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INFLUENCE OF ROOM HUMIDITY ON THE FORMATION OF NANOSCALE SILICON OXIDE PATTERNED BY AFM LITHOGRAPHY

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Nanometer-scale silicon oxide mask was patterned by atomic force microscope (AFM) lithography for fabrication of nanoelectronic devices. The oxide growth mechanism is similar to a well-known local anodic oxidation, which a negative voltage applied to conductive AFM tip in order to grow oxide patterns on silicon layer surface. The surrounding environment is one of the very important parameter on the formation of nanoscale silicon oxide patterns via AFM lithography. Therefore, in this work, the effect of relative humidity (RH) has been studied systematically in the range of 55–72%. Meanwhile, the applied tip voltage, exposure time, and scanning speed were kept constant during lithography process. From AFM topographic analysis on the fabricated nanopatterns found that the oxide width and thickness are significantly depending on the room humidity. These results proved that the room humidity is playing an important role on the fabrication of nanometer-scale oxide patterns by using AFM nanolithography.

Keywords: AFM lithography; silicon oxide; nanopatterns; silicon-on-insulator (SOI); humidity.

1. Introduction

Nowadays in complexity of electronic industry and device technology, application of nanometer-scale pattern is a must. These nanotechnologies are being dedicated to refinement of fabrication capabilities.[1–13] There are lots of technology approaches capable of producing nanostructures, the application of Atomic Force Microscopy (AFM) local anodic oxidation is one of it. In some referred publication considered it's as the ideal and generally acceptable tool to apply in nanometer-scaled patterning.[3–5,9] This application needs special efforts to control the oxide growth by tuning the operational parameters on nanometer-oxidation such as relative humidity (RH), exposure time, and amplitude of bias voltage, type of cantilever, tip speed and AFM operation mode. AFM nano-oxidation is going on when the ionic current flows

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between the conductive tip and the sample surface through and absorbed water layer. This process must depend on the humidity around the electrodes, because humidity determines the amount of absorbed water. Humidity is, therefore, one of the significant parameters along with the applied voltage.

In previous studies by referred journal, they only discussed the influence of AFM application mode, including bias voltage, exposure time, tip speeds, and the relative humidity in the booth. Therefore, in this work discussed the effect of room humidity on the formation of nanoscale silicon oxide patterned by AFM lithography. Moreover, the humidity inside of the chamber is assumed equal to the measured room humidity.

2. Experimental

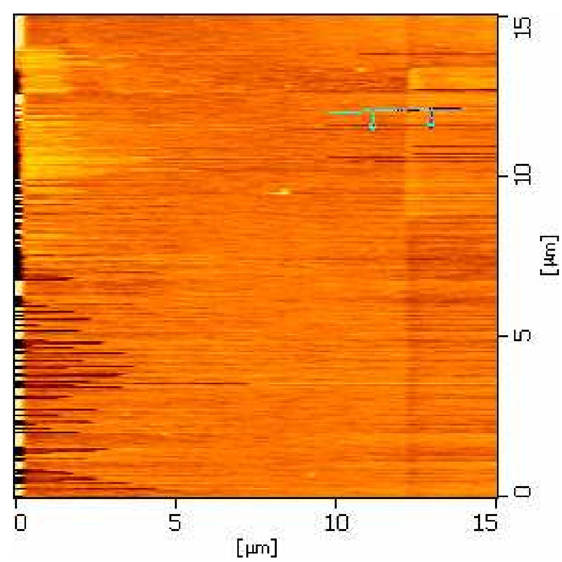
The samples with a surface area of 1–1.5 cm^2 were cut from p-type silicon-on-insulator (SOI) $\langle 100 \rangle$ wafers (Soitec, boron doped, resistivity 5–10 Ωm, diameter 6 inch, Si-layer thickness $\sim$100 nm and SiO_2 thickness $\sim$200 nm). The SOI was used as-grown and not subjected to any heat treatment. The samples were cleaned by using NH_4OH CMOS grade and H_2O_2 heated at 80°C for 15 min to remove the organic contaminants, followed by rinsing with deionized water (DIW). Solution from HCl and H_2O_2 were used to clean the ion metal on surface and heated at 80°C for 15 min, followed by DIW. Diluted HF, ratio 1:50, were used to remove the native oxide layer on SOI. All samples were pretreated with HF to give all samples the same starting conditions. The nanometer-scale silicon oxide pattern was fabricated on pre-cleaned SOI wafer via AFM lithography using SPM machine SII SPA300HV. The room humidity was recorded during lithography process.

3. Result and Discussions

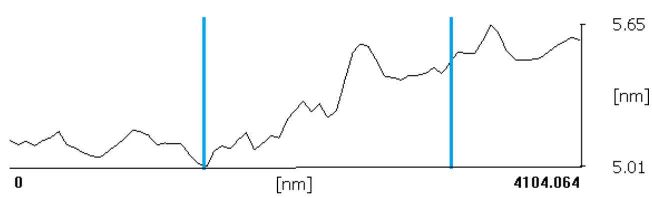
The pattern was fabricated by anodic oxidation, it happens when the certain voltage is applied to the Si sample, which the cantilever at a position in contact with the surface. Oxidation occurs at the air–oxide interface by the AFM tip when the oxyanions O^- and OH^- driven through the electric field and react with the holes h^+ at the silicon oxide interface to produce, silicon oxide, SiO_2.[6,9,10,13] The size of the pattern design is changed according to the voltage applied, the exposure time. In this experiment, the voltage applied to the cantilever (9 V) and exposure times are constant.

The size of fabricated shape is around 5 μm $\times$ 5 μm and was fabricated by raster programming for anodic oxidation. The conductive cantilever was applied voltage in contact with the surface. The shape of fabricated design is same according to the programmed, because the applied voltage and the exposure time are same, while the RH is different time to time and was measured by digital humidity data logger.

Figures 1(a)–5(a) show the topographic images of the fabricated shape 5 μm $\times$ 5 μm, while Figs. 1(b)–5(b) show the line profiles of the fabricated pattern at the different RH. Figure 1(a) at RH 55%, the average height for this shape is around 0.48 nm. While Fig. 2(a) at RH 60% shows the average height around 1.02 nm. Figure 3(a) at RH 65%, the average height of this shape is $\sim$ 1.53 nm. Figure 4(a) for RH 70%, the average height of



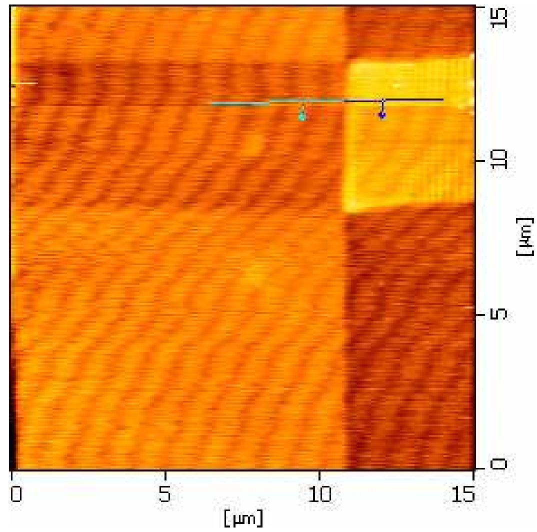
(a)



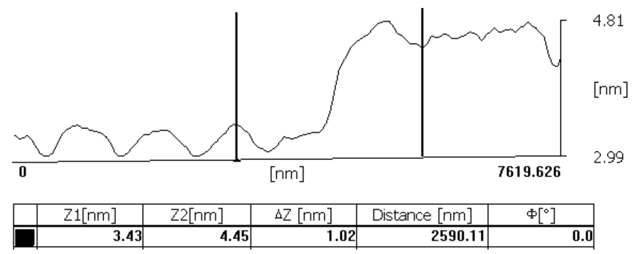
	Z1[nm]	Z2[nm]	ΔZ [nm]	Distance [nm]	Φ[°]
	5.02	5.49	0.48	1787.95	0.0

(b)

Fig. 1. (a) Topographic image of fabricated square shape pattern of 5 μm $\times$ 5 μm at RH 55%. (b) The line profile of fabricated pattern give the average height of the oxide growth is $\sim$ 0.48 nm.

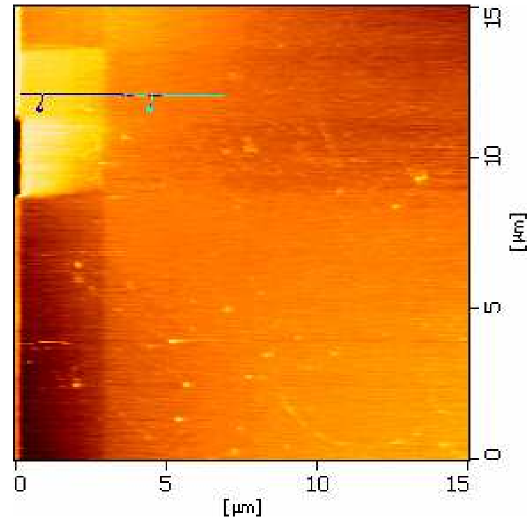


(a)

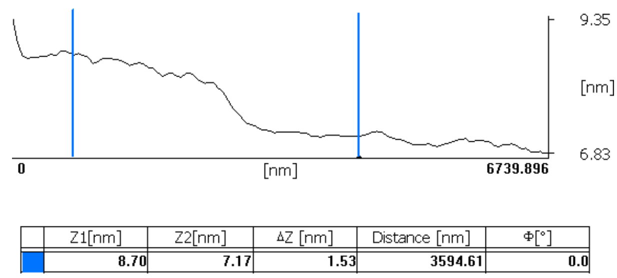


(b)

Fig. 2. (a) Topographic image of fabricated square shape pattern of $5\,\mu$m $\times$ $5\,\mu$m at RH 60%. (b) The line profile of fabricated pattern give the average height of the oxide growth is ~ 1.02 nm.



(a)



(b)

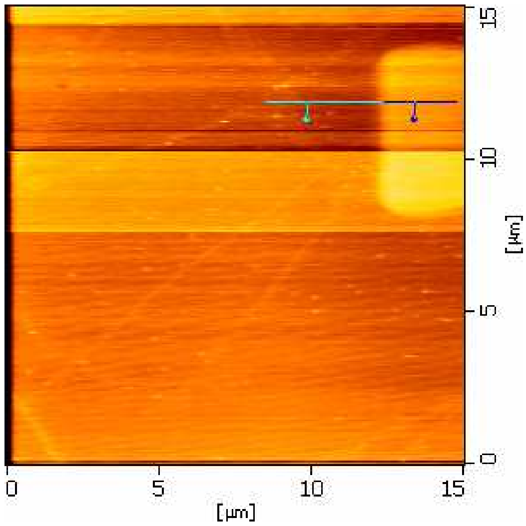
Fig. 3. (a) Topographic image of fabricated square shape pattern of $5\,\mu$m $\times$ $5\,\mu$m at RH 65%. (b) The line profile of fabricated pattern give the average height of the oxide growth is ~ 1.53 nm.

this shape is $\sim$2.47 nm. A topographic image for Fig. 5(a) at RH 72%, it shows the average height around 3.04 nm.

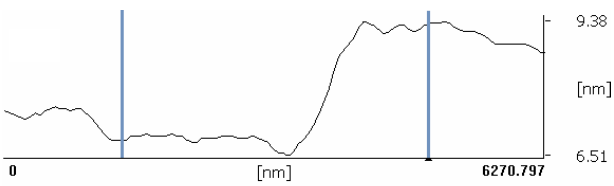
As mentioned in some previous paper,[3] when other parameters are constant, the humidity around the electrodes will give influences to the oxide growth on the surface.[5–11] This happens because the water bridge between the tip and the sample significantly relates to each other along with the applied voltage to growth oxide.

Here, the negative surface potential due to the surface charge effect and ionic diffusion through the water layer. The current flow and the surface potential around the core of the growing oxide become negative due to prevention of the isolative growing SPM-oxide.[1,3–6,8] At higher RH, the oxidation at the center of the growing oxide is prevented; the current still can go through the surface layer because it's horizontally expanded.[10] While RH decreased, surface charge effect and ionic diffusion become lower and it simultaneously will reduce the oxide growth on the surface.[3,9,10] Here, the average electric field for the formation of the water meniscus is deduced as a function of the tip-surface distance.[14]

Figure 6 shows the relation between the relative humidity percent with the thickness of oxide pattern. If the RH% increases the thickness of grown oxide will also increase simultaneously. As mentioned by Hsu and Lee[5] the oxidation rate is very sensitive to field strength at high RH. This experiment consider done in high voltage applied to cantilever, which it's will have saturated point of height increases. This is because of the space charge will build up to hinder the oxyanions diffusing in the oxide.[8–10] If we observe Figs. 4(a) and 5(a), it shows that the shapes are misaligned as programmed to be square pattern. This is due to defocusing of the electric field.[1,10] In tapping mode oxidation, by optimizing the control parameters such as applied bias voltage to the tip, scanning speed of the tip and oscillation amplitude of the cantilever, this



(a)



	Z1[nm]	Z2[nm]	ΔZ [nm]	Distance [nm]	Φ[°]
	6.86	9.33	2.47	3552.69	0.0

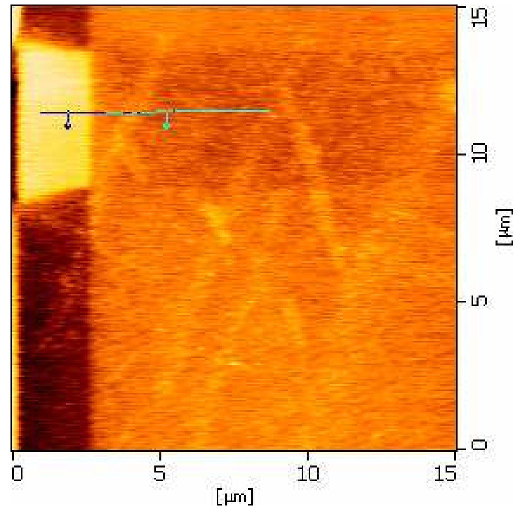
(b)

Fig. 4. (a) Topographic image of fabricated square shape pattern of 5 μm × 5 μm at RH 70%. (b) The line profile of fabricated pattern give the average height of the oxide growth is ~ 2.47 nm.

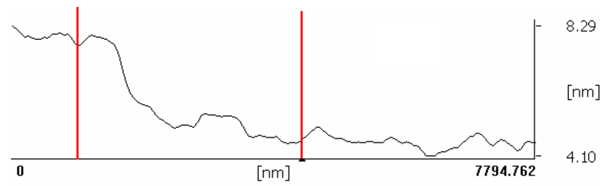
consequences can controlled nicely.[14] Here, at this higher RH > 65% for high voltage applied to the cantilever, the effect of ionic diffusion gained importance, the spread out of the shape shows the existence of the space charge.[1,3–5,10] This result shows the inter-relation of the space charge effect with assistance of the ionic diffusion will spread out the shape programmed through the water layer at high RH on the surface.

4. Conclusion

The effect of room humidity on AFM nano-oxidation is systematically quantified in the range of 55–72% relative humidity. The fabricated oxide increased simultaneously with increase of relative humidity in the room. At high relative humidity RH% and with constant high voltage applied to the cantilever (9 V), the shape programmed will misaligned. Inter-relation of the ionic diffusion and the



(a)



	Z1[nm]	Z2[nm]	ΔZ [nm]	Distance [nm]	Φ[°]
	7.70	4.66	3.04	3334.90	0.1

(b)

Fig. 5. (a) Topographic image of fabricated square shape pattern of 5 μm × 5 μm at RH 72%. (b) The line profile of fabricated shape pattern give the average height of the oxide growth is ~ 3.04 nm.

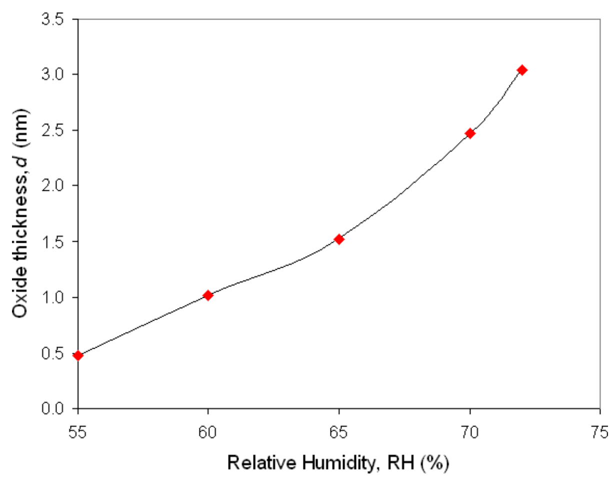


Fig. 6. Relation between relative humidity (RH) and thickness of oxide pattern.

water layer through the cantilever will have existence space charge effect applied to the surface. It shows that the oxide growth on surface becomes saturated. These results supported the previous studies on AFM nanooxidation, influences of room humidity will effect the oxide growth on silicon surface when the other parameters are constant.

Acknowledgments

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