Atomic Force Microscope Lithography를 이용한 선타입 옥사이드 구조물 패터닝

Patterning Line Type Oxide Nanostructures using Atomic Force Microscope(AFM) Lithography

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1. Introduction

Local Anodic Oxidation (LAO) performed by Atomic Force Microscope (AFM) is an attractive technique to fabricate nanometer scale oxide regions on silicon and metals for device patterning at laboratory conditions[1]. Despite important advances in understanding the physical growth process and in tuning LAO operational parameters, the application of LAO to nanofabrication is still in a strong development stage[2]. The most significant effect to control is the buildup of space charge, as it causes self-limiting growth that affects the aspect ratio of oxide features[3-7]. Voltage modulation technique was proposed to minimize this effect, resulting in aspect ratio enhancement by varying modulation frequency, reset time and reset voltage[8-11]. Keeping in mind such premises, in this paper we study how a finer control of the oxide patterns can be achieved through optimal use of pulsed waveform voltages by the analysis of the current behavior during oxide dot fabrication.

2. Experimental Method and Materials

The experiments were performed at 26-28°C and 40-44% of relative humidity. Probes used in our experiments were silicon cantilevers coated with 20-30㎚ of TiN. The height of the tip was in range of 10-15㎛ with a typical curvature radius of 35㎚. Samples were prepared by depositing a 7㎚ titanium layer on a commercial p-type silicon wafer covered with 0.1㎛ of thermally grown oxide. The tip and the sample holder set up were electrically isolated from the AFM unit. The AFM was operated in contact mode and the feedback circuit was always activated in order to maintain a constant tip-sample distance during imaging and patterning. A Keithley 236 source measure unit was coupled with a commercial AFM system (PSIA, XE-100) for tip biasing and simultaneous collection of current data. Constant or pulsed bias voltage was applied to target positions on the surface after obtaining a AFM image. In the case of dot fabrication, current data during the application of bias voltage was collected.

3. Results and discussion

The current behavior detected during the fabrication of TiO_2 dots by applying constant bias voltages from -7*V* to -10*V* shows three distinct stages in oxidation process, as shown in Fig. 1(a). In the first stage, the initial abrupt rise of the current can be attributed to the generation and transport of oxyanions by high electric field between the tip and titanium surface. The second stage is characterized by the suppression of the rising current, which emerges earlier with increasing bias voltage. The suppression of current is caused by the reduction of vertical transport of oxyanions by the well known space charge buildup during the oxide growth[3-7]. The third stage is defined as the linear region in the semilog current *vs.* time curves (dashed line in Fig. 1(a)). The lateral oxide growth continues in this region which leads to the decrease of the aspect ratio of oxide structures. As shown in Fig. 1(b), the height growth with time supports the power of time law which is found on the space charge limited growth behavior[4]. Our current data indicate an optimal duration of bias voltage in which oxide structures with higher aspect ratio can be obtained by avoiding the space charge buildup effect. In other words, a bias voltage duration within the second stage would

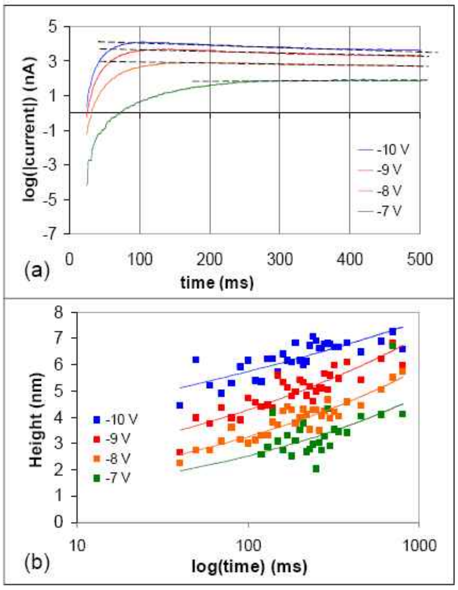

Fig. 1 (a) Semilog current versus time curves during TiO_2 dot fabrication under constant bias voltages, **(b)** Height growth as a function of the duration of bias voltage

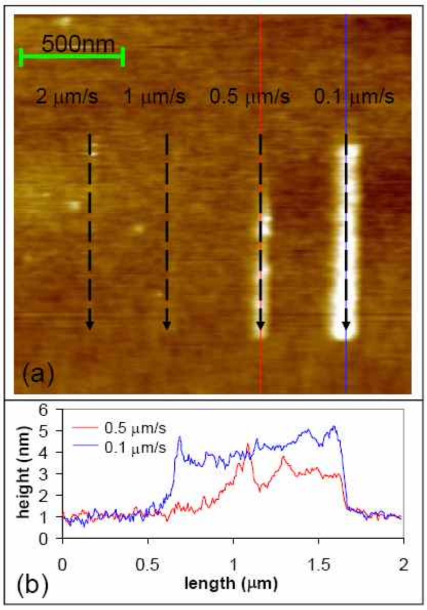

Fig. 2 (a) Oxide lines achieved by applying a bias voltage of -7*V* with various scan rates, **(b)** Profiles of line height in the scan direction be suitable for patterning higher aspect ratio oxides. The effectiveness of voltage modulation technique for this purpose also supports this indication because the duration of each pulse is within the second stage of the current data[8-11]. In the case of patterning oxide lines, the effectiveness of the voltage duration suggested above from the dot fabrication can be achieved by varying the scan rate. This assumption is supported by the consideration that a line is a sequence of dots. Despite the consideration of instability of water meniscus during the tip motion and of the curvature of the used tip, our experimental results support the feasibility of such assumption. Fig. 2(a) shows the AFM images of 1㎛ long oxide lines under the bias voltage of -7*V* by varying scan rates. The bias voltage with scan rate of 0.1㎛/*s* (=20㎚/200*ms*) produced stable oxide line; 20 nm is less than tip curvature, 35㎚, 200*ms* corresponds to the end of the second stage in the case of -7V of bias voltage in Fig. 1(a). Therefore, the oxide line with this scan rate is formed with a reduced space charge effect. The height of oxide line with 0.1㎛/*s* is 4.12 ㎚ while that of 0.5㎛/*s* is 2.89 ㎚ on average. A proper combination of scan rate and pulsed bias voltage can optimize patterning performance of oxide dots and oxide lines. Furthermore, this technique allows fast fabrication of highly reproducible oxide dot patterns. As shown in Fig. 3, the height variation as a function of period is not monotonous. Pulsed bias voltages with period from 500*ms* to 200*ms* produce smaller spaced dot structures with decreasing height. The decreasing height can be explained by shorter times of electric field exposure caused by higher scan rates. Pulsed bias voltages with period from 100*ms* to 10*ms* produce continuous lines with increasing height and aspect ratio. This is attributed to the superposition of dot structures produced by shorter pulse periods. Therefore, oxide lined or oxide dots may be patterned selectively just by choosing appropriate combinations of scan rate and period of the pulsed bias voltage.

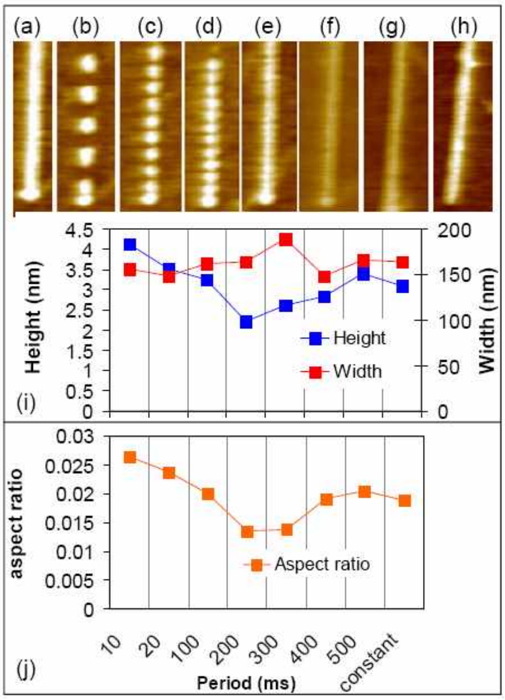

Fig. 3 Various oxide structures obtained using **(a)** constant bias voltage (-7*V*) and pulsed bias voltage of period of **(b)** 500*ms*, **(c)** 400*ms*, **(d)** 300*ms*, **(e)** 200*ms*, **(f)** 100*ms*, **(g)** 20*ms* and **(h)** 10*ms*. **(i)** height, width and **(j)** aspect ratio as a function of the period of bias voltage

4. Conclusion

The optimal duration of bias voltage for fabricating titanium oxide dot structures with higher aspect ratio has been determined from the second stage of the current profile during dot oxidation. This knowledge is extended to the fabrication of oxide lines, considering that a line results from a sequence of dots by varying the scan rate. By choosing proper combinations of scan rate and period of the pulsed bias voltage, selective oxidation of dots and lines may be achieved in a single scan.

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