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*Short Communication*

# Contact Mode Atomic Force Microscopy Cantilever Tips for Silicon Nanowires Fabrication

**S. N. Yusoh* and K. A. Yaacob**

School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia.
E-mail Address: haniah86@yahoo.com*

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**ABSTRACT:** This paper focuses on fabrication of silicon nanowires pattern using different types of contact mode AFM cantilever tips (Au, Cr/Pt, Al). The patterns were fabricated at different applied voltages (5, 6, 7, 8, and 9 V) with constant writing speed (0.3 µm/s) under relative humidity (55-65%). The patterns undergo for wet chemical etching process by using tetramethylammonium hydroxide and hydrofluoric acid solution to remove unwanted silicon layer and oxide mask layer. From the result it was found that oxide pattern is thicker with increasing voltage. The Au AFM cantilever tip at 9 V with 0.3 µm/s writing speed gives the best formation of silicon oxide structure and has potential to be used to fabricate semiconductors devices.
**Keywords:** Atomic Force Microscopy; Local Anodic Oxidation; Cantilever Tips; Wet Chemical Etching

## 1. Introduction

There are two approaches namely top-down and bottom up have been used to classify the fabrication of nanostructures. The top-down approach applies various lithographical techniques to create nano scale patterns from a featureless bulk starting material, while the bottom-up approach use the interactions of molecules and colloidal particles to assemble more than one dimensional structure. The conventional techniques for nanofabrication of top down approach are based on various lithographical methods such as photolithography [1], electron beam lithography [2] and focused ion beam lithography [3]. The conventional techniques are not really attractive due to some limitations which are expensive in operating cost, multiple-step processes, and poor accessibility [4]. Then, other alternative technique was introduced which known as unconventional technique for nanoscale patterning and fabrication, such as nano-imprint lithography [5], soft lithography [6], and atomic force microscopy (AFM) nanolithography [7]. These methods have the potential to be future low-cost techniques for nanoscale patterning fabrication.

AFM nanolithography is one of useful technique to fabricate or characterize microarrays, nanoscale structure, sensors or devices [8]. It can be classified as force-assisted nanolithography and bias-assisted nanolithography. Force-assisted AFM nanolithography uses a large force that applied onto the tip for pattern fabrication. The forces are larger than force used for AFM imaging loaded onto tip, where the tip surface has a mechanical interaction with the substrate. There are some methods for this category which are mechanical indentation and plowing [3], thermo-mechanical writing [9], nanomanipulation [10] and dip-pen nanolithography [3]. Meanwhile, a biased conductive tip in the AFM, acts as a conductive electrode to provide stimuli and monitor surface changes. This characteristic extends the AFM's application to local anodic oxidation (LAO). LAO is an electrochemical process, in which AFM with a conducting tip where negatively biased with respect to a semiconductor or metal substrate to induce surface oxide features. LOA has been used to define structures, modify and develop nano-electronic devices fabrication process with low cost and simple technique [8]. Bernal and Bonilla [11] reported LAO has been demonstrated on sputtered titanium films as well as on silicon substrates. Fabrication on silicon substrate can be influenced by applied voltages, writing speed as well as relative humidity [12]. During LAO, a biased AFM tip is operating under an ambient humidity to locally oxidize the surface of a desired sample [13]. For few nanometers gap between the tip and the surface, AFM tip bias would generate a voltage field. The available water meniscuses, as a water bridge in the gap, are dissociated by this negative tip bias. The oxidation occurs due to reaction between silicon surface (anode), AFM tip (cathode) and water (electrolytes). The tip can be operated in all three modes which are contact, noncontact, and tapping. In present work we performed optimized fabrication result using contact mode tip to study the reproducibility of AFM-LAO base. Contact mode is the operation of tip contacts the surface through the adsorbed fluid layer. A tip is scanned across the sample while a feedback loop maintains a constant cantilever deflection.

## 2. Experimental Section

The silicon nanowires patterns were fabricated by means local-anodic-oxidation (LAO) approach using AFM nanolithography (SPI3800N/4000). The p-type silicon-on-insulator (SOI) wafer was used as a substrate. Before the fabrication process, the SOI wafer was cleaned followed RCA cleaning standard. Then the oxide pattern was performed using AFM nanolithography at temperature of

24–26 ºC with relative humidity of 55-65%. The pattern was designed by using special language (vector scan) supported by AFM software. The Au (Budgetsensors Au coated ContGB-G), chromium/platinum (Budgetsensors Cr/Pt coated ContE-G) and aluminum (Budgetsensors Al coated ContAl) coated tip were used at varied applied voltages (5, 6, 7, 8, and 9 V) with constant writing speed (0.3 µm/s). The formation of oxide pattern during LAO process will act as masking layer in TMAH etching process later.

## 3. Results and Discussion

**Figure 1** shows AFM image for oxide patterns using different types of contact mode coated tips (Au, Cr/Pt, Al) on SOI surface. The voltage applied were 5, 6, 7, 8 and 9 V with writing speed of 0.3 µm/s. The oxide patterns using Au and Cr/Pt coated tips are more uniform compare to Al coated tip. The formations of silicon nanowires are very much depending on the environment factor such as room temperature and humidity. Because of this reason the repeatability of the same size silicon nanowires are very difficult. **Figure 2** indicated the relation of oxide thickness and applied voltage graph. It shows that the oxide thickness increased due to increment of applied tip voltages for all contact mode tips (Au, Cr/Pt, Al). If the oxide thicknesses between those tips were compared, the Au tip gives thicker oxide layer. From this results show that type of AFM tip affected the oxide thickness due to the coating layer of the tip which enhances the laser reflectivity of cantilever. Au coated tip actually reflects

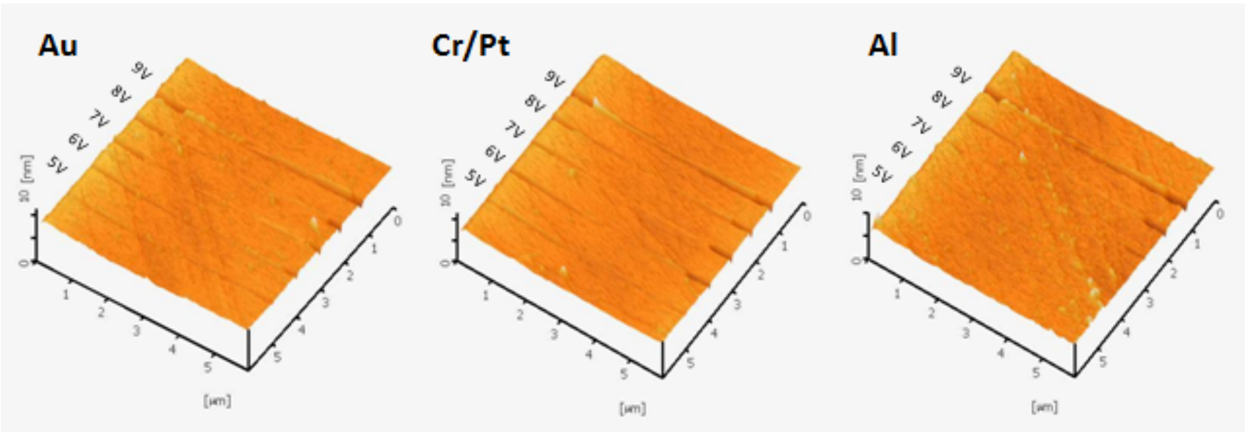


**Figure 1**: Silicon nanowires patterns using different types of tip (Au, Cr/Pt and Al) with different applied voltages (5, 6, 7V, 8, and 9 V) at 0.3 µm/s writing speed

higher voltage of laser reflectivity rather than Cr/Pt and Al tips. For Au tip laser reflectivity is between 7 V to 9 V, whereas the laser reflectivity for Cr/Pt and Al are between 3 V to 5 V. From the observation during experiment, these laser reflectivities also influence the LAO process. The higher value and stable laser reflectivity are needed to have a better formation of pattern. **Figure 3** shows the schematic of LAO process which localized electro-chemical reaction take place at water meniscus. Water meniscus only form when a voltage is applied. The $OH^-$ ions produced by the hydrolysis of meniscus water which is required for the electrochemical reaction. The $OH^-$ ions are driven through the oxide by the electrical field. At the $Si/SiO_2$ interface they react with holes h+. The oxidation reaction can be written as in equation (1):

$$Si + 4h^+ + 2OH^- \rightarrow SiO_2 + 2H^+ \quad (1)$$

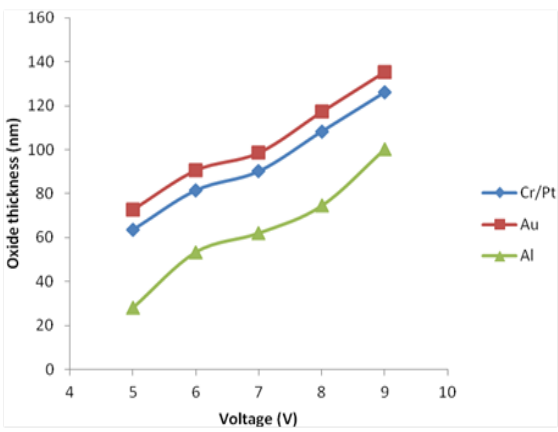


**Figure 2**: Relation of oxide thickness with different applied voltages for different types of AFM cantilever tips

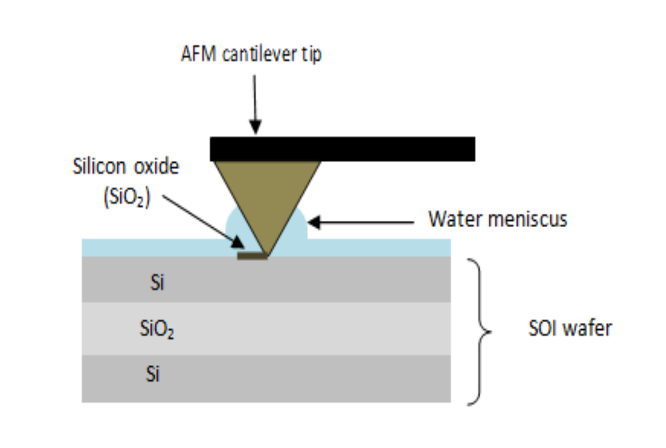


**Figure 3**: Concept of LAO process on silicon-on-insulator wafer

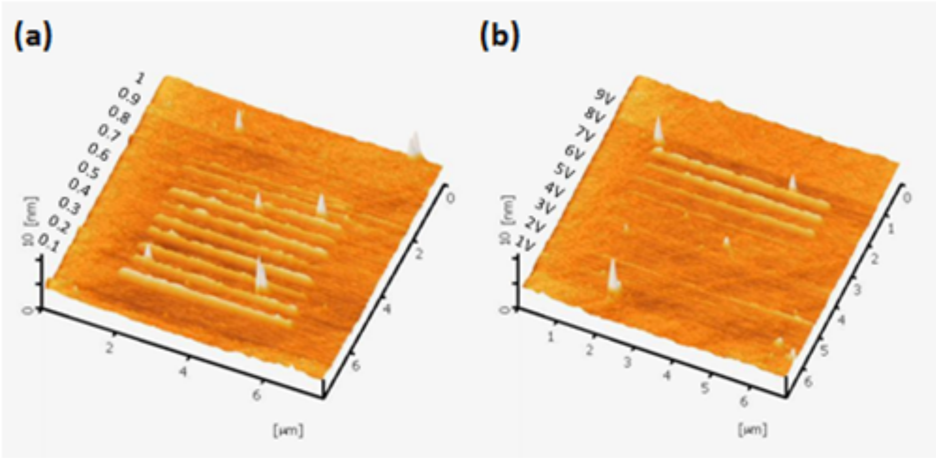


**Figure 4**: Silicon nanowires patterns at (a) different writing speed (1.0 μm/s, 0.9 μm/s, 0.8 μm/s, 0.7 μm/s, 0.6 μm/s, 0.5 μm/s, 0.4 μm/s, 0.3 μm/s, 0.2 μm/s, and 0.1 μm/s) (b) different applied voltages (9, 8, 7, 6, 5, 4, 3, 2, and 1 V) using Au tip

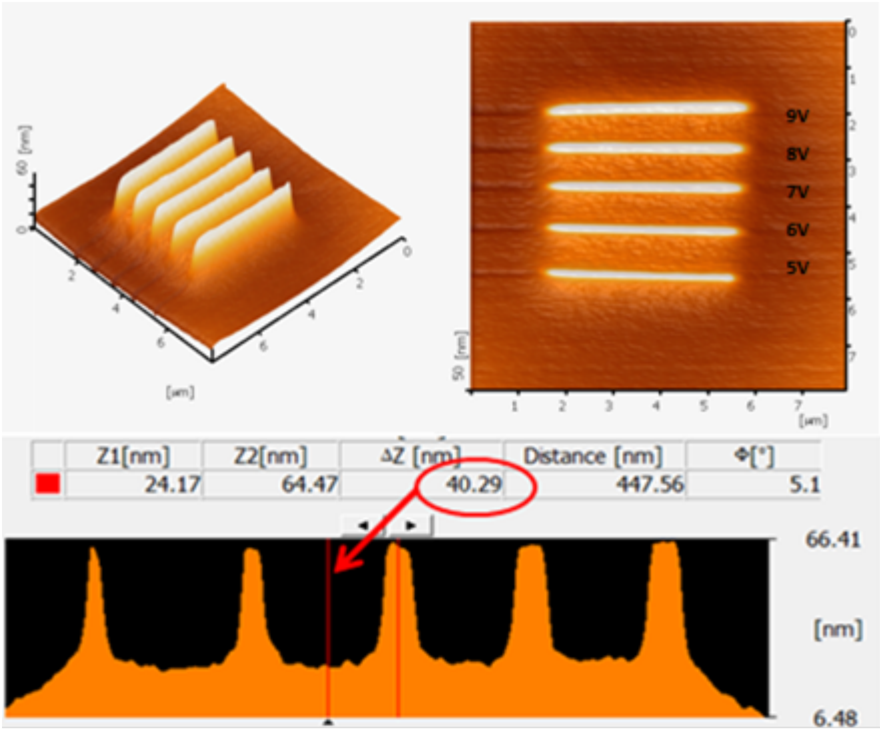


**Figure 5**: AFM profile image of silicon nanowires pattern using Au coated tip after etching process

The silicon oxide formed through the process act as etching mask. Meanwhile, the unoxidized silicon layer will be removed during etching process. AFM can fabricate silicon nanowires from the writing speed of 0.1 μm/s and above. **Figure 4(a)** shows the silicon nanowires pattern become unclear and unstable beyond 1.0 μm/s. The faster the writing speed applied, the thinner nanowires grown. Furthermore, AFM only can fabricate up to 9 V of applied voltage. The patterns become unclear at 5 V and below as shown in **Figure 4(b)** because there is less localized electrochemical reaction occurred due to applied voltage is low.

In this study, 25 wt % of tetramethylammonium hydroxide (TMAH) and hydrofluoric (HF) solution with deionized water (DIW) at ratio 1:50 were used. The SOI wafer with pattern was immersed in 25 wt % of TMAH for 30 seconds. TMAH was used in order to remove unoxidized silicon layer and HF was used to remove mask layer of oxide on top of SOI wafer. **Figure 5** displays AFM profile image of silicon nanowire pattern after etching process. The image is viewed at 7μm of image area. The unoxidized silicon around the oxide mask was successfully removed within 40.29 nm depth. The removal of unwanted silicon will demonstrated the silicon nanowires structure uniformly formed.

## 4. Conclusion

As a conclusion, AFM nanolithography was found to be successful to fabricate silicon nanowires on p-type SOI substrate by using optimized parameter. The best formation of silicon nanowires throughout this study were by using Au coated tip at 9 V applied voltage with 0.3 µm/s writing speed then followed by TMAH 25 wt % for 30 seconds and HF:DIW (1:50) etching. AFM is a promising and simple technique of silicon nanowires fabrication compare to other aforementioned techniques.

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