Synthesis of peapods directly on Si substrate for FET application

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Single-walled nanotubes (SWNTs) encapsulating fullerenes, so-called peapods, are attracting attention for semiconductor 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 C₆₀, C₇₈, and metalofullerenes as Gd@C₈₂, Dy@C₈₂, and so on [1,2]. The devices showed ambipolar behaviors, 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 SiO₂/Si substrate with electrodes. In this method, peapods were obtained as soot, dispersed in organic chemical solution, and then dropped on a SiO₂/Si substrate with electrodes. In this case, the yield of peapod FETs were quite low.

In this study, we have successfully synthesized C₆₀ peapods and Gd@C₈₂ peapods directly on SiO₂/Si substrate. The proposed procedure for the synthesis of peapods is as follows; 1) catalytic metal deposition on a SiO₂/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.

Figure 2 shows a TEM image of synthesized Gd@C₈₂ peapods. A one-dimensional array of Gd@C₈₂ fullerenes was observed. We confirmed the encapsulation of fullerenes into SWNTs annealed at temperatures above 450°C.

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