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Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp1262-1263

Resistance distribution of CNT network measured by conductive atomic force microscopy

Kousuke Housayama[1], Yuki Okigawa[1], Shigeru Kishimoto[1,2], Yutaka Ohno[1] and Takashi Mizutani[1]

[1]Department of Quantum Engineering, Nagoya University
Furo, Chikusa-ku, Nagoya 464-8603, Japan
Phone: +82-52-789-5387 E-mail: kousuke.housayama@c.mbox.nagoya-u.ac.jp
[2]Venture Business Laboratory, Nagoya University
Furo, Chikusa-ku, Nagoya 464-8603, Japan

1. Introduction

Carbon nanotube (CNT) thin-film transistors (TFTs) [1-3] have attracted much attention because of their potential for use in the fabrication of high-performance electronic components on flexible and transparent substrates. The performance of the device is dependent on the electrical properties of the CNT network rather than CNT itself. For instance, we have demonstrated that the island structure was formed in the channel at the subthreshold regime even for the high-density CNT network [4]. In order to implement high-performance CNT-TFTs, it is important to understand the electrical properties of the CNT network. However, there are not so many reports which investigated the electrical properties of the CNT networks which have CNT junctions [5, 6].

In this report, we studied the resistance distribution of CNT network using conductive atomic force microscopy (C-AFM) and evaluated the resistivity of the CNTs and junction resistance between CNTs.

2. Results and Discussion

Figure 1 shows the AFM image of the measured CNT network which were grown by thermal chemical vapor deposition at 800°C on p^+-Si substrate with SiO_2 thermal oxide using ethanol as a source gas. On the one end of the CNT network, Au contact electrode was formed. The CNT network has three paths labeled path 1, 2, and 3. Only path 1 is electrically connected to Au electrode. In the C-AFM measurement, Pt tip which acts as a scanning local electrode was used and voltage was applied between Pt tip and the Au electrode, as schematically illustrated in Fig. 2. Then it is possible to obtain both topography image and the resistance/current image. The inset in Fig. 2 shows an example of the measured current-voltage (V_{tip}) characteristics at V_{GS}=0 V, which show good linearity. Figure 3 shows measured current distribution image obtained by C-AFM. Here, tip voltage was 0.2 V and gate voltage was 0 V. Bright (White) region corresponds to the area of large current and dark (black and red) regions correspond to the areas of small current. Color of the current image changes gradually along the path 1 and path 2, as shown in Fig. 3, but no image was obtained along the path 3. This indicates that the path 1 and path 2 are electrically connected at junction A but path 1 and path 3 are electrically disconnected each other at junction B.

In order to study the electrical properties of each path in detail, the resistance distributions along the path 1 and path 2 are shown as a function of the distance from the Au electrode in Fig. 4 (a) and (b), respectively. Here V_{tip} was 1 mV and V_{GS} was 0 V. Solid lines are the guides for the eyes. In the case of path 1, gradient of the resistance distribution changes at about 250 nm and 800 nm which are denoted by arrows in the figure, indicating the change in the resistivity of the CNTs. This suggests the CNT channels consist of CNT bundle even though the possibility of chirality change is not completely ruled out. At distance below 250 nm, no detectable resistance change was observed, as shown in Fig. 5. This is probably due to that the CNT bundle consists of at least one metallic CNT at this area. From the figure, the sum of the contact resistance at the Au electrode/CNT and Pt tip/CNT was estimated to be about 1.3 MΩ. The resistivity increases at distance longer than 250 nm, suggesting that the metallic CNT is unbundled. The resistivity obtained by the gradients was 22 MΩ/μm between 250 and 800 nm and 121 MΩ/μm beyond 800 nm. These values indicate that the CNTs beyond 250 nm are semiconducting.

In the case of path 2, the resistance increases abruptly at 1250 nm (junction A), where path 1 and path 2 are in touch, as shown in Fig. 4(b). From the value of the resistance step, the contact resistance between semiconducting CNTs was estimated to be 19.3 MΩ. The resistivity in path 2 beyond junction A was 398 MΩ/μm.

3. Conclusions

We measured the resistance distribution of CNT network using conductive AFM. The resistivity change of the CNT channel was observed in the CNT channel, suggesting bundling and unbundling of the CNTs. Contact resistance between semiconducting CNTs was estimated to be 19.3 MΩ in the present CNT/CNT junction.

Acknowledgements

This work has partly been supported by a Grant-in-Aid for Scientific Research on Priority Areas from the Ministry of Education, Culture, Sports, Science, and Technology.

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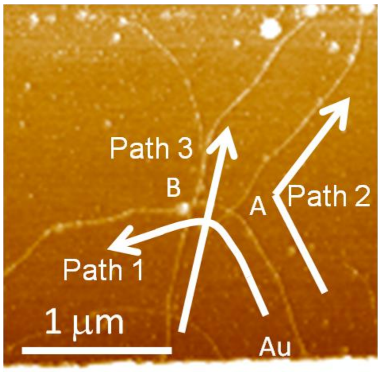

Fig. 1. Measured CNT network.

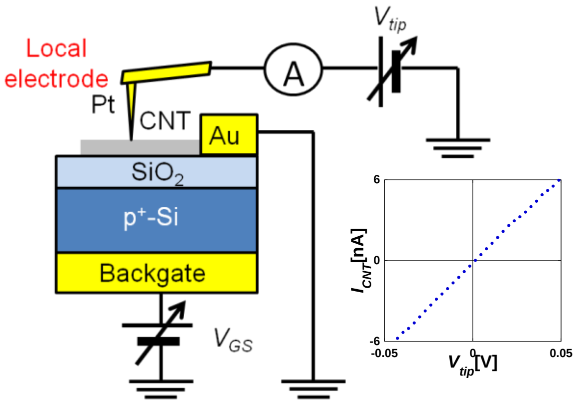

Fig. 2. Schematic view of the C-AFM measurement. Inset is an example of the current-V_{tip} characteristics of the CNT network.

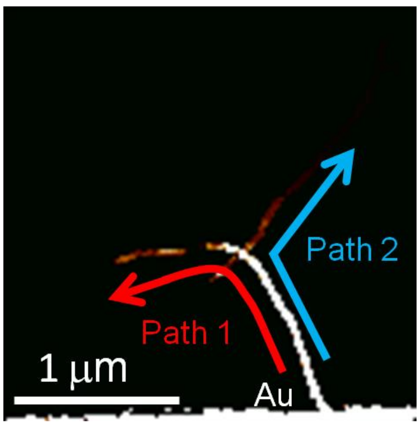

Fig. 3. Current distribution image of the CNT network obtained by C-AFM. V_{tip}=0.2 V and V_{GS}=0 V.

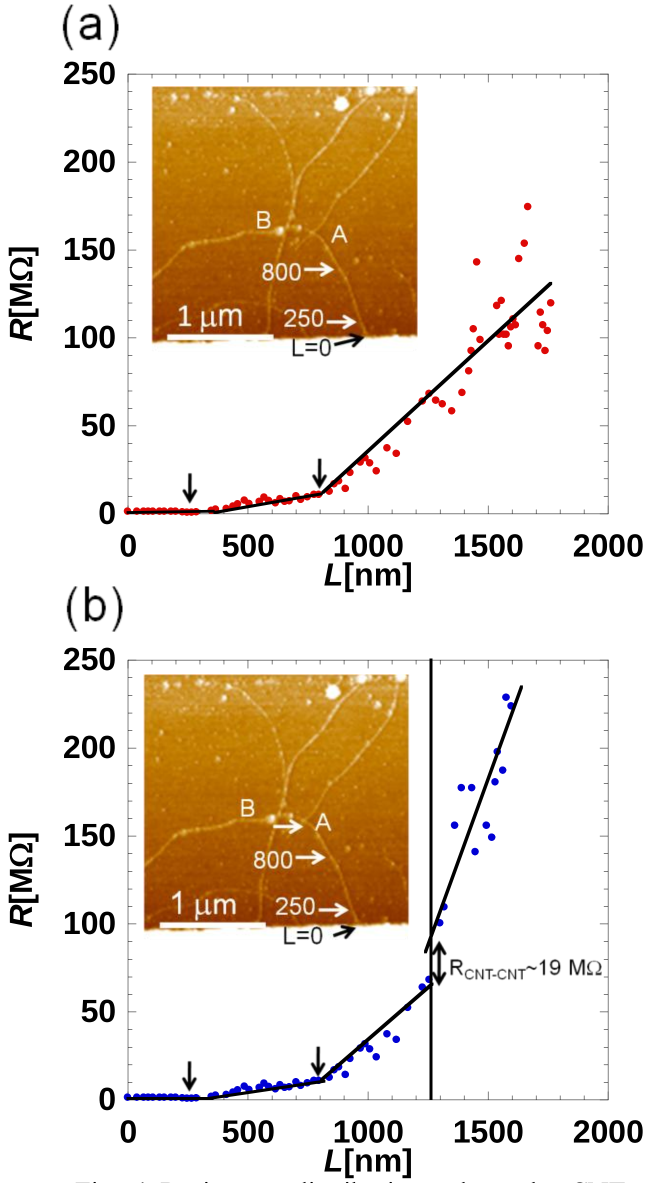

Fig. 4 Resistance distributions along the CNT channel. (a) path 1 and (b) path 2. V_{tip} was 1 mV and V_{GS} was 0 V, respectively.

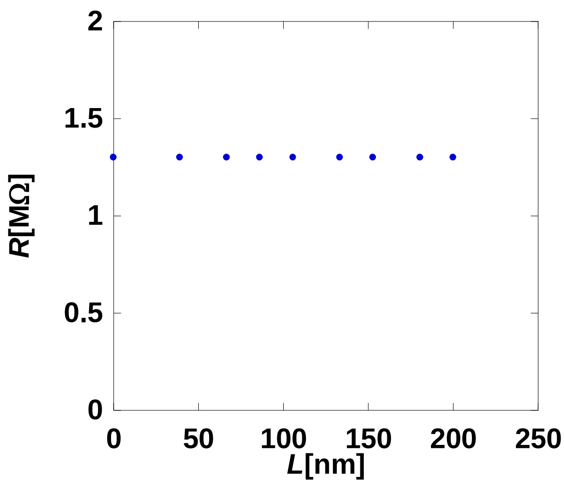

Fig. 5. Resistance distribution near Au electrode. V_{tip} was 1 mV and V_{GS} was 0 V, respectively.