. They've worked untold overtime, sometimes around the clock. Board member George de Kruiff brags that the light is always on at ASML, even if Philips' drab buildings go dark every evening at six p.m. sharp.

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But Gjalt Smit greets the jubilant mood with skepticism, certainly where the R&D team is concerned. Until there are definite orders, there's nothing to celebrate, and he knows from experience that cocky engineers are a perilous affair. Smit warns the management team to be wary of complacency and arrogance. And that's not all he has to say. Our people need to work as a team and not act like prima donnas, he tells management.

His R&D managers don't get off scot free, either. Smit tells them they aren't looking around enough: "You barely have any contact with the outside world and you don't know enough about what our customers and competitors are doing." To fix that problem, he asks analyst Rick Ruddell to hold company-wide sessions on the current state of the industry.

Coach Smit is increasingly bothered by the lack of incoming money. His engineers' work has earned them a serious assist, but his sales and marketing team isn't dunking the ball. Meanwhile, he's promised his board and investors El Dorado.

Smit doesn't saddle his employees with his financial woes. Senior management is aware of the profit and loss situation, but only CEO Smit and CFO Gerard Verdonschot know ASML's cash position—and they're not sharing that with anyone. The occasional developer who tries to fish for information always gets the same reassuring answer from Verdonschot: "Don't worry about that; just keep making the machines."

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In 1986 the total number of steppers in chip fabs around the world stands at fifteen hundred. In advanced chip processes, one-to-one scanning with projection aligners is definitively over. Steppers have become indispensable for making chips.

But the semiconductor crisis has turned the chip machinery market into a bloodbath. The global market for chip lithography hits an all-time low in 1986. That year, chip makers buy just 125 to 150 steppers. That's half what they bought the year before, a quarter of the number two years back. Three of the ten lithography suppliers leave the field in 1986, and there's still no end in sight to the war of attrition. "There is a real chance that (almost) all US stepper suppliers will disappear: GCA, Optimetrix, ASET, PE-Censor, and maybe Ultratech," Smit writes to his management team in early November 1986. "Leaving the market to Nikon, Canon, and maybe ASML." The expectation is that the market will bounce back in 1987, with sales of some 450 steppers. But no one knows for sure.

The stress mounts in Veldhoven. It's costing a growing fortune to develop the PAS 2500 and set up logistics, sales, and service. Not to mention setting up production. The millions of dollars that keep the young company going have come from ASM and Philips, the NMB bank, and government loans and grants. It's unclear how much damage the recession has inflicted on other stepper manufacturers, though ASML knows from its contacts at GCA that the former market leader is on its deathbed.

ASML barely had anything serious to offer in 1984 and 1985. But now that it has a machine in the second half of 1986, the moment of truth is at hand. Will the company succeed in selling its stepper to customers? It isn't looking that way.

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"The IC industry is in a crisis; recovery is not expected before mid 1987," Smit writes to his management team. There are barely any profitable chip fabs and machinery makers left. Only large customers are still buying machines, and then only the leading-edge technologies required for the new generation of chips. Stepper makers

On December 12, 1986 Wim Troost and Gjalt Smit welcome eighty-year-old Frits Philips to ASML for lunch. Frits is the son of founder Anton Philips, but that's not the only reason people know his name. He's also famous for being the multinational's social conscience, and he's revered in Philips' home town of Eindhoven.

are faced with production overcapacity. They start dumping their inventory, which sends prices through the floor.

Smit asks his management team once again: what is ASML's competitive edge? How can the company prevail in a suffocating market where competitors are dumping their machines and leading-edge technology sets the beat? There are two options: lower their prices, or compete on quality. From the start ASML has chosen the second. Better machines are the only way to beat its Japanese competitors. Smit and his team decide not to let themselves be seduced into competing on price.

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Meanwhile, ASML is doing a sloppy job of product marketing. In its hectic first years, the Dutch company barely notices that its target market has completely changed. The Japanese have won the memory chip war, and in the US chip makers are focusing primarily on ASICs, application-specific chips. American semiconductor companies like Cypress and LSI Logic that are starting to think about next-generation lithography machines suddenly have completely new requirements. That forces ASML to alter its machines, something it doesn't start doing until the fall of 1986. But not everything is an uphill battle. American companies have lowered their requirements on resolution. ASML's machines let them achieve a better overlay, and that lets them achieve better yields.

Smit tallies it all up and concludes that ASML isn't there yet, by a long shot. The major US chip manufacturers are dissatisfied with GCA, but they aren't looking to Holland. They're looking to Japan. In a briefing, he sums up the company's weak points: ASML barely understands the market, has no track record, has too few machines with which to demo its technology, and still needs to tackle a mountain of specs in order to ready the PAS 2500 for ASIC production. According to Smit, the sales team is following a me-too strategy and failing to convey the PAS 2500's unique advantages. To do that, they need to understand their competitors' internal strategies and their customer tactics: knowledge ASML simply doesn't have.

Smit's tone is reproachful. He says that employees barely know the company's policies, goals, and existing structure, which leads to a "lack of intelligent involvement at those levels and hence high costs and unreliable output."

Smit thinks his people are out of touch. Operations doesn't talk enough with engineering, and Veldhoven doesn't talk enough with Phoenix. He worries that ASML is too complacent. The company lacks sufficient awareness of the turbulent business environment that characterizes its industry, he writes in his briefing.

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In 1986, ASML not only has to get the PAS 2500 ready, but also do everything it can to get mass production up and running. Costs just keep climbing. It all takes more manpower and time than they'd predicted. At the end of 1985, the management team is still assuming ASML will have about 260 employees in the summer of 1986, but by year's end the roster exceeds that by a hundred—all of them hired to help them make their deadlines. Production is still struggling. Only twelve machines pass through the factory gates the entire year.[24]

It's a grueling battle with only modest results. At the end of the year ASML has just 5 percent of the American market despite formidable operational expenses for 360 employees. Losses are piling up. By the end of 1986, ASML has burned through $30.7 million.

Smit realizes 1987 will be a crucial year. The company will either sink or swim. After its record loss in 1986, ASML must substantially improve its performance. The challenge is to capture 15–20 percent of the market and achieve "a zero bottom line," according to the operating plan drafted at the end of 1986. That's the only way the company can "convey clearly to the market its commitment and ability to become and remain a market leader." There's no alternative. If ASML doesn't achieve these goals, it will have to close up shop.

Canon and Nikon are profiting from the crisis; together, they hold 70 percent of the market. The market leader in the early eighties, GCA, is essentially dead.

The crisis has also precipitated a shakeout among chip manufacturers, and that raises the pressure on machinery makers to perform. What's more, lithography's strategic value means stepper selection is increasingly a matter for senior management. These executives look at suppliers' long-term viability. Smit is worried about his company's limited access to customers' upper-level executives.

On paper, there are seven lithography suppliers in the world, and that's far more than the market can sustain. They'll all have to invest heavily in technology. It's a given that half of these contenders will go under in the coming years. That drives chip manufacturers to demand guarantees for the future. Customers still aren't taking the Dutch company seriously, and that's Smit's biggest headache.

Potential customers see ASM and Philips struggling, which isn't doing offspring ASML any favors. The joint venture partners are publicly traded, and everyone can read about their difficult battles. Customers ask Smit point-blank whether his shareholders are fully committed to the company, and if they'll keep ASML afloat if push comes to shove.

Smit experiences it firsthand in talks with his most important prospect, AMD. Jerry Sanders' company has been delaying its orders for months and continually adding requirements. Now it's demanding that Philips serve as ASML's guarantor. Smit knows that any such promise will be just an illusion. The parent company didn't found ASML to help it survive, but to split off a foundering project. Luckily, one member of Philips' executive board is willing to write a content-free but beautifully worded letter. AMD is satisfied.

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The skies seem to briefly clear in the fall of 1986. AMD gives its relevant managers the go-ahead to line up the paperwork to buy the PAS 2500. But at the very last minute, Sanders nixes the deal. His money's gone and he wants to wait until the market shows more serious signs of recovery.

Sanders' decision to cancel, for now, an order that would occupy half of ASML's production capacity hits Smit like a sledgehammer. No challenge is too great for his engineers, but the vicissitudes of the chip market and its customers are a mystery to the CEO. The longer it goes on, the more it eats away at him.

The uncertainty drags on. Customers still aren't ordering by the end of 1986. Winter descends; the days grow darker and Smit starts to have real doubts. His faith that ASML will capture a leading position in the US market slowly begins to crumble. He sees that the Japanese have already proven themselves and are having no difficulty penetrating the US market. But ASML can't get a foot in the door. A lithography supplier from tiny Holland all the way across the Atlantic: not a picture that fits into the American framework, Smit worries.

Others at the company begin to share his defeatist attitude. The engineers and production techs don't know the financial details, but everyone can see that nobody's ordering. They've spent two years working toward the ability to manufacture machines and deliver them to customers, but there's nothing to manufacture. Employees start talking about their adventure as a boulevard of broken dreams, referring to an annual theater festival in nearby Den Bosch.[25] ASML's team had a dream, and now it's threatening to fall apart. Some of the employees who came over from Philips in 1984 now make grateful use of their return-to-mommy clause.

53. **Take It or Leave It**

ASML keeps bleeding money, and tightening the purse strings isn't in its CEO's nature. Gjalt Smit's position is in increasing peril.

As the abyss draws closer, the grumbling about Gjalt Smit's spendthrift behavior grows. People are especially incensed at his use of external consultants. Smit's kept bringing in people from Hay without a backward glance. Hay's consultants are used to serving giants like Philips and Shell, but no one's as fun to work with as the guys at ASML. The tiny company exudes an endearing braggadocio in its quest to conquer the American market. What's more, ASML pays well. Despite an utter lack of funds, the company is one of Hay's biggest clients in the Netherlands.

Hay's Jos Bomers regularly attends ASML's management team meetings. It's an automatic breeding ground for new assignments; at some point Bomers stops proposing projects himself. ASML knows his daily rate is $700; Hay sends them the bill, and no one says a peep.

Except for one person. Gerard Verdonschot starts casting a more critical eye on Hay's activities. "Another good catch, huh, Jos?" the CTO says to Bomers after the latest of Hay's invoices lands on his desk. "No worries, Gerard; it's all above board," Bomers answers with a laugh. Their relationship remains cordial. Verdonschot isn't against investing; he just thinks the numbers could go down a little. But when he tells that to his CEO, it goes in one ear and out the other.

Hay's consultants may be expensive, but the real thorns in Verdonschot's side are the exorbitant trips to the US that Smit organizes for his management and sales teams. Twice per year, the CEO flies twenty employees to the US for a marketing and sales powwow with their American colleagues. Hay's consultants go with them on occasion. Everyone flies business class—even the men from Hay.

On those trips, Smit is like a whirlwind. He's the star of the show. He's always in motion, consumed by the game. Team building, Dutch and Americans together, weighing up strategies down to the quarter ounce. His mind isn't on what it's costing; it's on the most effective schedule. He loves brainstorming on the most efficient combination of flights and destinations. The team flies from Los Angeles to Phoenix for a meeting in a resort near the Grand Canyon. The schedule is flexible; the goal takes priority. When Smit decides on the spot that they need to go to San Francisco, it gets arranged then and there. For Hay's consultants, these trips are more like vacations. They don't have to be present the entire time. They meet with the team a couple hours here, talk to some of Hay's American employees a couple hours there, and spend the rest of their time playing tennis. Smit couldn't care less. Whether he spends a few dollars more or a few less, in the grand scheme of things it's all just peanuts. He never had to worry about money during his time at Philips and ITT. If he decided he needed to fly somewhere, he did. But his current colleagues think he's extravagant. Smit gradually spends more and more time arguing with Verdonschot.

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Verdonschot is a skilled financial fixer, someone who spends all his time coaxing money from reluctant investors. The CFO is constantly talking with Philips HQ. There, in the tax and accounting department, he finagles free advice on financial matters. He snags loads of government and private funding from the Netherlands, the EEC, the local province, and the banks. In those early years, ASML is teetering on the edge of the abyss. But it manages to stay alive through a steady stream of technology R&D grants from the Dutch Ministry of Economic Affairs and the occasional grand prize: millions in European subsidies. Verdonschot is an excellent treasurer. He's the mastermind working ASML's financial controls.

Verdonschot grows increasingly frustrated at the ease with which his boss spends the millions he's worked so hard to gather, all in the name of going for the gold. The hole in Smit's pocket gradually annoys him more and more. He starts calling Smit "the big spender," a nickname Arthur del Prado gleefully adopts.

"Gjalt, there's no real need to take those consultants from Hay with you to America, is there?" Verdonschot asks when Smit starts planning his umpteenth trip to the US. "We're a small company paying travel expenses for a huge one. Hay's guys do nothing but hang out with their American colleagues—on our dime. Doesn't that seem backwards to you? Why would you do that? This isn't ITT, you know." Verdonschot also worked for the telecom giant, where money was never a problem.

But Verdonschot's words fall on deaf ears. Hay's Bomers is also nonplussed by the amounts Smit spends, though it works in his favor that Smit doesn't care about the numbers. "Gjalt, take a look at what you're spending. How is it possible?" Bomers tells him repeatedly. But he also admires the CEO's courage. His client never hides anything; he's always open about what he spends. Smit's answer to all these criticisms is always the same: "If we want to get anywhere, it's going to cost us. Period. We can quit or we can keep going, but you can't complain about what it takes."

It's not just those close to Smit who hate the ease with which he spends money. The rest of the company is also aware of his extravagance. The ones who know that ASML is barely treading water are outraged every time he hops on the Concorde to the US. They see Verdonschot puffing on his pipe and pacing his office, wondering how to keep the company solvent. Meanwhile, Smit's out there practically giving money away.

Smit's personality also rubs many employees the wrong way. They view his leadership style as devious. When the CEO needs them, he's charming, but once that's over he doesn't give them the time of day. It doesn't help the company's mood.

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Del Prado's patience with the big spender is also wearing thin. At the end of 1986 it's become eminently clear to Del Prado that he's chugging full steam ahead toward a record loss. The latest calculations tell him he'll probably have to cough up more than $20 million that year, on top of the loss ASM suffered the year before.

Del Prado is under increasing fire from his board of supervisors. In those days, most of its members are trusted faces who rarely protest. Though ASM is publicly traded, Del Prado is still its majority shareholder. The supervisory board represents a limited group of shareholders, and it's subject to the whims of the company's CEO and owner. That makes it more of an advisory council than a controlling body. Nico Nobel is the main board member criticizing the way Del Prado runs the large group of companies. Nobel is trained as an accountant, and even he's having trouble seeing the forest for the trees. As time passes, he notices Del Prado is losing his grip on the company.

It's certainly true regarding ASML. Willem de Leeuw, who came to ASM from Fokker, has been carefully kept at arm's length during his regular visits to the joint venture. The attitude toward ASM is almost hostile. ASML's management and engineers look down on De Leeuw and lead him down the garden path when they talk to him. In their eyes he's incompetent, and all he does is pester them with senseless questions. They take care to keep real issues out of sight. That leaves Del Prado devoid of information about the true state of affairs at ASML.

After AMD cancels its order for a series of PAS 2500 machines, it's time for ASML's management team to visit ASM for a talk. Gjalt Smit, Gerard Verdonschot, and Joop van Kessel know what they're in for when they sit down at Del Prado's table. They've seen this show several times before, but this time you could cut the tension with a knife. Everyone knows how authoritarian ASM's CEO can be, how critical their financial situation is, and how tactless Smit can become.

Financial mastermind Verdonschot knows down to the last detail what Del Prado's going to say. ASML drew up a budget for 1986, but it's long since overshot it. Verdonschot has already traded words with Smit about it, and he knows Del Prado is fuming. The three men don't have to wait long. ASM's CEO hits the ground running. How is it possible that Smit's spent so much more than was budgeted? Does he have any idea what's happening in the market? Smit bristles and grows belligerent. The sparks are soon flying. "All of it is money well spent," Smit snarls, and then he rattles off a list of necessary expenditures.

ASML's CEO isn't afraid to lock horns with Del Prado. "I'm writing the checks, so I'm calling the shots," Del Prado repeatedly says. "That's unacceptable!" Smit bellows back. "This is my strategy. This is my approach. Take it or leave it." Verdonschot has told Smit several times that he can't afford to talk to his board member and primary investor this way. In moments like these, all he can do is look on helplessly as Smit loses all sense of social diplomacy.

* * *

Del Prado's fury is understandable. At the end of 1985 Smit promised him El Dorado. ASML would sell forty steppers in 1986, earning $28.5 million in revenue and a healthy profit of $2 million. Precious little of that has occurred. All in all, ASML sells just twelve machines in 1986 for a paltry revenue of $11 million. ASM itself is headed for a loss of $25 million and will have to share in the joint venture's pain—ASML will end the year more than $14 million in the red.

The only argument Smit can make that holds water is that the PAS 2400 and PAS 2500 have given the company a foot in the lithography market's door. ASML hasn't been able to nab any large orders. All their efforts and hopes were focused on AMD this past year, but Jerry Sanders still hasn't given the green light.

Even the $11 million in revenue leaves a sour taste in Del Prado's mouth. He knows full well that it's artificial. Parent Philips pays the full price for ASML's steppers, while American customers demand such large discounts there's barely any margin left.

Every company that's making lithography machines is dumping its inventory. That's hurting ASML's ability to haggle. The prices that American and Asian customers are demanding show just how much pressure ASML is under in 1986. All together, Cypress pays $1.725 million for two PAS 2500 steppers, Taiwan's Erso[26] buys one for $850,000, and MMI buys three PAS 2400s for $600,000 each. In contrast, Philips' two fabs, Elcoma in Nijmegen and Valvo in Hamburg, and Natlab paid the full price—$2.5 million—for each of the three PAS 2500s they've bought.

ASML's target market is the United States. All its attention and sales efforts are concentrated there, yet the Dutch company doesn't seem to be making any headway. The company reels in MMI and Cypress, but they don't add enough weight to the scale. It's bothering Smit more and more. ASML isn't credible enough, he explains; American customers seem to feel the risk is too great.

The recurring tune Smit heard at SEMICON West 1984 starts running through his mind again: chip makers won't buy from ASML until it's sold ten to twenty machines. That's what they keep saying, and that means he can't move forward. As the crisis continues instead of abates, he's increasingly aware of just how little influence he has on the two crucial factors: the market and potential customers. If chip manufacturers aren't looking to buy machines, then ASML can't possibly score any sales. In Smit's imagination, the American hurdle his company has to clear is growing larger and larger. Every passing month adds credence to his doom scenario. He tortures himself with the knowledge that he can't make the market play along; he can't even say whether ASML will survive at all.

The difference of opinion between ASM's owner and ASML's CEO ends in a stalemate. Del Prado is safeguarding his interests as a shareholder in trying to limit expenditures. Smit clings stubbornly to his mission to propel ASML to number one. The two don't manage to close the gap between them.

Gjalt Smit in 2012

54. **Eighty Bucks and Sayonara**

Arthur del Prado even talks with Japanese companies to try and keep ASML afloat. A large order from AMD is a welcome shot in the arm.

When a group of ASML employees visits SEMICON Europe in Zurich at the start of March 1987, they get their first real glimpse of the devastation afflicting the chip equipment market. Eaton-Optimetrix has closed up shop and ASET isn't demoing any machines. The survivors have little news to share. GCA and Perkin-Elmer are demoing steppers, but "they're old frames with new lenses," Frits van Hout writes in his trip report. Zeiss started developing the Europa lens[27] back in March 1986, but a year later there's no sign of the new optics. "Even Zeiss's booth at the show doesn't have a Europa lens," Van Hout records. He spies an opportunity for ASML. The only company offering an i-line machine is GCA, which is all but dead. "It looks like there's a clear opportunity to shut out the Japanese, because there's no serious i-line activity to be seen," he writes. He can only surmise that Zeiss is in serious trouble. Van Hout's suspicion is confirmed when Gustaf Pieper, a member of Zeiss's executive board, visits ASML a month after SEMICON Europe and discusses the gravity of the situation with Gjalt Smit. Zeiss is having difficulty manufacturing the complex lenses, but Pieper promises they'll get it working.

Pieper's promise turns out to be empty, which compels Smit to send a strongly worded fax[28] to Oberkochen. He's desperate to get specs on the Europa lens. ASML needs that information to make the required corrections to its machines. "Delayed delivery of the PAS 2500/40 with the first 58 lens is now the major obstacle in Philips' megabit project," Smit writes about the Europa lens, then notes that the latest acceptable delivery date for the Megachip group is just ten days away.

Zeiss can't get a handle on the production of an earlier i-line lens,[29] either. Smit spells out the problems for Pieper: Zeiss is running four to six weeks behind, and ASML has to send back half the lenses because the quality's too poor. Of the repaired lenses, 50 percent once again fail to meet the specs, Smit rails. ASML needs specific numbers for each lens so it can install it correctly in the steppers, but that information often arrives too late or is inaccurate.

All this causes serious delays and raises production costs at ASML, because the company loses incalculable time installing and removing the lenses. Smit estimates that six to ten steppers won't be delivered until 1988 as a result. "With in turn serious consequences for our bottom line and inventory as well as our customers (including Philips and AMD) to whom we've made commitments," Smit writes.

* * *

At Zeiss, Erhard Glatzel asks the young researcher Winfried Kaiser to investigate the problem. Kaiser's regular job is to take measurements in the camera lens department and he's happy to briefly escape the boring world of photography. He notices that his colleagues are all convinced the blame lies elsewhere. It can't be Zeiss's fault; they've been making lithography lenses for decades, and ASML has just arrived on the scene. The only possible explanation is that a couple of inept engineers in Veldhoven have made mistakes during acceptance testing.

But Kaiser unearths the problem in less than two weeks. The Europa lens's focal plane is mildly curved. As a result, the lens only focuses properly in either the center or the corners of a flat plane. It's an error shared by half the lenses. The other half barely squeaks by.

Because his colleagues are still pointing the finger at ASML, Kaiser decides to check out the situation there. In ASML's cleanrooms he's able to measure undeniable deviation. They've mounted the lenses in their steppers, and the microscopic images bear witness to the error in the lens. The curved focal plane means the structures in the photoresist are sharp in the center or at the edges, but not both. Kaiser locates the source of the problem in a metrology issue. Erroneous measurements have kept the curvature from being noticed. Once uncovered, the problem is relatively easy to solve. And so Zeiss is able to bring the development of its prestigious Europa lens to a happy close.

But in the year that follows, it becomes evident the Europeans' expectations are too aggressive regarding technology. Philips' and Siemens' Megachip project is targeting 0.7-micron chips they want to manufacture using an i-line stepper from ASML and Zeiss's Europa lens. The EEC is giving them grant after grant to develop this technology.

But Siemens can't seem to get its chip process up and running. The German multinational plans to use the technology being developed by the Megachip project for DRAM production. But the company's semiconductor division can't get a handle on the overall process. The bottleneck is the photoresist for the i-line. It still causes far too many problems.

Afraid of missing the 4-megabit DRAM generation, Siemens initiates an emergency backup plan. It buys the entire process for the new generation of memory chips from Toshiba—amid loud protest from German and European grantmakers. The Japanese have chosen a much safer route for their 4-megabit DRAMs: they use g-line light to expose them.

To that end, Canon has developed a stepper and optics with a higher numerical aperture. It's an advanced lens that further improves the resolution attainable with g-line light. While previous g-line lenses could image details around one micron, the new Canon stepper can image lines just 0.8 microns wide. True, that's a little larger than the 0.7 microns the i-line can image, but this Canon machine enables chip manufacturers to use the g-line from the 1-megabit DRAM process for the new generation of 4-megabit DRAMs. That means Toshiba can keep using familiar materials and equipment for a new generation of memories.

Siemens' about-turn has widespread implications for the choice of materials and machines with which it equips its chip fabs. For ASML and Zeiss it's a crushing disappointment. Siemens isn't taking any risks; the company has decided to copy Toshiba's entire

4-megabit DRAM process down to the last detail. That means a switch to Canon's wafer steppers. It marks the start of a long relationship between Siemens and Canon.

ASML and Zeiss are left out in the cold. It's a blow whose aftershock will be felt for years. A factor completely outside their control has thrown a wrench in the works. A seemingly minor factor, the photoresist, has driven the choice of equipment for an entire chip fab. That drives home the importance of proceeding with extreme caution during a technology transition.

* * *

There are also a few bright spots in 1987, even if they don't add up to much. In late January MMI places a second order for four PAS 2400 machines, and Texas Instruments and MSC each buy a PAS 2500. Siemens wants to buy two, Philips sixteen. The operating plan for 1987 lists ten prospects for the PAS 2400 and twenty-five chip makers who might buy PAS 2500 systems. ASML is projecting orders for four PAS 2500 steppers from AMD, Cypress, DEC, Hughes, TI, and VTI; the remaining numbers are lower. ASML needs to pull out all the stops. Its sales target for 1987 is forty-five PAS 2500s and fifteen PAS 2400s. The company made too many PAS 2400s in 1986, but MMI's enthusiasm indicates they're likely to get sold.

Meanwhile, the company is racked with growing pains. After oceans of blood, sweat, and tears, ASML finally gets production up and running. The problem is finding experienced people, an issue that's also starting to affect its field service. ASML launches a strategy that will grow into an integral part of the company's culture: it starts encouraging developers to switch to operations and service for a while, in exchange for a higher salary and better career prospects.

* * *

ASML's shareholders are also struggling. Philips' components division Elcoma is still in dire straits, and the Megachip project is experiencing delays. Meanwhile, the ongoing semiconductor recession has severely strained ASM International, which closed out 1986 with a record loss of $25 million[30] on top of a $5.8 million loss the year before. Arthur del Prado has had to reduce his staff in the US from six hundred to two hundred people. The sustained malaise also forces him to take action at home. In February 1987 he says goodbye to eighty-five of his three hundred and fifty employees in Bilthoven. And as ASM enters the new year, there's no sign of impending improvement. The company will manage to keep revenue steady, but will still close out the year with a loss of $23 million. Del Prado does manage to raise several million during the crisis years, however. In late 1985 the Dutch Ministry of Economic Affairs grants him $12 million to build a laboratory in Bilthoven, and he may also borrow $9 million from the NIB bank.

Del Prado is under immense pressure. The reigning opinion is working against him, and that chafes. He's created a high-tech pearl from scratch, but all it's brought him is criticism and disbelief. A tormented Del Prado speaks to the press: small-minded Holland simply refuses to understand that the current recession is all part and parcel of the laws that govern the chip industry.

In a variety of newspapers, Del Prado rages in early 1987 against his country's blinkered mindset and rigid labor laws. "It is quintessentially Dutch to instantly doom risky ventures such as ASM to failure," he tells the national *NRC Handelsblad*. "If our lights are on past ten-thirty three nights in a row, the labor inspector asks to see our work permits. Should we embrace the other extreme instead? Should we leave a key strategic industry entirely to America and Japan? Then I say: let's just be happy milking cows, churning butter, and growing tulips."

An aggrieved Del Prado says no one will acknowledge ASM's accomplishments: he's managed to increase his market share and is selling equipment in Japan to Hitachi, NEC, and Toshiba for the latest generation of chips. The outside world sees only his losses. One thing is certain: the water is up to Del Prado's neck.

In the press, ASM's CEO disparages the policy being followed by the state-owned private equity fund MIP, which is investing in

ASM's competitor Focus but not in Del Prado's company. If things keep going this way, he may have to succumb to acquisition by a Japanese company. "Japanese banks are highly interested in us, and given our operations in Japan, a Japanese M&A is quite likely," he threatens in the *NRC*. "In one way that's wonderful, of course, but at the same time it poses a grave danger."

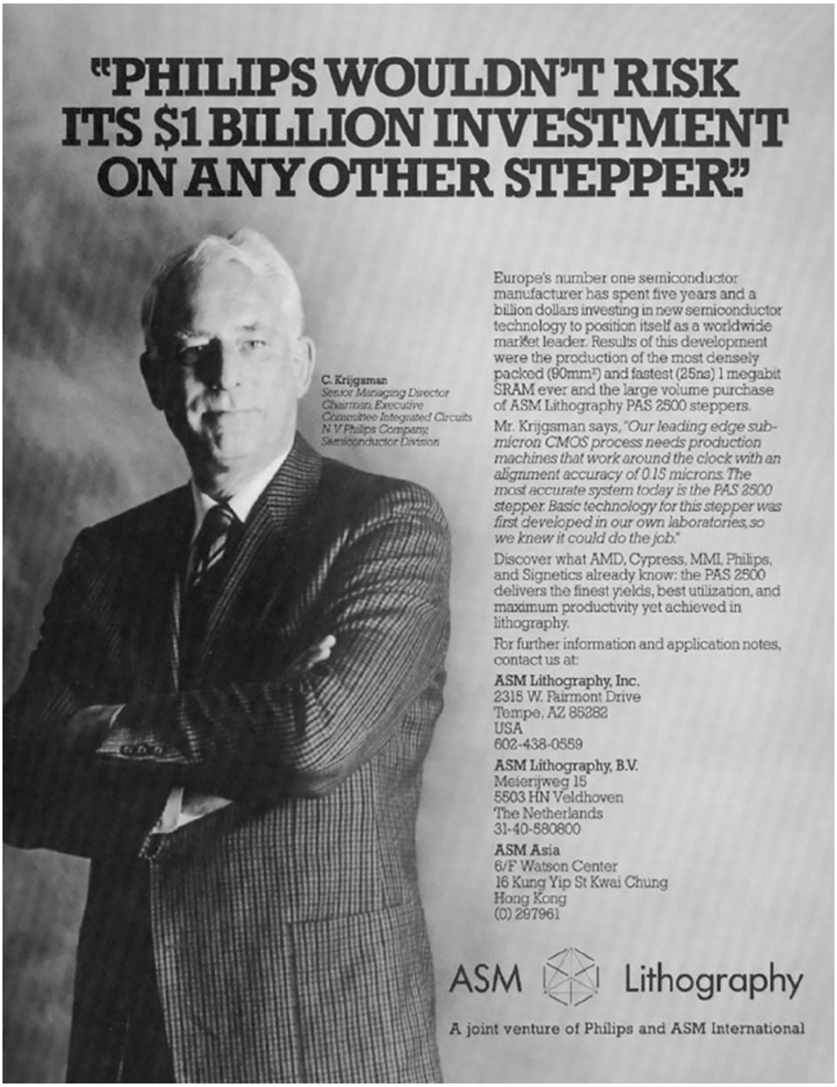
* * *

As 1987 progresses, Gerard Verdonschot has more and more trouble paying salaries at ASML. Meanwhile Del Prado is scouring the country, on the hunt for funding. The Japanese takeover ASM's CEO mentioned in the press is no bluff. In May 1987, a group from Sumimoto visits both ASM and ASML, then spends two months negotiating with Del Prado. ASM's CEO keeps his options open, and in the following year he enters talks with Mitsui.[31]

Smit's not too excited about that. He's more inclined to an American takeover and suggests Perkin-Elmer and Applied Materials, even though the latter company is at war with ASM.

Meanwhile, the poor performance of both ASM and ASML is putting increasing pressure on the relationship between the two CEOs. Del Prado detests Smit's spendthrift style. Smit also endures heavy fire at the annual gathering of ASM's division heads. He's been known for years as the big spender who's burning through all their hard-earned money: what ASM earns on furnaces and back-end assembly goes up in smoke at ASML. Every year, ASM's management team tries to put the screws on Smit. Tempers flare, and Del Prado and Smit even snarl at each other in the hallways.

When he updates his operating plan in February 1987, Smit humbles himself. He knows the board of supervisors will also read the document. ASML's ambitious goals and tight deadlines made it very hard to keep costs down over the past three years, he writes apologetically. Then he adds, "This year we will have to be extremely cost conscious to maintain our credibility as this company's management."



Kees Krijgsman at Philips Elcoma remains squarely on ASML's side even in difficult times. He's happy to let the company use him to achieve its marketing goals.

His words are just for show. In truth Smit doesn't mean a word of what he's saying. In fact, he believes the opposite: ASML should continue to invest aggressively. You don't win the gold medal by sitting still. End of discussion.

But Smit's position is growing precarious. The recession drags on. Not a single major customer rings the bell. Every now and then a university or research lab buys a stepper, but ASML can't live off crumbs like that. *Jesus, it's all going wrong*, Smit thinks. ASML still doesn't have an in in the US, the takeover of GCA fell through, and a deal with Ultratech never materialized. All the company's chances for success seem spent. Smit no longer believes in victory himself, and increasingly wonders how he can look his employees in the eye. These adverse market conditions are not a problem ASML can solve. Smit feels powerless.

Tensions with ASM mount. Del Prado sees that ASML isn't shipping machines and he hears about the delay to the crucial AMD order. The mood dampens. Smit's people openly ask him about the future, and the CEO can barely bring himself to wave away their fears. He feels the energy draining out of him. He talks about it at length with his confidants at Hay,[32] because he can't share his concerns with anyone at ASML. Still, when Germany's Leybold Heraeus feels him out for an executive position, he declines.

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In the course of 1987, ASML's success with MMI finally reaches AMD. Jerry Sanders' company is in the middle of acquiring the memory chip manufacturer, and when AMD's people arrive to tally up inventory, they see Perkin-Elmer's machines gathering dust in a corner. Meanwhile, the six PAS 2400s are constantly cranking out wafers under the watchful eye of ASML's service engineers. It's the final push AMD needs to say yes to ASML.

At last, on June 1, 1987, AMD signs a contract to buy twenty-five PAS 2500 machines—a year and a half after its first tests on the PAS 2400. Smit whistles down the hallways for the rest of the day.[33] With good reason: Sanders' company has also requested a quote for twenty-five to thirty additional machines.

AMD's order is a victory for Smit, but his expiration date as ASML's CEO has arrived. The company's perilous financial situation and his confrontations with a cornered Del Prado put him in an impossible position. When Leybold makes him another offer that summer, he says yes. The German company doubles his salary and gives him a company BMW.

On August 20, 1987 George de Kruiff announces the change to the rest of the employees: their CEO has accepted a position on the executive board of Leybold Heraeus in Hanau, West Germany. ASML's lower echelons are particularly glad to see Smit go. When the company passes the traditional hat around its three hundred employees for a going-away present, it raises less than eighty dollars.

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What shape is ASML in after Smith closes the door behind him in the fall of 1987? Financially speaking, a good deal worse than at its founding in 1984. By late 1987, the team in Veldhoven has burned through nearly $50 million. The promised sales haven't materialized. The honeymoon is over for ASM and Philips. Their joint venture is an ongoing hemorrhage. It's a miracle ASML is still alive three years later. But alive it is. The outside world can't see it, but since the summer of 1984 a well-oiled fighting machine has slowly but surely arisen. In three years' time, Smit has laid the groundwork for an inspiring organization.

The eighty-dollar middle finger that ASML's lower echelons give their former CEO is in stark contrast with his performance. With the gold medal as his goal, Smit didn't focus on the money; he invested where he needed to and did so consistently—though here and there he could certainly have spent less. But without this ruthless gambit to reach the top, Europe would never play a leading role in the world's most challenging industrial technology, chip lithography.

It may seem counterintuitive, but the deep and lengthy recession from 1984 to 1987 is what saves ASML from disaster. Smit will express his amazement at that for the rest of his life: the market's collapse while he was CEO was ultimately a godsend. If the market had continued to grow after 1984 the way analysts had predicted, Zeiss wouldn't have been able to supply GCA and certainly not ASML. The market was demanding a whole new generation of lenses, but the Germans couldn't make them with the required quality fast enough. Zeiss's production was in such poor shape that Canon and Nikon would almost certainly have captured the entire market without the recession.

The recession also gave the Dutch team the breathing space it needed to stay in the race. ASML had enough time to whip its development and production into shape. Ironically, the lack of sales also played a role. The assembly plant in Veldhoven simply couldn't have filled truly large orders in 1986 and 1987.

Smit will later brand the crisis and the accompanying delayed wave of machinery purchases an act of God: an event over which he never had control, but which in an unpredictable, miraculous way ensured ASML's survival. In the fall of 1987, no one in Veldhoven can feel that hand of God. It's the Japanese who are doing all the celebrating. Toshiba, NEC, and Hitachi have conquered the global market for memory chips, and Canon and Nikon dominate the lithography field. They've captured Japan's entire domestic market, and in the US Nikon has put the final nail in former market leader GCA's coffin.

The three-year crisis from 1984 to 1987 is in fact so destructive that only Canon and Nikon experience undisputed success. In terms of market share, ASML is barely in the same galaxy.

ASML's battle for the gold medal, an ambition Smit voiced in his first years, is just now getting started. There's an innovative and exceptionally self-reliant development team, logistics and mass production are nearing maturity, and sales and marketing are a serious force. The intense training required to propel the company onto the global winner's podium can finally begin.

Part 8

Running in Place
1988–1990

55. **The Fat Man**

Wim Troost says his last goodbyes—then ends up in the director's chair after all.

In the late summer of 1985 Wim Troost celebrates his sixtieth birthday, the age at which Philips employees retire. At his farewell party Gjalt Smit, Joop van Kessel, and Gerard Verdonschot come up and shake his hand.

"Wim, you've earned your retirement," Van Kessel says, "but if you want to show up on Monday to help us out, we'd love to have you." Smit and Verdonschot smile encouragingly. ASML is barely a year old then. The management team is swamped and several issues are going unaddressed. The young joint venture is also still entangled with Philips. The multinational's machine factories and glassworks continue to make many of the fledgling company's essential components, with the usual sluggish delays. With his gigantic network, Troost is just the man they need.

Troost is also a man who can't say no: even before he retired, he'd already accepted a seat on a thousand and one advisory committees. But he can't refuse a request from ASML. The next week he shows up on the company's doorstep. He and Smit agree that starting in September, he'll work three days a week as a part-time consultant. That same month, he oversees ASML's move to Veldhoven.

In his new role, Troost is responsible for the e-beam machine ASML is marketing globally for Phillips S&I. He also handles all the odds and ends that Smit and his management team don't have time for. His to-do list covers fifteen full pages. Set up the company's works council, arrange a series of open houses, hire security guards, take care of landscaping, parking, an evacuation plan, and protocols for important visitors: Troost handles it all.

But by March 1987, his work is done. ASML has a solid machine that's netted them a few American customers. Troost decides it's the right time to say goodbye. His wife is glad he's officially leaving. Now they can finally take those long trips they've been dreaming about for years.

On a warm day in the late summer of 1987, Troost is relaxing in the garden behind their white farmhouse in the nearby town of Nuenen. As the sun warms his skin and his wife tends her bees, the garden gate swings open. It's George de Kruiff, the towering S&I director who was Troost's boss for years. De Kruiff has a problem, and he cuts right to the chase: "Gjalt Smit's left the company."

De Kruiff begs Troost to step in and mind the shop for a while. A few days a week, that's all. Arthur del Prado is feverishly searching for a permanent replacement. It won't take more than a few months at most. They drink a second glass of wine, and then De Kruiff is gone.

Troost is Troost: he says yes. His heart and soul have always belonged to the stepper project, and if ASML needs him, he'll be there. And it's only for a short while.

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In Veldhoven Troost encounters a jittery ASML. Smit has vanished and no one knows what's going to happen. ASM International is still responsible for finding a successor, but all that's coming from Bilthoven is radio silence. Troost hears that the unions are coming in to talk that same evening. Cutbacks are on the way. The works council and the unions are demanding that ex-Philips employees be allowed to return to the nest as agreed upon.

Troost assumes Del Prado will soon show up with a new CEO. Meanwhile, the work is steadily piling up. The retiree is soon spending sixty hours a week in Veldhoven.

Painful weeks pass. Troost isn't officially authorized, but documents keep coming in that need a signature.

At last Del Prado walks into the boardroom trailing a short, fat man. The Englishman introduces himself to Troost as Clive Segal and says he's currently running Cambridge Medical Equipment. Not much else is said. Del Prado asks Troost to leave the room and stiffly adds that Segal will soon be installed as the company's new CEO.

Troost wants to roll out the red carpet for ASML's new leader and gets cracking. He and his management team are steadfastly convinced Segal will start after the holidays. In the first days of January 1988, a welcoming committee is on constant alert. Evert Polak, Joop van Kessel, and a few others keep watch in the lobby in one-hour shifts. But the expected CEO doesn't show up.

After a week Troost phones Del Prado: what on earth is keeping Segal? ASM's CEO is busy and assumes the new guy will soon arrive. That's all anyone knows. At last Troost gets hold of a telephone number in England. He calls it regularly, but Segal's secretary keeps telling him her boss is traveling. At some point he starts getting insistent: this is urgent. Her boss will soon be starting work in the Netherlands, and Troost wants to hear a firm date.

At last Troost speaks with a surprised Segal. The Englishman tells him he has no affinity whatsoever for the semiconductor business. He isn't planning to join ASML at all.

Troost explodes. Never has he encountered a situation so insane. He's livid as he shouts at Del Prado and De Kruiff over the phone. "I'm doing my damnedest here. I'm giving this everything I've got. You're just playing at running this business," he yells. Then: "First off, I want you to name me CEO as of this very second. I want a contract, so it's official and so I'm authorized to sign what needs signing. I'm through playing the fool around here."

A few days later, Troost receives a short letter from Willem de Leeuw. The letter appoints Troost ASML's CEO. Will he please sign?

And that's how the man who never once in his life asked for a promotion or a raise, the man who fought tooth and nail to keep lithography alive when he was at Philips, the man whose fellow S&I directors maligned him for his money-guzzling projects, the man who was passed over to lead ASML in 1984—that's how this man finally thrusts his hand in the air and demands the unconditional leadership of a company that would never have existed without his determination and persistence.

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Troost's administrative assistant, Fia Loozen, is struck by how different her new boss is from Gjalt Smit. Smit had no time for the little things and rarely double-checked a figure; the former Philips director is highly organized and obsessed with details. When Troost has to reschedule an appointment in his detailed planner, he carefully records where the appointment came from. On the page where the appointment was canceled, he adds a reference to the new date, with an explanation.

That's not his only quirk. When Troost hands someone his business card, he also gives them three old business cards from Philips. Loozen will call him "sir." He doesn't ask her to; everything about him simply makes it impossible to do otherwise. She also encounters a new phenomenon: she's expected to type up the letters and documents he dictates. *Holy cow, he's old school,* she decides.

Troost ushers in a wind of change. Smit spent money like water; the new CEO tracks every cent expended and studies every opportunity to cut costs. That includes ASML's expense allowance system. The company's employees receive a fixed monthly sum for business expenses. That figure doesn't include travel expenses, meaning it's really additional salary packaged in such a way the company doesn't have to pay tax on it.

Troost isn't used to this kind of arrangement. He's agreed to an annual salary of $110,000 and a maximum expense allowance of $5,000, the same amount Smit received when he started in 1984. But when he starts trying to cut the company's expenses, he just can't get rid of the fixed, contractually agreed reimbursements. Even his own assistant calls a colleague in the legal department to protest the move. Troost realizes there are some things he's just not going to be able to accomplish. Loozen can tell it's hard for him.

Smit's style of delegating was to say "Make it happen." Troost, in contrast, follows the rules in both spirit and letter and walks through every detail of a task with his employees. In her new boss Loozen sees a fighter, a man in the Philips mold who works day and night and expects those around him to do the same. But even Troost has his foibles. He has his business cards printed with "Dr."

in front of his name to impress their American customers. It's a habit he picked up at Philips, where it's common practice because foreigners don't have a frame of reference for the Dutch "Ir." title.

To help ASML survive, Troost has to trim the fat where he can from the four-hundred-employee company. He announces the measures he's taking at the end of 1987. First, he dials down their ambitious production plan. In early December, production manager Van Kessel passes the news on to his people and his suppliers: in 1988 ASML will build not eighty machines, but just sixty. Troost also tells everyone to expect sixty jobs to go. The Phoenix office won't be spared.

56. **Flat Broke**

ASM International has hit financial rock bottom. It can't continue its lithographic adventure and has to bow out.

At the start of 1988 ASM International is at a major financial low point. In the preceding three years, it turned a total loss of $64 million. The subsidiary in Veldhoven is a stone around Arthur del Prado's neck. Of the $23 million ASM loses in 1987, ASML is the greatest culprit, losing nearly $8 million.[1]

It's clear that ASM can no longer survive its adventure in lithography. Del Prado's search for a co-investor has so far failed to bear fruit. Even the Dutch government's private equity fund—created specifically to provide capital for this kind of risky, large-scale technology project—refuses to sign on. Del Prado has been openly criticizing the agency's policy for years. Rumor has it he's squandered all his credit as a result. ASM's CEO takes his search all the way to Japan, but no one is interested.

Del Prado's room to maneuver is shrinking. At complete odds with his natural style, he must put together a management team—at his bank's ultimatum—with a solid CFO. He approaches André van Rhee, a corporate veteran who's held the position for the past fifteen years at imaging equipment manufacturer Oldelft.

But ASM isn't the only one reeling; ASML's red ink is a disaster for Philips, too. The electronics company has no interest in its partner pulling out. Philips chose the joint venture structure precisely so it could split off its lithography activities. When the company's bank, NMB, decides things have gotten too perilous, it asks Philips to act as ASML's guarantor for an additional $25 million line of credit. That leads to a contract with Elcoma, which guarantees it will buy seventy-five steppers from ASML over the coming years.

* * *

Elcoma's Willem Maris signs a contract to buy seventy-five steppers in the presence of Wim Troost and Dick Aurelio (to the left and right of Maris). ASML and Elcoma issue a joint press release, without this photo.

When Van Rhee joins ASM International as its CFO in 1987, the company has been burning money for years. But even in that difficult time he meets a Del Prado whose optimism can't be shaken. The CEO talks incessantly of his vision: a group of companies capable of supplying the entire chip industry. Van Rhee is quick to realize that ASML is Del Prado's dream project.

These years are privately disastrous for Del Prado as well: in 1986 he loses his wife. But the energetic entrepreneur barrels on as if nothing's amiss. So much vision and perseverance—Van Rhee is astonished.

In the midst of the recession, a year before Van Rhee arrives at ASM, the company starts another joint venture, ASM Ion Implant, with four technology entrepreneurs in Boston. Del Prado frees up money for it even though things are tight. Now test equipment is the only branch missing from the ASM tree. In that same year, Del

Prado tries to convince Philips to acquire GCA. He also works vigorously on his Japanese adventure. In 1987 he sets up a factory in Nagaoka, and a year later ASM opens new headquarters in Tama.

In Bilthoven, meanwhile, construction has started on a laboratory for chip machines. If Del Prado had his way, the Netherlands would concentrate its semiconductor research there, just as Belgium is doing with IMEC in Leuven. ASM's CEO constantly reassures Van Rhee that things are going fine, and says time and again that a down cycle is perfectly normal in the semiconductor industry. The chip market follows a natural wave, and he's convinced the crisis will soon blow over.

But against all expectation, the recession continues. And then, on October 19, 1987, the global financial markets suffer another massive blow. This day, which will go down in history as Black Monday, slows recovery. At the time Del Prado is negotiating the sale of ASM Fico, a subsidiary specializing in chip packaging machines. The stock market crisis wipes that deal squarely off the table.

At the start of 1988 there's no way out left for Del Prado. He has to switch to a gear unfamiliar to him: selling off parts of the company in order to stay afloat. It's a hectic year, in which the backend division, ASM Pacific Technology, gets listed on the Hong Kong exchange.

In 1988, everything of value is on the chopping block in Bilthoven. In the end Varian buys the ASM Ion Implant subsidiary, created just two years earlier. ASM's management even debates the fate of the flagship, ASML. The company isn't looking to divest—at least, not yet. First, De Leeuw is tasked with writing a business plan in a last-ditch attempt to sway investors.

De Leeuw draws up a company profile.[2] At that time, ASML has 380 employees, 70 of whom work in Phoenix. It's in the process of letting some people go. De Leeuw emphasizes that no one, including new investors, will be getting the market handed to them on a silver platter. The semiconductor industry has had it rough in recent years and because lithography is a strategic investment, customers spend a longer time kicking the tires on new machines. "Evaluation periods of one year or more are no exception," he writes.[3]

At that point ASML has two versions of its PAS 2500 machine.[4] "Nevertheless continuing development is required for improvements, new features, and new versions in this highly demanding and performance-sensitive market," the profile states. It will take a capital infusion of $38 million to keep ASML alive until it first turns a profit in 1990.[5] "The current shareholders will not be able to make these monies available," De Leeuw writes, noting that to date ASM and Philips have invested more than $65 million in ASML.[6] The additional amount Philips has lent the joint venture now stands at $12 million.[7]

* * *

In the spring of 1988 ASML hits its credit limit of $25 million. That puts the next round of salary payments at the end of the month in immediate peril. Jaap Gooijer, who's in charge of finances for Philips' domestic divisions, calls Verdonschot to account. It feels like everyone's watching as ASML's CFO turns his flashy vintage Jaguar into Philips' parking lot across from the soccer stadium.

Gooijer greets Verdonschot with a loud "So, how are things at ASML?" The CFO has a short answer: "Not good. We need to pay salaries, but we don't have the money." Gooijer explains that ASM and Philips are in a stalemate: "Del Prado won't invest more. His money's gone. So we aren't going to invest more, either. This is the end of the road."

Verdonschot pretends surprise. "Are you serious, Jaap?" Gooijer doesn't budge. "We are absolutely not putting more money in. We're done. The gate is closing. Tell your people we're pulling out." Verdonschot scratches his head. Surely Philips doesn't let some financial guy make that call?

"Listen, Jaap," he says. "I'm just a simple accountant trying to do his best. But I'm not the shareholder. That's you. If you're pulling out, it's your job to tell everyone that, not mine." Verdonschot says he'll get everything ready for Gooijer's speech. "I'll set it all up. We've got a large meeting room. I'll gather everyone together at five p.m. I'll rig up a makeshift podium for you, and you can climb up on it and tell everyone Philips is pulling out of the venture."

Gooijer shifts uneasily. "No, no. I'm just a simple accountant on the company payroll, like you." Verdonschot stands up, says a polite goodbye, and repeats his offer. "Really, it'll be no trouble to set it up for you." A half hour later he gets a call from Gooijer: "How much are we talking about for those salaries?" One point three million dollars, Verdonschot tells him. Gooijer repeats the number. He'll transfer the money the next day.

This situation drags on for three months. During that time Del Prado tries to convince Japan's Mitsui to buy a stake in ASML, in vain. ASM is flat broke. Month after month it's unable to put money in, while Philips keeps transferring the cash to pay salaries. By mid-1988 there's no escaping it. The cash shortfall keeps growing. Philips keeps putting money in, keeping the company alive.

* * *

ASM can no longer keep its promises to Philips, and that's a bitter pill for Del Prado to swallow. There's no sign things will improve in the foreseeable future, either. He's run out of options. If he doesn't act now, ASML will drag its parent company down with it. Del Prado has no choice; he's forced to say goodbye to his flagship.

Now Philips has to decide what to do. ASML's fate lies with the multinational's executive board. To Troost's immense frustration, they don't invite him to attend the pivotal meeting. In those years, Philips' performance is abysmal. CEO Cor van der Klugt has to sell off parts of the company to keep the rest afloat. Almost no one at the executive level is enthused about continuing the adventure in lithography.

It's board member Gerd Lorenz who somehow manages to flip the mood around. Thanks to his impassioned plea, the company decides in August 1988 to keep ASML alive. Lorenz is German and has only been a member of Philips' executive board for a year. He has an outstanding track record, including stellar performance by Philips' semiconductor fab Valvo in Hamburg.

In the eighties, both the US and Europe are suffused by an often emotional discussion about being too dependent on Asia. Many people view relinquishing control of strategic technologies like lithography and memory chip production technology as a grave danger. Germany is particularly adamant about staying independent. Lorenz argues passionately for keeping this expertise in house. He manages to convince his colleagues.

In the end, Philips assumes ASM's shares and debts in the joint venture, without any additional settlement. That means Del Prado has forfeited his entire $35 million investment (read more about the final statement in appendix 12).

* * *

Unraveling the joint venture is a piece of cake, because there's hardly anything to unravel. ASM and ASML were supposed to join forces in sales and marketing, but that never got off the ground. The joint venture's service department is also fully independent. In the most important market, the US, parent and offspring are each pursuing their own path.

ASM and Philips end their partnership with a fairly simple contract. If ASML should have an IPO or be sold in the future, ASM will still benefit. It's a five-year agreement in which ASM's share in an IPO or sale goes down a little more each year. It will ultimately take seven more years before ASML goes public, in March 1995. ASML retains the right to keep using the ASM in its name for another ten years. That will lead to renewed negotiations in 1997.

After ASM's departure, Philips approaches ASML's bank, NMB, to help set up a corporate structure that will make it possible to keep receiving all the available government grants from the Netherlands and the EEC. Both Philips and ASML are making maximum use of these facilities to support research in the Netherlands. If ASML is fully owned by Philips, one of those paths will vanish entirely.

To preserve the two-stream situation, Philips must not have the power to fully dictate its subsidiary's course. So the electronics company sets up an organization in which the NMB bank takes ASM's place and Philips officially waives its controlling interest—all in close consultation with the Dutch Ministry of Economic Affairs.

57. **Promising Customers**

Micron Technology in America and TSMC in Taiwan play a crucial role in ASML's survival.

In the late eighties a curious American chip manufacturer comes onto ASML's radar. It's Micron Technology, a semiconductor company that doesn't adhere to Silicon Valley logic. Micron isn't located in the Bay area but in the potato-filled farmlands near Boise, Idaho, just under two hours' flight from San Francisco.

Micron's strategy also differs significantly from that of Californian chip companies. The firm is exclusively focused on dynamic random access memories—DRAMs. By the late eighties most US companies have ceded the DRAM field to the Japanese. In 1985 a whopping seven American semiconductor manufacturers threw in the towel and stopped making DRAMs; the Japanese now control nearly the entire market. But Micron stubbornly ignores the bloodbath and keeps making DRAMs.

Twin brothers Joe and Ward Parkinson found Micron in 1978 as an engineering firm designing custom chips for others. In 1980 they develop a product of their own, however, a 64-kilobit DRAM. At that time Motorola and IBM are the market's major players, but the Parkinsons manage to create a much smaller and appreciably cheaper design. A smaller chip means less need for expensive silicon and at the same time higher yields. If the brothers can successfully manufacture their new DRAM, they'll have a winner on their hands.

The Parkinsons go looking for investors so they can build a DRAM fab. They meet Jack Simplot, a man who made his fortune in the potato industry. Simplot invests a million dollars in Micron, in exchange for 40 percent of the shares. The deal will make him a billionaire.

* * *

Micron is nowhere to be found on the list of American prospects ASML drafts in early 1987. But that changes as the year progresses. ASML's US sales team contacts the DRAM maker. Micron is looking for production technology that will enable them to shrink their chips even further—much further—in the coming years. The Dutch lithography company has an appealing stepper to offer them.

That's because 1987 is the year in which ASML equips its PAS 2500 with a new i-line lens. That makes it possible to print lines thinner than a micron.[8] ASML sends a prototype machine to Philips, which wants to use i-line technology in its Megachip project. An order from Micron soon follows as well. At that time, the company is mass producing 256-kilobit memory chips.[9] In January 1988 the company finishes its first acceptance testing on the PAS 2500/40, and in the four months that follow it exposes more than a thousand wafers.

When Frits van Hout visits Boise in May 1988 to discuss the state of affairs, he learns how Micron does things. John Aiton shows him that the DRAM maker not only makes smaller chips; it also needs just seven exposures to manufacture its memories. That saves the company a great deal of money. Its Japanese competitors need double that number.

Micron bought ASML's i-line machine to dramatically shrink its 1.2-micron chips. Aiton is optimistic after the first tests using the PAS 2500/40. He thinks his company will be able to make three or four generations of memory chips with the machine. Micron is currently readying the PAS 2500 to make 4-megabit DRAMs, which require 0.7-micron lines. "We expect your systems to let us bring that down to 0.5 microns," Aiton says. That brings 16-megabit DRAMs within reach. "We've already printed chips with lines that small."

Aiton informs Van Hout that Micron's testing reveals the PAS 2500's conveyor belt produces way too much dust, ten times more than assembly robots. And that dust has made its way throughout the fab. As a result Micron is urging all its suppliers to switch to robots for wafer displacement.

After ASML has landed chip manufacturer TSMC as a customer, the company partners with Taiwan's Hermes Epitek. That marks the start of one of ASML's most successful market penetrations. In contrast to ASML's approach in the US, the partners opt for a local sales and service organization in Taiwan to support customers like TSMC. In the photo, Wim Troost is signing the partnership agreement with Archie Wang of Hermes Epitek.

But Aiton is also full of praise. No matter what chemical processes he exposes the wafers to between the lithographic sessions, it doesn't disrupt the ASML machine's alignment—quite a change from what Micron's used to with competing equipment. The PAS 2500 also came through a power outage with flying colors: the temperature rose throughout the factory, which disrupted production, but once the power came back on, Micron could resume production in less than four hours. They didn't have to tweak a dial on ASML's steppers.

* * *

The PAS 2500 does a number of tricks better than its competitors, but it's still a rickety machine. That's not always the fault of ASML's engineers. Chip manufacturers adjust the machine to match their own specific production processes. At Micron, too, those tweaks engender problems. When Aiton remains dissatisfied, ASML takes a step that will have a lasting effect on the way it engages with its customers. In consultation with Micron, it decides to station a service crew in Boise. They'll search for the root of the problems, not to assign blame but to solve all the issues as a team. The goal is to get the PAS 2500 to meet all the specs ASML promised, namely the average number of wafers per day and the machine's maximum downtime.

The Dutch company has one more condition: if its machine starts performing better, it will share in the profits. In the years that follow Micron steadily grows, and ASML benefits from that success.

* * *

The late eighties give rise to another newcomer who will be essential to ASML: the Taiwan Semiconductor Manufacturing Company. TSMC is a foundry, a chip company that doesn't design chips itself, but manufactures them purely for others.

When TSMC is founded in 1987, Philips receives 27.5 percent of the company in exchange for its chip technology and $58 million. The electronics conglomerate holds training sessions and shares the expertise required to build and run a chip fab. In the years that follow Philips lets Taiwanese engineers observe development in the Megachip project. Because the manufacturing processes are identical, Philips can transfer existing chip production lines as-is to Taiwan. That makes it an obvious choice for TSMC to use the same equipment in its chip production.

It seems like a simple stepping stone for ASML, but it's anything but. TSMC is convinced of the PAS 2500 i-line's technological advantages, but it is free to make its own purchasing decisions. ASML's relationship with Philips actually seems to work against it. TSMC is also a Philips subsidiary and it takes full advantage of the fact: the negotiations are tough and the Taiwanese present a fat package of requirements.

Wim Troost knows this deal is vital and makes sure he's available day and night. To his wife's annoyance, he even lets TSMC call him out of a dance performance they're attending on vacation in Bali.

With TSMC, ASML encounters a typically Asian attitude: customers refuse to pay for service. It's a culture shock for the Dutch, because the US equipment industry is used to signing service contracts. In Asia, in contrast, companies buying seven-figure machines expect years of cost-free service. That's what makes the negotiations so difficult. It's a bucket of cold water for ASML's engineers: a customer who doesn't want to pay for the value they deliver.

The two companies spend extended time on the phone, often late into the evening. At last TSMC sends ASML a contract that's two fists thick. But Troost doesn't stop there. He makes a deal with financial controller Theo Bartraij that they'll each work through half the document. Bartraij works until deep in the night, but he doesn't make it all the way through. The next morning he discovers just how boundless his boss's energy is. Troost has annotated his half from A to Z and edited it down to the last comma.

TSMC has barely finished installing ASML's machines in its fab when it sends a fax in late 1988: they need seventeen new machines pronto, because their factory's burned to the ground. It's a shot in the arm for ASML. The order provides vital financial breathing room at just the right time. TSMC sends all the wafer steppers from its factory back to Veldhoven. The cleanroom there is jam-packed with half-assembled PAS 2500s and the returned machines from Taiwan. Among the returned steppers are a few with only minimal smoke damage. A striking number of the machines are easily fixed. TSMC's insurance company—the formal buyer—is ASML's biggest customer in 1989.

58. **Nikon's Achilles Heel**

Richard George returns from the US to drive progress: the company needs a new generation of steppers, fast, that can absorb the next five years of technological development.

In 1986 Gjalt Smit sent an unwilling Richard George to ASML's Arizona office. During his exile, the former PAS 2500 project manager flies from Phoenix to customers week in, week out for two long years. He learns product marketing the hard way: customers show him wafer fabs in which new Nikon steppers are churning out chips, alongside older equipment from GCA, Perkin-Elmer, and Ultratech.

Nikon is the obvious lithography champion, with a market share of 75 percent in Japan and 50 percent in Korea, Taiwan, and the US. Its installed base is large, its machines' reliability high. Nikon steppers run nonstop without problems for an average of sixteen days. The company sells almost four hundred of them a year. Fab managers point satisfied fingers at the machines and ask George whether ASML can beat that kind of technological prowess. Not likely, they grin. Certainly not with the PAS 2500—George can see that for himself.

His intense conversations with American chip makers give George a feel for what customers want and need. Without exception they're wildly curious to hear his opinion on technology that will help them lower costs and raise margins.

Mercury i-line lithography has just arrived, but everyone's already looking to deep ultraviolet light (DUV) from krypton fluoride (KrF) excimer lasers to print even smaller details. Every chip manufacturer is also eager to increase production speed—*throughput* in chipmaking jargon. That can be achieved with larger exposure fields and faster machines. The entire industry is also sidling reluctantly toward the switch from six-inch to eight-inch wafers: it will take massive investments, but the payoff will be significant future savings. Topics like these are always good for lively discussion.

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Once he's definitively back from the US, George shuts himself up in the De Brug hotel in Mierlo along with Steef Wittekoek, Martin van den Brink, and their wives. Even before they sit down to dinner Friday evening, they're talking about lithography. GCA has just introduced a DUV stepper and the question is how ASML should respond. Will they make a successor to the PAS 2500 with a larger numerical aperture, or is it better to design an entirely new architecture? Customers are already clamoring for systems that can handle larger wafers. The evening is dominated by talk of 365 nm i-line, 248 nm DUV, and eight-inch wafers. The women are used to it.

For two whole days the men discuss technology. How can they keep their development pace high? New lenses will keep coming along in rapid succession. What are Nikon's strengths and weaknesses? ASML's machines will definitely need to be fast, George says, and support the smooth exchange of masks and wafers. That will take advanced control systems, and in addition their wafer steppers will need to communicate with other machines in the fab.

George tells the others about Nikon's Achilles heel. The Japanese company's service organization is slow to respond. He's heard several customers complain about it. "Which surprises me," he tells Wittekoek and Van den Brink. "Service is how they bested GCA." George also views the late introduction of an i-line lens as a weakness. "But they'll soon put out an i-line lens that looks better on paper than our /40 lens," he says. "And they're also planning to equip the machine with eight-inch wafer handling and advanced robotics."

They shouldn't underestimate Canon either. This Japanese optics specialist didn't launch a stepper until the end of 1983, after Nikon had already beaten GCA in the Japanese market. Canon now holds 20 percent of that same market, half the European market, and 10–15 percent in the rest of the world. "Canon competes on price," George says. "But their optics are good. The whole industry is talking about their g-line lens and its unusually large image field."

Canon's 28 mm image field hurts its resolution, but it lets fabs make larger chips. That makes it an interesting machine for both DRAM and ASIC manufacturers, George believes. "Everyone today wants lenses for larger images." Canon doesn't yet have an i-line lens, but the delays to its DUV technology mean the Japanese company will soon put out an i-line machine, George expects.

They have less to fear from the remaining Americans. GCA and Ultratech are now General Signal subsidiaries. GCA's main strength is its Tropel optics division. The US defense department is also supporting GCA in the development of a DUV stepper. "GCA still has the largest installed base," George says. "But their technology is far inferior to ours and the Japanese."

It's clear ASML's wafer stepper needs a complete revamp. The rapid pace of developments means they need a new machine architecture that can be easily adapted. Lenses and component systems need to be rapidly exchangeable. They need a flexible design that can last for at least half a decade, even though requirements change every year. The machine must be able to image eight-inch wafers, because that's where the future is headed, first with i-line and later with lasers. George, Wittekoek, and Van den Brink realize they've been far too aggressive in pursuing new technology these past years. ASML pounced on the i-line wavelength much too soon; because chip makers clung to the short-wavelength g-line longer than expected, i-line remained a niche for years. They don't want to make that mistake again.

The two companies' marketing statements indicate that Canon and Nikon plan to skip the i-line and move directly from g-line to 248 nm lasers. But George, Wittekoek, and Van den Brink are seeing i-line start to prove itself in the market. Once that wavelength becomes the standard, chip makers will cling to it longer than expected, they're convinced.

In the months that follow, George clears his mind and writes everything down. He pours two years of discussions with potential customers and the input from his two technical buddies into a document that will become the starting point for the wafer stepper with which ASML will truly strike a blow in the market: the PAS 5500.[10]

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George's experiences and the intense discussions that follow plant the seed for the product policy group: an elite corps of ASML employees that determines the company's product development strategy. Only the best experts take part. Every three months they meet to make decisions about the specifications for their lithographic machines. They consider not only what customers are asking for, but also what's manageable and technologically feasible.[11]

The product policy meetings develop a reputation. The group lacks any kind of hierarchy. Its members cross-examine each other without mercy. The sparring is all verbal, though Van den Brink often adds force to his words by banging a fist on the table. George and sales director Doug Marsh clash over deadlines, pricing, and the promises on which ASML can and cannot deliver. To the naive onlooker, it often looks like the men are street fighters lunging at each other's throats, but after the intense meetings the mood is always collegial: they drink a beer and are thick as thieves. It takes newcomers to the group a while to understand that the attacks are never personal.

After a few years, engineers from Zeiss start joining these quarterly meetings. It takes them a while to get used to what they view as incredibly rude Dutch frankness. When Hermann Gerlinger starts attending in the nineties, he watches with growing amazement as Van den Brink harangues his colleagues. He pushes, pulls, and twists. At some point Gerlinger's close colleague Winfried Kaiser and Van den Brink are screaming at each other. *What on earth is going on here?* Gerlinger thinks. *What in the world are they doing?*

It's Gerlinger's first encounter with ASML's culture. After the meeting he asks Kaiser how he was able to stay calm after Van den Brink's attack. Kaiser has to laugh. "Martin only fights with people he respects," he explains. "Sure, he's always on the offensive, but you'll learn that it's never personal. He gets caught up in the moment. He's just fighting to make sure product issues get solved, and his style is very vocal. Hermann, you've got a lot to learn."

The product policy meetings are always about making the best choices. In the nineties the Germans gradually adjust to ASML's culture, growing to appreciate the company's open communication style. The quarterly meetings will become the glue that binds ASML and Zeiss, laying the foundation for a sense of team spirit and a successful partnership.

59. **Cash Flow Positive**

For the first time, ASML earns more than it spends. Amid the jubilation Dick Aurelio suggests the company go public, but Wim Troost has misgivings.

In the early summer of 1989 a sigh of relief can be heard across all of Veldhoven. For the first time, ASML has earned more than it's spent. It's a year after its former parent company ASM International has said a permanent goodbye. Philips is on the edge of the abyss, but its subsidiary is once again in the mood to make plans. The entire management team leaves for an offsite retreat in the La Ville Blanche hotel in the southern town of Thorn to map out a strategy for the next five years.

The result is a business plan with a renewed sense of initiative. "As ASML passed through its fifth anniversary, we also crossed the important startup hurdles of positive cash flow, positive profits, and achievement of significant market share," the document crows.[12]

The mood is so upbeat that the plan even proposes a public offering in mid-1991. It's "an opportunity for customers to invest [...] while simultaneously reducing Philips' ownership percentage." The money ASML hopes to raise will go mostly to fund the R&D for its new generation of machines.

The idea to go public is Dick Aurelio's. ASML's senior vice president for commercial operations came over from Picker International, a General Electric subsidiary specialized in medical diagnostics. Just before he left, Gjalt Smit hired the American at Arthur del Prado's behest. Aurelio provides direction to the company's service, sales, and marketing divisions. He's based in the US, but often present in the Netherlands.

Aurelio knows what it takes to sell complex machines to customers. He's persuasive, a natural salesman with ambition. He enjoys his life of luxury and likes to splurge. His trademark style is neatly groomed, in sharp suits and designer Italian shoes. He's eager. A quick score: that's what he likes. When Smit's successor fails to show up and Wim Troost temporarily fills the gap, Aurelio—just a handful of months at the company—brazenly applies for the open CEO vacancy.

In the recession year of 1988, Aurelio and Doug Marsh get ASML's foot in the door at major companies like Micron and National Semiconductor. He also plays a role in approaching the American titans IBM, Intel, and Motorola. But in early 1988 the board of supervisors doesn't see him as the right person to keep ASML on course and they give Troost the job instead.

Troost is suspicious of Aurelio's ambitions. He has little affinity for the man's flamboyant lifestyle. The American is constantly suggesting they go public, but his experience is a mismatch for that of the reliable Philips man. "We don't have the strength to knock over a feather," Troost says in those discussions. "Let's first make sure we deliver machines and make a splash in the market."

Troost doesn't have much control of his management team, and none at all of his R&D department. The whole company barrels on like a runaway train. In five years' time, ASML has evolved into an organization filled with passionate people in development, logistics, sales, and marketing. The CEO's main task is to take care of the odds and ends.

When Aurelio once again mentions going public at the meeting in Thorn, Troost doesn't argue, even though he doesn't like the idea. The CEO falls back on his strategy of deliberate passivity, which he also employed as a manager at Philips. He can live with it if Aurelio adds a projected IPO in the summer of 1991 to the business plan. Troost knows the chip market is turbulent and paper is patient. He wants some peace and quiet at the company; there's no point in starting an argument. Plenty of time to correct things later.

* * *

In the summer of 1989 the management team has several reasons to predict a rosy future. In 1988 and 1989 the chip market is finally growing again. ASML has the wind at its back. The business

Wim Troost in 2016

plan[13] proudly reports that the company now has 15 percent of the global market for steppers. The management team is fudging a little here. The fire at TSMC added seventeen machines to ASML's 1989 count, exactly what it needed to move from red to black.

In truth ASML's position isn't good at all. The company still isn't a serious player in the lithography market. The PAS 2500 stepper isn't distinctive enough compared to its Japanese competitors. ASML's financial position is also terrible. Orders point to a doubling of its revenue and a profit of seven to nine million dollars in 1989, but in fact ASML's position is still weak. What's more, it's deeply in debt to Philips.

The chip market keeps maturing. Consolidation, specialization, and aggressive investing have created a premier league of major players. In 1989 thirty semiconductor companies are responsible for 80 percent of total worldwide chip equipment purchases. That makes it increasingly harder to attract the most important customers' attention, especially for smaller suppliers of production equipment and technology.

That doesn't sour ASML's mood. Under Aurelio's direction, sales and marketing optimistically project linear growth. He expects to ship eighty machines that year and to equal that number in 1990. In the three years that follow he's counting on sales of 90, 120, and 145 systems.[14]

As a salesman Aurelio has built up significant credibility. He can demonstrate that he's making headway with major customers. National Semiconductor and SGS Thompson are now buying from ASML, as are the rapidly growing accounts of Micron and IDT. ASML has given potential customers a peek at its plans for the PAS 5500 and titans like IBM, Intel, Motorola, and Siemens have indicated they'd like to help develop this new machine. "Solely on the strengths of our development plans, several major customers are willing to commit to cooperative agreements for the realization of that product," the business plan reads.

What's more, the Dutch Ministry of Economic Affairs and the EEC's ESPRIT project have approved substantial loans plus a $16.5

million grant to develop the PAS 5500. ASML estimates these will cover 60 percent of its total R&D costs.

* * *

In truth the company's whole strategy in 1989 revolves around the PAS 5500. The business plan states in no uncertain terms that ASML's future depends on this machine: "The cornerstone of our five-year strategic plan is the finalization and implementation of our next generation of product." It's obvious the machine's development is critical. "We are entering the next important period of growth, an area where most of our competitors have failed: the successful launch of a next-generation product that remains competitive and continues to gain us market share."

The failing competitors the plan's referring to are GCA, ASET, and Perkin-Elmer's stepper subsidiary, Censor. GCA is on government life support—the US doesn't want to lose its strategic chip lithography technology. The real competition is in the Far East. Nikon rules the global stepper market by a landslide. It's leading in Europe, Korea, and the US, and shares near-total ownership of the Japanese market with Canon.

But the big opportunities right then are in the Pacific Rim. New companies in Korea and Taiwan are growing fast thanks to support from their local governments. ASML wants to use those countries as a springboard to Japan. About the war it will have to wage there against Canon and Nikon, the business plan says the company will "finally attack their home markets through ASML's superior product, performance, and service."[15]

The PAS 5500 must become the industry workhorse for 16- and 64-megabit DRAM chips. At the time, 1-megabit DRAMs are in mass production and 4-megabit versions are in pilot production. In the late eighties, these kinds of memory chips are the engine driving the semiconductor market. They are the force behind technological development. The first company to install a new chip process can enjoy high margins on larger memories or cut costs significantly by shrinking older chip generations.

DRAMs form the lion's share of the chip market. At the end of the eighties, analysts are even convinced they'll soon comprise two-thirds of global semiconductor revenues. That's why ASML is focusing mainly on DRAMs for its new PAS 5500. But not entirely: the company is also targeting the US, which is mainly making ASICs and microprocessors. But if ASML can satisfy DRAM manufacturers, America will sit up and take notice.

* * *

In the product policy discussions taking shape in those years, the company's top engineers happily ascertain that they're on the right road. Thanks to Philips' and Siemens' Megachip project, they were able to hop on the i-line train early. Lithography at this wavelength is now globally evolving into the dominant chip production technology.

Canon and Nikon made a mistake there. Until recently, their strategy was to skip i-line and go straight from g-line to deep ultraviolet. But they've had a rude awakening. DUV has turned out to be incredibly complex and their machines can't get past the R&D stage. They need copious floor space and aligning the wafers is tricky. DUV is still much too unreliable for chip manufacturers. What's more, there isn't even a photoresist available for 248 nm. Canon and Nikon are now forced to consider i-line after all.

ASML went through such a rough time in 1988 that it couldn't even seriously invest in a DUV machine. Now the product policy group has decided to strengthen the company's position by releasing a transitional machine with a high-resolution i-line lens, the PAS 5000,[16] before launching the entirely new PAS 5500 in 1991.

Even so, in August 1989 ASML plays a leading role in *Semiconductor International*'s cover story on DUV. In the article, the Dutch company says it's equipped a PAS 2500 with a lens for DUV and a KrF laser. That work was made possible by a European R&D project for which Steef Wittekoek managed to wrangle funding from the EEC a year earlier.[17]

In *Semiconductor International*[18] Wittekoek gets the chance to broadcast an important message. He says the market can still keep

ASML's management team gathered together in Phoenix. Standing, from left to right: Anders Jacobsen, Evert Polak, Nico Hermans, Doug Marsh, Joop van Kessel. Sitting, from left to right: Gerard Verdonschot, Wim Troost, Dick Aurelio, Steef Wittekoek

going for now; the current progress with i-line lithography is still impressive: "We still see a relatively long period where i-line steppers will be used." ASML's executive scientist is certain that i-line steppers will achieve a resolution lower than half a micron. "All generations of 16M DRAMs, and even the fully shrunk version, will be predominantly produced on i-line steppers. Even the first generation of 64M could be produced with i-line."

* * *

Troost's intended term of office is short. His primary task is to keep ASML on track by serving as a sparring partner for the management team. He's signed on for eighteen months and wants to definitively wrap things up after that.

Aurelio makes no secret of his desire to be CEO. Troost hears it repeatedly during the many conversations he has with the sales and marketing man. And the American's reputation is solid at the end of 1989. His team members Ken Pynn and Doug Marsh know the managers at American customers from A to Z. Without this sales, marketing, and service team, ASML would be a goner.

But Troost is worried the American will instill a hierarchical culture at the company. Aurelio has no affinity whatsoever for the works council, while Troost believes a good working relationship with the employee organization is essential. The salesman also regularly says ASML would reach its full potential much better in the US, and particularly Silicon Valley. Troost views that as a threat. He's not impressed by American machine R&D and he doesn't want the whole company to move to the US. Aurelio suggests it regularly: the most important market is America, ASML needs to be close by. Service is easier to manage there and there are lots of suppliers, possibly even for lenses.

Philips ultimately passes Aurelio over for ASML's top job. The full owner selects a manager from its own stables to lead the machinery manufacturer. Aurelio draws his own conclusions and leaves ASML just over a year later, to run Varian.

60. **Turbo Mode Engaged**

Evert Polak underestimates the speed of the lithography market, is roundly criticized, and then saddles his engineers with a grueling task.

In 1988 Richard George sketches the first contours of an entirely new machine. It's the product of his experience, a brain dump of two years talking with chip makers in the US, and intense conversations with Martin van den Brink and Steef Wittekoek. He describes what a completely new stepper needs to look like to be able to absorb every innovation in the chip industry for at least five years. ASML has gotten i-line imaging down below a micron, but the goal is a machine that can easily be upgraded to image quarter-micron chips.

Now that George has put their starting points onto paper, they need to fill in the details and select a foundation for the machine's architecture. The primary requirement is that it enables ASML to rapidly implement changes and adapt to every new technological development.

ASML's executives still think Martin van den Brink and Frits van Hout have too little experience to lead this massive project. That means there's a desperate need to hire a senior project manager a.s.a.p. In the meantime Van den Brink and Van Hout are keeping things on track, but even customers comment that the pair seem extremely young. Signals like those regularly reach Troost's ears. What use does the lithography maker have for greenhorns who studied urban heating and low-temperature physics?

Troost is worried. He thinks the two can't handle the project in the long run. But applicants repeatedly drop out of the running. Some of them give it a try, but call it quits after a few weeks. The material is too complex. For lack of a better alternative, management has no choice but to keep the pair in charge of the project. Van Hout is the project manager; systems engineer Van den Brink is his right-hand man.

* * *

In May 1989 PAS 5500 development gets fast-tracked. The source of the urgency is the buzz surrounding eight-inch wafers at SEMICON West in San Mateo. According to Dataquest analysts, NEC and two other Japanese manufacturers have already set up pilot production. The market researchers project that all major chip makers will switch to eight-inch wafers in the coming years. More than ten companies in Japan plus IBM, Intel, Motorola, and Texas Instruments in America are preparing for the transition.

By then, Dick Aurelio has been leading ASML's US sales team for over six months. At Motorola he detects major interest in steppers that can expose eight-inch wafers, but he has nothing to offer them. Given the steep development costs and low sales projections, ASML hasn't even started doing R&D on eight-inch machines. In San Mateo, Aurelio harangues Evert Polak for not having any eight-inch machines in the pipeline. ASML will regret that decision for years.

From his conversations at SEMICON West, Aurelio concludes that PAS 2500 sales are in danger. ASML's image is still poor. Dataquest puts the Dutch lithography company in fourth and last place in its global ranking with a market share of just 6 percent, after Nikon (53 percent), Canon (18 percent), and GCA (10 percent). If ASML wants to be taken seriously, it's going to have to present an alternative.

For Polak, SEMICON West is a vicious wakeup call. Aurelio has nothing good to say about the Dutch engineers. They're out of touch with the market. Polak grabs the phone and calls Van den Brink. "Martin, get ready to put the new PAS 5500 in turbo mode. We've got to get that machine ready within two years." Polak's schedule is unrealistic. ASML is back where it started, facing the same challenge it faced in 1984: creating a brand-new machine from scratch in record time.[19]

* * *

With all the customer requests and complaints regarding the PAS 2500, there's actually no time to develop a new machine.

But there's no choice. So Van den Brink gets started, with only the PAS 5500 blueprint George put down on paper over the last months to guide him.

Van den Brink steps into the role of architect and starts designing a new generation of machines. It's a colossal task and he barely has any people. Yet he sequesters himself for three months to transform all the requirements into something that must become a revolutionary architecture.

A handful of engineers[20] raise their hands when Van den Brink asks for help. It will become a once in a lifetime experience, though they don't realize it at the time. To work it all out they choose a location in relative isolation, a meeting room at the Zwaga and Partners accounting firm across the street. There they roll up their sleeves and spend just under a hundred days creating the PAS 5500's architecture.

What's clear is that it will be a Lego stepper: a modular machine whose component systems can easily be clicked together. That flexibility is useful during assembly, to be sure, but it will also save chip fabs a lot of money if service techs can quickly switch out the lens, the light source, or another module. It also makes it possible to upgrade the system by replacing system components. That means semiconductor manufacturers can achieve higher resolution by swapping out the lens, say, instead of having to buy a whole new machine.

At first the engineers are concerned with more than just the machine's physical design. They also have to choose specific technologies and then expand on them. If a machine architecture isn't solid from the very start, everyone will have trouble with it later. It can create years of misery.

One of the uncertainties is the wafer table's precision. At that time ASML is using the H-stage with linear motors in its machines, but it's unclear how much play is left in that system. The requirements for alignment—and thus for precise positioning—are increasing, and no one knows exactly how long the H-table can keep meeting them.

The big question is whether they should even try to squeeze more out of the current design. In the mid-eighties, Natlab came up with a more accurate alternative. With an eye to the future, the lab's stepper research is using positioning tables for ten-inch wafers (the chip industry hasn't even moved to eight-inch as standard yet). The choice to use ten-inch wafers seems to endanger the ability to achieve high precision. To solve that, Gerard van Engelen at Natlab thinks up a long-stroke, short-stroke engine design that's more future-proof (appendix 13). The big question is whether the PAS 5500's architects should adopt it.

In addition to Natlab, ASML has been working since the start with the CFT, a bastion of mechanical, mechatronics, and electronics engineers who live a little closer to real-world production. The two blood groups—Natlab research and CFT development—have had a healthy rivalry for years. At the CFT in 1984 Van den Brink meets Jan van Eijk, someone who's just as stubborn and as passionate about engineering as he is.

Van Eijk is a down-to-earth idealist who studied high-precision engineering and then completed his alternative to military service with UNESCO in Pakistan and Sri Lanka. In 1984 the Dutch mechanical engineering legend Wim van der Hoek asks him to come work for the CFT, where he meets Van den Brink. They will spend the next few years working together on a sacred mission: perfecting systems for ASML.

In the eighties and much of the nineties, ASML is still outsourcing all its systems development and prototyping to the CFT and Natlab. That includes the wafer table. For the PAS 5500 it needs to become much faster and more precise, and it also has to travel a longer distance in order to step across an entire eight-inch wafer. That makes Van Engelen's experimental long-stroke, short-stroke Natlab motor worth considering, but Van Eijk believes there's still plenty of room to grow left in the familiar old H-table model. Van den Brink invites the two men to defend their viewpoints in a meeting.

The question is whether ASML should choose evolution: gradual improvement such as Van Eijk is suggesting. In that case, there's a chance they won't achieve the necessary precision as the requirements for overlay and resolution increase. The alternative is to pursue a breakthrough using Natlab's revolutionary long-stroke, short-stroke idea. In that case, they run the risk of encountering as yet unknown roadblocks during development: experience shows they always crop up with new principles. If that happens it's guaranteed to cost money, and if things go truly wrong the project will be delayed beyond rescue.

Chief architect Van den Brink is undecided. He wants to follow both paths for six to nine months. That means both the CFT and Natlab will create a functional model. Van den Brink hopes that will let him quickly see what fundamental problems they'll run into. Van Eijk and Van Engelen start their technology race.

In the end the trusty old H-stage turns out to have sufficient potential to position eight-inch wafers. So ASML takes the safe route. Van den Brink now has a good alternative in the wings for future generations of machines.[21]

* * *

What's instantly clear is that the PAS 5500 will also use the through-the-lens alignment whose foundation was laid in the seventies by Gijs Bouwhuis. In the second half of the eighties Van Eijk and Van den Brink greatly improve on this technology (appendix 10).

The problems created by Van den Brink's revolutionary machine are not solely technical, but also organizational: he doesn't have enough developers. Klaassen is in particularly urgent need of them. The man who got the crucial electric motor up and running during ASML's first year of existence is leading development on the PAS 5500's wafer stage—quite a challenge with all the increasing requirements.

The PAS 5500 will have a wafer table with six degrees of freedom, Van den Brink has decided. The wafer must be positionable in all directions and angles to extreme accuracy. Among other things, that makes it possible to lay the wafer flat for each exposure, which is important for properly focusing on the thin layer of photoresist.

Klaassen and his team are tasked with creating the drive and control systems for this 6DOF table.

ASML has placed a special request with Hewlett-Packard. The American company will develop an interferometer that can measure five degrees of freedom in order to track all the stage's movements in real time. The trick is to make sure that during exposure, the entire focal plane coincides with the layer of photoresist on the wafer. Vertically aligning a one micron thick layer of photoresist and keeping it flat across an image field of twenty-two millimeters on a side is like vertically aligning a soccer field to a precision of one millimeter. To do that, Natlab develops an altitude meter that can determine the distance from the lens to the wafer plus all the corners' deviations. Zeiss develops the accompanying optics.[22]

Klaassen has to turn it all into a working system. Once he's figured out exactly what has to be done, he pops into Van den Brink's office and dryly tells him how many people he needs. "What?" Van den Brink sputters when he hears the number is fifty. "No way! That's ridiculous!" The PAS 5500's architect can sometimes be tactless. His reaction also betrays how acutely aware he is that the company is desperate for technical talent. He's spent days wondering where to get enough manpower and how to deploy his people. Now Klaassen breezes in and asks for a sixth of ASML's development capacity.

You don't get anywhere with Van den Brink unless you can argue your case, so that evening Klaassen sits down to write everything out in detail. The next morning he slides the pages under the architect's nose. "I'm sure you know best, but just take a look at this." Klaassen has dissected every detail; Van den Brink can't ignore the obvious: it really is going to take fifty people to build the wafer table.

* * *

Klaassen does have an advantage on one component. The rise of digital technology works in his favor. Information technology significantly boosts the precision, predictability, and reliability that can be achieved. For the PAS 2500 and earlier machines, ASML

Martin van den Brink in 2000 holding a calcium fluoride crystal.

had to rely entirely on analog control systems. That meant the systems were never completely predictable.

But now the computer makes it possible to deeply optimize system characteristics. After the switch to digital controllers in 1991, ASML can optimize control through software, without having to switch out components. From that time on, the company has an extremely stable stage, which will help to lay the foundation for its future market domination.

* * *

Since its founding ASML has been on the lookout for opportunities to farm out the development and production of its component systems. With both engineers and money in short supply, outsourcing remains a top priority. In late 1989 the company gets the chance to develop its wafer handler within an EEC project. This system module is a robotic unit that moves the wafers into the machine. It takes them out of a cassette, coarsely aligns them, and then places them on the wafer table using a robotic arm. In the complex PAS 5500, that's quite a challenge.

The EEC's generous R&D grants are a highly appealing funding vehicle, and ASML seizes the opportunity with both hands. The company finds a partner in the tiny town of Évry just south of Paris. That's the home of Micro-Controle, a small sixty-employee company specialized in automating high-precision systems. As an added bonus, some of its employees once worked for Matra-GCA[23] and thus have experience in semiconductor lithography.

At the end of 1989 ASML and Micro-Controle sign a partnership agreement. Everything seems set. It's all been worked out with contracts, airtight specifications, and development documents. Micro-Controle has full responsibility; there's really no way for things to go wrong. But there's only one person at ASML keeping an eye on progress. That turns out not to be enough.

In the fall of 1990 ASML discovers that Micro-Controle isn't going to be able to deliver the wafer handling system for the PAS 5500. Evert Polak and Martin van den Brink decide to shock the Frenchmen into action. They take a Saturday flight through Dusseldorf to Paris—driving would be faster, but the weekend flight is designed to impress the gravity of the situation upon Micro-Controle's management.

Van den Brink and Polak tell the Frenchmen they're going to have to switch to a second source. That ultimately leads to a final settlement in March 1991. In addition to the open invoices, ASML pays four million francs—seven hundred thousand dollars—to terminate the agreement. That buys them all the intellectual property, which Micro-Controle may keep using for applications that don't compete with ASML.

Even though it's been sidelined, Micro-Controle maintains the illusion that it can still deliver its wafer handlers if it manages to get them working. It says it will continue development and asks

Van den Brink and Polak if it can make ASML another quote. The two engineers have no objection, and soon thereafter Micro-Controle sends its offer.

That frees ASML to turn to a second supplier. This time the company hires local talent: the Dutch engineering firm CCM and Philips' machine factory. The small mechatronics specialist will develop an alternative wafer handler, which Philips will then manufacture.

When the first project manager becomes overworked in January 1991, Van den Brink has no choice but to hand the project over to seasoned veteran Klaassen. He's worked himself to the bone getting the PAS 5500's wafer table sufficiently up and running, and now he's had the wafer handler project added to his plate.

The pressure is immense. CCM doesn't start working on the wafer handler until after the first PAS 5500 has been delivered to IBM. In Big Blue's chip fab in East Fishkill, NY, they're stuck using Micro-Controle's slapdash wafer handler prototypes, which ASML, CCM, and Philips have already significantly modified. This is one of the reasons why IBM's PAS 5500 goes down every seven minutes at first.

The wafer handler project is a pressure cooker, and that leads to substantial run-ins between Van den Brink and Klaassen. The latter does manage to get everything running smoothly, thanks in part to the fact that Philips' machine factory puts its best people on the job.

Sometime in 1992 Klaassen gets a phone call from Micro-Controle. The company is wondering what's keeping ASML's orders. Klaassen has disappointing news for the French engineers. ASML has set Micro-Controle's quote aside, in part because the price is so high. The lithography equipment manufacturer never issued an official confirmation or order. But Micro-Controle has already gone into production. ASML buys the usable material, but it's too late. The French company has invested so heavily that it goes belly up a few months later.

61. **IBM**

IBM challenges machinery manufacturers to build equipment for eight-inch wafers. ASML's sales team in America jumps on the opportunity.

In 1988 IBM boasts that it will be the first company to make chips on larger silicon wafers. The computer titan will equip a new fab in East Fishkill, NY with machines that can handle eight-inch wafers. Big Blue calls on the entire industry to develop suitable equipment.

In the late eighties IBM is one of the world's largest computer manufacturers. The company's management decides the new technology is crucial for its future generations of mainframes. The switch from six-inch wafers (the size of a saucer) to eight-inch (the size of a breakfast plate) promises to cut costs significantly. Big Blue is in such a hurry that it doesn't want to waste time discussing standardization. It decides to lead the charge alone and to pay the price for the number one spot.

That choice says a great deal about the company's style. The computer behemoth will ultimately spend one billion dollars on the project.

Maybe IBM's status leaves the company with no option. Mainframe technology is computing power and memory and if you want to be the best, you have to invest in the best chips. Big Blue is betting the farm on that. The company's R&D and IC production technology are pre-eminent. IBM is so large that it's one of the world's biggest chip manufacturers, even though it doesn't sell chips.[24]

The company that leads in chip technology leads in computing power and memory capacity. That means more powerful computers, a better competitive position, and higher margins. IBM is going all out. The entire company understands the importance of the eight-inch project. Failure is not an option, and everyone knows this battle for prestige will make or break careers.

Suppliers understand that, too. Companies that can sell their eight-inch equipment to Big Blue will graduate chip-machine-maker school summa cum laude and are assured of capturing the attention of the global industry. Whatever else happens, the winners can expect follow-up orders to deliver larger series to IBM.

ASML's sales team in America sees its chance and approaches IBM. Is Big Blue interested in a new generation of steppers? Yes, the chip engineers in East Fishkill are interested, but they make it clear to ASML's sales guys that there's not much hope for them. On IBM's list of global lithography suppliers, the Dutch company is in fifth place. In other words: at the very bottom. Really, they might as well give up now.

Snagging IBM is an ambitious goal and, for several reasons, not an obvious win. Nikon and SVG are the main suppliers for Big Blue's chip fab in Burlington, Vermont. The fab's ties with the Japanese superpower are strong and IBM is eager to maintain the status quo. Switching to another supplier will take a great deal of time and energy, so Big Blue's production people are highly suspicious of experiments with other stepper makers.

But the people setting up pilot production for eight-inch wafers in East Fishkill don't have any historical baggage. John Kelly, the director of IBM's Semiconductor Research and Development Center, is in charge of the eight-inch project, and he's open to new suppliers. He's starting with a clean slate and judging everyone on their merits.

* * *

ASML's US sales team turns on the charm to hook IBM, but in the end it's the technology that plants the seed for what will become a close and even warm relationship.

Kelly pays a visit to the Netherlands, and while he's there he becomes convinced of ASML's technological superiority. At the CFT he sees the new H-stage, but he also gets to peek into the future: the long-stroke, short-stroke air bearing wafer table. By that point, the CFT and Natlab have already equipped both systems with a lens and a dual alignment system.

The alignment ASML is able to provide will be the deciding factor in Kelly's ultimate choice. In those days alignment technology plays a major role, because it's increasingly difficult to accurately overlay exposures for the different chip patterns. Good alignment is crucial and already the number one feature on Kelly's wish list.

When Kelly sees the status of ASML's positioning technology with his own eyes, he instantly realizes this is the tool IBM's been looking for. He sees that ASML has the best approach and a substantial jump on its competitors. Kelly voices his preliminary support for the PAS 5500, though he knows he'll pay for that choice in a fierce internal battle with the production people at IBM's Burlington chip fab, who want to stick with Nikon.

Part 9

Stuck With Each Other
1990–1992

62. **The Circle Sir**

ASML's people are livid when they hear that Willem Maris will be running the company. They know him from Philips, and the impression he made there was never strong.

In early 1990 Philips announces that Willem Maris will now be leading the ailing ASML. The job he's assuming is no sinecure. The parent company is itself teetering on the edge of the abyss. It's pumped more than $35 million into its lithography offshoot. And that offshoot also has sky-high debts to repay.

No one in Veldhoven is cheering the move. Many of ASML's people already know their new CEO. A year earlier, he signed a contract on Elcoma's behalf guaranteeing Philips' purchase of seventy-five wafer steppers.

"Well, we're screwed now"—words to that effect are spoken among ASML's management team. Some of them jokingly add that they'd be better off with Troost, the dutiful and always proper product of Philips who never really fit into ASML's informal culture.

ASML has been rebelling against mother Philips for its entire existence. That attitude is part of the company's cultural heritage. It also affects the way they view Maris. He isn't exactly known for standing his ground; he's the kind of guy who avoids conflict. They don't see him as the decisive type it takes to lead an ambitious team in a ruthless battle against Japanese competitors. ASML's entire management team is utterly convinced that Maris has been exiled to Veldhoven. "Go run litho; it'll keep you off the streets." Something like that.

Maris can't look back on a particularly glorious career at Philips. He's fifty and never made it past the top layer of management at Elcoma. In the IC business unit he got off to a good start managing assembly and testing. But in his next position things went wrong. The Megachip project he ran with Kees Krijgman ended in failure. True, they made some good strides in terms of technology, but the new wafer fabs never came close to capacity. That's saddled the components division with huge losses, prompting hard measures. The vacancy at ASML is a perfect opportunity to get rid of Maris.

* * *

Willem Maris grows up in a sheltered environment. His father, Guus, is the director general of the national road and water authority and thus in charge of the Delta Works, a massive system of dams, sluices, locks, dikes, levees, and storm surge barriers being constructed along the Netherlands' southwestern coast. Willem is the youngest of five sons. To his mother he's Willie, the baby of the family. His four older brothers are smart and athletic boys who don't give their younger brother much room. Willem isn't someone who fights for his place.

But the youngest Maris does eventually prove himself, because he, too, is athletically inclined. He matures into a well-known tennis player, winning the Dutch national championship in 1958. He plays in the Davis Cup and even makes it all the way to Wimbledon. After earning his degree in mechanical engineering he moves to Eindhoven in 1964 to work for Philips. There he steadily climbs the ladder—university graduates don't have to stand out to get ahead at the electronics company. It's just a matter of counting the years and checking off the rungs.

When his first child is five months old, Elcoma moves Maris and his family to Mexico for four years. The Mexican work ethic—mañana, mañana—is hard for him to stomach. The three years he spends in Korea afterward are a joy to him, in contrast. He's there to open an office for Philips and sees how unbelievably hard his Korean employees work, and how can always count on them. In Seoul curiosity drives him and his wife to attend meditation sessions. The peace these bring him is so welcome that he will keep meditating for the rest of his life.

In the late seventies he returns to Holland. He and his wife want their two sons and daughter to attend Dutch schools. Maris is a protégé of Philips executive Dick Noordhof, but in the early eighties engineers like Noordhof are losing ground in the shifting balance of power at the multinational. The commercial guys are taking over the helm, which culminates in Wisse Dekker's appointment as CEO in 1982. When Maris declines a promotion to lead a division that doesn't appeal to him, it puts a blot on his record; you don't refuse an offer like that at Philips.

* * *

Maris is a man of the soft approach. He dislikes hierarchy and the accompanying politics. Those traits disqualify him by definition from penetrating the real Philips top, the arena of power and political games. At the electronics company people view him as a mediocre manager, someone unsuited for the real heavy lifting. Elcoma's chip division has already forgotten his successful stint in assembly and testing; mostly they remember that the Megachip project failed. The technology was there, but Maris couldn't manage to fill the extravagantly expensive wafer fabs.

No stomach for power plays and a failure: traits that first surface in the Glasmini project that Maris runs at Elcoma in the seventies. Glasmini is a small video recorder, a tiny glass tube just half a finger long filled with electronics. It's an attempt to make a portable version of Philips' renowned Plumbicon image sensor for TV cameras. They need to shrink its size significantly, so Elcoma is leaning heavily on Natlab. Countless research groups and several dozen scientists are involved.

Glasmini is divided into some twenty subprojects. To keep political games and hierarchy at bay, Maris coins a new word. He labels everyone, including himself, a "circle sir." He's trying to express the idea that everyone is working together on the same level. No one's the boss, no one can pull rank. It's Maris's way of combating rivalry and the infamous friction between the product divisions and the research lab.

Despite his abstract approach—no one knows exactly what a "circle sir" is—Maris is fairly successful in enthusing his stakeholders. His informal style is especially well received at Natlab. Maris is an industry guy, but one without the corresponding ego. What's more, he's someone who consistently practices what he preaches. He sets up in an office at the lab and regularly speaks with everyone, from assistants to group leaders.

Piet Kramer, one of Natlab's section directors, sees in Maris a charismatic man who can pull the project together. Someone who always manages to find just the right person at the lab. And a born communicator, too. Every two or three months, Maris knocks on Kramer's door. Often unexpected, always cheerful. On those occasions Maris provides an update on the fly. How Glasmini is progressing and the problems they're encountering. His words are always wrapped in a cushion of charm. Kramer adores his enthusiasm. He observes the researchers in his departments working for Maris with great pleasure. The man from Elcoma has everyone eating from his hand.

But Glasmini doesn't help Maris's career. By the early eighties, the concept is completely outdated. The glass recording tubes are no match for the much more compact CCD chips the Japanese are using in their camcorders. Under Maris, the Plumbicon that made Philips a star in television cameras comes to prove the adage that past performance is no guarantee of future results.

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When Fia Loozen hears that Maris will be running ASML, it gets her thinking. The executive assistant is wary: yet another fella from Philips. But when her new boss steps through the door on February 1, 1990,[1] he turns out to be cast from an entirely different mold than Troost. Maris is formal—she hadn't expected otherwise from a Philips man. But Loozen also encounters a charming personality. Maris is handsome besides, and he carries himself well.

The new CEO finds himself in an informal organization with many young employees, a team that starchy Troost never managed to understand. Loozen wants to keep it that way. Troost was the first person at ASML she addressed as "sir" and she's decided he's also the last. On Maris's first workday she tells him, with characteristic Amsterdam candor, "At ASML we're used to calling each other by first name."

She doesn't get much of a reaction, but in Maris's first days she continues to instruct him in company etiquette, Loozen style. For example, she notices that the new CEO is used to having his coffee served to him. She quickly kills that habit. He receives a thermos and a stack of cups so he can pour the coffee for his visitors himself. Maris accepts these first encounters with ASML's social norms; the little show his secretary is putting on is actually quite amusing.

Loozen watches Maris quickly thaw. In his first months, the new CEO spends much of his time getting to know the company and rapidly adapts to its informal culture. After his appointment becomes official that summer, he breathes new life into the employee newsletter, *PAS Time*. "After all, strong communication is a cornerstone of our company," the brand-new leader writes in the newsletter. "You'll regularly see me walking around your departments; feel free to stop me for a chat." In a year's time, Loozen sees him evolve from a fairly formal person into a relaxed man who inhabits his role with pleasure.

* * *

Maris joins the company just as the semiconductor market hits a slump. In 1989 ASML performed better than expected: the company brought in $94 million in total. Thanks in part to the fire at TSMC, a record seventy-four steppers were shipped, resulting in a profit of $7 million. Judging by the orders coming in, that number will be much lower in 1990. Nonetheless, Maris reports in the newsletter with some degree of enthusiasm that ASML is targeting the sale of sixty machines that year. But he knows that may not pan out: Iraq has just invaded Kuwait and the move has shaken the global economy.

In *PAS Time* Maris also reports that he's been infected by his employees' competitive spirit. "We're going to do better than Nikon and Canon," he writes. "We're going to beat them both."

On paper ASML's progress looks very reasonable. The machinery manufacturer now counts AMD, Micron, National, SGS Thomson, and TSMC among its customers. All of them are still relatively small players at that point—though Micron and TSMC are preparing to take their specific segments of the industry by storm. Now ASML is training its gaze on IBM, Motorola, Samsung, and Siemens. Maris pronounces the landing of these bigger fish the company's top priority.

But the chip industry crisis continues, global uncertainty remains high, and no orders arrive in Veldhoven. The closer the end of the year comes, the more Maris realizes just how serious the situation is. Ultimately fifty-four steppers will pass through the gates in 1990. With a lead time of at least nine months, it's clear that 1991 will be even worse. What's more, the crisis in the Middle East promises little that's good for the global economy. Meanwhile, Philips' new CEO, Jan Timmer, has ushered in a major reorg. ASML will end up on Timmer's chopping block, too—it's just a matter of time. The abyss is inching closer.

Maris needs to cut costs, but where? With the development of a new wafer stepper in full swing, ASML is burning money like crazy. CFO Gerard Verdonschot tells Maris that he certainly can't cut expenses there, or he'll be torching the company's future. The best he can do is cut a little here, cut a little there. The management team decides there will be no more flying business class. That puts its sales and service people's motivation to the test; there are months when they have to cross the globe multiple times.

Maris also does a lot of flying. Customers always insist on meeting the CEO. The fact that he, too, flies economy makes an impression. It especially resonates with the engineers who've come from Philips. They know from experience that their former employer reserves business class seats for its university graduates from their first day on the job. Maris's solidarity wins his employees' hearts. He adapts, showing everyone he's one of them.

In December the Marises invite the management team members and their wives to a Christmas dinner at their home. It's a symbolic gesture, but it reinforces the bond between them and the sense of team spirit. The people around him start to appreciate his laissez-faire approach to leadership.

* * *

On the cusp of 1991, it's clear to Maris that ASML is in the ICU. Grants from the Dutch government and the EEC constitute the feeding tube and respirator; mother Philips has her finger on the button that will kill the patient for good. Insolvency is just around the corner, because no one's placing orders. It's evident ASML will ship only a few dozen machines in the new year—the number will ultimately come out at a paltry thirty-six.

ASML needs a miracle cure, and everyone's hopes are pinned on the PAS 5500.[2] It must be the dream machine that will propel the Dutch machinery manufacturer onto global center stage. The stepper has psychological importance, too. Everyone's clinging to it like a lifeline; with this machine, they'll make the entire industry gape in admiring awe. Cutting costs on this revolutionary machine is simply not an option.

What's more, ASML has managed to pique IBM's interest. Big Blue's microelectronics division wants to include the PAS 5500 in an evaluation that includes their Japanese competitors. With a view to larger orders, ASML has promised to deliver the system to IBM on May 1, 1991.

"The PAS 5500 represents a completely new stepper generation that's far ahead of its time," the August 1990 edition of *PAS Time* writes. Development is in full swing and everyone in the company is warming up for the push to mass-assemble the machines. The drawings for the new cleanroom and offices are ready; the bricks have been ordered. Everything should be ready in the first months of 1991.

ASML has also managed to convey the importance of the PAS 5500 project to the Dutch government. In September 1990 the Ministry of Economic Affairs grants the company a technology development credit[3] of $19 million.

63. **German Stranglehold**

Compared to ASML, Zeiss isn't just another world; it's another planet, with a culture deeply shaped by history.

In his first year, Willem Maris encounters a fundamental dilemma—one his predecessors Gjalt Smit and Wim Troost also struggled with, and one he too can barely affect. ASML is bursting with ambition, yet completely dependent on a traditional German firm that moves at a snail's pace. In the early nineties Zeiss's upper management doesn't think much of the Dutch company. Semiconductor optics is at best a marginal business for the Germans. What's more, the 150-year-old company is weathering a crisis, both economic and existential.

ASML's major problem is its suffocating dependence on Zeiss. ASML's first CEO, Gjalt Smit, tried in 1985 and 1986 to establish a relationship with alternative suppliers Olympus and Wild, but both attempts failed. By the time Maris arrives, the fabrication of lenses for semiconductor optics is so complex that there are no other serious suppliers anywhere in the world. ASML's life is in Zeiss's hands. If ASML's going to be able to deliver the PAS 5500 wafer stepper in large quantities in the coming years, Zeiss is going to have to roll up its sleeves. Maris has to transform the German stranglehold into an embrace.

The situation at Zeiss makes everything even more complicated. It's a century-and-a-half-old company that's forgotten how to innovate. Few employees are receptive to new ideas. Take the photography division, for example, the company's absolute pride. Zeiss's employees have poured their hearts and souls into it, but in the seventies they lose a large part of the low-end business for photo and movie camera lenses to the Japanese.[4]

Apparently that isn't enough of a wake-up call for the Germans. Prestigious Hasselblad is also turning to Asia more often for cheaper parts. The Japanese succeed in building the first electronic shut-

Carl Zeiss *Photo: Zeiss*

Ernst Abbe Photo: Zeiss

ters into their objectives. Those cost much less than the extremely precise mechanical version that Zeiss's Prontor branch makes in the picturesque town of Bad Wildbad in the Black Forest.

Zeiss stubbornly clings to its mechanical shutters and continues to vaunt their superior quality in its marketing materials. That may be true, but the Japanese are only charging a tenth as much for the electronic variant. The photography magazines don't see a difference in quality. The Germans' self-confidence suffers a sharp blow when, at the start of the nineties, they also lose most of Hasselblad's business.

ASML and Zeiss: as distant in cultural terms as they are in alphabetical ones. ASML is a young and ambitious company with boundless energy. Zeiss is made of granite carved by German solidity and tradition. It has ironclad faith in its optical knowledge and expertise, but all of that is suffering heavy wear and tear.

* * *

Zeiss's history goes back to the middle of the nineteenth century.[5] In 1863 university lecturer Ernst Abbe knocks on the door of Carl Zeiss's workshop for optics and precision mechanics. He needs several instruments for his physics practicum, and at the university in Jena Zeiss is known as a quality craftsman who delivers on time. Three years later, that leads to a partnership between Zeiss and Abbe.

In 1866 Zeiss is manufacturing microscopes and other instruments. But the company has just been surpassed by Hartnack, whose magnifying instrument contains a water immersion objective—and with it a new leap in resolving power. Abbe pitches in to help Zeiss catch up.

* * *

Zeiss and Abbe develop a close relationship. The physicist plays a decisive role, in both technical and social terms, in the history of the Carl Zeiss company. His first big project is to thoroughly change the process by which they manufacture microscope lenses.

When Abbe and Zeiss first meet, that process is simple. Just as a violin maker does, a master craftsman in the Zeiss workshop works on just one microscope at a time. He assembles the entire instrument himself. Then he determines what needs to be adjusted, which lenses need additional polishing and where. He evaluates, decides, and adjusts based on long years of experience. When the master eliminates one error, other inconsistencies may rear their heads. The art is in balancing and simultaneously reducing all of them. This arduous trial-and-error process is exactly the reason why Carl Zeiss calls on Abbe for help. Zeiss is convinced the scientist will be able to inject predictability into his production process.

Abbe gets rid of the traditional trying, adjusting, and varying. He calculates lens deviation for each individual piece on its own, but also as part of the microscope's whole optics. That generates sizes and maximal deviations, which the workshop distributes across different groups. One group starts making the rough shapes, another works on the concave surfaces, another on convex lenses. Each group delivers its components at a quality that's within the agreed limits.

Everyone is subject to the same rules. Multiple people work on a microscope at the same time. It's a little bit like an assembly line: each worker carries out just one specific task. The final result is a microscope that meets spec from the start. Soon after Abbe's arrival, the workshop's twenty employees are delivering markedly more instruments. In the first five years, production grows without the need to hire more people. The price drops 25 percent in that same half decade.

Twenty years after Abbe's arrival, the Carl Zeiss company employs more than three hundred people. The physicist becomes part owner in 1875, and by the end of the nineteenth century the company has grown into an established supplier of advanced optics.

But Abbe's technical influence isn't the only reason for Zeiss's increase in prestige. When the company's namesake dies in December 1888, Abbe makes several wise decisions. The physicist puts all his shares in a foundation named Carl Zeiss and convinces Zeiss's heirs to do the same. Two companies are absorbed into the foundation: Optische Werke Carl Zeiss and Glaswerk Schott & Genossen. The latter was founded in 1884 after Zeiss and Abbe brought in "glass doctor" Otto Schott to improve the quality of their optical glass.

Abbe spends years hammering out the foundation's statutes, in which he records the rights and duties of both companies' employees. Five years before his death in 1905 he introduces the eight-hour workday. Since 1891 Zeiss has been a pioneer there, with six workdays of nine hours. In other German factories people still work an average of ten hours a day. Theodor Heuss, the first president of the Federal Republic of Germany, will later call Abbe a "rationalist saint." The scientist leaves a lasting legacy of strong solidarity within Zeiss. The company continues to grow steadily in the twentieth century, yet manages to retain the feel of a family business. Albeit one with a strict hierarchy in which its optics designers, known as "the mathematicians," are revered as if they were gods.

* * *

When General Patton and his Third Army invade the German state of Thuringia (where the city of Jena is located) in April 1945, the Carl Zeiss company is a strategic target. By that point the Americans have things fairly well under control. The threat of a German nuclear bomb has been averted and victory in Europe is near. But the war with Japan is still in full swing. Turning that battle into a decisive advantage now tops America's list of priorities.

In the wake of their troops, the Americans send an army of three thousand scientists and experts to Europe. They wear regular officers' uniforms, but they've come specifically to evaluate the captured technology.

For the defense department's specialists, Zeiss is the top priority from day one. The Allies know they'll encounter strategic technology in the factories in Jena, including for aerial cameras and bomb guidance systems. The city was bombed earlier that month, but despite the destruction Zeiss's employees have managed to restore two thirds of their production capacity.

The experts spend months analyzing Zeiss's factories, but by May 1945 the first major command has already been issued: Zeiss must produce 3,400 objectives for aerial cameras. It's wholly evident to the American scientists that the Germans are ahead of everyone else in that domain. The task is to manufacture the optics in such a way that they will fit onto the American Fairchild cameras.

But that command is subsequently withdrawn. During the Yalta Conference in February 1945, Churchill, Roosevelt, and Stalin had decided Thuringia would belong to the Soviet occupation zone. That decision doesn't go into immediate effect, however. After the Russians install puppet regimes in the Balkan states and especially Poland, an outraged Churchill suggests in June that the UK and the US dissolve the agreement and keep central Germany as a pawn for further negotiations. But the new US president, Harry Truman, wants to honor the Yalta agreement, and they ultimately cede official control of the area to Russia on July 1.

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The American experts hatch an ambitious plan to move Carl Zeiss's factories to the Western sphere of influence before that happens. They must transfer 2,456 machines, among them 490 lathes, 280 mills, and 210 grinders—all together, six hundred freight cars.

As the days pass and time grows short, the Americans keep having to adjust their ambitions. Eventually they decide that only the company's top management and scientific core will be moved. "We're taking the brain," the firm's shocked board is told. In total, eighty-four engineers and managers at Zeiss and forty-one people at Schott move to the West, where they ultimately settle in Oberkochen and establish the company anew. The rest of the firm remains in East Germany under the same name.

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When the Berlin Wall falls in 1989, the two incarnations of Zeiss make efforts to reunite in a single company amid political encouragement. The West German Zeiss is already in bad shape, and the reunion only makes things worse. The problems plaguing the unprofitable East German Zeiss even threaten to kill the company outright.

By then, the West German Zeiss has fifteen thousand employees worldwide. In Jena that's fifty thousand, many of whom are employed in name only.

Employees from Oberkochen who visit the East German division in the year after the Berlin Wall falls are shocked by the impoverished homes they pass along the way. They can't find new construction anywhere. That poverty stands in sharp contrast to the scientific level they encounter in Jena. The engineers there have been thoroughly brought on board. They know the West German norms and adhere to the same standards being used in Oberkochen.

Jena's vacuum technology, required for electron microscopy, turns out to be highly advanced. They have access to all the latest Western equipment—all of it items that the American embargoes prohibit from being sold to the Eastern Bloc.

Analysts from Boston Consulting are tasked by management in Jena to examine ten activities, together comprising half the company's revenue. They've already drawn their conclusions by the summer of 1990. Boston's experts see high-quality personnel and production, but their analysis is clear: "Carl Zeiss Jena will no longer be able to pay its bills by the spring of 1991 if no action is taken." In 1991 the foundation's board tells Jena's management to work with its works council to draft a reorganization plan. In the end part of the East German operations will go forward that year as Carl Zeiss Jena GmbH, a subsidiary of Carl Zeiss Oberkochen.[6]

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A year after German reunification, a small delegation leaves Veldhoven for Jena. ASML has read that Zeiss is building its own wafer steppers there. Martin van den Brink, mechanical engineer Cees van Dijk, and Steef Wittekoek decide to go take a look. They're very curious to see what the technological level will be in the former East German city. ASML can definitely use another good supplier, and a partnership might make sense.

In theory the two Zeiss offices could work together to build steppers. But the West Germans have absolutely no interest in joining forces with their long-lost East German cousins. Zeiss Oberkochen feels mainly the political pressure to welcome Jena back into the fold.

The trio from ASML takes a Tupolev operated by East Germany's Interflug airline from Dusseldorf to Leipzig. They're struck by how large the airplane's windows are. The plane shakes and vibrates much less than they're used to on Western aircraft. Van den Brink and Van Dijk cast an engineer's eye over the plane and determine that its natural frequency is low. The whole thing must be made of heavy materials.

Once they've landed in Leipzig, they're picked up in a Wartburg, one of Zeiss Jena's twenty company cars. They drive through wet snow in utter darkness toward Jena. When the only hotel's twenty rooms turn out to be full, they head to a youth hostel halfway up a mountain outside the city. Wittekoek is given the only single room. His younger colleagues are forced to share a bed in a bare room with a coal stove that Van Dijk thoroughly inspects to make sure they don't die of carbon monoxide poisoning.

The next morning the bedmates cross the frozen inner courtyard to wash themselves in Wittekoek's room. Only the executive scientist has a sink at his disposal.

It's a radiant day, but the deeper they descend into the valley, the dimmer the sun grows. The city lies under a choking blanket of smog. As they drive into Jena, they discover the source of this evil: brown coal briquettes are stacked beside every house.

They're amazed at Zeiss's factory, which turns out to be gigantic. The Dutchmen have never seen anything so big, and that's saying something, coming as they do from Philips-dominated Eindhoven. Machining equipment is lined up in long rows. Lathe after lathe, saw after saw. In Jena they make everything themselves: glass, glue, computers, lasers, and the list goes on.

Their wafer stepper isn't very advanced. This machine is in no way a threat to ASML, the three visitors conclude. But the device does work, and Zeiss Jena has shipped several machines to locations across the Eastern Bloc. None of them ever come back, because once they're delivered the rest is up to the customer. Installation, use, maintenance: Jena wants no part of it. That saves a bundle on travel and lodging, ASML's men matter-of-factly acknowledge.

But Zeiss's knowledge of optics production is colossal, and the trio agree with the East Germans that the Jena branch will start making parts for ASML. When they get back home, Van den Brink and Van Dijk send some drawings and a request for quotation, but they don't hear a word for the next year. The partnership doesn't get rolling until the office in Thuringia has been split into Carl Zeiss Jena and Jenoptik.

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In the early nineties Zeiss Oberkochen is fighting for its life and struggling with its identity. In the turbulent seventies and eighties, its employees withdrew into a protective cocoon and let themselves be overrun by the Japanese. Now they're paying the price for their lack of innovation and corporate potency.

Everything is focused on survival, on cutting costs and repairing the relationship with Jena. Zeiss Oberkochen is like a deer blinded by headlights, unable to see anything else. It doesn't hear ASML clamoring for its attention. The bulk of its precision optics is still meant for microscopes, cameras, and medical instruments. Senior management can barely spare a thought for the handful of lithographic lenses that occasionally get sent to Veldhoven—a fact that greatly astonishes Maris.

Stepper lenses are shelved in with Zeiss's special projects, just like space telescopes. The Dutch company has absolutely no track record in lithography. Zeiss's top management sees Canon and Nikon dominating the lithography market, precisely the companies that are making it so hard for Zeiss in the photography market.

That attitude threatens to create a disaster for ASML. The company receives lenses of mediocre quality. It's clear that Zeiss doesn't consider the semiconductor market a priority, let alone recognize that market's potential. ASML can't get through to them. There's no chance the Germans will feel compelled to deliver on time. They're sticking to their time-honored supplier model: place an order and we'll see when we get around to making it. It's never clear when the lenses will arrive in Veldhoven. It's up to ASML to convince Zeiss that it needs to ramp up production, big time.

64. **A Movie for IBM**

Iraq's invasion of Kuwait in early 1991 creates a bizarre twist. ASML's fate seems sealed, but Evert Polak thinks up a trick.

ASML's first stepper of its own, the PAS 2500, wasn't enough to interest high-caliber chip makers. The PAS 5500 is supposed to change that. But the machine contains a lens that's extremely critical and appreciably more complex than anything that's been made for wafer steppers so far. Lead customer IBM also views the lens as a potential showstopper. So everyone in Veldhoven breathes a sigh of relief when Zeiss says the optics are moving in the right direction.

If Zeiss can prove the optical column is of good quality, we'll win Big Blue: that's the steadfast conviction in Veldhoven. That means the November 1990 review meeting with the Americans in Oberkochen is crucial.

That month, ten people from ASML and IBM zoom to Brussels by taxi. John Kelly and his team have inspected the assembly activities in Veldhoven with representatives from Zeiss, and now Martin van den Brink and IBM account manager Ken Pynn are flying on to the actual goal: the optics in Oberkochen. Van den Brink is fully convinced that if IBM gives these lenses the green light, then the starting gun will have been fired and the orders will start coming in.

When the two taxis arrive at Zaventem Airport, it's a madhouse. Air traffic has been shut down. IBM's Boris Lipkin keeps insisting, "Call Willem Maris." Van den Brink starts to get annoyed. What's Maris supposed to do about it? Lipkin says Maris needs to wrangle them one of Philips' private jets: "This is mission-critical."

Van den Brink ignores Lipkin's request and takes Pynn to see if he can arrange two rental cars, but everything's gone. They finally find an obscure company that can give them a BMW 7 Series and a Jaguar X-Type. That little joke costs a few thousand dollars, but landing an order from IBM has priority. They pull out their credit cards.

By then it's nine p.m. They have a meeting at Zeiss the next morning. "Do you mind if I lean on the gas?" Van den Brink asks as Kelly gets in beside him, with Boris Lipkin and another colleague in the back. Once they're on the highway Van den Brink puts the pedal to the metal. His own car is a creaky Ford Sierra that runs on natural gas, and he happily cranks the BMW 7 past 125 miles per hour. The Jaguar, with Richard George at the wheel, is right behind him with the rest of the crew.

Van den Brink doesn't notice how his passengers blanch. Kelly points out to him that he's passing eighteen wheelers at twice their speed and notes that he'd pay a hefty fine for that in the US. Sweating, the IBM manager says it looks like the cars in the right-hand lanes are parked there. Van den Brink doesn't pick up the hint.

It's not until breakfast the next day that Van den Brink realizes his passengers were pissing themselves the previous evening: they discuss his driving style with visible relief. "Based on how fast you drive, you guys are going to build those machines in record time," Kelly jokes.

After Oberkochen the American visitors fly on to Japan, where they have another stepper review meeting in Tokyo. News of the drive precedes them. The Canon employees who pick them up at the airport apologize for not having a BMW or Jaguar, and for having a lower speed limit on the drive to Tokyo.

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Kelly is the man who writes the checks. His is the final vote and he's getting better and better at convincing his management team that they should buy their lithography equipment in Holland.

But all eyes at IBM are trained on him, so Kelly moves with extreme caution. Even after his visit to Zeiss Big Blue doesn't place an order, though the Americans are still interested in evaluating the PAS 5500 that ASML originally promised to send them on April 1, 1991. The deadline has since been adjusted, but it's now firmly set for April 30. Van den Brink knows how hard it is to get a chip maker to open its wallet that first time for machines from an unknown supplier. Purchasers aren't eager to lay out a few million if they're not sure a completely new wafer stepper is going to work.

Van den Brink also knows that development is running behind, but there's a growing need to convince IBM that ASML has a very promising stepper to offer—and on time, to boot. So he's thought up a plan. He wants to show Kelly that the system's almost finished and that everything's on schedule. To that end, he's invited IBM to come see it all with their own eyes in mid-January 1991.

Van den Brink has given all the project leaders clear instructions. When IBM arrives, each of them will demonstrate their own piece of the machine, one by one. All together there are ten or so subsystems: lens, reticle handler, wafer handler, wafer stage, and so on. It's a full day of programming that's been scheduled down to the minute, and the assembly teams will also get their moment in the sun. In just a few hours they'll connect up all the modules. It's a feat that's never been done before. Van den Brink is certain his modular approach will make a big impression, because there's no stepper in the world that can be whipped together and taken apart like a model kit. When service engineers have to replace a lens at a chip fab, it usually takes weeks and costs buckets of money.

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ASML's engineering effort has been a pressure cooker for months. Employees are starting to push back. Their wives complain they're never home. But in that fated weekend before IBM's visit, everyone absolutely has to be there to dot the i's and cross the t's. Van den Brink even goes so far as to call one of the company's partners. "Sorry for the late notice, but we desperately need your guy this weekend."

On Friday, January 11, 1991 Van den Brink gets a call from IBM. Kelly and Lipkin aren't coming. They aren't allowed to fly. The US Congress has given President Bush permission to take military action in the Middle East conflict and IBM has forbidden all its employees from traveling eastward. Van den Brink loses it. He doesn't give a crap about Iraq, Kuwait, or anything else. In his head there's only room for one thing: meeting the deadline for the PAS 5500.

Van den Brink carefully puts down the phone, and then he explodes. He knows damned well that ASML has hit rock bottom. Everything stands or falls with an order from East Fishkill. "We're not coming? We're not coming? They can't do that!" He stomps over to Evert Polak's office and storms in cursing. "We're fucked. Those bureaucrats aren't allowed to travel." Polak doesn't respond. "Evert, they're not coming and if they don't come, we won't get the order."

"Take a seat," says Polak. He's a man of few words. He lights a cigarette and doesn't say a thing while Van den Brink spits it all out. On that fated Friday, everything seems to be falling apart because of a war that isn't even theirs. Years of work for nothing. Game over.

Polak takes another drag on his cigarette. Then he suddenly says, "You know what? We'll just go to IBM!" Van den Brink is stunned. To IBM? But they don't have a machine, do they? "What can we do there?" Polak suggests they set up a video crew. "We'll run the whole show just the way we've planned," he says. "But we won't tell anyone. We'll make sure everything's ready Monday morning. Everyone will show up as planned. We'll run the scheduled program and record the whole thing. On Tuesday we'll fly to IBM and on Wednesday we'll show them the tape." Polak's thought up the whole solution on the spot. Van den Brink is ecstatic.

Polak hires a video production company. On Monday, a film crew records the entire demonstration. That evening Richard George takes the tapes and a video editor to an editing studio in Den Bosch, where he spends the whole night cutting and splicing.

The next morning Maris, Van den Brink, and Polak drive to Schiphol Airport, tape in hand. Only after they've boarded the plane do they leave behind their own cocoon of cleanrooms and deadlines. There, in economy class, they're suddenly plunged into the real world. You could cut the tension with a knife. Half the plane is filled with Jews flying through Amsterdam on their way from Israel to New York.

In New York they join up with ASML's sales director, Doug Marsh, who's flown from the West Coast to the East. The review meeting with Kelly and his team starts on Wednesday. They fall out of their chairs as they watch the film. They've never seen anything like it. The whole room is emotional. The teams from ASML and IBM have been talking for a long time now and both sides have been fighting to make this project a reality. Kelly's team needs to meet its deadlines, and those depend on the PAS 5500. They've been fighting a long, often political battle over it in their own company. But now they can see they're going to meet their goals. Some of them have tears in their eyes.

Kelly invites his visitors to dine that evening at the Culinary Institute of America, the international cooking school in Hyde Park, near Poughkeepsie. It's an extraordinary gesture. IBM employees occasionally take their suppliers out to dinner, but never to such an upscale establishment. "You guys are special," Kelly says during the meal. "You're not just our partners; you're also our friends."

A little before eight p.m. the waiter tells them that George Bush will shortly be making a televised address. Kelly and his guests rush into the kitchen, where the chef has installed a tiny TV. They watch as the president announces live that the US has started bombing Iraq. The next day the ASML men fly home. Once again in economy class, but this time they can stretch out on a whole row of seats. No one's brave enough to fly east.

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ASML delivers the first PAS 5500 on exactly May 1, 1991. Subsequent benchmark testing in East Fishkill proves that ASML has the best technology. What's more, Kelly is convinced that the Dutch lithography firm has the best road map. It's an extremely risky decision: ASML is, certainly by IBM's standards, a very tiny company with barely a track record to speak of.

Kelly is willing to put his career on the line because of one person: Martin van den Brink. He's never met a better engineering manager who can combine such depth of technical insight with effective leadership.

65. **The Folk with the Golden Fingers**

In Oberkochen, Paul van Attekum finds himself in a family business where the head of chip lithography stops work precisely at four p.m. every day to drink a glass of sherry with his secretary.

In the spring of 1991 Paul van Attekum shakes Gerard Verdonschot's hand. He's spent eleven years at Philips, most recently on the Megachip project that's just been canceled. Van Attekum has no desire to seek shelter elsewhere at Philips. He's fed up with working at a company where following all the rules is more important than producing results.

On Megachip Van Attekum led process integration, and he tells Verdonschot there's a pretty penny to be earned maintaining and upgrading existing machines. ASML now has a service department, but the company has scant attention for upgrades and related work. At that time, there are two hundred PAS machines at customers worldwide. "They can earn you money," Van Attekum says. Verdonschot is listening: "Show me. I'll give you the money and the people."

Thanks to his work on Philips' chip project, Van Attekum is well versed on ASML. He knows he's knocking on the door of a company that's fighting to stay alive. But in his first months as product line manager, he observes that his colleagues are far from defeated. He feels like he's working in a hive of busy bees. Everyone whistles down the hallways, practically oozing good cheer.

Engineers are furiously busy getting the PAS 5500 ready for delivery to IBM. They're working sixty to eighty hours a week, including weekends and sometimes all-nighters. They're impassioned people who will move mountains if they have to. To Van Attekum, the feel is a complete about-face from Philips, where everyone is mostly busy checking off to-do lists.

Van Attekum's position is high enough to put him completely in the loop information-wise. That makes him one of the few to notice the stark contrast between the company's positive atmosphere and its perilous financial situation. After a few months Verdonschot walks into his office to ask for help with a reorg. The situation is critical and Van Attekum needs to start preparing to let people go. In the end the reorg is unnecessary; Philips once again loosens its purse strings.

Most employees have no idea just how critical the situation is. All their attention is focused on getting ASML's flagship out the door as fast as they can. Once the PAS 5500 has proven itself, they can sit back and watch purchase orders and new customers flood in: everyone's sure of it.

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It's clear as day that Zeiss's optics production is the major bottleneck, so Willem Maris dials up the pressure on upper management in Oberkochen. Because that's where the real problem lies. Jobst Herrmann, who's been leading the German company since May 1992,[7] is skeptical about the potential of chip lithography optics. The numbers support his view. The semiconductor optics line on Zeiss's revenue sheet is barely a blip. Five lenses a month would be a lot. And in the past two years, ASML's orders have only dwindled. Growth potential in semiconductor optics? Hermann doesn't see it.

ASML is getting antsier and antsier about its recalcitrant supplier. It delivered the PAS 5500 to IBM in May 1991 and its sales managers are raising expectations among other chip makers. They're beginning to show real interest in machines that will help them prepare for a new generation of manufacturing processes—a.k.a. the next technology node. Once chip manufacturers get a handle on the technology, large orders will follow: ten to twenty machines per fab. The PAS 5500 does indeed have potential, and they're starting to feel it for real in Veldhoven.

But ASML can only cash in on this opportunity to grow revenue and profit if Zeiss significantly ramps up its production. Maris realizes he needs to improve communication with Oberkochen and gets permission to station an engineer there in Zeiss's production department. He picks Van Attekum. In part because Van Attekum speaks passable German, more a necessity than a luxury in a company where almost no one speaks English, not even the head of production.

And so for the next six-plus months Van Attekum drives from Veldhoven to Oberkochen every Monday evening to work there until Friday. He gets the owner of tiny Hotel Rathaus to agree to leave him a key somewhere so he can get to his room around midnight—by ten p.m. the streets of Oberkochen are deserted.

* * *

In his first months Van Attekum encounters a traditional company. Zeiss has thousands of employees, yet it exudes the feel of a family business. The elderly Hans Letsche is responsible for the photography and semiconductor lens business line. He stops work precisely at four o'clock to drink a glass of sherry with his secretary. Colleagues address each other by title and last name: Herr Letsche, Frau Hauber. The distance between academics and non-academics is vast. It's always *Herr Doktor* or *Herr Professor*. Van Attekum finds the lunchtime ritual particularly intriguing. Around noon, Zeiss employees wish each other *Mahlzeit*!—literally "mealtime!", colloquially similar to *bon appetit*.

The vast majority of employees in Oberkochen are working on high-end precision optics for telescopes, microscopes, medical equipment, and cameras. Only a fraction are focused on lenses for steppers. Everyone is still using traditional methods. Little has changed over the decades. It's always worked fine, including when the company helped America's GCA capture the market for wafer steppers. Back then, lithography optics were less complex. In the early eighties, they had essentially the same construction as high-end objectives for Hasselblad cameras. It wasn't hard for the Swedish camera manufacturer's main supplier to scale up to hundreds of lenses per year. But by the mid-eighties requirements have gotten much more stringent. Stepper makers want g-line optics with a larger numerical aperture and bigger exposure fields and are already asking for the shorter i-line wavelength.

The central optics production shop in Oberkochen in the fifties. Photo: Zeiss

The bar only gets higher in the early nineties. When Van Attekum is sent to Zeiss, they're working on the new generation of i-line lenses for the PAS 5500, which can image details of 0.5 to 0.6 microns. They also need to expose a larger field to achieve higher productivity. That means a significant increase in size. The lens diameters grow by 30 to 40 percent, which roughly doubles the surface that needs to be polished.[8] Where a g-line optical column has seventeen lenses, an i-line column needs thirty. ASML can see that Zeiss isn't ready for it. Zeiss can't handle the quantities and its deliveries aren't reliable, either.

Whether the optics are for microscopes, medical devices, high-end cameras, or telescopes, every business unit has Zeiss' central production shop make them. And the optics shop is still operating on a classical model: they decide which order gets filled when, not the product divisions.

Traditionally, the master's eye and instinctive skill have always played a large role. That's still true at the start of the nineties. The workshop in Oberkochen is filled with semi-automatic machines and instruments. They have standard equipment for grinding and sawing, but a great deal is still done using manual tools and special instruments, such as preformed dishes the craftsmen use to manually polish their pieces.

They perform the final steps by eye. By pressing the lenses against a reference surface, interference rings become visible. Specialized experts can translate those into irregularities.

Those irregularities are very carefully polished away by hand.[9] The polishing dishes are also very precisely preformed and must be adjusted by hand after just a few lenses. This is work that requires years of experience. The artisans who do it are rightly known in Oberkochen as having *Goldene Hände*—the folk with the golden fingers.

If the folk with the golden fingers make a small mistake, it often has massive consequences. Polishing too much or in the wrong place creates a tiny dip in the surface. Then they have to shave off a thin layer across the entire lens surface. Sometimes they fall into an endless spiral, in which dips keep creating days of extra work.

Larger lenses also means they need multiple shifts more often. But the transfer is a nightmare. Usually mistakes get made and everyone points a finger at someone else. The drama and the uncertain times at Zeiss cause frustration to mount.

* * *

On the optics production floor, Van Attekum encounters a proud department operating to high quality standards. He walks around and talks with people. He absorbs the process, trying to understand Oberkochen's approach. He observes that many of their methods aren't recorded anywhere. In optics production, the master's eye is still the major deciding factor.

Management has given Van Attekum permission to look around, but he soon realizes he can't get past the foremen. Some of them are unappreciative of his interest. It's an exercise in diplomacy. Sometimes he manages to engage them. But almost always, he hears the real scoop from the workers on the workshop floor.

What mostly strikes Van Attekum is that the old methods are no longer sufficient for the increasing demands made by the most advanced stepper lenses. He watches the workmen struggle. On some pieces they spend days fiddling. Based on his experience in Elcoma's chip fabs, ASML's man concludes that Zeiss isn't in control of its process. The question now is, how's he going to tell them that?

The Dutch nosy parker has to strike a balance. He can see how proud the Germans are, and how high their standards for quality. And he has immense respect for that. But now, like a young pup without the slightest experience in manufacturing optics, he has to tell them what's wrong. He can't tell them they're botching it all up. And they aren't, really—but he does have to make them see that it isn't good enough yet, despite all the energy they're putting into it. Slowly but surely, Van Attekum watches Zeiss thaw out and flip a switch: the optics specialist realizes it's going to have to take a completely different tack if it wants to supply ASML.

66. **Japanese Glass**

Completely unexpected problems start showing up in Zeiss's lenses. The Germans even have to turn to Japan for their optical glass.

In January 1992 IBM sends a serious delegation to Zeiss. Among them are George Gomba and a few people from ASML. Gomba started out at Perkin-Elmer and moved on to Big Blue when P-E sold its lithography operations to SVG Lithography in 1990. Now he's in charge of process development at the pilot fab in East Fishkill.

IBM visits Oberkochen every six months. At the time of this visit, Big Blue has already definitively selected ASML for its eight-inch project. But this time it's more than just the usual visit. The situation is grave. There are intractable problems with the lenses for the PAS 5500.[10] The lens errors in the i-line optics for 0.5-micron chips are dominated by an asymmetric magnification. The cause is unclear.

Gomba arrives on Winfried Kaiser's first day as head of Zeiss's R&D lab.[11] It's an instant baptism by fire. IBM's man chews him out: the quality of Zeiss's optics is abominable.

Zeiss's reaction is predictable. Its engineers are instantly on the defensive. Given that their work takes place in a rotationally symmetric system, they conclude that they can't have introduced the lens errors. Those must be measurement errors in ASML's machines, which use an orthogonal system of axes. A guy from Zeiss's metrology department gives an abstract presentation with a lot of math. He talks about types of distortion and how you should measure them. For this engineer, it's clear: there's no possible way that Zeiss is the source of the problems.

The review meeting is intense. Representatives from ASML, IBM, and Zeiss address the problems one by one and dissect the lens production process. The conversation doesn't plumb the full depths; as usual, the Germans don't want to share too many of their secrets. But in his time at Perkin-Elmer Gomba often worked with optics manufacturers, and he keeps poking. But no solution is found that day.

In the months that follow several more meetings take place. Not all the lenses are distorted. Kaiser asks ASML if they can fish out the problem cases and send them back. But in early 1992 there's a consuming need for new steppers. The financial situation in Veldhoven is so desperate that they want to ship every system as fast as they can. As soon as a lens arrives, another machine can be shipped to a customer. They can fix problems out in the field.

Nonetheless, Kaiser makes it happen. One returned lens earns him an annoyed phone call from Martin van den Brink, who thinks the customer is a higher priority right then. But now Zeiss can get down to work. On Maundy Thursday, just one day after the lens arrives, Kaiser gets a call from his test engineers. "Herr Kaiser, we've found something unusual. We can generate two kinds of results from our measurements. One is almost identical to our original tests, and the other matches the results we're getting from ASML." It's instantly clear to Kaiser that something's rotten in the state of Denmark—or Germany, as the case may be. And indeed, Zeiss's test method turns out to contain errors.

Zeiss first finds an error in the hardware. The electronics that process the information from the sensor are getting saturated, and that's masking the measured asymmetry. That prevents the deviation from being obvious in the images from the rotationally symmetric tests. Zeiss manages to fix this problem, but oddly enough there are still irregularities visible in the image. No one has a clue why.

There are several more meetings over the next months, where Gomba suggests a diagnostic technique he learned during his time at Perkin-Elmer. It's a simple method, and one Zeiss already knows, but has never adopted.

An optical column is a stack of lenses that have preferably been created from a single block of optical glass. That glass is shaped like a cylinder that first needs to be sliced into slabs. At Zeiss, those slabs go straight to the lathe and grinder to give them their initial shape.

Gomba suggests they first polish the flat slabs until they're clear and then run diagnostics. That was standard procedure at his old employer. But Zeiss first has to build the proper interferometry systems.

At last they find the source of the distortion using Gomba's technique. Kaiser and his colleagues are shocked. It's a pernicious problem they don't have an answer for and that isn't easy to correct. The errors originate in the optical glass, which isn't homogeneous. This is usually caused by thermal stress while the material cools off during the production process. That causes the refractive index to vary across the glass slab, which affects the path the light takes. Kaiser needs to visit his glass supplier, Zeiss's sister company Schott.

Kaiser can clearly show that Schott is delivering subpar quality. He kicks off an intense discussion. Zeiss still has optical glass for i-line in stock, but it's quite difficult to separate out the good material.[12] In May 1992 George Gomba is informed that it's going to take at least another nine months before he gets his PAS 5500/80.

* * *

In the years that follow, ASML and Zeiss are in desperate need of more and better glass for the PAS 5500/100 (0.4-micron) stepper. Schott, however, is unable to develop a better refinement process for optical i-line glass. The time between order and delivery is nearly a year. To start, it takes six months to produce uniform material. It's a grindingly slow process in which a block of glass is cooled from 800° C to room temperature. Kaiser has no guarantee that Schott will be able to pull it off.

What's more, Schott isn't prepared to scale up its current production of i-line glass. So Kaiser makes an unusual decision.[13] He travels to Japan to buy i-line glass from Ohara, Canon's main supplier. Canon may not make the best wafer steppers, but the Japanese company is famous for having the best optics. For Kaiser, Ohara is a godsend. The glass maker is independent of Canon and looking to expand internationally. In Japan, Kaiser sees they're already using the production techniques he recommended to Schott a week earlier. Ohara's glass also has better optical homogeneity. That settles it: the Japanese supplier is going to make i-line glass for Zeiss.

* * *

There's another pernicious problem. Micron Technology, which is making intensive use of ASML's steppers, is the first to report it. In 1990 and 1991 they send one lens after another back to Veldhoven from Boise. The longer the lenses are used, the less light they transmit. A reduction in lens transmission over time is particularly problematic for a mass manufacturer like Micron, whose profitability depends on throughput.

A few months after Micron's placed a large order, the light drops noticeably for the first time. At first they're highly enthusiastic about ASML's i-line steppers in Boise, but once the machines start spitting out memory chips round the clock in their fab, it's just a matter of weeks before the number of photons making it through the lenses plummets. Investigation quickly reveals that carbon compounds are depositing onto the glass.

The issue has some mysterious quirks. The strange thing is that the carbon contamination doesn't happen in the first generation of i-line optics for the PAS 2500, though the materials and glue used for the lenses and settings are the same. The soot problem only happens in the PAS 5000 and PAS 5500.[14]

The problem is so intractable that it nearly spells ASML's demise. In addition to Micron, TSMC is having the same problems, and in those years the two companies are by far the largest buyers of ASML's machines. ASML's reputation suffers growing damage as the news spreads through the chip industry. Meanwhile, Zeiss and ASML are feverishly searching for a solution.

In the beginning ASML can apply a logistical fix. The aloof relationship between Veldhoven and Oberkochen is ASML's salvation. It forces the company to create well-defined machine-optics interfaces and to build modular systems. That makes it easy to switch out the lens column. In 1990 and 1991 many replacement columns fly between Boise and Oberkochen.

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In a lens column, everything revolves around the refraction of light at the boundaries between glass and air. You often don't hear much about the spaces between the glass slabs, but in precision optics the composition of the intervening gas affects optical performance. Zeiss bases its designs for the second generation of i-line lenses on helium at low pressure. During chip production the column is permanently bathed in it. The rarefied noble gas has a refractive index whose variation is six times lower than that of air, which makes the systems less sensitive to weather and air pressure. Among other things, that's a major plus in Micron's Boise factory at an elevation of 4,600 feet.

The head of ASML's physics department, Jan-Willem Martens, eventually figures out how the contamination arises. In its i-line columns, Zeiss uses a glue that degasses during use. Volatile carbon compounds mix in with the helium. The energetic ultraviolet light causes reactions in the mix, creating heavier organic compounds that deposit onto the glass. Sometimes a column becomes unusable after as little as a month.[15]

And that's not the only problem. The i-line optics also contain what's called doublets, lenses made of two different types of glass bound together with glue.[16] Under the influence of the ultraviolet light, this connective layer changes color.

When mass production starts up, the wafer steppers are working twenty-four hours a day. Micron makes intensive use of the machines, meaning significantly more light passes through the lens each hour. The carbon layers deposit faster and the doublets also rapidly change color.

* * *

At some point Kaiser and Martens are on their way to TSMC in Taiwan to explain the issue. They still don't have a handle on the problem, but at ASML's office in Taipei they receive a fax. It's a chart that clearly shows how the carbon layer vanishes if they mix oxygen in with the helium.

Using that information, Kaiser and Martens think their way through the problem and reach the following explanation: the photons at the new i-line wavelength (365 nm) are much more energetic than the previously used g-line (436 nm) and, just as in the stratosphere, they turn oxygen into ozone in a lens column. Ozone is a powerful oxidant that breaks down large organic compounds.

That's why they didn't encounter the issue in the first generation of i-line lenses. Those were filled with air, a mixture of nitrogen and 20 percent oxygen. The ozone formation there must have been sufficient to oxidize the carbon, in contrast to the lenses that are bathed only in helium. And the problems aren't severe at first because customers are only using the initial i-line machines for IC process development, so the steppers aren't continuously running.

Martens and Kaiser aren't sure they should immediately disclose the diagnosis and cure to TSMC. In a bravado performance, the pair succeed in spinning a story that says: everything's under control.

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After that visit, ASML's chemists think up a way to directly tackle the carbon contamination without having to take the lens columns apart. They come up with a cleaning procedure in which maintenance engineers connect an ozone generator to the helium conduits for twenty-four hours in order to "scrub" the lenses clean. That means they no longer need to switch out dirty lenses, but the downside is that the steppers can't be used for twenty-four hours. So they need a definitive solution. It shows up in the form of mixing a few percent of oxygen in with the helium gas in which the lenses are bathed.

There's a remarkable synchronicity at play regarding the lens contamination and the creation of a chemistry group at ASML. In early 1989, ASML's executive scientist Steef Wittekoek is able to hire physicist Martens because a volume order from Micron gives the company some financial breathing room. And it's precisely that series of machines where the carbon issue first rears its head, and which Martens can then plunge himself into solving.

In the years that follow, ASML will keep needing chemistry expertise because the problems caused by photochemical reactions continue to grow as the wavelength shrinks—and thus becomes more energetic—in the deep ultraviolet (DUV) lines, 248 and 193 nm. In the nineties, both ASML and Zeiss will hire more and more chemists.

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In May of 1992 Kaiser meets Willem Maris for the first time when ASML's management visits Oberkochen. Maris has a lot on his mind at the time and isn't sure he'll be able to pay salaries at the end of the month. He brings up his worries and emphasizes that Zeiss is the bottleneck. By now there's plenty of interest in the PAS 5500, but ASML keeps having to wait on the optics from Oberkochen.

Kaiser explains the problem with the distortion and the contamination and shows Maris the steps he's taking. He says that Zeiss has hired Hermann Gerlinger to monitor their supply of i-line glass from Ohara, but that it will be 1993 before the first batches arrive in Germany. Maris is dissatisfied. He wants to see more progress and explodes in a fury. Kaiser is aghast, but there's nothing more he can do.

Kaiser is so unsettled by Maris's outburst that he considers resigning in the days that follow. He concludes that he can't do his job if he's having a conflict of this gravity with a customer's CEO. He calls Van den Brink and Martens to say goodbye. "It's really shaken me," Kaiser says. "I can't keep working on this. The difference of opinion is too great. It wasn't just that Maris was shouting; I couldn't get through to him at all."

But Van den Brink reassures him and simultaneously appeals to him: "Winfried, please don't give up. We have faith in you. You're doing the right things. It's pretty volatile over here. Yes, everyone wants things to move faster, but don't make any snap decisions. Stay and work with us."

67. **O-Lab**

Zeiss travels the globe in vain looking for optics specialists with golden fingers. Automating the process is an option, but the engineers haven't decided what the best choices are.

Zeiss may be a traditional family business, but it's consistently on the forward edge of technology. In the mid-eighties the sleepy valley town of Oberkochen is home to a company that's started mapping lens surfaces by scanning them with a laser. Zeiss thinks the technique has a future, so it decides to further develop its measurement instruments not only for its own use, but also to sell to others.

At the end of the eighties Gerhard Ittner, the head of Zeiss's R&D lab, also realizes that the company's manual production is eventually going to fall short, given the inevitable forward march of requirements. So he kicks off a massive project whose goal is to develop all the vital technologies, from interferometry and automated polishing to polishing with ion beams.[17]

At first the laser interferometry is fairly primitive. The topographical features of the glass are presented as analog rather than digital information: they're visible on paper or a monitor and recorded onto magnetic tape. In the early days, the optics workshop compares these images by eye to pictures of reference lenses—in the hope that the latter are nearly perfect.

To properly compare the lens quality to the original mathematical design, Zeiss starts digitalizing the measurement data in the early nineties. Developments in computer memory and electronics make that possible, but it's not an easy transition. In Oberkochen they have to develop custom systems, called frame grabbers, that are able to rapidly convert the analog measurements from the interferometers into zeros and ones. The measurements are accurate enough, but getting them takes a long time. If the train from Aalen to Ulm passes by at the wrong time, it creates so much vibration that the data can go in the trash can. Air turbulence also distorts the readings.

The digital techniques are still immature, and in those days computers leave a lot to be desired. To compare their readings with the mathematical lens designs, Zeiss has to rely on 286 PCs. It takes them an entire night to do one lens.

But the biggest bottleneck is the folk with the golden fingers. After the computer has mapped out the irregularities, these master artisans have to polish away the ridges based on the recorded images; they're too small to be seen with the naked eye. That polishing is done purely by feel, and that makes it a stressful chore. The polishers stare at the image, then rub off a tiny bit of glass by hand.[18]

* * *

In the fall of 1990, when Zeiss manages to produce the first i-line optics for the PAS 5500, the company has six golden-fingered employees. With a lot of blood, sweat, and tears, they manage to deliver ten i-line systems per year. In 1991 and 1992 the production woes swell to nightmarish proportions.

Interest in the PAS 5500 is growing. The first i-line lenses trickle into Veldhoven. With them, ASML can at least deliver machines that chip makers can use to set up their processes. Once they've done that, Zeiss needs to kick into high gear fast, because an order for a single machine usually generates a second order a year later for a series of ten. If Oberkochen doesn't jump on the surfboard to catch this natural wave, ASML can pack up and go home.

So ASML gets more and more insistent: Zeiss needs to increase its production. The major problem is that CEO Jobst Herrmann is immensely risk-avoidant. His mind is filled with an impending round of heavy-duty cost-cutting. Zeiss Oberkochen has been performing poorly for years, but the mandated reunion with Zeiss Jena might just bury it.

What's more, Herrmann has no affinity for chips, just like the majority of Zeiss's executive board. The conservative camp even wants to dismantle the semiconductor optics division. The figures support their skepticism. In the previous three years, the number of steppers that have left the factory in Veldhoven has dropped from seventy-four in 1989 to fifty-four in 1990 to thirty-six in 1991. The orders for 1992 promise little improvement. And so the advice from Zeiss's senior management is: keep everything the way it is and just make a few temporary hires to handle this momentary expansion.

The more complex optics require many more golden-fingered polishers: Zeiss estimates it needs forty in the short term. The major problem is that it takes an average of six to ten years before these artisans have developed the necessary skill. And so in 1992 Zeiss traipses across the globe in search of these top-of-the-line specialists. The company looks in Eastern Europe and in America. It even acquires a small defense company in South Africa because five folk with the golden fingers work there. But after a year Zeiss has found nowhere near the forty people it needs.

* * *

Meanwhile Zeiss's central research division, Optik-Labor (O-Lab), is working feverishly on the next generation of lens production techniques. The lab designs the machines and tools for the central production shop. To take new steps toward larger and more accurate lenses, manager Klaus Beckstette wants to make the existing manual tools more robust and automate them. Beckstette sees the cure in more rigid versions of these machines. He wants to make the existing lens-crafting tools more stable, among other things by equipping them with granite base plates. He also wants to make the machines more versatile by replacing the fixed-shape polishing dishes by ring-shaped tools that can make multiple lens versions and lenses with different curvatures. And these will be under CNC control instead of manual.

Beckstette assigns the task to Claus Lichtenberg, who's currently running the prototypes and tooling department. It's Lichtenberg's job to get it all up and running. The young engineer gets off to a reluctant start. He isn't stuck in the traditional optics-making mindset, because he was exposed to robotics at the university. Thanks to his experience with flexible systems, he sees more value in an approach where a robot polishes the surface using digital designs and metrology data.

Lichtenberg was exposed to the very first robots and CNC-programmable machining equipment while he was getting his degree in precision mechanics at the University of Stuttgart. At the end of the eighties in Zeiss's custom machinery department, he gains experience in developing semi-automatic control systems for grinding and polishing equipment and other lens-making tools. They're all specialized systems that can't be bought anywhere, designed and built by Zeiss itself, such as instruments to center the lenses in a column.

By the time Lichtenberg is pegged to lead the prototypes and tooling department in 1993, he's a seasoned expert in designing automated processes. He starts experimenting with closed-loop systems, working with Hermann Gerlinger and Winfried Kaiser in metrology. They pursue their work in an unassuming corner of the prototyping workshop, because no one else has faith in an approach that uses elastic systems to make extremely precise shapes.

Kaiser automates an interferometer that sends topological information in nanometers from the polishing surface to a computer. The computer compares these data with a digital blueprint and calculates the differences. Once the location and height of the irregularities are known, the computer can translate them into a post-processing model, a microscopic elevation map that tells the robot precisely where and how much it should polish.

They learn an important rule: make sure the interferometer and the robot both know the exact location of the lens. To do that, they anchor the lens and its holder during the repeated measuring and polishing.

It's rough going at first. These are massive amounts of data, almost too much to store and process on a computer. But Lichtenberg is in luck. Robotics manufacturer ABB lends him a robot, and lo and behold there's someone at the O-Lab who's willing to help him program it. Over and over they measure how long it takes to polish away dozens of nanometers using a polishing pen the size of a finger and ultrasonic vibrations. Slowly but surely they succeed in bringing the surfaces closer to perfection. They learn to modulate the polishing work and get the irregularities within tolerance. They can get them within an accuracy of several dozen nanometers, almost as precise as the ten nanometers that can be achieved using rigid custom machines.

In 1993 Lichtenberg also tries using ion beams to further increase precision down to the nanometer level, an idea he got from Martin Weiser, a scientist in the O-Lab. The O-Lab builds the required equipment. Ion beams are slow, but extremely precise: they can blast away one layer of atoms at a time. If Zeiss is able to hit a lens with ion beams at just the right place, then ultimate precision is within reach. Precision that's even better—much better—than the ten nanometers achieved using custom machines.

As the head of the prototyping department, Lichtenberg can't avoid making what Beckstette tells him to, but his experience with robots and automation tells him that flexible systems using polishing pens and ion beams have a much higher chance of reproducible behavior. For him it isn't rigidity that matters, but control.

That leads to a fierce battle over direction that lasts for several years. With a more robust version of the existing production tools, Beckstette's O-Lab is following a seemingly safer course. But the massive cost is a problem. Lichtenberg estimates the material and manufacturing cost of a custom machine to be between two and four million dollars. What's more, these traditional machines also use expensive tools: twenty-five to thirty thousand dollars apiece.

Lichtenberg concludes that O-Lab's strategy just isn't realistic. To meet ASML's demand, they'd need fifty to sixty custom machines for the traditional solution. All together, that will cost far more and create more headaches, because this approach remains dependent on human hands.

It's much cheaper to let a polishing robot work with an interferometer. In both cases they'll need a laser interferometer costing two hundred and fifty thousand dollars, but they can get a robot for just seventy thousand. Lichtenberg calculates it will cost twenty-five hundred to three thousand dollars to make one lens element with the robot-interferometer combo. Using custom machines, that cost is easily an order of magnitude higher.

68. **Running on Goodwill**

ASML's life has been hanging by a thread for years. Pure human trust is what's keeping the company afloat.

Since its founding nine years earlier in 1984, ASML has consistently burned through money. The financial department is constantly scraping the barrel. Resources are scarce. They're constantly shifting lines of credit, loans, and lease contracts around. Head of accounting Eef Heijmans and controller Theo Bartraij regularly check the bank account to see how much cash they still have on hand. Every week is another maze to navigate. Not infrequently, they've got cash in the low five figures to work with, though they need to pay out ten times that much.

In cases like that, they use the following priority system: cross out all payments to Philips. Next, scrap ASM and Fico—ASML buys parts from them, too. In the end, all that's left are the toolmakers and small suppliers around Eindhoven. They're essential to ASML and they need to be able to pay their employees every single month.

In addition, the accountants at Touche (now Deloitte) and Philips are breathing down their necks. Touche gets insistent every six months: guys, it's time to write off that inventory! "No," reply Gerard Verdonschot and his financial guys, "we can still sell all that." It's a little white lie. Touche's continued faith and willingness to let it slide is one of ASML's lifelines.

The lean times just keep lasting. In its first decade ASML makes a profit in exactly one year—1989. The R&D for the PAS 5500 places a heavy burden on the company. The number of employees keeps growing, and organizational complexity with it. HR, production, logistics, and the global service organization: it all needs a professional makeover.

Investments to improve the organization go on undeterred. In 1993 Willem Maris pronounces the adoption of total quality management the company's top priority, and two years later Hay Consulting puts the R&D department under a microscope.

For years, payroll and the prefinancing of their machine R&D are particularly heavy millstones around ASML's neck. The company's high burn rate makes it increasingly hard to bridge the deepening dips.

The whole industry's running on goodwill. Semiconductor manufacturers voice an intent to buy, but don't place actual orders. Chip machinery manufacturers develop and build their equipment in good faith while price negotiations are still running in the background. Often, orders don't arrive until the very last moment.

That's how R&D in Veldhoven burns through such massive piles of money between the drawing table and mass production. For example, work on i-line steppers begins in 1986, though they won't generate real revenue for ASML until three or four years later. And it will be another three years before this technology truly generates healthy profit margins, in the form of the first mass-produced PAS 5500 i-line machines.

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In the late eighties, sales director Dick Aurelio finds a financial lifeline in the US that will play a major role in 1990, 1991, and 1992. It's Comdisco, a company that leases major capital assets and has pronounced the chip industry its new strategic market. Comdisco issues lines of credit with machines under construction as collateral. Even the prototypes in the R&D department count.

Comdisco soon steps in to save the situation, when ASML is facing a shortfall of $10 million and Philips and the NMB bank both refuse to provide any further funding. It isn't long before a certificate is hanging on the wall in ASML's finance department, for passing $100 million in lease contracts—American suppliers are generous with their awards.

ASML's financial wizards make sure these huge numbers don't make it into the company's annual reports. Those only list tiny lease amounts. These are the loose ends left over after they've managed to temporarily pay off the big lease amounts at the end of the year, by using customer payments and letting the high R&D bills from the CFT and Natlab go unpaid. Once the new year's been rung in, it isn't long before the lease contracts are back up in the eight-figure range.

* * *

Another advantageous financing model arises in 1991 when ASML receives an unusual request. IBM wants to make all the chips for a mainframe computer on a single wafer. To do that, a stepper has to expose the wafer with a huge number of different patterns. Big Blue is asking for a system that can rapidly switch out masks; that's crucial to keep production costs under control.

ASML is happy to develop this reticle management system (RMS), but just then the PAS 5500 is demanding so much time and money that the machinery manufacturer truly doesn't have the capacity. But you don't say no to Big Blue, so ASML suggests that the project can get started once Big Blue has signed on the dotted line.

IBM agrees, and ASML farms out development to the CFT. There they create the system, with three slots for dust-free mask cassettes, the SMIF boxes, and two robots to quickly change out the reticles.

ASML receives a few million for the system, but by the time the CFT team successfully completes the project, things at IBM have completely changed. The new CEO, Lou Gerstner, flips IBM's mainframe strategy around and switches from power-guzzling bipolar chips to CMOS. That means they no longer need the reticle management system.

ASML decides to offer the RMS as an option with the PAS 5500. This subsystem becomes so successful that every single customer adds it, without exception. It's part of what makes ASML steppers' performance so superior.

In the years that follow, ASML continues to ask customers to commit up front wherever it's reasonable. For example, the machinery manufacturer doesn't start building lithography systems for 193 nm lasers and for twelve-inch wafers until it has hard orders from customers. For extremely risky projects such as 157 nm, EUV lithography, and eighteen-inch wafers, ASML even asks customers to share in the R&D risk. For other developments such as immersion lithography, customers are so enthusiastic that financial safety nets are unnecessary.

* * *

The entire semiconductor industry seems to revolve around business in good faith—and ASML's suppliers are no exception. For years, the machinery manufacturer has relied heavily on the trust of its suppliers, partners, and investors. They all have just one thing to hold onto: the verbal promises made by the company's managers and finance department.

In the early nineties, ASML searches in vain for a lease partner who wants to invest in the assembly plant for the PAS 5500. The cleanrooms in its first factory aren't tall enough, and the floors are too weak for the new stepper.

When they can't find a project developer, Verdonschot begs the contractor, Chris van Kasteren, to start construction anyway. The PAS 5500 can brook no delay. The CFO doesn't have any money. His company doesn't have any lines of credit left and he can't even make any promises about when they'll pay Van Kasteren back. But they desperately need a building to start mass-producing ASML's machines. Verdonschot reassures the contractor: in the coming months he'll do his absolute best to find an investor.

Van Kasteren can absorb a little up-front expense. He has a reputation as a reliable contractor thanks to his projects for Philips. He starts working on ASML's new building and finances it all with his own lines of credit. For the site, he takes over a farm in Veldhoven and facilitates the transplantation of several companies. Van Kasteren builds and builds, all with the intent to turn the whole thing over as fast as possible to the investor Verdonschot promised him. Even after he hears that ASML is having trouble getting new lease contracts, he keeps laying bricks.

One afternoon Theo Bartraij gets a call. An hour later ASML's controller is sitting at Van Kasteren's kitchen table. The contractor fries him an egg and pours him some coffee. Then he sits down and says, “Riek says it’s got to stop.” It turns out the contractor has poured several dozen millions into ASML’s new construction, all told. His wife is no longer willing to bear that burden.

When Verdonschot hears that, he knows it’s time to act. Still, it takes several months before he finds banks that are prepared to take over Van Kasteren’s financing and lease the buildings back to ASML.

69. **No-Brainer**

Philips is going through tough times, but shells out funds for ASML nonetheless—for the very last time.

In 1990 Jan Timmer takes over at Philips. The multinational is on the edge of the abyss, and he's been tasked with salvaging what he can. As soon as his appointment is official, he calls a handful of heavyweights: would they be willing to help him in this monumental task? One of the phones that rings is in the board room at the photocopier giant Océ van der Grinten. When Henk Bodt answers, a resolute voice says, "Henk, I want you to help me by taking our components and chips operations under your wing."

Timmer is asking Bodt because of his roots at the company. Bodt is one of the many Philips employees who start out low and rise to great heights. He first completes vocational school, followed by the industrial track at Philips' company school and then an assistantship position at Natlab. Evening classes help him work his way up, and by the seventies he's responsible for testing and measurement at S&I. By the early eighties he's the director for corporate planning, among other things, but he leaves the multinational in 1986 to work for Océ in Venlo near the southeastern border with Germany.

When Bodt returns to Eindhoven to help shape the major reorganization known as Operation Centurion, he's put in charge of components and chips. Timmer splits off Elcoma's chip activities and puts them in a separate division he names Philips Semiconductors. He and Bodt ruthlessly pare those activities down: they put an end to the Megachip project and cut one in five jobs at the twenty-five-thousand-employee chip division.

Bodt also has ASML in his portfolio. Starting in late 1990 he has monthly talks with Willem Maris and Gerard Verdonschot, who are having to fight for every penny at that time. During his visits to Veldhoven Bodt takes an occasional peek at the engineers in assembly and R&D. He encounters an energetic crew who, in contrast to many Philips divisions, is averse to corporate politics.

What should Timmer and Bodt do with ASML? It's clear the subsidiary in Veldhoven is not part of Philips' core business and to top it off it's performing poorly. Financially speaking they'd rather get rid of ASML, but they don't want to just pull the plug on its activities. The machinery manufacturer is relatively small and it isn't Timmer's biggest headache. Bodt says he sees potential and suggests they look for external investors and then divest the division. He and Timmer agree: Philips needs to get rid of ASML, but in a way that makes sense.

In the years that follow Bodt, Maris, and Verdonschot visit investors and banks, but no one wants to put money in a risky lithography adventure. During that time ASML nearly buckles under the weight of PAS 5500 development, and in 1992 it goes looking for partners to share in the research effort. The move is in keeping with the zeitgeist. Semiconductor manufacturers are also seeking each other out to share the first steps in chip development.[19]

* * *

In the first half of 1992 ASML can reach out and touch bottom. The year before it only sold thirty-six machines, which produced $77 million in revenue and a loss of $5 million. Specialists in Philips' Mergers & Acquisitions department advise the multinational to shut down the company. Meanwhile, the number of employees keeps on growing to satisfy the needs of PAS 5500 R&D. The $19 million technology development credit from the Ministry of Economic Affairs provides a temporary respite, but by late spring they've truly run out of money. ASML won't ship enough machines in the next few months to be able to pay its bills and salaries. "We've got to go see Jan Timmer," Bodt says to Maris and Verdonschot.

It's Friday, May 15, 1992 when Bodt and Timmer review the headache that is ASML at the Philips Netherlands headquarters in Eindhoven. Bodt tells Timmer that he has faith in the lithography company. When he talks with ASML's management team and walks through the company's buildings, he sees an enthusiastic crew that's focused on the market. Bodt tells Timmer that the chip industry is coming out of a slump and that ASML has a machine that's ready for future chip generations. The orders for the PAS 5500 are visibly increasing. "Nearly all the PAS 5500s that ASML is capable of making this year have already been sold," Bodt says. "If there was ever a chance, now is it. It would be extremely unfortunate to pull the plug now."

Bodt has another argument. If the doors have to close in Veldhoven, it will cost Philips one to two hundred million dollars in severance packages and customer service contracts. As the full owner, the electronics company will have to foot the whole bill. "While there's an excellent chance they'll be self-supporting in no time," Bodt says.

Then Maris, Verdonschot, and Doug Marsh enter the room. Timmer, clad in eye-catching suspenders—the CEO's trademark—is standing behind his desk. The interview is short. The trio from ASML underscore that keeping their company alive is a no-brainer, thanks to all the interest in and orders for the PAS 5500. Sales director Marsh recounts truthfully that even Japan's NEC is evaluating a PAS 5500 just then.

"How much time do you need?" Timmer asks. Maris says ASML can ship enough machines in nine months to pay back a loan. Timmer asks, "How much money do you need?" Verdonschot knows exactly how much he's short of being able to pay salaries for the coming three quarters and says, "Twenty-one million dollars."

Timmer does have a few conditions. ASML is living too large and will have to cut costs. Philips' CEO wants to meet with Maris and Verdonschot again in a year. "Can we agree that we'll shut the place down if it isn't going better by then?" Maris and Verdonschot seal the deal with a handshake and walk out of the room.

ASML is in the ICU and can count on nine more months of IV nourishment. A relieved Maris sends a company-wide letter announcing that Philips will provide temporary financial assistance until "ASML can operate independently." He also writes that in the first half of 1992 they have to ship sixteen to eighteen machines, but the goal for the whole year is to ship sixty. He also brings up a sore point. Some customers are delaying payment for their PAS 5500s and he emphasizes that it's critical to resolve the technical problems in the chip fabs, so that ASML can receive that money as quickly as possible. Maris urges his people to do their absolute best.

Part 10

Growth

1993–1996

70. **A Good Team**

Willem Maris is the good guy; Gerard Verdonschot the bad guy who does all the dirty work. The two aren't thick as thieves, but they are on the same page.

Jan Timmer's $21 million infusion gets ASML through the summer and fall of 1992, but at the end of that year it starts feeling the squeeze gain. In November's monthly meeting with Henk Bodt, Willem Maris and Gerard Verdonschot deliver a painful message: ASML's loss could exceed $30 million that year.

Bodt has stood up for ASML to Philips' board through thick and thin, but he can't get away with a loss of $30 million—and he tells Maris and Verdonschot so in no uncertain terms. The two must keep ASML's loss below $17 million or there won't be anything he can do. There's no avoiding it: the pair reluctantly start drafting a plan to drastically slash costs.

The first victim to fall is the customary Christmas bonus of an extra month's salary. No one will get a raise in 1993, either. Maris and Verdonschot also decide to cut seventy-five jobs.

As usual, it's Verdonschot and not Maris who delivers the bad news to the staff. During a meeting in the De Koningshof convention center in Veldhoven, the CFO stands before his troops. He manages to put a positive spin on his message. In his presentation he subtly reminds them once again that they're at war with the Japanese. Verdonschot is taking away nearly 10 percent of his employees' annual salaries, but they applaud when he stops talking.

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By then Verdonschot has been at ASML for more than eight years. He knows his way around the company and knows the CFO ropes. He's always aware of his stakeholders, and in the early years he regularly visits Arthur del Prado at parent company ASM. At Philips he has contacts everywhere that he can call upon to fight the good fight. In Veldhoven he strolls the factory floor and stops to chat with everyone.

That doesn't endear Verdonschot to all his colleagues, because in contrast to most people at ASML he enjoys the political game. He has a gift for bending others to his will. Some of them come out winners, but there are casualties as well. At ASML there are Gerard-friends and Gerard-foes. It's rough going for the foes, because Verdonschot can lash out pretty venomously. The best course of action is to seek cover when you've gotten on his bad side.

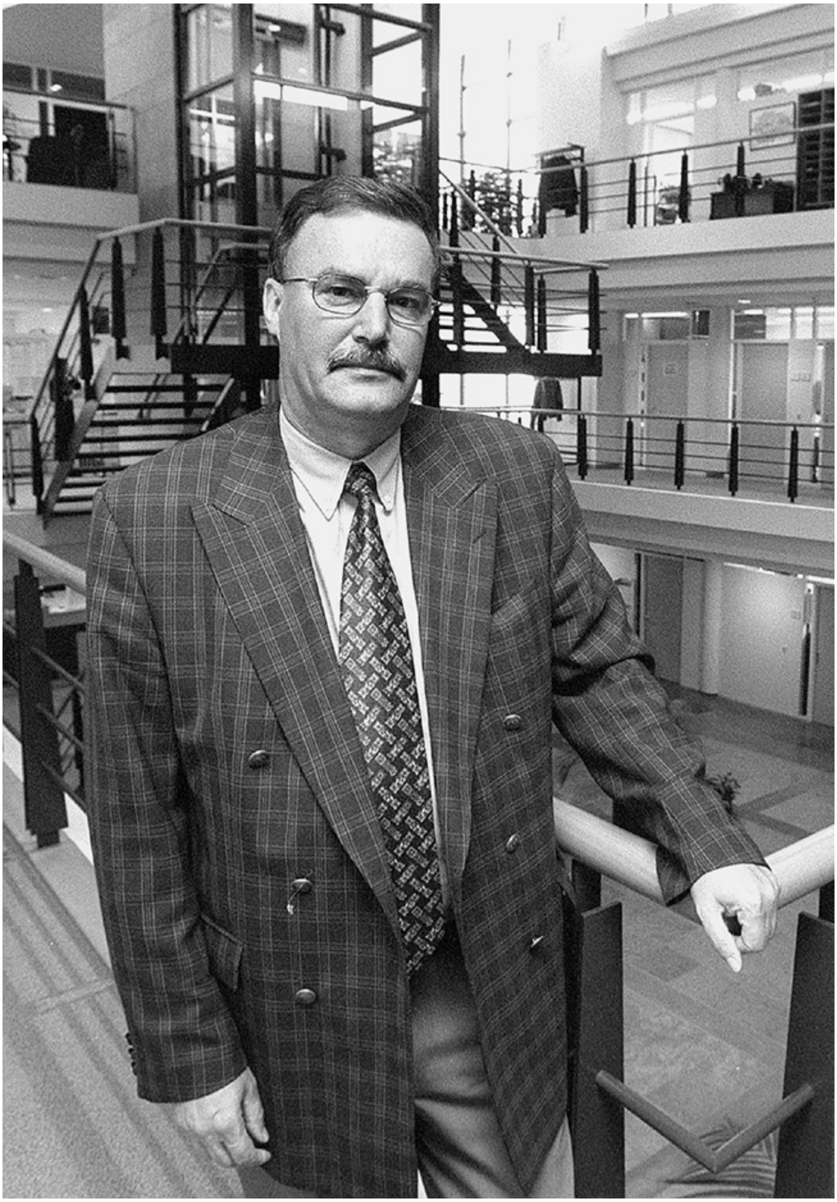
Verdonschot always manages without fail to pry money loose. He seems to be able to make anything happen. He's a man of relationships, not paperwork. He's part of the ASML generation that does business based on good faith. Colleagues who need a signature from Verdonschot can get one if they spin a good tale. He takes them at their word—reading through contracts and documents just isn't his thing. He rarely records agreements.

His method works. Everyone knows where they stand with Verdonschot, and also that you have to watch out for his financial sleight of hand. If honey doesn't work, he's not afraid to use vinegar on his opponents. People know that you're better off avoiding a run-in with Verdonschot.

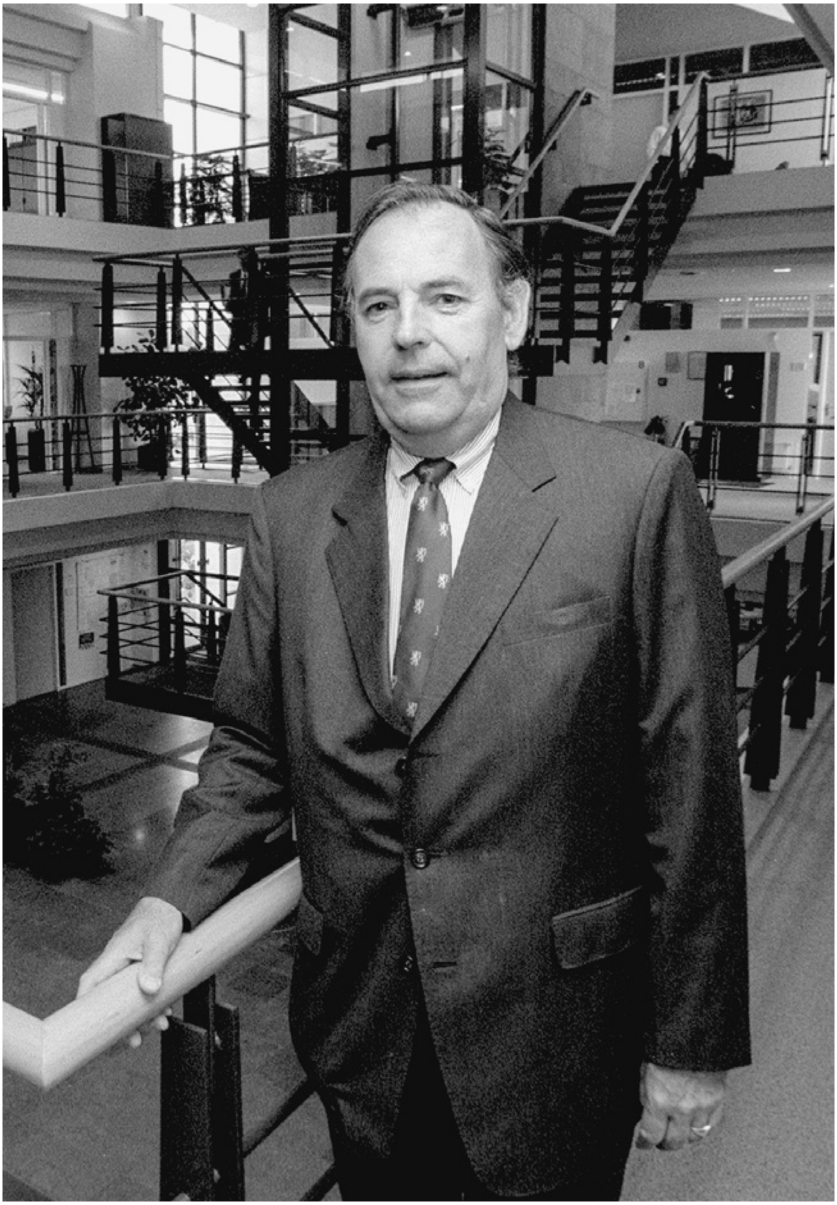
* * *

Verdonschot isn't your traditional cost-minded CFO. His motto is: it's not about costs, it's about profit. The two years when Wim Troost was in charge at ASML weren't Verdonschot's most enjoyable years. Troost pinched every penny he could find. In those days it felt to Verdonschot like the only thing he did was justify expenses, an activity he absolutely loathed.

No, Gjalt Smit was more Verdonschot's type. Smit also put opportunity in first place. The CFO did always grumble about the many unnecessary expenses his first boss incurred, but if he had to choose, he'd take the Smit doctrine over the Troost cut-costs-at-all-costs campaign. In a way, Verdonschot is also a big spender.



These photos were taken for the Eindhovens Dagblad daily paper, to accompany its interview with the departing Willem Maris and Gerard Verdonschot in late 1999. "Gerard is really more of a businessman," Maris says in the



interview. Verdonschot characterizes his former boss as follows: "Willem is good with people. He lets others share in the credit. He's no Mr. President."

He's the only one who ignores the early-nineties ban on flying business class. He's also a fan of business dinners with colleagues and customers. His enthusiasm for them is unflagging; the colleagues he invites eventually come to experience these meals as an obligation.

For a CFO, Verdonschot is strikingly enterprising. When everyone's floored by a $10 million expense, he just shrugs: "Guys, that's not the point; the question is whether we'll earn it back four times over, or five." When ASML manages to start selling machines after 1986 and money starts flowing in from customers, Verdonschot gladly spends it on logistics, R&D, and a dozen other things.

In its early years ASML burns through stacks of money. In the first three years alone ASM and Philips pour nearly $50 million into the black hole in Veldhoven. After ASM pulls out, Philips continues to pump funds into its lithography offshoot—thanks in part to Verdonschot's clever work, in which he picks exactly the right moments to beseech mother Philips for help.

The man is also a bit eccentric. He never celebrates his birthday at work. He'd rather skip the day altogether. Every time it rolls around, Maris has to ask Fia Loozen to order a cake. After everyone's been invited and the coffee's been poured, Verdonschot sits there looking pained. He's not a fan of presents; flowers are about the most he can tolerate. He feels uncomfortable at times like these. This isn't the way he wants to stand in the limelight.

During his lunches and dinners with colleagues and customers, in contrast, Verdonschot is the radiant center of attention. At moments like those he spins tales of his financial tricks with relish, conveniently forgetting half the story and exaggerating the other half. When he's pegged to lead a workshop on finance for his non-finance employees, he injects the course with heroic anecdotes featuring him in the leading role.

* * *

When Willem Maris arrives at ASML in 1990, the score is instantly 1-0 in favor of Verdonschot. The CFO has six years of roots there, and a soft-natured type like Maris doesn't stand a chance against him. In his first years, the new CEO is strongly under the influence of his new financial right-hand man.

Maris starts his tenure at the company looking to Verdonschot for direction. The decisions the CEO makes are often informed by his CFO. Verdonschot puts his ear to the ground everywhere, consults with everyone. He listens to every leaf on the grapevine and then tells his boss, this is how we need to do things, this is the direction we need to go in. And if Verdonschot says go left, that's where Maris goes.

Maris doesn't have that killer instinct. "We don't need to be the biggest, just the best," he tells his wife in his first years at ASML. But he does evolve, and over time he and Verdonschot begin to complement each other better and better. Maris recognizes his CFO's good qualities and gives him the space he needs, and that makes them a good team.

For Maris there's a plus in having a bad guy nearby. He's happy to let Verdonschot do the dirty work. The CEO prefers to lay low when painful decisions need to be communicated. Maris can't bear to do something so unpleasant as letting people go.

The management team appreciates Maris's ability to bring people together, but he doesn't make a particularly strong impression. When it turns out that one of ASML's senior managers has a drinking problem, the CEO avoids confronting him. Employees see the whisky bottle already under their colleague's desk when they arrive for work in the morning. The complaints increase, and Maris drafts a plan with Verdonschot and Nico Hermans in HR: they'll take the man aside on an ASML golfing day and tell him the news together. Verdonschot will draw up the termination contract. But their quarry escapes, and Maris can't clean up the mess himself. He asks Hermans to make sure it gets resolved.

* * *

While Verdonschot plays the bad guy, Maris is the good guy. The CEO evolves into a well-loved leader. The declaration he made in his first year, that he would be a frequent visitor to the factory floor, turns out to be more than just pretty words. When he knows his boys will have to work overtime through the weekend, he often drops by to show his solidarity.

At some point ASML adopts more stringent security protocols, and employees have to wear a badge at all times. One day when Maris is making his rounds, a new warehouse employee asks him, “May I see your badge?” The CEO says he doesn’t have one and adds, “By the way, I’m Willem Maris.” The young employee doesn’t accept his excuse and kicks the CEO out. Maris can appreciate the humor in that, and even praises the man for it later.

* * *

Just as Troost did, Maris begins his tenure with the baggage of a past at Philips. But where Troost never managed to truly become part of the ASML team in his two years there, Maris feels right at home after a few years. It feels like a dream job to him, and he tells his wife that it’s like he’s landed in a fairy tale adventure. His employees soon grow to love him.

Maris evolves into the role that’s perfect for him: *primus inter pares*, first among equals. He even calls it that among his team. ASML is a group of young bucks who want nothing more than to gambol and cavort. The leader understands that his pack knows exactly what needs to happen. What value can he possibly add for someone like Doug Marsh, the seasoned salesman who sold the world’s first stepper at GCA in 1978? Or for a headstrong go-getter like Martin van den Brink in R&D?

Maris has no control over people like those. ASML’s team consists of outspoken characters who know it all much better than he does. He’s not a powerful leader, and he knows that. His strength in the team is precisely that he’s aware of his weakness.

Father Willem gives his boys the feeling they can do whatever they like and if they have a real problem, they can always come cry on daddy’s shoulder. Because no one seems to have an issue with Maris being both a father figure and also just a little bit the boss.

Maris even experiences the relationship with Philips as a father-son affair, with ASML in the role of the rebellious teenager. In his first two years he's surprised by the conservative father's meddlesomeness. He has to invest a great deal of time and energy keeping the busybodies in Eindhoven at a distance.

It's largely Maris's contemporaries who've climbed the ladder at the light bulb company who constantly keep trying to interfere with the rebellious son in Veldhoven. They criticize the way ASML borrows money, how ASML deals with the guilder-dollar exchange rate, how ASML assigns amounts to separate months, and on and on and on. The teenager keeps saving his own skin at the last minute, before his conservative father has a reason to intervene.

* * *

Maris's ability to forge bonds also helps him bridge the cultural barrier between Veldhoven and Phoenix. The differences have their roots in the company's early days. In those first years, the organization on the other side of the pond has carte blanche and a leading role in sales. The US is the most important target market, and ASML smartly chooses Americans to charm Americans. The sales staff chart their own course. They're often seasoned veterans of the chip industry who know exactly how to run their business.

But when the two branches have to work more closely together to serve not only major American accounts but also Taiwanese and tough Korean customers, the differences begin to surface. The Dutch handle the technology, Doug Marsh and his team are the sales vanguard. Confusion and misunderstandings dominate in the beginning. The Americans coin an expression for their Dutch colleagues' arrogance: "If you ain't Dutch, you ain't much."

Maris recognizes that the lack of mutual understanding is a serious handicap and endeavors to resolve it. He views the bridging of internal barriers and cultural differences as a sacred mission. "We're going to break down those walls. We'll do it together, and we'll start with the management team," he tells sales director Marsh.

But Maris has a hard time making decisions himself. In his first years at ASML, Verdonschot gives him the necessary prompts, but the truly big decisions will later be made by the management team, and Maris will serve more as the catalyst for process than for content. He and his team regularly leave Veldhoven for several-day retreats to map out strategy and strengthen team spirit.

Maris has a good feel for his people and helps them work together as a team. Van den Brink's strength is the technology; Marsh knows what ASML's machines are worth, and Hermans and Verdonschot are politically savvy. Maris makes sure all those egos learn to understand each other and shows them that their whole is greater than the sum of their parts. He leaves decisions to the team. Along the way he provides encouragement and cuts conflicts off at the pass.

Maris moves easily among his people. In the afternoons he often walks into controller Theo Bartraij's office for a cigar when his own box is empty. They smoke one together then. Bartraij isn't part of the top management layer, but he can always knock on the CEO's door if his cigars have run out.

The same spirit applies to all the company's employees. People who come to confide their troubles to Willem are first asked if they know of a solution. If they don't, Maris says they truly have a problem. He then invites them to sit down, and he listens patiently to their stories. He doesn't ask for a pat on the back; his job is first and foremost to give ASML's giant egos room to breathe.

To stay in touch with the entire company, Maris invites a random set of ten employees to an informal monthly lunch. People are always eager to be part of it. Though his value as a point guard was never recognized during his years at Philips, the role fits him like a glove in ASML's flat organization. Maris's circle-sir idea from the seventies propels him to great heights at ASML in the nineties, though by then he's no longer calling it that.

Maris's greatest achievement is a massive improvement in the company's relationship with Zeiss in the years from 1993 to 1998. To develop and produce complex wafer steppers, you need an effective partnership and mutual trust. But Zeiss's recalcitrant management prefers to play its cards close to its chest and pursue its own agenda; it doesn't want to bind itself in an exclusive alliance.

Even after the strategy ASML's outlined proves successful in the mid-nineties, the German lens maker continues to resist. Maris knows the key lies with the company's top management and, using his unique talents as a relationship manager, creates openings. He invites key people to attend ASML's quarterly management meetings and later even to join its board of supervisors. These decisions, in which Maris is backed by supervisory board member Henk Bodt, dramatically improve the relationship between the two companies.

In terms of presentation, Maris is a match for Verdonschot. The CEO is ASML's figurehead, the face of the company. With customers, suppliers, and his contacts at Philips he plays the ambassador's role with verve. When he's invited to Natlab to present a peek into current industrial realities, the researchers give his talk a standing ovation.

* * *

For Maris, shareholder value is in second place. He prefers to focus on customers. He knows them by name, and that greases the wheels of many a negotiation. He's not saddled with a huge ego, and that makes it easy for him to see things from his customers' point of view. When he visits Samsung, he knows they're going to tell him his machines are inadequate. In Seoul they always put him in a room with twenty employees who've barely reached twenty-five and have them explain to the Dutch CEO just how many headaches ASML's machines are giving them. He knows the hoop he needs to jump through to get the order.

Maris envisions a modest yet important role for himself at ASML: continually expressing the message "value of ownership." It's a simple formulation of a strategy that everyone eventually understands and can explain to customers: the point isn't upfront cost, but rather the enduring value their steppers deliver. At some point five students from Rotterdam's Erasmus University interview ASML employees for their thesis, and they're amazed to hear the same philosophy from everyone they speak with. To Maris, that's a big compliment.

71. **Value of Ownership**

For the first time, the cash truly starts flowing into ASML, enabling Willem Maris and Gerard Verdonschot to make good on their promise.

In the initial months of 1993 money starts flowing into Veldhoven more quickly. Orders and deliveries are on the rise, and customers are paying considerably higher prices for the latest steppers. Income from servicing and upgrades is growing. In 1992 the company's annual revenue jumped from $81 million to $119 million. ASML's going to make it, all on its own two feet. The victory isn't visible from the outside yet; that year the stepper maker incurs a painful bottom-line loss of $20 million. The red ink is largely to blame on the PAS 5500's teething pains. But in early 1993 everything's largely under control; ASML has a reasonably reliable machine.

The popularity of the PAS 5500 keeps growing. The machine generates a growing positive cash flow, and for ASML that feels like an unfamiliar luxury. For the first time in the company's existence, more money is coming in than is going out.[1]

The dollars streaming in make it possible for Maris and Verdonschot to repay the $21 million they borrowed from Jan Timmer in one fell swoop. The dramatic moment comes nine months later during a meeting where, grinning like fools, the two lay a check on the table. "Henk!" Verdonschot shouts. "A promise is a promise!" Bodt and the others present applaud.

A day later, Verdonschot gets a sour phone call from the head of Philips' finance department. Would he please never again pay a large sum like that by check? It costs the company two days of float.

* * *

Despite the swelling optimism, ASML is still facing a headwind in early 1993. Its most important customer and early adopter IBM is bowing out. The computer company is weathering a storm, and Lou Gerstner has launched a thorough reorganization. The new

CEO has flipped IBM's mainframe strategy around, and that affects the chip fab in East Fishkill, which plays a key role in Big Blue's relationship with the Dutch lithography company. And so ASML loses momentum after all with this strategic customer.

The relationships with Micron and TSMC are growing, but the loss of IBM means that in effect, ASML still doesn't have a truly major customer. Chip makers of the stature of Intel, Motorola, Samsung, and Texas Instruments are still buying from Nikon at that time. Only the relatively small semiconductor manufacturers AMD, Cypress, IDT, Micron, and TSMC are ordering from ASML. That does have a positive effect on the company: these customers force the Dutch engineers to focus heavily on cost and performance.

That gives ASML the technological jump on its competition. Precision, higher resolutions, and higher throughput translate into customer advantages that the management team packages in its value-of-ownership strategy. It's a catchphrase that Maris powerfully expresses and that sounds much more positive than the far more frequently used cost of ownership. ASML's wafer steppers may be 25 percent more expensive than those of the competition, but their precision and productivity mean they pay for themselves faster. Per wafer, chip fabs have lower costs if they use ASML machines. In short: customers who buy in Veldhoven enjoy higher margins. The concept is a particular hit with companies strongly focused on keeping costs down, such as Micron and TSMC. In the early nineties these chip makers aren't yet leading the pack, but ASML's machines will enable them to grow into the market leaders in their segments.

As the machines' reliability grows, it becomes increasingly advantageous for ASML to sign no cure, no pay contracts. In these deals, customers might pay 80 percent of the official sales price, for example, and pay the rest based on performance achieved. That earns the company a great deal of goodwill.

In any case, ASML's technological head start and growing reputation attract increasing attention from the chip industry's gorillas. Smaller players Micron and TSMC are achieving ever greater success using ASML's machines. That doesn't go unnoticed by Samsung and the larger American companies, some of whom will soon take the trouble of paying a visit to the cleanrooms in Veldhoven.

72. **Scanning**

Henk Bodt torpedoes Martin van den Brink's dream project. That makes the systems engineer receptive to a generous offer from America. Willem Maris saves the day at the eleventh hour.

It doesn't take long for Martin van den Brink to stand out as one of ASML's engineering stars. He gives 200 percent and at the same time he's a headstrong rebel who does what he wants. Brink—as his colleagues soon start calling him—doesn't give a fig for convention and sticks his tongue out at status.

When the PAS 2500 is finished in 1986, Van den Brink decides to scope out Fokker, which is looking for project managers. The development of the first stepper was grueling and the engineer has watched ASML nearly buckle under the weight of setting up the machine's assembly, service, and logistics.

At Fokker a program manager tells Van den Brink how they do things at the aircraft manufacturer. Each project is a rigorous, several-year exercise in which its managers must do a lot of documenting. At their Schiphol Airport office they record everything, down to the last rivet. Van den Brink thinks, *If we started doing that at ASML, we might as well close up shop.* While he listens to the whole paperwork story, a cynical smile appears on his face. It doesn't go unnoticed. A week later he hears they found him unsuitable.

Van den Brink makes a rapid impression on Steef Wittekoek. ASML's executive scientist is a little jealous of his younger colleague's freewheeling behavior and his ability to completely be himself. Wittekoek is more of an ambassador, an impeccable diplomat, always proper, always considerate, never seeking confrontation. He's a gentleman scientist, though in his heart he wouldn't at all have minded being wild man Brink instead.

Right from their first years at ASML the young buccaneer and the elder statesman grow fond of each other. Wittekoek's door is always open, and Van den Brink often blows in to vent his problems. Brink raises hell, lashes out verbally, and looks for people who will listen to him rant and rave.

Wittekoek knows exactly how to calm Brink down. "Take a seat," he says as his young colleague storms in growling. Just hearing those words softens his mood. The two are soon attending the annual SPIE conference in Silicon Valley together. From the start they tack on a few days of skiing in Lake Tahoe. The two enjoy each other's company and have a lot of fun together.

Van den Brink is drawn to even-tempered men who can see the big picture. His immediate managers don't have time, and Wittekoek is open and inviting by nature. He's happy to play the part of coach and compass. He always makes time, no matter how often Van den Brink walks into his office. It always leads to a fruitful conversation about what exactly the problem is and how engineering should solve it.

But content is also part of Wittekoek's allure. In ASML's early years, the executive scientist serves as the company's technology ambassador. The Natlab-trained researcher knows prominent scientists at Bell Labs, IBM, and the R&D divisions at major chip manufacturers. That world of Nobel Prize winners and fascinating physics breakthroughs greatly appeals to Van den Brink.

* * *

When at the end of the eighties deep ultraviolet lasers emerge as the successors to mercury vapor lamps in steppers, Wittekoek is the link to technology partners and the people holding the purse strings of EEC funding. In the early nineties ASML starts working with Zeiss, Lambda Physik, and Bayer to use DUV technology in the PAS 5500.[2] Money from the EEC's JESSI program to stimulate the European chip industry forms the project's financial engine.

For ASML, this outside funding is an absolute necessity. In the second half of the eighties and the early nineties, the company doesn't have a cent to its name. Wittekoek and Frits van Hout travel incessantly to The Hague and Brussels to pry loose credits and grants. The Dutch and European governments are receptive;

the rise of information technology and new economic powers has created a sense of political urgency regarding technology strategy. ASML doesn't let the wealth of grants on offer send its head spinning. But once the company's mapped out a technology strategy, Wittekoek and Van Hout opportunistically squeeze the maximum out of the deal.

Strikingly enough, IBM's European branch also plays a role in the JESSI-funded DUV lithography project. The computer maker's chip division is already developing DUV systems in the US with its American partner SVG Lithography. But Big Blue wants to play it safe and is also investing energy into a European initiative to get this future lithography technology up and running. IBM's chip fab in Sindelfingen, Germany offers to serve as the project's pilot site: the wafer fab that will test the experimental DUV machines in actual use.

At the end of the eighties there's additional buzz in lithography: scanning instead of stepping. The American industry has been talking about it for years, because scanning makes it possible to keep the exponentially growing costs of lenses within limits. Van den Brink is soon brushing up on the material.

In a wafer stepper, the wafer table is stationary during exposure. The machine exposes the entire field, containing one or more chips, at one time. Then the wafer moves and—flash—there's a second exposure. In a scanner, in contrast, the machine exposes the photoresist using a slit of light. The exposure is a scanning movement, in which the wafer moves through the slit of light at a constant speed. Above the lens, the mask moves synchronously—in the other direction, with four times the constant speed of the wafer table.

Scanning exposure has the advantage that, for the same lens size, you can image circuits that are 40 percent larger. What's more, the smaller image field (the slit of light) is easier to focus, and lens errors average out in part during the scanning. A system that scans can thus use a smaller lens to expose the same size field as a stepper. That makes it a way to combat the growing complexity and cost of lithographic lenses. That's also the reason why every respected lithography company is looking into it in the early nineties.

Van den Brink and Wittekoek talk and talk and talk about it and conclude that scanning will eventually become inevitable. The scanning problem so intrigues Van den Brink that it mushrooms into a hobby. In 1989 and 1990 he's up to his ears in developing the PAS 5500, but he spends his rare free time on his hobby project: designing a step-and-scan machine. For him it's a way to escape the frenzy. It calms him down to immerse his mind in the puzzle of step-and-scan. He sounds out Wittekoek to test his ideas on the optical-mechanical architecture.

In America Sematech, a consortium of chip manufacturers, has been supporting the development of scanners for some time now. SVG Lithography and Perkin-Elmer are both working on experimental systems. The latter even has a prototype machine already. ASML, Canon, and Nikon don't have anything yet, but the guys at Sematech have informed ASML that there's money waiting for them if they start developing a scanner. Wittekoek also includes the strategy in his message to the EEC, and thus do the JESSI and ESPRIT programs provide welcome financial breathing room to start working on step-and-scan development together with Natlab.

* * *

In 1992 ASML and IBM start talking about step-and-scan. They know each other from their mutual European DUV project. By then Big Blue has been working with SVG Lithography for years on a step-and-scan system, but the company isn't fully satisfied with it; its American lithography partner is only making marginal progress. Just then competitor Perkin-Elmer is leading the pack with a machine design that uses mirrors. IBM wants to start covering ground and decides to ask for advice from ASML and Nikon.

Janus Wilczynski is managing the project on Big Blue's side. He contacts Ken Pynn in ASML's American sales team. The PAS 5500's reputation is growing, and Wilczynski wants to explore the options for working together to develop a new lithographic scanner.

Just like Herman van Heek at Natlab, Wilczynski builds a wafer stepper in the seventies for internal use at IBM's Thomas Watson

Research Center in Yorktown Heights, New York. In the years that follow he rises to great heights in the company's research echelons and receives the prestigious title of "fellow," which releases him from all operational tasks. Wilczynski is a free researcher who may chart the course of his own ingenuity.

Van den Brink is honored when Wilczynski's invitation reaches him. The IBM fellow is a titan. In addition, Big Blue was the PAS 5500's lead customer. He knows that partnering with the most important company in chip technology can do wonders for ASML. But there's also a third reason for his enthusiasm. By the time Wilczynski approaches him, Van den Brink already has a pretty good idea of how to build a wafer scanner. In fact, he's already got a presentation ready and waiting.

In the fall of 1992 Van den Brink and Wittekoek fly to Yorktown Heights to discuss their ideas. They arrive in a beautiful environment where the changing season has colored the trees in magical hues. The research center—a design from the fifties by the Finnish-American architect Eero Saarinen—also impresses them.

When they arrive in the lobby at Watson, they see Wilczynski's portrait among the gallery of IBM fellows. Van den Brink and Wittekoek inspect the photos and see that their conversational partner belongs to a select group of researchers, many of whom have received a Nobel Prize. The young physicist Van den Brink begins to wonder if he hasn't made an utterly misguided choice in working for tiny, insignificant ASML. "I'd have been better off working here or at Bell Labs," he quips to Wittekoek.

Van den Brink's presentation arouses interest. "Janus," he says, "we have no need whatsoever for such a complicated system of mirrors like the one Perkin-Elmer is building. We'll just keep building on our existing steppers." Wilczynski adores the bravado with which the young Dutchman says it. Nonetheless, he's not completely convinced. It seems to him that building a scanner on top of a stepper will lead to problems.

But ultimately, the IBM researcher says yes and asks ASML to push forward on its design. He does suggest that his own team design the optical column. The room is soon engulfed in a rare sense of enthusiasm. Wilczynski has a group of smart people around him who are brimming with ideas. They're meeting the Dutch engineers for the first time, yet they speak the same language. They exchange ideas in an excited fury. Wilczynski suggests both teams draft an optical-mechanical design for a step-and-scan system with a 0.7 numerical aperture lens.

Wilczynski also gives them a tour of his laboratories. He has access to spacious and well-equipped facilities. Wittekoek knows from experience that stepper research at Natlab was always the poor relation of the optics group—compact disc research always had a much higher priority. But at Watson, he sees incredibly well-equipped cleanrooms all in service of the lab's optical lithography research. The IBM team's mood remains high and Wilczynski's boss invites the Dutch visitors to his house for a drink. After that they take their own supply of wine and keep the party going in a restaurant.

On the way home Van den Brink and Wittekoek agree that they can't leave the optics to IBM. They've got to involve Zeiss. That means that both teams will be developing a step-and-scan system including the accompanying optics. In the end ASML's design turns out to be the better one, thanks to lens designer Gerhard Fürter at Zeiss. He designs an optical system with an object-image distance of a meter[3] —significantly more compact than the five-meter-long lens column that IBM's optics gurus think up. Wilczynski congratulates Van den Brink and Wittekoek and suggests they start building the machine right away.

But Van den Brink doesn't get the chance to flesh out his step-and-scan system. When supervisory board member Henk Bodt hears about the partnership with IBM from Willem Maris, his response is reserved. He knows that developing the PAS 5500 nearly killed ASML. Looking back on that incautious process, Bodt says to Maris, "What Brink did, we're never doing that again. We don't want another disaster like that. That project was so big it nearly killed the company. Starting up a mega R&D project like step-and-scan is just a bridge too far." Maris takes Bodt's side and calls an immediate halt to the step-and-scan project,[4] a decision that makes Van den Brink's blood boil.

* * *

In June 1993 Van den Brink gets a call from Boris Lipkin at IBM, the man who selected the PAS 5500 with his boss at the time, John Kelly. Lipkin has since moved on to Varian, which manufactures ion implant devices for chips, among other things. Varian's new CEO, Dick Aurelio, is also a familiar face.

Aurelio returned to the US after Philips passed him over for ASML's top position. But it's Lipkin who has a problem: he can't get his new machine working, and Van den Brink proved with the PAS 5500 that he can do it better than anyone. Would ASML's systems engineer be interested in becoming head of R&D at Varian?

Lipkin couldn't have timed it better. Maris has just informed Van den Brink that ASML will not be pursuing his ideas for a new lithographic machine design. "So we're not going to build a step-and-scan system?" Van den Brink asks the CEO one more time, just to be sure. When Maris confirms it, Brink's reaction is surly. "Then I guess that's it."

Van den Brink tells the head of R&D, Evert Polak, that he's taking a few vacation days and boards a plane to San Francisco. During the flight he can't resist opening his laptop to work on his step-and-scan presentation; next week he'll be visiting Sematech to show them his ideas. He's not thinking about his upcoming interview; he's only got eyes for his machine.

A warm welcome is waiting for Van den Brink in Silicon Valley. Aurelio invites him to his home, where he and his wife roll out the red carpet. Fine dining in San Francisco, a jazz club, that kind of thing. One by one, the marvelous details are revealed. There are two jobs available; Van den Brink can bring along his wife. The environment and the dynamics greatly appeal to him. "I really think we should do it. This is our chance," he tells his wife when he calls home. They don't have children yet; what's stopping them? In the plane home he works some more on his Sematech presentation.

When Van den Brink walks into ASML the next day, Maris is waiting for him. The CEO has had a call from the US. Lipkin has boasted to a mutual acquaintance that he's hiring away ASML's best engineer, and that person instantly called Maris to warn him. "Do you realize you're going to lose the guy if you keep on like this?"

"Brink, you're not going to do anything crazy, are you?" Maris asks when he sees Van den Brink walk in. ASML's CEO is furious when his engineer gives him the lay of the land. At home, Maris always relates the enjoyable things that happen at work, never his problems. But this time the leader is truly worried, and that night he says to his wife, "If Martin leaves, we can forget it. Then it's over and out."

A week later, when Maris and Van den Brink attend the Sematech meeting in the US, the CEO throws him a curve ball. "Brink, shall we just go ahead and do it? We won't say a thing to Henk. We'll just go ahead and do step-and-scan."

And that's not all. Maris also asks Van den Brink if he'd like to be head of R&D. He's already discussed it with Polak. "They asked you to do it at Varian, so you can do it for us as well," Maris says. As icing on the cake, he offers Van den Brink a seat in the management team.

Van den Brink says yes, and Maris is enormously relieved. The CEO does have one condition. The engineer must think up a machine that keeps pace with and is compatible with the existing stepper. Last but not least, Maris wants his systems engineer to broaden his horizon beyond just technology. "Before you start on step-and-scan, you're going to take a six-week senior management course at Wharton in Philadelphia."

* * *

When Van den Brink starts leading all of ASML's R&D at the age of thirty-seven, he realizes he has a problem. He hasn't exactly endeared himself to people over the years. To meet their aggressive R&D goals, he's put a lot of pressure on the people around him: the technical managers that were on his same level. These people are ready to drink his blood, and now he's going to be their manager.

Van den Brink decides to ask for advice from his former R&D buddy Frits van Hout, who has since left for a Swiss company. "Frits, what should I do? There's a good chance I'm going to fail. I've bulldozed right over people these past few years. You know how badly I ignored everyone. They're going to roast me, because they've never felt like I involved them in my work, while I always sailed blind on their help. How can I possibly lead them?"

HR manager Nico Hermans advises him to call on Jos Bomers at Hay, the man who helped him set up ASML's salary and review system in the mid-eighties. Hay's consultants will spend a year taking ASML's R&D department apart and putting it back together again, better.

* * *

Wittekoek knocks on the EEC's door once again and manages to get ASML the financial resources to get step-and-scan up and running. Just as with the PAS 5500, Van den Brink sequesters himself for several months. With the same system architects as in 1988 plus Erik Loopstra, who joined the company a few years back, he's going to flesh out the ideas put forth by ASML and IBM. All this results in the award of a large JESSI project in which ASML will work with Natlab to develop a wafer scanner.

Because the market's acceptance of step-and-scan is low at that time, ASML and Zeiss think up optics that can be used in both a stepper and a step-and-scan system. In Oberkochen they design a lens that in stepper mode has an image field of twenty-two millimeters per side and in scan mode has an exposure slit of twenty-six by five millimeters.[5]

That leads to a stepper prototype in 1996; the scanner prototype sees the light of day a year later. The combined optics R&D will make this one of Zeiss's most successful lens applications.[6] The machine's optical column reduces the chip patterns by a factor of four, so the mask table has to move four times as fast as the wafer table. In the prototype, the mask moves one meter per second and the wafer 250 millimeters per second.

* * *

Everyone realizes the H-table isn't going to be able to achieve the required precision at such high speeds. Natlab researcher Frank Sperling dusts off Gerard van Engelen's long-stroke, short-stroke principle and taps designer Ad Bouwer. They select Lorentz motors for both the short and the long stroke and stack them. Sperling and Bouwer equip the mask table's drive system with a balance mass, which makes the whole system extremely stable.

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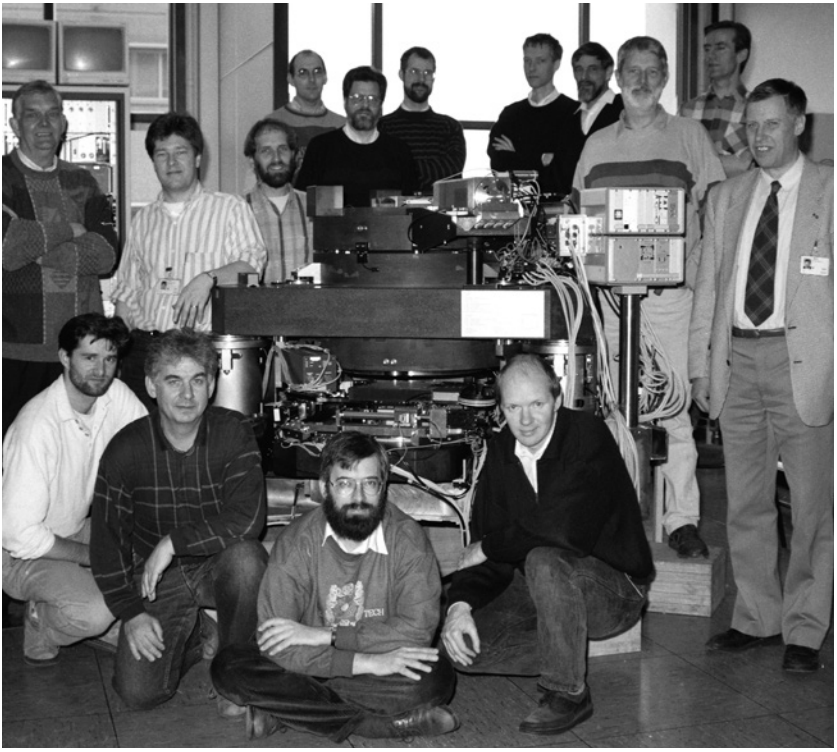
The balance mass ensures that the tables don't transmit the cyclical forces to the rest of the machine, despite the extremely high accelerations.

That enables them to keep the positional deviation under fifteen nanometers, sufficient to project successive chip patterns over each other with the required precision. The system is so stable that a coin placed on its side on the stepper's frame will stay that way during scanning. A delegation from America's Sematech consortium visits the CFT and Natlab during that time, where they're first exposed to the superior concept that ASML is still using in its wafer scanners to this day.

In April 1996, the internal Natlab newsletter proudly reports on the prototype scanners. To make clear how precisely synchronized the tables' motion is in the experimental system, the article compares it to two vehicles simultaneously moving. If both travel at thirty thousand kilometers per hour, the difference between them must be less than half a millimeter to achieve a precision comparable to their scanner prototype.



There are four departments at Natlab involved in developing the wafer scanner prototype: two research groups—Budi Sastra's mechanics group and Cees van Uijen's optics group—and two workshops—Jan van Eekelen's mechanical engineering shop and Wim Joosen's electronics and instrumentation shop.

Many of the researchers involved are in this photo. Standing, from left to right: Ad Bouwer, Frank Sperling, Marius van Kuick, Jos van de Ven, Gerard van Someren, Pierre van de Kerkhof, Peter Dirksen, Henk Sanders, Jan van der Werf, Jan Nent, Henk Bartelings. Sitting, from left to right: Eric Janssen, Peter van Kasteren, George de Fockert, Jacques Leijsen.

73. **The Korean Gorilla**

Recalcitrant Samsung is finally interested in ASML's machines. Gerard Verdonschot doesn't let the Korean purchasers take advantage of him, providing the golden assist for a Maris slam dunk.

Somewhere in the fall of 1993 sales director Doug Marsh picks up the phone and hears, to his surprise, a Korean voice at the other end of the line. It's a purchasing manager at Samsung who asks him in broken English if he's interested in coming to Seoul to talk about future opportunities. Marsh has never experienced anything like it in his life. In the fifteen years he's been in the stepper business, no customer has ever called him up and invited him to discuss a potential multimillion dollar deal.

Samsung rolls out the red carpet for ASML's man. The purchasing manager even has Marsh picked up from his hotel in a taxi. They talk for a few hours, and then they go out for dinner in Seoul. As the *soju* and *anju* arrive at their table, two senior directors join them, one responsible for chip manufacture, the other for purchasing.

With customers in the US Marsh always talks about prices, delivery dates, specs, and uptime guarantees. But as his hosts poke their stainless steel chopsticks into the *bulgogi* and *kimchi*—Marsh himself isn't too fond of Asian cuisine—there's only one thing on their minds: how can ASML help Korea? How can the Dutch machinery manufacturer assist their chip company in its ambition to be number one?

In the early nineties Samsung is brimming with self-confidence. Microsoft's Windows operating system is driving up demand for PC RAMs. Korean memory chip vendors are beating out their Japanese competitors in that wave of sales. Samsung is the absolute killer. The corporate conglomerate had zero market share in 1984, but by 1993 it's the number one DRAM manufacturer and owns over 10 percent of the global market for memory chips. In that year, Samsung's DRAM revenue grows by 72 percent, surpass-ing $2 billion. The company is leaving Japan's Hitachi, NEC, and Toshiba in the dust and looking eagerly toward the future.

The unusual proposal surprises Marsh, but he has no idea what's driving this sudden interest from Korea. Oddly enough, they didn't pick his brain about ASML in Seoul. If Samsung's doing so well using Nikon's steppers, then why did they call him? He knows about the historically charged relationship between Korea and Japan, but that can't be the main reason.

It's several weeks later, when Marsh is in the US visiting Micron, before he learns more about the why and wherefore. Micron has given the Koreans permission to observe its production process, and that's where they learned all about the Dutch lithography supplier. In Boise, PAS 5500s are exposing chips with phenomenally high throughput and low downtime.

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Samsung's reaching out is in stark contrast to ASML's previous experiences. After Marsh joins ASML in late 1988, he tries to contact the company several times. Willem Maris even sends him to Korea, but there they play hard to get. They're satisfied with Nikon.

Marsh isn't the only one throwing himself at Samsung's door in the early nineties. ASML's engineers also hold fruitless conversations with the Koreans. Martin van den Brink, Richard George, and Evert Polak fly multiple times to Seoul, but never develop a click.

It surprises Van den Brink most of all that he can't break the ice. He's almost always been able to convince the lithography experts at potential customers. It always follows the same pattern. At first, chip makers find Van den Brink to be an exceptionally arrogant know-it-all, but as time passes they all start to appreciate his frankness and expertise.

With the Koreans, it's like Van den Brink is looking into a mirror. He finds them exceptionally obstreperous. Samsung always shows up with a laundry list of demands and custom requirements. If ASML can't meet them, they refuse to talk further. The door simply stays shut.

Van den Brink has a practical reason for his own lack of flexibility. ASML is relatively small and can't afford to deliver custom work for every company that buys. It doesn't have the time to set up large-scale R&D for individual customers. If it bowed to every customer's beck and call, then in no time they'd have ten different machine lines in Veldhoven, and that would make development, assembly, and logistics much too complex.

So ASML's entire sales and marketing effort revolves around offering a standard machine. Of course the goal is to deliver a wafer stepper that vastly surpasses the specs once it's installed in the fab. This one-size-fits-all strategy works, and it's a perfect fit for Van den Brink. He's always busy convincing people he's right. That's the way he is. He'll go on talking until chip makers see his point and adjust their list of demands.

But Samsung isn't budging. What's more, in Korea Van den Brink finds himself in a culture that's the poster child for his own frank style. When the Asians don't get their way, they sometimes even get physical and objects start flying through the room. If the Dutch engineers mouth off too much, the Koreans have been known to take away their passports and forbid them to leave the complex. The sales people in Seoul are stubborn. They keep clinging to a long list of demands and specifications. Van den Brink sees months of extra R&D ahead and refuses to concede to all their wishes. In the early nineties the negotiations consistently end in a stalemate. Van den Brink rarely throws in the towel, but in Samsung's case he does. "We're never going to land this one," he tells George and Polak.

* * *

By the time Marsh lets his colleagues know there's an opening with Samsung, the situation in Veldhoven has changed appreciably. The problems with Schott's optical glass and the carbon deposition are under control, and after three years the PAS 5500 is beginning to run smoothly. Interest is high. They already have three machines at IDT and TSMC. UMC is evaluating the steppers and IBM, Siemens, and Toshiba[7] are coming to Veldhoven for demos. All that has also given ASML more financial breathing room. In the second half of 1993 it's clear that for the first time in four years, the company will turn a profit.

Van den Brink discusses the situation with George and Polak. If they snag Samsung, they'll be able to deliver at least a hundred steppers in the coming years with a value that will rise above half a billion dollars. In return, the Koreans want to see their wishes honored—all of them without exception. "We can keep being stubborn," Polak and Maris say, "but we're talking about a damned lot of machines here." The engineers see an opportunity to start up special R&D projects. They abandon the principle of one size fits all and start meeting Samsung's demands.

* * *

The months that follow culminate in a clash of cultures. ASML's American sales managers are in charge of bringing in Samsung, but their negotiations with the Korean customer get out of hand. When the situation escalates, Maris decides to step in and handle it himself. That decision does wonders. The CEO flies to Seoul monthly, and more often if he needs to, to talk with Samsung's top.

Maris's experience is useful there. From his time with Philips in Korea, he knows better than anyone that you don't have to nail down every detail with Koreans; with them, the key thing is trust, and a handshake means more than a stack of contracts.

After several months Marsh and Gerard Verdonschot travel to Seoul to conduct the final negotiations on price. Once again they encounter an extremely confrontational style. "We determine the price you will receive for your machine," the head of purchasing says before they've even sat down.

Marsh politely asks what his customer means. The purchasing manager says the price will drop by 30 percent, period. Verdonschot can feel his blood pressure rising. He takes a deep breath and then calmly answers, "Gentlemen, I believe we have a major misunderstanding here. We thought you had invited us to help you create more efficient production processes and better products. Apparently we misunderstood you. You're now asking us for development aid. I'm sorry, but you'll have to go elsewhere for that. We can't deliver our machines for the price you're offering, so if you'll excuse us."

Verdonschot stands up. "Come one, we're leaving," he whispers to a dumbfounded Marsh. Marsh resists: "We can't do that." Verdonschot puts a hand on Marsh's shoulder. "Doug, we're leaving. There's nothing left to do here. This is pointless. Let's go back to our hotel and grab a beer." One of Samsung's junior salespeople tries to stop them, but Verdonschot is resolute. "Where's the elevator? We're going home."

"Gerard, you've fucked it all up. We've lost Samsung for good," Marsh moans once they're perched at the hotel bar. "How could you do that? You can't do that to a purchasing manager." Verdonschot remains calm. "If you turn out to be right, I'll admit it, but I think you're wrong. If we agree to thirty percent, we won't earn a thing on the deal." Marsh: "But don't we need to consider the long term?" Verdonschot: "We're not letting them fuck us, and we're not Mother Teresa."

* * *

While they drink a beer to recover from their adventure, three Americans show up. They sit down at the bar in obvious stress. They turn out to be salespeople from the machinery manufacturers Applied and Novellus, and Samsung's purchasing people have just wiped the floor with them. They complain about the tough negotiations and say they've agreed to discounts of 25 and 30 percent. The Korean orders are so sizeable they don't want to lose them.

Verdonschot's anchor in negotiations like these is the strategic value-of-ownership concept that Maris introduced. Using financial models, ASML can convincingly show customers how quickly a machine will pay for itself. Chip manufacturers provide their figures and ASML feeds them into models, which then make it crystal clear that the Dutch machines are more advantageous than those of Canon and Nikon. ASML's systems are more expensive, yet a more appealing purchase, because customers earn more with them.

Shrewd Verdonschot also knows perfectly well that Samsung can't wait any longer to set up a new fab. If DRAM manufacturers can bring their chips to market faster than their competitors, it will make a difference of dozens to hundreds of millions of dollars per month. That means you're not losing sleep over the price of five-million-dollar machines.

After a month, Samsung beseeches ASML to reopen negotiations. Maris flies to Seoul and seals the deal with a handshake. The Koreans agree to pay an acceptable price, but they do issue a request to deliver quickly. Marsh shuffles the memory manufacturer closer to the front of the waitlist, and so the first PAS 5500[8] arrives at Samsung's R&D facility in February 1995. There they'll use it to develop a 0.26-micron process for 16-megabit DRAMs. In the years that follow, the Koreans transition 100 percent to the Dutch wafer steppers.

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Thanks to the size of the business from Korea, ASML considers opening an office there. But Samsung's people have a different proposal. "We think we can help you find a partner to set up operations in Korea," they tell Marsh. The salesman acknowledges that having a local support organization would also be best for ASML. By now he knows from experience how vast the cultural differences can be.

The Dutch company partners with Hantech, following the same strategy it used in Taiwan: partnering with a company that understands how things work locally and can handle the service aspect of things. In the years that follow this will turn out to be a brilliant move.

It isn't long before Korea's Hynix switches to the PAS 5500. This company learns about the machines from employees it's stationed at the IMEC research institute in Leuven, Belgium, where they're developing chip processes using ASML's systems. Hynix installs its first PAS 5500[9] in October 1996. The system will come to be known at the chip manufacturer as the Robocop machine, because it stamps out wafer after wafer without a hitch. in 1998, Hynix even becomes ASML's biggest customer.

74. **Forty Thieves**

Henk Bodt looks for investors to help ASML scale up. Zeiss torpedoes his plans.

In the early nineties the PAS 5500 livens things up for ASML. The machine's introduction in 1991 is liberating, and when the system starts running reliably a year later, money starts flowing back into Veldhoven again. The resurging chip market gives it an extra push: customers are buying machines like crazy to set up new fabs for high-volume production. In 1993 all that boosts ASML's annual revenue by 50 percent. For the first time since 1989 it turns a profit: $11 million. After a decade-long struggle to stay alive, ASML suddenly finds itself with a luxury problem: meeting chip manufacturers' growing demand. The company needs capital to expand its mass production, infrastructure, and R&D for new PAS 5500 generations. It's clear that the DUV generation of steppers and scanners will require deep investments. Zeiss will also have to significantly ramp up its output. The lens maker needs to make over a hundred stepper lenses in the next few years just for Samsung alone.

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Supervisory board member Henk Bodt thinks up a way to get investors to cough up funds. He sets ASML's value at $50 million and asks investors to buy a share of the Philips subsidiary. The NMB bank, the MIP fund, and a handful of other industry investors show interest. The MIP even wants to sign up for 50 percent. Bodt knows this ASML adventure will only succeed if Zeiss commits to it. So he decides that his plan will only go through if the Germans are also on board. Willem Maris welcomes a stronger tie with Zeiss. The Dutch company desperately needs the optics specialist. Though its performance has been strikingly subpar, it's the only company with the potential to deliver. A share in ASML will surely strengthen its commitment.

In April 1994, to celebrate ASML's ten-year anniversary, Willem Maris treats the company's founders and former CEOs to dinner in the Michelin-starred restaurant De Karpendonkse Hoeve. As a memento, he sends them a photo

of the evening. In his accompanying note to George de Kruiff, Maris writes, "A good manager just needs to make a good decision every now and then. This was a great one. Thanks, Willem"

Maris gets the ball rolling. He feels out Dieter Kurz, who at that time has just taken over the company's commercial stepper lens operations. Is it likely Zeiss will invest? Kurz conveys the message to director Thomas Bayer, who's responsible for contact lenses and photography at Zeiss. His response is enthusiastic: "Yes, we definitely should!"

But there's an obstacle. Zeiss and Schott are inextricably bound together in the Carl Zeiss Foundation. Decisions on major investments must always be made together. In 1994 Zeiss is penniless, making it completely dependent on sister company Schott and its comfortable bank account for investments.

Maris and Gerard Verdonschot are given the opportunity to present their plan and offer in Oberkochen. Four executive board members each from Zeiss and from Schott will be there. Kurz thoroughly prepares his own representatives. "If we don't do this, we're crazy," he says. "This business is going to grow like a weed, and we're the bottleneck. If we deliver, it will grow wings and fly."

Kurz then tells Maris it's vital that he present his offer in German. "There are people at Schott who can't speak English very well. They'll be completely turned off if you start talking about technology. They don't have the faintest idea what a wafer stepper or semiconductor is."

Kurz knows that Maris speaks fairly good German, but when ASML's CEO starts talking in the famed Ernst Abbe room at Zeiss, the words that come out are in English. The reason why is unclear. Maris says he still owes the Foundation. There are still outstanding invoices that he previously refused to pay on grounds of poor quality and late delivery. All in all, it adds up to $5 million. ASML's CEO proposes that the Carl Zeiss Foundation exchange half the unpaid invoices for a 5 percent share in ASML. He'll pay the rest of the open invoices when he gets home.

Kurz can see by the Schott executives' attitude that it's a lost cause. *This is not the market for us*, he reads in their faces. At that time Zeiss is losing money on a daily basis and no one from Schott is interested in investing in an unknown Dutch company.

In recent years the glass supplier has even asked itself why it's had to make such incredibly difficult-to-manufacture i-line material in the first place.

A consultant in the room goes for the kill. He points out the hard times Siemens is undergoing in the semiconductor market. A large R&D project for lithography based on x-rays is just starting up in Germany. Referring to this heavily hyped initiative, the consultant says that optical chip-making methods are on their last legs. Within thirty minutes the meeting is over. Schott's message is clear: we have enough problems, so please pay the outstanding $5 million a.s.a.p. Less than four years later, a 5 percent share in ASML has grown a hundredfold, to $250 million.

When Bodt hears the bad news from Maris, he instantly comes up with plan B: an IPO, posthaste. In the spring of 1994 Philips and ASML's executives rush to get everything ready for an introduction on the NASDAQ. The economy and the industry are still on the rise, and Bodt wants to strike before a new crisis rears its head.

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To raise money on the NASDAQ, ASML has to catch the attention of American investors. And those are fond of certainty. The investment banks CS First Boston and Morgan Stanley, which are helping ASML and Philips with the IPO, say that the custom in the US is to bind crucial people to the company. American investors won't invest otherwise. Bodt reserves 5 percent of the company's shares for that. Philips holds it in escrow.

Maris and Verdonschot then start selecting people who are vital to ASML and may share in the 5 percent pot. They initially choose themselves and a small circle around them. But after some discussion they decide they can't do without a much larger number of people, including crucial engineers. They subsequently add dozens of people to the list and divide them into six categories. In the weeks that follow, the group expands like an oil slick. Insiders notice that by the end, the list is primarily adding people who get along well with Verdonschot. The CFO even adds a brother-in-law who's recently joined ASML. The head of PR and the executive secretary are also marked as strategically important. In the end there are forty shareholders over whom the 5 percent will be divided.

Maris and Verdonschot have the idea they're chopping up a couple million dollars, at most a couple dozen. Almost no one among the selected has any idea what kind of present they'll be opening at the start of 1998 if they stay on at ASML—they won't know that until after the IPO.

No one, not even Maris and Verdonschot, has any idea exactly what they're divvying up, and certainly not the potential for growth the shares have. By the time everyone realizes just how vast the bounty is, the group is already known as Ali Baba and the Forty Thieves.

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Though ASML has been independent for ten years, Verdonschot still regularly visits Philips' finance and legal departments for help. Once it's clear who'll be getting a share in ASML, he also knocks on the door of the multinational's tax specialists. They recommend he work out a deal with the Dutch tax authority right away. Then he won't have to pay the bill four years from now.

When ASML's CFO explains the plan at the tax office in Eindhoven, the discussion instantly turns to the company's present value. Zero, Verdonschot deadpans; he's good at this kind of acting. He's prepared and he has a couple of convincing arguments: ASML's net worth is zero, and the company has sky-high outstanding debts at Philips and several banks. "We don't have anything, only debts," Verdonschot says with a straight face. "So the company's worth nothing."

But the tax inspector doesn't let him off that easy. Verdonschot then suggests they assume a total value of $5 million. That makes the 5 percent share package worth a quarter of a million. That seems reasonable to the tax inspector. A short while later, ASML pays tax over that $250,000. When the shares mature in early 1998, their value will have increased by two orders of magnitude.

75. **The Medicine Man**

The Carl Zeiss Foundation appoints Peter Grassmann as Zeiss's CEO with the mandate to clean house.

On June 1, 1993 the Carl Zeiss Foundation adds a member to its shareholder council. It's Hermann Franz, previously of Siemens' supervisory board. His mission is to save the day. Zeiss is still busy integrating its West and East German incarnations, but it's also fighting to survive. Shortly after Franz is appointed, it's clear to him that he can't avoid making profound and unpopular changes.

In March 1994 he addresses the assembled shareholder council. Added together, the offices in Oberkochen and Jena are operating at a loss, he tells them. The Foundation will exhaust its reserves within a year. Franz advises that they hire Boston Consulting, the firm that helped catalog the situation in Jena a few years back. "We need to act right now. There's no time for discussion," he tells the council.

Seven months later, the Foundation announces bad news: it must scrap 2,500 jobs at Zeiss, or its losses will run into the hundreds of millions. "Three years after the merger of the companies in East and West Germany, the tradition-rich optics and electronics company Zeiss is once again facing a life-threatening crisis," *Der Spiegel* reports in an analysis.[10] The paper calculates that the move will cut costs to the tune of $155 million and writes that Zeiss plans to completely scrap several of its activities. "Industry analysts aren't ruling out the forced departure of CEO Jobst Herrmann," *Der Spiegel* writes.

In 1994 Zeiss's employees in Oberkochen are tripping over external consultants at every step. Everything is focused on cutbacks and downscaling. Right exactly then, Willem Maris and Gerard Verdonschot make their futile offer of a share in ASML.

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In that turbulent year, ASML receives Samsung's phenomenal order. The Koreans want to buy 110 systems in the coming years, and thus the same number of lens columns. Claus Lichtenberg has just taken the helm of optics production and CEO Herrmann has commanded him to cut deep. Two-thirds must go, the order reads. Of the workshop's 450 employees, just 150 may stay.

When Lichtenberg hears about the mega-order, he instantly starts running the numbers. New generations of optics contain more lenses that must meet stricter requirements. The lens diameters and surface area to be polished keep increasing, and tolerances keep narrowing. To be able to supply lens systems for i-line and 248 nm DUV light in the coming years, he needs to scale up from the current 20–25 optics systems per year to 130–150. That means not six hundred but four thousand lenses. The number of lens surfaces to be polished jumps from twelve hundred to eight thousand. And each stepper needs a few dozen additional lenses for the illumination system.

Even with his current manpower and technology, there's no chance Lichtenberg can meet that demand. He has twelve folk with the golden fingers working for him, but when he translates the orders to the handcraft required, he comes out at nearly three hundred for 1995 and 1996. There's no time to train all those people. The only possible solution is fully automated mass production.

But he can't get Herrmann to listen. The CEO wants to reach the break-even point as quickly as possible; his mind isn't on investments. He's completely focused on reducing costs and cutting jobs because production volumes are dropping for camera objectives, medical instrumentation, and high-end microscopes. He's blind to the opportunities offered by exotic semiconductor optics. In Oberkochen, that line of business (just like astronautics) lives in the category of "projects," things that only get worked on in the spaces between the real work.

In the time that Herrmann puts young Lichtenberg in charge of the central optics workshop, he also puts Dieter Kurz in charge of Zeiss's semiconductor division. In those days the two departments, production and commercial, operate fully independently of one another.

In semiconductor optics, Kurz is instantly under immense pressure. Maris must find a way to manage exponential growth and invites him to all the quarterly management meetings at ASML. There, they hammer relentlessly at him: in 1994 Kurz must double his 1993 output of $25 million.

And that's not all. In the coming years semiconductor manufacturers will be transitioning to the production of chips using DUV light. So that exponential growth in revenue needs to continue in the years that follow. The numbers are growing and lenses are becoming more complex and expensive, Kurz is told time and again in Veldhoven.

Kurz's problem is that his executive board has little understanding of the chip industry. The company is bleeding and senior management is avoiding every risk. Investments must immediately recoup themselves. At home, Kurz ramps up the pressure on Lichtenberg. The semiconductor lenses must reach a revenue of $70 million. That leads to bitter confrontations. Kurz has no authority over the head of production, but is dependent on him. Lichtenberg needs to cut costs; Kurz wants to scale up, but isn't adding money to the pot. The situation drags on for months, with no progress.

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In the fall of 1994 council member Franz has his eye on the man who should handle the major reorg at Zeiss: Peter Grassmann, head of Siemens' medical division. Franz calls Grassmann and a few days later explains his problem in a three-hour meeting. He tells Grassmann about Zeiss's culture, the works council, and his resolution to clean house among the company's senior management. "I think you're the right person," he tells Grassmann. "You have a feel for running a high-tech business."

But for Grassmann it's a step down. Zeiss is appreciably smaller than the medical division he's currently leading at Siemens. What's more, he's always been a vocal critic of lateral movers, managers who haven't come up through the ranks of the company culture.

But Franz firmly emphasizes that there are no internal candidates who can do the job. He's looking for someone with an objective view. Someone from the outside.

Grassmann, a born skeptic, has little interest in the job. He's also unfamiliar with the optics business. His hesitation grows when Zeiss is all over the news in October 1994. It's chaos there. His communication with Oberkochen reinforces that image. One day they send him a fax announcing that the entire board of directors is leaving; the next day he receives a message saying that's not the intention at all.

His distaste dissolves when, on Franz's advice, he reads the history of Zeiss published in 1989. Armin Hermann's book[11] describes how Ernst Abbe could have been a rich man, but chose instead to donate his shares in the two companies Optische Werke Carl Zeiss and Glaswerk Schott & Genossen to a foundation named for his former partner.

In their 150-year existence, the Zeiss and Schott companies have developed an excellent reputation. In the nineteenth century Zeiss was already known for its high-quality products and socially progressive policies. In the twentieth century it wowed the world with its camera objectives. As Grassmann keeps reading, his interest grows. "The fascination begins," he writes in his journal.

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Zeiss employees call their company "an optics university with its own workshop." Grassmann gets a taste of that atmosphere when he comes to take a look in the Swabian valley. Everyone there is focused on crafting high-quality products. But innovation, growth, and a healthy pursuit of profit? That isn't in the culture. If an activity is bleeding money, as is the case with microscopy just then, no one takes much notice. Everyone believes that sooner or later, imposing Zeiss will emerge unscathed from every crisis. Just as in the seventies, when it lost the battle for inexpensive camera objectives to the Japanese. In Oberkochen problems always solve themselves.

Abbe's spirit still blows through the buildings in Oberkochen, Grassmann notes. The sense that the optics company belongs to its employees is deep-seated. Grassmann sees a high-tech company, but one without leadership or focus.

Boston Consulting's analysis gives Grassmann a good overview of the company's current state. The situation is serious, but not hopeless. The existential crisis that began with the fall of the Berlin Wall has compelled everyone to see the necessity of running the company based on sound economics. Grassmann has also noted that in his dealings with the works council. It's the last hurdle he needs to clear before he says a definitive yes to the position of CEO.

Grassmann sees that the company can only be cleaned up if the employees give him the space to find a way out. They do. The works council says it will cooperate, though it's evident it's going to hurt. They do pose one requirement. Grassmann must divide the pain evenly across all layers of the company: management, researchers, and production staff.

Though Grassmann realizes that will make the whole operation expensive, he says yes. His medical background is a good impetus for the local paper to build a bridge to the future. "A medicine man to the rescue," the paper writes in big, bold letters.[12]

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Grassmann not only has extensive experience leading a large company; he also knows what it means to invest in complex technology. At Siemens in the late seventies, he leads a reorg of the loss-making computer tomography division. With a \$90 million investment, he turns the division into a profitable branch in just a few years. In the eighties, the division even grows to become Siemens' strongest division.

In 1983 Siemens asks Grassmann to add magnetic imaging to his division. He allots \$200 million to the endeavor, which includes the acquisition of Oxford Instruments, a British company that has just developed the first superconducting magnet that can image an entire human body. When Grassmann takes Franz's call from Zeiss in 1994, Siemens' MRI division has grown to \$2.5 billion dollars in revenue.

76. **An Audience with The Tank**

Zeiss is busy helping drive ASML into the ground. Jan Timmer can't let that happen.

At ASML they know at the end of 1994 they've got a winning machine in the PAS 5500. They've been putting huge pressure on Zeiss for years, but the Germans aren't delivering. They're busy fighting wars on other battlefields, the medical and photography markets. The merger of their East and West German halves has also stripped them of cash.

ASML's head of purchasing, Ton van Zwam, keeps telling Zeiss's managers that they've got to do much better. Performance, delivery dates, reliability: all of it is subpar. Van Zwam doesn't buffer his criticisms. "Your photography business is a dying cause. Farm that production out to make room for semiconductor optics. That's where your future lies."

Van Zwam means it and makes sure they know he does, but this kind of behavior ruffles the feathers of Zeiss's upper management.

In that time the Germans are already suffering many humiliations. Among other things, they're busy moving the production of their famous Contax cameras to Japan and Belarus. They think Van Zwam is too direct. At Zeiss he's known for his exceptionally tough style. But the campaigns ASML's head of purchasing wages do have an effect. Slowly but surely, men like Claus Lichtenberg and Hermann Gerlinger become convinced there's a market waiting for them.

Van Zwam discusses the situation with Willem Maris. He explains that Lichtenberg is caught in a balancing act. Since late 1993 he's been in charge of the central optics workshop. There, they're experimenting with new technology that can help them ramp up production. But Lichtenberg isn't getting any room to work. Upper management has just ordered him to cut back. Dieter Kurz is pressuring Lichtenberg to increase production, but he isn't providing the production head with the money to make investments—to ASML's frustration.

Van Zwam sees that it's a deadlock in Oberkochen and tells Maris that Lichtenberg should be able to increase production with a few dozen millions. ASML's CEO doesn't have any money, either, but his company is on the rise and the outlook is rosy. So he uses the continuing crisis at Zeiss in late 1994 to warn Henk Bodt and Jan Timmer. The IPO is slated for March 1995 and the company's German optics supplier is evolving into a major risk factor.

Meanwhile, ASML has built up the necessary credit with Philips' top dogs. The 1992 slump is behind them and preparations for the IPO are running smoothly. In 1994 ASML is able to reduce its outstanding $50 million debt to Philips by half.[13]

Maris shows Bodt and Timmer that his 1994 revenue will surpass $275 million, a growth of 70 percent relative to the previous year. ASML expects to end the year with $22 million in profit. In addition they're in talks with Samsung, which is interested in buying the formidable number of at least 110 steppers in the coming years. That will push the number of machines that leave the factory in Veldhoven in 1995 up near two hundred.

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In late 1994 Philips summons Zeiss's soon-to-be CEO to Eindhoven. Peter Grassmann has come straight from Siemens and brought Lichtenberg with him to present the situation in Oberkochen to Philips' board of directors. Grassmann also has an agenda: Zeiss is flat broke, but it needs to make crucial investments to scale up its production to the level ASML's asking for.

In Eindhoven Philips' CEO keeps the pair waiting for an hour. Grassmann isn't used to that kind of treatment. The niceties he and Timmer exchange are brief. Then Timmer, who's already earned the nickname The Tank, cuts to the chase: Zeiss is running ASML into the ground. As sole owner, Philips can't let that happen.

As Lichtenberg is about to start his presentation, Maris and Van Zwam join the group. The German production manager explains that he wants to replace all of Zeiss's manual production labor. As candidates for upscaling its optics production and assembly, Zeiss has two systems under development: rigid custom machines and closed-loop polishing robots. Lichtenberg can't yet guarantee which method will turn out to be the best and how much money he needs.

Grassmann then adds that he can't pay for the scale-up. Timmer asks just two questions: does Zeiss's CEO believe in the business, and will he be able to scale it up? When Grassmann answers yes to both, Philips' CEO says, "I'll support it because we want to reach that IPO." He then lends Grassmann $19 million.

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With $19 million Lichtenberg can finally put on his running shoes. He installs new probes and laser interferometers and replaces the machines that do coarse and precision grinding. For that he buys precision lathes from Hermle, which he then has customized for optical production.

Lichtenberg sets up the polishing process in two ways. For the construction of experimental custom machines he hires Schneider Optik and equips the tools with CNC control systems. It's the first time they've had a fully programmable, reproducible polishing system at Zeiss. These are classical polishing machines, but automated and equipped with ring-shaped tools and a granite base plate.

In a neck-and-neck race with the rigid custom machines, Lichtenberg has the closed-loop systems built. To automate the interferometers he works closely with the metrology department. In the end the precision he achieves with the interferometers and polishing robots is comparable to that of the custom machines. As a final step he and Klaus Beckstette in the O-Lab install ion beam equipment, again in a closed feedback loop with interferometers.

The robots end up winning out. These systems are free of all dependence on the folk with the golden fingers. From that moment on, what the company mainly needs are software specialists to program it all. The surface precision is satisfactory and Zeiss is ready to scale up further.

77. **Grassmann's Baptism by Fire**

Zeiss makes a second plea for ASML's financial aid. Gerard Verdonschot makes it easy and doubles the requested amount.

At the start of 1995 everything at Zeiss is a mess. The relationship between the employer and its employees is impaired and the mistrust between Oberkochen and Jena runs deep. It's Peter Grassmann's first months at the helm and he's annoyed beyond relief. At the company's sluggishness, its political games, the excuses and the avoidance of problems. It's obvious to the CEO: this company is missing leadership. There's no pressure to perform, no enterprise, no pursuit of profit, no one who's seriously tackling the problems.

Shut down loss-making activities? No such thing at Zeiss. Just like financial controls. Justifying financial decisions and drawing up a budget with a well-founded investment strategy? Grassmann can't find it in Oberkochen.

People nestle comfortably in the warm maternal lap of their employer. Carl Zeiss is their company, and the firm's social function has top priority. People who leave, leave with generous pension plans.

Grassmann bumps up against the limits of his power and struggles with that on a personal level. He sees the inanity of his agreement with the works council. The deal is to cut jobs evenly, which means many good physicists must also leave. That hurts his heart. He has to send employees away who are still valuable to the company, people who put their hearts and souls into their work and don't know what to do with themselves at home if Grassmann sends them into retirement at the age of fifty-six.

On January 1, 1995 Jobst Herrmann leaves and it's clear to Grassmann that the rest of the board of directors will soon follow. Otherwise there's no possible way for him to change the company's culture. He lets on that he doesn't need the other three board members.

Based on Boston Consulting's advice, Grassmann shuts down ten of Zeiss's twenty-six activities in his first year. He partitions the rest into five business units. In Jena he sends an additional thousand people away, on top of the planned number.

Grassmann rips through the company and his short temper soon earns him a reputation. When business managers present their strategic plans, he's not afraid to hand them their heads on a plate right then and there. "I don't want to hear any more of this nonsense. You're fired. I'll get someone else in to take your place."

Grassmann's gaze also falls upon Dieter Kurz. It's clear the semiconductor division needs an investment plan for multiple years. The next step in chip production is DUV lithography. That creates new opportunities—and new threats. I-line made ASML and Zeiss serious contenders, but if they succeed in making the step to lasers, they'll be playing in the same division as the Japanese.

Kurz tells Hermann Gerlinger and Winfried Kaiser to collect the relevant figures so he can present them to the board of directors. Before the two give him the numbers, they ask him to make sure he's sitting down. They've calculated they'll need a whopping $85 million over a period of two years. "Not possible," Kurz barks. "Surely you don't think I can go to the board of an almost insolvent company and ask for eighty-five million? They'll throw me out into the street! Redo the calculations and make them come out with something acceptable, because this isn't going to cut it."

But after they've gone through it all again, they come out at the same amount. They need $85 million to keep doubling revenue in the coming years and catch the DUV wave.

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Kurz breaks out in a cold sweat when he hears all the stories about run-ins with Grassmann. A few people have even lost their jobs during their conversations with the CEO. When Kurz, shivering in his shoes, finally gives his presentation, his superior plays the villain as predicted. Grassmann sees a traditional Zeiss employee who's beating around the bush. Irritated, the CEO starts haranguing Kurz about the numbers and colors in the man's charts. There's no chemistry between them, that much is clear. After twenty minutes Kurz thinks, *Let me just spit out the eighty-five million; maybe then Grassmann will stop*.

Kurz collects himself and says, "Look, this is a business that doubled last year from $25 million to $50 million. Revenue will double again this year. This pursuit is anything but pointless—but to get us there, I need $85 million."

Then Grassmann takes a tack that's unlike anything Kurz has ever experienced in conversations with his previous bosses. He doesn't know that the man across from him is playing a game with him. Grassmann's already heard about the required investment in the halls. "Would you invest that much if it were your own company?" the new CEO asks. Kurz gathers every scrap of courage he has and says, without blinking, yes. "Then you'll get it," Grassmann tells him.

The finance guy who's also present is stunned and begins to stammer, "But we don't have that kind of money." Grassmann says, "Be quiet. Kurz, you'll get it."

Grassmann has an instinctive feel for opportunity. The amount doesn't faze him. In his time at Siemens he learned two things: first, you have to develop your own vision and investment strategy for a baby business with great potential. Second, a Western company doesn't have to be afraid of the Japanese. At Siemens, by making mega-investments at the right time he turned the business for CT scanners and a few years later MRI systems into a multi-billion-dollar success. He knows that ASML has high-profile customers—and that the machinery manufacturer can't do without Zeiss. ASML spends a quarter of its purchasing budget in Oberkochen.

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It's clear to Grassmann that semiconductor optics is a business that's likely to grow substantially in the coming years, though he's surrounded by alarmists. His CFO tells him time and again: the chip market is cyclical and much too risky. But Grassmann also knows that making chips is a capital-intensive business. The self-fulfilling prophecy that is Moore's law drives semiconductor manufacturers to keep ramping up their demands. To stand out

Dieter Kurz *Photo: Zeiss*

Peter Grassmann *Photo: Zeiss*

in this rat race, chip makers continually need new, more advanced machines. So everything will keep growing, Grassmann has decided. The investments, wafer stepper prices, and also the optics' share of the total bill of materials.

What's more, Zeiss's position is comfortable: it's at the top of a business with a very high barrier to entry, a practically unbridgeable hurdle that makes it nearly impossible for competitors to enter the market. That feels wonderfully safe.

But the skeptic in Grassmann also has its doubts. His experience in the high-tech industry is that whatever can go wrong, will. At Siemens he supplied hospitals throughout the world, and he knows how hard it is to serve customers across great distances with complex machines. ASML's business is primarily in the US, Korea, and Taiwan, and that means a lot of time in airplanes. Staying on the radar of manufacturers like TSMC and Samsung requires constant management attention. What's more, sensitive technology requires intensive service on location.

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Grassmann calls Kurz. He's shoved aside his CFO's protests and asks if Kurz can present his story to Schott's board of directors, too. These are the men they need to convince, because Zeiss doesn't have a penny of its own. And there's another hurdle after that. Kurz must also manage to win over shareholder council member Hermann Franz. Grassmann may have a good relationship with Franz, but he knows the Foundation's representative is biased by Siemens' continuing struggle in the chip market.

Grassmann's premonition is spot on. Franz isn't instantly enthused when he hears that the meeting with Schott will be about the semiconductor industry. If not even Siemens can handle the chip market, why would a nearly insolvent company like Zeiss be able to survive it? But Grassmann has built up sufficient credit with him, and after Kurz's presentation Franz says, "Sounds interesting, but you'll need to ask ASML to underwrite part of the eighty-five million."

Kurz hesitates. He's had to endure many verbal beatings from his Dutch partner. To Franz he says, "We're not their best supplier. I don't think we'll convince them to give us a cent. I'm sure they'll say we need to deliver first."

Kurz crawls off to Veldhoven with one of Zeiss's financial controllers. They plan to ask for $10 million of the required $85 million. That's enough to make Grassmann happy. They'll find the rest somewhere else.

In Veldhoven the Germans meet with Gerard Verdonschot and Ton van Zwam. Verdonschot knows the pair has come to beg. He's impatient and asks how much they're talking about. "Ten," Kurz says. Verdonschot starts to grin. "That's not enough, is it? You need more, don't you?" he fishes. "Yes, I need more," Kurz answers. "What about twenty?" Verdonschot says. "Twenty is obviously better than ten," Kurz answers. "I'll give you twenty," Verdonschot decides.

ASML is heading for a successful IPO; it has plenty of orders and Verdonschot knows all too well that Zeiss is the major bottleneck. Every good lens from Oberkochen means another multi-million-dollar stepper in Veldhoven can pass through the factory gates.

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In those days Grassmann is insatiable. When Kurz returns from the Netherlands with $20 million, no applause is waiting for him. He's done what he was sent to do and he did it. Zeiss Semiconductor is a pearl with immense growth potential, both in cash flow and profitability. Grassmann knows that semiconductor optics will help him successfully rehabilitate the company.

Executive board member Thomas Bayer reminds Grassmann almost weekly that it's past time for him to visit ASML. After the CEO gets the reorg started in his first three months, he can finally visit Eindhoven. He asks Kurz to prepare the visit. "It would be good for me to catch you up before you go," Kurz warns him. "This customer behaves a little differently than you're used to." But Grassmann doesn't want to hear of it. "We'll see each other the night before in the hotel in Eindhoven. I'll give you ten minutes."

Kurz and Bayer drive to Eindhoven and take rooms in the Cocagne hotel,[14] where Grassmann is also staying. Kurz waits in the lobby until midnight, when his boss finally storms in in a state of stress. Grassmann's mind isn't on a conversation. "We need to talk about tomorrow's visit," Kurz says anyway. But Grassmann won't listen. He's tired and he wants to go to sleep.

In the morning Kurz encounters a crabby Grassmann at check-out. Both men have slept poorly. "Drive behind me," Kurz counsels his boss. "They're doing a lot of roadwork and we're short on time." But Grassmann doesn't think that's necessary; he has a car and driver, after all.

Kurz and Bayer wait half an hour in the parking lot at ASML for their boss to show up. All that time, Willem Maris and his management team are twiddling their fingers.

When Grassmann finally arrives, the three men walk into the building. Kurz is acutely aware of the insult implicit in showing up so late. His CEO is dismissive. Maris is taken aback: what kind of man is this?

Martin van den Brink has just been added to ASML's management team and makes immediate use of the opportunity to impress upon Grassmann just how badly Zeiss is failing. He gives the new CEO a healthy piece of his mind: "You guys are absolutely worthless! Kurz, Gerlinger, and Kaiser simply aren't doing their jobs. You're too lame to provide us with quality goods. You're wrecking our business." Van den Brink just keeps on spewing. Maris doesn't rein him in.

Kurz is laughing up his sleeve. All this time his brusque and brutal boss has refused to listen to him, and now he's being put in his place by the youngest man in the room. For Kurz it's a welcome shot in the arm. Van den Brink is doing him a great favor with this dressing down, which Kurz will never stop viewing as the turning point in Zeiss's relationship with ASML.

And Grassmann? The verbal violence doesn't seem to affect him during the meeting. As the head of Siemens' medical business, he's had similar run-ins with the Russian minister of health and safety. If you can handle those, you're really made of Teflon. Grassmann doesn't defend his employees; he instantly backs ASML: "Gentlemen, it's good you've told me this. I'll take action."

Yet the confrontation does get under Grassmann's skin. In the parking lot he blasts Kurz. Kurz is on the brink of quitting his job, but he restrains himself. Then Grassmann asks Bayer to ride with him back to the Frankfurt airport. Kurz follows in the other car. When they arrive at the airport, Kurz sees Bayer stagger out of the car, white as a sheet. Grassmann shouted at him for the entire three-hour trip.

The next day Grassmann invites the managers of the optics production and assembly workshops to his office on the top floor of Zeiss' executive building. The CEO is soon in full Grassmann mode. First he turns on the assembly manager. "You've got two choices," Grassmann bellows as he strides to the window. "If you're going to make damned sure we give ASML what they need, you can walk out that door there." Then he opens the window. "If you can't guarantee that, then you can leave the room this way."

Then Grassmann turns the firehose on Lichtenberg and the optics workshop. Lichtenberg doesn't let Grassmann finish his tirade; he interjects, "I'm not going to answer you, but I am definitely going to walk out the door, and I always will."

* * *

At the start of 1995 Lichtenberg has been heading up optical production for a year. Now he has to do two things at once: speed up traditional production and simultaneously install and scale up automated production processes. In the past year he's been unable to convince top management to invest in technology, but now Grassmann is freeing up money. But to program and operate the new machines, Lichtenberg desperately needs well trained people.

Robotics programmers and engineers who know their way around CNC systems are a whole different kettle of fish from the artisanal wizards who can perfect a lens with a few strokes of the finger. What's more, that craft is on its last legs. The demands posed by DUV lenses can't be met by golden fingers.

While Grassmann is focused on a tough reorg that requires layoffs, Lichtenberg needs more employees for the semiconductor business. The two men are in a tug-of-war to achieve their goals. Lichtenberg says he can't meet Grassmann's cutback targets. How can he ramp up production if he has to send people home? The head of production suggests that at a minimum they hold on to the people they need to keep semiconductor optics running, which right now is some forty folk with the golden fingers. In addition, he's looking for educated people to help him automate it all. After much discussion Grassmann finally agrees. But the CEO and the head of production are living in two different worlds. Grassmann has pinned his reputation on making Zeiss healthy again and has announced major cutbacks. Lichtenberg's task is to make sure the chip optics business can grow exponentially.

These differing goals slam headlong into each other in 1995, when Grassmann closes the Zeiss office in Bopfingen. Some eighty people work there, purely on machine-based mechanical production. These are precisely the people that Lichtenberg needs: well-qualified engineers who can program robots and know their way around advanced six- and seven-axis machining equipment.

Lichtenberg knows several of these people personally. These are good relationships from the time when he led the prototyping department. Some of them he knows from the works council, where he served for a while as a management representative. All that works to his advantage when he decides to convince the employees in Bopfingen to come work for him.

Zeiss's HR department has set up a special company for the Bopfingen crew for "worker retraining and employment." This organization's task is to teach the employees new skills and then help them get another job. These are exactly the things that people appreciate about socially oriented Zeiss. Lichtenberg walks into HR and asks if they can agree to let him absorb several of these employees. That turns out to be no problem. Then Lichtenberg sets up a meeting in Bopfingen. He stands before the assembled crowd and says he's looking for people for optical production. He'll set up a bus line between their old location and Oberkochen—forty minutes each way. He also asks the machiners and robotics programmers if they're willing to work in three shifts. At his own central production shop more than one and a half shifts is unspeakable. But in Bopfingen they're used to working around the clock and no one thinks it's strange when Lichtenberg suggests it.

Lichtenberg's plan succeeds. The majority of the engineers from Bopfingen start working for him. No one shows up at the retraining office. In a few days' time, Lichtenberg has added fifty well-trained experts who can help with his plans to expand. All of them are loyal to the company. What's more, they're the kind of engineers who love to learn new things.

But Lichtenberg's cover-of-night operation doesn't make him any friends. The HR manager is furious and threatens to fire him. Nor is Grassmann amused. He's trying to make a show of force by closing down an office, and now Lichtenberg has made him look foolish by poaching the people from Bopfingen and keeping almost everyone on Zeiss's payroll. But Grassmann accepts it. He knows this move is ultimately in the company's best interest.

* * *

After he's led Zeiss for half a year, Grassmann visits a barber in Oberkochen. He normally gets his hair cut in his own town, but this time his secretary made an appointment for him after work. As he sits before the mirror, Grassmann brings up Zeiss. He's noticed that no one has recognized him. The CEO asks what people are saying about the company. "We no longer need our curtains," the barber says. "What do you mean?" Grassmann asks. Then the barber tells him that Zeiss employees always used to come in during work hours, and he had to close the curtains. But that's no longer necessary. Now everyone comes on their lunch break. Grassmann concludes that he's on the right track.

78. **On Its Own Two Feet**

In a single stroke, the IPO dissolves all ASML's financial problems and the company can prepare for the coming war with Japan.

Henk Bodt has spent years defending ASML to Philips' board of directors and has undertaken countless attempts to detach the offshoot from its mother company in a way that's productive. But Zeiss's unfortunate refusal to buy in is the final straw. In early 1994 he throws in the towel and makes a surprising announcement to Willem Maris and Gerard Verdonschot: "ASML is going public."

Maris is highly surprised. Their financial situation isn't yet optimal. "We've turned nothing but a loss these last years! How can we go public?" Maris has always understood that a company first has to turn a profit for six quarters before an IPO is in the cards. "We've only been turning a profit for a couple of quarters," he says to Bodt.

But Bodt believes an IPO is feasible. In 1993 ASML's bottom line showed a profit of $11 million and its cash flow is steadily rising through the sale of PAS 5500s. Its portfolio of orders easily guarantees another four positive quarters. And with the way the chip market is now, demand will stay high. Besides, they'll need some time to prepare everything.

With Philips' support an IPO must surely be possible, Bodt argues. But they need to act now. The chip industry is on the rise, but experience shows that the climate can change in the space of mere months. If they don't latch on to the current momentum, it might be several years before a suitable time frame reappears.

Bodt then works with Philips' CFO, Dudley Eustace, to explore whether an IPO is feasible. They also feel out financial partners. The NIB bank is prepared to take a quarter of the shares for $50 million. Bodt doesn't accept that offer; he believes that 25 percent of ASML is worth at least $75 million at that time, but now he knows he's on the right track.

When Bodt, Maris, and Verdonschot go looking for companies willing to underwrite the IPO, their own bank declines. It doesn't believe that ASML can stand on its own two feet. The bank believes a strong parent company is essential in the highly cyclical market in which the lithography company operates. And so the trio end up at the ABN AMRO bank and the Dutch branch of Germany's Commerzbank. Both banks are prepared to invest in an independent ASML in the coming years.

When Maris and Verdonschot start their rounds of Dutch investors, they can present three profitable quarters. What a difference: they always used to lean on Philips, and now they can show their own burgeoning health. Based on those figures, they tell potential investors that the company is worth at least $250 million. But their reception at home is lukewarm. Pension funds don't even remotely believe them. A Dutch technology company that's going to conquer the world? That sounds too good to be true. ASML's executives can't manage to convince conservative organizations like that.

ABN AMRO and the Dutch branch of the Commerzbank then advise them to look beyond Amsterdam to the NASDAQ technology exchange in New York. That's how the American investment banks CS First Boston and Morgan Stanley become involved.

At Philips, Verdonschot runs up against an organization that has no experience in spinning out high-tech subsidiaries. His discussions with the M&A department about the shares' offering price almost make him want to weep. His talks with Eustace are also thorny. Maris and Verdonschot want to include not a handful, but a group of forty key people in a stock plan with the goal of binding these people to ASML for the next several years. Philips' CFO doesn't want to reserve 5 percent for that. Not even Verdonschot can change Eustace's mind.

But one of ASML's American investment banks has a trick. If Verdonschot plays good cop, the bank will play bad cop. When the two walk into Philips and Eustace once again refuses to budge, the banker says, "Mr. Eustace, it's a very simple story. If you don't make five percent of the shares available for the key people at

ASML, then I'll rip the prospectus in half right now and call the whole thing off. We're on the brink of going public and you're telling me you're going to torpedo the whole thing. Have you lost your mind? Everything's ready to go, all the work has been done. Do you have any idea how much damage this will cause? I can promise you our lawyer will be in touch."

Eustace doesn't answer. The next day Verdonschot gets a call from Philips HQ. He may draw up a list of the people who are crucial to ASML. The train can leave the station.

* * *

Once they've got the prospectus ready, Maris and Verdonschot kick off their American roadshow. Over two exhausting weeks, they meet with potential investors across the country. It's a twenty-four-seven endeavor: explain everything, travel, explain everything again, always to an audience of angry young men who grill the Dutchmen exhaustively.

The financial world has plenty of doubts about Maris's claim that ASML is going to conquer the world. Its dependence on a single product is immense, its fate depends entirely on Zeiss, and with a market share of just 18 percent the Dutch machinery manufacturer has to take on two Japanese superpowers who rule a combined three-fourths of the lithography market. Oh, and by the way, where is the Netherlands again?

But Maris comes through with flying colors. He's the star of the show. Verdonschot watches in admiring awe. After two weeks of nonstop performance, the CEO is on the brink of exhaustion. He asks his financial right-hand man to give the final major presentation in New York. In the end Maris only needs to jump in to answer a couple of questions. Maris and Verdonschot think it's a good idea to shore up ASML's financial position. They ask Eustace for permission to issue three million shares themselves, on top of the eight million shares that will be offered on March 15, 1995 and the total of thirty million shares currently owned by the parent company. But Philips' CFO is not enthused. He's afraid it will water down the electronics company's interest. But in the end he yields to the argument that Philips will also profit from its subsidiary's increased financial muscle.

* * *

Positive results propel expectations upward in the run-up to the IPO. A few months in advance, ASML can flaunt a net profit of over $20 million in 1994. Its revenue growth is also impressive. At $265 million, ASML has brought in 60 percent more than in 1993.

Based on those figures, analysts estimate the machinery manufacturer's value at $500 to $600 million in early 1995. It's clear that by issuing eight of its total thirty million shares, Philips can expect a generous return on its investment.

Philips will ultimately earn $125 million on the IPO. At an initial NASDAQ offering price of $18 (the shares rose to a closing price of $22.50),[15] the three million shares that ASML issues itself create a healthy financial buffer of nearly $63 million. The lithography company can instantly repay all its loans and lines of credit. A few months after going public ASML announces that it's going to expand significantly. It will build a new warehouse and a new assembly plant. ASML soon becomes the darling of the stock market. The circumstances are excellent. The chip industry is on the rise and in 1995 grows from $100 billion to $155 billion. Even renowned analysts like those at Gartner Dataquest are predicting the semiconductor industry won't see another crisis before 2000. That fall ASML's shares rise to 90 guilders (roughly $56), more than three times their offering price.

In early 1996, when the price has dropped to 62 guilders (roughly $37), the Dutch news weekly *Elsevier* lists ASML as number one in its list of stock tips. The magazine calls the company the absolute favorite for that year—and for 1997 as well. "The order pipeline at this supplier to the chip industry is full to bursting, which promises annual profit growth of at least 25 percent for the next two years," the magazine writes, also calling a "valuation at less than 60 guilders" absurd.

Just over a month later, *Elsevier* goes a step further: "Investors in ASML are assured of robust growth for the next two years. The current price of 78 guilders is ridiculously low."

* * *

Maris is promising investors the moon, but the American investors' reservations are burned into his mind. He knows they're right when they say the relationship with Zeiss offers no guarantees when push comes to shove; ASML has nowhere else to go for its optics. Maris realizes the company's dependence on its German partner will only increase with new generations of steppers. He has to make the bond with Oberkochen as tight as he can.

From the moment he met Peter Grassmann, Maris has told Zeiss's CEO how vital it is that they strengthen the bond between the two firms. Once 1995's IPO is behind him, he keeps pushing: a joint venture with Zeiss's optics division seems like the best option to him.

But Grassmann disagrees. In his view, a joint venture will be hard to control. By now he's gotten to know Zeiss's "family company." Grassmann explains to Maris that his employees are used to "working in the spirit of Zeiss" and it will be hard to motivate them to put effort into a new organization with two parent companies.

Grassmann does guarantee Maris that Zeiss won't sell off its optics division. It can't, because the division is part of a foundation in which Schott is firmly riveted to Zeiss. But just like Maris, Grassmann can see the limitations. The dependence is indeed risky. If the business is profitable, everyone's happy. But if the going gets rough, it will soon lead to tensions. Grassmann promises Maris he won't spring any surprises on ASML.

* * *

Simultaneous with the IPO and the PAS 5500's rising popularity, Zeiss miraculously manages to free its lens production of all dependence on human hands. With the chutzpah to invest despite an empty bank account, Grassmann has turned semiconductor optics into an extremely profitable activity. That's part of how he helps the entire Carl Zeiss concern regain its health in the second half of the nineties.

The CEO runs things at Zeiss in an ASML-like no-nonsense style. And it doesn't take long before the management team in Veldhoven sees that things are progressing. On Grassmann's watch, the partners grow closer together and develop a respectful, even friendly, relationship.

Thanks to Grassmann, Claus Lichtenberg is given the room he needs in the mid-nineties to install simple robots that move polishing pens the size of a finger across glass surfaces. At the same time Hermann Gerlinger is bringing into production another crucial technology: the measurement techniques they need to map lens surfaces down to a nanometer's precision. The link between measuring and polishing frees lens production from any dependence on humans. Scaling up is now a question of investing. ASML's concurrent IPO and the cash it generates reduce the scale-up to a manageable problem.

In June 1996 Zeiss opens its new optics production line in Oberkochen. By then the invested cost has run to $87 million. Twenty polishing robots and three ion beam machines shape lens elements to a precision of just a few atoms.[16]

In 1993 and 1994, a few hundred people at Zeiss are involved in the optical and mechanical production and assembly of one hundred semiconductor optics a year. By 1996 Zeiss needs just eighty people to manufacture more than two hundred lenses—and much more complex ones, to boot.

* * *

Despite Grassmann's guarantees to Maris, Zeiss does present ASML with an unwelcome surprise. In early 1996 it becomes clear that, prior to attending a management meeting at ASML's Phoenix office, Kurz made a stop in Wilton, Connecticut. There he offered his services to SVG Lithography. The news comes like a bolt out of the blue and the relationship with Zeiss takes a huge hit.

It turns out that Kurz was sent to SVGL by Peter Grassmann. ASML is deeply hurt by the fact that its partner has approached an American competitor—and with the technology and expertise its Dutch stepper customer has funded, no less. ASML feels betrayed. They've spearheaded the strategy, dragged Zeiss along kicking and screaming, and years later when it turns out to be a success, the German company hops into bed with someone else. For the Dutch engineers, the incident is once again proof that Zeiss's management is highly resistant to fundamentally improving its relationship with ASML.

The incident generates intense discussions. ASML makes it extremely clear that Zeiss supplying to SVGL is unacceptable. This is one of the many instances when Willem Maris displays his unique ability to manage relationships. Backed by Henk Bodt, he asks Grassmann to join ASML's board of supervisors. The goal is to create an exclusive partnership in which Zeiss supplies only to ASML. This ultimately leads to Grassmann's appointment to ASML's board at the annual general meeting in April 1996.

A little later—in 1997—the two companies sign a covenant that will be the cornerstone of their partnership until 2017. In that year the relationship becomes even tighter when ASML takes a 24.9 percent interest in Zeiss's semiconductor optics division SMT. The Dutch company also finances the new generation of an optical system for extreme ultraviolet, the High NA EUV.

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At the start of 1996 ASML is financially independent at last. It has plenty of money in the bank, and the ABN AMRO and Commerzbank banks have raised the company's lines of credit to a total of $120 million. What's more, both banks are going to underwrite the real estate that ASML needs for its scale-up.

In terms of technology, the company is in excellent shape. Its PAS 5500 i-line wafer steppers have evolved into reliable chipfab workhorses and in early 1996 ASML introduces its DUV version, which can image quarter-micron details. These machines, with a price tag of $6 million, will make it possible to construct 256-megabit DRAMs and will ready the company for its next growth spurt. Around this time ASML takes a $2.4 million interest in Cymer Laser Technologies to strengthen its relationship with the laser source supplier. And that same year its R&D partners the CFT and Natlab are putting the finishing touches on step-and-scan, which a few years later will serve as the foundational technology for large-scale chip production.

In early 1996 ASML announces that over the next few years it will invest heavily in facilities and the power to grow. It plans to hire an additional two hundred people that same year, on top of the existing eight hundred. The company promises to set up a stock option plan in which all employees can share in the profit.

All that success leaves the company wanting more. It's particularly eager to teach the Japanese a permanent lesson. Soon ASML employees are walking around in T-shirts whose message leaves no doubt: "We will beat the Japanese."

Appendices

Appendix 1

Computer Chips and Lithography in the 1950s: A European Perspective

In April 1952 a delegation from the Philips Physics Laboratory (Natlab for short) travels from the Netherlands to AT&T's Bell Labs. Among the travelers are Piet Haaijman and Hajo Meyer. In Murray Hill, New Jersey, the Natlab researchers learn all there is to know about the fabrication and use of transistors. Other researchers from Europe have made the trip as well, representing Telefunken, Siemens, GEC, and Ericsson. The future inventor of the integrated circuit, Jack Kilby of Texas Instruments, is also among the visitors. In 1952, the world of semiconductor electronics is still small and readily understood.

It's the first time AT&T has thrown open its doors. The American telecom company's success has always been based on filing patents and leveraging its technology expertise. It's always responded ruthlessly to patent infringements. But after it invents the transistor, the telecom titan takes an amazing turn.

AT&T has a good reason for its about-face. Since 1949 it's been under fire from the US Department of Justice, which wants to limit the company's monopoly by splitting off Western Electric.[1] Countless small companies are eager to start making the transistors that are already beginning to penetrate AT&T's switchboards. These corporate parasites are fully prepared to suck up Bell's semiconductor expertise free of charge. AT&T has no desire to play Goliath against dozens of Davids.

And so in the spring of 1952 at the Transistor Technology Symposium, Bell Lab's researchers tell twenty-five American and ten foreign companies all the ins and outs of transistor technology. The price is reasonable. For $25,000—a down payment on future licensing fees—Philips and the other participants can learn all there is to know about manufacturing the superior junction transistor patented by William Shockley in 1948.

The participants are given detailed documentation to take home, and with "Ma Bell's Cookbook" at his side, Haaijman soon masters the art. By the end of 1952 Natlab is already making hundreds of junction transistors. It's soon developing its own improvements. Leo Tummers and Piet Jochems acquire lab-wide fame as the co-inventors of the pushed-out base transistor, an electronic component that Philips launches around 1958 which becomes a major commercial success.

* * *

In America, it's mostly the Department of Defense that's stimulating research into the miniaturization of electronics. US companies have emerged from the Second World War at full speed and are continuing to profit from a generous government budget for the development of military semiconductor applications. Micromodules filled with transistors form the new "brains" in weapons systems. Small companies are also raking in defense contracts.

Compared to the US, Europe is another planet in the decades after the war, in both economic and technological terms. Countries like England and France are putting money into defense technology, but not the billions the Americans are investing. Large industrial companies like Philips and Siemens primarily serve consumers and other companies. There's barely room for tiny semiconductor startups; they lack both the capital and the customers.

Developments in the US follow each other in rapid succession. Driven by the defense and aerospace industries and with thousands of transistors available, computers become increasingly complex. Engineers are looking for new ways to connect all those tiny components. It's soon clear that the end is nowhere in sight: electronics can be made far more compact. In 1952, Geoffrey Dummer at the UK's Telecommunications Research Establishment declares that the advent of the transistor makes it possible to envision a time when electronic equipment will be available "in a solid block with no connecting wires."[2] Someone just needs to think up a way to do it.

* * *

Amid that dazzling world of new ideas, seemingly endless possibilities, and generous military budgets, the US National Bureau of Standards is the birthplace in the fifties to the process we now know as photolithography. During the Second World War the NBS developed proximity fuzes,[3] top-secret detonators for bombs and rockets that the Americans used with immense success against Japanese kamikaze pilots and the unpiloted V1 and V2 bombs with which the Germans terrorized London. The lab's leadership realizes that the transistor now makes it possible to greatly miniaturize such systems.

Proximity fuzes use radio signals to determine distances. They detonate before the explosive reaches its target; once a bomb or rocket is within a few yards, it explodes. That significantly increases the hit rate. The heart of the fuze is a radio transceiver containing vacuum tubes the diameter of a pencil and the length of a finger bone. The NBS's strategists realize that the transistor makes it possible to perform this distance measurement using much smaller projectiles.

Jay Lathrop is ordered to start experimenting with semiconductors.[4] He joined the Department of Defense's Diamond Ordnance Fuze Laboratory fresh out of college; there, with his colleague James Nall, he sets up a transistor production process from start to finish. He orders germanium and works with the lab's mechanical craftsmen and glass blowers to build furnaces, etchers, deposition systems, and saws. They purify the germanium through recrystallization. That results in a rod as thick as a broomstick, which they subject to a heat-based process called zone refining to remove most of its impurities. Then they saw the bar into thin slabs of crystalline germanium.

Lathrop and Nall make the transistors on these germanium wafers. The transistors are a thousand times smaller than the one-inch slabs themselves. Then they cut out the minuscule components, which they must connect to resistors and capacitors using conducting wires to create electronic circuits.

Soldering the aluminum and gold contacts by hand is a hopeless task; the required conducting paths are just a few dozen microns wide. Lathrop and Nall come up with the idea to use photographic techniques. They stumble across a light-sensitive coating made by

Kodak to etch rivet holes into airplane wings. The coating is called a photoresist: a layer that's sensitive to light but can withstand chemical treatments such as etching. The pair of engineers order the liquid and discover that the photoresist also works for tiny details.

In those days, the semiconductor industry doesn't yet have a method for making masks with the resolution that Lathrop and Nall need. To lay down the tiny tracks, the two decide to use a trinocular microscope: one with the usual binocular viewport plus a third port for taking a photo. Instead of a camera they put a pattern of contacts and tracks above the third port. Above that comes a lamp. This enables them to project the mask details in miniature through the microscope onto the photoresist on the ceramic slides.

They align the system by hand, using a micromanipulator. Lathrop and Nall use the binocular viewport and red light to line up the ceramic slide straight. Once it's in place, they remove the red filter for a few seconds to expose the photoresist. They repeat the process for each layer they need: expose, etch, then deposit new material. They also use the resist as a layer to isolate the conducting tracks from the substrate.

Lathrop and Nall publish their "photolithographic fabrication technique" in October 1957 and are granted a patent on it a few years later. It's the first time the term "photolithography" has been used in conjunction with the fabrication of semiconductor devices. "It's a misnomer, of course," Lathrop later writes in the *IEEE History Center Newsletter*. "It's really a photoetching process instead of a photolithographic process, but somehow photolithography rolls off the tongue more easily than photoetching."

In 1958 Lathrop moves to Texas Instruments, where he and Jack Kilby work on an electronic circuit whose components are not connected on a ceramic base, but right on the tiny slice of germanium on which they are created. Lathrop and Kilby don't cut out the transistors before they connect them. That leads to the first integrated circuit, the first chip, with transistors, capacitors, and resistors connected by fine gold wire to produce an oscillator and then an amplifier. TI announces Kilby's "solid circuit" concept in

March 1959 and starts selling its first commercial device a year later, a binary flip-flop priced at $450.

* * *

Soon after, Robert Noyce at Fairchild builds the first monolithic circuit of the kind we know today: a sheet of crystalline silicon containing tiny electronic components—diodes, transistors, resistors, capacitors, and connecting tracks. He uses a planar process to make his circuit. While Kilby is soldering tiny gold wires to connect the components on the slice of germanium, Noyce uses the lithographic process to lay down aluminum tracks between the microcomponents. He uses another Fairchild invention in the process. To isolate the contact tracks from the silicon, he first deposits a thin layer of silicon oxide. And so Noyce, who will later cofound Intel, makes the first chips to use the method that we still employ today.

That gives birth not only to the computer chip, but also the lithographic process we know today: a complex process that constructs the microelectronics layer by layer through pattern imaging (lithography) and chemical and physical treatments such as etching, oxidation, and deposition. In July 1959 Noyce files a patent for his "semiconductor device-and-lead structure," and Fairchild's engineers manufacture the first integrated circuits with it in May 1960. Not as Kilby did, using tiny arcs of fine gold wire, but with aluminum tracks on top of the silicon, isolated by a layer of silicon oxide.

Appendix 2

The David W. Mann Company

The history of the David W. Mann Company begins in the 1930s at Harvard University's Jefferson Physical Laboratory. There, the astronomer David Mann is analyzing the light from stars and nebulas. To do so, he sends the light from the telescope through a spectroscope (an advanced prism) onto a photosensitive glass plate. That gives him an optical fingerprint in the form of a black-and-white pattern of lines.

Mann wants to measure that unique code as precisely as possible and so he makes his first comparator, a ruling engine with a lead screw and micron-sized lines. He places the glass plates containing the photographically recorded information on a table that he can move using a hand wheel with intervals of a micron. That enables him to characterize the spectral lines with high accuracy.

Colleagues are impressed and they encourage Mann to commercialize his comparators. And so the David W. Mann Company is born, a company that develops mechanical measurement instruments. The precision of one-thousandth of a millimeter that his "micron wheel" achieves is an incredible accomplishment for a fully mechanical instrument in the late thirties.

In 1959 the Geophysics Corporation of America (GCA) acquires the tiny firm, two years after its founder and namesake has passed away. At that time, the company is selling positioning tables that can make precise displacements along two perpendicular axes: six inches in one direction, four inches in the other.

In 1960 GCA's Mann division piques the interest of Clevite Transistor Products. An engineer there thinks Mann's precision table can help him manufacture transistors. He wants to use the instrument to project micropatterns onto photographic glass plates with high precision.

Clevite is so pleased with Mann's positioning mechanics that it asks the precision specialist to build a device to make masks for contact printing. It wants an imaging instrument whose lens shrinks patterns and then images them onto a photographic plate at high resolution. The light from a xenon flash lamp must project the patterns one by one through the lens onto a glass plate with a photosensitive coating. Mann's precision stage must position the images with enough accuracy to successfully overlay the successive masks for a transistor.

Mann's engineers attack the problem. The company screws a microscope objective from Bausch & Lomb above its positioning table, thus building the first fully manual step-and-repeat camera, or photorepeater. It introduces the Model 971 in 1961, and in the following year it sells twenty-three of them at $30,000 apiece. Its customers include Pacific Semiconductor, IBM, Shockley Semiconductor, Texas Instruments, and Philips Elcoma in the Netherlands. A year later, Mann's Model 971 will also arrive at Philips' Natlab.

The 971 is operated entirely by hand. It's significantly more expensive than everything else available in the early sixties, but it's worth it. Competing instruments can just barely achieve a positioning precision of twenty-five microns, but Mann's photorepeater is able to expose the patterns onto the photographic glass plates at a precision of one micron.

Appendix 3

Miniaturization at Philips' Natlab in the Early 1960s

In the early sixties, every part of the Philips conglomerate is working on miniaturization—which places heavy demands on Frits Klostermann's service department for photographic negatives (the mask center). His four assistants service Natlab and ten other Philips divisions.

That work still has little to do with microelectronics. Most of it is coarser work: contact masks on foil twice the size of a postcard with patterns for strain gauges, ultrasound components, and spiral negatives for spiral groove air bearings and for rotors in Philishave electric shavers. It's Klostermann's first major assignment and he quickly learns all the ins and outs of the materials, processes, and equipment used in technical photography.

The increase in photolithographic work at the micron scale means an increase in obstacles for Klostermann and his assistants. They need a cleaner working environment. Cleanrooms don't yet exist at that time; they have to battle dust during exposure and contact multiplication. Klostermann complains about the poor filters in the water pipes and the dust particles in the air—particles of one to five microns are particularly problematic for them. Vibrations are also an issue. "It has become clear to us that vibrations of the basement floor in building WD with an amplitude of one micron cannot be accepted," Klostermann writes in his quarterly reports, in a diplomatic reference to the constantly running compressor there.

In the summer of 1963 Klostermann and his assistants adopt a dust elimination regime. They throw all non-essential equipment outside. Smoking is forbidden inside the workshops, an unheard-of phenomenon in a time when cigarettes are deeply embedded in Dutch culture. Lighting up is encouraged by popular sayings such as "a man's a joke if he can't smoke." Natlab even provides the cigars and cigarettes that group leaders use to make a hospitable gesture during meetings.

One of the assistants starts scrubbing down the newly smoke-free rooms. "As soon as possible he will start wiping down all horizontal surfaces with a damp cloth before work begins. We are now waiting for instructions and cleaning materials," Klostermann notes in June 1963. The lab area is inching ever closer to what will later be called a cleanroom: everyone starts wearing nylon coveralls, new filters are installed in the water pipes, and the assistants start using dust-free working fluids.

Appendix 4

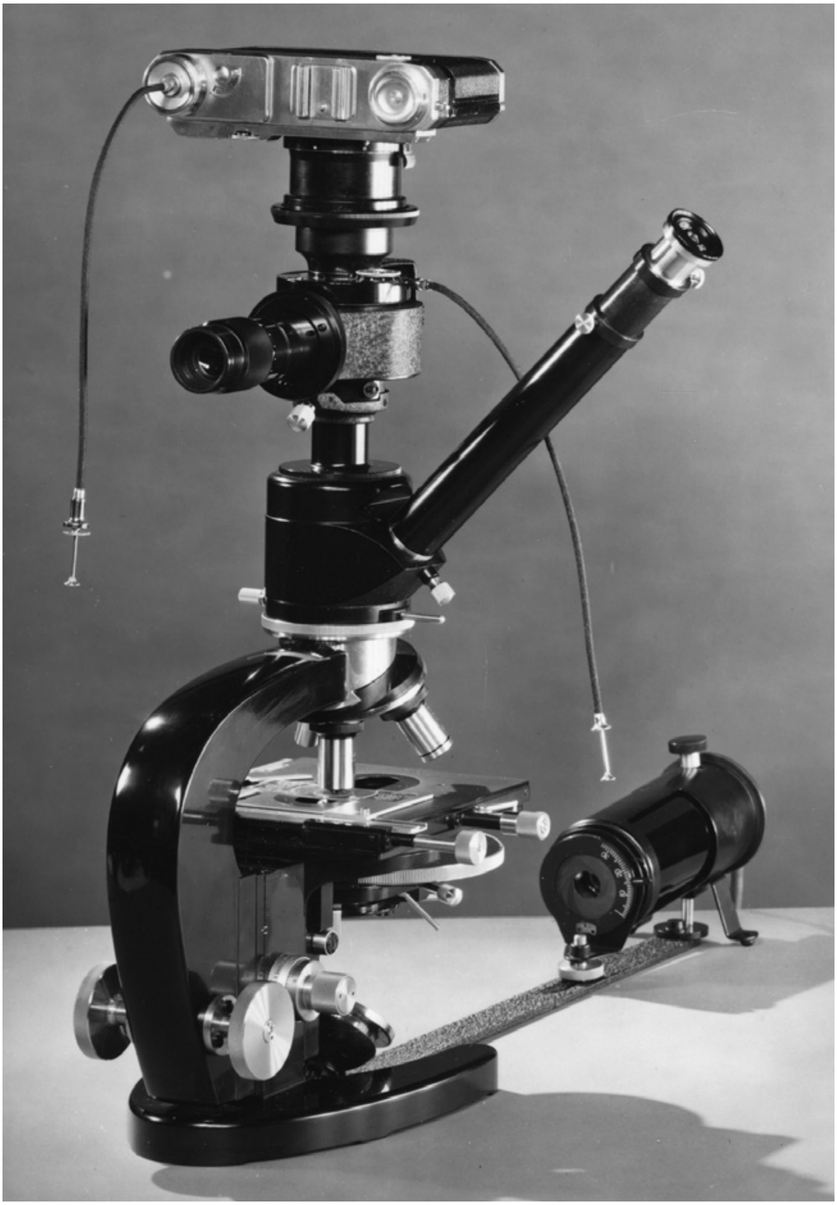
Zernike's Phase Contrast Microscope and De Lang's Phase Grating

Hendrik de Lang, who's developing the phase grating measurement system at Natlab, is a student of Nobel Prize winner Frits Zernike. Back in 1933, Zernike demonstrated how you can use phase shifts in transparent biological tissue to make minuscule details visible. Based on that principle, Zeiss built the first phase contrast microscope during the Second World War. The linear measurement system that De Lang thinks up at Natlab expands on the same principles, though there is a small difference. In De Lang's system, height differences (and not differences in the speed of light through different materials) form the basis for the phase shift.

De Lang uses Zernike's principle to read phase gratings. Those gratings consist of a row of lines—actually shallow grooves—that are evenly spaced. By detecting the height differences using optical sensors and then averaging them, De Lang's system can determine position very precisely.

De Lang has built his own machine to make the gratings. This system uses a microscope objective to project a dot of light shaped as a well-defined square or rectangle. This "light pen" draws thin lines just twenty millimeters long and five microns wide in the photoresist on a glass slide coated with aluminum. After an etching bath the result is a ruler with a mini grating, which a measurement system can use to read off position using a vibrating mirror.

The precision required to draw the gratings comes from a laser interferometer, a system that isn't yet on the market in those days and which can measure distance extremely precisely using a laser beam and interference phenomena. Using that information, the grating-maker knows when to draw its minuscule lines. The only challenge is variations in air pressure, which cause variations in the speed of light and thus in the length measurements. To combat that, De Lang equips his grating-maker with a control system that can take the barometric pressure into account. During the mask-making



In the Second World War Zeiss built the first phase contrast microscope based on the principle of phase shifts in light passing through transparent tissue that was invented by Nobel Prize winner Frits Zernike.

process, the operator at the machine's controls has to continuously monitor the pressure reading and enter it into the machine.

The same phase-shift principle is later used by De Lang's colleague Gijs Bouwhuis to read out a compact disc, another Natlab invention.

Appendix 5

The Opthycograph

Thanks to Frits Klostermann and Ad Bouwer, at the end of the 1960s Philips is in possession of an advanced step-and-repeat camera. But the master masks, the original patterns the photorepeater must shrink down, are still made in a fairly primitive manner. At Philips Elcoma and at Natlab, they first cut chip circuit designs into massive, several-foot rubylith sheets, then shrink them down in a photographic step.

The cutting of the patterns is partially automated. Then the manual work to peel off the top layer of the rubylith in the huge patterns begins (photo). It's extremely precise work that can't be automated. What's more, it's a hellish task to check the increasingly complex circuits for errors.

The manual cutting and peeling can take up to six weeks before the contact mask is ready for the chip fab. That problem intrigues Klostermann. On his bike rides home from Natlab in the summer of 1967, he thinks up a way to simplify the process. He envisions a machine that writes the patterns directly onto the photographic glass slide using a fine beam of light. The design information goes directly into the drawing machine's computer, which then automatically draws the master masks. It eliminates the need for all the yards of rubylith, the light tables, the cutting machine, the peeling process, and the reduction camera.

Klostermann's idea is actually fairly obvious. And he isn't the only one who thinks up a way to create master masks in a single step. Elsewhere in the world, chip makers and suppliers such as David Mann and Varadyne are also developing concepts to multiply the master masks using photographic writing or printing techniques. Even the engineering departments at Philips' chip fabs in Hamburg and Nijmegen are working on their own methods. But Klostermann is Klostermann: he's going for the ultimate solution. He calls his device the Opthycograph, derived from "optical hydraulic computer-driven graphical machine."

An employee peels the cut top layer off the transparent bottom layer of the rubylith. The remaining pattern is then photographically shrunk. The Opthycograph eliminates this peeling and the photographic step by directly drawing the patterns onto a glass plate negative with a light pen.

Ad Bouwer with the Opthycograph

Perfectionist Klostermann wants to be able to draw every possible shape using his Opthycograph. His objectives are a good match for those of the IC groups at Natlab, where they're interested in being able to draw curves and circles for analog circuits.

By then Klostermann has earned his stripes. The Opthycograph isn't an official project, but once again his group leader and section directors don't stand in his way. Just as with the photorepeater, he draws from Natlab's technological plenty. The hydrostatic carriages come down off the shelf again—only this time a little longer, so they can write patterns up to eight inches on a side. The oil system's pressure is raised to seventy bars; the hydraulic servo valves need that to control the complex movements. Klostermann also dusts off the phase grating measurement system created by Hendrik de Lang. And he once again taps Ad Bouwer as his designer; he wants only the best.

Where the photorepeater's control system is made of hardwired electronics, Klostermann opts for a programmable system for the Opthycograph. The pattern generator needs a continuous flow of information to describe the masks. To that end, Klostermann equips the light-writing machine with a Philips P9201, a computer that's just become available and that lets him load in the chip patterns using punched tape.

In those days, engineers are already designing their chips on computers. They put the IC designs onto rolls of punched tape that can be hundreds of yards long. A chip with eighty components such as transistors, capacitors, and resistors can be captured in two thousand characters, a total of sixty yards of punched tape.

Klostermann, Bouwer, and a handful of colleagues finally present the 4,500-pound pattern generator in October 1969. It can draw masks up to eight inches on a side using free-form lines between two and fifteen hundred microns wide.

The Opthycograph's design, particularly its base and stage, will be adopted wholesale by Herman van Heek. That foundation will enable him to complete his first wafer stepper within just a few years.

Appendix 6

The Electron Beam Pattern Generator

Two years before Philips S&I takes the wafer stepper over from Natlab, Wim Troost also takes a machine to write chip patterns using electron beams under his wing.

In early 1976 Wim Troost receives a visit from Jim Beasley, Nick King, and a few of their colleagues at Mullard Research Laboratories. This lab in Redhill, England became part of the Philips family in 1926, when the Dutch electronics company took over British vacuum tube manufacturer Mullard. Troost calls in physicist Ronald Beelaard, one of his best men, to join them.

Beasley describes a device that Beelaard has never heard of: a machine that uses a beam of electrons to draw microscopic lines. The Englishman proudly explains how it works. The prototype electron beam pattern generator (EBPG) that he and his team have developed contains a computer that automatically controls the entire writing process. It turns a beam of electrons on and off while the beam zigzags across the surface, writing ten million tiny lines per second. Just like the electron beam in a black-and-white TV that draws the images on the screen, the EBPG draws its images on a tiny square just a few millimeters on a side. It can be used to create the features on chips. But the electron beam writer can also make masks for optical projection.

Beasley's EBPG is quite advanced. It writes using a beam that's a quarter micron in diameter. Four hundred of those lines beside each other are the width of a strand of hair. But the EBPG is slow. It takes one to three hours to create a two-inch-square mask. The machine steps across the surface in two-millimeter-square chunks, writing each one precisely, then shifting the glass plate coated with a layer of metal and photoresist. The computer ensures that the 625 tiny chunks line up with each other precisely, until the entire pattern has been drawn.

Beasley and King ask Troost whether S&I would like to take over development to commercialize the device. Their story is convincing, and their lobbying is effective. A few months later their research even makes it into Philips' annual report, published in mid-1976. In a piece on scientific research, the Dutch conglomerate praises the English lab's research.

The annual report describes both Natlab's wafer stepper and the electron beam pattern generator. Regarding the optical technology, Philips says at that time, "Thanks to extensive experience in optics, mechanics, and control systems, our research lab in Eindhoven, working with the Elcoma product division, has succeeded in developing equipment that can limit deviations in displacement to 0.1 microns over distances up to 10 centimeters during this process."

The article hints that the end of optical lithography is on the horizon: "Regarding level of detail, the stepper has reached the practical limit of what is possible using optical methods. For finer details [...] other projection methods will need to be adopted, such as electron beam techniques."

Troost is crazy about new projects like these. He's known for taking on the wildest things. His environmental sensor projects are winding down and in 1976 the EBPG offers him the chance to keep people employed. No doubt about it: he's game.

Beelaard is also excited. He's a talented young physicist whose research at the Delft University of Technology was on electron and nuclear spin resonance in the low temperature research group. At S&I he started working on cyclotrons in 1970, but they pulled the plug on that in 1974. In 1976 Beelaard is already two years into automating dairy plants in Germany, England, and Ireland. But pasteurizing milk and making butter and cheese aren't his thing.

The EBPG intrigues Beelaard. He sees immediate parallels with the cyclotron he worked on for four years. The heart of that machine was a high-vacuum space of 280 cubic feet that brought several disciplines together. The e-beam machine is also brimming with technology: this complex device contains high-vacuum technology, electron optics, electronics, advanced control systems, and a heavy-duty computer for feeding in digital chip designs. It appeals to Beelaard's physics ambitions.

Appendix 7

Moore's Law and the Rules of the Chip Machine Game

Moore's law, named for Gordon Moore, defines progress in chip production technology, expressed as the increase in the number of chip components over time. This progress has been a self-fulfilling prophecy for years, primarily bounded by progress in lithography.

Moore, one of Intel's cofounders, observed and published this law first. He claimed that every three years, the number of transistors that would fit on a given piece of silicon would quadruple. Over the years his law has been redefined several times. Intel was particularly fond of reformulating its founder's principle, depending on the needs of its marketing department.

Moore's rule of thumb has held true for more than forty years. Sometimes progress moves a little faster, sometimes a little slower. In recent years the industry has assumed the number of transistors per integrated circuit will double roughly every two years (you can search online for other and more precise formulations).

Moore's law is based on technological progress, but is above all a symbol of economic progress in the chip industry. Chips with smaller structures are faster. If more transistors fit on a wafer, then chips are also cheaper.

* * *

Moore's law makes the chip industry one that's driven by road maps and time. This had and still has profound consequences for chip machinery R&D and for the way ASML operates in general.

The chip industry's playing field is nothing like that of other markets. It might be painful for suppliers of medical devices and cars to delay a product's launch, but they can survive it. Their highest priority is safety and reliability. But chip machinery manufacturers are playing a different game. Their customers, the semiconductor fabs, require—or, rather, demand—new equipment at very specific times.

Where hospitals and car drivers would find it unacceptable for an MRI scanner or car to break down every day, chip makers are satisfied with faltering new wafer steppers at first. The machines' complexity and the continuous integration of new technology mean the first units break down at the drop of a hat. That's acceptable because chip makers' priority in bringing new generations of chips into production lies in testing and adjusting their processes. They spend roughly a year thoroughly preparing and don't truly step on the gas until they've got the process down pat. They don't need perfect machines to set up new processes, just ones that work. That's a fundamental difference from other markets.

But chip manufacturers don't have any choice. They have to work with steppers and scanners that have just barely advanced beyond the prototype stage. That's because they're embroiled in a merciless race: the IC maker that gets its production process for a new chip generation up and running first benefits from sky-high margins and earns enormous profits. Those who are late to the party are consigned to compete on price in a glutted market.

There's roughly a year between delivery of the first test equipment and the finished, mass-produced machines. While chip makers are getting used to the latest technology, machinery makers take advantage of the lull to improve their machines: to make them even more precise and most of all reliable. All to help the chip fab soon stamp out chips twenty-four-seven.

There's a lot riding on it for machinery manufacturers. A machinery maker that misses out on the first test-technology sales has no chance of selling large numbers of steppers a year later when mass production gets going.

The current introduction of EUV machines is an exception to this rule. This generation of equipment has been delayed time and again, thanks to the extreme complexity and technological challenges it's facing. In this case, that turned out to be acceptable for ASML: those same steep hurdles caused Canon and Nikon to throw in the towel, leaving ASML with no competition to speak of at this time.

Appendix 8

The Joint Venture Agreement: The Valuation

S&I's finance department wants to squeeze as much money as it can out of the joint venture deal with ASM. It drafts a long list[5] of the value contributed by Philips.

The list contains big-ticket items like a PAS 2000 prototype machine at 1,327,500 guilders (roughly $414,600 in 1984), a spectrum analyzer at 31,498 guilders (roughly $10,000), and an Olympus microscope at 9,643 guilders (roughly $3,000). But the accountants don't forget the little items, either, such as a P843 microprocessor at 455 guilders ($142) and a P830 floppy drive at 795 guilders ($248). All together, the assets that Philips brings into the joint venture add up to 1,483,713 guilders (roughly $463,400). They also list the subassemblies and materials in inventory. Last but not least, they estimate the hours that Philips employees have put into them, the "work in progress." ASM Lithographic Systems must pay for it all.

The list is accompanied by several surcharges. "In accordance with the calculations in the business plan, we add to the previously computed amount for materials and labor another 19.3 percent for unanticipated costs and 3.1 percent for space," reads the appendix to the contract. But Philips' bean counters aren't done yet. They calculate another surcharge over the full amount for "work in progress" of more than 40 percent. They neatly list all the specific surcharges as percentages. That list includes the craziest things, from design changes (2 percent surcharge) to budget risk (1.5 percent), yet more budget risk (5 percent), and another five surcharges for logistics and the factory. Even then Philips isn't finished. "The amount thus calculated is increased by 25 percent of the costs budgeted in 1984 for PAS 2000 shipping." For R&D they charge 26 percent. Everything still in the warehouse is going to the joint venture for the price Philips paid for it, "plus a 12 percent surcharge for the cost of purchasing logistics," the appendix dryly states.

The appendix also keeps Philips' options open. Everything is valued at 1984 prices and budgeting rates, "pending yet-to-be-determined indexing for cost increases as of January 1, 1984." In other

Duurzame produktiemiddelen

De specifieke produktiemiddelen zullen worden overgedragen tegen de Philips boekwaarde x (100 / (100 - actueel WIR percentage))

De bedrijfsmiddelen die in ieder geval ingebracht worden, zijn:

Omschrijving	Inv. nr.	Boekwaarde
Olympus microscoop P05	546 767	Hfl. 1.459
Autocollimator	546 769	- 3.845
4 Kwadranten regelaar	546 771	- 1.850
Fotonic sensor KD 100	546 779	- 5.309
Micro-bank satz M	546 780	- 3.116
Micro-bank satz 0	546 781	- 4.934
Olympus microscoop	551 115	- 9.643
P856 CPU + rack	551 129 00	- 6.591
P843 32 kw memory	01	- 4.773
P843 processor	02	- 455
P809 Lineprinter X-1425	03	- 6.705
P810 Lineprinter cu	04	- 1.136
P817 VDU + keyboard	05	- 1.932
P824 Disc X-1215	06	- 5.909
P824 CU X-1215	07	- 2.273
P830 Shelf floppy	08	- 795
P830 Floppy drive	09	- 1.705
P830 CU Floppy disc	10	- 1.023
P849 Cabinet	11	- 1.932
Vlakplaat + tafel	546 770	- 4.818
PM 3234 Oscilloscope	537 619	- 3.702
PM 3540 Oscilloscope	537 628	- 2.532
Gain/Phase meter	537 630	- 6.690
Optometer 80X	546 768	- 3.118
Spectrum analyzer	546 788	- 31.498
Stroommeettang	545 791 00	- 7.306
A 6302 Versterker	546 791 01	- 1.656
PM 8252 Recorder standard	546 794	- 2.240
PM 3217 Scope del Sweep	546 795	- 2.630
PM 3244 Oscilloscope	6537648	- 5.843
PM 3243 Oscilloscope	6537651	- 7.468
PM 3234 Oscilloscope	6537652	- 4.627
Infraroodkijkers	551 130	- 6.250
PAS 2000 (ontw. mach.)		Hfl. 1327.500
TOTAAL		Hfl. 1483.713

Op bovenstaande boekwaarden zijn aanpassingen mogelijk i.v.m. de herwaardering per 01-01-1984.

List of "Durable goods" that Philips transferred to the joint venture. This list is from appendix E of the joint venture contract. No documents regarding the value of the sixteen PAS 2000 machines under construction have been found (see also appendix 9).

words: Philips isn't losing a dime on its inventory, materials, and labor. On the contrary—it's raising their price above the amounts originally paid.

Appendix 9

The Joint Venture Agreement: The Initial Math

ASM International and Philips create two companies as of April 1, 1984: a limited partnership (LP) and a limited liability company (LLC). The joint venture agreement signed on March 9, 1984[6] stipulates that the two founders will each invest 6,750,000 guilders (approximately $2.1 million in 1984) in the LP. The contract also says that Philips "will first fulfill its financial obligation through the transfer/contribution" of the goods described in the contract. The LP is managed by the LLC, whose name is ASM Lithographic Systems BV.[7] Each parent company will also deposit 250,000 guilders (approximately $78,000 in 1984) into the LLC's bank account. This construction ensures that ASM and Philips are both liable up to the amount invested by them, that is, seven million guilders apiece.

The goods described in the contract which Philips may reconcile with its promised investment are "completed products in inventory, work in progress, and components for the Systems as well as specific production tools for the Systems." Should their value be higher than seven million guilders, then Philips is entitled to invoice ASM for the difference. Based on the value of the prototype machine listed in an appendix to the contract—1,327,500 guilders—the total amount including the sixteen copies of that machine will be much higher than seven million.

Yet on April 1, 1984 ASML's accountant encounters one million guilders in ASML's bank account, followed by a seven-million-guilder deposit by ASM a few days later. No one can find definitive documentation supporting Philips' ultimate deduction of just six million guilders. The sixteen PAS 2000 machines aren't listed in the joint venture contract, nor is their value. There's just a reference to "assets."

ASML's tentative conclusion is that thanks to Wim Troost's intervention, the total that Philips decided to charge for assets transferred at the start of the joint venture has been reduced to six million guilders. That somewhat softens the blow to ASML's finances.

Strikingly, an appendix to the contract provides an extremely detailed list of Philips' assets (microscopes, spectrometers, various electronics, in total 156,213 guilders) and surcharges, and also lists the price of a PAS 2000 prototype (1,327,500 guilders), but leaves out the sixteen PAS 2000 steppers under construction. See also appendix 8, "The Joint Venture Agreement: The Valuation."

The electric table is not part of the joint venture agreement. "Concerning payment for specific research and development projects currently under development at Philips (including the next-generation stepper based on [an] electric table) and/or to be awarded to Philips in the future [...] separate arrangements [...] will be made," the contract states. See also appendix 11, "The Mystery of the Electric Table."

Appendix 10

Alignment: Global, Die-by-Die, and Dual

The alignment system in Natlab's and later ASML's steppers has always, to this day, been a key competitive advantage. Using a single measurement, the machines establish the wafer's position and then "fly blind" until the whole wafer has been exposed. This global alignment technique raises throughput. Competing steppers have to measure the wafer's position before each exposure, a technique called die-by-die alignment. That takes time and thus lowers throughput.

Global alignment is based on what's called dual alignment. These improvements to the alignment system occur in 1984. That year, Jan van Eijk bumps up against several limitations in the system while he's designing a new mask handling system for ASML at the CFT.

The machinery manufacturer has tasked the CFT with redesigning the way masks are switched out in the PAS 2500. The system used in the first stepper generations is well past its prime. Those use a turntable containing two masks: one beneath the light source, the other waiting in the wings. An operator can switch out the mask that's in this reserve position.

ASML wants to create a library system of eight masks or even more. The major challenge is to make this automated handler so precise that it places the mask in the best possible exit position. In the mid 1980s Rien Koster takes the helm from Wim van de Hoek at the CFT, and he joins Van Eijk in exploring ways to achieve ASML's desired system. They run into a fundamental problem regarding alignment. Because an alignment measurement in the stepper uses a single position on the mask and a single position on the wafer, any torsion in the path of the measurement ruins things.

Van den Brink and Van Eijk quiz each other on the assumptions underlying the reticle handling system and discover that there's a much better way to do alignment. The first two generations of steppers at Natlab pre-align the whole system before exposure based on a single reference mark on the mask and a single optical path through the lens to the wafer. By moving the stage, a series of reference marks on the wafer become visible. That works fine as long as the wafer and reticle remain at the proper angle relative to the machine's frame. If that angle changes—from a rise or drop in temperature, a bump, or some other cause—it instantly torpedoes alignment.

Richard George, the project manager for the PAS 2500, isn't originally open to the arguments Van den Brink and Van Eijk present. Nor is he interested in additional work. Koster and Van Eijk give their arguments literal force by bringing a five-foot torque wrench from the CFT with them the next day. Koster suggests they give the machine's frame a controlled yank between two alignment measurements. That exposes significant rotational errors and George is instantly sold.

Van den Brink and Van Eijk conclude that they can eliminate a whole lot of misery if they start using two reference marks on both the mask and the wafer. A spate of discussions with the Natlab team follows before their ideas are accepted. Eventually everyone realizes that dual alignment will allow them to correct every inaccuracy that could slip in along the entire path from mask to wafer, such as torsion and parts distorting.

Not only can the stepper automatically correct for the wrong angle using dual alignment; it's also possible to undo magnifications that arise as the distance from the mask to the lens varies. Dual alignment was an essential development for the PAS 2500.

The dual alignment technique ultimately results in an overlay precision of eighty-five nanometers in the first PAS 5500 steppers. Natlab also contributes to improving the technology.

Appendix 11

The Mystery of the Electric Table

Why was one of the major technological success factors behind ASML, the electric table, not an integral part of the deal between ASM International and Philips? Why was the joint venture deal based on the PAS 2000, which was unsellable thanks to its oil-based drive system? That may be the greatest mystery from the company's early days, because the seventeen hydraulic clunkers that Philips transferred to ASML were in fact white elephants—and Philips S&I knew it. ASM was being taken for a ride, but to be fair it didn't inspect the deal closely enough, either.

To this day the electric table, the superior alignment technology, and Zeiss's lenses are ASML's technological bedrock. Its super-fast, super-precise stage and alignment have been unique selling points for decades, the reasons why chip makers buy the Dutch lithography machines. The electric table makes ASML's steppers the most productive in the world, and the alignment system ensures that despite that high speed, everything runs at ultra precision.

So how is it possible that Philips' engineers clung to the old technology for so long? In 1979 Wim Troost sent his edict to save S&I's project and build an oil-based machine. With the caveat: we need that electric table, but we'll do it later. Five years later, when ASML was finally gathering steam, the joint venture finally turned to the development of an alternative wafer table. There was absolutely no way to put it off any longer.

Call it a lack of realism, tunnel vision, or conservatism; the fact is, this blunder meant ASML had no income for its first two years. But the company was saved by a happy accident. In late 1984 a deep crisis in the chip industry brought progress to a standstill. If the machinery market had thundered on, ASML wouldn't have been able to sell anything, killing it dead as a doornail.

It's a great example of an early advantage turning into a liability. When Ad Bouwer built the first stepper at Natlab in 1973 for Herman van Heek, the oil-based table was way ahead of its time. That positioning technology was superior for at least a decade. At the end of the seventies S&I couldn't manage to think up a good alternative. Everyone clung to the oil-based drive system.

* * *

After ASM and Philips decide to partner, Philips S&I writes several fat reports. They all end up on Arthur del Prado's desk. In June, Jacques de Vos diplomatically writes[8] that the "hydraulic motors are an expensive part of the machine." He leaves it at a comment that the PAS 2000 is in need of an upgrade. To that end, his 1984 report states, the hydraulic table will be replaced by a table driven by linear motors. Then they can axe the power-guzzling generator needed to keep the oil pressure constant. "With the removal of the bulky hydraulics, the machine will also take up less floor space, which is a huge plus in cleanrooms, where every square foot is valuable," De Vos writes.

His report doesn't mention that hydraulics are unacceptable to chip manufacturers. Nor does the business plan that reaches Del Prado three months later. In that document, S&I's Ger Janssen says almost nothing about the downsides of hydraulics. By then the disadvantages of oil have been known for years, but the document implies that S&I doesn't view it as an insurmountable problem.

Perhaps this fact needed to be kept hidden from ASM, but that doesn't seem to be the case. S&I's engineers simply weren't looking outside their own building; they'd never heard of product marketing, never talked with customers, and suffered from a disease that was widespread at Philips in those days: the illusion that superior technology will sell itself.

The 1983 business plan does say that hydraulics will not be able to meet the required precision in the future. But the fact that an oil-based drive system in a cleanroom makes the system unsellable? Not a word.

If ASM had done any market research, it would have been aware of the need to remove the oil from the PAS 2000. The business plan that Philips drafted in September 1983 said the development of a linear magnetic table as an upgrade to the PAS 2000 was planned for 1984. As a reason to look into a new wafer stage, the plan cited the hydraulic system's high cost and the extra floor space the electric generator took up. It didn't mention that oil was unacceptable in chip fabs—if only because the hydraulic pressure pumps made so much noise they'd need a soundproofing room around them that was bigger than the stepper itself.

The necessity of replacing the hydraulics *tout suite* apparently didn't register for Arthur del Prado and his technical right-hand man, Willem de Leeuw. The September 1983 business plan listed the electric table purely as a future upgrade. The joint venture contract they signed six months later noted that the electric table had been shelved at Natlab. Yet the component fell outside the agreement.

It seems that ASM didn't realize the importance of this technology—and didn't want to. In their policy meetings with Philips, Del Prado and De Leeuw talked with George de Kruiff mostly about ramping up the sales and marketing efforts. Troost agreed, but warned that ASML would then be putting the emphasis on the sale of an oil-based machine with a dubious lens and an insufficiently strong service organization.

ASM was the joint venture partner that enjoyed bragging about its sales abilities. But in 1983 the company was completely blind to the fact that oil is a showstopper in the chip industry. Steppers were hot that year, and unaware of the issues, Del Prado and De Leeuw ramped up the pressure to manufacture oil-based steppers. The first man should have known better; the second had just come from Fokker and had no understanding whatsoever of lithography. There is nothing that indicates that ASM did any research into chip manufacturers' acceptance of hydraulic steppers.

At S&I no one had taken the trouble to talk with customers in the preceding years. Faith in its own technology reigned supreme. In 1983 high-precision positioning systems based on oil were still superior. Even IBM's chip fab in Burlington, Vermont, which took S&I's first and only machine for in-depth evaluation, didn't highlight oil as an insurmountable problem in its evaluation reports.

In 1982 and 1983 S&I's engineers did ask, time and again, for Natlab's electric table, but there was no money to continue its development. It didn't help that the lab's scientific egos clashed with the practical egos in the product division.

In late 1983 Troost, who had the steppers in his S&I portfolio, reported to management his doubts about ASM's rush to ramp up production of the oil-based steppers. But his boss De Kruiff, who knew little about chips himself, was certain that the veteran supplier to the industry surely knew what it was doing. In truth, ASM had no idea.

* * *

When Gjalt Smit conducted his first discussions in March 1984 with the senior engineers who would be joining his team from Philips, it became clear that a hydraulic table was unacceptable. A short while later, potential American customers ruthlessly confirmed Smit's view, during his visit to the SEMICON West chip machinery show.

Richard George and Joop van Kessel did point out to their future director that there was a promising electric table at Natlab, but in fact it was no more than a proof of concept. No one knew the value of that drive system, whether the electric motors were precise enough, or whether they could be mass produced. The striking thing is that the H-table had been patented, but the electromagnetic linear motors hadn't—Philips' patent department had set that proposal aside.[9] The alignment technology, in contrast, was patented to the max in the early seventies.

So right from his first few months, Smit was already acutely aware that oil was unsellable. But amazingly enough, his company still didn't make any hard decisions. In his August 1984 business plan, Smit even listed twenty oil-based steppers as a goal in the schedule, to be sold the following year. Around that time ASML even ordered materials so it could manufacture ten machines on time, albeit with an option to cancel on January 1, 1985. Smit's business plan did clearly state "No PAS 2000 sales after 1985."

The illusion that the PAS 2000 could still be sold was possibly reinforced by the purchase of two of these steppers by Philips' fabs in Nijmegen and Hamburg. Despite their complaints, the two sites were actually using the machines, and ASML regularly dispatched service engineers.

Only in late 1984 did all those involved finally realize the choice facing them. Only then did the curtain decisively fall on hydraulics. Only then did Frans Klaassen know he needed to develop an electric table like a bat out of hell, a task upon which ASML's continued existence would hinge. Only then did Frits van Hout, the young engineer who was given responsibility for R&D on the oil-based PAS 2000 in the company's first months, hear that his project had truly reached its end. Evert Polak, dressed as Santa, told him the news at the company's Christmas party: "Frits, your oil days are over! It's finally been decided."

Once the electric drive technology showed what it was capable of in 1985, it was clear as day: this was the way to go. In the years that followed, the electric table gained a massive reputation. It was the force that drove the steppers' high throughput; semiconductor manufacturers could make more chips using ASML's steppers than using Nikon's and Canon's machines.

It's highly likely that electric positioning became such an obvious choice in subsequent years that it has greatly clouded the events surrounding the oil-based stepper—it's easy to say in hindsight that Philips should have dusted off its electric table much earlier.

Because it wasn't just the electric table that was superior: the hydraulic stage was superior, too. Natlab's oil-based precision technology had an excellent reputation. Frits Klostermann used it to make his photorepeater, a device that was far ahead of its time. Philips' fabs manufactured chips with it for years. Why would S&I's engineers need to develop a new drive system when they still had something that had worked well for years?

Appendix 12

The Joint Venture Agreement: The Final Statement When ASM Pulls Out

The joint venture contract between ASM and Philips records an agreement that the joint venture's net worth may never be negative. ASML's annual report must list an equity of zero or higher. In an emergency the company can draw on lines of credit, but once they're tapped out, the two shareholders must both add funds, always right after the annual report has been approved. In keeping with that agreement, between 1984 and 1987 ASM and Philips each pump 66 million guilders (roughly $32.5 million) into the joint venture. In that same period, they each bear a loss of 44 million guilders (roughly $22 million).

In truth this official loss of 88 million guilders is fictional. On December 31, 1987 the balance sheet lists inventory valued at 91 million guilders (22.5 million in materials, 40.2 million work in progress, 28 million products ready to ship). ASML lists an inventory write-off of just 11.6 million guilders. That might be for oil-based PAS 2000 machines that are no longer sellable. The write-off could have been much higher, say 30 million guilders, but then the bottom-line loss would have crossed the magical boundary of 100 million guilders. By accepting a high value for "materials and components," "work in progress," and "finished products," ASML's total loss remained under 100 million—the psychological limit, according to insiders, that the joint venture's owners were willing to accept.

Had the joint venture's loss ever exceeded that amount, Philips would very likely have pulled the plug. According to insiders, this accounting trick would no longer be possible under today's more stringent financial regulations.

Appendix 13

The Long-Stroke, Short-Stroke Motor

The history of ASML's long-stroke, short-stroke positioning technology begins in 1983, at a point when little is left of Natlab's lithography ambitions. Internal customers—the Philips departments doing IC research—aren't excited about the homegrown wafer steppers. They're using Steef Wittekoek's Silicon Repeater very much against their will. They're definitely not interested in a third generation of Natlab steppers. They'd rather buy in America.

The final bell seems to have tolled for Natlab's lithography program when Wittekoek leaves for Philips' medical division in New York in 1983. Ad Huiser, the head of Natlab's optics group, is about to pull the plug at the end of that year. But the start of the Megachip project and the founding of ASML breathe new life into the research through subsidies. Natlab can hitch a financial ride on the abundant EEC funding for Megachip, and that's reason for Natlab director Kees Bulthuis to give the green light for the Silicon Repeater 3.

Just like ASML, Natlab starts further R&D on the linear motor. Its inventor, Rob Munnig Schmidt, is now working two hours away on electric shavers, but in January 1984 his successor Gerard van Engelen picks the project back up in the optics group. He needs to get the H-stage and its linear Lorentz motors working, and he's in constant communication with Frans Klaassen. The latter is working on the same task at ASML and serves as a mentor to Van Engelen.

At Natlab, Van Engelen experiments with new servos and control systems to coax the best possible performance from the H-stage. The electric Lorentz motors make it possible to very rapidly displace things over dozens of inches. But they have their limits. Using these linear motors, it's pretty hard to achieve both a long stroke and positioning accuracy in tenths of a micron. Future, more stringent positioning requirements will bring Lorentz motors to the edge of their abilities, Van Engelen concludes.

In those days, Van Engelen is also working on the laser beam pattern generator (LBPG), a system that writes patterns using an optical spotlight to create holographic lens elements for use in optical recording systems (CDs and DVDs). The substrates in the LBPG are at most a half inch on a side, so the wafer stage's stroke only needs to be half an inch long. But its positioning needs to be extremely precise and fast.

For this device, Van Engelen is also using a linear Lorentz motor, but one with a stroke of half an inch. The results he's able to achieve are so good that he wonders if there's a way to combine the stage designs for the LBPG and the stepper. He wants to know if he can achieve the mini-table's incredible precision with the much larger wafer stage in the Silicon Repeater.

Both designs use Lorentz motors, and Van Engelen discovers that the mini and maxi versions of these drive systems can indeed be combined to excellent effect. A motor with a short stroke is a thousand times more precise than its bigger brother, but turns out to work just fine on top of that one without the two touching or disturbing one another. Van Engelen succeeds in isolating the small Lorentz motor and the wafer stage from the vibrations the coarser long-stroke motors create.

The researcher then designs the combined wafer stage and Ad Bouwer helps him build a prototype. After they've designed an initial embodiment, they file for a patent.

For the PAS 5500, ASML decides to play it safe and build upon the H-stage. The first PAS 5500 steppers that hit the market in 1991 can achieve a positioning precision of fifty nanometers. ASML starts using the long-stroke, short-stroke principle in the second half of the 1990s when it switches to machines that expose the wafers using a scanning motion. ASML is still using that superior design in its wafer scanners to this day. The current stages, which are still based on the long-stroke, short-stroke principle, achieve a precision of just a few nanometers.

Cast of Characters

Antonis, Gerard - Instrument maker in Natlab's Precision Engineering Group (PEG). *78, 87*

Attekum, Paul van - Left Philips in 1991 after the definitive dismantling of the Megachip project. Joined ASML as the product line manager for the PAS 2500. Currently ASML's senior vice president for corporate strategy and marketing. *485–487, 489, 490*

Aurelio, Dick - Hired as ASML's vice president for marketing and sales in September 1987. Left for Varian a few years later after he was passed over for ASML's top position. *422, 439, 440, 442, 445, 446, 448, 505, 535*

Bartelings, Henk - Natlab researcher in embedded software. *140, 141, 149, 539*

Bartraij, Theo - ASML's financial controller. *432, 504, 507, 524*

Beasley, Jim - Head of R&D for the electron beam pattern generator at Mullard Research Laboratories. *598*

Beckstette, Klaus - Manager of Zeiss's central research division Optik-Labor (O-Lab) in the 1990s. Worked with Claus Lichtenberg to introduce ion-beam equipment for nanometer-scale polishing of lens surfaces. *500, 502, 560*

Beelaard, Ronald - Head of e-beam and optical lithography at Philips S&I. *112–115, 117, 119, 137, 138, 148, 175, 179, 598, 599*

Bertrand, Will - In 1984 and 1985, created the system that laid the logistical foundation for ASML's outsourcing strategy. *213–217*

Bodt, Henk - Philips executive under CEO Jan Timmer from 1990 on, with the semiconductor division and its offshoot ASML in his portfolio. Later a member of ASML's supervisory board. *145, 509–*

511, 516, 525, 526, 529, 534, 535, 547, 551, 559, 572, 573, 578

Bomers, Jos - Consultant at Hay. *328, 329, 331–334, 338, 339, 396, 398, 537*

Boor, Ide van der† - The NMB bank's director and Gjalt Smit's confidant. *365*

Bouwer, Ad - Head of Natlab's Precision Engineering Group. Helped design the Philips Photorepeater and the Silicon Repeater 1. Co-inventor with Steef Wittekoek of the H-stage (Silicon Repeater 2). After Philips, worked at ASML on designs for the PAS 5500, Twinscan, and EUV systems. *19, 41–43, 47–49, 60, 72, 73, 75–78, 87, 109, 111, 115, 133, 134, 136, 140, 142, 148, 208, 238, 538, 539, 594, 596, 597, 608, 615*

Bouwhuis, Gijs† - Leading optics expert at Natlab, inventor of fundamental technologies such as through-the-disc CD reading and the wafer stepper's alignment system. *60, 63–67, 69–75, 81, 85, 96, 108, 238, 347, 451, 593*

Braat, Joseph - Natlab's optics researcher. *85, 228–232, 238, 347–350*

Brink, Martin van den - From 1986 on head of systems engineering for the PAS 2500 and architect for the revolutionary PAS 5500. Uncontested mastermind behind ASML's technological breakthroughs and machine development. Played a crucial role in bringing major customers such as IBM, Intel, and the major Japanese chip makers on board. Currently ASML's president and CTO. *235–238, 283–285, 294, 325, 332, 340–342, 346–349, 351, 435–437, 447–455, 476–478, 480–484, 492, 497, 522, 524, 529–537, 541–543, 568, 606, 607*

Bulthuis, Kees - Succeeded Pieter Kramer as head of Natlab's optics group and later the lab's managing director. *130, 131, 133, 134, 226, 250, 280, 614*

Carasso, Marino - Head of Natlab's optics group working on the Silicon Repeater 3 as a lithographic backup for the Megachip project in the early 1980s. *17, 250, 280*

Casimir, Hendrik† - Appointed as one of Natlab's three managing directors who took over from Gilles Holst in 1946. From 1956 to 1972 member of Philips' board of directors in charge of research. *51, 53, 54, 60*

Dekker, Wisse† - Philips' CEO from 1982 to 1986. Reorganized the company, splitting off non-core activities such as lithography. Under Dekker's leadership, Philips and Siemens began the money-guzzling Megachip project to surpass the Japanese in semiconductor memories. *151, 169, 170, 174, 328, 464*

Doesburg, Cees - Software developer for the electron beam pattern generator at Philips S&I. In ASML's early years, head of software development. *206, 307*

Eijk, Jan van - Leading mechatronics engineer at Philips CFT. Guided development of the mechatronic concepts for steppers and scanners. Invented dual alignment with Martin van den Brink. *450, 451, 606, 607*

Engelen, Gerard van - Invented the long-stroke, short-stroke motor at Philips Research in the 1980s, which ASML went on to use in its wafer scanners a decade later. *450, 451, 538, 614, 615*

Engelen, Henk van - ASML employee. *303*

Frima, Heico - The single ASM International employee who trans-

Henderson, Rebecca - British researcher whose 1988 doctoral dissertation at Harvard University explored the downfall of stepper pioneer and market leader GCA. Title: "The Failure of Established Firms in the Face of Technological Change: A Study of Photolithographic Alignment Equipment." *39, 123, 124, 375, 378, 383*

Hendriksen, Wim - Joined ASML in 1984 as a software engineer on the PAS 2500. After Cees Doesburg's departure in 1987, head of software development. *16, 21, 255, 256, 282–284, 307–309, 337, 361, 362*

Hermans, Nico - Joined ASML in 1984 as R&D manager; later HR and organizational manager; later head of global service. *219, 287, 289, 301–304, 306, 307, 312, 324, 332, 336–339, 445, 521, 524, 537*

Hout, Frits van - PAS 2500 project manager; currently member of ASML's board of directors, responsible for sales. *235–238, 284, 308, 335–337, 339–342, 346, 403, 429, 447, 530, 531, 537, 612*

Hugues, Edgar - French scientist and CEO-owner of optics specialist CERCO (Centre de Recherches et de Calculs Optiques). *37, 83, 85, 228, 229, 233*

Huijser, Ad - Head of Natlab's optics group in the 1980s; later CTO and member of board of directors at Philips. *230, 238*

Hulst, Victor van der - Assistant in Natlab's optics group under Frits Klostermann and later Herman van Heek. *87, 189–191*

Ittner, Gerhard - Head of Zeiss's R&D lab in the 1980s. *230–232, 498*

Janssen, Ger - Product manager at Philips S&I. *112–114, 143, 144, 167, 205, 206, 225, 245, 260, 609*

Maris, Willem† - ASML's CEO from 1990 to 1999. More coach than leader. Known for his talent in bringing people together. Guided the company's 1995 IPO and was succeeded by Doug Dunn in 2000. *16, 267, 278–280, 337, 422, 462–469, 478, 480, 483, 486, 497, 504, 509–512, 516, 518, 520–527, 529, 534–536, 540, 541, 543–545, 547–553, 555, 558, 559, 568, 572–574, 576–578*

Marsh, Doug - Sold the world's first wafer stepper, GCA's DSW4800, to Texas Instruments in 1978. Left GCA for ASML in 1988, where he became vice president for worldwide sales. *124, 437, 440, 445, 446, 483, 511, 522–524, 540–545*

Martens, Jan-Willem - Created ASML's chemistry group; later responsible for imaging development and systems engineering; later head of the physics group. *495–497*

Meyer, Hajo (Hans Joachim)† - As a section director at Natlab, merged optics and precision technology with photochemical expertise in the optics group where both the compact disc and the wafer stepper came of age in the early 1970s. *17, 51–57, 60, 62, 66, 82, 100, 110, 129, 130, 132, 133, 135, 136, 138–140, 582*

Meyer, Rein - Test engineer PAS 2000. *143, 323, 361–363*

Moore, Gordon - See appendix 7, "Moore's Law and the Rules of the Chip Machine Game." *112, 222, 335, 379, 563, 600*

Munnig Schmidt, Rob - Invented the electric-drive wafer table, later ASML's head of mechatronics. *17, 118, 119, 128–135, 140–142, 148, 614*

Nall, James - Invented the photolithographic process with Jay Lathrop. *584, 585*

Noordhof, Dick† - Member of Philips' board of directors. *49, 463*

Noyce, Robert† - Invented the first monolithic integrated circuit; Intel's cofounder. His chip was a vastly improved version of Jack Kilby's IC, which connected transistors using gold wire. Noyce was the first to use aluminum for those connections in a planar process (the same process used to create the individual microelectronic components on a circuit). *586*

Polak, Evert† - Originally an aerospace engineer employed at Philips S&I. Left for ASML, where he was the project manager for the PAS 2400 and R&D manager. Later moved into marketing. *293, 298–300, 302, 332, 339–341, 346, 356, 418, 445, 447, 448, 454, 455, 480, 483, 535, 536, 541–543, 612*

Prado, Arthur del† - Founded ASM International, which launched ASML with Philips in 1984. *21, 152, 161–167, 169–175, 178, 181, 197–200, 202, 205, 206, 217, 219, 221, 222, 246, 248, 281, 312, 320, 334, 369–372, 397–401, 403, 407, 408, 410, 411, 417, 418, 421–426, 439, 516, 609, 610*

Pynn, Ken† - Head of global service at GCA. Moved to ASML in 1985. *357, 371, 380, 382, 446, 480, 532*

Resor, Griff - Project manager for the wafer stepper at GCA's Mann division. *95, 96, 121, 122, 375*

Rhee, André van - ASM International's CFO from 1987 to 1990. *421–423*

Rifenburgh, Richard - American investor hired by Mellon Bank in 1986 to save GCA. *369–371, 373, 386, 387*

Rogers, Thurman John, "TJ" - Founded Cypress, one of ASML's first customers. *363, 364*

Rosmalen, Gerard van - Self-taught engineer and inventor who

Glossary of Terms

193 nm - A wavelength in the far-UV region of the electromagnetic spectrum. Currently the standard for fabricating the most advanced chips. The successor to 248 nm. See also **DUV** and **immersion**.

Alignment - Lining up the wafer and lens to reduce overlay error to a minimum. ASML made a name for itself in the 1980s with an alignment system based on a phase grating reference mark, which was part of the company's logo for years.

ArF - Chemical abbreviation for argon fluoride, the gas used by a deep ultraviolet (DUV) excimer laser to generate 193 nm light.

ASIC - *Application-specific integrated circuit*, a chip designed for a particular use. In contrast to a general-purpose microprocessor or memory chip, most of an ASIC's functionality is fixed.

Automatic global alignment - The wafer stepper first measures where the silicon wafer is and then automatically exposes it, step by step, without having to check its position between exposures. Contrast with **site-by-site alignment**.

CD - *Critical dimension*, the size of the smallest feature in an image. One of the key parameters used to describe a lithographic image and its quality.

Cleanroom - Dust- and particle-free space. Essential for chip fabrication.

Contact mask - Glass plate with hundreds of identical chip patterns at actual size, used to pattern the mask layer for a wafer in one go. The wafer stepper made this production method obsolete.

Continuous-source flash system - A pattern generator that makes master masks by exposing small blocks on a two-inch-square photographic glass plate.

Die - A "naked" chip, that is, before it's packaged in plastic. Plural can be die, dies, or dice.

Die-by-die alignment - Technique in which the stepper measures the wafer's position before each exposure.

DRAM - *Dynamic random access memory*, a working memory that loses its data when the power is shut off. Basic building block in computers and now data centers. DRAM makers, such as Micron and Samsung, are one of ASML's key customer groups.

Dual alignment - Alignment based on two reference marks each on the wafer and mask.

DUV - Deep ultraviolet, a wavelength range of light. Excimer lasers are used in chip production to generate DUV light; 248 nm (krypton fluoride laser) and 193 nm (argon fluoride laser) are the most common wavelengths.

EBPG - Abbreviation for *electron beam pattern generator*, which writes substrates using a beam of electrons.

Electron beam pattern generator - See **EBPG.**

Europa lens - The i-line lens Zeiss developed for the Megachip project. The European Economic Community awarded sizeable grants for this development.

Excimer laser - Light source in DUV scanners.

Fab - Factory where chips are manufactured (fabricated).

Farm out - Outsourcing not just the production but also the development of a machine's components or modules. A hot topic among ASML and its suppliers.

Flash memory - Type of memory that keeps its data when the power is turned off. Flash chips are at the leading edge of Moore's law and thus have the smallest features (and the most regular ones, too). Flash manufacturers are one of ASML's key customer groups.

Foundry - Chip maker that doesn't design chips itself, but manufactures others' designs. One of the markets that ASML serves, with TSMC as its largest customer.

G-line - The peak at 435.8 nm in the spectrum of a mercury vapor lamp. See also **i-line**.

Global alignment - Technique in which the stepper uses a single measurement to determine the wafer's position and then exposes the whole wafer "blind" in a series of steps. This significantly increases throughput compared to die-by-die alignment.

Half-pitch - Half the distance (in nm) between two identical structures on a chip. A measure of the size of the chip features imaged onto a chip. (See also **node**.) Intel uses the half-pitch as a marketing term; the specified value thus does not reflect the actual half-pitch.

H-line - The peak at 404.7 nm in the spectrum of a mercury vapor lamp. See also **i-line**.

H-stage - An electric drive system with three linear motors in the shape of an H that makes it possible to move a wafer stage in the x and y directions and to rotate it slightly. A tiny difference between the positions of the H's vertical bars causes the connecting bar to rotate.

I-line - The peak at 365 nm in the spectrum of mercury. Before the introduction of lasers in the 1990s, mercury vapor lamps were used as the light source in wafer steppers. The i-line succeeded the g-line and was the last spectral line of mercury to be used and the last non-laser light source.

KrF - Chemical abbreviation for krypton fluoride, the gas used by a deep ultraviolet (DUV) excimer laser to produce 248 nm light.

Logic - Umbrella term for chips that perform arithmetic functions, especially processors, ASICs, and ASSPs (*application-specific standard parts*). Logic chips have the most irregular structures and are thus the most difficult for lithography.

LSI - *Large scale integration,* name for the generation of chips in the late 1970s and early 1980s with details larger than one micron.

Mask - Also called *photomask* or *reticle*. Opaque plate with transparencies that determine the chip pattern.

Master mask - Chip pattern at a size of two by two inches. In the 1960s and 1970s this pattern was projected onto a contact mask at less than a hundredth of its actual size.

Megachip project - Also called the Megaproject. European effort to surpass the Japanese in the memory chip market. Philips and Siemens invested over one billion dollars and received government subsidies of roughly 250 million. To make 0.7-micron chips, the project targeted an i-line lithography lens Zeiss was developing for ASML.

Metrology - Umbrella term for various measurement techniques to monitor the lithographic process. The results can be used to make adjustments without having to take the machine offline.

Micron (measurement) - Common term for *micrometer*, one millionth of a meter, whose symbol is μm.

Moore's law - Law that defines progress in chip production technology and bears the name of Gordon Moore, Intel's cofounder. See appendix 7 for a more detailed explanation.

NA - See **numerical aperture**.

Node - Designation for a chip generation, expressed as the half-pitch and rounded to a whole number. See also **Moore's law**.

Numerical aperture (NA) - Number that characterizes the quality of a lens. The higher the NA, the better.

Opthycograph - Pattern generator that creates master masks by writing patterns with a light pen. In contrast to the continuous-source flash system, the Opthycograph could handle a photographic glass plate of eight by eight inches. The Opthycograph's base and stage were adopted wholesale by Herman van Heek for the first wafer stepper. This was one reason why Natlab was able to complete the first stepper within a few years.

Overlay - Extent to which successive layers of a chip are displaced relative to each other, currently on the order of a few nanometers. If the layers don't line up properly, the chip won't work.

PAS (as in PAS 2500 and PAS 5500) - Philips Automatic Stepper, recast by ASML as Pre-Alignment Stepper.

Pellicle - Membrane that protects the mask. Any nanoscopic debris that lands on this film is far enough away that it won't be imaged.

Photo lacquer - See **resist**.

Photorepeater - Shrinks the chip pattern on a two-inch-square master mask and flashes hundreds of copies one by one onto a contact mask.

Resist - Abbreviation of *photoresist*; also called *photo lacquer*. Light-sensitive material into which the mask pattern is burned.

Reticle - See **mask**.

Scanner - See **wafer scanner**.

Showstopper - An essential part or process or machine. Famous potential showstoppers are a stepper's lens and light source, or the photoresist or pellicles for a new technology node.

Site-by-site alignment - The wafer stepper measures the wafer's position before each exposure. Contrast with **automatic global alignment**.

SMIF box - Box using the Standard Mechanical Interface (SMIF) isolation technology to transport wafers contamination-free from one machine to another in a chip fab. Also called *SMIF pod*.

Stepper - See **wafer stepper**.

Uptime - Time that a machine can work continuously without needing maintenance or breaking down. Important economic indicator for lithography machines.

VLSI - *Very large scale integration,* a name for the generation of chips that arose after the second half of the 1980s and had details smaller than one micron.

Wafer - Round, thin disk of very pure crystalline silicon on which chips are made. Larger wafers lower costs in the chip production process, but each new generation of wafers requires extremely high investments, mostly for new machines. Currently eight-inch and twelve-inch wafers are most used.

Wafer fab - Synonym for **fab**. Factory where chips are made.

Wafer scanner - Latest generation of lithography machines, in which the wafer stage moves under the lens and a slit of light exposes the photoresist in a scanning motion. The mask simultaneously moves through the beam of light above the lens. Compared to a stepper, a scanner can expose a larger field. To achieve the required precision, particularly in terms of overlay, both the wafer stage and the mask stage must move with extreme precision.

Wafer stage - A platform on which the wafer lies during the exposure process in the wafer stepper. The stage can move and position the wafer very precisely.

Wafer stepper - Lithographic machine that shrinks patterns and projects them step by step onto the layer of photoresist that coats a wafer.

XBMS - Comprehensive business management system (made by Xerox) that ASML adopted in 1984 and 1985. The company intended for XBMS to integrate all parts of its organization at the IT level.

Yellow room - Section of a cleanroom with yellow lighting to prevent unintended exposure of the photoresist layer on wafers.

Endnotes

Part 1. **Wafer Stepper Prehistory, 1962-1969**

1 No one knows where Piet Haaijman got the chip from. There's even a rumor at Natlab that he secretly nicked it when no one was looking, but the true story has been lost to history.

2 At the end of the sixties, the typical photomask for contact printing is a square that's two inches on a side, containing (for example) forty by forty chip patterns laid out in a checkerboard. Each row is moved into position manually, and then the Mann repeater automatically exposes each pattern in the forty columns.

3 The Bausch & Lomb microscope objectives that David Mann has been using for years are fine for transistors, but insufficient for integrated circuits containing transistors, resistors, and other components. David Mann won't put a significantly improved and automated version of its photorepeater on the market until 1969, using Nikon lenses to achieve an exposure field that's eight millimeters in diameter.

4 In those days it takes six patterns to make a single chip, step by step. After one pattern has been imaged in the photosensitive lacquer (photoresist), several chemical steps follow, after which the next layer of photoresist is applied and the next pattern can be imaged. By using a six-barrel projection system to simultaneously illuminate six contact masks, Klostermann wants to make it easy to precisely align the hundreds of micropatterns (contained in each mask) across the complete mask set for a chip.
Here's a way to visualize it: if you tape two pencils together and then draw a letter, that single movement will produce two virtually identical copies of the letter. The two copies will align perfectly with each other and will be what lithographers call "in register." In the same way, Klostermann wants to use six reduction lenses in a single block to simultaneously "draw" on six photographic plates.
In this case, the projected patterns aren't identical; each one provides the details for one layer of a chip. Just as books and magazines have different layers for cyan, magenta, yellow, and black ink, chips are constructed by precisely overlaying different layers of components. And just as with books and magazines, the layers must align exactly or the result will be fuzzy. If the micropatterns in a chip are shifted too much relative to each other, the entire integrated circuit won't work. The greater precision that Klostermann is aiming for will enable higher yields during chip production.

5 The carriage holding the six photographic plates doesn't stop moving for each exposure; it moves uniformly forward and the plates are exposed on the fly. The flash is fast enough to achieve sharp images even while the system is moving.

6 All in all, the five-micron-wide lines on the phase gratings in the grating measurement system have small systematic errors of 0.2 microns, but the point is their mutual fit. The measuring head examines a field the size of a millimeter on the grating. The system averages the position of some twenty microlines, and that results in the required repeatability of 0.1 microns, accurate enough for the projections in Klostermann's photorepeater.

7 LEP stands for Laboratoires d'Electronique et de Physique Appliquée, or Electronics and Applied Physics Laboratories. CERCO stands for Centre de Recherches et de Calculs Optiques, or Optical Research and Data Center.

[8] Rebecca Henderson, "GCA and the Stepper: A Brief and Preliminary History of Product Development" (internal draft report, Harvard University, 1987), 4.

[9] The first Philips step-and-repeat camera is ready even earlier, in the spring of 1967, making Klostermann's race to catch up a major success.

[10] Stick-slip is caused by the difference in value between the static frictional force (when two objects are at rest relative to one another) and the dynamic frictional force (when the objects are moving relative to one another).

[11] The Mann repeater automatically burns a row of patterns in the x direction, after which an operator must manually move the table in the orthogonal direction in order to burn the next row. During exposure in the x direction, the carriages that move in the manual y direction have time to sink to the bottom of their oil film. As a result the metal carriage and slideway very briefly touch. The contact is short, but it causes definite wear and tear. And after a year of use, the Mann repeater's performance has considerably degraded.

[12] The gate length of two microns is the most critical detail in these transistors.

[13] F. T. Klostermann, "A Step-and-Repeat Camera for Making Photomasks for Integrated Circuits," *Philips Technical Review 30* (1969): 66.

[14] Natlab later receives an order for a double six-barrel step-and-repeat camera from La Radiotechnique RTC, an Elcoma office in Caen, France. Natlab delivers the machine in March 1968.

[15] Provided by the Rudolf Lehmann Fund, founded by a Dutch citizen unrelated to both the German SS officer and German military judge of the same name.

Part 2. **A License to Print Money, 1970-1975**

[1] By then Piet Kramer has succeeded De Lang as leader of the optics group.

[2] Frits Philips' triumphalism is understandable. In 1910 Van Heek & Co. had 2,639 employees, making it the Netherlands' largest company. But the firm didn't file for bankruptcy; rather, it closed its doors in 1967.

[3] In those days, chip fabs have already transitioned to masks whose patterns have been created using chrome. That makes them more durable, but chip makers have also started using epitaxy. In this process, the semiconductor material grows directly on the wafers, often forming microscopic mounds. Those mounds damage the masks during contact printing.

[4] After two name changes in 1964 and 1981, the organization is now simply SPIE, with the tagline "the international society for optics and photonics."

[5] A whopping thirty chip startups are founded between 1966 and 1972.

6 The lens system in Perkin-Elmer's Microprojector only transmits light in a narrow twenty-nanometer band of the ultraviolet spectrum. That's necessary to avoid the problem of dispersion. Dispersion occurs because a lens bends different wavelengths at different angles, creating blurred images. That can be corrected by combining lenses of different materials and only using a narrow wavelength band of light. The Microprojector's sixteen-lens optics make it hard to operate. Because the device has been designed to use ultraviolet rather than visible light, operators can't look through the lenses to see whether the wafer is in position, making alignment difficult. Perkin-Elmer tries using the night-vision technology it developed for use in Vietnam in the sixties. It works: with the help of image intensification, the ultraviolet light is converted into a visible image and operators can align the wafers. But this stopgap solution makes the Microprojector prohibitively expensive.

7 Van Heek and Bouwhuis also have CERCO run the numbers again on their optical design for one-to-one projection. Just to be sure, because they're already claiming in their technical reports that one-to-one exposure systems are a dead end. Once the drawings are complete, that claim grows even stronger. It's not realistic or feasible to manufacture optics that can simultaneously expose all the chips on a silicon wafer the size of a brandy snifter's foot.

8 This is the same problem that Perkin-Elmer struggled with in developing its Microprojector.

9 At Philips Elcoma in Nijmegen, Joop Andrea is building his own steppers based on Natlab technology. There they call the machine the Wafer Repeater. Andrea's first machine meets with catastrophe. In Nijmegen they've connected the device's exposure column to the fume hood to cool the thousand-watt mercury lamp. During a thunderstorm one night, acidic water seeps into the column, then into the open oil system. From there the pump and the circulating oil do the rest: all the aluminum parts are eaten away. The next morning, Andrea finds a few screws left. The rest of his machine can go on the scrap heap.

10 Spherical aberration is the optical effect in which light refracts differently from the edge of a lens or concave mirror than from the center, causing a blurred image. Offner's solution compensates for this.

11 Launched in 1958.

Part 3. **Death Throes, 1976-1983**

1 Natlab and Philips Elcoma are using simple manual scanners made by Kulicke & Soffa, another American supplier.

2 Mullard is a Philips Research subsidiary in Redhill, England.

3 R. A. Beelaard and G. A. M. Janssen, "Business Plan for a Philips Lithographic Activity," internal document dated August 1978.

4 Both Natlab in Eindhoven and Mullard in Redhill are working on this.

5 Beelaard and Janssen write that for the next two years S&I will concentrate on selling to Philips' fabs at Elcoma (Netherlands), Signetics (US), and Faselec (Switzerland). They suggest moving the production or assembly of lithographic equipment to America.

6 GCA Mann also uses lead screws and rotating nuts in its wafer steppers.

7 Internal memo dated October 5, 1979.

8 Mann leaves Bausch & Lomb's microscope objectives for Nikon's camera lenses because the Japanese product has a larger field of view.

9 GCA's total engineering staff numbers two hundred in 1981.

10 The situation looks rosier for the e-beam machines, but there, too, they've fallen short of the goals in the 1978 business plan.

11 The European Economic Community, which was absorbed into the European Union in 1993.

12 Reluctance is the term for the resistance experienced by magnetic flux in a magnetic circuit.

13 The Censor stepper's mechanical table was the machine's best selling point. ASML service technician Jos Vreeker, who worked for Perkin-Elmer for years, attributes its excellence to auto manufacturer Porsche's involvement with Censor.

Part 4. **The Deal, 1983-1984**

1 Up through 1974, everything Philips touches turns to gold. But then things start going downhill, and the company is forced to follow global trends. It automates its processes, focuses more squarely on its core activities, moves production to low-wage countries, and lays off large numbers of employees. The departure of CEO Henk van Riemsdijk in 1977 marks the definitive end of the Philips family's influence (Van Riemsdijk was married to the daughter of founder Anton Philips). Massive layoffs follow in 1980—something that's never happened before at Philips. At its peak in 1974, the company employs 412 thousand people; by late 1982, that number has dropped to 336 thousand.

2 Between January 1981 and early 1984, Elcoma cuts a total of three thousand jobs.

3 It will be another four years—March 4, 1968—before ASM is officially registered as Advanced Semiconductor Materials BV. (BV is the Dutch equivalent of LLC.)

4 Elmont International makes equipment for automatic die inspection and die bonders; Plating Industries manufactures lead frames.

5 Only later does anyone object to the unfortunate acronym, which calls up associations with the fatal neuromuscular disease abbreviated the same way.

6 There's an earlier proposal in which Philips gets half the shares and ASM and MIP split the rest, but in the end the private equity firm backs out. Del Prado vents his irritation at that decision in the press. His annoyance is understandable, given that Ab de Boer joined MIP's board of trustees after he left Philips. It's the former director's way of impeding the joint venture. Del Prado openly criticizes MIP's behavior. In his point of view, the state-owned investor is happy to pour money into foreign companies but unwilling to support Dutch ones, even though that's what it was created for.

7 In the weeks after the joint venture is announced, the team drafts a list of components for the ten systems whose wait times exceed six months. The list includes optics, invar, slides, motors, and integrators.

8 This machine must have an electric rather than hydraulic wafer stage and be ready for the coming generation of VLSI chips.

9 The name isn't changed to ASM Lithography, abbreviated ASML, until months after it launches.

Part 5. **A Leveraged Die-Out, 1984**

1 The PIT division (Products for Industrial Applications, in Dutch: Producten voor Industriële Toepassingen) changes its name to S&I (Science & Industry) in 1971.

2 "A New Challenge in Machines That Print Chips," *Business Week*, February 15, 1982.

3 The three layout projects are called machine layout, electrical layout, and computer systems and software. There are also submodules for reticle handling, the reticle table, alignment, the lighting system, the projection lens, wafer handling, and the wafer stage.

4 Smit wants a system that integrates every facet of the company at the IT level. A change in one parameter in one part must instantly reflect the consequences for other parts. Xerox's XBMS is one of the few systems that makes this possible in 1984. It combines operations, R&D, sales, personnel records, purchasing, and accounting.

5 In fact, both sites are actually using the PAS 2000 machines. One sign of that is the service that ASML employee Frits van Hout conducts on the systems in Nijmegen and Hamburg.

6 In 1982, the American company TRE Semiconductor developed an i-line stepper using a Zeiss lens, but the machine is virtually unsellable. The technology is too far ahead of its time. The chip industry doesn't yet have the infrastructure and photosensitive lacquers to work with i-line lithography.

7 The move from analog to digital switchboards.

8 In the September 1, 1983 business plan that defines the joint venture, the electric table is described as the "linear magnetic table." This positioning table is part of an upgraded PAS stepper that will be constructed in 1984. The contract that ASM and Philips ul-

timately sign on March 9, 1984 calls this stage an "electric table." The contract reads: "Concerning payment for specific research and development projects currently under development at Philips (including the next-generation stepper based on [an] electric table) and/or to be awarded to Philips in the future [...] separate arrangements [...] will be made."

9 The business plan contains a reference in the "assumptions and notes" section stating that an extra fee of three million guilders (approximately $930,000 in 1984) has been reserved to pay Natlab for R&D and engineering in 1985 to develop the PAS 2500. This may refer to the wafer table. In private correspondence with the author on August 12, 2012, Gjalt Smit said the figure was four million guilders (approximately $1.25 million in 1984).

10 Steef Wittekoek devises this approach in the mid-seventies for his Silicon Repeater 2 project at Natlab, to achieve better photoresist uniformity. He's having trouble with vertical standing wave effects in the photoresist. These make the structures burned into the resist narrow in some places, wider in others. It's a complex phenomenon that depends on several variables such as exposure wavelength, resist thickness, resist type, and numerical aperture. By exposing patterns using two wavelengths from a mercury lamp (the g-line at 405 nm and the h-line at 436 nm), Wittekoek can largely suppress the standing wave effect, because the waves from each wavelength are out of phase.

11 CERCO's measuring technology wasn't up to snuff, and the company didn't realize how important that piece of the picture was.

12 The Hologon and Distagon objectives. Glatzel's Distagon design is the basis for the first lenses the German optics specialist sells for chip lithography.

13 The visit recounted here highlights the cultural differences between the two companies and a temporary rift in their commercial relationship. At that time the Dutch engineers are paying frequent visits to Oberkochen, and when it comes to discussing technical challenges, their interactions are often quite pleasurable. The attitude in Zeiss's R&D department is identical to that at Natlab, its envoys discover: faced with an engineering puzzle, everyone works readily to solve it, no strings attached.

14 The development committee is an advisory board that meets every two weeks. When Van Hout joins, the committee consists of chairman Nico Hermans and members Cees Doesburg, Kees van Dijk, Richard George, and controller Theo Bartraij.

15 Michael S. Malone, *The Microprocessor: A Biography* (New York: Springer-Verlag, 1995), 186.

16 Eindhoven, where ASML was located at the time, was still very much a Philips company town in those days. The light bulb manufacturer even erected a concert hall, the Philips Ontspannings Centrum (Philips Recreation Center). Local residents weren't the only ones who enjoyed themselves at the center; the company itself also held large meetings there.

Part 6. **The Deadline, 1984-1986**

1 Gjalt Smit, "Business Plan ASM Lithography B.V.," internal document dated August 6, 1984.

2 The orders do include an option to cancel on January 1, 1985.

3 The company changed its name from G. van der Leegte to GL Precision in 2000.

4 ASML's business plan says the PAS 2500 must be ready on January 1, 1986. The date is based on market expectations. ASML views the PAS 3000 as its second-generation stepper. It must be ready on January 1, 1988. In the end, the PAS 2500 and PAS 3000 will merge into a single PAS 2500 line, with versions for g-line and i-line imaging.

5 In the crisis years, 1983 and 1984, unemployment in the Netherlands rose to 10 percent. Source: Statistics Netherlands, "Comparing the economic crises in the 1930s and 1980s," 2008 (in Dutch).

6 In documents, the PAS 2400 is listed as the PAS 2000B, with the PAS2000A being the hydraulic machine. The PAS 2400 will use the PAS 2000's existing CERCO lens and machine architecture to handle four-inch photomasks. It will contain the new electric table in combination with ASML's unique alignment system.

7 When ASML made the decision to use a standard Zeiss 10-78-46 lens, it had to convert the entire alignment system to what's called an off-axis alignment system, outside the lens.

8 This is Zeiss's 10-78-46 g-line lens.

9 Zeiss is still using this solution to this day.

10 F. J. van Hout, "Trip report Semicon Zurich 1985," internal document dated March 28, 1985.

11 "ASML May Someday Be World's Largest," *NRC Handelsblad*, May 11, 1985 (in Dutch).

12 In addition to ASML's PAS 2400, AMD will be testing GCA's Model 8000, Perkin-Elmer Censor's 9000, and Nikon's model 515 (Gjalt Smit, "Internal Memo to All ASML Employees," internal document dated July 17, 1985, 1).

13 Martin van den Brink visits the mask shops at Ultratech, KLA, and Asyst, among others.

14 On October 11, 1985 Martin van den Brink, Richard George, Frits van Hout, Hans van Kimmenade, and Hans Verdonk hold a Reticle Handling Plan Review to discuss the scheduling problems and map out the state of affairs for the five machines being assembled. On March 1, 1986 a PAS 2500 must be delivered to Natlab. It's a g-line machine that must work without a reticle handler—they won't manage to get that working by then. The machine that will go to SEMICON West in May will have a working wafer handler and reticle handler, and as extras a SMIF (standard mechanical interface)

box and a reticle library. The other three machines have the goal of accelerating testing and integration for exposure and projection, alignment and software qualification, and wafer and reticle handling.

15 There is a problem, however: Zeiss will have to adapt its standard lens (10-78-46) for ASML's through-the-lens alignment. This system uses an infrared helium-neon laser, which has a completely different wavelength than the blue g-line.

16 The Silicon Repeater 3, or SiRe 3.

17 This phenomenon is also known as negative float.

18 ASET is the continuation of TRE Semiconductor, which was split off after Alcoa acquired TRE.

19 ASML and Zeiss won't reach this point until the second half of the nineties.

20 ASML R&D department, untitled internal document dated June 29, 1987, 13.

21 The relationship with Olympus doesn't officially end until some years later. When it does, ASML receives a reprimand from Philips Japan's legal department. ASML failed to follow the rules in finalizing its contact with Olympus, and that reflects poorly on Philips. Wim Troost travels to Japan to wrap up matters the right way. At first Olympus threatens to sue for $45 million, but ASML gets off with just $6 million.

22 Original title "Ontwikkeling van lenzen binnen ASML," report by M. A. van den Brink and F. J. van Hout to E. Polak, dated September 10, 1986.

Part 7. **The Big Spender, 1986-1987**

1 Gjalt Smit, "Operating Plan 1986," internal document dated May 6, 1986, 1.

2 The first PAS 2500/10 is a 5x reduction scanner with a Zeiss lens (the 10-78-46) that exposes 14-by-14 mm fields on four-, five-, and six-inch wafers using the spectral g-line emitted from a mercury vapor lamp.

3 The interface development effort between ASML's engineers and track builder Silicon Valley Group (SVG) is necessarily long-distance, with no face-to-face contact. To get the machines to communicate properly, five engineers led by Frans Couwenberg spend three months on the software. ASML doesn't have a wafer track on hand in Veldhoven, so Couwenberg's team mimics the complex communication between the stepper and the track using a ZX Spectrum home computer.

4 ASML, "Info Bulletin," issue 2, July 1986, 6.

5 Joel Kotkin, "The Third Wave," *Inc. Magazine*, February 1984, http://www.cypress.com/file/90841/download.

6 Brian Dumaine, "America's Toughest Bosses," *Fortune*, October 18, 1993, http://archive.fortune.com/magazines/fortune/fortune_archive/1993/10/18/78470/index.htm.

[7] Author's interview with Gjalt Smit, August 6, 2012.

[8] 1986 industry report by Ruddell & Associates viewed by the author.

[9] Del Prado sends Frank de Weeger; Rifenburgh's financial right-hand man, Philip Ablove, is also at this first meeting. Source: Jorijn van Duijn.

[10] The meeting on August 28, 1986 is attended by Richard Rifenburgh, Philip Ablove, John Bruning (GCA's CTO), Arthur del Prado, Willem de Leeuw, Gjalt Smit, George de Kruiff, Fred Engel (Philips' CFO), and Steef Wittekoek.

[11] GCA's total revenue in 1984 was $308.6 million, $201.2 million of which came from its steppers.

[12] ASM and Philips will each pump more than $12 million into ASML in 1986. Touche Ross Nederland, "ASM Lithography Annual Report 1987," 13 (in Dutch).

[13] David E. Sanger, "Big Worries over Small GCA," *New York Times*, January 19, 1987, www.nytimes.com/1987/01/19/business/big-worries-over-small-gca.html?pagewanted=print&src=pm.

[14] Ibid.

[15] Rebecca Henderson, "The Failure of Established Firms in the Face of Technological Change: A Study of Photolithographic Alignment Equipment" (PhD diss., Harvard University, 1988).

[16] In 1979 GCA licenses a system based on Fresnel diffraction. But while Philips is already using a through-the-lens alignment system as early as 1973 in Natlab's Silicon Repeater 1, David Mann's engineers can't seem to get the principle working—not even when they introduce an improved system in 1982, also based on Fresnel diffraction. Through all those years, GCA keeps running its alignment outside the lens. Ony in 1987, when the company is already dead in all but name, does GCA introduce a dark field alignment system based on an IBM design.

[17] Rebecca Henderson, "GCA and the Stepper: A Brief and Preliminary History of Product Development" (internal draft report, Harvard University, 1987), 8.

[18] Author's interview via email with Ken Pynn, January 7, 2013.

[19] The 10-78-46.

[20] Full name: NSR-1010G.

[21] According to Klaus Maier, a sales manager at Zeiss at the time, Zeiss ultimately sold these shares at a profit. That probably happened during the IPO for SVG, which took over GCA's surplus inventory. Some eighty to ninety Zeiss lenses were found at the American lithography company, Maier says. His explanation is that GCA tried to buy up Zeiss's entire inventory in an attempt to block delivery to competitors.

[22] Ralph E. Grabowski, "Who Is Going to Buy the Darn Thing?," *Proceedings of the IEEE Electro International*, June 1995, 69–97, http://marketingvp.com/papers/whois/4-avoid.htm.

[23] Richard J. Elkus, Jr., *Winner Take All: How Competitiveness Shapes the Fate of Nations* (New York: Basic Books, 2018), 146.

[24] Gjalt Smit, "Operating Plan 1987," internal document dated February 2, 1987, 1.

[25] Boulevard of Broken Dreams started in 1983 as a touring theater festival in the Netherlands that later went international.

[26] The later TSMC.

[27] The Europa lens is the Zeiss 10-78-58 and is also referred to as the 58 lens.

[28] Gjalt Smit, "Delivery Litho Lenses," telefax, June 22, 1987.

[29] Type Zeiss 10-78-46.

[30] ASM International's revenue in 1983, 1984, 1985, and 1986 was, respectively, $76, $110, $105, and $134 million dollars.

[31] These talks run from March to June of 1988 (Jorijn van Duijn, "ASM International," PhD diss., University of Maastricht, to be published).

[32] Smit has since started working with Jos Bomers' colleague Bob Manschot.

[33] Wim Hendriksen, private journal, June 1, 1987.

Part 8. **Running in Place, 1988-1990**

[1] The total loss the joint venture partners must mutually absorb in 1987 is $16 million, half of which is ASM's burden to bear (Touche Ross Nederland, "ASM Lithography Annual Report 1987," 13 (in Dutch)).

[2] Willem de Leeuw, "ASM Lithography: An Overview," February 1988.

[3] Ibid, 15.

[4] The PAS 2500/10 (g-line) and PAS 2500/40 (i-line) with resolutions of 0.9 and 0.7 microns, respectively.

[5] Ibid, 6.

[6] Ibid, 6.

[7] Touche Ross Nederland, "ASM Lithography Annual Report 1987," 12 (in Dutch).

[8] In April 1987 Frits van Hout sends his colleagues the first images of photoresist ex-

posed using the PAS 2500 i-line stepper. The results were presented a few months earlier at the SPIE conference in Santa Clara. The photos show microscopic ridges just 0.7 microns wide. "The PAS 2500/40 is a true submicron stepper," Van Hout writes to his colleagues. (F. J. van Hout, "PAS2500/40 prototype, D721," internal document dated April 22, 1987.)

9 At the start of 1988, Micron is using a 1.2-micron process to manufacture 256-kilobit DRAMs. By the end of the year it wants to manufacture 256-kilobit SRAMs using a 1.0-micron process. In early 1989 the company wants to move to a 0.7-micron process in a new fab to manufacture 4-megabit DRAMs.

10 The PAS 5500 will turn out to be a truly revolutionary machine, but its development will take years to complete. Until that time ASML keeps expanding on its old platform. That produces the PAS 2500/30 (a 0.8-micron g-line stepper with a high numerical aperture), the PAS 5000/50 (0.5-micron i-line), and the PAS 5000/70 (0.45 -micron 248 nm).

11 Ten years earlier, this is exactly the product strategy GCA is missing. The early-eighties leader can't get a handle on the market. The company can't manage to distill the flood of requirements and complaints into something that leads to clear long-term goals. It ultimately proves fatal for GCA.

12 ASML, "Business Plan 1989–1993," internal document dated July 1989.

13 Ibid, 1.

14 Ibid, 16.

15 Ibid, 3.

16 The PAS 5000 extends the PAS 2500. This machine for six-inch wafers is meant for customers who want to test the technology for i-line and DUV. They can then switch to the eight-inch PAS 5500 platform for high-volume production.

17 The funding was granted by the EEC's ESPRIT technology program. In the DUV project, ASML works with Zeiss (lenses), Heraeus (quartz glass), Lambda Physik (excimer lasers), semiconductor companies, and photoresist manufacturers. The work leads to the PAS 2500/70.

18 Pieter Burggraaf, "Deep-UV Lithography: Crossing the Half-Micron Threshold," *Semiconductor International,* August 1989, 62.

19 The only relief during the PAS 5500's development is the financial breathing room provided by a large order from Micron.

20 Hans Franken, Hans Jaspers, Rob van Kooten, Henk Meijer, and Martin Prins.

21 ASML will start using the long-stroke, short-stroke principle in the second half of the nineties when it moves to machines that expose wafers through a scanning motion. ASML is still using the superior design in its wafer scanners today.
The H-stages in the first PAS 5500 steppers that launch in 1991 achieve a positioning

precision of fifty nanometers. ASML's current stages, which are based on the long-stroke, short-stroke principle, achieve single-digit nanometer precision.

22 Jan van der Werf develops the meter at Natlab, and Gehard Fürter develops the optics at Zeiss.

23 Matra-GCA is a joint venture between Matra in France and GCA in the US. During that time Matra also had a semiconductor divsion, Matra-Harris. Matra became part of the Lagrardère Group in 1994.

24 IBM is what's known as a captive supplier, a company that only manufactures chips for its own use. Captive suppliers aren't included in the rankings distributed by analysts. Those only contain merchant semiconductor companies such as Intel, NEC, Texas Instruments, and Toshiba.

Part 9. **Stuck With Each Other, 1990-1992**

1 Willem Maris joins ASML on February 1, 1990 and is named CEO on June 1, 1990.

2 The name PAS 5500 is confusing. The machine bears no relation to the PAS 5000, which is a variant of the PAS 2500. The PAS 5500 is a completely new machine generation, built on a modular architecture. That makes modules such as the lens easy to replace, which saves a lot of time in the chip fab.

3 The Dutch Ministry of Economic Affairs established its technology development credit program to bridge the period in which new products are being developed. In the program the Dutch government covers 60 percent of the R&D costs up front. The loan must be paid back in installments that start as soon as the new product is available for sale.

4 Zeiss's East German incarnation manufactured its Pentacon and Praktica cameras in its own factory in Dresden. The Contax and Contarex cameras were manufactured in Stuttgart in West Germany. In 1973 the Western company joined forces with Yashica, which was acquired by Kyocera in 1983. At the end of the nineties Zeiss also moved the production of its high-end Contax cameras to Kyocera.

5 Armin Hermann, *Die abenteuerliche Geschichte einer Deutschen Firma* (Munich: Piper Verlag, 1992). Professor Hermann wrote this book (whose title translates to "The adventurous story of a German company") on assignment for Zeiss.

6 A year earlier, on June 29, 1990, the first Carl Zeiss Jena GmbH was founded in Jena, with thirty thousand employees. The company split in two a year later, into Jenoptik and a second Carl Zeiss Jena GmbH. (Armin Hermann, *Und trotzdem Bruder, Die deutch-deutche Geschichte der Firma Carl Zeiss* (Munich: Piper Verlag, 2002), 440.)

7 Jobst Herrmann succeeds Horst Skoludek as Zeiss's CEO on May 31, 1992.

8 Chip dimensions were becoming larger and larger. This required a larger imaging field, which drove the growing overall size of the optics. The larger field size (and economic arguments) also triggered a larger wafer size. With the transition from six-inch to

eight-inch wafers, lens size increased by the same amount, from roughly six to eight inches in diameter. The two developments had no further correlation.

[9] The irregularities are long wave deviation, which the folk with the golden fingers correct by rubbing. Lateral deviations in the micron range are not visible with an interferometer. These defects are visible only in a darkroom with directed light. If they are too big or too many they require a total repolish.

[10] The PAS 5500/60.

[11] Kaiser succeeds Gerhard Ittner.

[12] For the PAS 5500/80 (0.5 microns), Zeiss and Schott lost a lot of material, including material already processed for lenses. After six months of preparation, not all the material at Schott had the right properties for use in lithographic lenses. All this significantly reduced the production volume.

[13] Kaiser's colleague Hermann Gerlinger was also deeply involved.

[14] The PAS 5000/50 and PAS 5500/60.

[15] By then some ten molecular layers have been deposited onto the glass.

[16] The two types of glass in a doublet have contrasting refractive indices and dispersion. That makes the lenses achromatic, which makes it possible to use a broader band of i-line light. That in turn sends more light, and thus energy, through the optics. The result is faster exposure and more productive steppers.

[17] Ittner's project was funded by the EEC's JESSI program, which also provided funding to ASML.

[18] Every sweep removes roughly ten nanometers, a hundredth of a micron.

[19] In those years a consortium develops among IBM, Siemens, and Toshiba. In early 1992 Philips Semiconductors and SGS-Thomson partner to develop a 0.5-micron production process in Crolles, France.

Part 10. **Growth, 1990-1992**

[1] In 1989 ASML's cash flow was briefly positive, but that was temporary and also a fluke. A fire at TSMC meant ASML could deliver seventeen new systems.

[2] The PAS 5500/90.

[3] This Starlith lens was used in the PAS500/300 stepper as well as in the PAS5500/500 scanner and had a track length of one meter.

[4] Only later will Van den Brink pick the project back up, and it will be 1997 before ASML's first step-and-scan system, the PAS 5500/500, enters the market with a 248

nm DUV lens. The PAS 5500/500 scans using a light slit of twenty-six millimeters. ASML will also sell an adjusted version of this lens in a stepper (the PAS 5500/300) with an exposure field that's twenty-two millimeters on a side.

5 The Starlith/300 and Starlith/500 lenses had the same design but were adjusted to their specific use, so they were in fact not the same. The /300 had a field size of 22 x 27.4 mm and 0.57 NA; the 500 had a slit length of 26 mm and 0.63 NA).

6 In relative respect to time. Roughly two hundred each of the /300 and /500 were sold. More recently, over a thousand of the latest DUV lens, the /800, have been sold, making it probably the most successful DUV lens overall in the market.

7 IBM, Siemens, and Toshiba decide in the early nineties to develop new generations of chip processes together. They visit ASML in early 1994 for a demo of the PAS 5500/90. That doesn't immediately generate orders because both Siemens and Toshiba have a long relationship with Canon.

8 ASML calls this version the PAS 5500/100B.

9 The PAS 5500/200.

10 Armin Hermann, *Und trotzdem Brüder* (Munich: Piper Verlag, 2002), 462.

11 Armin Hermann, *Die abenteuerliche Geschichte einer Deutschen Firma* (Munich: Piper Verlag, 1992), 480.

12 Armin Hermann, *Und trotzdem Brüder* (Munich: Piper Verlag, 2002), 477.

13 At the end of 1993 the balance sheet notes a debt to Philips of 98,805,000 guilders (roughly $50 million); at the end of 1994 that debt is 52,394,000 guilders (ASML's annual report, 1994).

14 Now the Pullman Eindhoven Cocagne hotel.

15 "A Steal," *Financieele Dagblad*, March 18, 1995 (in Dutch).

16 The latest /500 lenses for deep ultraviolet light from KrF lasers (248 nm) have a numerical aperture of 0.63 NA and a 26 mm slit. The latest DUV system (ArF, 193 nm) is the /800 with NA 0.80 and the same slit of 26 mm. They contain 110 pounds of glass and quartz and 440 pounds of steel. For a DUV lens, engineers assemble some twelve hundred different components in about twenty lenses in barrel at a temperature of 22° C ± 0.1° C. The individual lens elements are cut from cylinders of homogeneous optical glass or a mix of quartz, optical glasses, and fused silica. These are first cut into discs, after which precision grinders provide initial shaping with a precision of one micron. The polishing and ion beam steps come next, in that order.

Appendices

1 Dirk Hanson, *The New Alchemists* (Boston: Little, Brown & Co, 1982).

2 "1958: All Semiconductor 'Solid Circuit' Is Demonstrated," Computer History Museum, accessed April 1, 2014, https://www.computerhistory.org/semiconductor/timeline/1958-Miniaturized.html.

3 "Radio Proximity Fuse-weapon behind Victory," National Archives and Records Administration 1945 - ARC 39087, LI 208-UN-179, https://www.youtube.com/watch?v=EH8caTR9gmk.

4 Jay W. Lathrop, "First Photolithographic Transistor Fabrication," *IEEE History Center Newsletter*, July 2008, 7.

5 Stibbe, Blaise, & De Jong, "Joint Venture Agreement between Advanced Semiconductor Materials International and Philips," legal contract, March 9, 1984 (in Dutch).

6 Ibid.

7 BV is the Dutch equivalent of LLC.

8 Philips S&I, "Wafer Stepper R&D Plan for 1983–1987," internal document dated June 1983, 2.

9 In Natlab's optical group, the stepper had to compete with the compact disc for the patent attorneys' attention. Philips also assigned the CD system this group developed a much higher priority. That was the right choice at the time, but that focus continued well into the nineties and left ASML with an initially weak patent portfolio. Nikon seized on that in 2000 to start a patent war.

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During the long months of writing, I often thought of Evert Polak and his calming words whenever his R&D team lost sight of the forest for the trees: "Just get started, and solve each issue one by one."

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Afterword

The sources at my disposal for this book were surprising and plentiful. First, more than eighty people spoke with me openly and candidly—from factory workers to senior management, at ASML and beyond. Even my most elderly conversational partners were strikingly animated and had sharp memories.

From the start I made it clear this was an independent work of journalism, yet ASML never threw up a single barrier to my quest for information. Wim Hendriksen gave me all his journals from the years 1984 through 1990. Wim Troost showed me many documents from his Philips S&I days. Frits van Hout handed me a massive stack of team reports and internal memos from the company's early years, 1984 to 1988, the very first time we met. When a supplier called CEO Peter Wennink to ask if it was okay to speak with me, the answer was an immediate yes.

The sixties and seventies, when the first lithographic technology was being developed at the Philips Physics Laboratory (a.k.a. Natlab), turned out to be extremely well documented. Philips' archives remained closed to me, but key pieces always turned up somewhere. Among these fortuitous finds was the 1971 Technical Note in which Herman van Heek, Gijs Bouwhuis, and Ad Bouwer put their first thoughts on paper regarding the construction of a wafer stepper. With Frits Klostermann's notes, I was able to largely reconstruct the pioneering sixties.

I also ran across Rebecca Henderson's reports. In 1987, while Henderson was getting her PhD at Harvard, she explored the rise and fall of the lithography market's former leader, GCA. Henderson spoke to seventy engineers, marketing managers, and users of lithographic equipment. That produced a wealth of insights into the American company's struggles with such complex R&D in the technology's early years. Several people from GCA ended up at ASML in the mid-eighties, among them movers and shakers like Doug Marsh and Ken Pynn.

Henderson isn't the only person to have described the crucial 1980s. GCA's demise was a traumatic experience for the whole country. In the late eighties other analysts and researchers also studied the deterioration of America's strategic lithography industry. One such effort is *The Weakest Link: Semiconductor Production Equipment, Linkages, and the Limits to International Trade*, an August 1987 report from the University of California's Berkeley Roundtable on the International Economy, which thoroughly examined the US-Japan balance of power in the semiconductor industry.

In the late eighties, the *New York Times* published several articles on lithography's strategic importance and the lead the Japanese had taken. For this book's brief recap of pioneer Perkin-Elmer's history, I made grateful use of Daniel Burbank's "The Near Impossibility of Making a Microchip" in the fall 1999 issue of *Invention & Technology Magazine*.

The reports of analysts and researchers such as Rebecca Henderson enabled me to largely reconstruct the history of the lithography industry. There are a few blank spots I didn't manage to fill in. The largest of these are the initial lithography efforts in the 1970s at chip makers such as IBM and TI. I would also have liked to know more about the culture and practices of the engineers and executives at Canon and Nikon. For both topics, my time was too limited.

Closer to home, former ASML employees pointed me toward several sections of an earlier, unfinished effort by the Eindhoven University of Technology to write a book about ASML. ASML's first CEO, Gjalt Smit, wrote a chapter for that unpublished book, "Chance and Necessity: The First Years of ASM Lithography," which was a useful checklist for my chapter on his tenure at the company.

I am also deeply indebted to Jorijn van Duijn. In 2013 he began his doctoral research on ASM International's history, which granted him access to the private archives of CEO and owner Arthur del Prado. Van Duijn checked the accuracy of crucial data and facts for me, and supplied a great deal of the information for the biographical sections on Del Prado. He also put me in touch with people at ASM who played a role in the joint venture between ASM and Philips, as well as those who were involved in ASM's painful 1988 withdrawal from this mutual endeavor.

To convey the cultural differences between ASML and Zeiss, I was privileged to rely on two detailed histories: *Die abenteuerliche Geschichte einer Deutschen Firma* (1992) and *Und trotzdem Bruder* (2002), both by Armin Hermann.

My primary goal in this book was to tell a story: historically accurate, but not a watertight scientific treatise. The wealth of documentation and interviews made it possible to reconstruct a vivid and factually accurate past. But to make for good reading, I also wanted to bring that history to life. Many internal reactions and quotes are thus reconstructions based on memories and written reports. They necessarily lack 100 percent accuracy, but do provide a reasonably faithful picture of how things must have actually gone.

One last short note on company names. I used ASML, the company's current name, wherever possible, though ASM International and Philips initially agreed their joint venture would be called ASM Lithographic Systems, abbreviated ALS. For ASM International, wherever possible I used the abbreviation the company itself uses: ASM.

Translator's Postscript

There are, roughly speaking, two schools of thought on translation. The first strives to maintain the grammatical and cultural features of the original text, to give the reader a taste of foreign ways of thinking and being. The second strives to elicit the same effect in the reader that the original had on its audience. Happily, René Raaijmakers agreed with me that his book was best served by the latter. He'd written a rollicking good tale, more like a corporate thriller than a dry history, and that's what he wanted US readers to read.

To that end, we made the following choices. We converted monetary figures from Dutch guilders to American dollars, to help the reader feel their magnitude. We changed Dutch cultural references to American ones when that better preserved the intended sentiment. And we presented document names and newspaper headlines in English without reference to the original title. Throughout, our guideline was "don't distract the reader from the story."

That made for some puzzles along the way. For example, one passage compared ASM's revenue over several years—but dynamic exchange rates meant the numbers went down in guilders, up in dollars. Our fix was to change the text to compare profit and loss instead, which exhibited the same trend in both currencies. In other sections, differing cultural baggage made some phrases in the original feel unpleasant or even untrue in translation—such as when a Dutch engineer who was in the US the day Kennedy died noted how unemotional the Americans around him seemed. Another engineer made a reference to Vietnam that hits an entirely different set of nerves in the US than in the Netherlands. Keeping that reference in the translation would have given it a weight it simply didn't have in the original.

Quoted material also offered the occasional thorn. Some of the original documents were written in imperfect English by non-native speakers. The original book converted these to correct Dutch, but for the translation, we were obligated to use the actual quotes, even when poorly formulated. We solved this with a three-tiered system. Wherever possible, we used the unvarnished quote if the reader was unlikely to be distracted by its oddities. We made minor cosmetic fixes when we thought errors might distract the reader. And when the original English was truly mangled and would take more than an additional "the" or "that" to fix, we rephrased it and took away the quotation marks.

I thank René Raaijmakers for entrusting me with his many-year labor of love, and for being such an encouraging and engaged author during translation. I've done my best to preserve his unique and compelling voice. I hope readers will enjoy this book as much as I enjoyed the original.

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