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Paper ID: 403

Fabrication of a Stepped Shape Tip using a Self-descending Phenomena of Meniscus

Chang-Sin Park, MI-Hyun Kang, Bo Young Choi ,Dong-Weon Lee
Chonnam National University

Abstract - We first introduce a novel fabrication method of a tungsten tip for STM applications. It uses a gradual meniscus descending phenomena caused by a Teflon structure with the hydrophobicity. The fabricated tungsten (W) tips with high aspect ratio have curvature radius of 20nm or even less. Field emission behaviors of the fabricated W tips are characterized in a high vacuum condition. Good reproducibility is experimentally demonstrated using the new system.

Paper ID: 418

Fabrication of Complicated Three Dimensional Structures Utilizing Multi-stack Bonding

Mingda Zhou, Yilong Hao, Chengchen Gao , Zhihong Li, Qifang Hu, Difeng Zhu
Peking University

Abstract - Hybrid multi-wafer bonding which combines both anodic bonding and silicon direct bonding together is one of the most promising manufacturing techniques for creating complex three-dimensional (3D) structures. However, some key microfabrication technique will directly influence the performance of 3D multilayered devices. These problems include: (1) electrical conduction property across the interface of hydrophilic direct bonded wafers; (2) the fabrication of silicon bridge. Some key techniques are developed to solve these problems. These solutions are also applicable to fabricate other Microelectromechanical System devices with complex 3D structures.

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Fabrication of a Stepped Shape Tip using a Self-descending Phenomena of Meniscus

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Abstract **— We introduce a novel fabrication method of a tungsten tip for STM applications. It uses a gradual meniscus descending phenomena caused by the thanks of a Teflon structure with the hydrophobicity. The fabricated tungsten tips with high aspect ratio have curvature radius of 20nm or even less. Good reproducibility is experimentally demonstrated by the use of the new etching system. Finally, field emission behaviors of the fabricated tungsten tips are characterized in a high vacuum condition.**

Keywords ***— Scanning tunneling microscope, Tungsten tip, Meniscus, Teflon, Hydrophobicity,***

I. Introduction

The unique sensitivity of STM stems from exponential dependence of the measured tunneling current on tip-sample separation. The sharpness of conductive tips is the most important factor which affects the resolution of the STM image. The mechanism and fabrication methods of a tungsten (W) tip etching have been extensively studied. Among the common methods used to produce high-quality tips, an electrochemical etching method is a fast and the most convenient way to obtain reliable tips for mass production. Various parameters such as wire diameter [1-2], electrolyte concentration and composition [3-4], voltage [5], hydrogen bubbles [3-7], immersion depth of the tungsten wire, and cut-off time of the electrical circuit [5-9] have been evaluated by many research groups [1-13]. All methods mentioned above are only focused to minimize the curvature radii of the tip. However, many STM researchers has another strong interest to produce a novel tips with a high aspect ratio, as well as high spring constant to minimize flexural vibrations [14-15]. In this article, we proposed a novel electrolytical etching system with the aim of fabricating a stepped sharp tip with a high aspect ratio, as well as higher spring constant. Self-descending phenomena of meniscus during electrolytical etching of metal wires in a Teflon bath is firstly observed. Reliable fabrication of the stepped tip has successfully demonstrated using the proposed method.

II. Fabrication of a Novel W-tip

Figure 1 was shown a schematic diagram of Teflon bath and the electrolytical etching system employed for the fabrication of sharp tungsten tips. It consisted of a DC power supply, a LabView system, two micromanipulators and a Teflon bath. We employed the Teflon bath instead of conventional glass baths because a unique phenomenon during the tip etching process is observed due to hydrophobic property of the Teflon bath. After tungsten wire preparation based on a conventional cleaning process, the wire was etched in 2M KOH solution. Bias voltage applied between two electrodes was about 5 V_{dc}.

The etching bath for the tungsten tip fabrication was formed from a Teflon block, shown in Fig. 2 (a). The dimension of the bath is 30 × 30 × 10 mm^3. A channel defined in the bath was 5 mm in a width and 10 mm in a length, respectively. It was fabricated by the use of a table milling machine. The tungsten wire with a diameter of 0.5 mm (99.98%, Nilaco Co.) is dipped into the etching solution and 8 mm from the bottom of the tungsten wire was only sunk in the solution. Both W wires of the tip and the electrode were fixed to a micro XYZ manipulator. Hence the position of the wires was exactly controlled in micrometer scale. The tungsten wire to be etched adjusted to a center after filling of the etchant in the Teflon bath. Meniscus arises due to the hydrophobic property of Teflon was generated as shown in Fig. 2 (b). Electrochemical etching of the tungsten wire was mainly occurred at the interface between air and electrolyte. Unbalance of acting force caused by the different distance from the wall to the tip was induced self-descending phenomena of the meniscus.

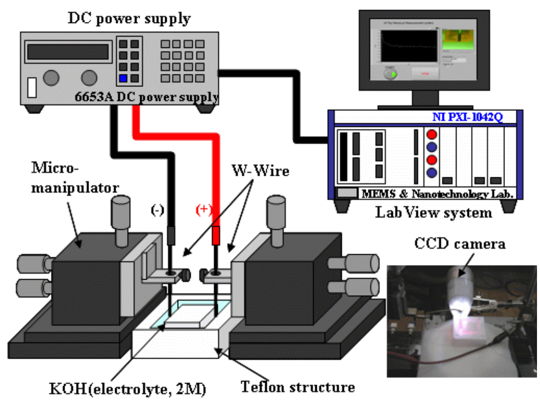

Figure 1. Schematic diagram of electrolytical etching system for stepped sharp tip fabrication.

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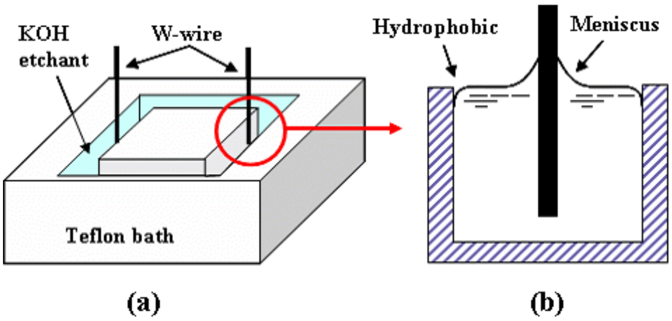


Figure 2. Schematic diagram of a Teflon bath (a) and air/electrolyte interface

The electrolytical etching process for the fabrication of stepped tungsten-tips was shown in Fig. 3. As the tungsten wire was etched in the Teflon bath, an initial height of meniscus was gradually descended and the change of meniscus shape was continuously captured using a CCD camera. Details of electrolytical etching were explained below. First, when the etching solution filled in the Teflon structure, the contact angle of the meniscus on the surface of the tungsten wire surface was increased by the hydrophobicity of Teflon (Figure 3-a). Due to thanks of the hydrophobicity (Figure 3-b, -c and -d), the height of meniscus was gradually descended and a part of the tungsten wire dipped in etchant became very thin. Finally, it was dropped into the etchant with the break of the meniscus (Figure 3-e). At the same time, the applied voltage was immediately stopped without any help of electrical circuits to reduce cut-off time. The change in current according to bias voltage was also obtained by the use of the LabView system. These results were plotted in Fig. 4. We also clearly confirmed that a sudden drop of the current level was only observed at a moment of reformation of the meniscus. Figure 5 was shown SEM images of the stepped sharp tip fabricated by the use of our proposed etching system. The fabricated W tip had a curvature radius less than 20nm. Good reproducibility was also successfully demonstrated by the use of the proposed etching system.

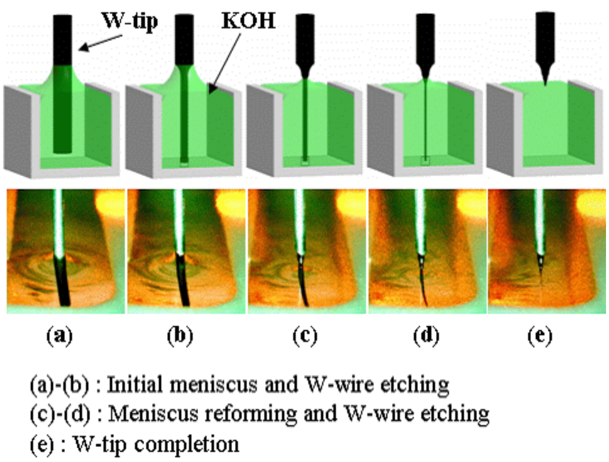


Figure 3. Conceptional views and optical images of self-descending phenomena of meniscus during electrolytical etching of a W-tip.

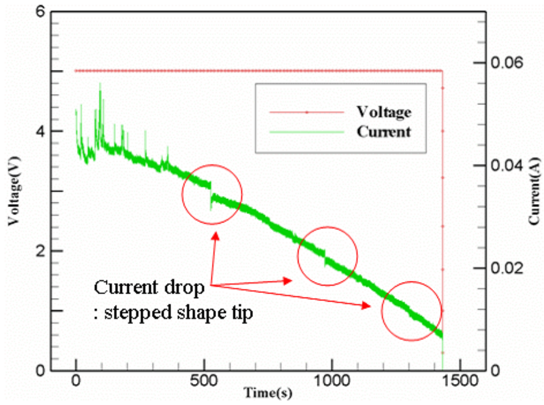
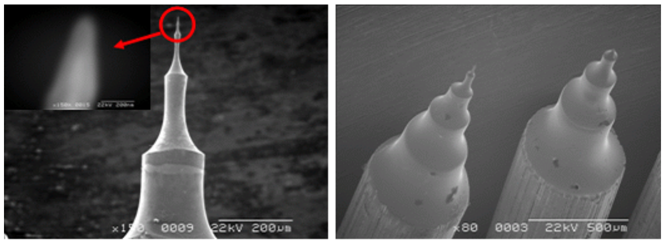


Figure 4. Current vs. voltage characteristics as a function of etching time.



(a) (b)

Figure 5. Scanning electron microscope images of fabricated tungsetn tips with a high aspect ratio.

III. RESULTS AND DISCUSSION

The piezo-scanner with the sharp tip is one of important elements in the STM configuration. Basically the scanner is the device that moves the tunneling tip across the sample surface, and it provides motion for the gap spacing control. The requirements of a good scanner are as follows; (1) good resolution – the necessary resolution is about 0.1 nm for *x* and *y* scanning directions and 0.01 nm for the vertical direction, (2) orthogonality – each of the three axes should not affect the positions of the others, (3) linearity – the amount of movement should be proportional to the variation of applied voltage, (4) mechanical rigidity – if the scanner or tip is rigid, it has a high mechanical resonance frequency so that we can increase the speed of scanning and feedback response, and (5) large range – it is desirable to cover as large a sample area as possible. At the number of (4) and (5), especially, for the good efficiency, the scanner requires a high resonance frequency of the tungsten tip, as well as a high spring constant to minimize flexural vibrations. Due to these reasons, lower aspect ratio for the tungsten tip is desired in the STM applications. However, the proposed etching system can provides a high resonance frequency and a high spring constant even though the fabricated tungsten tip has a high aspect ratio. Figure 6 was shown the results of FEM simulation to understand resonance behavior of the fabricated tungsten tip. Material properties of the tungsten for the simulation were as follows; Young's modulus of 410 GPa, Poisson's ratio of 0.25 and density of 1930 kg/m^3, respectively. All scales for the tip design were based on the SEM images. This result indicated that our tungsten tip was better than conventional one with a low aspect ratio for various applications.

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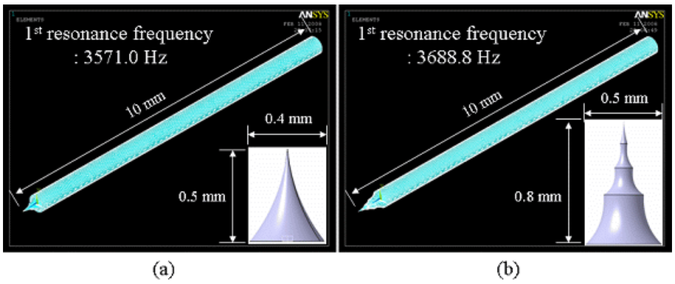

Figure 6. Simulation results of the normal and stepped W-tip. The tip shape is modeled based on the fabricated tip.

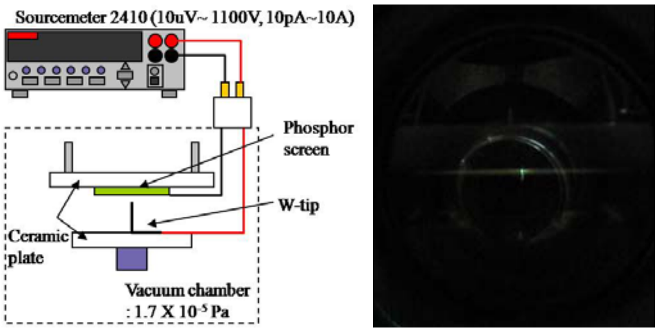

Figure 7. (a) Experimental setup for the field emission test with the fabricated tungsten tip and (b) An optical image of light emitted from the tip.

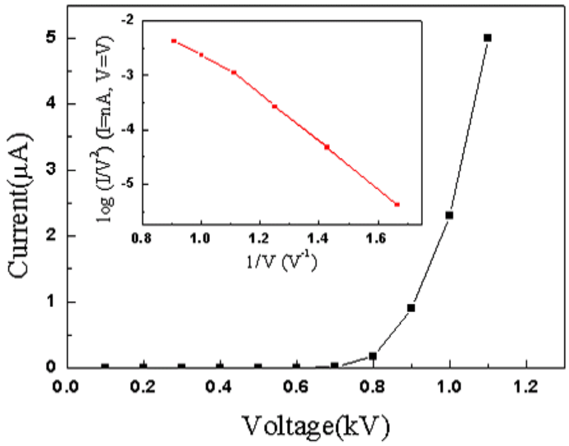

Figure 8. The field emission current–voltage (I–V) characteristic with the inset showing the corresponding Fowler–Nordheim (F–N) plots.

The sharpness of tungsten tip is one of the most critical parts in the STM because it directly determines the resolution of the microscope. It is mandatory to have a very sharp tip for a true atomic resolution. A field emission method is another method to get some information of the fabricated tip. The field emission is the process by which a flow of electrons can be emitted from a sharp object by building a high voltage potential across a tiny gap. Some atoms get dislodged by the emission current. This process can be also used to re-shape a blunt tip [16].

Experimental setup to measure the field emission behavior of our fabricated tungsten tip was shown in Fig. 7 (a). This measurement system also enabled us to investigate the I-V characteristics of the tungsten tip. The fabricated tungsten tip was mounted on a metallic sample holder, and then introduced in a vacuum chamber, with a base pressure ranging from 1.5×10^{-5} Pa. The vacuum system was evacuated by a turbo molecular pump (TMP) with a 420 l/s pumping speed; assisted by a rotary pump that is used to reduce the exhaust pressure, enabling the TMP to start up. The distance between the cathode (tip) and the anode (fluorescent screen) is about 1.0 mm. Field emission measurements were carried out with a ceramic structure including the fabricated tungsten tip, which controlled the emission of electrons from the cathode. This configuration allows obtaining lower threshold voltages for electron emission, due to the proximity of the controlling tungsten tip to the cathode. The anode provides high energy to the electrons accelerated onto the fluorescent screen, controlling the intensity of the emitted light. In this measurement system, the cathode was grounded to 0 V, and the tungsten tip electrode was biased to a positive voltage in the range from 0 to 1.2 kV to apply a strong enough electric field for modulating the extraction of electrons from the tungsten tip. Extracted electrons, that flow through the tungsten tip, striking the phosphor screen, can be observed from a side view port of the vacuum chamber, by means of the generated field-emission-microscopy images. The result was shown in Fig. 7 (b). The electrical current emitted from the cathode was measured using a source meter (Keithley 2410). The measurement system contained protective resistors and a Zener diode to prevent a high current flow due to unexpected phenomena. The emission current-time characteristics were recorded at the current level by means of a computer controlled acquisition system, using Labview software and is plotted as a function of applied voltage. These results were shown in Fig. 7. The inset was also shown a Fowler-Nordheim plot of the I-V curves. The turn-on voltage of the fabricated tungsten tip for field emission was observed about 0.6 kV_{DC}.

IV. CONCLUSIONS

In summary, we have found a simple and reliable fabrication method of a tungsten tip that has a high aspect ratio as well as higher resonance frequency in comparing with conventional tungsten tips. The proposed method employed a gradual meniscus descending phenomena caused by the thanks of a Teflon structure with the hydrophobicity. In addition, the etching system doesn't require an external circuit to control cutoff time. The fabricated tungsten tips with a high aspect ratio have curvature radius of 20 nm or even less. Good reproducibility is experimentally demonstrated by the use of the new wet etching system. Finally, field emission behaviors of the fabricated tungsten tips were characterized in a high vacuum condition.

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