

Analysis of the influence of the applied voltage and the scan speed in the atomic force microscopy local oxidation technique

C Mendoza^{1,2}, A Plata¹, Z Lizarazo¹ and C A Chacón^{1,2}

¹ Universidad Industrial de Santander, Bucaramanga, Colombia.

² Laboratorio de Microscopia, Parque Tecnológico Guatiguará, Piedecuesta, Colombia.

E-mail: carolinamendozaluna@gmail.com

Abstract. The local nanolithography oxidation technique is implemented by using an atomic force microscope (AFM) for the fabrication of nanoscale patterning structures on a silicon substrate covered with a thin film of silicon nitride. During the fabrication process, the microscope is operated on air and contact mode utilizing a silicon tip covered with a hard Cobalt-Chromium coat. The dependence of the oxide growth with the applied voltage was investigated varying this parameter in a range of 1 to 10V to constant scanning speed; the influence of the writing speed in the dimensions of the oxide formed is also analysed varying the speed values between 0.1 to 1 $\mu\text{m/s}$. It is found that the dimensions of lines depend on scanning speed and voltages applied.

1. Introduction

The fabrication of micro-scale and nano-scale devices is a fundamental part of the nanoscience, nanotechnology research and some of their new applications. However, this introduces a technological challenge due to the requirement of the high-resolution nanolithography technique that allows defining with precision the geometry of the desired pattern. For this purpose, there is a range of lithography techniques to transfer the patterns onto different kind of substrates such as the Scanning Probe Lithography technique (SPL) and electron, ion and light beams [1,2]. Thus, compared with other micro and nano-scale fabrication techniques, the Scanning Probe Lithography is a low cost option; the AFM techniques offer the possibility to write directly patterns under flexible environmental conditions and can be implemented through different mechanisms. Thus, the surface of a sample can be modified under the influence of an intense localized electric field, similarly used for the anodic oxidation, surface decomposition, modification by thermal effect or by the tip indentation and others [1-4].

Among the SPL techniques, the local oxidation has been widely used in conductive and semiconductive materials for the direct fabrication of different kind of devices such as: dielectric barriers, mask for selective etching, and the fabrication of a wide range of electronic and mechanical devices/structures at nanoscale that includes conductive nanowires, transistors, quantum rings and dots, microlenses, etc [1,2,5,6]. Due to the versatility of this technique and with the purpose of continuity to previous works realized by the laboratory in the fabrication of diffractive elements using AFM [7]. In this work the anodic local oxidation technique is implemented to create the pattern desired. The first step in the implementation of the local anodic oxidation lithography is the analysis of the experimental parameters that influence the oxide height and width [8]. Such, different scanning speeds and voltage values, to find the minimum lateral dimension possible to achieve for the experimental conditions described in this paper.



2. Local Anodic Oxidation

The local oxidation SPL technique consist in the application of a positive voltage between the AFM tip and the surface of the sample in an atmosphere with relative humidity greater than 50%, this will induce the local oxidation on the surface of the substratum. The humidity in the ambient generates a meniscus of water between the tip and the surface of the sample, the applied voltage ionizes the molecules producing OH^- ions, which are accelerated through the surface where the oxidation reaction occurs; the required local electric field must be higher than the critical electric field whose value is around 1V/m [9,10] then the OH^- ions are transported to the surface of the sample guided by the electric field forming oxide structures while the reaction with the atoms of the surface take place. The oxide growth will depend on experimental conditions like scanning speed, applied voltage, ambient humidity and others.

The oxidation process reveals an electrochemical nature due to the presence of currents of order of picoamps that induce the oxidation along with the presence of a meniscus of water creating basically an electrochemical nanocell. For the silicon nitride the oxidation reaction on the anode (surface of the sample) occurs based on $\text{Si}_3\text{N}_4 + 6(\text{OH}^-) \rightarrow 3\text{SiO}_2 + 6e^-$ [9, 11].

3. Experimental parameters

For the local oxidation process and the acquisition of images a di-CPII Veeco Atomic Force Microscope is used, to generate oxide lines the Nanolithography 1.9 software is used and for image treatment and its analysis the SPMLab Ver. 6.02 software is used. Then, the Voltage-Pulse operation mode allows applying a voltage difference between the AFM tip and the sample up to $\pm 10\text{V}$.

For the experimental study of this parameters in the local oxidation nanolithography process, lines with a separation of $1\mu\text{m}$ are created on a substrate of nitride on silicon wafer p type <100>, resistivity $0.001\text{-}0.005\Omega\text{cm}$ with a RMS roughness of 0.4nm , using a silicon AFM tip with a hard Co-Cr coat, with a nominal radius of 35nm ; the microscope is operated under environmental conditions of humidity and temperature (65% y 20°C , respectively). Then, each of the parameters is varied as follows: scanning speed values between 0.1 and $1\mu\text{m/s}$ are taken applying a constant voltage of 10V . The variation of the voltage from 1 to 10V is perform to constant speed of $0.5\mu\text{m/s}$ and finally the oxide dimensions, height and width, are measured along the line to obtain an average value.

4. Results

The local oxidation was induced on a silicon wafer with a thin layer of silicon nitride, varying the scanning speed with a constant voltage of 10V . For the characterization of the oxide dimensions an AFM image was taken in contact mode and the height and width are measure form the profile Figures 1 and 2. The average height and lateral dimensions in function of the scanning speed are showed in Figures 3(a) and 3(b). For the voltage analysis, the same procedure is used varying the applied voltage between 1 to 10V forming lines with a step of $1\mu\text{m}$ for the scanning speed of $0.5\mu\text{m/s}$, the results are showed in Figures 4(a) and 4(b).

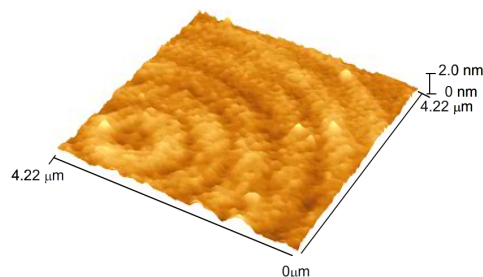


Figure 1. 3D AFM image showing the results for anodic oxidation for six of the ten values of scanning speed (0.1 to $1\mu\text{m/s}$ from centre to edge).

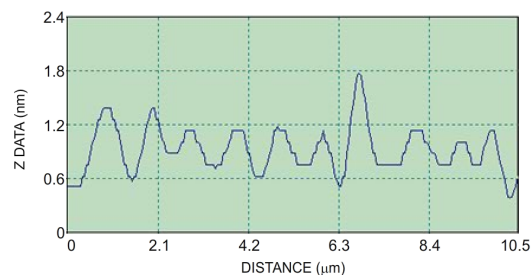


Figure 2. Profile of the oxide lines generated using different values of scanning speed between $0.1\mu\text{m/s}$ to $1\mu\text{m/s}$ (from left to right).

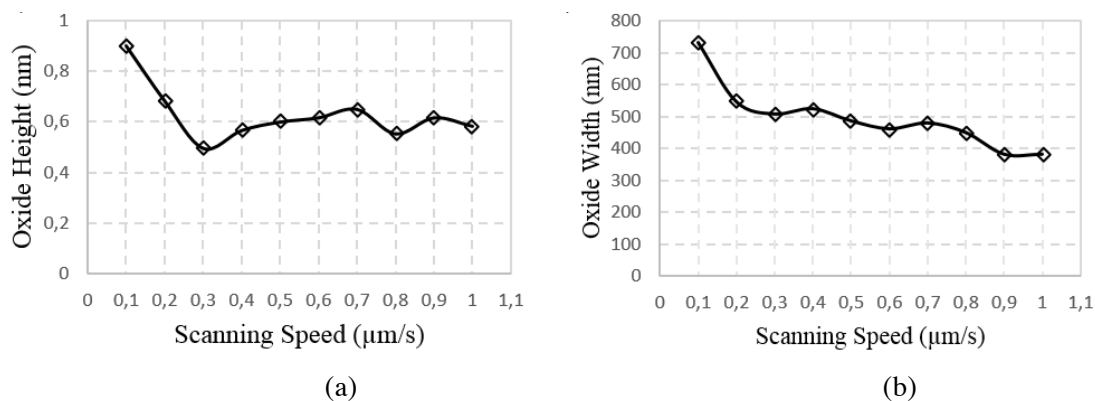


Figure 3. (a) Average oxide height in function of the scanning speed, (b) Average oxide width in function of the scanning speed.

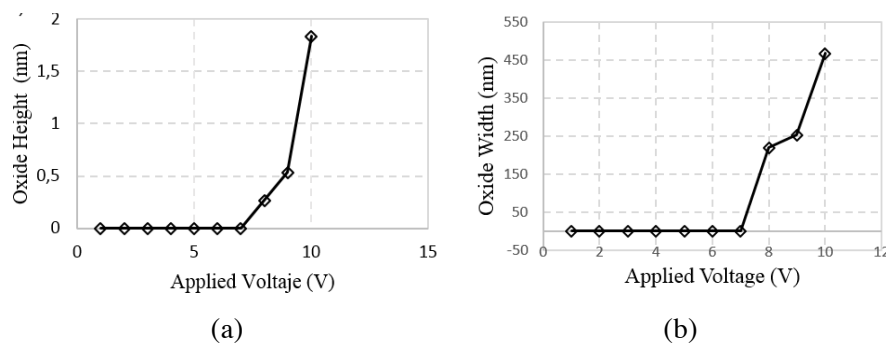


Figure 4. (a) Average oxide height in function of the applied voltage, (b) Average oxide width in function of the applied voltage.

5. Conclusions

The implementation of the local anodic oxidation lithography technique allow produce homogeneous lines with high fidelity. An inverse relation in the oxide height compared with the scanning speed is found with low variation in this dimension for speeds greater than $0.3\mu\text{m/s}$. The same relation is found between the lateral dimension of the generated line and the scanning speed, obtaining a minimum width for a speed of $1\mu\text{m/s}$. Also, a direct relationship between the lines dimensions and the applied voltage, finding that is required a voltage greater than 7V to induce the local oxidation of the surface. Such that, these are the optimal values for the implementation of the local anodic oxidation lithography technique with an Atomic Force Microscope.

References

- [1] Barnett M R, Nave M D, Bettles C 2004 *J Mater Sci Eng A* **386** 205
- [2] B Bhushan 2010 *Handbook of nanotechnology 3rd ed* (Berlin: Springer)
- [3] Hans-Eckhardt Schaefer 2010 *Nanoscience the science of the small in physics engineering chemistry biology and medicine* (Berlin: Springer)
- [4] Zheng Cui 2008 *Nanofabrication principles capabilities and limits* (US: Springer)
- [5] A Majumdar, P I Oden, J P Carrejo, L A Nagahara, J J Graham, et al 1992 *Appl Phys Lett* **61** 2293
- [6] Luis Guillermo Villanueva, Oscar Vazquez-Mena, Cristina Martin-Olmos, Veronica Savu, Katrin Sidler and Juergen Brugger 2013 *Micromachines* **4** 370
- [7] J A Dagataa, F Perez-Murano and G Abadal K Morimoto, T Inoue, J Itoh and H Yokoyama 2000 *Applied Physics Letter* **76-19** 2710
- [8] Bharat Bhushan 2010 *Scanning probe microscopy in nanoscience and nanotechnology* (Berlin: Springer)
- [9] Marta Tello, Fernando García and Ricardo García 2002 *Journal of Applied Physics* **92-9** 5539
- [10] P Avouris, T Hertel, R Martel 1997 *Appl Phys Lett* **71**, 285
- [11] Avouris, R Martel, T Hertel, R Sandstrom 1998 *Appl Phys A Materials Science & Processing* **66** S659