CHAPTER 8

CONCLUSIONS AND FUTURE PROSPECTS

This chapter outlines the main conclusions drawn from the present study, which deals with the synthesis, characterization and investigation of physico-chemical and electrochemical properties of reduced graphene oxide-polypyrrole nanotubes and reduced graphene oxide-polyaniline nanotubes nanocomposites and their swift heavy ion irradiation effects. The chapter also discusses the future prospects of research in this field.

8.1 Conclusions

The present thesis deals with the synthesis and characterization of nanocomposites of reduced graphene oxide and conducting polymer nanotubes viz., polypyrrole and polyaniline nanotubes. The physico-chemical and electrochemical properties of the nanocomposites have been studied by varying the concentration of reduced graphene oxide. The nanocomposite exhibiting the highest electrochemical performance has been irradiated with 85 MeV C^{6+} swift heavy ions to investigate the irradiation effects. Four different fluences of 6×10^{10}, 3.6×10^{11}, 2.2×10^{12} and 1.3×10^{13} ions cm^{-2} have been chosen to irradiate the nanocomposite films to investigate the fluence dependent electrochemical performance. The results of the work carried out in the present thesis are discussed in chapters 4, 5, 6 and 7 and the main conclusions drawn chapter-wise are summarized below:

Chapter 4: Reduced Graphene Oxide – Polypyrrole Nanotubes Nanocomposite Electrode System

1. Nanocomposites of reduced graphene oxide (RGO) and polypyrrole nanotubes (PPyNTs) have been synthesized by *in situ* reduction of graphene oxide (GO). Four nanocomposites have been prepared by varying the GO concentration as 5, 10, 20 and 40 wt. % with respect to PPyNTs. HRTEM micrographs confirm the formation of RGO and PPyNTs, where the average diameter of PPyNTs is

measured to be 132 nm. SEM micrographs display aggregation of PPyNTs at a low RGO concentration of 5 wt. %, while a homogeneous distribution of PPyNTs onto the RGO nanosheets is observed with increase in RGO concentration.

2. XRD patterns of the nanocomposites exhibit a broad diffraction hump in 2θ range of 19°-30°, which is due to overlapping of the XRD peak of RGO at 24.6° and broad hump of PPyNTs in 2θ range of 20°-30°. The degree of crystallinity calculated from the XRD data reveals an increase in crystallinity of the nanocomposites with increase in RGO concentration. This is attributed to the increasing content of crystalline RGO component in the nanocomposites.

3. FTIR analysis demonstrates a shifting in the absorption peaks of the nanocomposites from 1544, 1460, 1178 and 903 cm^{-1} to 1557, 1475, 1197 and 927 cm^{-1}, respectively. This shifting of peaks towards higher wave numbers suggests π-π interactions between PPyNTs and RGO nanosheets.

4. Thermogravimetric analysis reveals an increase in degradation temperature of the nanocomposites with increase in RGO concentration, which is attributed to the presence of RGO that acts as a mass transport barrier stabilizing the volatile and thermally decomposed components of PPyNTs.

5. The I-V characteristics of the nanocomposites follow a symmetric and non-linear variation of current with voltage as a result of their inhomogeneous structure consisting of conductive RGO nanosheets in amorphous PPyNTs matrix. The conductivity of the nanocomposites increases from 0.34 S cm^{-1} for pristine PPyNTs to 4.47 S cm^{-1} for the nanocomposite with 40 wt. % of RGO, which is ascribed to the presence of RGO nanosheets, which provide a low resistance path for charge transfer between PPyNTs.

6. The CV curves of the nanocomposites exhibit an enhanced current response and larger CV area upon incorporation of RGO. With increase in the concentration of RGO, a transition in the shape of the CV curve from non-rectangular to nearly rectangular shape is observed, which indicates the increased contribution of EDL charge storage arising from RGO in the nanocomposite. For 40 wt. % RGO-PPyNTs nanocomposite, the CV curve exhibits a quasi-rectangular shape with a slight distortion signifying the presence of both EDLC and pseudocapacitance contributions from RGO and PPyNTs, respectively in the nanocomposite.

7. The nanocomposite electrodes after incorporation of RGO display a longer discharge duration than that for pristine PPyNTs electrode as revealed by GCD

measurements. This implies enhanced charge storage capacity of the nanocomposites, which increases with increasing RGO concentration. The specific capacitance is calculated to be 128 F g^{-1} for pristine PPyNTs, which increase to 299 F g^{-1} for 40 wt. % RGO-PPyNTs nanocomposite electrode. The improved specific capacitance of the nanocomposites is attributed to the combined charge storage mechanisms of electric double layer from RGO and pseudocapacitance due to faradaic charge transfer from PPyNTs. PPyNTs onto the RGO nanosheets act as spacers and suppress the re-aggregation of RGO resulting in improved EDL contribution. Moreover, RGO nanosheets with high conductivity and surface area facilitate charge transport within the electrode and increase the electrode-electrolyte interfacial area. A maximum energy density of 24 W h kg^{-1}, power density of 192 W kg^{-1} and coulombic efficiency of 96% are achieved for the nanocomposite electrode with 40 wt. % of RGO loading.

8. EIS studies indicate significant decrease in the equivalent series resistance and charge transfer of the nanocomposite electrodes upon incorporation of RGO. Reduced Warburg impedance is observed in the nanocomposites, which indicates short ion diffusion path lengths and decreased obstruction of ion movement to and within the electrode.

9. The cyclic stability of the nanocomposite electrodes increases with increasing RGO concentration exhibiting a maximum capacitive retention of 77% after 1000 cycles for 40 wt. % RGO-PPyNTs nanocomposite as compared to 59% for the pristine PPyNTs electrode. This is attributed to the synergistic effect of both RGO and PPyNTs, where the hollow structured network of PPyNTs facilitates the electrolyte ion accessibility and multilayered RGO nanosheets assist in overcoming the volumetric strain in the electrode during the faradaic reactions.

Chapter 5: Swift Heavy Ion Irradiation of Reduced Graphene Oxide – Polypyrrole Nanotubes Nanocomposite Electrode System

1. The RGO-PPyNTs nanocomposite with RGO concentration of 40 wt. % have been irradiated with 85 MeV C^{6+} swift heavy ions at four different fluences of 6×10^{10}, 3.6×10^{11}, 2.2×10^{12} and 1.3×10^{13} ions cm^{-2}. The FESEM images reveal enlarged pores on the surface of the nanocomposite upon irradiation and the pore size increases with increasing SHI fluence. HRTEM micrographs depict decrease in diameter of PPyNTs from 132 nm for pristine nanocomposite to 117 nm with

increase in irradiation fluence to 2.2×10^{12} ions cm^{-2}. Highly fragmented and decomposed PPyNTs are observed at the highest fluence of 1.3×10^{13} ions cm^{-2}.

2. XRD results indicate that the crystallinity of the nanocomposite is not affected upto a SHI fluence of 2.2×10^{12} ions cm^{-2}, beyond which the crystallinity decreases, which may be attributed to chain scission and bond breaking of PPyNTs resulting in loss of local ordering upon ion irradiation. This is further corroborated by the FTIR results, which reveal weakening of the characteristic absorption bands of PPyNTs viz., C=C and C-N stretching vibrations at the highest irradiation fluence of 1.3×10^{13} ions cm^{-2} used in the present work.

3. The disorder parameter (I_D/I_G) is calculated from the micro-Raman spectra, which decreases at a fluence of 6×10^{10} ions cm^{-2} followed by an increase with increasing fluences upto 1.3×10^{13} ions cm^{-2}. The decrease in disorder parameter initially is attributed to the annealing or ordering of carbon atoms in RGO at moderate temperatures caused due to the energy deposited by the incident SHI. With increasing fluence, the energy loss of SHI is high enough to dominate over the energy loss required for annealing resulting in induced structural defects and loss of translational symmetry, which increase the disorder parameter. The disorder parameter is highest for the SHI fluence of 1.3×10^{13} ions cm^{-2}, which gives rise to the appearance of the defect induced D' band at this fluence.

4. TG curves upto 800 °C exhibit slight decrease in thermal stability of the nanocomposites upon irradiation upto a fluence of 2.2×10^{12} ions cm^{-2}, beyond which the nanocomposite suffers a dramatic weight loss with complete carbonization around 700 °C. This is attributed to the defect induced fragmentation and degradation in the nanocomposites at the highest irradiation fluence of 1.3×10^{13} ions cm^{-2}.

5. Decreased non-linearity of I-V characteristics is observed with increasing irradiation fluence upto 2.2×10^{12} ions cm^{-2}, which indicates reduced hopping barriers in the polymer matrix facilitating the charge transfer. Increase in conductivity is obtained upon irradiation from 4.47 S cm^{-1} for pristine to 7.18 S cm^{-1} for 2.2×10^{12} ions cm^{-2} irradiated nanocomposite, which is attributed to the generation of additional charge carriers due to breaking of bonds in the nanocomposite. Removal of oxygen containing functional groups from the surface of RGO upon SHI irradiation may also give rise to the increased conductivity. At the highest fluence of 1.3×10^{13} ions cm^{-2}, however, the decrease

in conductivity is attributed to the increased defect density of RGO and complete degradation of PPyNTs disrupting the π-electron delocalization.

6. N_2 adsorption-desorption isotherms reveal an increase in BET specific surface areas of the nanocomposite upon irradiation from 208 m^2 g^{-1} for pristine to 263 m^2 g^{-1} for 1.3×10^{13} ions cm^{-2} irradiated nanocomposite. The pore size distribution in the pristine nanocomposite is in the range of 1-9 nm, which increases to 4-30 nm and 6-50 nm upon irradiation at fluences of 2.2×10^{12} and 1.3×10^{13} ions cm^{-2}, respectively. The increase in specific surface area and porosity with increasing irradiation fluence is ascribed to the large electronic energy loss upon SHI irradiation resulting in the formation of damage tracks at the ion impact sites in the nanocomposite leading to widening of the pores. The decrease in diameter of PPyNTs with increasing fluence of irradiation may also give rise to enhanced specific surface area.

7. Contact angle measurements depict a decrease in contact angle of the nanocomposite upon irradiation from 83° for pristine to 59° for 1.3×10^{13} ions cm^{-2} irradiated nanocomposite, which implies increased surface wettability of the electrode upon irradiation and is confirmed by surface energy calculations using OWRK method. The lower contact angle values for the irradiated nanocomposites are ascribed to the enhanced specific surface area and porosity of the nanocomposite films with increasing irradiation fluence.

8. CV curves demonstrate that SHI irradiation results in increased current response and larger enclosed CV area upto a fluence of 2.2×10^{12} ions cm^{-2}, which signifies improved charge storage characteristics of the nanocomposite electrode upon irradiation. With increase in SHI fluence to 3.6×10^{11} ions cm^{-2}, a deviation in the CV curves from quasi-rectangular to non-rectangular 'leaf-like' shape is observed, which becomes most prominent covering a larger area at the fluence of 2.2×10^{12} ions cm^{-2}. This transition is attributed to the increased contribution of pseudocapacitance in the nanocomposite electrode due to the enhanced specific surface area and porosity with increasing SHI fluence. The enhanced porosity increases the electrochemically active sites of PPyNTs due to its higher ratio than that of RGO in the nanocomposite, which could not be accessed by the electrolyte ions in the pristine nanocomposite giving rise to a non-rectangular 'leaf-like' CV shape. At the highest fluence of 1.3×10^{13} ions cm^{-2}, the CV shape reverts back to the original quasi-rectangular shape with decreased current response and CV area

indicating the dominant contribution of EDLC and decline in pseudocapacitance at this fluence due to degradation and fragmentation of PPyNTs.

9. GCD measurements indicate prolonged discharge duration of the nanocomposite electrode upon irradiation. The specific capacitance increases upto a fluence of 2.2×10^{12} ions cm^{-2} followed by a decrease at higher fluence. The highest specific capacitance obtained is 346 F g^{-1} as compared to 299 F g^{-1} for that of pristine, which decreases to 268 F g^{-1} at the highest fluence of 1.3×10^{13} ions cm^{-2}. An increase in energy density from 24 W h kg^{-1} to 28 W h kg^{-1} is achieved upon SHI irradiation. The improved electrochemical performance of the nanocomposite with increase in irradiation fluence upto 2.2×10^{12} ions cm^{-2} is attributed to the enhanced specific surface area and porosity, which allow faster ionic diffusion across a densely packed bulk electrode in a short pathway and increase the available electrochemically active sites thus enhancing the capacitance.

10. A lower equivalent series resistance and charge transfer resistance of 6.47 Ω and 1.5 Ω, respectively are recorded for the 2.2×10^{12} ions cm^{-2} irradiated nanocomposite signifying reduced interfacial contact and charge transfer resistances for the nanocomposite electrode upon irradiation. The widened pores reduce the ion diffusion path lengths in the electrode, which is evident from the reduced Warburg impedance for the 2.2×10^{12} ions cm^{-2} irradiated nanocomposite electrode. The resistances however increase at the highest fluence of 1.3×10^{13} ions cm^{-2} due to high defect density in RGO and decomposition of PPyNTs.

11. The cyclic stability of the nanocomposite electrode increases upon irradiation exhibiting a maximum capacitive retention of 89% after 1000 cycles at the fluence of 2.2×10^{12} ions cm^{-2} as compared to 77% for the pristine nanocomposite. The enhanced porosity upon irradiation increases the cycle life by accommodating the volume changes due to swelling/shrinkage during faradaic charge transfer across the electrode-electrolyte interface.

Chapter 6: Reduced Graphene Oxide – Polyaniline Nanotubes Nanocomposite Electrode System

1. Reduced graphene oxide-polyaniline nanotubes nanocomposites have been synthesized by dispersing different amounts of GO viz., 5, 10, 20 and 40 wt. % with PAniNTs followed by *in situ* reduction of GO in presence of PAniNTs as spacers between RGO nanosheets to prevent their re-stacking. HRTEM

micrographs reveal the formation of the nanocomposites with an average diameter of PAniNTs around 134 nm.

2. XRD results reveal an interlayer spacing of 0.36 nm of RGO nanosheets and semi-crystalline nature of PAniNTs. The crystallinity of the nanocomposites is found to increase with increasing concentration of RGO as RGO is more crystalline than PAniNTs.

3. In FTIR spectra of the nanocomposites, shifting of bands corresponding to C=C stretching in quinoid rings (1562 cm^{-1}), C=C stretching in benzenoid rings (1477 cm^{-1}), C-H in-plane bending (1107 cm^{-1}) and C-H out-of-plane deformation (795 cm^{-1}) of PAni to 1587, 1496, 1130 and 814 cm^{-1}, respectively has been observed, which is attributed to the change in chemical environment due to the π-π interaction between PAniNTs and RGO.

4. The micro-Raman spectra of the nanocomposites depict the D and G bands of RGO. The D band indicates structural defects in the nanocomposites, while the G band corresponds to stretching vibrations of sp^2 bonded carbon atoms. A red shifting of the C-H bending vibration from 1196 to 1180 cm^{-1} and C-N stretching vibration from 1266 to 1233 cm^{-1} of PAni is observed in the nanocomposites, which is ascribed to the electron cloud delocalization of C-H and C-N bands of PAni due to the presence of RGO.

5. Thermogravimetric measurements exhibit increase in thermal stability of the nanocomposites with increase in RGO concentration, which is due to the presence of thermally stable RGO resisting the degradation of PAniNTs upto a higher temperature range.

6. I-V characteristics indicate a significant increase in current in the nanocomposites upon incorporation of RGO. Conductivity measurements display improved conductivity of the nanocomposites from 0.61 S cm^{-1} for pure PAniNTs to 8.04 S cm^{-1} for 40 wt. % RGO-PAniNTs nanocomposite, which is attributed to the increased hopping sites for charge carrier transport in PPyNTs due to presence of conductive RGO.

7. The CV curves of PAniNTs exhibit two redox peaks corresponding to the leucoemeraldine-emeraldine and emeraldine-pernigraniline faradaic transitions of PAni. Upon incorporation of RGO, the CV curve of the nanocomposites displays a larger enclosed area and high current response implying increased specific capacitance. The intensity of the PAni redox peaks decreases in the CV curve of

the nanocomposites, which suggests the increasing contribution of EDLC from RGO. A quasi-rectangular CV shape with two distinct PAni redox peaks for 40 wt. % RGO-PAniNTs nanocomposite reveals the presence of both EDL and pseudo charge storage mechanisms in the nanocomposite.

8. The GCD curves of the nanocomposites display longer discharge duration as compared to pristine PAniNTs. The discharge curves are non-linear similar to that of PAniNTs upto a RGO concentration of 10 wt. %. For 20 and 40 wt. % of RGO concentration, an initial linear and faster discharge occurs followed by a slower discharge deviating from the initial linear behavior. The initial linear discharge is indicative of EDL characteristics of the electrode, while the latter slower discharge arises from the combination of EDLC and pseudocapacitance. The internal resistance (IR drop) is reduced in the electrode, which is of crucial importance for electrodes producing less heat during charging and discharging. A maximum specific capacitance of 448 F g^{-1} and coulombic efficiency of 97% is obtained for the nanocomposite with 40 wt. % of RGO as compared to 194 F g^{-1} and 90%, respectively for pristine PAniNTs. A highest energy density of 30 W h kg^{-1} is achieved at a power density of 174 W kg^{-1} for 40 wt. % RGO-PAniNTs nanocomposite. The presence of RGO in the nanocomposites enhances the total specific capacitance by providing a capacitive double layer for charge storage and simultaneously a high surface area backbone that increases the contact area between the electrode and electrolyte.

9. The presence of conductive RGO nanosheets reduces the equivalent series and charge transfer resistances of the nanocomposite electrodes as evident from EIS studies. The nearly vertical line parallel to the y-axis observed from Nyquist plot at low frequency for 40 wt. % RGO-PAniNTs nanocomposite electrode demonstrates purely capacitive behavior.

10. With increase in RGO concentration, an increase in the cyclic stability of the nanocomposite electrodes is observed from 62% for pristine PAniNTs to 89% for the nanocomposite with 40 wt. % of RGO after 1000 cycles. The enhanced electrochemical stability of the nanocomposite electrodes is attributed to the flexibility of multilayered RGO nanosheets that can adapt to the volume change experienced by PAni during the faradaic reactions resulting in a stable capacitance.

Chapter 7: Swift Heavy Ion Irradiation of Reduced Graphene Oxide – Polyaniline Nanotubes Nanocomposite Electrode System

1. Nanocomposites of PAniNTs with 40 wt. % of RGO have been irradiated with 85 MeV C^{6+} swift heavy ions at varied fluences ranging from 6×10^{10} to 1.3×10^{13} ions cm^{-2}. The nanocomposite upon irradiation show shortened PAniNTs indicating SHI induced fragmentation. The outer boundary and the inner hollow core of fragmented PAniNTs are not much distorted upto a fluence of 2.2×10^{12} ions cm^{-2}, above which indistinguishable inner hollow core and outer surface of PAniNTs are observed indicating highly distorted structure at the fluence of 1.3×10^{13} ions cm^{-2}.

2. XRD patterns reveal unaffected crystallinity of the nanocomposite upto the fluence of 2.2×10^{12} ions cm^{-2} and decrease in crystallinity at the highest fluence of 1.3×10^{13} ions cm^{-2} employed in the present work. The unaffected crystallinity upto a fluence of 2.2×10^{12} ions cm^{-2} may be attributed to the fact that cylindrical damaged regions do not overlap till that fluence, beyond which overlapping of the damaged regions along the ion tracks leads to primary amorphization and decrease in crystallinity.

3. FTIR spectra display reduced intensity of C=C stretching, C-H in-plane bending and C-H out-of-plane deformations of PAniNTs at the highest irradiation fluence indicating chain scission and breaking of bonds of PAni backbone chain.

4. The disorder parameter (I_D/I_G) as evaluated from micro-Raman spectra reveals annealing or re-arrangement of carbon atoms at a low fluence of 6×10^{10} ions cm^{-2} and growth of defects and distortions in the nanocomposite with further increase in irradiation fluence.

5. A slight increase in weight loss of the nanocomposite upon irradiation from 32% for pristine to 45% for 2.2×10^{12} ions cm^{-2} irradiated nanocomposite is observed from thermogravimetric measurements. A rapid degradation of 85% occurs for the nanocomposite irradiated with the highest fluence of 1.3×10^{13} ions cm^{-2}, which is attributed to multiple fragmentations and destruction of bonds due to overlapping of cylindrical ion tracks at this high irradiation fluence.

6. I-V characteristics indicate enhanced current of the nanocomposite upon irradiation upto the fluence of 2.2×10^{12} ions cm^{-2}, which implies reduced tunnelling barriers between conductive regions for charge carrier hopping.

Conductivity measurements show improved conductivity of the nanocomposite from 8.04 S cm^{-1} for pristine to 9.63 S cm^{-1} for the nanocomposite irradiated at the fluence of 2.2×10^{12} ions cm^{-2}. The conductivity increase may be ascribed to the generation of additional hopping sites for charge delocalization in the nanocomposite due to breaking of side-bonds upon irradiation. As the SHI fluence is increased to 1.3×10^{13} ions cm^{-2}, the conductivity decrease to 6.32 S cm^{-1} due to severe degradation of the nanocomposite.

7. BET results depict an increase in specific surface area of the nanocomposite from 196 m^2 g^{-1} for pristine nanocomposite to 231 m^2 g^{-1} for the nanocomposite irradiated at a fluence of 1.3×10^{13} ions cm^{-2}. An increase in the pore size distribution from 2-4 nm to 2-6 nm is observed upon irradiation indicating the increased porosity of the nanocomposite films, which is attributed to SHI induced fragmentation of PAniNTs resulting in shorter nanotubes of higher surface area.

8. A significant decrease in contact angle values of the nanocomposite films is obtained upon irradiation, which indicates improved surface wettability and increased electrode-electrolyte interaction.

9. CV curves display an increase in the intensity of PAni redox peaks with increasing fluence of irradiation upto 2.2×10^{12} ions cm^{-2}, beyond which complete disappearance of the redox peaks is observed. This indicates increased pseudocapacitive charge storage in the nanocomposite electrode upto a fluence of 2.2×10^{12} ions cm^{-2} due to enhanced specific surface area caused by shortening of PAniNTs upon irradiation. With further increase in fluence to 1.3×10^{13} ions cm^{-2}, PAniNTs are completely fragmented and degraded leading to the absence of redox peaks and decrease in specific capacitance.

10. GCD curves reveal a linear discharge with a slight curvature upto a fluence of 2.2×10^{12} ions cm^{-2} indicating the presence of both EDLC and pseudocapacitance in the nanocomposite. The specific capacitance as evaluated from GCD curves increases upon irradiation from 448 F g^{-1} for the pristine nanocomposite to 482 F g^{-1} for 2.2×10^{12} ions cm^{-2} irradiated nanocomposite. The increase in specific capacitance is attributed to enhanced pseudocapacitance of the nanocomposite upon irradiation. The capacitance decreases to 394 F g^{-1} at the highest fluence of 1.3×10^{13} ions cm^{-2} due to chain scissioning and structural breakdown of PAniNTs, which limits its charge transfer reactions at this fluence.

11. Nyquist plots indicate lower interfacial contact resistance and easier transfer of charges across the electrode-electrolyte interface with increasing ion fluence upto 2.2×10^{12} ions cm^{-2}.

12. Cyclic stability studies reveal improved capacitive retention of the nanocomposite upon irradiation from 89% for that of pristine to 92% for the nanocomposite irradiated at a fluence of 2.2×10^{12} ions cm^{-2}. This is ascribed to the enhanced surface area and additional electrochemically active sites for charge storage in the nanocomposite electrode upon irradiation, which stabilize the capacitance with increasing cycles.

8.2 Future prospects

The field of supercapacitors has recently witnessed a dramatic expansion due to the disadvantages of batteries like low power density and poor cycle life. Although extensive research work has been going on in this field and improved electrode performance has been achieved, supercapacitors are still unable to overcome the performance of batteries. In this work, the electrochemical performance of conducting polymer nanostructured electrodes viz., polypyrrole and polyaniline nanotubes have been improved by nanocompositing them with reduced graphene oxide and by swift heavy ion irradiation for improved performance as supercapacitor electrodes. The future prospects of the work in this research field are discussed below:

1. In the present work, the electrochemical performance of nanocomposites of PPyNTs and PAniNTs has been investigated with varying concentration of RGO. This work can be further extended for PEDOT nanotubes as well as for other nanostructures of conducting polymers like nanofibers, nanorods, nanoparticles etc. Further studies can be carried out on nanocomposites of similar type of conducting polymer nanotubes with other materials like carbon nanotubes, graphene oxide, metal oxide nanostructures (MnO_2, RuO_2, NiO etc.). Moreover, investigation of electrochemical performance of the nanocomposites with varying diameter of conducting polymer nanotubes will be a challenging research problem to work on.

2. Swift heavy ion irradiation of nanocomposites of RGO-PPyNTs and RGO-PAniNTs has been carried out with 85 MeV C^{6+} ions at four different fluences.

Our studies have shown that specific surface area, porosity, surface wettability and electrochemical properties of the nanocomposite electrodes have been enhanced upon irradiation with specific fluences. Similarly, plasma irradiation, low energy ion irradiation etc. can be carried out in order to investigate the modifications in structural, electrochemical and surface properties of the nanocomposite electrodes. Besides, similar type of RGO-conducting polymer nanocomposites can be irradiated at high energies with different ions such as oxygen, nickel, silicon etc.

3. In all the systems investigated in this thesis work, we have employed aqueous electrolytes for evaluation of electrochemical performance of the nanocomposite electrodes. This work can be extended to different electrolytes like organic electrolytes (acetonitrile, propylene carbonate etc.), ionic liquid electrolytes (pyrrolidinium and imidazolium based electrolytes), polymer-based electrolytes (polyethylene glycol, polyvinyl alcohol, poly (vinylidene fluoride)) etc. to obtain high electrochemical performance. Moreover, synthesizing ternary nanocomposite electrodes of conducting polymers and graphene with transition metal oxides and dichalogenides for supercapacitor application is an emerging field of research.