Gas Pressure Effect on Density of Horizontally Aligned Single-Walled Carbon Nanotubes Grown on Crystal Quartz Substrates

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§1 Introduction

Toward device applications of single-walled carbon nanotubes (SWCNTs), the alignment control is of great importance. Since the postgrowth manipulations of SWCNTs usually cause degradation of SWCNT properties due to the dispersion process, the direct growth of aligned SWCNTs is desired. Horizontally aligned SWCNTs, which are the ideal configuration for the fabrication of field effect transistors (FETs)[1], have been grown by chemical vapor deposition (CVD) using surface atomic structures of crystal quartz or sapphire substrates[2,3]. Because the performance of FETs fabricated from horizontally aligned SWCNTs depends essentially on the density of SWCNTs, high-density growth is necessary for high performance FETs. In this study, we examined the effect of gas pressures on the growth process of horizontally aligned SWCNTs.

§2 Experimental Method

R-cut crystal quartz substrates (Kyocera Corp.)[4] were used in this study. Chemical etching by ammonium hydrogen fluoride for 5 min and annealing in air at 900 °C for 12 h were performed in order to improve the crystallinity of quartz surfaces. Patterned iron nanoparticles were prepared as catalysts by photolithography and vacuum evaporation. Horizontally aligned SWCNTs were grown by alcohol CVD method[5] using ethanol as a carbon source gas at different gas pressures. SWCNTs were investigated by scanning electron microscopy (SEM), atomic force microscopy (AFM), and Raman spectroscopy.

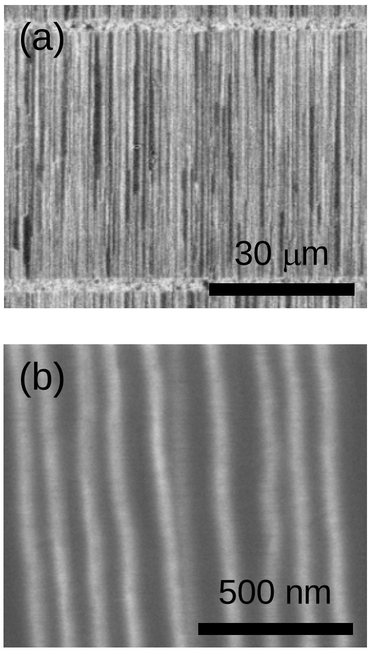

Figure 1 (a) Low and (b) high magnification SEM images of SWCNTs grown at 60 Pa for 10 min.

§3 Results and Discussion

Horizontally aligned SWCNTs were grown on R-cut quartz substrates under different gas pressure conditions. SEM images showed that the density of horizontally aligned SWCNTs increased with decreasing gas pressures (Figure 1). Moreover, we observed the growth process of horizontally aligned SWCNTs by changing the growth time. The time evolution of SWCNTs (Figure 2) grown under 60 and 1300 Pa showed a large difference. The number of SWCNTs continued to increase even after 5 min under the low pressure condition, while that almost completely saturated within 3 min under the high pressure condition. We examined the distributions of the incubation time by subtracting the number of SWNTs in each growth time, and found that the incubation time is longer and the distribution of that is wider at low pressure. Since the simultaneous start of SWCNT growth may cause forming bundles of SWCNTs above the substrates and prevent the horizontally aligned growth, the wide distribution of the incubation time is considered to reduce the possibility of the simultaneous start of neighboring SWCNTs and enable high-density growth.

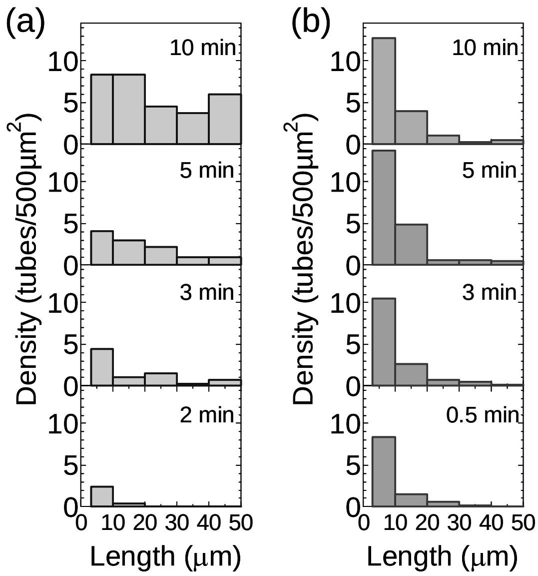

Figure 2 Length distributions of SWCNTs grown at (a) 60 and (b) 1300 Pa.

§4 Conclusions

We studied growth of horizontally aligned SWCNTs on R-cut crystal quartz substrates under different gas pressure conditions. Density of horizontally aligned SWCNTs increased with decreasing gas pressures. We found that the lower gas pressure extended the incubation time and widened the distribution of that. The underlying mechanism of the gas pressure effect was discussed based on the incubation time.

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