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Ultra-low Energy Nitrogen-ion Irradiation for Improvement of Carbon Nanotube Channel Single Electron Transistor

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1. Introduction

Carbon nanotube is one of the best elements for nano scale electronic devices. Single electron transistor operated at room temperature was realized using carbon nanotube. There is some difficulty, however, to fabricate the single electron transistor in high yield. In order to realize in higher yield, it is necessary to control the diameter of dot site to be about a few nano meters. It is difficult to control such a small structure in a process applicable to large scale integration for carbon nanotube single electron transistor.

In this paper, we report the new technique for controlling dot size on carbon nanotube single electron transistors using ultra low acceleration energy ion irradiation, and show the improvement of single electron transistor characteristic..

2. Device Fabrication

The sample was prepared as follows. A p-type silicon wafer with a thermally grown oxide (100 nm) was used as the substrate. The layered catalysts of Fe/Mo/Si (3nm/10nm/10nm) were patterned on the substrate using the conventional photo-lithography and lift off processes. The distance between two catalysts for the source and drain was 4μm. SWCNT was grown between two catalysts by chemical vapor deposition (CVD) using methane gas. Pt/Au (30nm/400nm) electrodes were deposited on the patterned catalysts and the back side of Si substrate. Thus, back gate type carbon nanotube field effect transistor (FET) structure was fabricated (Fig. 1). Finally, the sample was irradiated by the nitrogen-ion ($^{14}N^+$) with an acceleration voltage of 30V in vacuum condition. The number of irradiated nitrogen-ions are estimated to be 2.5×10^{14} and 3.7×10^{15} ions/cm^2.

3. Electrical Properties of Devices

Fig. 2 shows drain current-gate voltage characteristics of the device irradiated with different density of nitrogen-ions at the constant drain voltage condition at room temperature. These characteristics indicate p-type semiconducting property, because the current decreases with gate voltage increase at positive bias region. The drain current without nitrogen-ion irradiation indicates coulomb oscillation peaks because of naturally formed defects on carbon nanotube during the device fabrication process. The both drain current characteristics irradiated at 2.5×10^{14} ions/cm^2, and 3.7×10^{15} ions/cm^2 show coulomb oscillation peaks with larger periods. The amount of drain current was decreased from 100 nA to 1 nA after nitrogen-ion irradiation.

Fig. 3 shows contour plot of coulomb oscillation characteristics at room temperature (coulomb diamonds plot). The clear coulomb diamond characteristics are obtained even at room temperature. Coulomb gap and period of coulomb oscillation peaks become large with increasing the density of irradiated nitrogen-ions. The change of the characteristic indicates change of dots sizes on carbon nanotube. It may be due to damage or defects induced by nitrogen-ion irradiation. When dots sizes become small, the total capacitance C_Σ and gate capacitance C_g of single electron transistor also become small. C_Σ before and after 2.5×10^{14} ions/cm^2 and 3.7×10^{15} ions/cm^2 nitrogen-ion irradiation are calculated to be 3.0×10^{-19} F, 2.3×10^{-19} F and 2.0×10^{-19} F, respectively.

Fig. 4 shows Coulomb gap characteristics at room temperature. Coulomb gap becomes larger with and leaky increasing the density of irradiated nitrogen-ions. Coulomb gap increased from0.53V (before nitrogen-ion irradiation) to 0.70V (after 2.5×10^{14} ions/cm^2 irradiation) and 0.82V (after 3.7×10^{15} ions/cm^2 irradiation), respectively, which correspond to the improvement of the charging energy ($e^2/2C_\Sigma$) of confined single electron in dot, 270meV, 350meV and 410meV respectively. The leaky current may come from the amorphous carbon formed by the irradiation.

4. Conclusions

We have succeeded in improving the single electron transistor characteristics at room temperature using ultra low acceleration energy nitrogen-ion irradiation. The charging energy of confined single electron in dot was become large after nitrogen-ion irradiation. This is attributed to be the size reduction of the dots on carbon nanotube by nitrogen-ion irradiation.

References

1) K. Matsumoto et al., Jpn. J. Appl. Phys. 42, 2415 (2003)
2) M. Suzuki et al., Appl. Phys. Lett. 81, 2273 (2002)
3) N. Yoneya et al., Appl. Phys. Lett. 79, 1465 (2001)

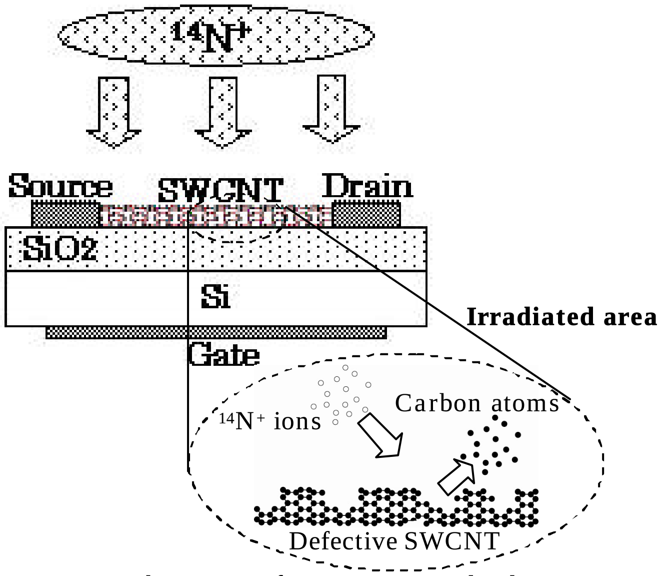

FIG.1, Schematic of cross-sectional device structure and nitrogen-ion irradiation image. The device structure is three terminals.

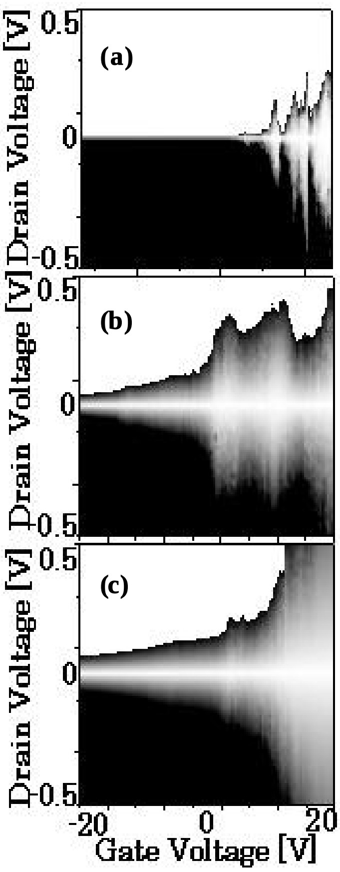

FIG.3, Coulomb diamond plot measured at room temperature (a) before nitrogen-ion irradiation, (b) after 2.5×10^{14} ions/cm^2 irradiation, (c) after 3.7×10^{15} ions/cm^2 irradiation. The white color regions indicate current suppressed regions.

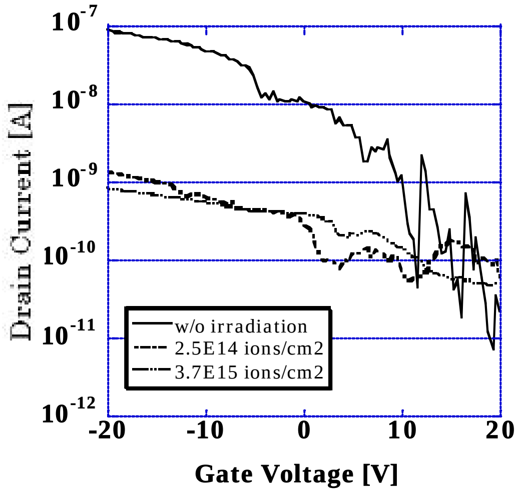

FIG.2, Effects of nitrogen-ion irradiation of I-V characteristics. The amount of drain current decreased from 100 nA to 1 nA after nitrogen-ion irradiation.

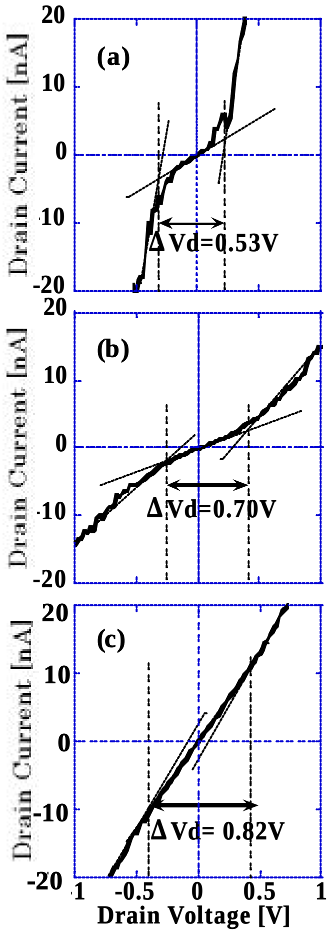

FIG.4, Coulomb gap characteristics measured at room temperature (a) before nitrogen-ion irradiation, (b) after 2.5×10^{14} ions/cm^2 irradiation, (c) after 3.7×10^{15} ions/cm^2 irradiation.