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Fabrication of Peapod FETs Using Peapods Synthesized Directly on Si Substrate

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1. Introduction

Single-walled nanotubes (SWNTs) encapsulating fullerenes, so-called peapods, are attracting materials for electronics applications because of their interesting electronic properties [1,2]. Recently, we have reported the fabrication and characterization of FETs of various types of peapods such as fullerenes C_{60}, C_{78}, metalofullerenes Gd@C_{82}, Dy@C_{82} and so on [3,4]. The devices showed ambipolar characteristics, and the off-state gate voltage width of transfer characteristics, which corresponds to the bandgap of the peapod channel, was varied with the kind of encapsulated fullerenes.

In the previous studies on peapod FETs, the peapods were obtained as soot, scattered in organic chemical solution, and then dispersed on a SiO_2/Si substrate with source/drain electrodes. In this fabrication method, the yield of peapod FETs with an isolated peapod channel was quite low. In order to characterize peapod FETs in detail and to apply them to nano-electronics, it is important to develop a fabrication process using the direct synthesis on a substrate similar to SWNT FETs [5,6].

In this report, we have successfully fabricated peapod FETs using peapods synthesized directly on a SiO_2/Si substrate.

2. Experiments

Figure 1 shows a schematic of the peapod FET. The p^+-Si substrate was used as a back gate through a 100-nm thick SiO_2 film. The peapod channel was synthesized directly on the SiO_2/Si substrate. The procedure for the peapod synthesis is as follows; 1) patterning of the catalytic metal on the SiO_2/Si substrate, 2) thermal CVD of SWNTs, 3) cap opening of the SWNTs by annealing in dry air, and 4) fullerene doping in vapor phase. The device fabrication was completed by the formation of the source and drain electrodes (Ti/Au, 100/300 nm) fitting on the catalyst pattern. The channel length was 2 μm.

The condition of the cap opening of SWNTs was determined by Raman scattering spectroscopy measurement. Here, in order to facilitate Raman scattering characterization and TEM observation, we used samples with high density SWNTs synthesized on a quartz substrate [7]. Figure 2 shows the Raman scattering spectrum of the SWNTs. The large G-band/D-band intensity ratio (G/D) suggests that the synthesized SWNTs is of high quality. The cap opening was performed by annealing in dry air for 30 min. The cap of SWNTs has pentagonal rings which are easily oxidized compared with hexagonal rings of graphen sheet. Then, only cap of SWNTs would be eliminated without any damages in the nanotube wall. The G-band intensity and G/D ratio are summarized in Fig. 3 as a function of annealing temperature during the cap-opening process. Both the G-band intensity and the G/D ratio did not change after annealing at temperatures below 470°C, whereas significant decrease in them was observed after annealing at temperatures above 500°C. This suggests that the annealing below 470°C did not cause any detectable damages in the SWNTs.

The insertion of fullerenes into the cap-opened SWNTs was carried out by vapor phase method [8]. The substrate with the SWNTs was put into a sealed glass ampoule with fullerenes, and then heated at 500°C for 2 days. Figure 4 shows a TEM image of synthesized Gd@C_{82} peapods. A one-dimensional array of Gd@C_{82} fullerenes was observed. We confirmed the encapsulation of fullerenes into SWNTs annealed at temperatures above 450°C.

Figure 5 shows I_D-V_{GS} characteristics of the fabricated devices, (a) Gd@C_{82} peapod FET and (b) SWNT FET. The peapod FET shows p/n-type ambipolar characteristics, while the SWNT FET shows p -type characteristics. The ambipolar characteristics can be explained by Schottky-contact-current-control model of nanotube FETs with a narrow bandgap nanotube. These results are consistent with the previous work [3], suggesting that the proposed method is promising for the fabrication of peapod FETs.

3.Summary

We have successfully fabricated peapod FETs using peapods synthesized directly on a SiO_2/Si substrate. The cap of the SWNTs synthesized on a substrate was eliminated by annealing in dry air at 450~470°C for 30 min without any damage in the carbon wall. The insertion of fullerenes into the cap-opened SWNTs was performed by vapor phase doping method. The fabricated Gd@C_{82} peapod FET showed ambipolar characteristics.

References

[1] S. Okada, *et al*., Phys. Rev. Lett. **86** (2001) 3835.
[2] J. Lee, *et al*., Nature **415** (2002) 1005.
[3] T. Shimada, *et al*., Appl. Phys. Lett. **81** (2002) 4067.
[4] T. Shimada, *et al*., Phys. E **21** (2004) 1089.
[5] H. T. Soh, *et al*., Appl. Phys. Lett. **75** (1999) 627.
[6] Y. Ohno, *et al*., Jpn. J. Appl. Phys. **42** (2003) 4116.
[7] Y. Murakami, *et al*., Chem. Phys. Lett. **385** (2004) 298.
[8] K. Hirahara, *et al*., Phys. Rev. Lett. **85** (2000) 5384.

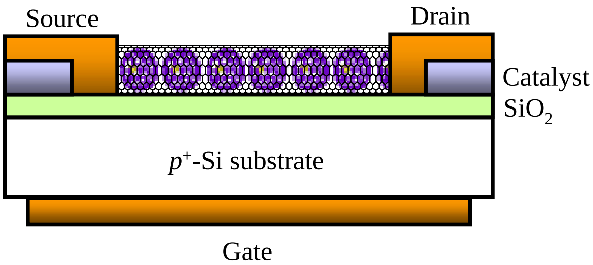

Fig.1 Schematic of peapod FET.

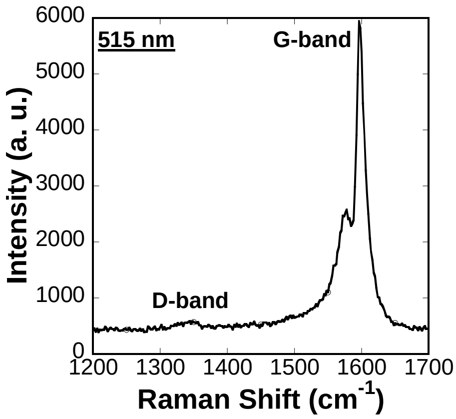

Fig.2 Raman scattering spectrum of the SWNTs.

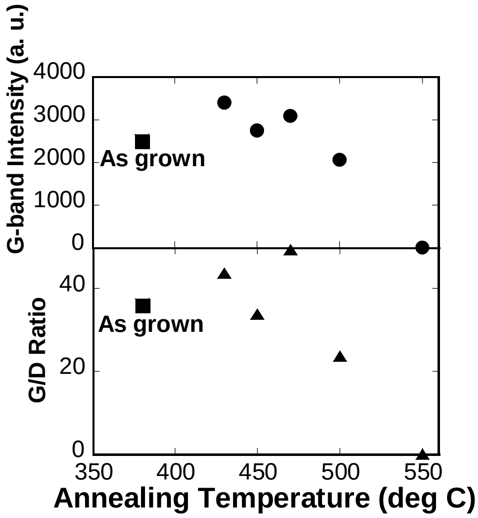

Fig.3 G-band intensity and G/D ratio versus annealing temperature.

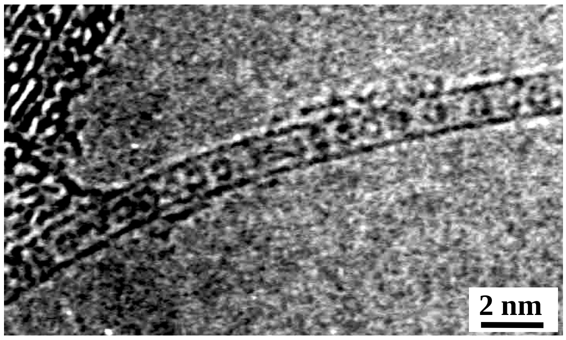

Fig.4 TEM image of Gd@C_{82} peapods.

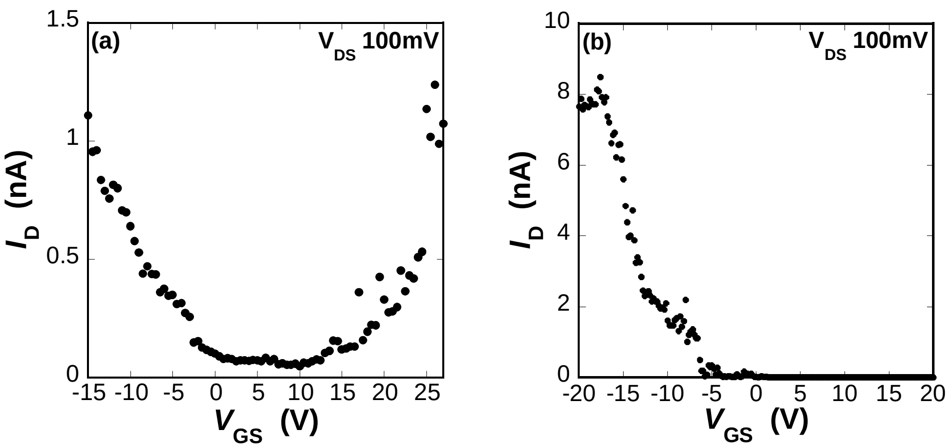

Fig.5 I_D-V_{GS} characteristics of (a) Gd@C_{82} peapod FET and (b) SWNT FET.