Nanowire Formation Using Electron Beam Lithography

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Abstract. Miniaturization and performance improvements are driving the electronics industry to shrink the feature size of semiconductor device. Because of its diffraction limit, conventional photolithography is becoming increasingly insufficient. In this paper, the recent development of the silicon nanowire based on electron beam lithography technique is reviewed. EBL technology is a best tool to fabricate patterns having nanometer feature sizes. In this project, the exposure process was carried out by an in-house modified electron beam writing system using JOEL JSM 6460LA SEM integrated with ELPHY Quantum pattern generator. Following an introduction of this technique, the software description, pattern design formation and resist development are separately examined and discussed.

Keywords: Electron beam lithography; Nanowire design; ELPHY Quantum
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INTRODUCTION

Reducing the scale of semiconductor devices is one of the most significant issues in large scale device integration as expressed in the International Technology Roadmap for Semiconductors [1]. For decades, there were many intensive research topics on scaling down the size of devices. Although photolithography gives the best throughput, it is not achievable to pattern smaller than ~30nm features because of its resolution limit [2]. Scanning electron microscope (SEM) based electron beam lithography (EBL) is a method that used in this work. A Raith Elphy Quantum pattern generator was used to design the written pattern structures. This technique allows a large number of ohmically contacted nanoscale devices with controllable length to be placed on a single substrate [3]. EBL offers higher patterning resolution than photolithography because of the shorter wavelength possessed by the 10-50 keV electrons that it employs [4]. Besides, the advantages of e-beam lithography over conventional photolithography include versatile pattern formation can generate in smaller size. In a typical EBL system, electron beam with width of on the order of a few nanometers is generated by an electron gun that is shaped and focused by an electron column. EBL has been normally used to generate masks and reticles from computer-aided design (CAD) files [5].

The definition of nanoscale lithography here follows that provided by the US National Science Foundation, and it can be construed as using lithographic tools for fabrication of any structures having feature sizes less than 100 nm [5].

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Characterization and optimization of nanowire is the first steps in this project research. It's extremely important to produce the perfect nanowire at the nano-scale resolution and edible transmission for single electron transportation. Figure 1 shows the example of nanoscale structure created by electron beam lithography technique.

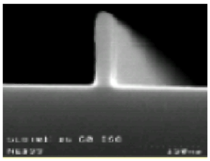
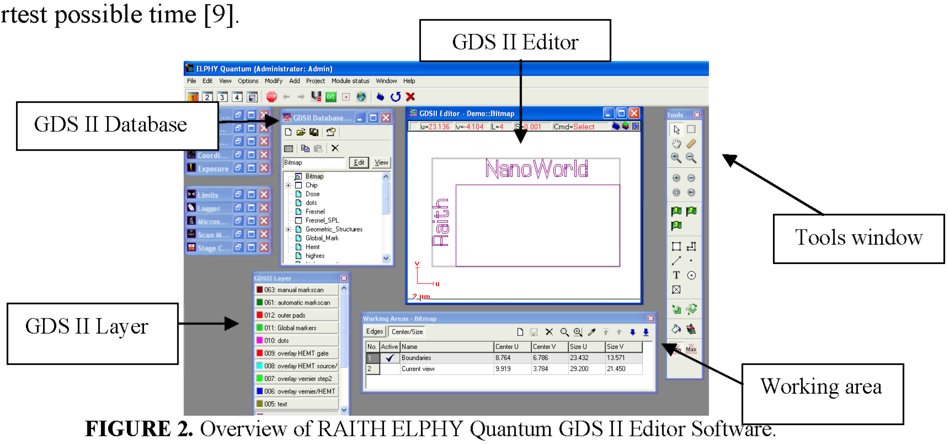


FIGURE 1. The SEM image of 60 nm single layer pattern produced on Si substrate by EBL method [6].

GDS II EDITOR SOFTWARE AND EBL SYSTEM

ELPHY Quantum is a universal lithography attachment which makes it possible to produce micro and nano structures by means of electron beam writing in connection with scanning electron microscope (SEM) system [7]. The University Malaysia Perlis Cleanroom's e-beam lithography system, called Elphy Quantum GDS II from Raith, consists of a scan generator electronic (hardware) and a PC-based operating software.The system has the control in three major areas of Scanning Electron Microscopes (SEM): Beam Blanker control, Scan & Signal control and Stage control. All required functions are fully integrated into one software, from pattern design, exposure parameter management, pattern overlay alignment to step and repeat exposures [8]. Elphy Quantum is Windows-based operating software as shown in Figure 2 and its functionality is based upon a modular design. Editing and pattern design is made simple with a GDSII internal editor. This allows users to build hierarchy patterns on different levels and designs with any dose level within the shortest possible time [9].



No.	Active	Name	Center U	Center V	Size U	Size V
1	✓	Boundaries	8.764	6.786	23.432	13.571
2		Current view	9.919	3.784	29.200	21.450

FIGURE 2. Overview of RAITH ELPHY Quantum GDS II Editor Software.

The main program window comprises the entire functionality to control the Raith software. For this, it offers (from top to bottom) the: (1) GDS II Database window shows the name of the opened database file and list of all included structure in tree

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view; (2) GDS II Editor window used to design or modify the pattern structures; (3) Tools window which contains buttons for creating various design pattern; (4) GDS II Layer selector window display the layer that selected from several process steps. One layer represents all the elements used in one process step and each layer distinguish with different colors; and (5) Working Area window shows the size and part of the pattern which will be exposed on the sample [7] [10]. The EBL system used in this research work, consist a JOEL JSM 6460LA SEM integrated with Raith ELPHY Plus pattern generator (Advanced SEM Nanolithography System). Figure 3 shows the EBL system at UniMAP's Microfabrication Cleanroom.

FIGURE 3. The EBL system at UniMAP's Microfabrication Cleanroom

DESIGN AND PROCESS DEVELOPMENT

Electron beam resists are normally covered on the sample surface to record the image of the pattern to be transferred. The final pattern made by the EBL is a relief structure in the coated resist layer representing the pattern being exposed. In this section, the distinguish using negative resists and positive resist is discussed. There are two types of e-beam resists utilized as the recording and transfer media for e-beam lithography. Positive resists undergo breaking when exposed to electron and become more soluble in the developer solution, whereas negative resists form bonds and become less soluble [11].

The general nanofabrication process for nanowires formation consists of four main elements such as sample preparation, pattern design editor, electron beam exposure and resists development. First, the liquid phase resist is dropped onto a silicon substrate spread on top. There are two types of resist that used; ma-N 2405 and PMMA for negative resist and positive resist respectively. The nanowires are designed using GDS II editor software and the designs are differentiate for negative resist and positive resist. Then the pre-designed pattern was written with beam of electrons on the substrate. The total time for negative resist exposure is 2 min 58sec, while for positive resist exposure is 12min 44sec. The PMMA exposed sample is developed using 1:3 MIBK: IPA and then dipped in IPA for the stopper process. For ma-N 2405 exposed sample, ma-D 532 is used as the developer and the developed resist films are

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thoroughly rinsed with deionized (DI) water. Figure 4 shows the pattern differences generated from the use of positive and negative resist.

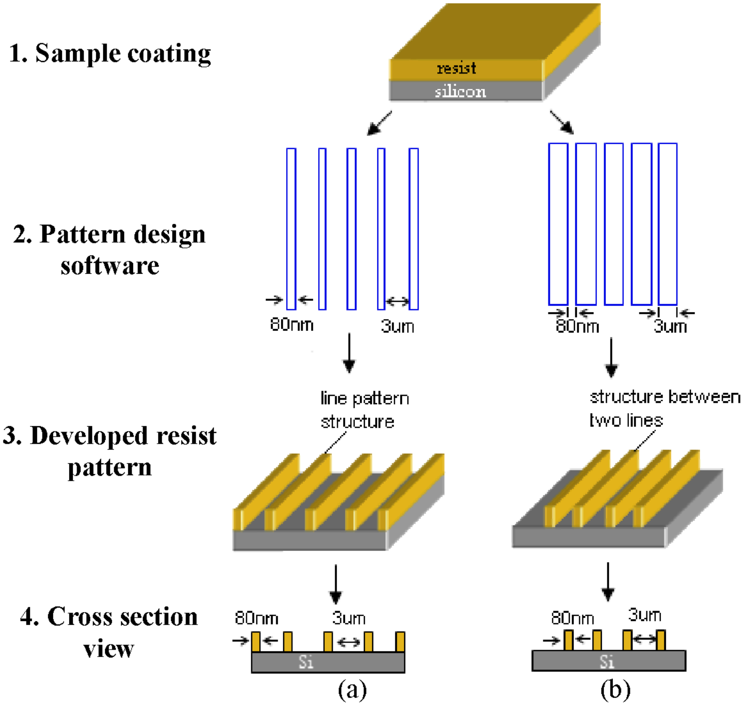

FIGURE 4. Nanowires pattern design for: (a) Negative resist (b) Positive resist.

The final remaining resist for the ma-N 2405 resist mask and PMMA resist mask is shown in Figure 5. The cross section view shows the line pattern design for negative is formed as nanowires structure while for positive resist, the gap between the boxes are formed as nanowires structures [12]. That's mean, the resist mask formed from negative resists contains an exact copy of the pattern which is to remain on the wafer while positive resist behave in just opposite manner. The positive resist developed sample contain in the inverse of the pattern transfer design. The unneeded silicon layer is removed and finally the silicon nanowire underneath the resist is performed.

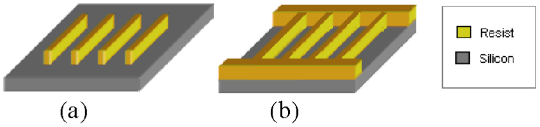

FIGURE 5. Final remaining resist on the Silicon substrate (a) ma-N 2405 (b) PMMA resist.

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CONCLUSION

Conventional lithography methods are not capable to produce nanowires and even with advance nanolithography sizes below 100nm is not easily to be achieved. These fabrication techniques demonstrate the versatility of electron beam lithography for realizing nanoscale structures. ELPHY Quantum GDSII Editor Software is used for design of the pattern to be written. The software is used to design the nanowire pattern to develop on negative resist and positive resist. The main differences between both designs are the way on how to produce the nanowires and the material of the nanowire it self. For e-beam system, the use of negative resist produce the same structure of the exposure design pattern while positive resists is vice versa. In other words, by using negative resist, the nanowires can formed exactly as the design.

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