Physica E 41 (2008) 146–149

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

Fabrication of nanopatterns on H-passivated Si surface by AFM local anodic oxidation

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ARTICLE INFO

Article history:
Received 8 May 2008
Accepted 26 June 2008
Available online 2 July 2008

PACS:
81.16.Nd
81.16.Pr
81.16.Rf

Keywords:
Nanopattern
Local anodic oxidation
Atomic force microscopy
Pulse bias voltage

ABSTRACT

Nano-sized patterns resulted from localized electrochemical oxidation by using atomic force microscopy (AFM) were fabricated on H-passivated Si surface. In this paper, the fabrication of nanopattern by local anodic oxidation (LAO) on H-passivated Si surface is presented. A special attention is paid to finding relations between the size of oxide nanopatterns and operational parameters such as tip-sample pulsed bias voltage, pulsewidth and relative humidity to fabricate oxide nanopattern. The LAO process shows the highly potential of solution processes for fabricating nano/micro-devices constructed from semiconductor materials for visible-light-emitting devices.

1. Introduction

Over the last decade, nanotechnologies have become one of the promising research areas which might bring a significant process into material and device development [1]. At present, there is a wide spectrum of technological approaches capable of producing nanostructures; however, none of them can be considered as an ideal and generally acceptable tool [2]. Local anodic oxidation (LAO) performed by atomic force microscopy (AFM) is an attractive technique to fabricate nanometer scale oxide regions on the surface for device patterning [3]. In previous studies, AFM LAO has been demonstrated as the most promising tool for fabricating nanodots and lines on several types of materials ranging from metals and semiconductors [4–12]. However, the outermost part of metal and silicon converts to their oxide under ambient conditions, which might reduce nanopatterns lateral resolution, and the effect of environmental conditions such as relative humidity have seldom been reported.

The H-passivated Si substrate was hydrogen passivated by leaking H_2 into UHV chamber, where atomic H was created by creaking H_2 molecules on a hot tungsten filament. The process can prevent silicon converting to an uneven native oxide [13]. In order to improve oxide nanopatterns resolution, we focus on specific nanoobjects and their fundamental properties on fabrication of nanopattern on H-passivated Si by LAO.

2. Experimental

Fabrication of nanopatterns was performed by using a commercial AFM (CSPM 4000). The LAO was carried out in contact mode and in the regime of the contact force using silicon cantilevers with electrically conductive tips coated by platinum (budget sensor). The tip is conic and radius is below 25 nm. The AFM software is extended with a program package for the well-defined movement of the tip over a sample. The facility associated with control of other tip-sample parameters gives us possibilities to accomplish pre-defined patterns at various pulsed bias voltage, pulsewidth and write speed in contact mode. For environmental control, relative humidity was controlled by introducing a mixture of dry and moist nitrogen stream inside the booth, while the temperature was maintained at $10 \pm 1\,^{\circ}C$. The relative humidity was controlled to range from 15% to 80%. The LAO process performed by AFM is illustrated in Fig. 1. In this nanolithography process, oxides grow on a chemically reactive substrate by the application of a pulse bias voltage between a conductive tip and a sample surface which acts as an anode.

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doi:10.1016/j.physe.2008.06.015

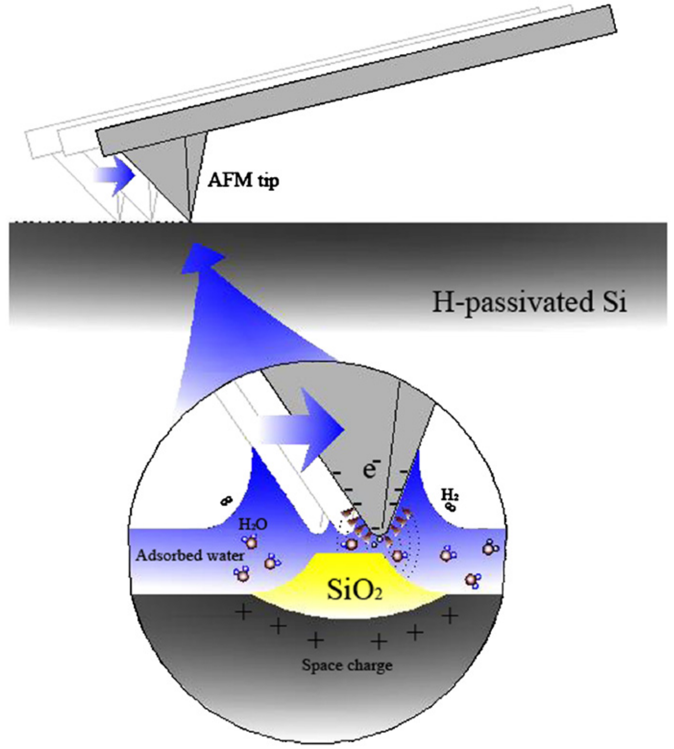

Fig. 1. Schematics of the local anodic-oxidation process induced by a biased conductive AFM tip.

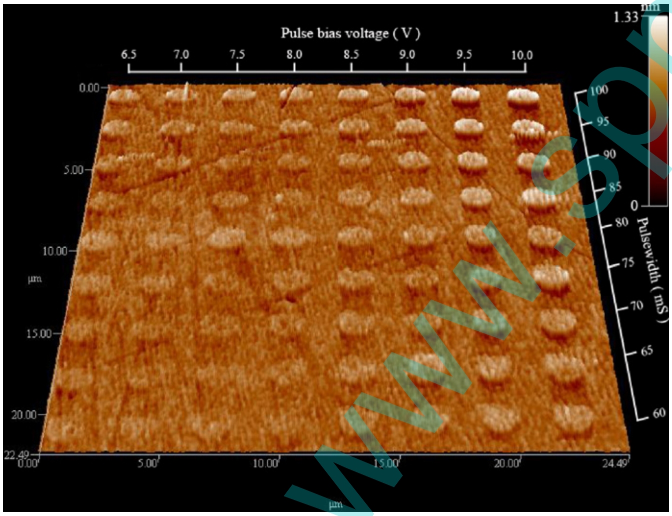

Fig. 2. A testing array of Si pillars prepared at different tip-sample voltages and pulsewidths on a Si substrate (relative humidity of 15% RH, temperature of 10 °C).

3. Results and discussion

Fabrication and application of nanopattern for a study of their quantum properties and for building new nanodevices or surface modifying requires a reliable control of individual technological steps. To be able to prepare nanopattern of required dimensions and properties, the relations between the operation parameters should be well-known and understood. The LAO process is controlled by several major parameters as follows: pulsed bias voltage, pulsewidth and humidity.

Fig. 2 shows a testing array of Si oxide pillars that was prepared at different tip-sample voltages and pulsewidths on H-passivated

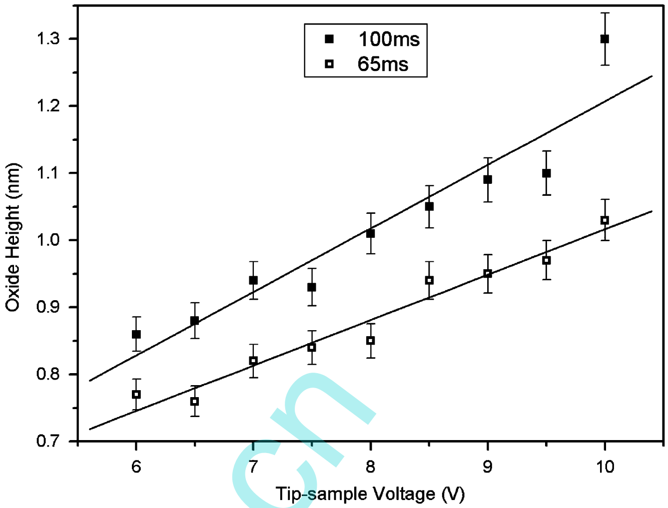

Fig. 3. The oxide height as a function of tip-sample pulse bias voltage for two distinct pulsewidths at humidity of 15%.

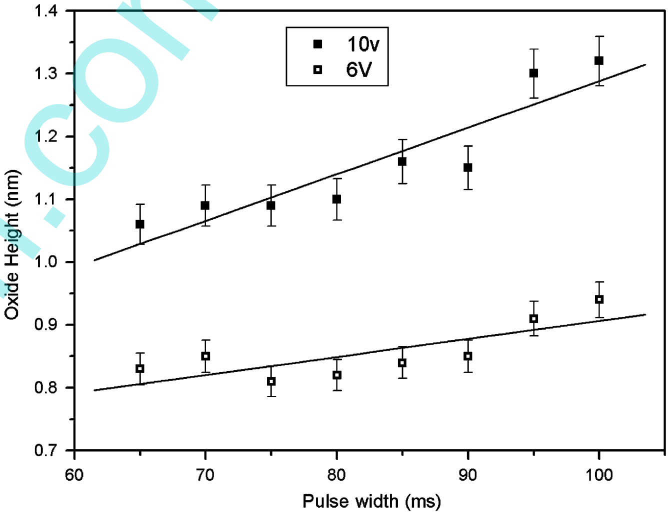

Fig. 4. The oxide height as a function of pulsewidth for various tip-sample pulse bias voltages at humidity of 15%.

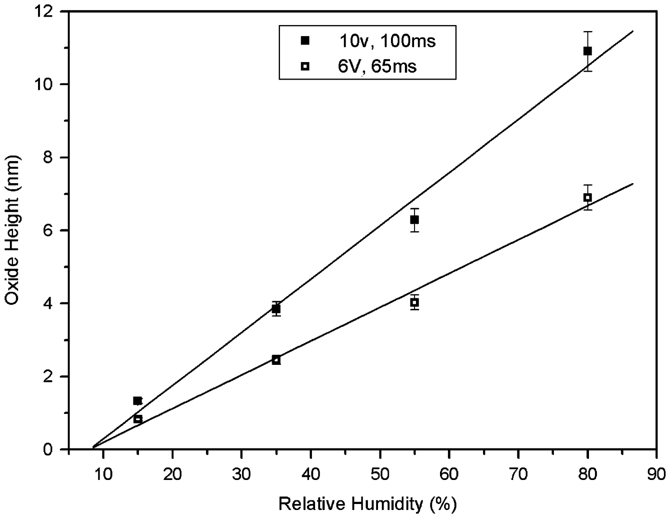

Fig. 5. The height of Si oxide as a function of relative humidity for two distinct optional parameters (pulse bias voltage and pulsewidth).

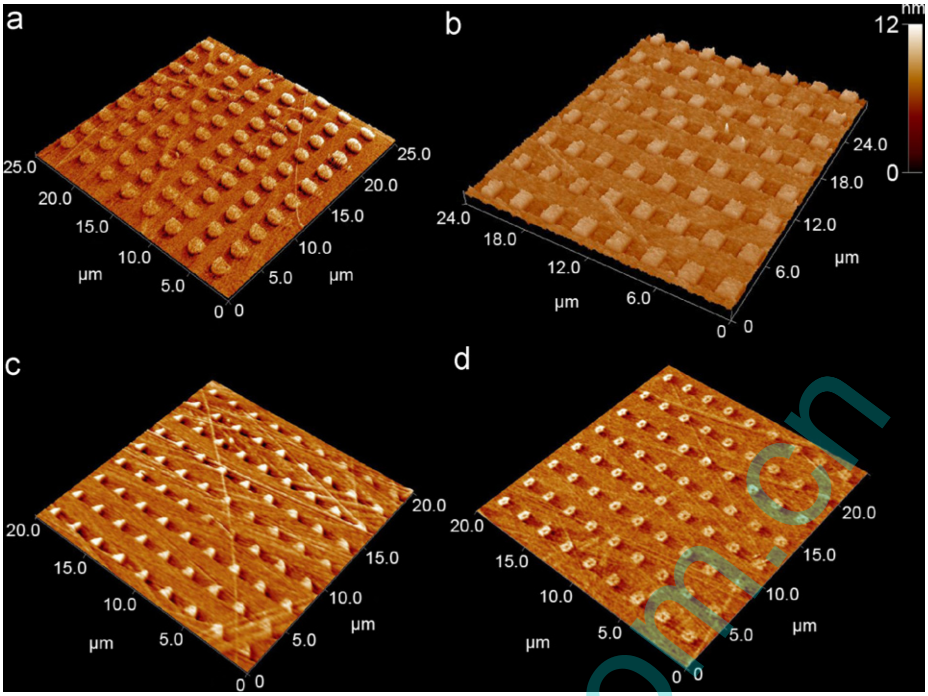

Fig. 6. Nanotexture pillars of (a) circle, (b) square, (c) triangle and (d) ring were fabricated by LAO.

Si substrate (relative humidity of 15%, temperature of 10 °C). From top to bottom in this figure, the pillars were prepared at progressively lower tip-sample pulse bias voltages. On the other hand, going from right to left, the pillars were made at progressively decreasing pulsewidths. It is obvious that the pillar was prepared at the highest tip-sample pulse voltage and the longest pulsewidth is best developed one in height. Such a testing pillar array makes it possible to find the relations between the height of pattern and operational parameters.

Fig. 3 shows the oxide height as a function of tip-sample pulse bias voltage for two distinct pulsewidths at humidity of 15%. The height of Si oxide pillar showed a linear dependence on tip-sample pulse bias voltage. From the experiment, the lowest value (0.76 nm) of the pillar was approached at a pulse bias voltage of 6 V and pulsewidth of 65 ms. On the other hand, the highest value (1.3 nm) of pillar was achieved at a pulse bias voltage of 10 V and pulsewidth of 100 ms. Fig. 4 shows the oxide height as a function of pulsewidth for various tip-sample pulse bias voltages at humidity of 15%. As shown in the figure, the height of Si oxide pillar exhibited a linear increase with pulsewidth. In the case of patterning oxide pillars, the effectiveness of the tip-sample pulse bias voltage suggested that the pillars fabrication can be achieved by varying the pulsewidth. It is evident that the lower pulse bias voltages and short pulsewidths result in lower anodized oxide pillars. The reason for that could be due to no enough voltage or time for reaching the saturation height. In anodic-oxidation process, the anionic and cationic transport are important factors in determining the kinetics of oxidation. In test condition, the driving force is the faradic current flowing between the tip and sample surface with aid of the water meniscus. Compared to previous study [14–16], the H-passivated Si can have higher growth rate and lager saturated oxide height than that of common p- or n-type Si under similar oxidation conditions. Fig. 5 demonstrates the linear dependences of the oxide height as a function of relative humidity. The height of Si oxide pillar was proportional to relative humidity for two distinct optional parameters (pulse bias voltage and pulsewidth). The reason for that could be due to the differences in the thickness of the water film. In any case, the present results demonstrate that the AFM tip-induced local oxidation can be a viable tool for fabricating well-controlled oxide patterns provided proper operation conditions are chosen.

The LAO process can be used not only in fabrication of nanodevices but also adhesion-resistance as surface texture. For contacts of solid surfaces without adhesive agents, adhesion is proportional to the real area of contact. As an example of nanotextures, pillars of circle, square, triangle and ring were fabricated by LAO for this aim is shown in Fig. 6a–d.

4. Conclusions

In the paper, the application of tip-induced LAO for the fabrication of nanopatterns on H-passivated Si is presented. Result indicated that the LAO process is controlled by several major operational parameters as tip-sample pulse bias voltage, pulsewidth and relative humidity. The H-passivated Si shows higher growth rate and lager oxide height than that of common p- or n-type Si under similar oxidation conditions. The pillar of various pattering was fabricated in height ranging from 0.7 to 11 nm, for the aim of adhesion-resistance. We believe this technique to be potentially applicable to the fabrication of nanodevices and surface modification.

Acknowledgment

This work was funded by the Innovative Group Foundation from National Natural Science Foundation of China (NSFC) under Grant number 20773148, NSFC 50675217, and National 973 Program: 2007CB607601.

References

[1] G. Timp, Nanotechnology, Springer, New York, 1999.
[2] Nanotech, Scientific American September (2001) (special issue).
[3] J.A. Dagata, Science 270 (1995) 1625.
[4] Z. Chen, S. Hou, H. Sun, X. Zhao, J. Phys. D: Appl. Phys. 37 (2004) 1357.
[5] P. Avouris, T. Hertel, R. Martel, Appl. Phys. Lett. 71 (1997) 285.
[6] M. Yang, Z. Zheng, Y. Liu, B. Zhang, Nanotechnology 17 (2006) 330.
[7] Y. Okada, S. Amano, M. Kawabe, J.S. Harris, J. Appl. Phys. 83 (1998) 7998.
[8] S.R. Jian, T.H. Feng, D.S. Chuu, J. Phys. 38 (2005) 2432.
[9] F.S. Chien, J.W. Chang, S.W. Lin, Y.C. Chou, T.T. Chen, S. Gwo, T.S. Chao, W.F. Hsieh, Appl. Phys. Lett. 76 (2000) 360.
[10] X.N. Xie, H.J. Chung, H. Xu, C.H. Sow, A.T. Wee, Appl. Phys. Lett. 84 (2004) 4914.
[11] X.N. Xie, H.J. Chung, H. Xu, C.H. Sow, A.T. Wee, J. Am. Chem. Soc. 126 (2004) 7665.
[12] S.F. Lyuksyutov, R.A. Vaia, P.B. Paramonov, S. Juhl, L. Waterhouse, R.M. Ralich, G. Sigalov, E. Sancaktar, Nat. Mater. 2 (2003) 468.
[13] K.A. Ratter, J.W. Lyding, Nanotechnology 19 (2008) 15704.
[14] T. Teuschler, K. Mahr, S. Miyazaki, M. Hundhausen, L. Ley, Appl. Phys. Lett. 67 (1995) 3144.
[15] P. Avouris, T. Hertel, R. Martel, Appl. Phys. Lett. 71 (1997) 285.
[16] J. Cervenka, R. Kalousek, M. Bartosik, D. Skoda, O. Tomanec, T. Sikola, Appl. Surf. Sci. 253 (2006) 2373.