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Quasinanoscale dots on ultrathin titanium film are discussed preliminarily with SPM as fabrication and analysis tool. The possible mechanisms are suggested and discussed.

Keywords: nanoscale structure; SPM

INTRDUCTION

Various STM-based nanofabrication schemes for future device manufacturing have been proposed and examined. Previous work on STM as nanofabrication tool include surface modification of H-passivated silicon[1], nanolithography of ultrathin polymer resist[2], localized anodization of Ti film[3], and mechanical scratch on sample surface, et al. In this paper, we report our results of nanoscale dots obtained with STM on ultrathin Ti film.

Sample Preparation and Experiments

For substrate preparation, 500 nm thick SiO_2 is thermally grown on (100) n-Si,

with ρ=2~10 Ω·cm. Then Ti film was grown on SiO_2. The thickness of Ti film is about 20 nm. An AFM image of the film suggests its RMS(Rq) is 0.386 nm and mean roughness (Ra) is 0.300 nm within an arbitrarily chosen 0.996x 1.051 μm^2 box.

Our experiments were conducted on Nanoscope® III STM/AFM system from DI Co. operating in air at room temperature. Electrochemically etched PtIr tips were used. The electrolyte is 60: 36: 4 of saturated $CaCl_2$ aqueous solution: H_2O: HCl. PtIr tips were etched for about 5 minutes and then examined. Thus we obtained sharp and symmetrical tips, which is proved avail to our experiments. To further strengthen the ohmic connection between Ti surface and the base, we pasted our sample to the clip with silver glue.

The sample was imaged at voltage bias = 1.32V and setpoint current = 1.04 nA. The scan rate is set to 10.2 HZ. For lithography, the STM tip is held over a specific position and a voltage pulse is applied between the tip and the sample for a period of time.

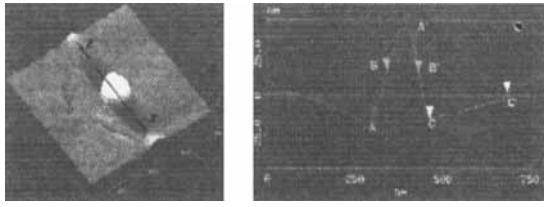

Fig.1 (a) An image scanned immediately after lithography is executed on our Ti sample. For imaging, voltage bias=1.32V and setpoint current=1.40 nA. (b) The cross section of the dot in Fig.1 (a) along ZZ' axis.

In our experiment, we set the lithography voltage bias = -8.0 V and bias time = 600 ms. After lithography, an image was acquired, as shown in Fig.1(a). The dot is about 100 nm in diameter and 40 nm in height. Fig.1(b) is the cross section along ZZ'-axis of the dot we obtained in Fig.1(a). The vertical distance of AA' and CC' are 56.005 nm and 16.075 nm, respectively. And the

horizontal distance of BB' is 92.029 nm. To further reduce the dimension of the dots, we changed several vital lithography parameters, such as the voltage applied to the tip and sample surface and the bias time. Fig.2 is the image of several dots formed under different conditions. The smallest feature size we acquired is approximately 18.006 nm in height and 47.266 nm in diameter. In our experiments, we found out that for voltage smaller than a certain threshold value, dots cannot be formed despite of long bias time. For our sample and STM system, the threshold value is about 5.00 V. The smallest feature size we acquired is about 40 nm in diameter and less than 15 nm in height.

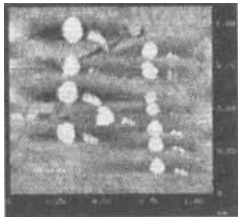

Fig.2 An image of dot array formed under different condition. For the left dots, voltage bias time is 400 ms and bias voltage is -8.0 V, -7.0 V, -6.0 V, -

and bias time is 400 ms, 300 ms, 200 ms, 100 ms, 50 ms, 10 ms, 5 ms from top to bottom respectively.

Possible Mechanism

There are two major factors for our experiment results. One is field-induced evaporation. According to the tip and sample atom transfer theory[4], when the tip and sample distance is close enough and the electrical field is strong enough, atoms can either transfer from the tip to sample or in the opposite direction. The evaporation field of atoms can be obtained, given the binding energy of the atom on the tip, the total ionization energy of the atom, surface work function, the atomic radius and tip-sample distance. The other factor of

our result is tip-induced anodization[5]. In such cases, oxide grows on Ti surface through electrochemical reaction. The dimension of oxide is affected by surrounding humidity through adsorbed water on Ti surface. Our experiment results were obtained in relative humidity above 70%. Since STM image is based on the tunneling current between the tip and sample, no current

white dots in Fig.2 are formed. During imaging scan after lithography, the STM tip will crash into the oxide film, which was formed through anodization, and scratch the top of the dots. This is the case because the dots are shortened in height. As STM gathers data needed for imaging unidirectional, the unexpected small dots appear in only one side. The smallest feature size of these dots is 30.078 nm in diameter and 8.519 nm in height.

One issue that greatly reduces repeatability of our experiments is the difficulty of imaging poorly conducting film. This is still under research.

Acknowledgments

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