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Arbitrary Cutting of a single CNT tip in Nanogripper using Electrochemical Etching

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ABSTRACT

Recently, many research results have been reported about nano-tip using carbon nanotube because of its better sensing ability compared to a conventional silicon tip. However, it is very difficult to identify the carbon nanotube having proper length for nano-tip and to attach it on a conventional tip. In this paper, a new method is proposed to make a nano-tip and to control its length. The electrochemical etching method was used to control the length by cutting the carbon nanotube of arbitrary length and it was possible to monitor the process through current measurement. The etched volume of carbon nanotube was determined by the amount of applied charge. The carbon nanotube was successfully cut and could be used in the nanogripper.

Key Words : CNT tip, Carbon Nanotube, Nanogripper, Electrochemical Etching

1. Introduction

Since the discovery of carbon nanotube in 1991[1], many research results have been reported in various fields because of its superior mechanical and electrical properties. Especially, researches on nano-tips have been abundant due to its excellent rigidity. After the nano-tip was developed by Dai in 1996[2], a carbon nanotube was attached on a conventional silicon tip and the lateral measurement resolution of AFM was improved. In 1999, Kim developed the nanotweezer by attaching two carbon nanotubes on a tapered glass pipette under an optical microscope and showed that the nanotweezer can be used to grip nanoclusters[3]. Another nanotweezer was made in the SEM environment by Akita in 2001[4].

Since a nano-tip using a carbon nanotube has an excellent lateral resolution compared with a conventional silicon tip, it was reported that the performance of AFM with nano-tip was superior to the conventional AFM Tip[2]. However, due to the variation in length of carbon nanotube, it is very tedious to find out carbon nanotube having proper length and to attach the carbon nanotube on the substrate.

To control the length of carbon nanotube in nano-tip, the difficulties caused by the size effect and the binding force among carbon atoms in carbon nanotube must be solved. In 1997, Venema showed a new method of carbon nanotube length control by applying a voltage pulse on the carbon nanotube to cut the carbon nanotube[5]. In 1998, Wong found another control method using a bias voltage between nano-tip and counter electrode[6], but it was impossible to control the length freely because the carbon nanotube was cut at the position with maximum resistance. A nano-mechanical method with diamond particle which was basically different from nano-tip cutting was proposed by Stepanek[7]. However, the separation of carbon nanotube from the diamond particle was very difficult after processing. Finally, the electrochemical etching method was applied to cut the carbon nanotube in nano-tip by Ito[8]. This method took a long time in cutting and resulted in very poor cutting resolution.

In this paper, a new carbon nanotube length control

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method was developed by using electrochemical etching with current measurement and the cut volume was estimated based on the applied charge. It was shown that the developed method provides successful carbon nanotube length control.

2. Manufacturing Tungsten Tip and Nano-tip

First of all, a tungsten tip was made with electrochemical etching method for fabricating a nano-tip. The initial diameter of the tungsten rod was 500 μm and its final diameter was a few micrometers. The radius of apex of the manufactured tungsten tip varied from tens of nanometers to hundreds of nanometers. Fig. 1 shows the electrochemical etching system and the immersing depth of the tungsten rod in the 5 mole of KOH (potassium hydroxide) electrolyte was controlled by a step motor and an optical stage. The shape and final diameter of the tungsten tip could be determined by the immersing depth and applied current. The images of manufactured tungsten tip were obtained by Nikon optical microscope at a magnification of 2,000 times.

The carbon nanotube used in this research was grown by the chemical vapor deposition method. Since the average diameter of carbon nanotube was about 100 nm, the overall process could be done under the optical microscope. Prior to making the nano-tip, the carbon nanotubes were ultra-sonicated for about 2 hours with isopropyl alcohol (IPA). Through this process, some of carbon nanotubes were untangled and those untangled ones were used to make the nano-tips.

The attachment of carbon nanotube on the tungsten tip was done by the mechanical assembly process with two tungsten tips. First, ultra-sonicated carbon nanotube solution was poured on a slide glass and the carbon nanotube remained on the slide glass after the evaporation of IPA. Then, some of the carbon nanotubes on the slide glass were adhered on the first tungsten tip by scratching. A carbon tape was pasted on the second tungsten tip. Finally, two tungsten tips were approached under the optical microscope and the proper carbon nanotube on the first tungsten tip was attached to the end of the second tungsten tip using the adhesive force of carbon tape on the second tungsten tip. The fabricated nano-tip is shown in Fig. 2. The left image was obtained by an optical microscope and the right image was obtained by a SEM.

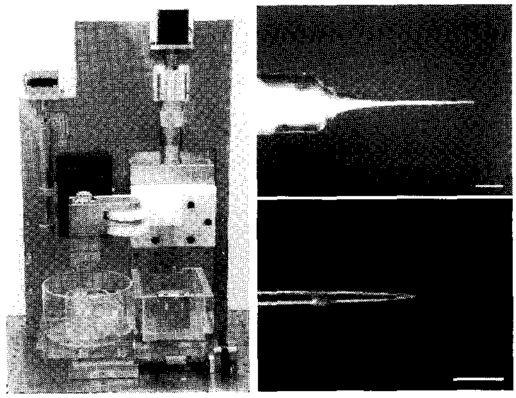

Fig. 1 Electrochemical etching system and manufactured tungsten tip (scale bars: 200 μm (upper), 10 μm (lower))

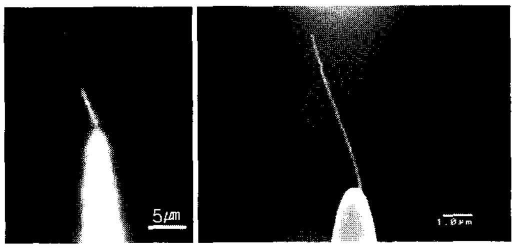

Fig. 2 Manufactured nano-tip images obtained by optical microscope and SEM

3. Length Control with Electrochemical Etching

The electrochemical etching method was used to control the length of carbon nanotube of a nano-tip. Fig. 3 shows the schematic of the electrochemical etching system. The electrolyte was placed on the slide glass and the manufactured nano-tip was placed on the nano-stage driven by a piezo actuator. The nano-tip was immersed in the electrolyte while monitoring with an optical microscope and a digital multimeter checked the current during the process. The P-282.30 PI nano-positioner was used as the nano-stage and KOH was used as the electrolyte. The digital multimeter used for current measurement was 3458A model from Agilent technology and the applied voltage was 20 volts.

The results of experiment are shown in Fig. 4. The first two images obtained by SEM are the nano-tips before and after processing and the lower one is the current profile. As shown in Fig. 4, the processing time was about 0.7 second and the cut length of carbon nanotube was about 2 μm . The etched volume of the nano-tip was about 0.016 μm^3 because the average diameter of carbon nanotube was about 100 nm . The magnitude of applied charge was about 5.8 nA sec . In Fig. 4, the carbon nanotube was cut at the arrow position. Even through the cutting accuracy is determined by the nano-stage, this system had about several hundreds of nanometer resolution because of the limitation of optical microscope.

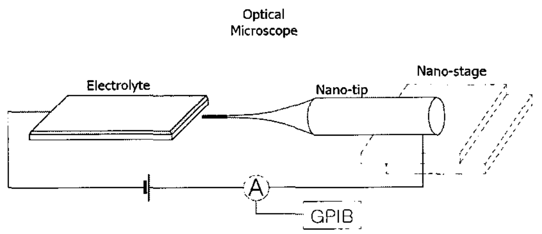

Fig. 3 Schematic of cutting system

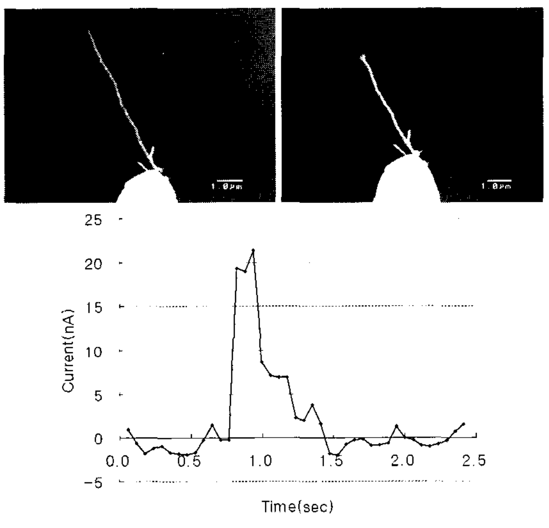

Fig. 4 SEM images of nano-tip of before and after processing and current profile during the cutting process

The next experiment was to find out the relationship between the etched volume and the magnitude of applied charge. Consecutive cutting was obtained on the same nano-tip and the SEM images were captured. The SEM images are shown in Fig. 5 and the arrows indicate the cut points in each etching process. Since the impurity circled in Fig. 5(a) is not a part of the carbon nanotube, the cutting process is not affected by that material. As shown in Fig. 5, the etched volume was proportional to the magnitude of applied charge and the cut length also could be calculated based on the charge.

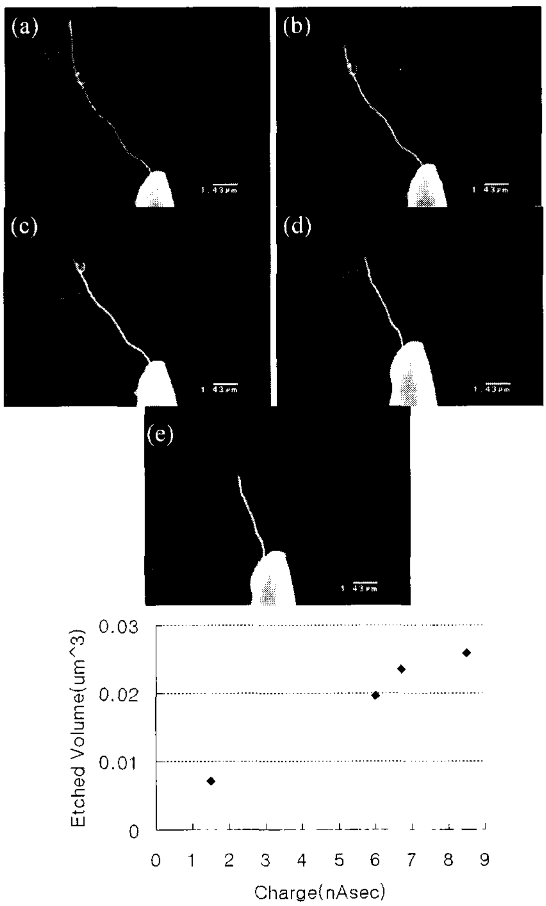

Fig. 5 Consecutive SEM images of nano-tip in cutting process and the relationship of the amount of applied charge and etched volume

To increase the reliability of the relationship between the applied charge and etched volume, more experiments about the etching process of the single CNT tips were performed and the values displayed in Fig. 6 were obtained. As shown in Fig. 6, the slope was about 0.003 $\mu m^3 / nA$sec and the value was similar to that shown in Fig. 5. From these results, we concluded that the etch rate of the CNT used in this paper was about 0.003 $\mu m^3 / nA\sec$.

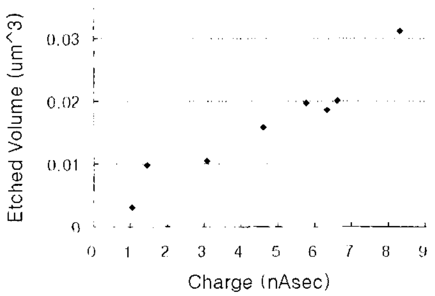

Fig. 6 Relationship between the magnitude of applied charge and etched volume of several single CNT tip

4. Conclusion

In this paper, we proposed a method to make a nano-tip and to cut the carbon nanotube of the nano-tip by electrochemical etching method. According to the experimental results, the etched volume was proportional to the magnitude of applied charge and the length of nano-tip could be calculated by this relationship. This method was beneficial to control the length of nano-tip because of the short processing time due to the high applied voltage. Currently, we are constructing a nano-gripper using the manufactured nano-tip that has a proper length condition.

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