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Carbon Nanotube SPM Probe Fabricated by NanoEngineering

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2-1, Yamadaoka, Suita, Osaka 565-0871, Japan**1. Introduction**

The tip shape of the probe is crucial for obtaining a high-resolution image for scanning probe microscope (SPM) measurement. In recent years, carbon nanotubes have been widely used as the probe tips of SPMs¹⁻³, because the nanotubes have a high aspect ratio and sharp tip. Nanotweezers^{4,6} with the nanotube arms are also used for processing and manipulating in nanometer-scale regions. The control of the tip shape is important for these nanotube nano-tools, because the tip radius limits not only the resolution of the SPM but also the minimum size for manipulation. Furthermore, engineering of the nanotubes is also useful for fabricating the nanomachines and the nanoelectronic devices.

Recently, we have developed a series of processes for preparing the carbon-nanotube probes and the nanotweezers. The main developments are a nanotube cartridge⁷ where nanotubes are aligned at a knife-edge to be easily picked up one by one and a scanning-electron-microscope (SEM) manipulator, so called nanofactory,⁸ by which a nanotube is transferred from the nanotube cartridge onto a substrate under observing its view. The recent additional developments are the electron ablation of nanotube to adjust its length⁹ and the orthopedic treatment of multiwalled nanotube to extract its inner layer with or without an end cap.^{10,11}

In this study, we demonstrate the series of processes for preparing the carbon nanotube devices using the nanofactory.

2. Manipulation of nanotubes

Multiwalled nanotubes were synthesized by an arc discharge method. The temperature in the arc was enhanced by cooling the gas surrounding the arc using a water coil, resulting in a narrow distribution of diameters of nanotubes and a high purity of nanotubes against the nanoparticles.¹² Nanotubes thus prepared had multiple walls, 1 to 5 μm long and an average diameter of 10 nm. The nanotubes were aligned on the knife edge using an alternating current (ac) electrophoresis method, where the edge was coated by Pt in order to improve the electric conduction.

The attachment of the nanotubes was carried out in the nanofactory. For making a conductive probe, the current passing through the nanotube was monitored at the bias voltage of ~ 2 mV during the attachment process. It should be noted that it was difficult to measure the current just after the contact because of the high contact resistance. The current flow could be measured after the irradiation of the

electron beam for 3 ~ 60 s at the contacted portion of the nanotube and the electrode. The electron beam irradiation might induce the elimination of the adsorbed layer on the nanotube surface or an increase of the contacted area due to the amorphous carbon layer deposited on the nanotube.

3. Nanoprocessing of nanotubes*Electron ablation of nanotubes*

A method for the processing of an individual nanotube, which is based on the thermally assisted field evaporation process, has been performed using the nanofactory. One nanotube is placed opposite another at a distance of about one micrometer and voltage is applied between them as schematically shown in Fig. 1(a). As the voltage is increased, one of the nanotubes is locally heated by electron bombardment at the tip and is shortened by thermally assisted field evaporation, where another nanotube is used as an electron emission source. A nanotube for an atomic force microscope probe has successfully been processed on a scale of ~ 100 nm as shown in Fig. 1(b).

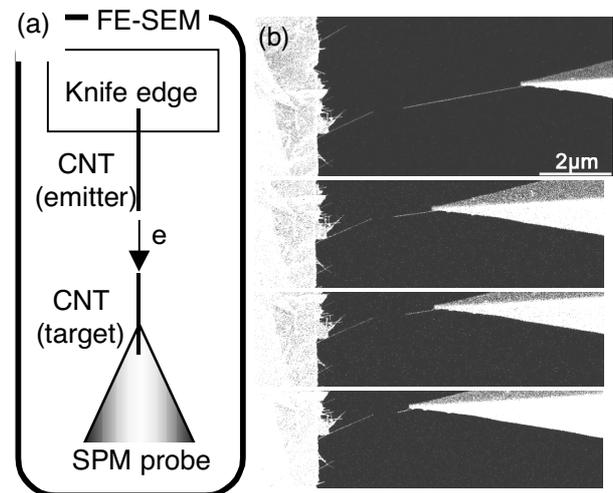


Fig. 1 (a) Schematic diagram of the electron ablation process of CNT and (b) a series of SEM images of the process.

Sharpening of nanotubes tip

We have also developed a process of length adjusting and tip sharpening of multiwalled carbon nanotube (MWNT) using electrical breakdown process. We applied

voltage carefully to the nanotube in order to break nanotube layers electrically. As the voltage is increased, the electrical breakdown is started with stepwise decrease of current as shown in Fig. 2(a). The length of the MWNT was almost half of the gap between the knife-edge and Si tip and both end of cut nanotubes were sharpened. Figure 2(b) shows a TEM image of the nanotube tip. Thus the length of MWNT was adjustable by changing the gap of two electrodes. We have applied the sharpened nanotube tip to the atomic force microscopy (AFM) measurements. The sharpened nanotube tip has effectively acted as a probe with high resolution imaging.

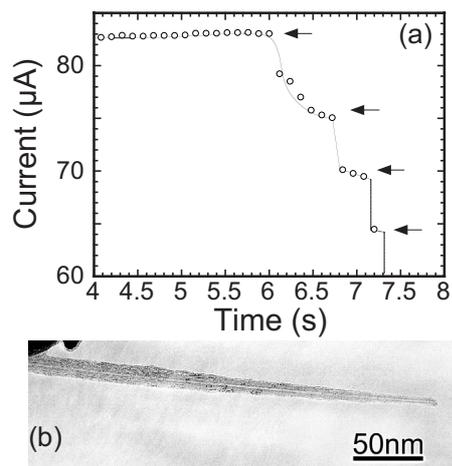


Fig. 2 Electrical breakdown process. (a) the temporal variation of the current, (b) TEM image of sharpened nanotube tip.

Extraction of inner layer of nanotubes

We demonstrate the extraction of the inner shell of the multiwall nanotube using a combination of the well-controlled electrical breakdown and the manipulation processes in the nanofactory as schematically shown in Fig 3(a). Figure 3(b) shows a TEM image of the extracted nanotube. The nanotube has a nanotube as thin as ~3 nm in diameter as a tip. Its length is ~80 nm. As shown in this figure, the very tip of the extracted portion has a rounded structure and can be observed as a capped structure. The measured sliding force for the extraction of the inner shell is consistent with the theoretical prediction based on the van der Waals interaction between the inner and the outer shells of the nanotube. Hence, the proposed process realizes the ideal sliding of the interlayer of the nanotube.

4. Conclusions

We have developed a series of processes for processing a single nanotube using the nanofactory. These are promising methods to provide optimized carbon nanotube probes and tweezers that operate in a SPM.

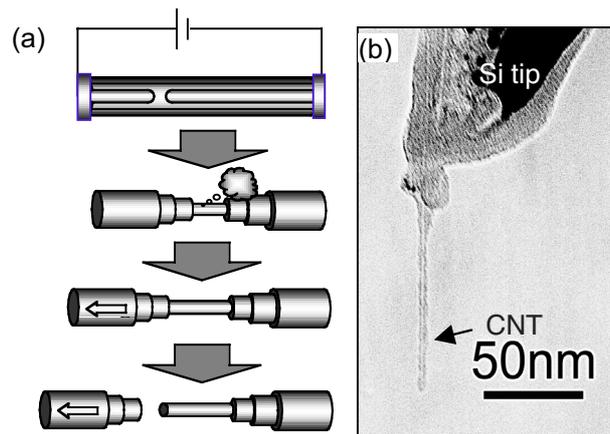


Fig. 3 Extraction process. (a) schematic procedure of the extraction of the inner layer of CNT, (b) TEM image of extracted nanotube tip.

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