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Author(s)	Mohd Ambri, Mohamed
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Device operation and functional design of carbon nanotube field-effect transistor fabricated by direct growth method

Mohd Ambri Bin Mohamed (0740019)

Carbon nanotubes (CNTs) have attracted great attention as a material for the next-generation electronic devices, because of their high electric conductivity, high mechanical strength, and light weight. From the viewpoint of electronic properties, they can be either metallic or semiconducting, depending on the molecular structure. Actually, field-effect transistors (FETs) and spin valve device using CNTs have been demonstrated. Their performance is, however, still much lower than expected. One of the most important issues is weak electric contact between CNTs and electrodes. Direct growth method, where CNTs are directly grown from the electrodes and bridging them, is an ideal method for solving existing issues. This thesis has unraveled characteristics of devices with metallic and semiconducting CNTs fabricated by direct growth method, and opens the possibility to apply this technique for the application to spin devices.

In metallic-CNT devices, magnetoresistance of up to 1.8 % was observed as shown in Fig. 1. The sharp peaks at about ±110 Oe correspond to the averaged coercive fields of electrodes. Therefore, the MR observed can be attributed to the spin dependent transport through SWNTs. In semiconducting-CNT devices, the transfer curve showed ambipolar characteristics where the behavior can well be explained in terms of carrier injection barrier modulation of the Schottky-type FET. Application of V_{DS} and V_{GS} was found to be responsible for the effective reduction of Schottky barrier, and the current enhancement was due to the reduction of activation energy, E_a. Fig. 2 shows the intrinsic potential barrier reduction with the application of V_{GS}. Ideal formation of Schottky barrier was realized for electron injection barrier, since the experimental values correspond to the theoretical values. In addition, effective barrier height was reduced significantly with only small bias voltages. Fig. 3 shows *M-H* curve of 9,000 pairs of Co electrodes with shape anisotropy after the direct growth process. Two steps in magnetization were confirmed even after annealing at 850 ℃ for 20 min. The electrodes retain their structure, and their magnetic properties shows two steps in magnetization which can be applied as spin devices. The FET characteristics of these devices are consistent with CNTFETs with symmetric electrodes.

In conclusion, from the systematic and detailed research on CNT device fabricated by direct growth method, three significant contributions to the progress in the development of CNT devices have been realized. They are: 1) success in fabricating the metallic CNT device which shows MR up to 1.8 %, 2) clarification of low voltage operation of CNT-FET with intrinsic Schottky contact between CNTs and electrodes, and 3) success in fabricating the CNT device with designed ferromagnetic electrodes.

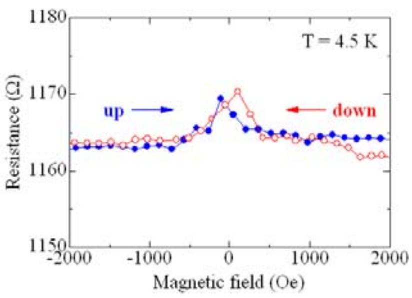

Fig. 1. MR effect of metallic-CNT at 4.5 K

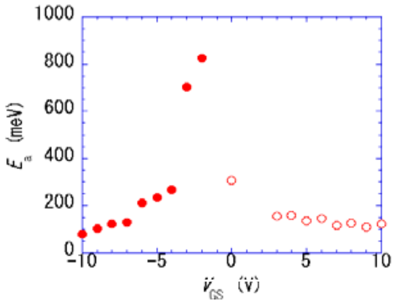

Fig. 2. Potential barrier reduction at applied bias

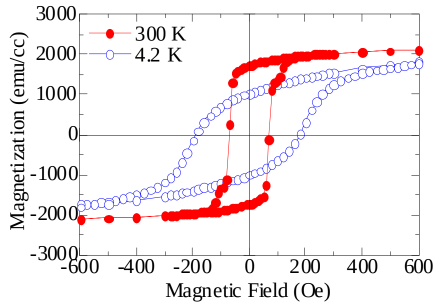

Fig. 3. *M-H* curve for electrodes annealed at 850 ℃