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Title of Ph. D. Thesis : **Growth and characterization of Carbon Nanotubes by CVD system and its optimization at different parameters**

ABSTRACT

Science has gone beyond Moore's law and with advancements in nanotechnologies conventional technological limitations and thresholds are being overcome. Carbon nanotube is one of the materials opening new opportunities in the field of sensors and nanodevices. Present work involves growth of various forms of Carbon nanotubes and characterized via studying several parameters such as kinetics of precursor kinetics, carrier gases, growth temperature, temperature ramp, catalyst engineering and pre-growth substrate treatment etc. Controlled and selective growth of CNTs has been difficult, thus limiting the mass production of high quality CNTs. Cost is yet another constraint. My Ph.D. research has provided detailed study of CNT growth process and parameter optimization to produce high purity CNTs. A low cost solution as well researched and developed for the same.

Flow properties of CNT forming gas is one of the important determinants of the CNT quality and yield. The optimization for smaller diameter and sufficient length and yield of grown CNTs was achieved at 20-sccm flow rate and 12-min flow duration. Argon as carrier gas was used for CVD based CNTs fabrication. Height of grown CNT carpet was found to increases with increment in flow rate of Ar gas (from 0sccm to 60sccm) followed by a decrease. On the other hand, diameter and number of walls in grown CNTs varied inversely with height. Graphitic structural quality of CNTs also varied with flow rate of Ar gas and the best quality of CNTs with optimized length, diameter and structural quality was found with 60 sccm Ar flow rate. This study paved the way for better understanding of growth mechanism of CNTs and its industrial applications where customized physical characteristics are needed.

Temperature is yet another parameter crucial to CNT growth using Thermal CVD. It was observed that the temperature has an effect on the structure and morphology of CNTs. Diameter,

length and yield of CNTs can be controlled via temperature based hydrocarbon decomposition optimization. Catalyst breaking and structural qualities of CNTs can be controlled via controlling temperature increasing rate. My Ph.D. work concluded that best quality CNTs can be grown at 800°C growth temperature with as high as possible temperature increasing rate and the size of catalyst does not play any role in deciding the diameter of CNTs as in every case diameter of CNTs found to be much lesser than diameter of catalyst particles.

Catalyst material and deposition adds cost to the overall CNT growth process. A detailed study of CNT growth was performed on flat alumina (Al_2O_3) substrate, scratched silicon substrate and use of an unconventional material. It was found that catalysts particle only helps the CNTs growth by providing activated nucleation sites. Once the CNTs growth starts role of catalyst ends. Also, catalyst free CNT growth is possible on any substrate whose top surface is rough and can bear 700°C temperature. Unconventional sources such as HB pencil and green plant extract were used as catalyst, which brought down growth temperature to a low value (575°C) and exceptionally high yield in comparison to other catalysts reported so far; This method is low cost and environment friendly. Growth of SWNT as well as carbon Nano-ribbon are also observed when growth temperature increased to 800°C, and this observation was confirmed by microscopic and spectroscopic analysis. Literature survey reveals that this phenomenon perhaps is observed first time by our group. The experiments were executed for other plant extracts taken from garden grass, rose, and neem. MWCNTs growth was observed in all the extracts. The formation of nano-ribbon and SWCNTs were not observed in other extracts at CVD temperature 800°C. With HB pencil catalyst, we were able to grow patterned CNTs on any design without used any lithography type technique. Different orientation growth strategies for the growth of vertical as well as horizontal networks of CNTs were also studied. Oxygen plasma pretreatment was found to change the orientation of CNTs. Without plasma treatment a horizontal network of CNTs was observed whereas, with Oxygen plasma pretreatment a dense carpet of vertically aligned CNTs was observed. Through this research work it is also concluded that for synthesis of vertically aligned CNTs, ferric nitrate as catalyst can be used and for horizontal network cobalt nitrate can be used. Besides, magnesium nitrate as catalyst was found to have poor catalytic quality among all the three catalysts but still we can use magnesium nitrate where low density of nanotubes is required.