1. INTRODUCTION

1.1 POLYIMIDES

Polyimide is one of the excellent high performance polymers and has higher thermal stability along with good mechanical strength, chemical resistance and better electrical properties. It has become an important polymer in the materials used in high temperature and flexible conditions. Polyimide nanofibers have received great attention among the researchers for their applications in different fields such as membrane, fuel cell, solar cell, sensor devices, filtration assemblies etc., The performance of polyimide nanofibers are being improved by incorporating fillers such as carbon nanotubes, graphene, metal nanoparticles, etc. and utilized in various applications.

Polyimide (PI) is a polymer having imide group linkage in its backbone. Since 1955, polyimides have been prepared as mass production. The common chemical structure of polyimide backbone is shown in Figure. 1.1, in which, R1 & R2 denotes alkyl & aryl groups [1].

![Chemical structure of polyimide backbone chain.](image)

Polyimides (PI) are commonly synthesized using dianhydride and diamine monomers. The polycondensation reaction of dianhydride and diamine leads to formation of poly(amic acid) (PAA) the precursor of polyimide. The thermal imidization of amic acid results in forming polyimide with water molecule. The first synthetic polyimide namely, Kapton (Figure. 1.2) is a commercial polyimide which
was synthesized by Dupont. This polyimide was synthesized using pyromellitic dianhydride and 4, 4'-oxy dianiline monomers [2].

![Chemical structure of Kapton polyimide.](image)

Polyimides are classified into mainly three types based on the composition of their main backbone chain. They are

(i) Aliphatic (linear polyimides).

(ii) Semi-aromatic (combination of aliphatic and aromatic polyimides).

(iii) Aromatic: these are the most widely used polyimides because of their higher thermal stability compared to aliphatic and semi-aromatic polyimides.

Polyimides are further classified into two types based on the type of interaction between the main chains. They are

(i) Thermoplastic polyimides: They are often called pseudo thermoplastic.

(ii) Thermosetting polyimides: They are available in the form of uncured resins, laminates, thin sheets, and machined parts.

There are many methods to synthesis polyimides, among them two methods are being used [3]

(i) The reaction of a dianhydride with a diamine (widely used method).

(ii) The reaction of a dianhydride with a diisocyanate.

A few examples of dianhydrides include pyromellitic dianhydride (PMDA), benzophenone tetracarboxylic dianhydride, naphthalene tetracarboxylic dianhydride. Some of the diamines include 4, 4'-oxy dianiline (ODA), 3, 3'-diamino diphenyl methane, and m-phenylene diamine (MDA). There have been several dianhydrides and diamines examined to improve the physical, chemical, and processing characteristics of these monomer materials to obtain polyimides.
The charge-transfer interactions between the polymeric planar structures cause the polyimides to become insoluble [3].

Polyimides have excellent heat resistance, high mechanical properties, and good chemical resistance. Due to these properties, polyimides have become a superior high performance polymer and widely utilized in many fields such as membranes in fuel cell, solar cell, gas filtration, sensors and reverse osmosis of water. They have also been used in aerospace components, printed circuit boards, adhesives, and matrix material in composite fabrication because of their excellent thermal stability, mechanical properties, chemical resistance, and electrical properties. However, the properties and application areas of polyimides are generally determined by the molecular structures of the monomers and also the number of different monomers used in the polymerization process [4].

Generally, dianhydride and diamine monomers are reacted and form the precursor poly(amic acid) and then the thermal imidization of PAA gives polyimide film. There have been different monomers systems selected and developed different types of polyimides to improve their thermal, mechanical and electrical properties. The researchers have also tried to develop copolyimides by choosing the combination of monomers such as two or more different dianhydrides with one diamine, otherwise one dianhydride with two or more different diamines [4, 5].

A slight modification in the chemical structure may often result in a significant change in polymer properties. Only some of the investigators have studied the relationships between monomer structure and polyimide properties. However, considering some limitations in experimental conditions, it is not economical to synthesize all the possible polyimides. There have been a lot of literatures on different types of polyimides and manipulation of properties based on the requirements. However, there are only a few literatures on more flexible copolyimides. The flexibility and processability of polyimide can be improved by introducing bulky and flexible groups such as iso-propylidine, hexa fluoro propylidine, etc. into copolyimide structure. The prepared flexible copolyimides
can be used as flexible substrate, membrane and electrodes in solar cells, fuel cells, and sensor applications respectively.

1.1.1 Polymer nanofibers by electrospinning method

A material is considered to be a fiber when it has an aspect ratio (L/D) more than 100 i.e., length to diameter ratio. There are several polymeric fiber materials produced by various methods namely dry spinning, wet spinning, melt spinning etc. In dry spinning [6], polymers must be dissolved in solvent and solidification is done by solvent evaporation. This can be achieved by a steam of air or inert gas sending through the chamber, from which, the polymer comes out as fiber form. The advantages of this method include no precipitation of liquid involved, the fiber does not need to be dried, and the solvent is more easily recovered. Some of the fibers being manufactured are acetate, acrylic, and poly benzimidazole fibers. Figure. 1.3 (a) is attributed to the schematic diagram of dry spinning process.

In Wet spinning [6], polymers are to be dissolved in a suitable solvent. The spinneret is submerged in a chemical bath and this causes the fiber to solidify, as it emerges. Figure. 1.3 (b) shows the schematic diagram of Wet spinning process. Acrylic, rayon, and aramid, are manufactured using this process. Melt spinning [6] is used for the polymers which must be melted to process it. The molten polymer solidifies in water bath by cooling after being extruded immediately from the spinneret. The schematic diagram of Melt spinning is shown in Figure. 1.3 (c) Nylon, polyolefin, and polyester are produced via this process. When the diameter of the polymer fiber materials is reduced from micrometer to nanometer level, there may be many excellent characteristics appeared such as high aspect ratio, large surface area to volume ratio, flexibility and superior mechanical properties compared with conventional polymer materials. These properties of polymer nanofibers make them optimal candidates for many applications [7].
There are a number of processing techniques used to prepare polymer nanofibers such as fiber drawing, phase separation, template synthesis, self assembly of fibers, electrospinning, etc. The fiber drawing process is similar to dry spinning of fibers, which is only used for viscoelastic materials (Figure 1.4). The phase separation process (Figure 1.5) involves the dissolution of polymer in different solvents, formation of gel by freezing and drying for extraction of polymer materials resulting in nano-porous foams. However, this process takes long time to convert polymer into nano-porous foams [8].

Figure 1.3: Schematic of fiber spinning processes: (a) Dry spinning, (b) Wet spinning, and (c) Melt spinning (After Carraher, C. E., Jr. 2002. Polymer News, 27, 3, 91).
In the template synthesis [9, 10], the nanoporous membrane is used as template to prepare nanofibers. This method can be utilized for polymers, metals, and carbon materials. However, this technique cannot be used to prepare one-by-one continuous nanofibers. The preparation of polymeric porous nanostructure is shown in Figure. 1.5.
Molecular self-assembly is a powerful approach being explored for novel supramolecular nanostructures and bio-inspired nanomaterials. The process (Figure 1.6) contains the pre-existing materials which organize themselves into the patterns. Recent researches concern the self-assembly of de novo designed artificial peptides and peptidomimetics into nanofiber structures, specifically towards developing a new class of soft-materials. These nanofiber architectures have potential use not only in biomedical applications, such as 3D-matrix scaffolds for tissue engineering and biomineralization, but also in nanotechnology such as nano-templates and dimension-regulated functional nano-objects. But, this process is also a time-consuming in producing polymer nanofibers. Thus, the electrospinning is a process to be the only technique to produce continuous nanofibers for mass production from different polymers [11].
Electrospinning was first introduced by Formalas et al. in 1934 and he published many patents during 1934 to 1944 on production of polymer filaments by developing experimental setup using an electrostatic force [12]. Recently, polymer nanofiber technology is growing rapidly as nanofibers find in several applications in different fields. The electrospinning technique involves the use of electric field on to a polymer solution. The opposite electric charges are applied to polymer solution and the collector. Once the polymer jet is produced and ejected from the spinneret, the solution jet gets evaporated and forms fibers which are collected on the rotating drum collector [13]. The schematic of an Electrospinning setup is shown in Figure. 1.7.

![Figure. 1.7: Schematic of an Electrospinning setup (Adapted from [14]).](image)

Electrospinning process mainly depends on the polymer characteristics such as structure, solubility, molecular weight, melting temperature etc, and applied electrical voltage. These parameters interact and results in the creation of electrified polymer jets from a polymer solution. When a strong electrostatic field is applied, the charges are induced and the ions carry the charges, the
charged polymer moves towards the metal collector having opposite charge. The pendant drop emerging from the spinneret is prevented by the surface tension of the polymer solution at low electric field. When the electric field is increased, the charges induced on the liquid surface repel each other and forms extension of the drop into conical shape. The charges of polymer jet emanating from the conical drop lead to continuous jet during the continuous applied high voltage. The solvent of the polymer solution jet gets evaporated and forms solid polymer nanofibers before being deposited on the drum collector [13].

There are many other parameters involved in the electrospinning process such as polymer viscosity, flow rate, applied voltage, distance between the spinneret and collector, rotating drum collector speed, etc. [15]. These parameters have to be optimized to produce smooth, continuous and uniform nanofibers. The polymer nanofibrous membranes prepared by electrospinning method, can be effectively used as optical sensors, tissue-engineering scaffolds, protective clothing, and nanocomposites.

1.1.2 Carbon nanotubes

Carbon nanotube (CNT) is an allotrope of carbon with a cylindrical nanostructure. The nanotubes have very high length-to-diameter ratio [16], which is specifically larger than the other existing materials. Carbon nanotube was first discovered by Iijima (1991) and it has been a potential candidate for many applications such as advanced nanocomposites, sensors, optoelectronics, gas storage devices etc.,. The CNTs possess excellent properties including strength and stiffness to weight ratio. In particular, owing to their extraordinary thermal conductivity, mechanical, and electrical properties, carbon nanotubes find applications as additives to various structural materials [17].

A carbon nanotube, the name is derived from its very long, hollow structure with the wall formed by one atom thick graphene sheet. These graphene sheets are rolled at specific angle, and the combination of the rolling angle and radius decides the properties of nanotubes. Individual nanotubes
naturally align themselves into ropes held together by van der Waals forces, more specifically, \(\pi\)-stacking. The chemical bonding of nanotubes is composed of \(sp^2\) bonds, similar to those of graphite. These bonds, which are stronger than the \(sp^3\) bonds found in alkanes and diamond, provide nanotubes with their unique strength [17].

Many research papers were published by the researchers on mechanical and electrical properties of CNTs. They proved that the mechanical strength of CNTs is 100 times higher than that of steel and the density is six times lower [5]. There exists mainly two types of CNTs, namely single walled carbon nanotube (SWCNT) and multi walled carbon nanotube (MWCNT) shown in Figure.1.8. Single-walled carbon nanotubes (SWCNTs) have nearly 1 nm diameter and a length that can be a few millions of times longer. The one atom thick graphene layer wrapped up into a cylinder shape which forms the structure of a SWCNT. The SWCNTs have been an expensive material for wide applications; however, they are forecast to make a huge impact in electronics by 2020 according to The Global Market’s report on Carbon Nanotubes. Multi-walled carbon nanotubes (MWCNTs) comprise of multiple rolled graphene layers. The interlayer distance in multi-walled carbon nanotubes is approximately 3.6 Å. The individual shells of Russian Doll structure could be described as SWCNTs [16].

Recent developments focus on the incorporation of CNTs into polymers to produce new composite materials with improved thermal, mechanical and electrical properties. The dispersion of CNTs in polymer matrix is a major challenge in composite fabrication. Therefore, good dispersion of CNTs and interfacial bonding between CNTs and polymer matrix are essential to improve the mechanical properties of CNTs reinforced polymer nanocomposites [18]. Due to their nature, CNTs have poor solubility in most of the organic solvents and also chemically not compatible with polymer matrix. The chemical inertness and formation of bundles of CNTs present difficulties in fabrication of composite materials. The three dimensional structure of single walled and multi walled carbon nanotubes is shown in Figure. 1.8.
The modification of CNTs structure by the oxidation of CNTs has acquired a lot of attention in purification and enhancing the chemical reactivity. The oxidation of CNTs can be done by acid treatment, oxygen plasma, photo-oxidation, or gas phase treatment. The acid treatment is a simple method and has been utilized widely to oxidize both SWCNTs and MWCNTs. The oxygen-containing functional groups such as carboxyl and hydroxyl found to be attached on the surface of the carbon nanotubes. The presence of carboxyl (-COOH) and hydroxyl (-OH) groups reduce the Van der Waals forces between the CNTs, which strongly facilitate the exfoliation of CNT bundles and separate into individual tubes [19].

The oxidation of CNTs is carried out by refluxing the CNTs in a mixture of concentrated sulfuric acid and nitric acid treatment. This process leads to the opening of carbon nanotube caps and also holes formation in the side walls. The acid mixture etches the side walls with evolution of carbon dioxide and the final nanotube fragments have length between 100 and 300 nm. The oxygen containing functional groups such as carboxyl and hydroxyl groups are attached to the side walls of carbon nanotubes [20].
The dispersion of acid functionalized CNTs in a polymer matrix is highly effective due to the exfoliation of CNTs and also the enhancement of interaction between functionalized CNTs and polymer matrix. This interfacial adhesion results in the transfer of unique properties of CNTs into polymer CNT based nano composites [21]. It has also been described that the acid functionalization of CNTs affects the rope size and results in exfoliation into smaller nanotubes. These challenges are important in the fabrication of molecular electronics, high sensitive sensor devices.

The chemical modification of CNTs by less vigorous acid treatment leads to the formation of functional groups on the side walls. The acid groups functionalized carbon nanotubes from this treatment mostly retain their pristine CNTs’ mechanical and electrical properties [19].

1.1.3 Graphene oxide

Graphene is a single atom thick layer of graphite with 2-dimensional structure of sp² bonded carbon atoms. This single layer of graphite has superior properties such as high thermal and electrical conductivities, excellent mechanical strength, good transparency, flexibility and large surface area. Due to these outstanding properties, many research works are being carried out in recent years in different fields such as microelectronics, energy storage devices, opto-electronics, and polymer nanocomposite materials. Graphene based materials are used as active materials or transparent conductive electrodes in solar cells, counter electrodes in organic dye-sensitized solar cells, electrocatalysts in fuel cell for oxygen reduction, photo catalysts in water splitting, and high-performance electrodes in super capacitors and lithium ion batteries [22].
The layered structure of graphite exhibits 3-dimensional (3D) order, which is shown in Figure. 1.9 (a) and schematic of graphene oxide layer in Figure. 1.9. (b). In graphite, the adjacent layer of graphene sheets are separated each other by 0.335 nm and held together by weak van der Waals forces. Thus, the graphene layers can easily slide off from one another and this provides graphite layers with soft and lubricating nature [23]. The graphene sheets incorporated polymer matrix composites have poor adhesion between the graphene layers and polymer matrix. Hence, there have been many approaches carried out to improve the adhesion of graphene sheets by modifying the structure.

There are three modified graphitic structure which are termed as graphene oxide (graphite oxide), expanded graphite and graphite intercalated compounds. The first form, graphene oxide is prepared by simple and inexpensive method of acid treatment of graphite. During this treatment, graphite is oxidized and producing graphene oxide sheets. The functional groups such as carboxyl, hydroxyl and epoxy groups present on the graphene layers prevent the agglomeration of graphene sheets. This improves the interaction between the graphene oxide and polymer matrix in polymer composite fabrication [24-25].

The properties of graphene oxide are transferred to the polymer matrix and hence, the mechanical, thermal, and electrical properties are improved for
the GO-polymer composites. The manufacturing of polymer composites requires graphene sheets to be homogenously distributed into the matrix. However, the graphene sheets do not readily exfoliate from the graphite to yield individual graphene sheets. It is essential to prevent the agglomeration of individual graphene sheets and also improve the adhesion between the graphene sheet and polymer matrix. The interfacial interaction between graphene sheet and matrix can be improved by modifying the structure of graphene sheets [26]. This modification or attaching functional groups such as carboxyl, hydroxyl groups on the surface of graphene layers can be achieved by oxidation of graphite using acid treatment. The organic functional groups intercalated between the graphene sheets. The gap between the adjacent layers is increased due to the steric hinderance of same groups present. This leads to reduce the van der Waals forces acting on the adjacent layers, thereby, exfoliation of graphene oxide layers occur. These functional groups also interact with the polymer matrix and form strong adhesion between graphene oxide layers and matrix.

1.1.4 Polyimide nanofiber composites

Most of the aromatic polyimides (PI) are highly rigid and more conjugation of backbone structure. Due to this property, aromatic polyimides have relatively poor processability in fabrication and may have limited applications especially in fiber forms used in high temperature resistant separation technology. This is due to their excellent thermal, chemical and mechanical properties. In the conventional wet spinning process, polyimide fibers can be produced up to a few micrometer ranges in diameter. The reduction of the diameter of the fibers from micro level to nanoscale range may be utilized greatly in improvement of the properties and performance of the fibers. This is because of the large surface area to volume ratio of nanoscale diameter of the fibers [27, 28].

In the past two decades, the electrospinning technique has been used to produce non-woven fabrics of nano-scale fibers. Electrospinning is a low-cost but effective method to continuously produce polymer nanofibers. Several polymer electrospun nanofibers have been reported, only a few literature has been found
in polyimide nanofibers [29-31]. Polyimide nanofiber properties can be improved by reinforcing nanofillers such as carbon nanotubes, graphene oxide, and nanoparticles in polyimide. There are two methods namely, solution mixing and \textit{in-situ} synthesis of nanofillers with polymer to prepare polymer composites. In the case of \textit{in-situ} synthesis, one can achieve the effective dispersion of nanofillers in polymer compared to mere mixing of nano fillers in polymer solutions [32].

Carbon nanotubes (both SWCNT and MWCNT) can be used as reinforcements to prepare polyimide nanofiber composites by the combination of in-situ synthesis of polyimide with CNTs and electrospinning of prepared CNT-polyimide solution. The pristine SWCNTs and MWCNTs have poor dispersion in polyimide solution due to the agglomeration of CNTs. Hence, surface functionalized CNTs are being used to improve homogenous dispersion and interfacial interaction between CNTs and polyimide matrix. Especially, acid treated CNTs have good adhesion and dispersion in polyimide matrix and the resulting polyimide nanofiber composites have improved mechanical, thermal and electrical properties [33].

1.1.5 Carbonization of polyimide nanofibers

Carbon fibers were first produced from rayon fibers in 1959 by the US Air Force Materials Laboratory. Due to the development of nanotechnology, carbon nanofibers (CNFs) are being prepared from polymer nanofibers. In recent days, CNFs are being used in many fields, namely rechargeable batteries, high temperature filters, templates for nanotubes, supporting material for high-temperature catalysis, nanoelectronics, super capacitors, gas adsorption materials, and mainly as reinforcement in composite materials due to their good high temperature resistance, excellent electrical and thermal conductivities. There are many conventional methods used for preparation of CNFs such as vapour growth method, substrate method, spraying method and plasma-enhanced chemical vapour deposition method [34, 35].
The chemical vapor deposition [36] (CVD) is the dominant commercial method in the preparation of vapour grown carbon fiber (VGCF) and carbon nanofiber (VGCNF). In this method, the reactant gas is passed in a quartz tube at high temperature. Due to high temperature, the gas phase molecules decomposed and deposited on the substrate in the presence of metal catalyst, where the fibers are grown around the catalyst particles. This process consists of several steps such as the decomposition of gas, carbon deposition, growth and thickening of fibers. Then, the graphitization and purification results in carbon nanofibers and their diameter mainly depend on the catalyst size. The schematic diagram of catalytic chemical vapour deposition process is shown in Figure. 1.10. These methods are very complicated and costly and therefore, the simple and inexpensive method called electrospinning process followed by, carbonization has been currently utilized to produce continuous CNFs. The heat treatment of polymeric nanofibers can also be done by Induction heating method.

![Figure. 1.10: Schematic diagram of Catalytic chemical vapour deposition](Image)

(Adapted from [36]).

Induction heating is a process of heating an electrically conducting material by electromagnetic induction, through which heat is generated in the object by Eddy current. An induction heating material consists of metal wire coil (electromagnet), and an electronic oscillator which passes the alternating current
through the electromagnet. The rapid penetration of alternating magnetic field in the conducting material, which generates electric current in the conductor called Eddy currents. The flow of eddy currents through the material generates heat [37].

![Schematic diagram of Induction Heating coil](adapted from [37])

An important advantage of the induction heating method is that the heat is generated inside the object itself and it does not need an external heating source. Thus, the material can be heated rapidly. Induction heating is used in metallurgy, crystal growth, semiconductor industry, and in melting of refractory metals which require very high temperatures. The schematic representation of Induction-heating coil is shown in Figure. 1.11.

The Radio-frequency induction heating setup contains three important parts namely, a radio-frequency (RF) generator with induction coil, a quartz chamber and a high vacuum system. Figure. 1.12 shows the schematic diagram of Radio Frequency Induction heating setup. The efficiency of the induction heating depends mainly on coil current, number of turns in the coil, and the shape of the specimen to be heated [38-40]. Graphite boat can be used for carbonizing the polymer nanofiber web. Heating power can be varied by increasing the RF generator oscillator plate current. The level of heating requirement can be achieved within the maximum input current in the radio frequency power stage. The advantages of RF-induction heating method are
pollution free source of heating, ability of producing heat to very high level efficiently, and absence of thermal Inertia (i.e. rapid start up).

Carbonization of polymer involves the heat treatment of a material which leads to crosslinking, coalescence of cyclized polymer chains, and structural transformation of polymer material from a ladder structure into a graphite one. The morphology of the material also changes from smooth to wrinkle texture. This process is carried out at high temperature around 1000°C, and hence it needs dynamic inert gas atmosphere such as nitrogen, argon, helium, etc., to prevent oxidation and also remove the volatile molecules such as H₂O, NH₃, H₂, CO₂ and CO. This carbonization process can also be carried out in vacuum condition, but the carbonization degree is lower than that in inert gas atmosphere.

Figure. 1.12: Schematic of Radio-Frequency Induction Heating setup (Adapted from [40]).
Polymer nanofibers have been recently carbonized to produce carbon nanofiber. The fiber shrinkage and sometimes fusion may occur during carbonization of polymer nanofibers. Polyimide nanofiber webs can be carbonized at high temperature around 1000°C [41]. In addition, CNTs reinforced polyimide nanofiber composites can also be carbonized which has been tried in this work. Carbon nanofibers, with their lower cost and outstanding electrical conductivity, are promising fillers in polymer nanocomposites compared to CNTs.

1.2 THESIS ORGANIZATION

This thesis consists of nine chapters

Chapter 1. Introduction

This chapter deals about the fundamentals of polyimide and its structure modifications. A brief description about polymer nanofibers and electrospinning technique is discussed. The polyimide nanofiber composites with nanofillers such as carbon nanotubes and graphene oxide are explained along with carbonization process of polymer nanofibers briefly.

Chapter 2. Literature overview

A review of literature on preparation of polyimide films, nanofiber composites is carried out. This literature review presents the previous publications related to existing experimental technique, electrospinning of polymer nanofibers, polyimide nanofiber composites with functionalized carbon nanotubes and graphene oxide. The objectives and scope of the present work have been given at the end of this chapter.

Chapter 3. Experimental work

This chapter deals about the detailed experimental work carried out in synthesis of polyimide from different dianhydride and diamine monomers. The working principle and optimization of electrospinning technique to get uniform polyimide nanofibers are explained. Acid functionalization of carbon nanotubes
and oxidation of graphite into graphene oxide (GO) are elaborately discussed. A detailed description about in-situ synthesis of polyimide with SWCNTs, MWCNTs, and GO and preparation polyimide nanofiber composites is given. The preparation of functionalized CNTs and GO reinforced polyimide nanofiber composites is explained in detail. The preparation of carbon nanofiber from polyimide nanofiber composite by carbonization process is also discussed.

Chapter 4. Synthesis and Characterization of PMDA - ODA and PMDA – ODA - IDDA polyimide films

This chapter outlines the synthesis and properties of polyimide and copolyimide films. The characteristics of these polyimide films using FT-IR, X-ray diffraction, thermogravimetry analysis, dynamic mechanical analysis, UV-Visible spectroscopy are explained in detail.

Chapter 5. Preparation and Characterization of f-SWCNT reinforced polyimide nanofiber composites

In this chapter, the acid functionalization of single walled carbon nanotube and its incorporation in polyimide nanofiber web by in-situ preparation of PAA with f-SWCNTs (0, 0.5, 1 and 2 % w/w) are discussed in detail. The characterization and properties of PI/f-SWCNTs nanofiber composite are studied and discussed.

Chapter 6. Preparation and Characterization of Polyimide - Graphene oxide nanofiber composites

The conversion of graphite into graphene oxide by Hummer’s method is carried out and the properties of graphene oxide are determined using FTIR, XRD and Raman spectra. The studies carried out on graphene oxide reinforced polyimide nanofiber composites with different weight percentages of GO are explained. The morphological studies of PI/GO nanofibers and formation of beads in nanofibers are discussed. The properties such as thermal and electrical conductivity of PI/GO nanofiber composites are also studied and reported.
Chapter 7. Carbonization of Polyimide/f-MWCNTs nanofiber composites and their properties

In this chapter, the carbonization of polyimide nanofibers has been carried out to get carbon nanofiber. The comparative studies on electrical conductivity of CNF prepared from neat polyimide nanofiber web and PI/f-MWCNTs nanofiber composites are reported. Also, the effect of carbonization temperature on electrical conductivity is discussed.

Chapter 8. Conclusions

This chapter concludes the findings of this research work on polyimide modifications, properties of their nanofiber composites and the effect of carbon nanotubes and graphene oxide fillers on polyimide nanofiber composites.

Chapter 9. Scope for future work

The further requirement of this present work on polyimide nanofiber composites for future is mentioned here.