331h Synthesis of Millimeter Long Vertically Aligned Single-Walled Carbon Nanotubes by Point-Arc Microwave Plasma Cvd

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A decade has passed since the discovery of single-walled carbon nanotubes (SWNTs), but the main methods for synthesizing SWNTs such as laser ablation, arc discharge and thermal (or catalytic) chemical vapor deposition (CVD) are still subject to the following disadvantages; high (800-1200°C) growth temperature requirement, low production yield (the mass ratio of SWNTs to catalyst) or high catalyst contamination, and out of control of the as grown SWNTs (usually randomly oriented, entangled bundles or ropes). All these make the purification and application of SWNTs very difficult. Plasma assistant CVD is good at controlled growth of multi-walled carbon nanotubes (MWNTs) at low temperatures. However it rarely succeeded in the growth of SWNTs. In this study, we demonstrate the low temperature (600°C) synthesis of very dense (1E16/m2) and vertically aligned SWNTs by point-arc microwave plasma CVD [1], which overcomes all the above mentioned disadvantages. Vertically aligned SWNTs were synthesized at a low temperature of 600°C on Si substrates coated with a sandwich-like structure Al2O3 /Fe /Al2O3 (/Si). Al2O3 between Si and Fe is a buffer layer to prevent them from reacting. On the other hand, Al2O3 above the Fe film works as a barrier of the surface diffusion of catalytic atoms so that the aggregation of Fe atoms can be suppressed during the pre-heating time. As a result, dense catalytic particles can be formed and extremely dense and vertically aligned SWNTs can be synthesized. To identify the SWNT samples, TEM and Raman spectroscopy were used. TEM observations show that almost all tubes are single-walled. Raman spectra of as-grown SWNTs have fingerprint features of SWNTs: the sharp tangential mode G peak, the shoulder of G peak and the radial breathing mode (RBM) peaks. From the RBM peaks, their diameters range from 0.5 to 3.0 nm. The thickness of SWNTs can increase as the growth time increases, and the lifetime of the catalyst is more than 10 hours at the growth rate of 2 μm/min, so millimeter long vertically aligned SWNTs can be synthesized. A production yield (mass ratio of SWNTs to catalyst) and a volume density are 2,500,000% and 66 kg/m3, respectively. The production yield is 50 times as high as that reported by Hata[2]. Up to now, the growth temperature about 600°C is the lowest, while both the volume density and the production yield are the highest for the synthesis of SWNTs. We have also succeeded in position control of SWNTs, showing potential for applied researches such as field emitters and vertically aligned field effect transistors using our as-grown vertically aligned SWNTs without further purification. [1] G. Zhong et al., Chem. Vap. Deposition 11, 127 (2005) [2] K. Hata et al., Science 306, 1362 (2004)