Producing nanowire and investigating effect of environmental parameters on nanolithography with atomic force microscope

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Abstract:

Nanolithography is the main process in many nanoelectronic projects for instance; nanowiring, nanotransistor and nano scale data storage. Therefore considerable attention is nowadays paid to nanolithography. The present applied research reveals the experimental results of nanolithography performed with atomic force microscope and investigates the effect of various parameters on this process.

In this study silicon wafer with high flatness (roughness below 1 nm) is used as sample and platinum coated and gold coated cantilevers (with coating thickness of 15 nm and 20 nm respectively) of tip radius less than 35 nm is employed. After auto approaching and when the tip is positioned in the region of 400 nN repulsive force, with a distance of 0.5 nm from the sample surface, the script language program is executed. The program is produced by software called 'script generator' which has been written for nanolithography purposes. In certain points in the program a DC voltage of 6 Volts is applied. This voltage level proved to be sufficient for the oxidation process of Si atoms (by using H_2O molecules existing in air) if applied for a duration time of 1 ms. The resulted SiO_2 molecules produced 3.5 nanometer height hills on the sample surface. With this method of nanolithography the word ARA is written on the silicon surface in a scanned area of 10µm*10µm. Sharp images of this word are then obtained by post scanning of the surface in non-contact and also contact modes. In continuation of the experiments nano wires are produced and effect of the level and time duration of the applied voltages, tip movement speed and environmental humidity on the quality of nanolithography is investigated.

Sticking of the SiO_2 molecules to the tip during imaging resulted in extreme reduction of tip conductivity. This made usage of new cantilevers in the consequence nanolithography experiments inevitable. This unwanted process was seen to be less when gold coated cantilevers were used instead of platinum coated ones.

Keywords: nanolithography-nano wiring-atomic force microscope

Introduction:

More than 20 years is passed since using of atomic force microscope in nano technology. The functioning principle of this microscope is based on variation of Van Der Waals forces generated between the atoms at tip end and those on the sample surface (Fig. 1). This force variation in turn causes vertical deflection of the cantilever (Fig. 2). Recording of this deflection variation which in fact represents the hills and valleys heights on the sample produces nanometric topography of the sample surface.

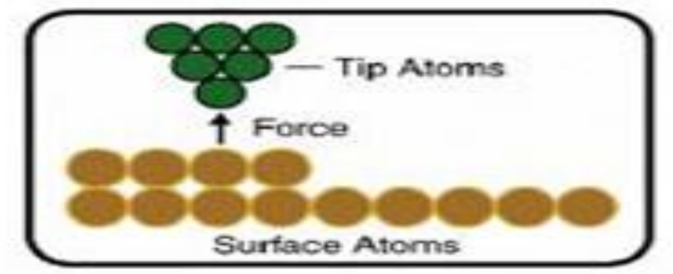

Fig. 1- Interaction of atoms at the tip end with atoms on the sample surface

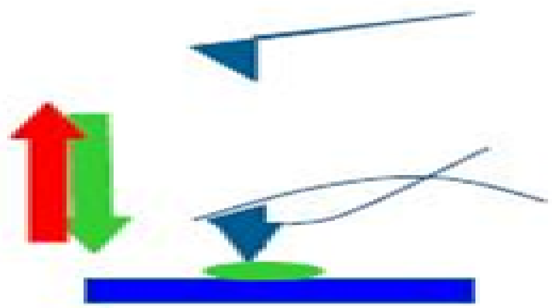

Fig. 2 – vertical deflection of the cantilever depending on attractive or repulsive Van Der Waals forces

Wan Der Waals forces which are ignorable when tip is far away from the sample, build up as attractive forces when tip gets close to the sample surface and their value increases with decrease of tip sample distance. Attractive force reaches a peak value and then decreases to zero with further reduction of tip sample distance. From then on when tip gets closer to the sample repulsive force starts to build up and increases by further decrease of the distance going to infinity if one tries to bring tip end too close to atoms on the sample surface. Of course cantilever breakage occurs before force gets too high [1]. This variation of Van Der Waals force with tip sample distance is schematically shown in Fig. 3.

Imaging in the region of attractive forces is called non-contact mode imaging and when in the repulsive force region is named contact mode imaging as shown below in Fig. 3.

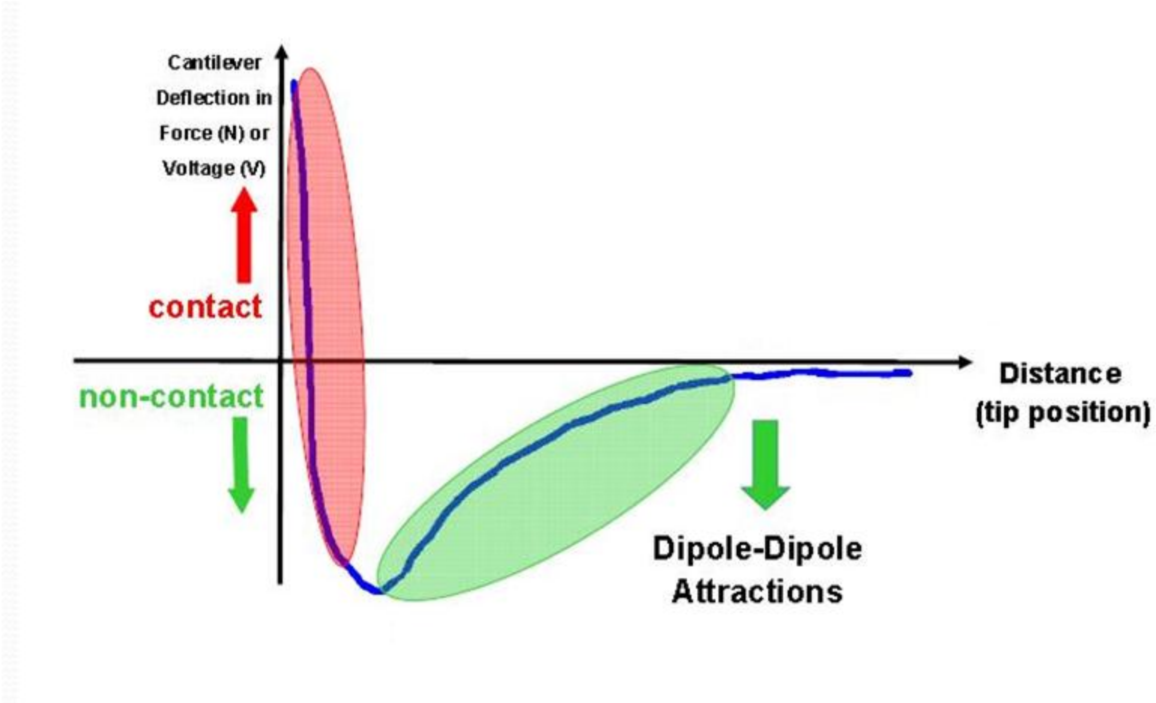

Fig. 3 Schematic graph showing the variation of Van Der Waals force relative to tip-sample distance.

Apart from imaging of material surfaces in nano scale, many other applications have been defined and experienced with atomic force microscopes [2]. Nanolithography is one of these applications which has opened a new era in nanoelectronics [3].

Nanolithography

The experiments for practical nanolithography are performed by using an atomic force microscope made in Iran, modeled ARA-AFM (Fig. 4). The advanced feature of ARA-AFM which makes is suitable for this study is the ability of generating script language and using it as a batch file during scanning. Various functions such as approach, applied voltage level, time duration for applied voltage, displacements in X and Y directions, scanning speed, angle of scanning, etc could all be changed within the script language program and functioned line by line.

Fig. 4 – Atomic Force Microscope made in Iran, modeled ARA-AFM, used in nanolithography

Using silicon cantilevers with conductive coating provides the opportunity for applying voltage difference between the tip and sample. Two different kinds of conductive cantilevers, both type NSC18 from MikroMasch, are used for this purpose. The first cantilever with titanium coating of 10 nm and platinum post coating of 15 nm and the second one with chrome coating of 20 nm and gold post coating of 20 nm. The geometrical and dynamical specifications of the used cantilevers are shown in table 5.

Table 5 - geometrical and dynamical specifications of the used cantilevers

Cantilever Series	Length l ±5μm	Width W ±3μm	Thickness t±0.5 μm	Resonant Frequency KHZ		Force Constant N/M	
				(typical)	(range)	(typical)	(range)
NSC18	230	40	3.0	75	60-90	3.5	2.0-5.5

Silicon wafer with high flatness (roughness bellow 1 nm) is used as sample. Both used cantilevers carry a tip end of less than 30 nm diameter. After auto approaching of tip to the sample and situating in the 400 nm repulsive force region, with a distance of 0.5 nm from the sample surface, script language program is executed. Voltage of 6 V is applied in certain points with 1 ms halt time at each point. This time duration was enough for the oxidation process of Si atoms, by using H2O molecules existing in air, to take place. The resulted SiO2 molecules produced 3.5 nanometer height hills on the sample surface. With this method lines of 250 nm were drawn on silicon surface (Fig. 6). Shapes like no 8 were then drawn (Fig. 7) and finally by this procedure of nanolithography the word ARA was written on the silicon surface in an scanned area of 10µm*10µm. A sharp image of the mentioned word on the sample surface is obtained in a post scanning of the surface in contact mode (Fig 8).

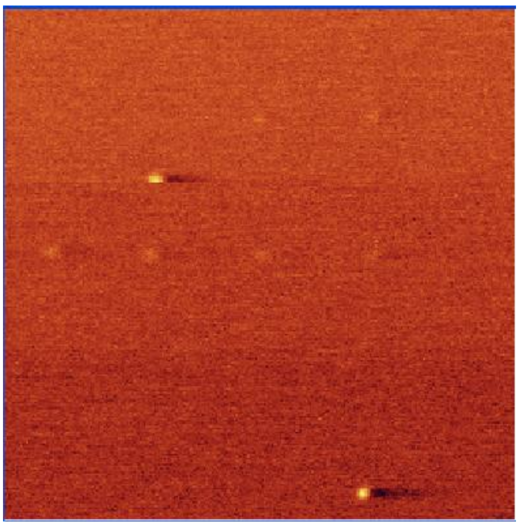

Fig. 6 – Phase image obtained in non-contact mode after nanolithography process

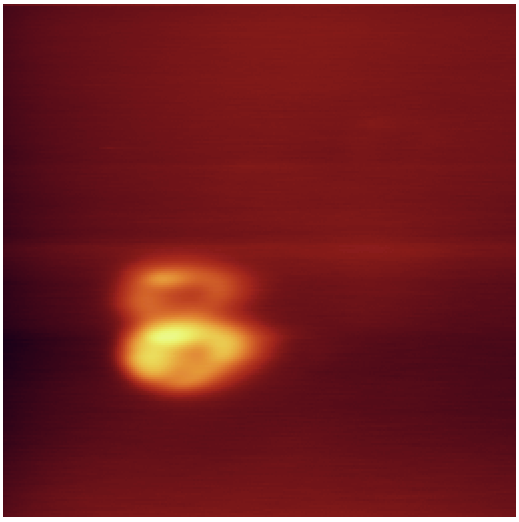

Fig. 7 – Topography image obtained in contact mode from nanolithography on silicon surface.

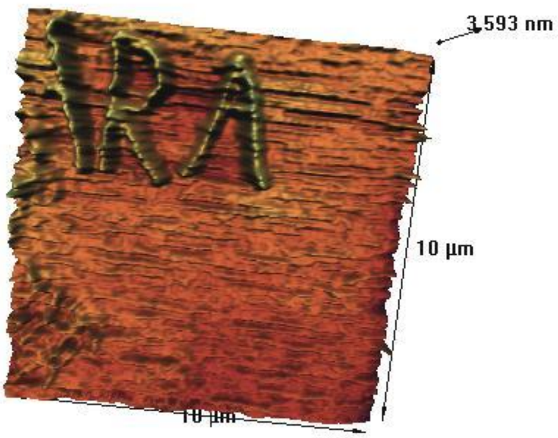

Fig. 8 – Word ARA written on the silicon surface by nano lithography. 3D view of topo image obtained in contact mode is shown.

Various experiments were performed with different ambient humidity level. For humidity under 30% proper image could not be carried out and from then on up to 55% the nanolithography quality increased. This quality remained unchanged for humidity up to 60% and decreased for further increase of humidity.

All the experiments were performed with both cantilever types of NSC18 group from MikroMasch. Sticking of SiO2 molecules to the tip end during imaging in contact mode caused highl decrease of electrical conductivity and therefore the cantilever could not be used for further nanolithography experiments. This reduction of conductivity was seen to be less for cantilevers with gold coating in comparison with those with platinum coating.

Maximum potential difference of 7 volts could be applied to the tip sample points but the voltage level was kept to the constant level of 6 Volts and the holding time for applied voltage changed between 1 to 3 millisecond.

Conclusions

If the voltage difference between the tip and sample is higher than certain amount, the trapped water molecules in between are broken into OH^- and H^+. These elements are very active and unstable [4] therefore rapidly synthesized with atoms of the sample material. In case of silicon sample it results in:

$$\mathrm{Si} + 2\mathrm{H_2O} \rightarrow \mathrm{SiO_2} + 2\mathrm{H_2}$$

In nanolithography of various experiments humidity should be kept between 30 to 60% and lithography could not be performed in vacuum.

Contamination of tip end with SiO2 and the subsequent electrical conductivity reduction is lower in cantilevers with gold coating in comparison with those carrying platinum coating.

Future study:

The present study clarifies various parameter effects on nanolithography over silicon wafer. This opens the avenue for further applied research in nanoelectronics using atomic force microscope. Producing nano transistor is suggested for future study [5].

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