Nanofabrication of channels using Electron beam lithography

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ABSTRACT

Nanofabrication is a collection of techniques used for the design and manufacture of devices at the nanoscale. The three major avenues for nanofabrication are thins films, lithography and etching. Of the techniques of nanolithography key among them is Electron Beam Lithography(EBL), which is a high-resolution technique to fabricate structures with high resolution (~ 10 nm). In this project, we are going to demonstrate patterning of channels on oxidized silicon wafers which can be potentially used for movement of molecular motors such as actin filaments, NEMS, SETs and others. This process is carried out in three steps: Sample preparation (spin coating), patterning of channels (EBL) and development of channels (wet etching). The developed samples are then characterized using Atomic Force Microscopy (AFM), Scanning Electron Microscope (SEM) and ellipsometry, which is used to measure the thickness of the surface before and after etching. Also, the effect of the etching rate and the importance of motility of molecular motors on the channels are studied.

KEYWORDS: Electron beam lithography, AFM, SEM, Ellipsometry

1. INTRODUCTION

Nanotechnology is the ability to control and manipulate the matter at nanoscale. Nanofabrication is a collection of techniques used for the design and manufacture of these devices at the nanoscale [1]. The three major avenues for nanofabrication are thins films, lithography and etching. Using these techniques, the semiconductor industry was able to keep up with the Moore's law for decades. Currently, FETs devices have achieved miniaturization of structures dimension of 10 nm due, in part, to the progress made in nanolithography. Moreover, nanolithography is key driver in optical, biological and chemical systems.

Electron beam lithography (EBL) is one of lithography systems which could actually achieve this low structural dimension. EBL like UV lithography has the similar steps. A focused beam of electrons is scanned on the desired surface covered with material sensitive to the beam [2]. Depending on the material property, its solubility in developer, a different chemical solution, is changed based on the exposure energy, leaving behind a pattern. This pattern can be characterized by various methods. In this study, AFM, SEM and ellipsometry is used.

Scanning electron microscope as the name suggests involve scanning the surface of the sample under interest with a focused electron beam. The electron beam undergoes various interactions with the surface atoms. Based on the intensity of the reflected electron beam, the composition and the tomography of the sample can be determined [3].

Ellipsometry is optical technique which works on the change in polarization of light when it gets reflected or transmitted. The sample of interest is exposed with light of particular wavelength and its polarization is detected with a detector. This observed data is compared with a theoretical model adjusted for the measurement setup. Based on this comparison, material composition can be determined [4]. Ellipsometry is used mainly for characterizing dielectrics and some organics.

Atomic force microscopy is a probe based microscopy, in which the surface of the sample under interest is scanned by a mechanical probe. When the mechanical probe undergoes any deflection due to contact with the surface, piezoelectric sensors are used to measure that height deflection from the rest position. Based on the signals obtained from these sensors, the surface can be characterized [5].

In the following sections, the methodology of implementing the above techniques are discussed. Then, parallel channels of varying width are patterned using EBL, which is the characterized by SEM. Also, a study of resist thickness with respect to spin rotation speed is done using ellipsometry.

2. METHODOLOGY

In this project, two studies are conducted.

In the first study, correlation between resist spin rotation speed and its thickness on the sample are studied. For this, two 2' Si wafers are spun with EBL resist ARP at rotation speeds of 2500 rpm and 5000 rpm. They are then baked for 2 minutes to improve the adhesivity to the Si surface. They are then characterized with ellipsometry.

In the second study, a channel pattern is made using EBL lithography in two one-inch Si die. Length of the channels are kept constant at 1 mm while width is 1.5 µm. The pitch between the channels are kept constant at 1.5 µm. The schematic of the pattern is shown in Fig. 1. Based on the AFM and SEM images of the sample, the proximity effects of the EBL are analyzed for the various channel widths. To that end, the effect of resist thickness on proximity effects are also analyzed by using two samples with two different resist spin rotation speeds of 2500 rpm and 5000 rpm. The thickness for the above are found using the methodology from first study.

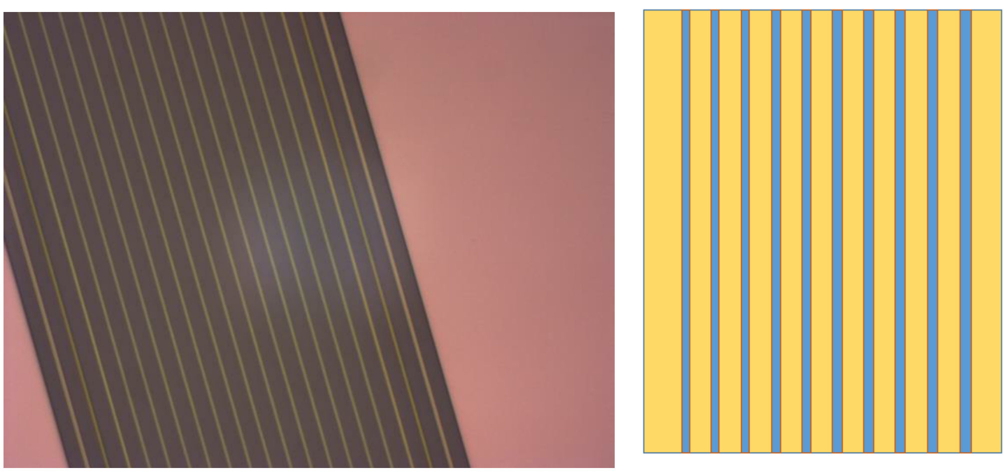

Figure 1(a): Optical microscopy image of the EBL pattern (b) Schematic of EBL channel pattern. Blue represents the channel whilst yellow represents the Si surface

3. **RESULTS AND DISCUSSIONS**

4.1 Ellipsometry

The following figures Fig 3, Fig. 4 show the spectroscopic data obtained with ellipsometry for the two samples. The system is fed with the structure of the sample measured, which in this case, is a stack of Si<100>, Silicon Oxide and photoresist. Silicon Oxide is included to account for the formation of native oxide in the Si surface. In general, their thickness tends to be less than 4 nm. The thickness of Si layer is 525 µm. The results obtained are tabulated in Table 1.

	Si (µm)	Native oxide - SiO_2 (nm)	PMMA thickness (nm)
Sample – 2500 rpm	525.1	2.47	528
Sample – 5000 rpm	525.7	3.55	384.53

Table 1: Thickness of PMMA as obtained from ellipsometry

Based on the results obtained, it is clear that the spin rotation speed inversely affects the resist thickness. This is due to the increase in centrifugal force acting on the resist with rotation speed. From the results, it is clear that the viscosity of the material also plays a role in the resultant thickness.

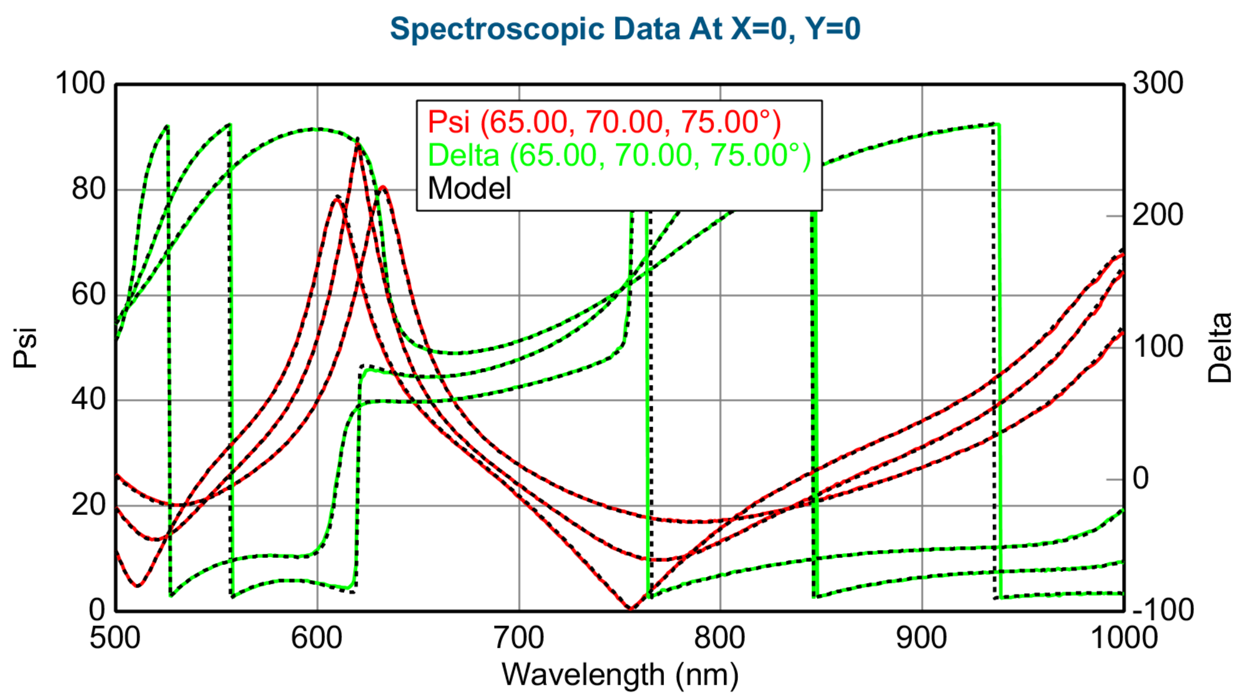

Figure 1: Spectroscopic data from ellipsometry for 2500 rpm sample

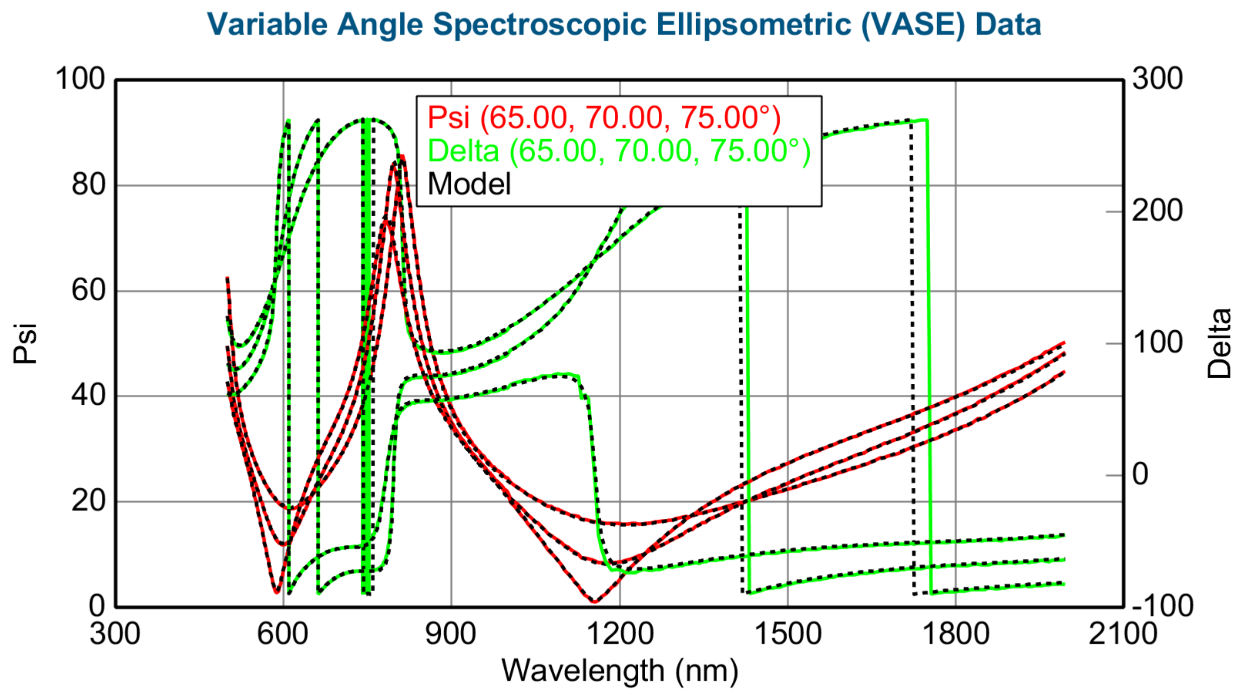

Figure 2: Spectroscopic data from ellipsometry for 5000 rpm sample

4.2 AFM

Only one of the samples (one with 2500 rpm) are inspected using AFM. The other one could not be characterized because the equipment failed. The obtained AFM image is shown in Fig.5. Based on the channel formed from EBL, it is clear that there is no proximity effects. The resolution of the channel width is quite high as it has the desired value of 1.5 µm. Also, the thickness of the photoresist can be observed. The height of the trench formed is 485.2 nm which agrees well with the ellipsometry data of 528.1 nm. The slight variation is due to different dimension of the samples (1 inch die vs 2-inch wafer) which affects the viscosity of the resist.

Figure 3: AFM image of sample with 2500 rpm

4.3 SEM

The samples are inspected using SEM. Based on the results obtained from ellipsometry, the resist thickness in the first sample is 528 nm while in the second sample is 384 nm. Unfortunately, we were not able to do the SEM analysis on the samples because the equipment was down.

4. CONCLUSIONS

In this project work, nanofabrication of channels using Electron beam lithography was performed and analyzed using AFM and Ellipsometry. High resolution channels were formed and it showed no proximity effects. The influence of the sample dimension and resist spin rotation speed on resist thickness was studied as well, which showed an inverse relation.

5. REFERENCE

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APPENDIX

This section discusses the tools and conditions required for carrying out this project.

1 The clean room:

Since the device dimensions are in nanometer scale any contamination from the environment has to be avoided. Thereby the processing of devices are conducted in a special environment, called the cleanroom. In a clean room the, environmental parameters; temperature, pressure and humidity are controlled. They are designed to maintain extremely low levels of particulates, such as dust, airborne organisms, or vaporized particles. Based on the amount of particles per cubic meter, the cleanrooms are rated from ISO 1 through 8. ISO 1 being the cleanest and ISO 8 being the dirtiest. This project was carried out in ISO 5 cleanroom, which has about 100,000 particles of 0.1-micron size per cubic meter.

In case of photolithography process, the ambient light of the room plays a role. The resist source used might be sensitive this light. Thereby, lighting is necessary for photolithography process, to prevent unwanted exposure of photoresist to light of shorter wavelengths and save it from decomposition. In case of EBL lithography, resists used are insensitive to ambient light as they are selected for their sensitivity towards energy of electron beam.

2 Clean up the samples:

The aim of this step is to remove contaminations from the surface of the sample to get good adhesion between polymer and sample surface. In this project, the sample are immersed in acetone in an ultrasonic bath. This is then followed by IPA dip. Samples are dried using Nitrogen gun.

3 EBL resists and developer:

The EBL resist are polymers with properties like that of a photoresist, but they differ in that the EBL resist sensitive to energy of e-beam. When the e-beam hits the polymer layer a chemical or physical change is induced by interaction. This change lead to easy pattern of resist. As with photoresists, there are positive and negative electron resist. For a positive electron resist, the polymer-electron interaction causes chemical bonds to be broken and to form shorter molecular fragments. This results from the molecular weight is reduced which is subsequently dissolved in a developer solution that attacks low-molecular-weight material. Positive electron resists can achieve resolutions of 0.1 μm or better. For the negative resist the interaction makes the polymer chains harder in the area of irradiation and then this area will remain after the development process. For both type of resists there is a special kind of developer are used to dissolve it. The development time also play an important rule. In this project amyl acetate is used. It is good option to use IPA cleaner after developing process to clean and stop etching process.

4 Resist coating of the samples:

Depending on the lithography process we can choose which kind of resist we use. For EBL, electron sensitive resists are used. In this project, PMMA was used. Before and after spin coating, the samples are baked on a hot plate for 2 minutes to get perfect adhesion between the polymer and the surface of the sample and evaporate any remnant of liquid. A rotation rate of spin also plays an important role in defining the thickness of the resist.

5 Electron Beam Lithography (EBL) process:

The core of our project is EBL stage. As we mentioned before there is a process, we called photolithography depending on using photo sensitive resist and a mask to pattern the sample´s surface and EBL is primarily used to produce photomasks because of the high resolution of defining the small size feature in deferent masks. Using of EBL became more than produce photomasks and it became an exposure tool used to pattern and define structure direct on the sample´s surface without using a mask.

EBL tool consists of several parts as shown in Fig. 1**.** The electron gun generates a beam of electron with suitable current density. The electrons are generated by heating materials like tungsten or lanthanum hexa-boride (LaB6) or by applying high electric field to extract the electrons from the top of the electron gun. After that, the electromagnetic condenser lenses are used to focus the electron beam to a spot size in range of several nanometres in diameter. Beam-blanking plates are used to turn the electron beam on and off. The required pattern is then obtained by manipulating the path followed by the electron beams. There are two methods to scan the wafer, raster method and vector method. In raster method depending on scanning all positions on the wafer and switch on/off when it required or not, whereas in vector method, the beam is directed only to the requested pattern features and jumps from feature to feature, rather than scanning the whole chip, as in raster scan, thereby saving time. These two types of scanning are achieved by deflection coils, which use electric and magnetic field to deflect the electrons. Beam deflection coils are computer controlled and operated at MHz or higher rates to direct the focused electron beam to any location in the scan field on the substrate.

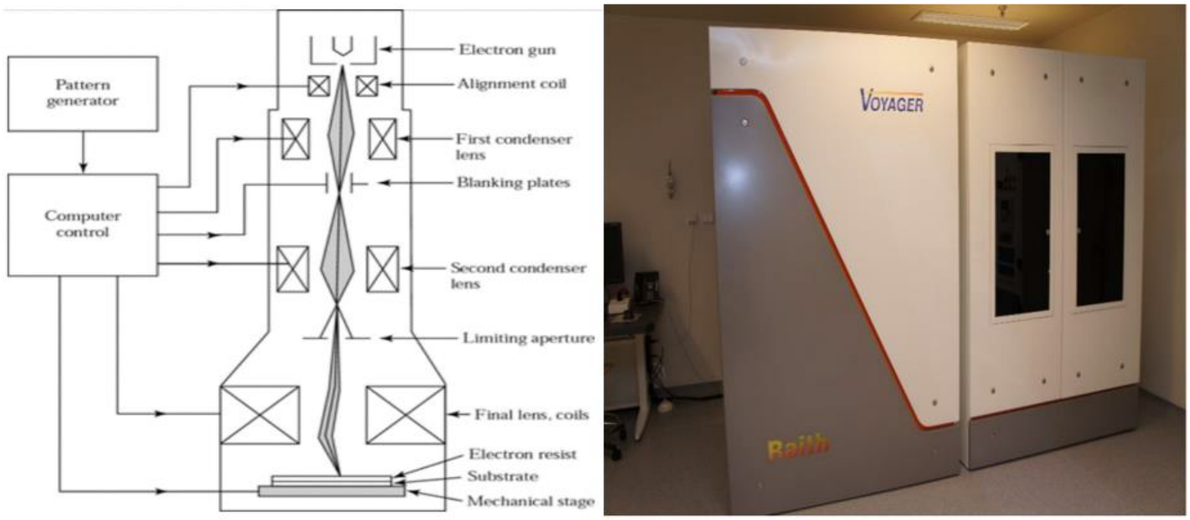

Figure A: (a) Schematic of an electron-beam machine. (b) EBL Raith Voyager

EBL thus allows nm-scale pattering of sample surface, with the high resolution. As no mask is required, it gives more flexibility when changing design. EBL has extremely low throughput related to a serial exposure process and has higher probability to damage the sample because of e-beam bombardment. The resolution of EBL is limited by proximity effect produced by scattered electrons. Also, it is expensive than optical lithography.

After EBL exposure, the samples are developed in amyl acetate developer.

6 Characterization process:

For this purpose, many techniques can be used to give details about thickness, roughness, doping concentration and other material properties. In our case we used different spin rate to get different thickness and an ellipsometry device used to determine the deference in thickness. Ellipsometry is an optical technique measures the change of polarization upon reflection or transmission and compares it to a saved model. It is very sensitive to the change in the optical response of incident radiation that interacts with the material being investigated and always the sample should be flat to get reasonable result. Other characterization techniques used were optical microscope, SEM and AFM, to detect at the channel length and width or pitch between channels.