Synthesis of peapods directly on Si substrate for FET application

°Y. Kurokawa[1], Y. Ohno[1,2], T. Shimada[3], Y. Murakami[4], A. Sakai[1], M. Ishida[3], S. Kishimoto[1], T. Okazaki[3], K. Hiraga[5], S. Maruyama[4], H. Shinohara[3,6,7], and T. Mizutani[1]

[1]Grad. School of Eng., Nagoya Univ., Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
[2]PRESTO/JST, [3]Dept. Chem., Nagoya Univ., [4]Dept. of Mechanical Eng., Univ. of Tokyo,
[5]Inst. for Materials Research, Tohoku Univ., [6]CREST/JST, [7]Inst. for Advanced Research

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

In the previous studies on peapod FETs, the devices were fabricated by dropping peapods on a SiO_2/Si substrate with electrodes. In this method, peapods were obtained as soot, dispersed in organic chemical solution, and then dropped on a SiO_2/Si substrate with electrodes. In this case, the yield of peapod FETs were quite low.

In this study, we have successfully synthesized C_{60} peapods and Gd@C_{82} peapods directly on SiO_2/Si substrate. The proposed procedure for the synthesis of peapods is as follows; 1) catalytic metal deposition on a SiO_2/Si substrate, 2) thermal chemical vapor deposition (CVD) of pod SWNTs, 3) cap opening of the pod SWNTs by annealing in dry air, and 4) doping of pea fullerenes in vapor phase [3].

In the present work, in order to obtain sufficient amount of peapods for the characterizations such as TEM observation and Raman scattering, we employed the dip-coating method for catalytic metal deposition on the substrate and the alcohol catalytic CVD for the synthesis of pod SWNTs [4]. We determined the condition of the cap opening of SWNTs by Raman scattering spectroscopy measurement. The G-band intensity and G/D ratio are summarized in Fig. 1 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.

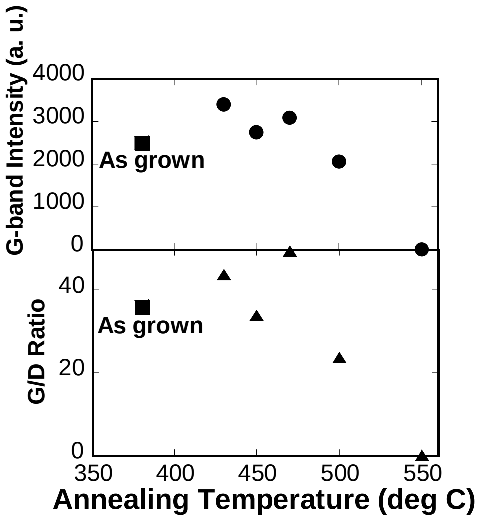

Fig. 1 G-band intensity and G/D ratio versus annealing temperature.

Figure 2 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.

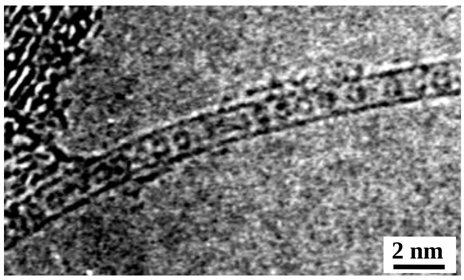

Fig. 2 TEM image of Gd@C_{82} peapods.

[1] T. Shimada, *et al.*, Appl. Phys. Lett. **81** (2002) 4067.
[2] T. Shimada, *et al.*, Phys. E **21** (2004) 1089.
[3] K. Hirahara, *et al.*, Phys. Rev. Lett. **85** (2000) 5384.
[4] Y. Murakami, *et al.*, Chem. Phys. Lett. **385** (2004) 298.
Corresponding author: Y. Ohno, E-mail: yohno@nuee.nagoya-u.ac.jp