Chapter

New Perspective of Nano Fibers: Synthesis and Applications

Deepthi Sista

Abstract

Nano fibers are most attractive materials in the scientific world due to their enormous applications in various fields. Their applications start with generation of energy, solution to environmental problems and continues with medical field and many more. Nano materials got much importance from their peculiar electrical, optical, mechanical and thermal properties. Fibrous materials are obtained from several sources and by different mechanisms these materials are converted into nano materials. As of bulk fibers include specific properties compared to other materials, the generation of nano fibers enhance all the properties. The synthesis of nano fibers from natural and synthetic polymers, metals, semiconductors, composite materials, carbon based materials lead to new perspective in science and engineering fields. Most pronouncing techniques that include conventional and modern methods are available to fabricate nano fibers from these materials. Of them some are being used from a long time and some are emerging techniques to generate flexible substrates. Electrospinning, template based synthesis, polymerization, self-assembly, sonochemical synthesis are the conventional methods for the production of nano fibers. New technologies include electro hydrodynamic writing, plasma induced synthesis, centrifugal jet spinning, CO_2 laser supersonic marks a trend in development of nano fibrous materials. This chapter give details about fabrication materials and provides synthetic routes to generate them along with applications. Also this chapter focuses on the challenges in development of nano fiber technology in commercial perspective.

Keywords: Nano fibers, fabrication materials, synthesis techniques-conventional and modern

1. Introduction

Scientific and technological world at present focuses on nano meter range fibrous materials which have excellent physical, chemical, biological and optical properties. Materials made from these fibers have great fundamental importance due to their flexibility and high directional strength. These are light weight with well-regulated pore structures and high surface to volume ratio. Fibrous materials at nano scale have shown excellence in every fundamental property. Nano fibers are well suitable in designing functional materials, used in tissue engineering, filtration, sensors, clothing and can also be used for energy storage. Specific morphological characteristics of nano fibers resembles original cellular matrix impacts living nature.

Unambiguous properties of nano fibers intend to modify or reinforce polymer matrices that have large beneficiations to mankind.

2. Importance of nano fibers to the present day perspective

Today's world is facing many challenges to run things in a smooth manner. Many man made things outburst as a threat to human life. In order to overcome such challenges researchers looked into fabrication of nano fibers that have substantial benefits in various fields. For example, globalization and modernization brought many hazardous things like plastic into day to day life of common man. Plastic is one of major pollutant that cannot decompose easily into Earth. Likewise, many materials are bringing challenges for better livelihood.

Nano fibers are alternative resources for many materials due to their excellent properties. These materials are emerging as substituents for original materials due to their low cost, low density, high porosity, high energy. These unique features enable nano fibers for novel applications.

Nano science and nano technology have been vital applicative for scientific world since antiquity. Impact of nano on the present world empowers and drives one to develop new aspects in many areas. Researchers thrive to dwell the inherence of nano to synthesize from different materials. Fibrous materials have been used as best replacement for many non-renewable sources with less cost. They have been used in day to day applications like mobiles, solar cells, batteries, filtration membranes etc. In many cases these materials are taken from end users or wastes. For example, cellulose nano whiskers can be prepared from coconut fiber [1]. Sea algae is also being used to prepare nano fibers with numerous applications [2]. Different methods like electron spinning, self-assembly, template synthesis, thermal induction and phase separation etc. are used to make nano fibers [3]. These methods include chemical and mechanical techniques. Nano fibers extracted from natural and synthetic polymers are authentic besties to nature.

Flexibility, high tensile strength is the major advantage of these fibers with enhanced properties. Knowing about the various types of nano fibers, their synthesis, properties with basic as well as commercial applications at one glance is the main emphasis of this chapter.

3. Generation of nano fibers

Nano fibers are generated from diverse materials show differences in physical properties as well as application potentials. Natural polymers, synthetic polymers, carbon based materials, metals, ceramics, semiconducting materials and composite materials are used for the preparation of nano fibers [4]. **Figure 1** shows the materials used to synthesize nano fibers. Each of these materials have specific importance and applications.

4. Natural and synthetic polymers

Dominance of renewable sources in the preparation of nano fibrous materials has been increased drastically in this decade due to their environment friendly properties. These renewable sources include polymers were paid much attention from their biocompatible, bio degradable and bio active nature. Starting from

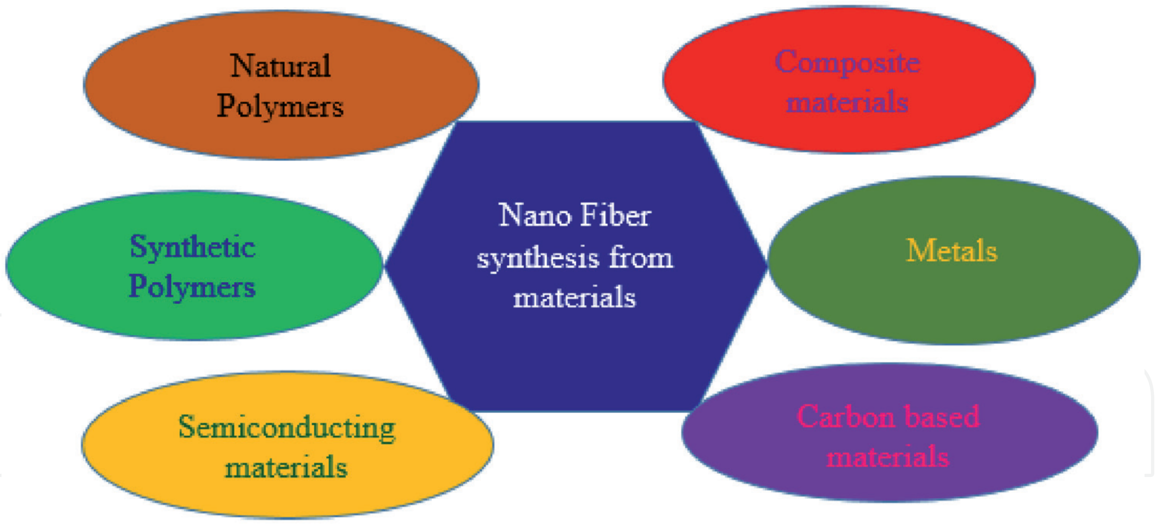

Figure 1.
Synthesis of nano fibers from various materials.

physical properties proliferation, adhesion, migration, cell adhesion are most evitable properties the makes one to rely to produce nano fibers.

Collagen, Cellulose, silk fibroin, keratin, gelatin and polysaccharides (chitosan, alginate) are the natural polymers and can be used to synthesize nano fibers using various techniques [5–7].

4.1 Collagen

Collagen is an excellent protein in the extra cellular matrix found in connective tissues of body. The structure of collagen is helical with amino acids bound together which is elongated fibril also known as collagen helix. Nano fibrous materials generated from this regenerative biopolymer are used in reconstruction of tissues [8].

4.2 Cellulose

Nano structured cellulose fibers are commonly referred as cellulose nano fibers. Cellulose nano crystal, cellulose nano fibers, nano fibrillated cellulose and bacterial nano cellulose are the nano fibered cellulose with different physical, chemical and biological properties [9].

These fibrils are with high aspect ratio that is 5–20 nm width and some micrometers length. Many plant based products, biological products, sea products are the basis of cellulose. As an example the nano fibers from cellulose develops microfiber 3D printing network [10].

4.3 Silk fibroins

Silk fibroin is produced from silkworms and spiders. It has excellent mechanical properties with biological compatibility, morphological flexibility used to produce nano fibers mostly using electrospun technique [11]. The stability of fibers from silk is obtained from chemical treatments such as methanol, ethanol, propanol and water vapor. If viscoelasticity of silk fibroins is increased with blending them with polymers an improvement in mechanical properties were observed while biological properties remain [12].

4.4 Keratin

One of the most abundant non-food protein is Keratin. Components of hair, feathers, nails, horns of mammals and birds are the many sources of keratin [13]. Despite of having so many good characteristics the keratin wastes are being pollutants. If the wastes are brunt they would release toxins due to Sulphur content. Instead of burning them and make as pollutants one can produce nano fibrous out of keratin by electrospinning technique that finds application in tissue engineering and many filtration devices [14].

For example, human hair mixed with polycaprolactone (PCL) in proper proportions to produce nanofibrous membranes that have excellent applications to develop composite materials and also can be used in various biomedical applications [15].

4.5 Gelatin

Gelatin is a natural polymer which is renewable acquired by fractional hydrolysis of collagen. It is most favorable bioengineering material due to its low cost, high biocompatibility and biodegradability [16]. Electrospun gelatin nano fibers face a difficult in water solubility with poor mechanical strength. To overcome this problem crosslinking technique like drying, heating and UV light exposure with some chemical treatments are induced [17].

4.6 Polysaccharides

Chitosan is one of polysaccharide obtained from deacetylation of chitin polymer. It is a natural source found in exoskeleton of insects, crustaceans and fungi. With excellence in properties like biodegradability, biocompatibility, nontoxicity chitosan suits for biomedical applications. Large variety of fungi, yeasts, bacteria can be inhibited by chitosan and through electrospinning technique nano fibers are prepared [18]. These specifications made chitosan ample with opportunities in biomedical and other fields of industry.

5. Synthetic polymers

Polyvinyl alcohol Polycaprolactone (PCL), polyurethane (PU), poly(lactic-co-glycolicacid) (PLGA), poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV), and poly(ethylene-co-vinyl acetate) (PEVA) are the synthesized polymers that can be used to prepare nano fibers with different techniques [19–21]. Poly Lactic acid (PLA), Poly glycolic acid (PGA) and their copolymer (PLGA) are biodegradable found applications in medical field [22].

These all are water soluble polymers with good mechanical properties. Some of these synthesized polymers are strong enough with good antimicrobial and anti-fungal activities. Combining with natural polymers these synthesized new scaffolds were prepared for various applications [23].

6. Semiconducting materials

In the present day scenario semiconducting materials looks forward to develop many new technologies that relates to environment and society. Reduction of a material to its nano size exhibit numerous novel properties with a wide range of applications include energy materials, optoelectronic devices, biomedical imaging etc. [23]. The size dependent tuneable band gaps of semiconductors exhibit excellent properties and are used to generate nano fibers. Many fibrous materials that possess semiconducting properties can be prepared from versatile techniques. Three different sources acetylene, ethanol and cotton were used to prepare semiconductor carbon nano fibers. Many electronic functionalities like light emitting diodes, photonic compounds, field effect transistors are used to fabricate nano fibers [24].

6.1 Metals and composite materials

Metals and composite materials have explicit optical, physical and electrical properties. These special features avail the materials amalgamate with nano fibrils to develop new fibrous materials [25]. The newly developed materials exhibit stability, flexibility, bio compatibility, selectivity and improved sensitivity.

6.2 Carbon based materials

Formation of stable organic as well as inorganic molecules is possible from high flexible nature of carbon. Notable mechanical, thermal, electrical properties versatile carbon materials and intrudes the formation of carbon nano fibers [26]. These CNF's also acts as essences for composite materials.

Nano fibers from these materials can be obtained from various physical, chemical or mechanical techniques explained in detail further in this chapter.

7. Synthesis Mechanism

Synthesis of nano fibers include various chemical and mechanical and optical methods. From their early preparation till to date so many techniques keep on coming to generate fibrous materials in nano size. Nano fibers are generated from various technologies electrospinning, self-assembly, template based synthesis, polymerization, sonochemical synthesis [27]. **Figure 2** shows the synthesis mechanism of nano fibers from various techniques. Along with these methods freeze drying or lyophilization is another technique used to produce nano fibers from cellulose materials. There are few ongoing and upcoming new technologies to synthesize nano fibers. Few of them are electro-hydrodynamic writing, plasma induced synthesis, solution blow spinning, centrifugal jet spinning, CO2 laser supersonic drawing.

Of all the availability techniques electrospinning is adaptable mechanism for the production of nano fibers [28–31]. In this technique simple experimental arrangement is used to prepare nano fibers. An electric source, a syringe with nozzle, a counter electrode, target and a pump is the experimental setup to generate fibers at nano scale as shown in **Figure 3**. The principle of this technique is the electrostatic repulsion force produced in a high electrical field. The ejected solution forms into Tylor cone due to the potential difference. The solvent in the solution evaporates that leads to the formation of nano fibers and collected at collector. New improvisation in conventional electrospinning technique is done to generate nano fibers with enhanced properties. There are several types of electrospinning methods that includes multi axial, Co-axial, tri axial electrospinning, bi-component, mutlineedle electrospinning, needle less- bubble, two-layer fluid, splashing electrospinning are the techniques implementing to improve the nano fiber productivity [32].

Majority of fibrous materials from natural and synthetic polymers are generated from electrospinning and its related techniques.

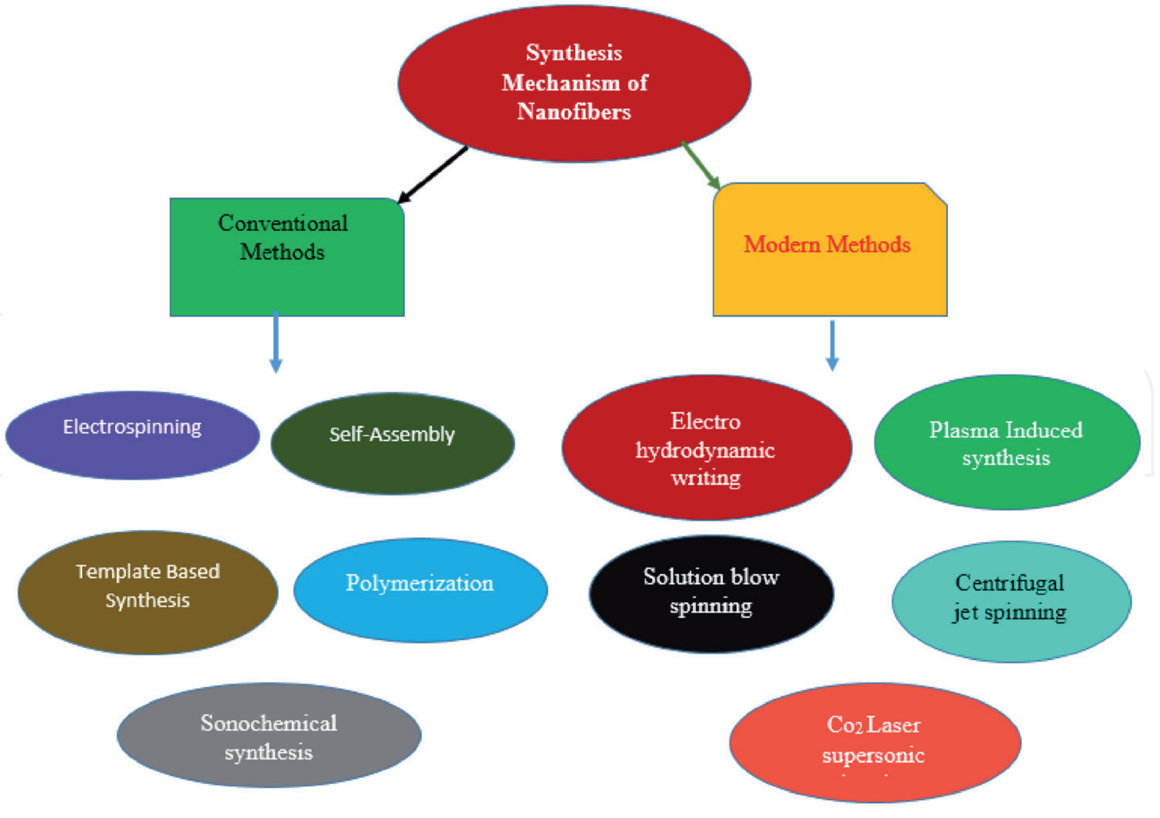

Figure 2.
Representation of Conventional and Modern Methods for synthesis of nano fibers.

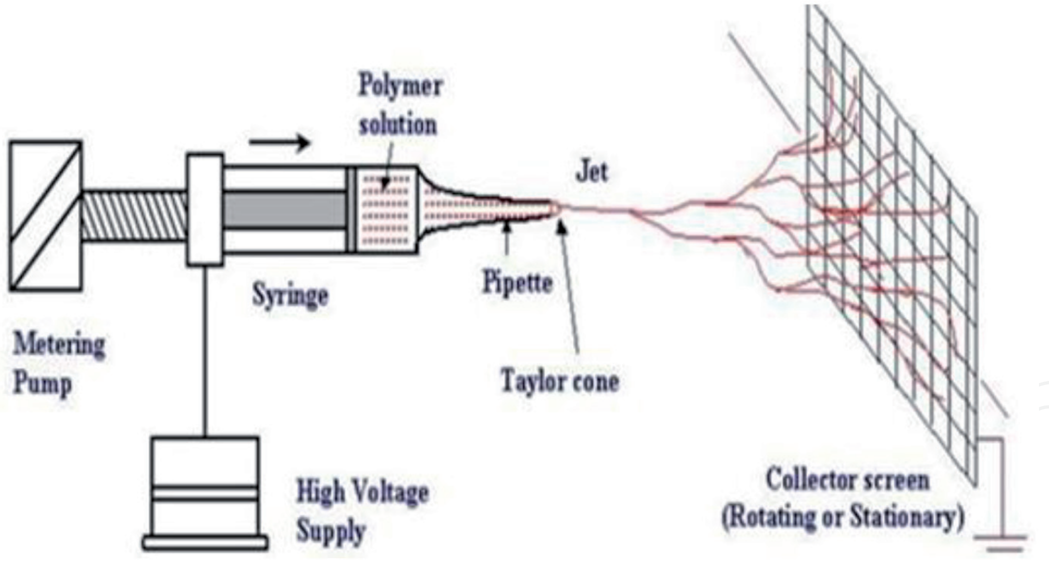

Figure 3.
Representation of nanofiber production with basic electrospinning method [32].

7.1 Self-assembly

Self-assembly is one of the technique used to produce a variety of nano fibers. Self-assembly peptides are capable of producing scaffolds that improvises luminescence efficiency of nano clusters. Natural structural materials are self-assembled by acquiring desirable properties such as mechanical strength, thermal stability and biocompatibility. Peptide and peptide amphiphiles nano fibers are synthesized using self-assembly (**Figure 4**) [33].

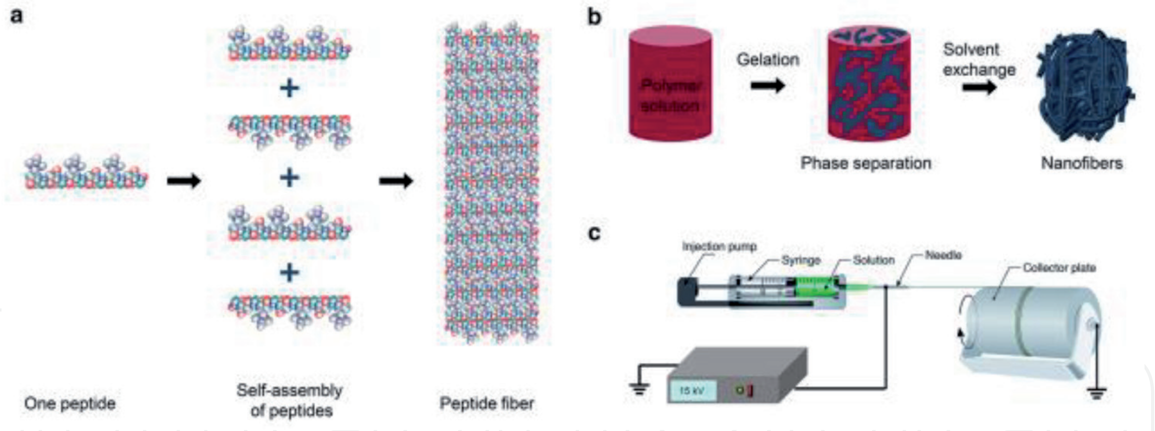

Figure 4.
Generation of nano fibers through self-assembly, phase separation and electron spinning [33].

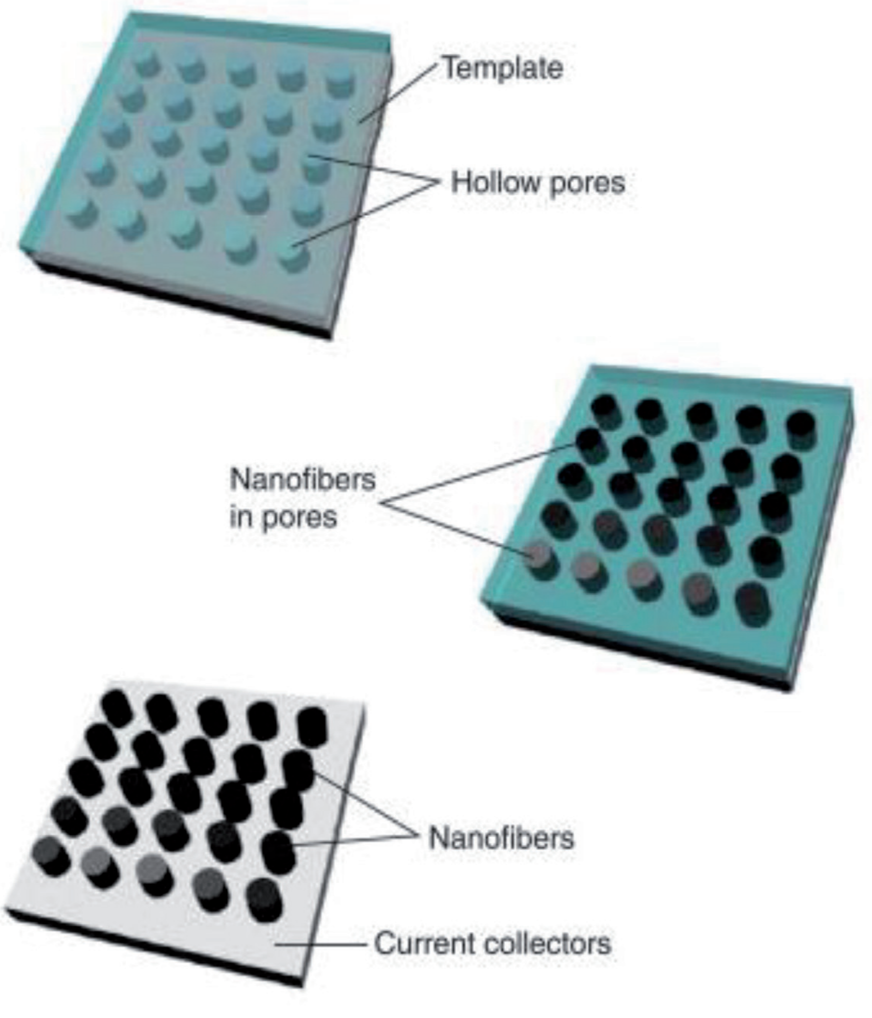

Figure 5.
Nano fibers from template synthesis [34].

7.2 Template synthesis

Nano fibrils and hollow nano fiber are produced by template synthesis mechanism. Nano fibrils are prepared within the microporous membrane or any solid pores. Desired morphology of nano fiber is obtained by pre-configuration. **Figure 5** shows a method for preparation of nanofibers. Sol–gel or electrodeposition are used to fill cylindrical pores at nano scale. Nano fibers are formed below the template [34].

7.3 Polymerization and sonochemical synthesis

Polymerization is a specific method used to synthesize nano fibers from polyaniline [35]. Three major methods are used to produce nano fibers. Chemical oxidative polymerization, interfacial synthesis and rapid mixing reactions [36]. A traditional way of obtaining fibers from polyaniline is the chemical oxidative polymerization. Polymerization takes place with the addition of aniline and an oxidant in acidic solution. By this method nano fibers without fine structure are formed. However, ultrafine nano fibrous material is produced when potassium biiodate is used as oxidant, then crystalline fine structured nano fibers were formed [37]. Polyaniline nano fibers were produced with homogenous nucleation. In this process overgrowth of molecules occurs and is controlled by the formation of nano fibers.

A powerful ultrasound irradiation is utilized for chemical reaction of molecules is sonochemical synthesis. Using this methodology, the molecules undergo high temperature and pressure conditions to produce varied range of nano structured materials. Polyaniline nano fibers can also be obtained from this method [38].

7.4 Electro hydrodynamic writing

Electro hydrodynamic writing is a modern technique that drew attention of many with great potential in rendering nano fibers into highly flexible and controllable substrates. This technology gives highly controllable, flexible aliened micro/nano fibers [39]. Output obtained through electro hydrodynamic writing in developing nano fibers is so popular due to low cost, high flexibility and intense applications in various fields. Direct writing is possible from mechanoelectrospinnig to obtain direct hierarchal nano or microfibers. Unlike the general electrospinning mechanisms this method uses mechanical force that stimulates positioning of fibers with controllable morphology. **Figure 6** shows the mechanism is used to produce nano fibers from assisted air flow with constrained force and additional stress that enhances jet stability. A versatile system is being developed for the production of ultrafine, highly flexible and stretchable electronics using nano fibers and there by applied in the formation of sacrificial structures [40].

7.5 Plasma induced synthesis

Plasma induced synthesis is used to generate nano particles in different shapes and nano fibers in five steps. (i) rapid bombardment of radicals on electrode surface (ii) atomic vapor deposition (iii) plasma expansion (iv) condensation of solution (v) in situ reaction of oxygen and growth of nano fibers [41]. In the production of nano fibers plasma generation is the key role. It is generated from discharge of pulse between electrodes in solution by direct current. Silver nano particles are induced on chitosan nano fibers are to confirm antibacterial activity [42].

7.6 Solution blow spinning

Solution blow spinning is a new emerging modern technique in fabrication of nano fibers. Both electrospinning and melt blowing elements are combined to organize this technique for the production of micro and nano fibers. Using this method production rate increases drastically. **Figure 7** shows the experimental arrangement of solution blow spinning. A syringe pump is used to deliver polymer

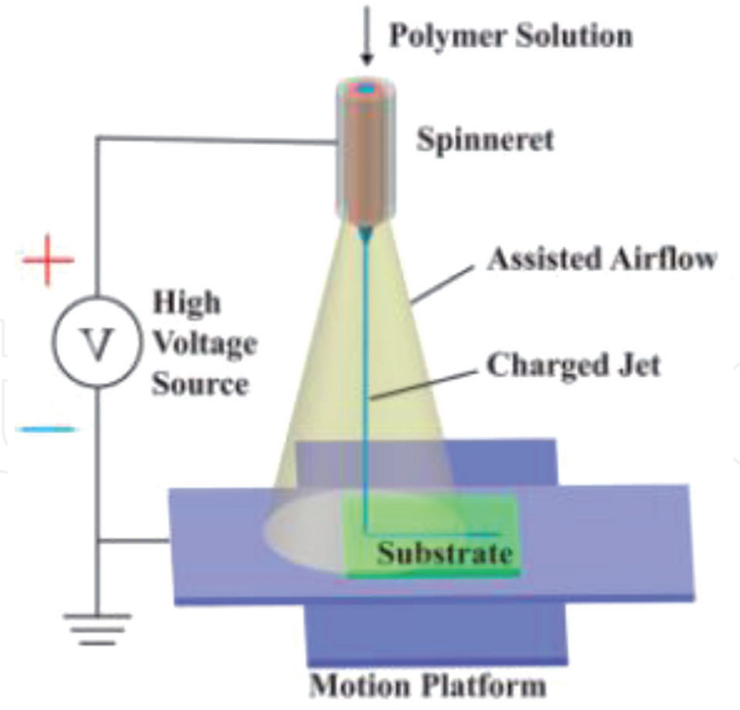

Figure 6.
Electro hydrodynamic writing to produce nano fibers [40].

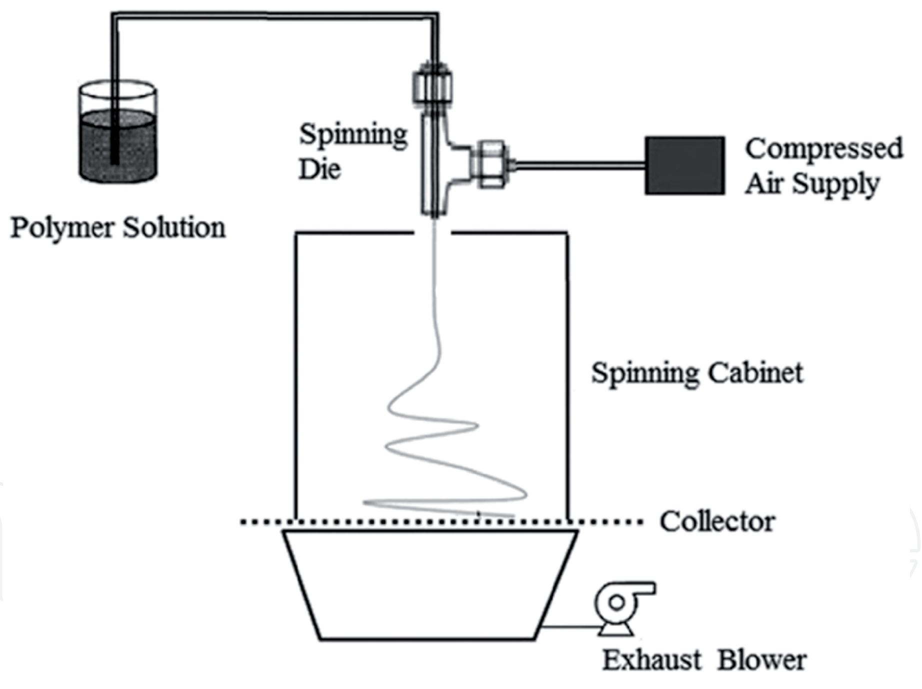

Figure 7.
Representation of solution blowing technique [43].

solution pumped through a nozzle under compressed air supply. This is used in situ deposition of nano fiber mats and mostly used for tissue engineering applications [43]. As an example nano fibers generated from solution blow spinning are used for composite air filter masks [44].

7.7 Centrifugal jet spinning

A new technique with high efficient, low cost and greater throughput to fabricate nano fibers is centrifugal jet spinning. **Figure 8** shows a dc motor with flexible air

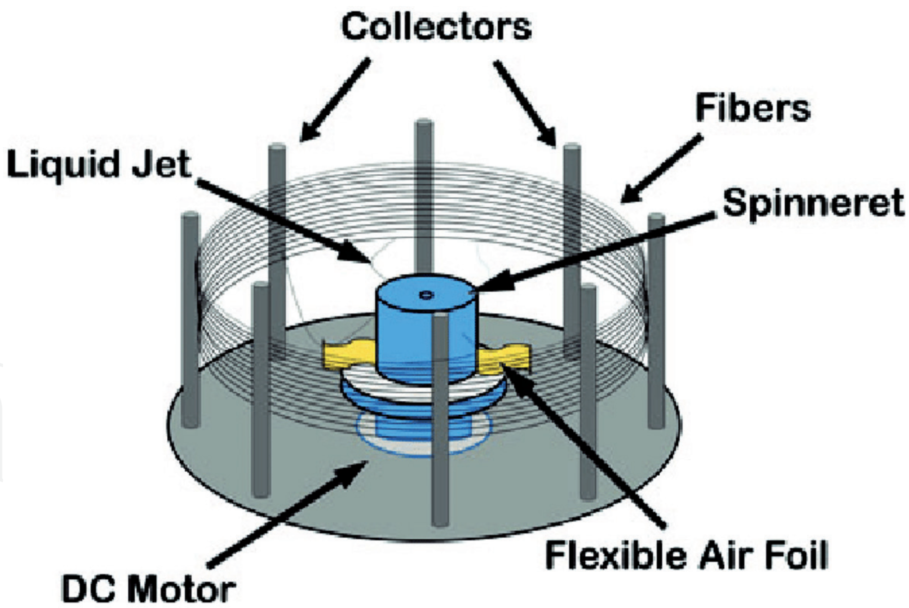

Figure 8.
Schematic diagram shows centrifugal jet spinning [45].

foil with liquid jet and spinneret is used to produce fibers. Two collectors are there to collect the obtained nano fibers [45]. When the centrifugal force overwhelms surface tension of polymer liquid material that stretches out the solution forming nanofibers in solid form. As an example a new spin nano fibers are used to produce nano fibers that is used as a fibrous mat scaffold for bone regeneration [46].

7.8 CO_2 laser supersonic drawing synthesis

This technique is a novel method to develop long nano fibers by irradiation with CO_2 laser at supersonic velocities. Melted fibers are gone through supersonic airflow to draw nano fibers in the range of diameters. Estimation of flow velocity is done by computer program. Through this process several natural and synthetic polymers are being used to yield nano fibers [47].

8. Applications

Numerous applications of nano fibers are fascinating world due to their use in generating energy, many biological, medical field, in defense, food industry, water and environment. Each of these fields have specific developments from nano fibers as shown in **Figure 9**.

8.1 Energy applications

Nano fibers emerged as best replacement for electrodes from anode and cathode materials used in lithium ion batteries. Many factors like electrochemical performance, limited capacity, high cost of materials affect the usage of lithium ion batteries as large scale storage devices [48]. Introduction of nano fibers as electrode materials paved way for generation of energy in batteries and fuel cells. The advantage of nano fibers being used as electrodes came from the properties such as high porosity, large surface area. The capability of nano fibers has extended from lithium-ion batteries to three dimensional interconnected networks. Metal organic frame works derived from metal oxides were intruded

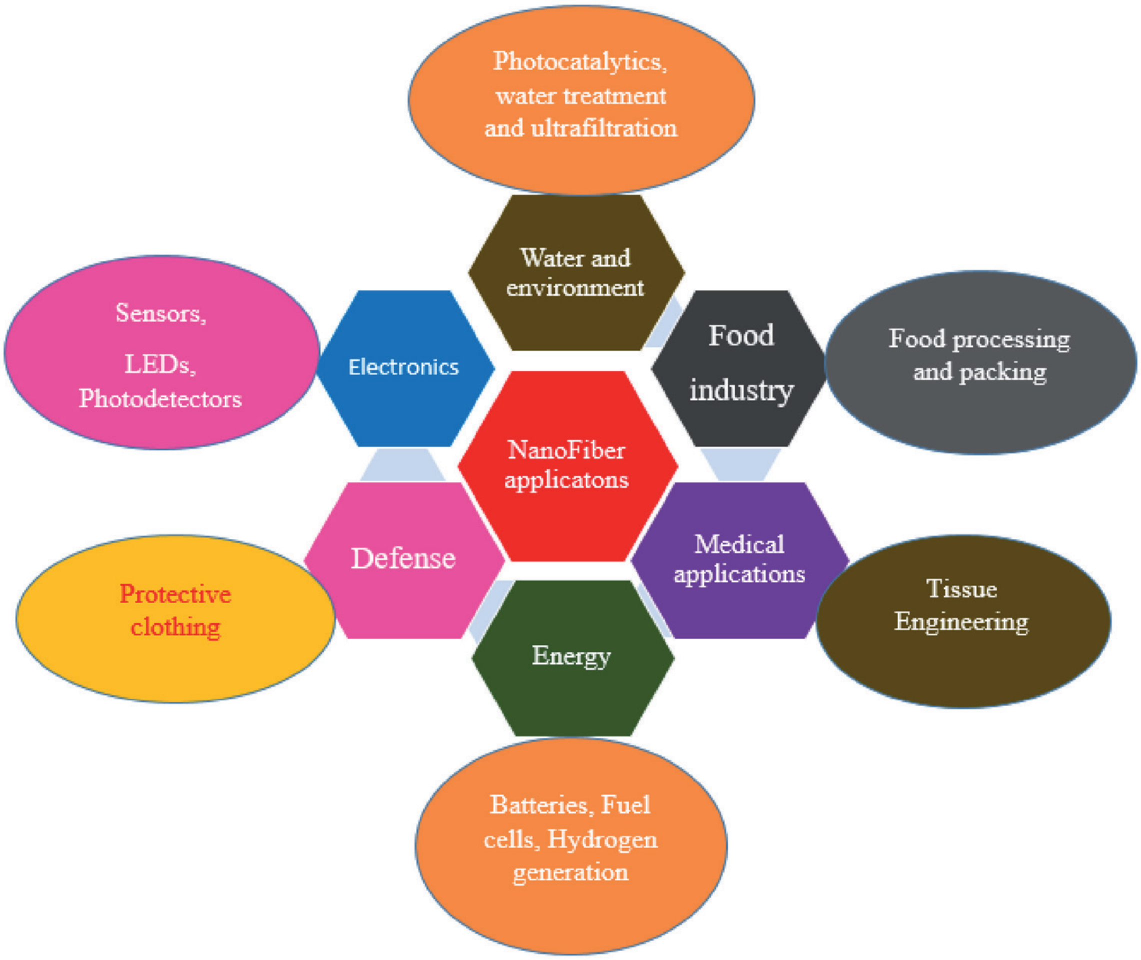

Figure 9.
Applications of nano fibers in various fields.

in carbon nano fibers through electrospinning to improve electrical conductivity with excellent rate capability [49].

Hydrogen is one of the future energy generation sources best carrier for renewable fuels due to its high energy content. Limitation in the availability, economical storage and generation are the challenges in the use of hydrogen as energy carrier. Nano fibered structures are synthesized to improve hydrogen storage.

8.2 Medical applications

Nano fibrous materials acts as best alternative scaffolds for tissue engineering as well as regenerative medicine [50]. Specific properties of nano fibers make them biologically active. Replacement of cells or tissues to exhibit proper body mechanism is the regenerative medicine. Transplantation of cells or tissues is done by various biologically active materials. Of them scaffolds developed from nano fibers are important as these are favorable layout for cellular growth, proliferation [51]. Natural or synthetic fibers are majorly used for tissue engineering as they have biocompatibility, biodegradability. As an example improved angiogenesis (development of new blood vessels) is improved through nano fibers for tissue engineering applications. Hard and soft tissues reconstruction is done by nano fiber scaffolds [52].

8.3 Food industry

The use of nano fibers especially cellulose nano fibers from various materials like fruit peel extracts, sea alga, bacteria, fungi have been utilized in food industry.

The use of nano fibers in food industry starts from packing, protecting aromatic and unstable compounds in beverages, monitors storage and in detection of pesticides [53]. Also nano sensors are used for quality assessment.

8.4 Water and environment

Morphology of nano fiber materials is attracting researchers due to numerous applications in environmental and water related issues in recent developments. Membranes of nano fibers developed from electrospinning technique shows greater prospective in waste water treatment and recycling. Many water treatment functionalities such as separation, adsorption, photo catalysis and antimicrobial activities can be treated effectively by nano fiber membranes Fiber mats prepared from nano fibers act as best filtration membranes that minimizes pressure drop with better efficiency than conventional mats. The contaminants in water and air were absorbed from the membranes of nano fibers with large surface to volume ratio and shows an increment in the life time of these mats [54].

8.5 Electronics and defense

Many micro and nano electrical devices like ultra-light weight space craft materials, electrostatic dissipation, nano solar cells, LCD devices are manufactured with nano fiber materials in electronics [55].

Types of nano fibers	Fabrication techniques	Advantages	Applications
Natural Polymers	Electrospinning, Template based synthesis, Electro hydrodynamic writing, CO_2 laser supersonic, centrifugal jet spinning, plasma induced synthesis	Natural Polymers are obtained from renewable sources, eco-friendly and low cost	Food industry, medical applications, water and environment, protective clothing
Synthetic Polymers	Electrospinning, Electro hydrodynamic writing, self-assembly, polymerization	Synthetic polymers provide optimal support to cell attachment with improved mechanical strength.	Wound dressing, filters, drug delivery, cytotoxicity studies
Semiconducting, metals and composite materials	Electrospinning, centrifugal jet spinning, solution blow spinning	With specific physical, chemical and mechanical properties nanofibers obtained from these materials intrudes into many devices.	Biomedical, optoelectronic, bio imaging and sensors
Carbon based materials	Electrospinning, sonochemical synthesis, template based synthesis	These are the materials which produce three dimensional graphene structures with high surface area, porosity, flexibility.	Super capacitor, air purifier, batteries and sensors

Table 1.
Types of nano fibers advantages and applications.

Nano fibers are the fantastic materials that found applications in defense. Face masks, chemical protective clothing liners, decontamination wipes etc. were prepared from nano fibers to improve their efficiency at low cost. Polyethylene oxide nano fibers serves as detoxifying substances against chemical war fares [56].

Table 1 shows the synthesis of nano fibers from various materials, their fabrication techniques, advantages and applications.

9. Conclusions

Nano fibers are excellent materials designed from various materials like natural, synthetic polymers, metals, semiconductors and many more. These nano fibers have been developing since ages till to date with lot of improvement in their synthesis mechanisms. With a drastic improved properties nano fibers have pronounced applications in different fields. The fabrication methods include conventional methods like electrospun, template based synthesis, polymerization, self-assembly and sonochemical methods and modern methods like electro hydrodynamic writing, plasma induced synthesis, solution blow spinning, centrifugal spinning and CO_2 laser supersonic technologies. New technologies to fabricate nano fibers are being developed day by day to meet the requirement of society. These nano fibers are synthesized from natural, synthetic polymers and from different materials like semiconductors, carbon based materials and many more. Applicative orientation makes these nano fibers a specific alternative to non- renewable sources. Still researchers are keenly looking into the real time applications of these nano fibers at huge.

10. Challenges and future research work

There is a huge demand of nano fibers due to their numerous applications in various fields. These acts as best alternatives for solving many life leading problems that include water and purification, health related issues, electronics, energy derivatives etc. Nano fiber entrustment in all areas with commercial acceptance is the present challenge to the scientific world. Novel development in the fabrication of nano fibrous materials is the ongoing and future research work.

Author details

Deepthi Sista
Department of Science and Humanities, Lendi Institute of Engineering and Technology, Vizianagaram, India

*Address all correspondence to: deepthi.sista@lendi.org

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