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Synthesis of Inorganic-Compounded Nanowires using Carbon Nanotube Templates

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1. Introduction

Since carbon nanotubes (CNTs) have intriguing physical properties such as small tip radius, high aspect ratio, well-defined atomic configuration, chemical stability and bending flexibility, they are suitable for use as the tips of scanning probe microscopy (SPM) [1]. Regarding atomic force microscopy (AFM) using a CNT tip, the high aspect ratio and small effective radius offer the possibility of probing the deep grooves with a high lateral resolution compared to the conventional Si tips. Another feature is that the CNT tip has mechanical flexibility, which can reduce damage to delicate organic and biological molecules [2,3]. In the course of studies, we have synthesized the inorganic-compounded nanowires using CNT templates by pulsed laser deposition (PLD) [4]. Using this technique, we have recently developed a metal-coated CNT tip for scanning tunneling microscopy/spectroscopy (STM/STS) [5]. The STM/STS observation using the metal-coated CNT tip demonstrated the stable atomic imaging and atom-resolved STS. These results provided the potential versatility of the functionalized nanowire probe for the multipurpose SPM measurements on nanoscale.

In this study, we have successfully synthesized with inorganic compound nanowires such as superconducting and magnetic materials using PLD for CNTs. Inorganic-compound layers with nanometer thickness uniformly wrap around CNTs.

2. Experimental

Figure 1 shows the PLD equipment used in this study. A pulsed Nd:YAG laser with a wavelength of 355 nm and a pulse duration of 5 ns was focused onto a target at a repetition rate of 10 Hz with the laser energy of 140 mJ. An isolated multi-walled CNT (MWNT) attached to the edge of a Mo plate (diameter of 3mm) by electrophoresis [6], was used as a specimen. The Mo plate was set at the specimen holder, and was placed 40 mm apart from the target. The angle between the axis of the holder and the normal direction of the target was 45°. The azimuth angle of the specimen was changed during PLD. In this experimental configuration, the coating of MWNTs with Nb_3Sn, CoFe (35 : 65 at.%) and SiO_2/PtIr was carried out at room temperature. Internal structure and chemical composition of the resultant inorganic-compound-coated MWNTs were characterized by transmission electron microscopy (TEM) and energy dispersive X-rays spectroscopy (EDXS), respectively.

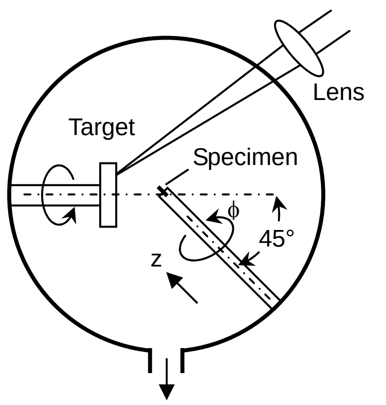

Fig. 1 Schematic illustration of a pulsed laser deposition equipment.

3. Results and Discussion

Figure 2(a) shows a TEM image of the Nb_3Sn-coated MWNT synthesized by 30 min of PLD. The Nb_3Sn layer with homogeneous thickness was covered around both the top and side walls of the MWNT. Figure 2(b) shows a magnified image of the Nb_3Sn-CNT interface in Fig. 2(a). The thickness of the coated Nb_3Sn thin layer was approximately 3 nm and the fringes of graphite layers were clearly observed, indicating that the crystallinity of the inner MWNT was maintained. Figure 2(c) shows an EDX spectrum from the Nb_3Sn-coated MWNT. Peaks originating from C, Nb, and Sn were dominantly observed. The Mo peak stems from the Mo plate of the specimen holder. From the intensity of the peaks, the compositional ratio of Nb to Sn was estimated to be 75 : 25. Thus, the product was found to have a stoichiometric composition of Nb_3Sn.

Next, a multicore shell structure, a double layer of SiO_2/PtIr, was synthesized by performing PLD repeatedly. A PtIr layer was deposited on CNTs in vacuum and a SiO_2 layer was subsequently coated on the PtIr-coated CNTs at an oxygen partial pressure of 1.3 x 10^{-2} Pa. Figure 3 shows a TEM image of a SiO_2/PtIr-coated MWNT. The thicknesses of SiO_2 and PtIr were approximately 5 nm and 4 nm, respectively. We found that multilayer can be uniformly coated on a CNT by PLD, while the crystallinity of the inner MWNT was maintained.

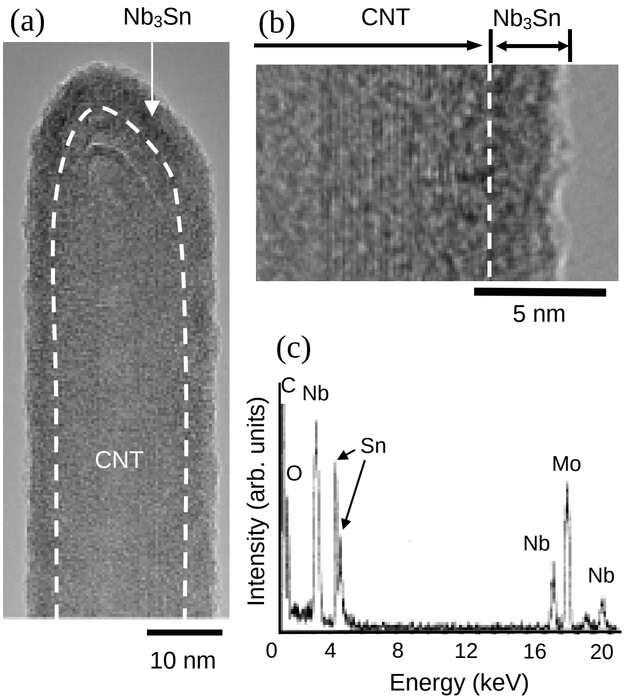

Fig. 2 (a) TEM image, (b) HRTEM image and (c) EDX spectrum of the Nb_3Sn-coated MWNT synthesized by PLD.

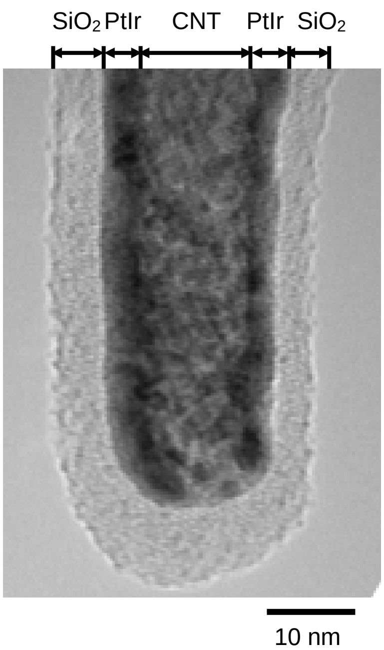

Fig. 3 TEM image of the SiO_2/PtIr-coated MWNT synthesized by repeated PLDs.

4. Conclusion

We have successfully synthesized inorganic-compounded nanowires using CNT templates by PLD. Stoichiometric layers were wrapped with a precisely controlled thickness around a MWNT, and reflected the shape of the MWNT. Furthermore, the MWNT was uniformly covered with the multi-layers. These results indicate that PLD a versatile method for synthesis of inorganic-compounded nanowires. Thus fabricated inorganic-compounded nanowires are appropriate for nanoprobe applications such as the functionalization of SPM probes.

Acknowledgements

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