CHAPTER 6
CONCLUSION AND FUTURE SCOPE

Nanocarbons are grown with different process technology at different deposition conditions has different morphology, dimension, composition (such as sp²/sp³ bonding ratio) and different properties. The study of nanocarbon series includes nanodiamond, fullerene, carbon nanotubes, graphene, nanowall, taC and nanocluster carbon. Most of these nanocarbons are grown at high temperature process, except the nanocluster carbon, which is grown at room temperature using cathodic arc system. Nanocarbon has good electrical, electronic, mechanical and chemical properties, so they find their importance in molecular level engineering. To understand the surface details or morphology of the nanocarbons studied their SEM /AFM micrographs. To understand the similarity or dissimilarity among the group of nanocarbon considered random set of nanocarbon grown at different process, but having different bonding ratio. A group of nanocarbons consisting 32 samples including nanocluster carbon, nanodiamond, CNT, graphite rich sample, and diamond are grouped into 3 nanocarbon classes. In this group diamond has sp³ bonding and graphitic like nanocarbon film has sp² bonding rich. The other nanocarbons have their shape or structure different from diamond or graphite may have mixed phase of sp² and sp³ along with bond disorder are described with the bonding ratio.

The reported cathodic arc (either as continuous or pulsed arc) process is one of the best process technologies to grow nanocarbons. It has already been demonstrated as suitable for applications in the areas like tribology, low K dielectrics and conformal metal coating for VLSI/ULSI. This process is of great interest because it offers great opportunity for tailoring nanocarbon based materials over a wide range of properties from conductor to semiconductor to insulating. The low temperature nanocluster carbon growth process may be one of the best
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process techniques. This process is more compatible with the conventional microelectronics industry. The low temperature process enabled growth also promises usage of theses nanocarbons for flexible electronics or electronics on glass or plastic.

Reported here one of the first studies on room temperature grown nanocluster carbon deposited using cathodic arc system. The samples are seen grown at various process conditions such as helium partial pressure (0.1torr-50torr), with different nitrogen partial pressure such as $10^{-3}$ or $10^{-4}$torr. However its morphological, dimensional and compositional properties are dependent on the process parameter such as Temperature, Pressure, Compositional Gas ratios, Ion energy, Arc type (continuous arc or pulsed arc), Bias voltage across anode & cathode, Arc current and Arc voltage. Also the graphite source, the compositional gas has a great influence on the property of the nanocarbon film. The growth of clusters are observed with a set position of around 150mm -250mm, with an applied bias of 10V-50V at 0.5amperes.

The developed image processing approach for cluster dimension estimation and analysis is helpful in the in-situ process technology. Where estimation of median dimension or evaluating the details of the distribution of cluster decides the quality of the film as well quantify the number of clusters having the same dimension. The approach for cluster identification and estimation of the cluster area, along with the histogram plot evaluates the thin film surface characteristics indicating the median size cluster and structure distributions.

Raman measurement could be done quickly, without sample preparation so it is instantaneous. There is no sample preparation process such as dissolving or compressing or pressing, thus the sample physical or chemical structure is not altered and makes this measurement non-destructive. This makes Raman spectroscopy ideal for investigating physical properties such as $sp^2$-$sp^3$ bonding details (composition) and indirectly helps in
understanding the quality or nature of the film. Thus among many characterizing techniques Raman spectroscopy offers the option of nondestructive, instantaneous characterization and is an indirect method used for nanocarbon analysis. Raman measurements of low temperature grown nanocluster carbon has shown that they are amorphous and disordered nature. The statistical based or Principle component based classification of nanocarbons are clearly indicates possibility of identifying or grouping the nanocarbon based on their structure or composition. This pattern based grouping approach follows the feature extracted from the Raman response. Indicated possibility of grouping nanocarbons having varying sp² / sp³ ratio based on the features extracted from Raman response. The quality analysis and correlation study of SEM and Raman responses helps in automation of the production of nanostructures.

To understand whether the nanocluster carbon is metallic or semiconducting studied the electrical, electronic nature, carrying out conductivity measurements. The conductivity study of nanocluster carbon has promised its semiconducting nature and also temperature sensing nature. The vacuum diode configured display unit ensures the cathodic arc based low process technology for large area electronics.

The morphological, structural, dimensional and the compositional based study would support the in situ applications of nanocarbons. The proposed image processing approach for cluster dimension estimation and distribution, along with the Raman analysis would be a good model for the future molecular engineering (bottom up approach). Further optimizing and generalizing this may be used along with the controlled growth or self-aligned growth of nanocarbons.

Nanofabrication techniques such as Hot Filament Chemical Vapor Deposition (HFCVD), Thermal Chemical Vapor Deposition, and cathodic arc process, have unfolded different self-aligned nanomaterial’s which function as the building blocks of future nanoelectronic
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devices or expected to be a part of SoC or SiP. The promising nanocarbon materials are expected to be part of smart systems for biomedical applications and especially looking at novel sensors and systems to be used within the body. CNT field emitters installed in miniature low power X-ray tubes has a focal spot is in terms of few tens or hundreds micrometers. The nanodiamond is a promising material for tribological coating on implants or surgical tools. Especially the low temperature grown nanocluster carbon films may be used along with large scale electronics or can be used as a semiconductor. The graphite like thin films may be used in the design of sensors.

Once these materials are tested with biocompatibility, then the proposed nanocarbons may be used in the developments of invasive sensors or along with the implants in biomedical engineering.