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Nano-Device Formation in a Multi-Wall Carbon Nanotube

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1. Introduction

Multi-wall carbon nanotubes (MWNTs) are one of natural nano-size bricks. The MWNTs are conductive narrow wires, and would be useful materials for a component of nano-electronics [1-6]. By building up the MWNT bricks, nano-scale device structures, which cannot be fabricated from three dimensional balk materials, can be constructed. For the construction, the nano-bricks need to be cut to fit to designed structures. In this report, we proposed an etching technique to cut the MWNTs into three pieces for a single-electron transistor (SET). The SET is a useful device to show that the constructed structure has an expected small element. In the MWNT-SET, we observed the Coulomb blockade effect with island capacitance of 4.2 aF at 4.5 K. The observed Coulomb blockade effect meant a quite small island was formed in the MWNT. This result is an essential step for use of the carbon nanotube in nano-electronics.

2. Device fabrication process

A scanning electron microscope image and schematic view of a device are shown in Fig. 1. To form the structure, MWNTs was dispersed on Si/SiO2 substrate which had pre-defined Pt/Au address patterns. We mapped the MWNTs out using a scanning electron microscope and recorded relative positions of the MWNTs with respect to the address patterns [4,7]. Pt/Au contact patterns were defined by electron beam lithography so as to overlap the positions of the mapped MWNT. In addition, a gate electrode was attached at apart 1.5 μm away from the MWNT. For an island formation, we used ZEP electron beam resist as an etching-mask. Two narrow trenches were exposed by a second electron beam exposure on the spin-coated ZEP resist. Using oxygen plasma, we etched the MWNT through the trenches on the ZEP etching-mask. The processes are illustrated in Fig. 2(a) as a schematic cross section of the device.

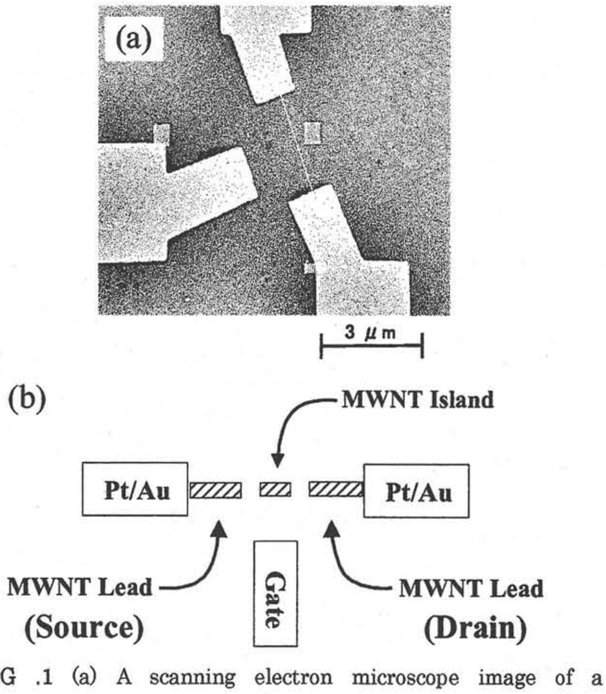

FIG .1 (a) A scanning electron microscope image of a MWNT-SET. A white line is drawn on a low-contrast MWNT to support the eyes. The MWNT is a 5 μm in length and 10 nm in diameter. (b) Two parts on the MWNT were etched to form a MWNT island with MWNT leads.

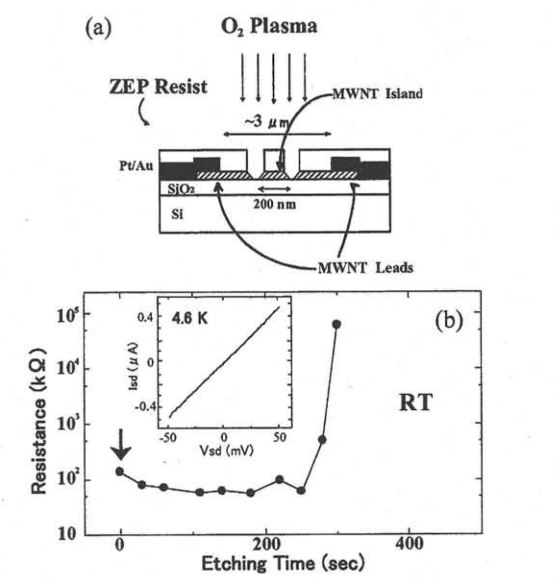

FIG .2 (a) A schematic cross section of the device in the etching process. (b) Semilogarithmic plot of the resistance of the MWNT device in the oxygen plasma etching process. Plasma power is 150 W, and lowered to 50 W from 280 seconds. The resistances were measured in air at room temperature. Inset: Isd-Vsd characteristic before the etching in vacuum at low temperature.

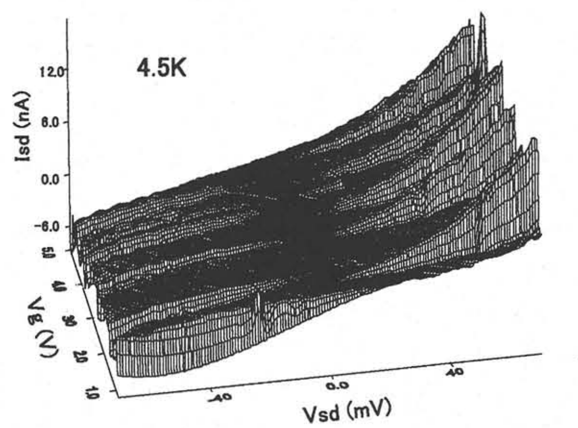

FIG .3 Isd-Vsd characteristics by changing Vg from 1 V to 5 V at low temperature (4.5 K).

3. Measurement

Before the etching, the device showed an ohmic current-voltage (Isd-Vsd) characteristic with the resistance of 138 kΩ at room temperature. At 4.6 K, the Isd-Vsd characteristic also showed ohmic characteristics in the measured bias voltage range while the resistance changed to 96 kΩ (inset of Fig. 2(b)). During the etching in oxygen plasma for 280 seconds, the room-temperature resistance did not drastically change and the device kept the ohmic characteristic at 4.5 K. In a further 20 seconds etching with plasma power 50W, the resistance increased to 62 MΩ

When we cooled down the device to 4.5 K, we observed switching of rhombic Coulomb blockade regions in the Isd-Vsd (Fig. 3) by changing a gate voltage (Vg). From a charging energy of about 38 meV, an island capacitance is deduced to be 4.2 aF. The 4.2 aF is much smaller than the junction capacitance of about 30 aF observed in a single-wall carbon nanotube (SWNT) reported in Ref. 1, although an original diameter of the MWNT is ten times larger than the SWNT. If we assume the cylindrical island with 10 nm in MWNT diameter, the island length is estimated to be several tens nanometer.

4. Conclusion

In conclusion, we establish a new fabrication method to form a nano-size electric device by cutting the specific places of the MWNT in oxygen plasma. For the demonstration, we fabricated the SET which has MWNT island with MWNT leads. This method brings out an advantage of the tiny structure of the carbon nanotubes over the other three dimensional bulk materials.

Reference

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