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Contact Potential Measurement of Carbon Nanotube by KFM

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1. Introduction

Recently, carbon nanotubes (CNTs) have attracted increased interest because of their potential for new electronic devices such as a transistor with an ideal 1D-channel and a field emitter. In order to realize such kind of devices, it is very important to study electronic properties of the CNTs. In this report, we measured the contact potential of CNT by using Kelvin probe force microscopy (KFM). Work function of the CNT and the potential distribution of the CNT under bias voltage were studied.

2. Experiments

KFM is based on the measurement of atomic force and the electrostatic force. In order to improve the spatial resolution, we used a CNT tip with a diameter of about 20 nm as a KFM probe. The CNT tip was fabricated by electrophoresis technique [1]. Figure 1 shows a schematic experimental setup for electrophoresis. By applying AC voltage between two electrodes dipped in a CNT suspension, CNT dispersed in the suspension moves to the Au-coated AFM tip and is attached to it. Figure 2 shows a SEM image of the fabricated CNT tip attached to the conventional Si cantilever tip. Short CNT protrusion length of 200 nm was used to suppress mechanical vibration of the CNT tip, because the mechanical vibration would degrade the spatial resolution. The measurements were performed in air condition.

To investigate the spatial resolution of the CNT tip, contact potential of multi-walled CNT (MWCNT) synthesized by CVD was measured. The MWCNTs were dispersed in ethyl alcohol and deposited on a SiO_2/Si wafer with Au/Ti electrodes. Si tip was also used for the KFM measurement as a reference. Figure 3 shows contact potential images of the CNT measured using both tips. A clear image was obtained in the case of the CNT tip in contrast with a poor image obtained using the Si tip. Full width at half maximums were 30 nm and 110 nm for CNT tip and Si tip, respectively.

Figure 4 shows a contact potential image of the CNT deposited on Au/Ti source and drain electrodes. Clear potential image of the CNT on the electrodes was obtained. Figure 5 shows the line profile across the CNT on the source electrode. The potential difference between CNT and Au was about 6 mV. Potential difference reflects a difference of work function in the KFM measurement. Then, the work function of the CNT is estimated to be about 5.17 eV taking into account the work function of Au (5.2 eV) and voltage correction factor of 5 which depends on the measurement system. This value is comparable to those obtained by photoelectron spectroscopy [2, 3].

Figure 6 shows potential distributions along the CNT under bias voltages (V_b) of 0 V and 0.5 V. In the case of V_b=0.5 V, the potential increases monotonically from source to drain suggesting that the present CNT behaves as a diffusive conductor. This is quite different from the report that no potential drop was observed in the bundle of the single-walled CNTs [4].

3. Summary

In summary, the contact potential of the CNT was successfully measured by the KFM. The spatial resolution of the KFM was improved by using CNT tip. The work function of the CNT was estimated to be 5.17 eV. Potential drop was observed in the CNT under bias voltage suggesting that the present CNT behaved as a diffusive conductor.

References

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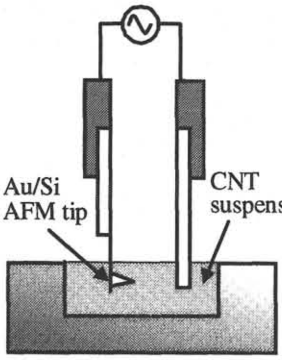

Fig.1: Schematic experimental setup for electrophoresis.

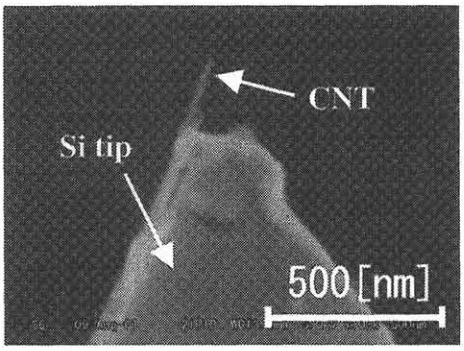

Fig.2: SEM image of a CNT tip attached to the Si cantilever tip.

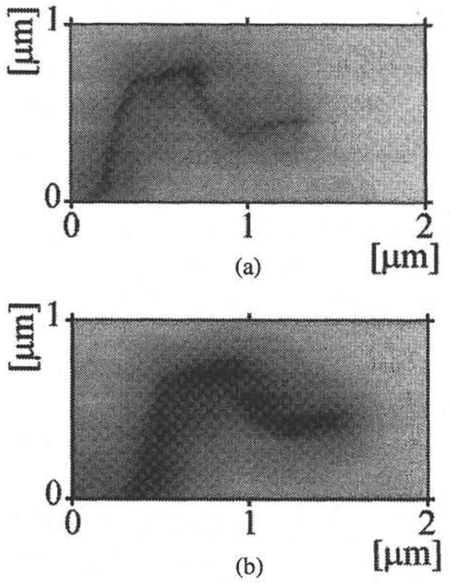

Fig.3: Contact potential images of a CNT measured using (a) CNT tip and (b) Si tip.

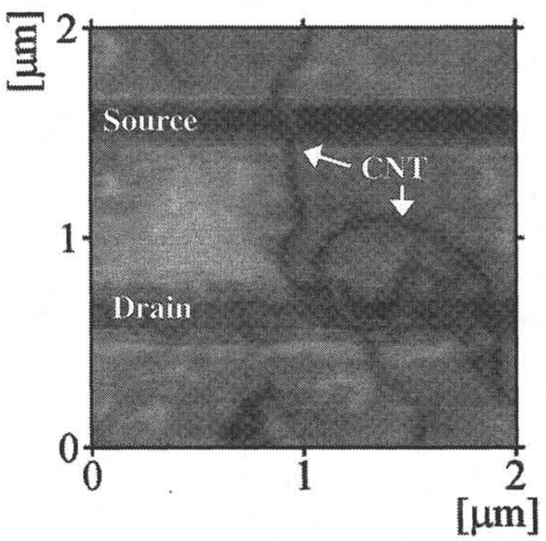

Fig.4: Contact potential image of a CNT deposited on Au/Ti electrodes.

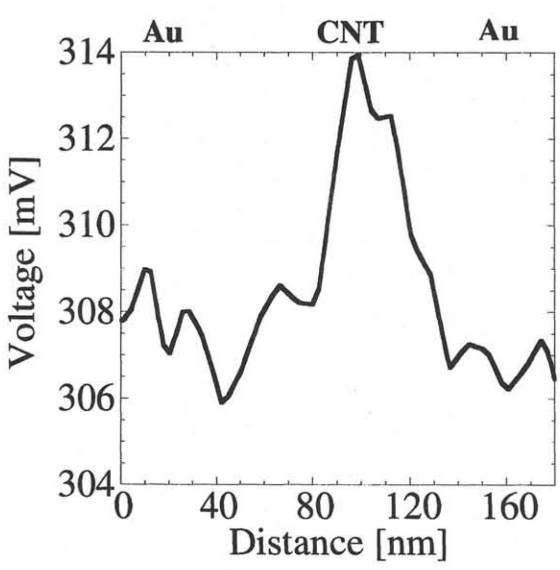

Fig.5: Potential difference between Au electrode and the CNT.

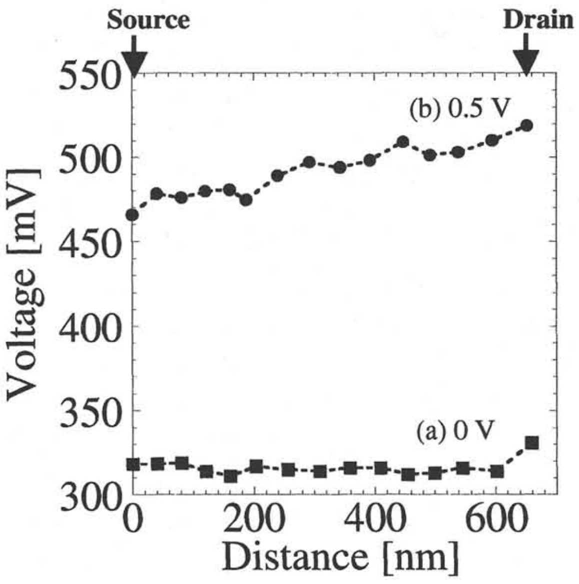

Fig.6: Potential distribution along the CNT under bias voltages of (a) V_b=0 V and (b) V_b=0.5 V, respectively.