Chapter 6

6.1 Conclusion

Carbon based nanomaterials like graphene, carbon nanotubes (CNTs), etc. are the new face of technology that has the power to revolutionize the world. New heights have been achieved in terms of technology, courtesy of the different allotropic forms of carbon. The synthetic routes of nanocarbon production are more or less established, but there is still a large scope for improvement when it comes to their efficient application. In this thesis, we have provided significant insights into synthesis method and characterization of various carbon based nanocomposites (*viz.* carboxylated multi-walled CNT/polyaniline nanotube (c-MWCNT/PAniNT) nanocomposite, carbon black/polyaniline nanotube (CB/PAniNT) nanocomposite, polyaniline nanotube/reduced graphene oxide (PAniNT/rGO) nanocomposite aerogel, silver nanorod/reduced graphene oxide (AgNR/rGO) nanocomposite aerogel and Pt/carbon dot (CD)/TiO_2 nanocomposite). Different techniques like *in situ* polymerization reaction, sol-gel synthesis and hydrothermal reaction have been employed to produce these nanomaterials. We have also established a route for synthesizing carbon dots with different coloured emissions by manipulating the carbon source and the solvent during solvothermal reaction process. These materials have been successfully applied in different areas like sensors, solar cell, supercapacitor and catalysis. The major outcomes of our studies are summarized below:

1. A Room Temperature Methanol Vapor Sensor Based on Highly Conducting Carboxylated Multi-walled Carbon Nanotube/Polyaniline Nanotube Nanocomposite.

(i) A novel c-MWCNT/PAniNT nanocomposite (with varying wt% of c-MWCNT) has been successfully prepared by *in situ* chemical oxidation polymerization of aniline in the presence of c-MWCNT.

(ii) The electrical conductivities of the nanocomposites show as increasing trend with increasing c-MWCNT quantity upto a threshold of 6 wt%.

(iii) The nanocomposite has been studied as a potential sensing element for methanol vapour.

(iv) The c-MWCNT/PAniNT (6 wt%) nanocomposite shows a quick change in resistance (60 s response time) on exposure to methanol vapour at concentration as low as 50 ppm.

(v) Density functional theory (DFT) computations affirm that the response of the nanocomposite upon exposure to alcohol vapour occurs due to formation of hydrogen bonds between the methanol molecules and the conjugated PAni chains.

2. A Low Cost Carbon Black/Polyaniline Nanotube Nanocomposite as Efficient Electro-catalyst for Triiodide Reduction in Dye Sensitized Solar Cells.

(i) A novel CB/PAniNT nanocomposite (with varying amount of CB) has been successfully prepared by *in situ* chemical oxidation polymerization of aniline in the presence of CB.

(ii) The nanocomposite has been studied as a potential Pt-free counter electrode material for dye sensitized solar cell (DSSC).

(iii) Cyclic voltammetry, impedance analysis and current density-voltage characteristic plots show that CB/PAniNT (0.75 wt%) nanocomposite exhibits significant ability to reduce triiodide ions at par with a Pt counter electrode.

(iv) A high photo-conversion efficiency of 6.62% has been realized with a DSSC fabricated with 10.58 μm thick nanocomposite film as the counter electrode in liquid electrolyte, while replacing the liquid electrolyte with a poly(methyl) methacrylate based polymer gel electrolyte produces an efficiency of 4.82%.

(v) The feasibility of CB/PAniNT (0.75 wt%) nanocomposite as a counter electrode is attributed to an increased catalytic surface area provided by the mesoporous CB.

3. Flexible Asymmetric Supercapacitor Based on Functionalized Reduced Graphene Oxide Aerogels with Wide Working Potential Window.

(i) A simple organic sol-gel technique has been successfully used to functionalize rGO aerogel separately with AgNRs and PAniNTs to obtain two different types of nanocomposites: AgNR/rGO aerogel and PAniNT/rGO aerogel by.

(ii) A flexible asymmetric supercapacitor (ASC) has been fabricated with AgNR/rGOA as the negative electrode (electrochemical double layer capacitive behavior) and PAniNT/rGOA as the positive electrode (pseudo-capacitive behavior) with H_2SO_4/polyvinyl alcohol acting both as a polymer gel electrolyte and a separator.

(iii) The ASC operates at a wide working potential window of 1.8 V, with significant energy and power densities.

(iv) Flexibility studies carried out on the device showed negligible effect of bending (upto 150º) on its performance.

4. Hydrothermally Synthesized Carbon Dots as Sensitizer for TiO_2 Supported Pt Photo-electrocatalyst for Broadening the Sunlight Response Region in Methanol Oxidation Reaction.

(i) A novel CD sensitized TiO_2 supported Pt catalyst (with different loadings of CD and Pt) has been designed by using a combination of hydrothermal method (with citric acid as the carbon source) and chemical reduction of chloroplatinic acid.

(ii) The catalyst (Pt3/CD2/TiO_2) exhibited superior performance for methanol oxidation reaction in terms of catalytic activity, CO poison tolerance and stability.

(iii) Two different types of catalytic processes occurred simultaneously during the reaction: photo-catalysis by CD sensitized TiO_2 and electro-catalysis by Pt.

(iv) CDs acted both as an inhibitor of CO poisoning and also as a sensitizer to TiO_2 by harvesting visible sunlight and providing extra photon energy to TiO_2 by using their unique up-conversion property.

5. Solvothermally Synthesized Green Emitting Carbon Dots as Co-sensitizer in Dye Sensitized Solar Cell.

(i) Green emitting CDs have been synthesized using solvothermal route with citric acid as carbon source using DMF as the reaction medium.

(ii) Elemental analysis places a high N content as the factor responsible for imparting them with green color.

(iii) CDs have been studied as a potential co-sensitizer for photo-anode in DSSC, and a high photoconversion efficiency of 6.9% has been realized with DSSC fabricated with G-CD and N719 dye co-sensitized TiO_2 photo-anode.

(iv) CDs improves the charge extraction process by absorbing higher energy blue light in addition to the green light by N719 dye molecules.

(v) The coincidence of the emission spectrum of CDs and the absorption spectrum of the N719 dye gives rise to a high probability of energy transfer occuring between CDs and the N719 dye, and also adds to the efficiency of the DSSC.

6. Solvothermally Synthesized Blue Emitting Carbon Dots as Fluorescence Sensor for 2,4,6-Trinitrophenol Detection in Organic Medium.

(i) Blue emitting CDs have been synthesized using solvothermal route with gallic acid as carbon source using DMF as the reaction medium.

(ii) CDs have been studied as a potential sensing element for 2,4,6-trinitrophenol (TNP) detection.

(iii) CDs show very fast and selective sensitive behavior towards TNP with a detection limit of 0.75 µM.

(iv) The sensing mechanism is based on the fluorescence quenching behavior of CDs in presence of TNP due to a combination of effects like inner filter effect and hydrogen bonding.

6.2 Future scope

Carbon based nanomaterials (standalone or nanocomposite) are structurally very important materials. They have and will, in the future, continue to attract the scientific community due to their exceptional properties and versatility in applications. Keeping that in mind, future work will be focused on:

(i) Improving and optimizing the synthesis protocols to obtain better properties like

(a) increased aspect ratios of the one-dimension al nanostructures,

(b) higher conductivities of the nanocomposites, and

(c) higher porosity and active surface area, etc.

(ii) Exploring the carbon based nanomaterials in related fields like

(a) water-splitting reaction, and

(b) carbon dioxide conversion to fuel, etc.