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Three-Dimensional Evaluation of A Multi-Walled Carbon Nanotube Probe by Using High-Resolution Transmission Electron Microscope

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Carbon nanotubes have been studied for various engineering applications by many researchers, and are considered to be the next frontier of nanotechnology. One such application may be to use an independent carbon nanotube for the tip of a scanning probe microscope. Indeed, the use of an independent carbon nanotube (CNT) tip for metrology of large-scale integration (LSI) was suggested [1]. In general, the arc-discharge method has been used to produce multi-walled carbon nanotubes (MWNT) for preparing an independent MWNT probe because it can produce a satisfactory probe for device manufacturing. Fabrication of the probe requires discharge cutting to adjust the carbon nanotube to the proper length as a probe. The aim of the present study is to evaluate the damage to the MWNT probe caused by discharge cutting with a high pulse current within a few microseconds. In this report, we introduce a new sample preparation technique for high-resolution tomography and describe the remarkable results obtained by this method.

Installation of the independent MWNT on the rotation axis of the needle rotation device is the most critical step of the sample preparation. We used a high-resolution scanning electron microscope (S-4300, Hitachi High-Technologies Co.) with a dual stage that allows individual motion of each stage so that pulsed direct current can be introduced through a bridge made of the MWNT between the two stages [2,3]. The MWNT was welded on the needle by chemical vapor deposition of gold with electron beam irradiation. A high-resolution transmission electron microscope (HF-2000, Hitachi Ltd.) was operated at 100 kV with the needle rotation device. Electron microscopic images were taken every two degrees of 180-degree probe rotation in order to reconstruct the MWNT tip by using tomography. We used the simultaneous iterative reconstruction technique (SIRT) [4] built into commercial software (EMIP, Hitachi High-Technologies Co.)

Figure 1 shows slice sections of the reconstructed MWNT. Figure 1 (a) shows a vertical slice section of the reconstructed MWNT. The lattice fringe of the graphite layer of the MWNT spacing with 0.34 nm can be clearly observed in the reconstructed image. An amorphous layer coating the surface of the MWNT is also observed. There were some graphene sheets within the MWNT. Figure 1 (b) shows transverse slice sections of the reconstructed MWNT. Each section is separated by 5.3 nm. The number at the top left in each image of Fig. 1 (b) corresponds to the slice section indicated in Fig. 1 (a). The longitudinal section of the MWNT shows peeling-off of the interior walls and encapsulation of graphene at the tip. Although the outer walls seem to cover the tip of the MWNT, they may bend over to protect the capped MWNT at the tip. The amount of debris becomes greater closer to the tip. At the center of the tip where the outer walls swelled, a lattice image could be taken, but the graphene sheets were wavy.

In summary, tomography with HREM was a useful method for diagnostic analysis of the internal structure and surface geometry of an independent MWNT. This three-dimensional technique can also be used for analyzing other types of probes.

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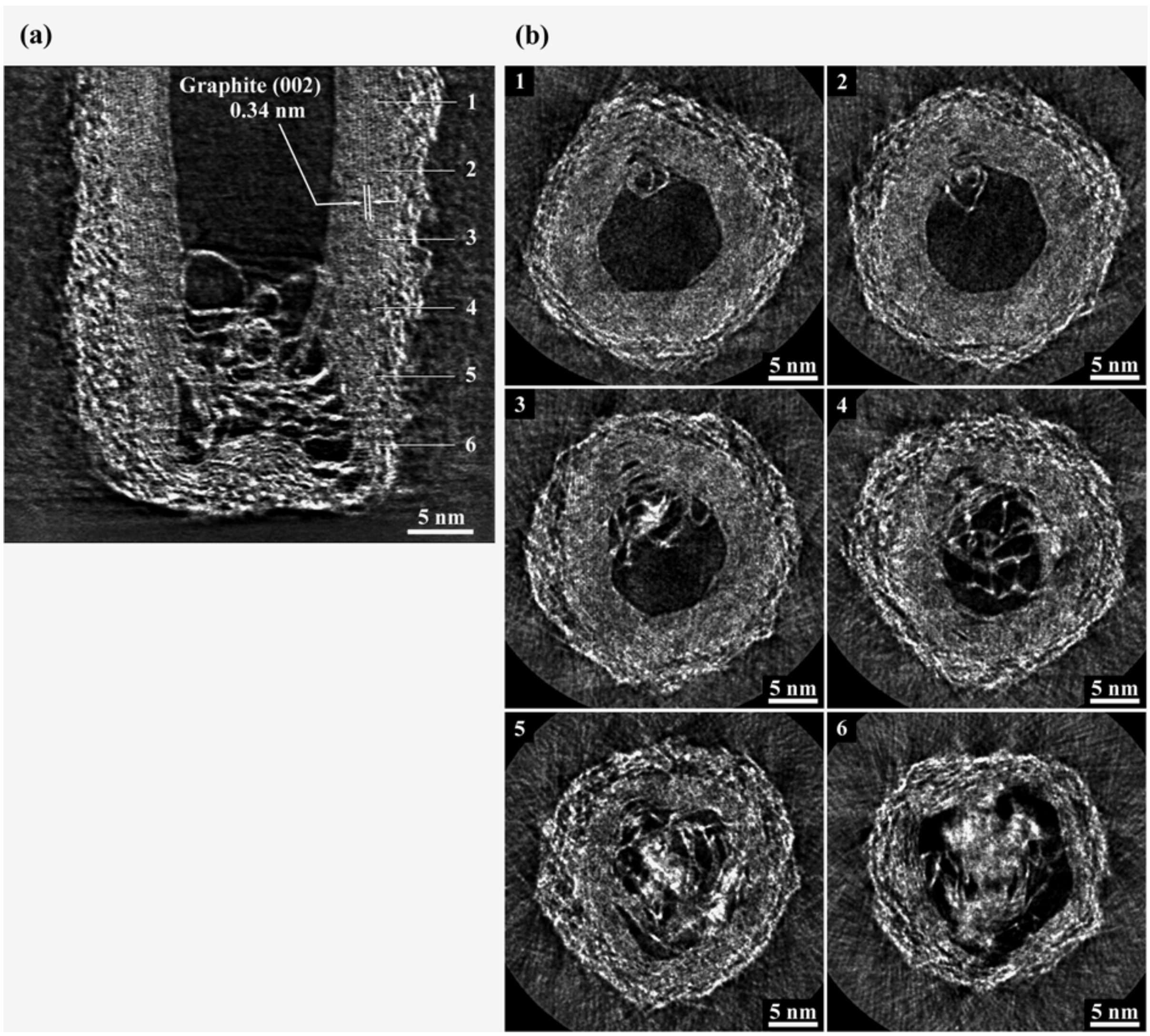

Fig. 1. Slice sections of the reconstructed MWNT: (a) Vertical slice section. (b) Transverse slice sections of the reconstructed MWNT. The positions of the transverse slice sections are indicated in (a). 1: 0 nm, 2: 5.3 nm, 3: 10.6 nm, 4: 15.9 nm, 5: 21.2 nm, 6: 26.5 nm from the point of 1, respectively.

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