Title of Thesis:	***Synthesis of Carbon Nanotubes for Device Applications***
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ABSTRACT

Carbon nanotube (CNT) is the most versatile material due to nano scale dimensions, high electrical conductivity and strength along with other physical and chemical properties which make them a unique material for electron field emitters. Field emission (FE) properties of CNTs have been sustained area of research, which led to the development of various devices like flat panel display, cathode ray tubes, lighting lamp, scanning probe microscope, microwave amplifiers, etc. in the last many years.

This research work was focused on synthesis of CNTs on silicon substrate by LPCVD and PECVD techniques for FE based devices. Single walls as well as multiwall CNTs have been synthesized and the growth parameters were optimized for vertical alignment of CNTs. Preliminary experiments show the role of catalyst in alignment of MWCNTs. I found that aligned MWCNT arrays can be obtained on Fe catalyst while randomly oriented MWCNTs on Co catalyst. Furthermore, in-depth studies on the nature of this self-alignment have been carried out and findings suggest that adhesion between Fe catalyst and Si substrate also have significant effect on alignment. FE characteristics of as grown MWCNTs/SWCNTs have been studied in diode configuration. To enhance the FE behaviour of CNTs different treatments have been employed.

Dual layer deposition method concludes that it is very effective method to improve the aspect ratio and also number of field emitters. As a result of this, field enhancement factor is enhanced approximately ~3.4 times from 4000 to 13500 and contributed to give much better current at very low electric field. Dynamic-oxidation of CNTs exhibits robust improvement in emission current density and their results have been analyzed. Dynamic oxidation improves FE behavior of CNTs by removing amorphous carbon and C-type impurities on the surface of CNTs. The effective emitting

area is increased after D- oxidation treatment of CNTs film which is responsible for high current density and low turn on field. Repeatability of CNTs based FE devices have been studied by high voltage treatment with hysteresis. Although, all FE parameters are affected by this treatment, stability and repeatability of emission current are significantly improved. Thus, the high voltage treatment is demonstrated to be an effective way to improve the stability of CNTs field emitters.

To alter the surface as grown SWCNTs, N_2 plasma treatment was very effective and wide capacitive approach. In this approach, N_2 molecules are attached on the surface of CNTs and create new emission sites for electrons. After N_2 plasma treatment, current density of SWCNTs was improved more than three-fold. Hence, this significant increment in current density may be attributed with modified surface with N_2 molecules by providing extra emitting sites for emission of current. Considerable reduction in the turn-on electric field was also observed. Plasma treatment is very efficient and versatile physical technique for modification of CNTs. Plasma study suggests that other gases may be employed in place of N_2 gas to well tune the FE properties of CNTs. This study may be continuing to further research. These proposed approaches have significant role in improving the performance of CNT field emitters in term of current density, turn on field, field enhancement factor, emission stability and repeatability. Thus, these results offer remarkable enhancement in FE behaviour of MWCNTs as well as SWCNTs. These can be easily utilized in CNT based field emitters for various potential applications in nanoscale devices.

Fowler-Nordheim equation is the best way to analyse the FE data. In this research work, mathematical formula for estimation of effective emitting area was derived using Fowler-Nordheim equation. Derived formula shows that emitting area of the CNT based field emitters mainly depends on the applied electric field, current density, field enhancement factor and the work function. It was found that high electric field is required for the emission of electrons from a small area of uniformly distributed CNTs film. For high electric field, low effective area is required for optimum emitting current. It was also estimated that device area should be in the range of 1 cm^2 for obtaining the 1 A current. Therefore, it may be concluded that $1cm^2$ area of uniformly distributed CNTs film is sufficient for making FE based devices. These results will be helpful in further study of field emission behavior of CNTs for device applications.