High-Aspect-Ratio Nanofabrication Using Carbon Nanotube Probe in Scanning Tunneling Microscope

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Abstract

We have developed a fabrication method for a high-aspect-ratio nanometer-scale pit using a carbon nanotube (CNT) as a scanning tunneling microscope (STM) probe. CNT probes used in this study were manufactured by the pulling method that we developed originally. Nanometer-scale pits were fabricated on Au thin films in an ambient pressure and room temperature. The results of our experiment show that the depth and diameter of the fabricated pit increased with the bias voltage and tunnel current, respectively. The depth of the fabricated pit increased with the fabrication time, but its diameter showed a slight change. Therefore, we realized that the fabricated pit achieves a diameter of 60 nm and an aspect ratio of 4.5 for a fabrication time of 90 s. Moreover, it was found that this fabrication method is not only applicable to Au thin films but also low-resistivity single crystal silicon and HOPG. These demonstrate that STM fabrication by using a CNT probe can be useful in fabricating high-aspect-ratio structures from a single nanometer-scale to several tens of nanometers by controlling the diameter of the CNT.

1 Introduction

The fabrication of high-aspect-ratio nanoelectromechanical systems and nanodevices is becoming increasingly important as microelectromechanical systems shrink to nanoscale dimensions. The nanofabrication technique that employs a scanning tunneling microscope has been demonstrated by several researchers for a wide range of sizes: from atom manipulation [1] to several tens of nanometers [2]. However, the fabrication of high-aspect-ratio nanostructures is not yet realized. This is because the fabrication configuration depends on the probe configuration. A probe that has both nanometric dimensions and a high aspect ratio is required. We focus on a carbon nanotube (CNT). In this study, we established a fabrication method for high-aspect-ratio nanoscale pits using CNT probes. We clarified the relationship between the fabrication conditions and configuration of the fabricated pits.

2 Experemental

The CNT probes used in this study were manufactured by a pull method. The pull method utilizes the viscosity and surface tension of a solvent and electrophoresis of a CNT. Figure 1 (a) is a schematic diagram of the pull method. Using a bias voltage, the CNT can be attached to the apex of the tungsten probe by a pull-up process from the CNT dispersion liquid. Isopropyl alcohol was the solvent used in this study. The attached CNT was similar to the closed CNTs (BU-200, Bucky USA) with diameters of 10–40 nm. Figure 1 (b) is the scanning electron microscope (SEM) image of the CNT probe manufactured with a CNT concentration of 0.05 mg/mL, probe bias of –14 V, and pull-up speed of 14 μm/s. Nanoscale pits were fabricated on a Au thin film, low-resistivity Si(100), and highly oriented pyrolytic graphite (HOPG). The Au thin film was prepared on a mica substrate by magnetron sputtering. The fabrication and surface observation by the STM were carried out using a constant current mode under ambient pressure and room temperature. The fabrication was carried out by applying a positive bias to the substrates.

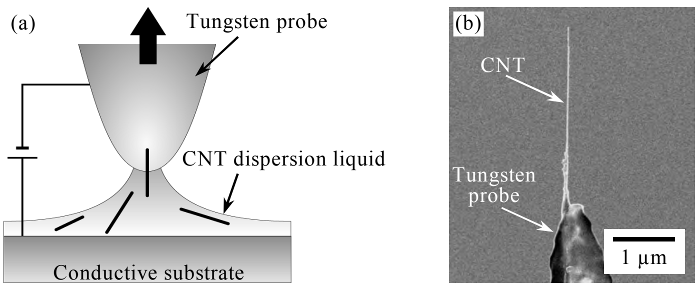

Figure 1: (a) Schematic diagram of the pull method, and (b) SEM image of a manufactured CNT probe

3 Results and Discussion

The pit configuration obtained due to the STM changes with the bias voltage, tunnel current, and fabrication time. The relationship between the fabrication conditions and pit configuration was investigated by using a Au thin film. First, the bias voltage was varied in the range of 1–5 V with a tunnel current of 2 nA and fabrication time of 60 s. The depth and diameter of the fabricated pit increased with the bias voltage. For the pit fabrication, a threshold value exists between 1 V and 2 V. A bias voltage of 3 V was the optimum condition. Next, the tunnel current was varied in the range of 1–8 nA at a bias voltage of 3 V and fabrication time of 60 s. In the case of the change in the pit configuration with the bias voltage, the depth and diameter of the fabricated pit increased with the tunnel current. A tunnel current of 4 nA was the optimum condition. Finally, the fabrication time was varied in the range of 10–90 s under the optimum conditions. Figures 2 (a) and (b) are the STM images and cross-sectional diagrams of the fabricated pit at fabrication times of 10 s and 90 s, respectively. The depth of the fabricated pit increased with the fabrication time, with a slight change in the diameter of the fabricated pit. This can be attributed to the one-dimensional configuration of the CNT. For a fabrication time of 90 s, the diameter and depth of the pit were 63 nm and 286 nm, respectively. Figure 3 shows the comparison of the CNT and tungsten probes with regard to the aspect ratios of the fabricated pit at a bias voltage of 3 V, tunnel current of 4 nA, and fabrication time of 90 s. The aspect ratios of the fabricated pit using the CNT and tungsten probes were 4.5 and 0.1, respectively. In other words, the aspect ratio achieved using the CNT probe increases 45 times.

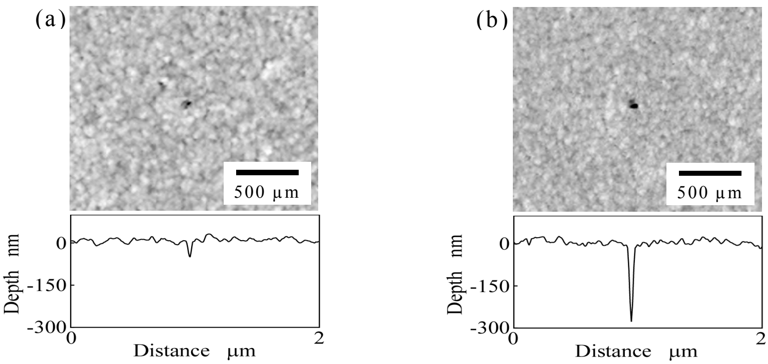

Figure 2: STM images and cross-sectional diagrams of the pit fabricated at a bias voltage of 3 V and tunnel current of 4 nA at fabrication times of (a) 10 s and (b) 90 s

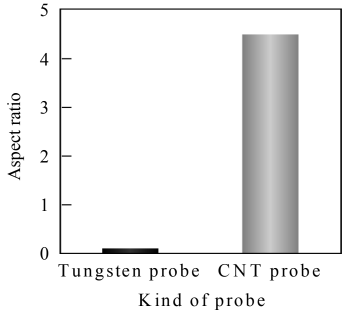

Figure 3: Comparison of the aspect ratios of a pit using a CNT probe and tungsten probe

Nanoscale pits were fabricated on low-resistivity Si(100) and HOPG taking into consideration the practical application of this fabrication method. The tendency for a change in the depth and diameter of the fabricated pit with an increase in the bias voltage, tunnel current and fabrication time was the same as that exhibited by the Au thin film. From the result, it was found that this fabrication method is applicable to not only Au thin films but also low-resistivity Si(100) and HOPG.

This study demonstrates the fabrication of a high-aspect-ratio nanoscale pit using a CNT probe in a STM. Moreover, STM fabrication using a CNT probe can be useful for fabricating high-aspect-ratio structures.

4 Conclusions

This study characterized the relationship of the pit configurations between the bias voltage, tunnel current, and fabrication time. A bias voltage of 3 V and tunnel current of 4 nA were found to be the optimum conditions for the fabrication of the high-aspect-ratio nanoscale pit in the Au thin film. For a fabrication time of 90 s, the diameter, depth, and aspect ratio of the pit were 63 nm, 286 nm, and 4.5, respectively. The aspect ratio of the nanoscale pit fabricated using the CNT probe was increased to 45 times that of the usual tungsten probe. This fabrication method is applicable to not only Au thin films but also low-resistivity Si(100) and HOPG..

References:

[1] D. M. Eigler and E. K. Schweizer: Nature. 344, 524–526 (1990).

[2] H. L. Zhanga, et.al.: Microelectronic Engineering 63, 381–389 (2002).