The Dawn of Miniature Green Lasers

Semiconductors can generate laser light in all colors except one. But new techniques for growing laser diodes could soon make brilliant full-spectrum displays a reality

By Shuji Nakamura and Michael Riordan

On a rainy Saturday morning in January 2007, Henry Yang, chancellor of the University of California, Santa Barbara, took an urgent phone call. He excused himself abruptly from a meeting, grabbed his coat and umbrella, and rushed across the windswept U.C.S.B. campus to the Solid State Lighting and Display Center. The research group there included one of us (Nakamura), who had just received the Millennium Technology Prize for creating the first light-emitting diodes (LEDs) that emit bright blue light. Since that breakthrough over a decade earlier, Nakamura had continued his pioneering research on solid-state (semiconductor) lighting, developing green LEDs and the blue laser diodes that are now at the core of modern Blu-ray disc players.

As Yang reached the center about 10 minutes later, people were milling about a small test lab. "Shuji had just arrived and was standing there in his leather jacket asking questions," he recalled. Nakamura's colleagues Steven DenBaars and James C. Speck were speaking with a few graduate students and postdoctoral researchers as they took turns looking into a microscope. They parted for Yang, who peered into the eyepiece to witness a brilliant blue-violet flash emanating from a glassy chip of gallium nitride (GaN).

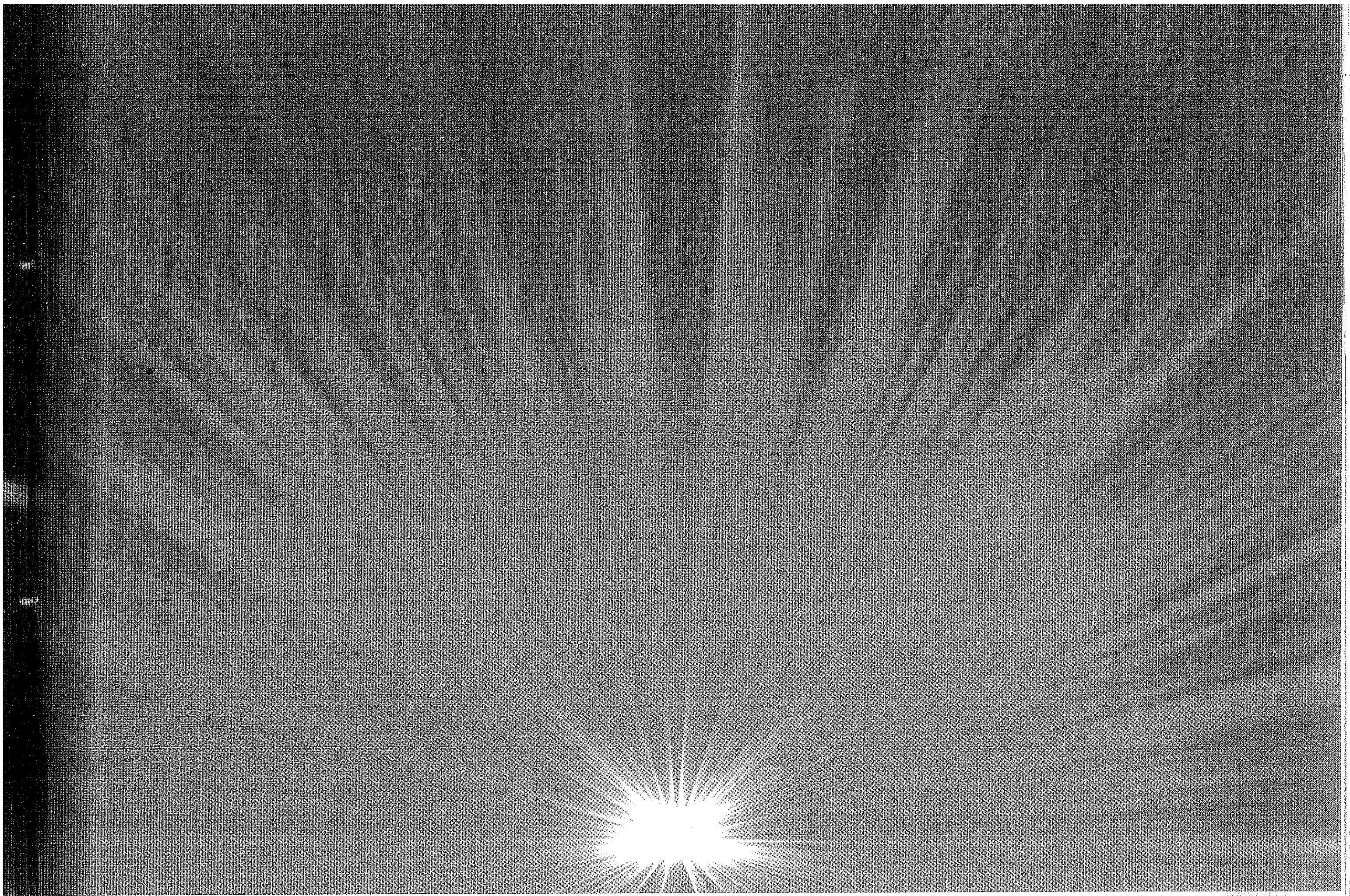
Within days another group of researchers at Rohm Company in Kyoto, Japan—a partner in the U.C.S.B. center—duplicated the feat using similar materials. Although blue laser diodes are not in themselves very revolutionary [see "Blue-Laser CD Technology," by Robert L. Gunshor and Arto V. Nurmikko; SCIENTIFIC AMERICAN, July 1996], Nichia Chemical Industries (based in Tokushima, Japan, where Nakamura worked until 2000), Sony and other companies were still struggling to produce inexpensive GaN laser devices for the Blu-ray disc market. These diodes had previously been fashioned using a method with stubborn limitations that have kept manufacturing yields down and diode costs high.

The groups from U.C.S.B. and Rohm are developing a new way to grow the crystalline layers of gallium nitride and related alloys that make up a laser diode. The early successes of the approach not only promise greater yields but also buoy hopes of an even bigger payoff: rugged, compact GaN diodes that emit green laser light—a goal that has long eluded scientists and engineers. The technique should also lead to

KEY CONCEPTS

- Solid-state lasers can produce light in the red and blue parts of the spectrum but not the green.
- Recent research suggests that this "green gap" could be plugged as early as this year.
- The advance will allow for laser-based video displays that are small enough to fit in a cell phone.

—The Editors



high-efficiency green LEDs that emit much more light than existing devices.

These achievements would fill a gaping void in the visible spectrum where evolution has trained our eyes to be most sensitive, plugging the "green gap" in the red-green-blue triad needed for full-color laser projection and displays. They should help speed the introduction of laser projectors for televisions and movie theaters—which will display much richer colors than other systems—and of tiny, handheld "pico projectors" to be used, for example, in cell phones. And high-power green diodes might even be employed in such diverse applications as DNA sequencing, industrial process control and underwater communications.

A New Angle

The key advance that led to bright blue solid-state lighting was the mid-1990s conversion to LEDs and laser diodes made of gallium nitride and its alloys [for a profile of Nakamura, see "Blue Chip," by Glenn Zorpette; SCIENTIFIC AMERICAN, August 2000]. Before that, most researchers had focused their efforts on zinc selenide and related compounds. In the new approach, an exceedingly smooth, nanometers-thin layer of indium gallium nitride (InGaN) is sandwiched between two layers of GaN, forming what is called a heterostructure or quantum well [*see box on next page*].

By applying a suitable voltage, researchers set up an electric field perpendicular to these layers that drives electrons and holes—positively charged quasiparticles corresponding to the absence of electrons—together within the InGaN active layers. Inside this narrow trench, the electrons and holes recombine, annihilating one another and generating photons with an energy precisely determined by the properties of the active semiconductor material. By increasing the indium concentration in the alloy, one can lower this energy, thereby increasing the wavelength of the light and changing its color from violet to blue to green.

In LEDs the photons leave the well almost immediately, perhaps rebounding once or twice before exiting the device or being absorbed in the other layers. But in laser diodes, which produce coherent light, the photons stay largely confined within the trench. Two highly reflective mirrors—generally polished crystal surfaces at ei-

WHAT ABOUT GREEN LASER POINTERS?

The green lasers that have long been available employ a complicated two-step process to generate light. Semiconductor lasers inside these devices emit infrared radiation with a wavelength around 1,060 nanometers. This radiation then pumps a crystal that oscillates at half this wavelength—about 530 nanometers, solidly in the green. The process is costly, inefficient and imprecise—the second crystal can heat up, altering the wavelength of the resultant green light. Laser diodes that generate green light directly would avoid these problems.

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