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Imaging of $NbSe_2$ nanotube by STM

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Abstract. $NbSe_2$ nanotubes were studied by scanning tunneling microscopy (STM). Topographic images of $NbSe_2$ nanotubes on the substrate of HOPG were taken at room temperature. The length of nanotubes is estimated as 300-2000 nm. Diameter of nanotubes is found to be several nm, which is much smaller than that of multi-walled nanotubes, suggesting single-walled one. The bundle structure, which consists of several ten nanotubes, and Y-junction were found similarly to carbon nanotubes.

1. INTRODUCTION

Nanotube materials as well as carbon nanotube have attracted much attention because of their topological structure. The electronic state can be controlled by the chirality. Recently, $NbSe_2$ nanotube was synthesized independently by two groups [1, 2]. Tsuneta *et al.* [1] reported that the nanotube is multi-walled and the stacking is determined as $2H$ from electron diffraction. On the other hand, the nanotube synthesized by Nath *et al.* [2] has $6H$a stacking. It should be emphasized that $NbSe_2$ nanotube is the first nanotube material, of which bulk phase exhibits the condensed state. The bulk phase of $2H$-$NbSe_2$ undergoes the incommensurate charge density wave (CDW) at 33 K, and moreover, the superconductivity at 7.2 K. Our interest is how the condensed state, which is characterized with the coherence length, survives in nano-scaled electronic system.

The tunneling spectroscopy using STM, *i.e.* scanning tunneling spectroscopy (STS) is useful method to investigate the condensed state such as the superconductivity, charge and spin density wave because of non-contacting tip configuration.

The goal of our study is elucidating the ground state of nano-scaled topological material by STS at low temperature. As the first state of our study on $NbSe_2$ nanotube, in this paper, we report STM images of $NbSe_2$ nanotubes at room temperature and discuss about the diameter of tubes.

2. EXPERIMENTAL

$NbSe_2$ nanotubes were synthesized by the chemical vapor transport (CVT) method. After purifying, the nanotube sample for STM measurement was prepared by dropping $NbSe_2$ nanotubes agitated ultrasonically in 2-propanol on cleaved highly oriented pyrolytic graphite (HOPG). We used low temperature STM equipment, in which temperature is variable from room temperature down to 1.2 K. A mechanically sharpened Pt-Ir alloy wire was used as an STM tip, which is attached to a tube type piezoelectric scanner.

3. RESULTS AND DISCUSSION

Figure 1 shows a typical STM image of $NbSe_2$ nanotube on HOPG substrate. The fiber-like structures are almost straight and have length of about 300-2000 nm. We conclude that the linear structure corresponds to $NbSe_2$ nanotube from dimension and linearity of the structure. At present, we cannot obtain the atomic resolution to determine the chirality of nanotubes. The scan profile across the linear structure, which

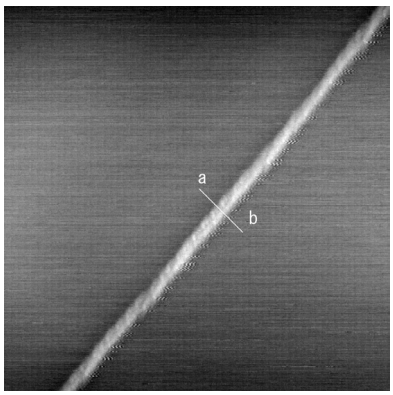

Figure 1. (left) Typical STM image of $NBsE_2$ nanotobe on HOPG. Scan area is $200 \times 200\,nm^2$. The tube diameter is estimated as abut 10 nm from the scan profile.

shows a peak, suggests that the structure is nanotube. Diameter of $NbSe_2$ nanotubes observed at present work is ranging from 1 to 20 nm. In much case, the tube diameter is distributed from 4 to 10 nm. The obtained value in the present work is much smaller than that reported by TEM study [1] on multi-walled $NbSe_2$ nanotubes. We speculate that thick tube in the present STM study is multi-walled and thin nanotube is rather single-walled. The present result of diameter of several nm is almost consistent with the theoretical calculation [3] for single-walled $NbSe_2$ nanotubes.

The bundle structure of $NbSe_2$ nanotube was found similarity to carbon nanotube as shown in Fig. 2. The bundle with diameter of about 70 nm consists of several ten nanotubes with diameter of a few nm, which are spaced closely and arranged in parallel. It is noteworthy that $NbSe_2$ nanotube has much similarity with carbon nanotube in structure.

We also note the Y-junction of $NbSe_2$ nanotube. The Y-junction was often found in carbon nanotubes [4]. The Y-junction of $NbSe_2$ nanotube suggests the possibility of an application to nano-scaled devices in the CDW and superconducting state.

We are interested in the CDW and superconductivity in nano-sized sample. We are trying to study STS on $NbSe_2$ nanotubes at low temperature.

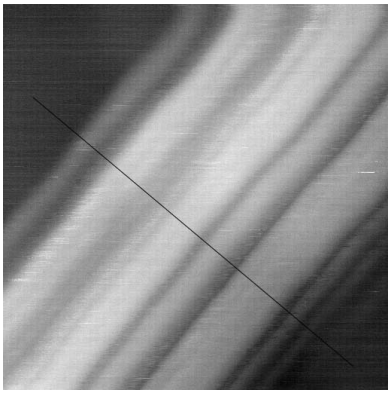

Figure 2. (right) STM image of bundle structure of $NbSe_2$ nanotbes. Scanarea is $87.4 \times 87.4\,nm^2$.

Acknowledgments

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