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Control of Electrical Property in Multi-Wall Carbon Nanotube using Electrical Breakdown

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1. Introduction

Recently, there has been great attention to the transport properties of carbon nanotube for the application to future nano-scale devices. In the case of a single-wall carbon nanotube (SWNT), it can be applicable for a field effect transistor or a single electron transistor. In contrast, in the case of a multi-wall carbon nanotube (MWNT), it is hardly modify the electron density by the external gate voltage. However, considering the high conductivity, MWNT would be more applicable than SWNT for electrical wiring and a transistor in nano-scale circuits, if we can control the electrical properties of it by any way. One of the ways to modify the properties of MWNT is an electrical destruction of the walls by electrical breakdown shown by IBM groups [1,2]. It has been reported that, by applying high bias on MWNT and flowing high current in air, the outermost wall of the tube is destructed, which bring the modification of the electrical properties and tunable by a gate voltage. However, it has not cleared that there is no damage on the remaining walls of the MWNT due electrical destruction, which would be very important for the device application. In this paper, we measured the temperature dependence of the conductance of MWNT before and after the electrical destruction, and discuss the change of electrical properties paying attention to the one-dimensional Tomonaga-Lattinger (TL) like transport property.

2. Experimental Details

The MWNT employed here was prepared by arc discharge method provided by Shinkuyakin Co. Ltd. It was diluted with a solvent, and purified only by a centrifugal separator, which was not annealed for the purification. The solution was dispersed on a SiO_2 layer on *p*-type Si wafer using a spin coater. The electrical contacts were made using Ti/Au and lift-off process by a high-allayment photo- lithography system. A SEM image of the sample is shown in Fig. 1 and the distance of the electrodes was about 2 μm. The electrical breakdown was performed using dc source-measure unit with a suitable bias voltage (2-terminal method).

3. Results and Discussions

At low bias voltage, a current-voltage (*I-V*) characteristic of the MWNT sample has showed liner response, however, it becomes nonlinear at high voltage. Exceeding the voltage about 3 V, the current reaches to a maximum and begins to decrease. Figure 2 shows a typical time dependence of current at a high constant voltage (3 V). Some current steps were observed although the step size was not constant, and it finally became to zero. Figure 3 shows typical variation of the *I-V* characteristics after performing some destruction using the same sample. The resistance increased with progressing the destructions, however the characteristics remained linier at low bias. However, the value of resistance occasionally decreases as shown in the Fig.2 ($0 \rightarrow 1$). Some reasons can be considered, but it has not been clear yet. One of the possible mechanism is a metalization at the contact region between Ti/Au pad and MWNT with making carbide by thermally increasing with a high bias application [3].

It is well known that a temperature dependence of a resistance of carbon nanotube shows one-dimensional behavior, which is often analyzed using by Tomonaga-Lattinger liquid model [4]. It is characterized to show a linear response on the log-log plot of the temperature dependence of conductance at higher temperature regions ($k_BT >> V$) and to saturate at low temperature region. Moreover, at low temperature ($k_BT << V$), the d*I*/d*V* characteristic at high bias voltage region also shows a linear response on the log-log plot. The results of the *G-T* and the d*I*/d*V* curves before destruction (filled circles) in Fig. 4 show a typical TL like behavior and the slopes (α) is almost the same value of 0.6. On the other hand, in the case of the progressing heavy destruction (filled squares), the values of α exceeds 2, and show different value on the *G-T* (3.6) and d*I*/d*V* (2.5). It suggests that TL like transport behavior should not be applicable for the transport in the MWNT after heavy destruction. As for a possible understanding of the transport properties for heavy destructed MWNT, we tried to plot the result using the $T^{(-1/4)}$ axis as shown in Fig. 5, which showed almost linier response. It indicates that the transport regime of three-dimensional variable-range hopping could be applicable in this sample. It suggests that, by the electrical destructions, many defects would be introduced on MWNT, which behaves a trapped site on the hopping transport.

3. Conclusions

We investigate the variation of the transport properties of MWNT by electrical destruction of the walls. After heavy destruction, TL-model cannot be applicable for the transport. It indicates that there introduce many defects on the surface of MWNT after the electrical breakdown.

Acknowledgements

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References

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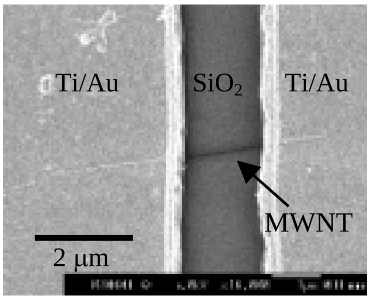

Fig. 1 SEM image of a sample. Two pads of Ti/Au electrodes contact on a MWNT with 2 μm gap.

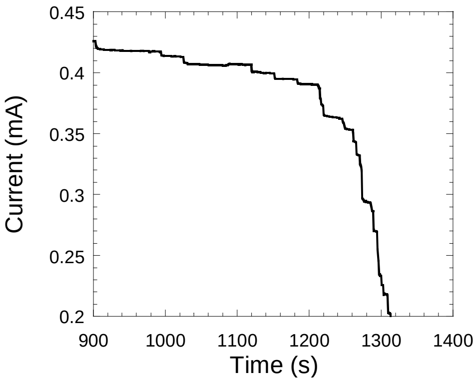

Fig. 2 Typical time dependence of current at constant bias voltage of 3.0 V.

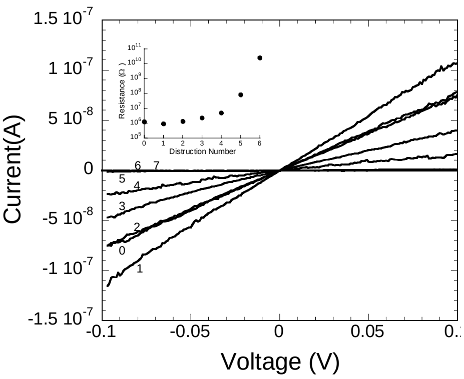

Fig. 3 *I-V* characteristics of the sample with progressing the electrical destruction. The inset shows the change of the 2-terminal resistance.

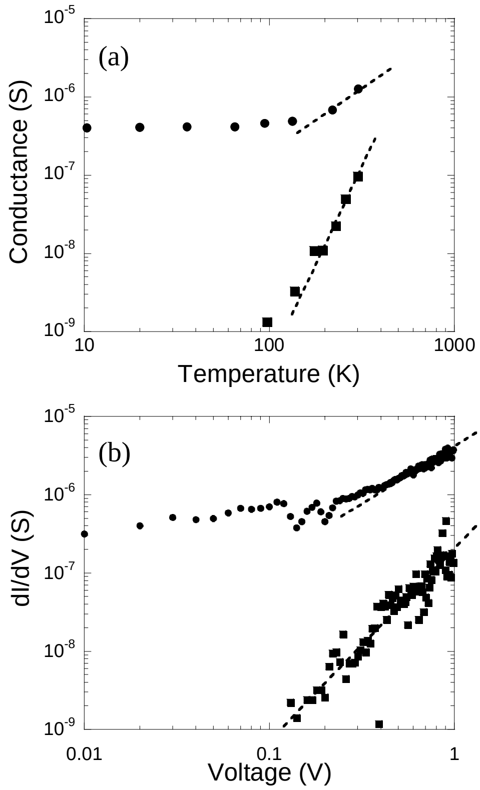

Fig. 4 Temperature dependence of conductance at constant bias voltage of 10mV (a) and voltage dependence of the conductance at 4.6 K (b). The filled circles and filled squares indicate before and after heavy destructions. The dotted lines are guide for eyes.

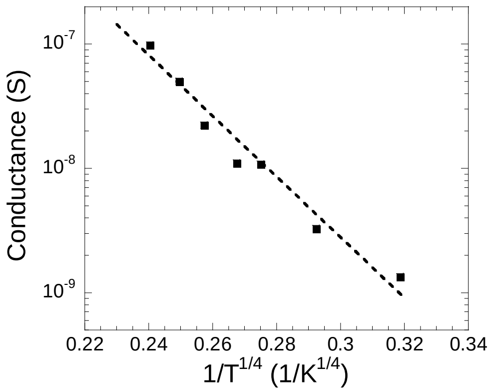

Fig. 5 Temperature dependence of conductance of heavily destructed sample using $T^{(-1/4)}$ on the horizontal axis. The data is the same as Fig. 4 (a).