CVD Growth of Carbon Nanotubes: Catalyst, Growth, and Structure

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Carbon nanotubes (CNTs) exhibit extraordinary mechanical and unique electronic properties and hence have been receiving much attention in recent years for their potential in nanoelectronics, field emission devices, scanning probes, high strength composites and many more applications.

In the early years of CNT research, the primary approaches to produce nanotubes consisted of laser vaporization and arc-evaporation of graphite electrodes. More recently, catalytic decomposition of hydrocarbon or CO feedstock with the aid of supported transition metal catalysts - also known as chemical vapor deposition (CVD) - has become popular (1-5). CVD provides a simple approach to growing CNTs on patterned substrates and proceeds at temperatures below 1000° C, substantially lower than in laser ablation and carbon arc processes. More recently, low temperature plasmas have been used in growing CNTs (6-15). The conventional wisdom for plasma processing in microelectronics is that it allows preparation of thin films at substrate temperatures significantly lower than that possible with thermal CVD. Such an advantage is highly desirable in many applications that stand to lose certain characteristics of the processed substrate at elevated temperatures (for example, charring of the photoresist or melting of the substrate). This advantage of the plasma may not be realizable in CNT growth since the catalyst activity is significant only above a temperature of 550°C. Nevertheless, a plasma process is useful as it grows more vertically aligned nanotubes than thermal CVD.

We have used ion beam sputtering (IBS) for the deposition of the metal catalyst for the growth of single walled carbon nanotubes (SWNTs), multi-walled carbon nanotubes (MWNTs), and multi-walled carbon nanofibers (MWNFs). IBS allows for the deposition of the catalyst over a large area with uniform deposition and for the shadow masking or lithographic patterning of the catalyst. By controlling the catalyst formulation and the growth conditions, the type and density of the CNTs grown can be controlled. This flexibility of growth allows for the construction of a variety of different structures and applications based upon CNTs and for a number of generalities to be drawn between these systems.

In this presentation, we will present our results on SWNT, MWNT, and MWNF growth using both CVD and PECVD. Characterization of these structures has been performed using SEM, TEM, Raman spectroscopy, and EDX. The catalyst surface has been characterized using AFM and STM to determine the particle size. We have been able to develop an understanding of the effects of catalyst composition as well as layer thickness on the resulting structure of the CNTs. In addition, we have also conducted parametric studies varying pressure, feedstock composition, growth temperature, and applied power (in PECVD) to determine their influence on the growth characteristics.

The aim of this invited talk is to present important results on CVD of nanotubes along with the application potential, while emphasizing the need for diagnostics and modeling-an area where the ECS/ EURO CVD community has made past contributions related to semiconductor and other materials.

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