Nanowire formation for Single Electron Transistor using SEM Based Electron Beam Lithography (EBL) Technique: Positive Tone Vs Negative Tone E-beam Resist

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ABSTRACT

Experimental studies of nanowires formation are carried out by using Scanning Electron Microscope Based Electron Beam Lithography (EBL) Technique with critical dimensions in less than 100nm. In order to complete the design cycle for the best nanowires, many contributing factors are considered. These factors include electron beam resists, resolution, working area/write field, structure size, step size, beam current, dose factor, exposure parameters and exposure time. The nanowires are designed by the powerful RAITH ELPHY Quantum GDSII Editor. The RAITH ELPHY is a CAD program for EBL and directly transferred on the sample coated with positive tone and negative tone e-beam resist. Comparison dimensions of both e-beams resist are included and discussed in this paper.

Keywords: Electron Beam Lithography, nanowire, Scanning Electron Microscope, PMMA, ma-N 2405 resist.

1 INTRODUCTION

Many applications of nanofabrication techniques like Single Electron Transistor (SET) now require the production of nanowires with critical dimension ~<100nm [1]. Nowadays, fine structures with critical dimension are commonly created with utilized more advanced nanolithography techniques. Electron-beam lithography (EBL) [2][3] is one of the nanolithography techniques for fabricating patterned nanowires. It offers high resolution capabilities of this technology, versatile pattern formation [4] and direct writing approach. Normally, the direct writing approach use a fine scanning beam to directly write the designed patterns stored in a computer into electron-sensitive polymer e-beam resist materials. Most EBL has utilized PMMA and ma-N 2400 Series as the e-beam resist. E-beam resists are normally coated on the substrate to record the image of the pattern to be transferred. Positive tone e-beam Polymethyl Methacrylate (PMMA) has been used for many years as the high-resolution resist for EBL [5]. PMMA is based on polymeric material and has different molecular weight (MW) that ranging from 50,000 to 2.2 million [6]. PMMA has many capabilities in microelectronic applications such as, as a protective or structural layer [7], as a bonding adhesive [5] and as masking material for silicon micromachining [8]. Its ultimate resolution has been demonstrates to be less than 10nm [9] although recent work has suggested that line as small as 6nm are possible. Negative tone e – beam resist ma-N 2405 series consisting of two components a phenolic resin (novolak) as polymeric bonding agent and a bisazide as photoactive compound (PAC) [10][11]. This resist works without chemicals amplification consequently its processing does not comprise any critical steps. Therefore it shows a wide process latitude and a good etch stability. Recently first results of electron beam expose of this resist were present with minimum feature size of 100nm [11][12]. The pattern design for nanowires generated with RAITH ELPHY Quantum. It is a lithography system which makes it possible to produce micro and nano structures by means electron beam writing in connection with scanning electron microscope (SEM) [13]. The operating system built in the software is very user friendly, comprehensive, most stable and widely used for lithography pattern generation. After the design for nanowires is completed, now it is ready for fabrication process. In this paper, the result of nanowires formation of both e-beam resist using Raith ELPHY Plus generated by customized JEOL 6460 scanning electron microscope (SEM) as a lithography system and equipped with software from Raith Gmbh will be discussed.

2 EXPERIMENTAL

The nanofabrication process for nanowires formation consists of four main elements such as Sample Preparation, The software and pattern design, EBL system and SEM imaging.

2.1 Sample Preparation

All fabrication process was done on P-type <100> silicon wafer. The wafer thickness is 475-575μm and the resistivity is 1-20μΩ. There are three steps in cleaning process. First step, wafer is cleaned using RCA 1 to remove organics or particles on the wafer. It is dipped in the solution for 10 minutes at 70^0C and rinse in DI water. Then the wafer is dipped in BOE for 10-15 seconds to remove oxide. After rinse with DI water, the wafer is dipped in RCA 2 for 10-15 minutes at 80^0C and spin dried. After cleaning process, wafer is bakes on hot plates for 60-90 seconds at 90^0C to remove the residual water during cleaning process. The wafer is leave to cool down in ambience about two to three hours before proceed with resist coating process. After cleaning process, wafers are cut into small pieces which size are 1cmx1cm and then continued by e-beam resists coating process. PMMA is a positive tone resist and normally it is coated on the wafer surface to record the image of the transferred pattern. The PMMA liquid is dropped onto the substrate and then spun at 6000rpm for 45sec to form a thin layer coating thickness of about ~70nm [8]. This is followed by soft bake processing for 90sec at 180^oC using hot plate to bake out casting solvent. While for negative tone, ma-N2405 is spanned on the substrate for 30sec with 3000rpm to form about 300nm.Then it is baked on the hot plate at 90^oC for 90sec.The last step for the both sample preparation is thickness measurement using F20 Filmetrics to measure the thin layer coating coating thickness.

2.2 The Software and Pattern Design

ELPHY Quantum is a lithography system which makes it possible to produce micro and nano structures by means electron beam writing in connection with SEM [14]. ELPHY Quantum consist operating software is called RAITH ELPHY Quantum GDSII Editor. The software package includes all the features needed to expose micro and nano scale structures starting from a structure design, post processing and design modification. It can be carried out online version or offline version running on a computer. The operating system built in the GDSII Editor is very user friendly, comprehensive, most stable and widely used for lithography pattern generation.

The patterns for nanowires were designed using RAITH ELPHY Quantum GDSII Editor is shown in Figure 1. The designed nanowires can be applied as a gate for Single Electron Transistor (SET) applications. The gate was designed with various gate widths.

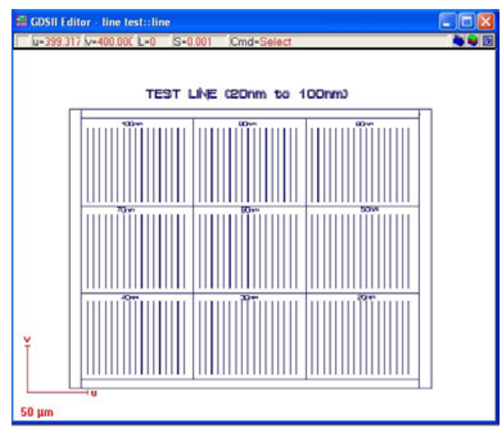


Figure 1: Pattern design for nanowires

From Figure 1, it shows a pattern design for nanowires consist of a 400um x 400um working area with nine 100um x 100um cells. Every cell represents in various nanometer scale size from 100nm down to 20 nm gate width and separated with 16 line structures. The distance of two line structures is about 5um.

2.3 EBL System and SEM Imaging

We used a modified JEOL 6460 SEM with EPLHY Plus pattern generator and equipped with RAITH ELPHY Quantum GDSII Editor. The sample is loaded into the SEM followed by beam focusing and system coordination before expose. Both steps are very important to obtain possible resolution, defocusing and astigmatism should be minimized to get a good pattern placement and to know where to expose the pattern on the sample. After the beam focusing and system coordination is completed, setup the exposure parameters and then proceed with the exposure process. After exposure, the wafer is leave about

5 minute before it is was unloaded from the SEM then proceeded with development process. The positive tone is developed using typical developer 1:1 MIBK: IPA for 30s and removed the developed regions by rinsing in pure IPA for 30s. While, the negative tone is develop using ma-D 532 for 40s and the developed resist films are thoroughly rinsed with deionized water for about 5min. Finally, the structure images can be observed in SEM.

3 RESULTS AND DISCUSSION

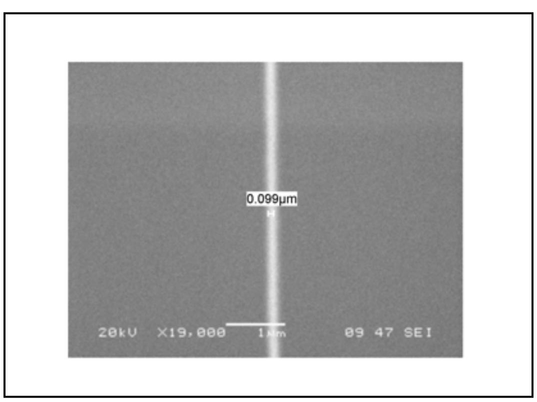
We exposed the pattern design with an exposure parameters involved are listed in Table 1 below. The exposure time was done automatically 2min 58sec for this design.

Table 1: Exposure Parameters

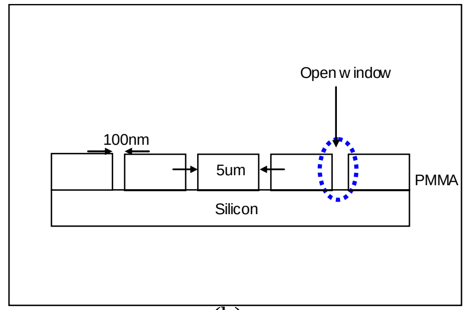
Acc. Voltage	20 kV
Working Area	400 µm
Magnification	200 x
Dose Factor	1.0
Beam Current	0.075 nA
Area Dose	100 µC/cm^2
Area Step Size	7 pixels

3.1 Positive Tone E-beam Resist

Figure 2(a) presents an image of positive tone e-beam resist with lines opened in the PMMA after development, while a cross section image of open window shown in Figure 2(b).The linewidth is in the 99nm with good uniformity and high resolution. The pattern was designed 100nm line to provide a transferred area on PMMA can be considered an open window or nanogap.



(a)

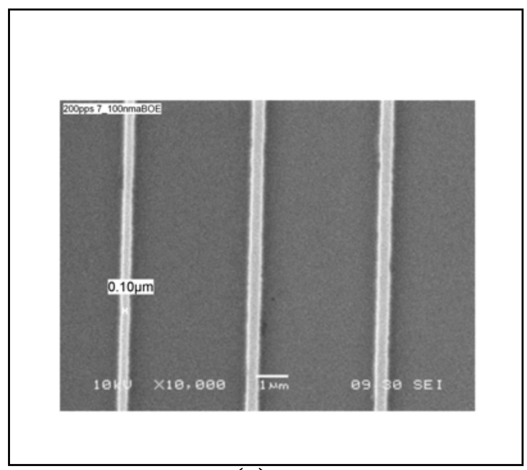


(b)

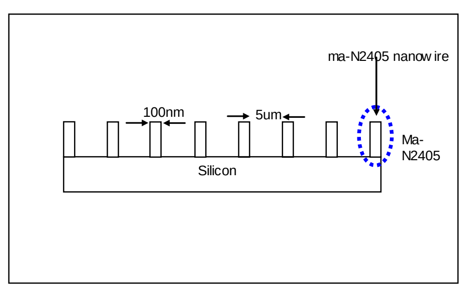
Figure 2: (a) SEM image show the PMMA nanowire; (b) a cross section image of PMMA nanowires

3.2 Negative Tone E-beam Resist

Figure 3(a) presents an image of 100nm ma-N2405 nanowire as confirmed by SEM, while cross section image ma-N2405 shown in Figure 2(b).The pattern was designed 100nm line to produce nanowire on the wafer surface. After developed, the pattern remains on the wafer can be considered ma-N2405 nanowire



(a)



(b)

Figure 3: (a) SEM image show the ma-N2405 nanowires; (b) a cross section image of ma-N2405 nanowires

4 CONCLUSION

From the experimental results, it can be confirmed that both of the pattern represent of different nanowires formation in nanometer scale. The main difference between both designs is the material of the nanowires itself. The PMMA nanowires and ma-N2405 nanowire can be achieved at sized less than 100nm using SEM based EBL technique. The image of positive tone e-beam resist is the same as the pattern design by using RAITH ELPHY Quantum GDSII Editor and the image of negative tone e-beam resist is the reversed pattern design.

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