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Scanning probe lithography as a tool for studying of various surfaces

Sedigheh Sadegh Hassani*, Zahra Sobat, Hamid Reza Aghabozorg
Catalysis Research Center, Research Institute of Petroleum Industry (RIPI), P.O.Box 18745-4163, Tehran, I.R., (IRAN)
E-mail : sadeghs@ripi.ir

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ABSTRACT

Atomic force microscope (AFM) is an increasing popular tool for characterizing and manipulating of various surfaces. In this work, nano–lithography on different surfaces was studied with Atomic Force Microscope. The scratches on various surfaces were created using contact mode by silicon and diamond tips. These scratches made on the polymethylmethacrylate (PMMA) coated on silicon were compared with scratches created on the polyethylene (PE) substrate. Effects ofapplied normal force, time of applying pressure and number of scratching cycles on the geometry and depth of scratches were studied. This study shows that there is a critical tip force to remove material from various surfaces.

KEYWORDS

Nano-lithography;
Nano-patterning;
Force lithography;
Atomic force microscopy;
Scanning probe lithography.

INTRODUCTION

The high-resolution lithography techniques are very important due to the fact that they allow the development of micro or nano-electromechanically devices. Many techniques have been applied with scanning probe microscopes in the last decade to visualize, analyze and manipulate material in such small scale[1]. The controlled patterning of nanometer scale features with the SPM, known as scanning probe lithography (SPL), is one of the SPM usages[2]. Application of various SPL techniques to semiconductor processing, has led to the high resolution and alignment accuracy[3-4]. Therefore, allowing the fabrication of reliable nanometer scale electronic devices, which could not be achieved by conventional lithographic techniques[5-6]. The AFM has found many applications, mainly in the study of surface topography, friction force[7], surface adhesion[8-9] and deformations. Scratching soft material, which is performed by applying force through AFM tip, has developed the AFM usage for nanofabrication. Lithography techniques can be carried out on the film of polymers such as polymethylmethaacrylate (PMMA), chloromethyl phenyltrichlorosilan (CMPTS), polyethylene (PE) and others[10]. This capability can potentially be extended to evaluate nano-scale material response to indentation and would be ideal for evaluation of mechanical characteristic of surfaces[11-12].

In this work, making scratches by using two types of cantilever tips on the various surfaces are presented. Silicon nitride cantilever tip with average spring constant is used to investigate PMMA thin film coated on the silicon as a soft surface. A diamond cantilever tip with high spring constant is used for hard surface of polyethylene. The effects of various parameters on the depth of scratches, created on the two surfaces are investigated.

EXPERIMENTAL

The nano-lithographic process and imaging in this paper were performed on polyethylene substrates and silicon substrate, which is covered by PMMA, thin films.

A commercial scanning probe microscope (Solver P 47 H, NT-MDT Company), operated in AFM mode, equipped with (NSG11) and (DCP20) cantilevers were used to perform the lithography of surfaces.

The NSG11 cantilever made of silicon nitride, has a rectangular shape, and its lengths, widths and thickness are 100±15μm, 35±3μm and 1.7-2.3μm respectively. Its normal bending constant measured by supplier is 11.5 nN/nm.

Another cantilever which is used in this process is DCP20 Cantilever made of diamond with the length, width and thickness 90±5μm, 60±3μm and 1.7-2.3μm respectively. Its normal bending constant measured by supplier is 48 nN/nm.

These two types of cantilever were selected to reach deformation of different types of surfaces and also for obtaining good image of scratches.

Our experiments were designed to fabricate scratches on the various surfaces with the different rigidity: PMMA (LG-IH 830) thin film (which is coated over the silicon substrate) and PE substrate.

To prepare the PMMA coated on the silicon substrate, a spin coater with 6000 rpm were applied for 30 seconds. For this purpose, a very small amount of diluted PMMA/$CHCl_3$ solution was put over desired surface. Then, the coated substrates were dried in an oven at 130^0C for 30 minutes. The thickness of coated layer was 150 nm measured by AFM.

Polyethylene surface was cleaned by washing and sonicating in acetone-ethanol (50-50%Vol) for 15 minutes at room temperature.

The lithography process was executed with the use of lithography menu supported by the microscope software.

First, the tip was brought into contact with the sample surface using the smallest force possible to minimize any undesired surface modification. An image of surface was prepared in order to choose a suitable surface area free of defects for lithography; afterwards the nano-litilography program was executed.

For AFM-scratching, the force is increased by applying a higher voltage to the piezo-scanner in order to reach the cantilever deflection (ΔZ) corresponding to the force (F) range where plastic deformation of surface occurs. The force is calculated using the Hook's law ($F=k\times\Delta z$)[13-15].

In this work, cantilever deflection in nano ampere (nA) unit is converting to nano meter (nm) unit.

Scratches were made in Y direction on the surface of PMMA on silicon and PE substrates, while scanning velocity, time of applying pressure and number of cycles was kept constant, so in this way the influence of applied normal force was investigated. Then, surface was scanned by atomic force microscope in non-contact mode to observe and evaluate the shape and depths of scratches.

Also, the effect of number of scratches and time of applying pressure were investigated on these two substrates.

RESULTS AND DISCUSSION

The topography image and profile of the PMMA thin film and polyethylene surface were investigated. It is seen that the roughness of surfaces were low and surface profiles were appropriate for lithography. An accurate study was performed on these substrates in order to find the optimum patterning conditions.

Making scratches were performed over PMMA coated on silicon substrate by exerting various normal forces by NSG 11 tip. In figure 1, the groove depths

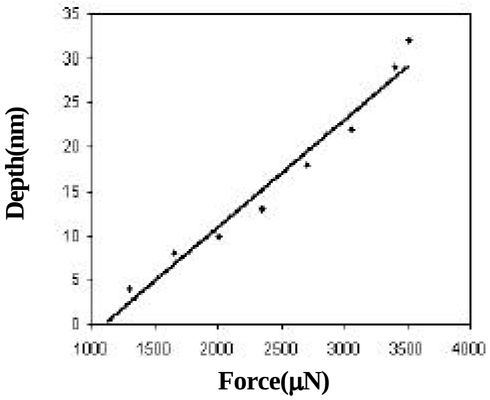

Figure 1: Dependence of scratches depth with the applied normal force for PMMA/Si, while scanning velocity, number of scratching cycle and time of applying pressure was 1400Å/s, 10, 25 ms respectively

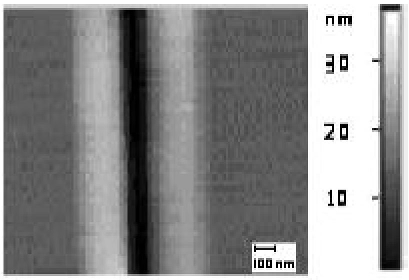

Figure 2: Topography image of scratches on PMMA/Si, while the applied normal force, scanning velocity, number of scratching cycle and time of applying pressure was 3000nN, 1400Å/s 10, 25 ms respectively

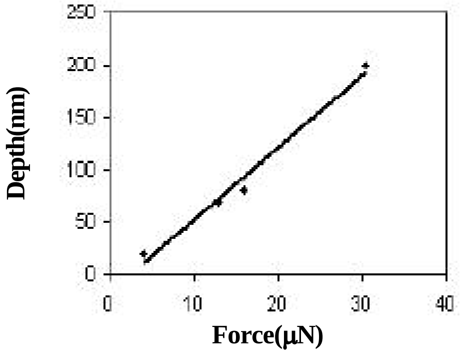

Figure 3: Dependence of scratches depth with the applied normal force on the PE substrate, while scanning velocity, number of scratching cycle and time of applying pressure are 1400Å/s, 20 and 50ms, respectively

are plotted as a function of the normal applied force for this substrate. However, the most uniform scratches were achieved by applying 3000 nN force load, while scanning velocity, number of scratching cycle and time of applying pressure were 1400 Å/s, 10 and 25 ms respectively. Topography image of this scratch is shown in figure 2.

This experiment was also performed on the polyethylene substrate. This substrate was more inflexible than PMMA thin layer, so performing any modification over PE needed more rigid cantilever tip. Our observation verified this comment. Scratches were just made by maximum amount of force load, which was equal to 4µN for NSG11 cantilever tip that was the threshold of force for modifying the PE substrate. We continued the investigation of force effect on the PE substrate by DCP20 cantilever with diamond tip. The force load created by this tip was sufficient to make modification on the PE substrate because of higher spring constant.

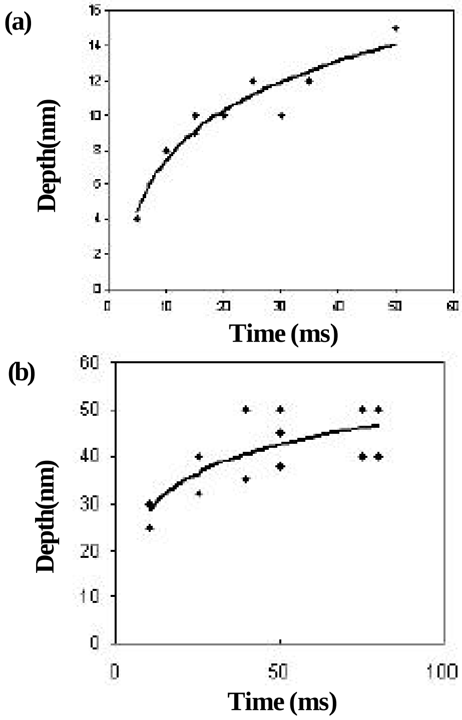

Figure 4: Indentation depth dependence to time of applying pressure, while normal applied force, scanning velocity and number of scratching cycle are 4µN, 1400 Å/s, 10 respectively for (a) PMMA/Si and (b) PE

A topography image of nano-scratche made on the PE showed that the best quality of scratch is obtained by performing 4µN force load. Investigation showed the uniformity of scratches reduced by increasing force load.

Accumulation the vicinity of scratches was occurred because increasing the applied force induced additional plastic deformation.

Figure 3 shows the linear increase of scratches depth on the PE substrate as a function of applied normal force.

Meanwhile, increase of applied force caused cumulating of material at the start and end point of the grooves. This deformity was occurred because of cantilever bending at the start point of moving tip through the surface. In this way cantilever reached the desired force to create scratch[14].

Finally, PE and PMMA coated on silicon substrates were selected to investigate the effect of number of scratching cycle and time of applying pressure at constant conditions.

The indentation depths are plotted as a function of

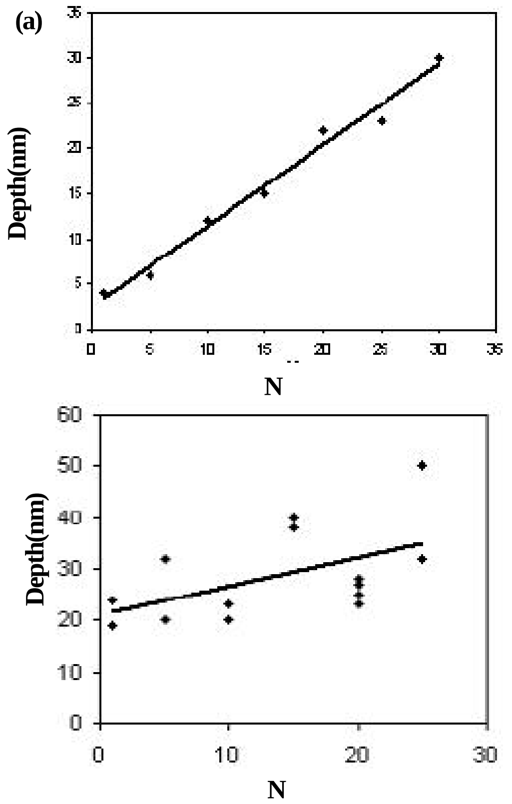

Figure 5: Indentation depth dependence to number of scratching cycle while normal applied force, scanning velocity and time are 4µN, 1400 Å/s, 25ms respectively for (a) PMMA/Si and (b) PE

the time of applying pressure and number of cycles for PE and PMMA coated on silicon substrates (figures 4 and 5).

The results show that the dependence of depth to time is not quite linear. According to reference[16,17], indentation depths increase with time nearly linear or exponentially.

Figure 5 shows the linear increase of scratches depth with number of cycles, as expected. According to figures 4 and 5, repeatability of results for PE substrate is less than PMMA layer. It refers to roughness and flexibility of PMMA thin film. Making scratch over very uniform and flexible PMMA thin layer was much more successful than others.

SUMMARY AND CONCLUSION

This paper summarizes the study of the force microscopy lithography process on various substrates.

Drawing pattern was studied using atomic force microscope in a controlled way, over four substrates.

For soft polymeric surface, NSG11 tip with average spring constant we used. The load force produced by this tip was sufficient to deform and make scratch on the PMMA thin layer. However to exert scratch on the hard surface, NSG11 tip was disabled to perform any change, so diamond tip was applied. It must be mentioned that the minimum necessary force to modify the PE surface was about 4µN that can be achieved by NSG11 and with maximum force load, but for further investigation, higher forces were needed, so DCP20 tip was applied.

The necessary parameters to control the depth of scratches on the surfaces were studied. As we expected, the depth of the lithography mark increased with the increase of the normal force linearly.

The increase of the lithography depth with loading time suggested that the plastic deformation on surfaces was time dependent, but its behavior wasn't completely linear. The dependence of scratch depth with the number of cycles were investigated, it is seen that the depth of lithography pattern increases linearly with the increase of the number of scratching cycle.

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