

Controlled Synthesis of Carbon Nanotubes by Various CVD and PECVD Methods

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Introduction

Due to their unique structure and properties, carbon nanotubes (CNTs) have attracted a great deal of attention as model systems for nanoscience and for various potential applications, including composite materials, electrode materials, field emitters, nanoelectronics, and nanoscale sensors. Prominent current challenges are controlled synthesis in ways that allow the potential applications of CNTs to be explored. The most important challenges of CNT synthesis at present include the following aspects: (i) CNT production with low-cost, large-scale and high quality; (ii) control over structure and properties; (iii) control over the location and orientation of the produced nanotubes on a flat substrate; and (iv) the development of a thorough understanding of the growth mechanisms of CNTs [1]. The main synthesis methods of CNTs include arc discharge, laser ablation and chemical vapor deposition (CVD). While first two methods use high-energy input to release the carbon atoms from carbon-containing precursor molecules, CVD relies on carbon atomization via catalytic decomposition of carbon precursors on the surface of transition metal particles such as Fe, Co, Ni or their alloys. The CVD method is thought to be a very effective synthesis route for economically producing CNTs in bulk and on a substrates as aligned, patterned structures [2,3,4]; however, the required high temperatures limits the scope of applications. Plasma Enhanced CVD (PECVD) has the main advantage that the molecular dissociation does not entirely rely on substrate temperature. The energetic electrons in plasma contribute significantly to the decomposition of hydrocarbon molecules, which in turn allows one to grow semi-conducting single-walled CNTs [5]. In this presentation, a brief review of PECVD techniques and some examples of CNTs synthesized by CVD and PECVD will be given.

Experimental

Both microwave and RF plasma excitation techniques have been used in our laboratories. The PECVD device used for this study (SPT420H, developed by PLASMIONIQUE Inc.) is a computer controlled hybrid reactor that allows in-situ substrate cleaning, deposition of catalyst, post treatment of catalyst, synthesis of CNT and subsequent deposition of active particles/films on the synthesized CNT, without exposing the samples to atmosphere. The reactor includes three sputtering magnetrons and a radio-frequency (RF) plasma source. Provisions for substrate heating and biasing is also included in the system. Typical base pressure in the chamber is in the range of 10^{-7} torr. The substrate can be

moved in order to achieve optimum distances between substrate and source for process control. Substrate temperature can be controlled between room temperature and 800 °C.

In experiments reported here, Fe films (0.3-1 nm) with 30 nm Al buffer layer were sputtered on n-type Si wafers and Si with a 600 nm layer of SiO₂. The processing pressure for CNT synthesis was in the range of 1-5 Torr. The substrate was heated to temperatures of 550-600 Celsius. Methane gas was used as carbon source while Ar and, for some experiments, a low flow of H₂ were included in the processing mix gas. The metastable Ar atoms in plasma improve the ionization and decomposition rate, and additional H atoms help to remove the loosely bonded graphitic carbon from the synthesized film. After experiments, the deposition chamber was left under vacuum to cool down to room temperature in an inert atmosphere. FE-SEM, TEM and HRTEM were used to characterize the samples.

Results

A carpet-like CNT films were grown on substrates and characterized using different techniques. The SEM image shows aligned and clean CNTs on silicon substrate. The length of the CNTs is 17 microns. For these particular experiments TEM observations reveal that the tubes have uniform diameters ranging from 6 to 10 nm. In addition, we can grow patterned CNTs (Fig.1) with controlled area sizes. We will further present and compare various controlled synthesis of CNTs by CVD and PECVD techniques, and will elaborate on measurements of the infrared response of simple CNT-base devices, and their dependence to temperature.

References:

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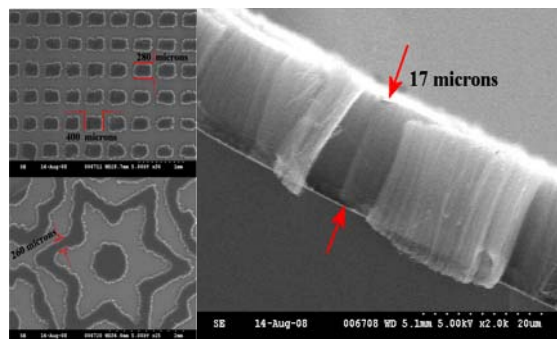


Fig.1 SEM images of the patterned MWCNTs by PECVD