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Single Electron Transistor with Ultra-High Coulomb Energy of 5000K using Position Controlled Grown Carbon Nanotube as Channel

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1. Introduction

Carbon nanotube is one of the best candidates for the key element of the nanodevices. The major problems of the carbon nanotube for the application of the device, however, is the difficulty of the position control. In this paper, we proposed the new and quite easy technique for the positioning of the carbon nanotube. Using this positiron controlled carbon nanotube as a channel, the single electron transistor was fabricated which showed the ultra-high Coulomb energy of 5000K and Coulomb diamond structures even at room temperature.

2. Device Structure

The positioning of the carbon nanotube was successfully achieved using the patterned chemical catalyst process. Using the conventional photolithography process, iron (Fe) metal of 3nm thick was patterned on the substrate. Using CH_4 gas in the thermal CVD process at 900C for 30 minutes, one single wall carbon nanotube started to grow and bridged between two patterned chemical catalysts as shown in Fig. 1. Using this position controlled grown carbon nanotube as a channel on the 100nm thick SiO_2 substrate, the single electron transistor was fabricated as shown in Fig.2. The source and drain ohmic contacts were formed onto the patterned chemical catalyst after the growth of the nanotube. The back gate contact was also formed on the silicon substrate.

3. Electrical Properties

The electrical properties of the device were all measured at room temperature. Figure 3 shows the drain current-drain bias characteristics using the gate biases as parameters. At the gate bias of 0.8V, the drain current shows the large leaky characteristics and shows no Coulomb gap characteristics. By increasing the gate bias, the drain current begins to decrease. At the gate bias of 1.6V, the drain current shows the lowest value, and shows the Coulomb gap characteristics. The Coulomb gap size is as large as about 800 mV though there is a leak component. The total energy of the device was as high as 400meV which corresponds to the Coulomb temperature of ~5000K. Further increase of the drain current up to 2V, the drain current does not decrease more, but increases. When the gate bias becomes 2V, the Coulomb gap disappeared completely again, and the drain current increased drastically. Therefore, the drain current does not increase monotonically, but oscillates by the increase of the gate bias.

The gate bias dependence of the drain current was shown in Fig. 4 with the drain bias as parameters. The drain current oscillates with the increase of the gate bias and showed the room temperature Coulomb oscillation characteristic. The modulation ratio of the Coulomb oscillation is as high as 96~99% owing to such a high charging energy. The structure of the Coulomb oscillation is quite irregular concerning the periods and peak height. From these periods of the Coulomb oscillation, the gate capacitance of the device is roughly estimated to be of the order of Cg=1E-19F.

The dependence of the drain current on the gate and drain biases is shown in Fig. 5. In Fig. 5, the black shadow area is the Coulomb blockade area which shows the clear Coulomb diamond structures even at such high temperature of room temperature. Figure 6 is the contour plot of Coulomb diamond structures. Five Coulomb diamond structures with different size are seen. The different size of the Coulomb diamond structures may be attributed to the multi-dot Coulomb islands structure in the carbon nanotube, which may come from the residual Fe catalyst and/or the defects of the nanotube.

4. Conclusions

We have succeeded in controlling the position of the carbon nanotube using the patterned chemical catalyst. Using this position controlled grown carbon nanotube as a channel, the single electron transistor was fabricated which showed the Coulomb diamond characteristics even at room temperature. The Coulomb energy is as high as 400meV and Coulomb temperature of 5000K. Owing to such high Coulomb energy, the device operated at room temperature.

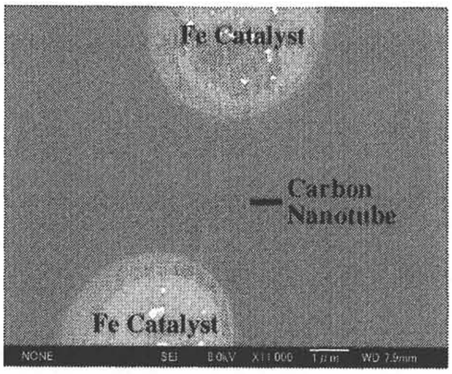

Fig. 1, Position controlled grown carbon nanotube using patterned Fe catalyst.

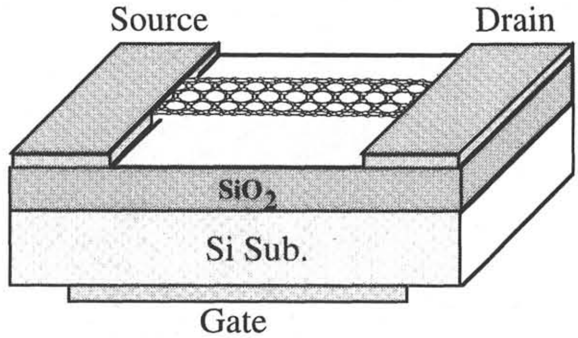

Fig. 2, Structure of single electron transistor using position controlled grown carbon nanotube as channel.

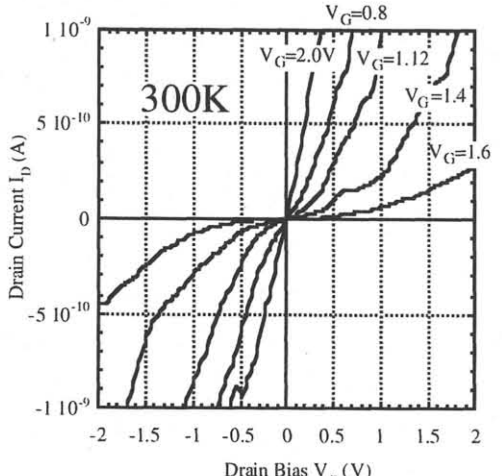

Fig. 3, Coulomb gap characteristics at room temperature. Gate bias was changed from 0.8V to 2V.

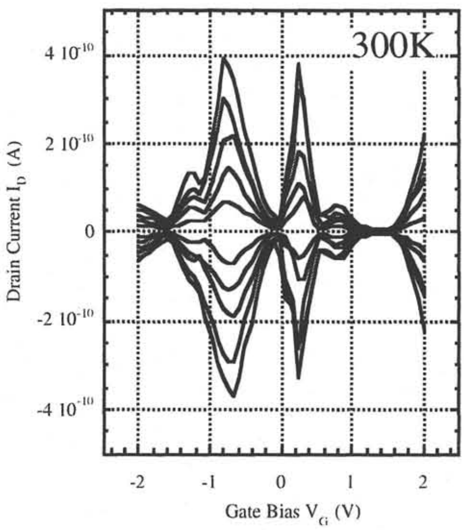

Fig. 4, Coulomb oscillation characteristics at room temperature. Drain bias is changed from -0.1V to +0.1V with 0.02V step.

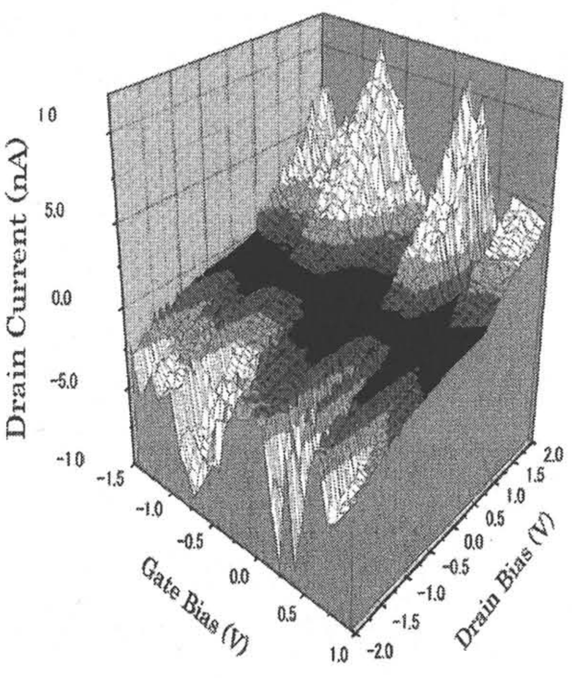

Fig. 5, Room temperature Coulomb diamond structure in carbon nanotube single electron transistor.

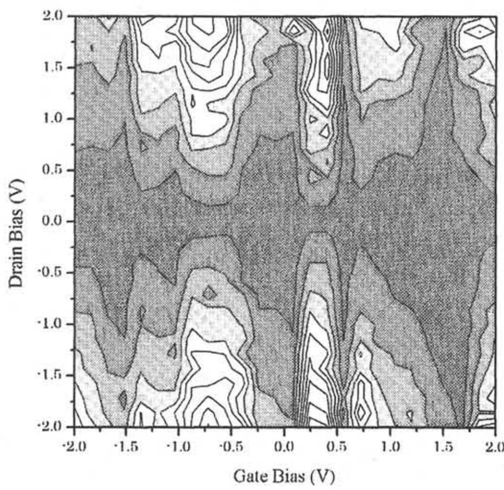

Fig. 6, Contour plot of Coulomb diamond structure at room temperature in carbon nanotube single electron transistor.