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Title of Thesis : **Growth & Characterization of Carbon Nanotubes Using Catalysts**

Abstract

We aimed to grow single wall carbon nanotubes (SWCNTs) and multi wall carbon nanotubes (MWCNTs) using plasma enhanced chemical vapour deposition (PECVD) system with optimization of process parameters like pre-treatment, temperature and pressure, application of different catalysts in different forms which also lowers the growth temperature and its impact on the synthesis. We also aimed to synthesize MWCNTs using different catalyst by low pressure chemical vapor deposition (LPCVD) System. Because of the huge installation and safety obligations of the PECVD system, the infrastructure requirements specially two stage wet scrubber, gas safety cabinet, ultra high purity piping, equipment and pump enclosures exhaust, final exhaust delivery, dampers, associated sensors etc were indigenously designed, got fabricated, commissioned and tested in our laboratory. After installation of PECVD system, we have performed many experiments with optimum growth conditions/parameters to optimize the growth of SWCNTs using different catalyst and with varying growth conditions such as pre-treatment temperature, pressure, flow of gases and also the growth temperature, growth pressure, flow of the source gas during growth process. SEM micrographs of different samples depict the uniform and vertically aligned growth of SWCNTs with diameter distribution in the range of 1 – 4 nm and length up to hundreds of microns. The structural analysis has been done using HRTEM which also reveals the diameter distribution of different samples in the range of 1-4 nm. To evaluate the quality of nanotubes, we performed Raman characterisation of as-grown CNTs using a laser with an excitation wavelength of 633 nm. The presence of radial breathing mode (RBM) peak in all the as grown samples clearly confirms the existence of SWCNTs. The diameter of grown SWCNTs was also estimated using the correlation, $d = 248/\nu$, which is found in accordance with SEM results. The field emission measurements were carried out in a vacuum chamber

under pressure of 10^{-6} Torr to minimize the electron scattering and degradation of the emitters. FE measurements reveal the high current density at low turn on field with good field enhancement factor which is in favor of field emission devices. Multi wall carbon nanotubes have been grown using LPCVD system on Fe coated Si substrate. The Fe catalyst films were prepared by electro-chemical method, a unique and low cost method, as well as using RF sputtering system. SEM images reveal that synthesized MWCNTs are aligned and uniformly distributed with a high density. HRTEM micrographs depict the structural analysis of grown MWCNTs with diameter in the range of 20 to 50 nm. In almost all the samples of Raman spectra, The G-band is higher than D-band, which indicates that grown MWCNTs are highly graphitized. J-*E* curve and *F-N* plot of as grown Fe catalyzed CNTs were analysized and found that our results are in good agreement with the other workers. In another study, vertically aligned CNTs with optimal combinations of density, diameter and length have been grown using PECVD system on the Fe and Ni coated Si substrates for large area applications. The field emission behaviour of CNTs is affected by these factors, especially in the device applications. Using FESEM the rough diameter of grown CNTs is found in the range 30-80 nm with length of several micrometers. FE characteristics of the grown MWCNTs were recorded and found that MWCNTs grown on Ni catalyst are better field emitter than MWCNTs grown on Fe catalyst. Apart from the experimental work, we have also tried to make an effort on modelling and simulation of SWCNTs. As, it might not be feasible to experiment a dozen or a hundred processes to make SWCNTs suitable for various applications therefore in this correlation, we have used a theoretical/computational model so that theoretical results can simulate best optimization experimental condition for the synthesis of SWCNTs for a choice of applications. In this regard, we have optimized the performance of SWCNT based field effect transistors (CNT-FETs) by changing the transistor's structural parameters such as CNT diameter, gate dielectric thickness, and gate dielectric constant. Using these parameters, I-V characteristics have been measured under different parametric variations.