Perspective

Recent Nanofiber Technologies: A Perspective for a Special Issue of Polymer Reviews

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This article is a Perspective that includes a brief introduction in nanofiber production method, its potential applications, and three review articles in the field of nanofibers. Although the full range of applications that best exploit these new developments are yet to be developed, the emerging innovative applications of nanofibers in biomedical, sensor, electronic, and other areas will likely to be enabled or enhanced by these recent advances in several key techniques. Three articles review distinct but interrelated of technical researches and developments, and possible applications for several industries in the polymer nanofiber arena.

Keywords Nanofiber, Electrospinning, Nonwoven membrane, Spinning apparatus

For almost 100 years,[1] it has been known that polymer fibers can be generated from an electrostatically driven jet of polymer solutions or melts. This process, known as *electrospinning*, has received a great deal of attention in the last decade because of its ability to consistently produce polymer fibers ranging from 5 to 500 nm in diameter. The crucial patent, in which the electrospinning of cellulose derivative, such as cellulose acetate, for the production of artificial filaments was described for the first time, appeared in 1934 with A. Formhals.[2] Despite these early discoveries, the procedure was not utilized commercially. Electrospinning gained substantial academic attention in the 1990s, which was partially initiated by the activities of Reneker's group.[3] The schematic diagram for a typical electrospinning apparatus is depicted in Fig. 1. Briefly, the basic electrospinning process uses a polymeric solution driven from a syringe into a needle by a syringe pump. A high voltage is applied to the syringe needle, causing the surface of the drop to distort into the shape of a cone, which is known as Taylor Cone. When a critical voltage is exceeded, a jet of solution erupts from the apex of the cone and is accelerated toward the electrically grounded collection target by the macroscopic electric field. As this jet travels through the air, the solvent evaporates leaving behind a polymer fiber (*via electrospinning*) or polymer nanoparticles (*via electrospray*) to be collected on an electrically grounded target. Baumgarten[4] first imaged the chaotic nature of the electrospinning jet motion. Recent work by Reneker et al.[5] suggests that this chaotic motion, or 'bending instability', results from repulsive forces originating from the charged elements within the electrospinning jet. In general, deposition of electrospun fibers on a stationary target is essentially random due to the chaotic motion of the electrospinning jet as it travels to its target. This is particularly useful for membrane and filter applications, which take advantage of the small pore size obtained by the random morphology of the nonwoven electrospun membranes.

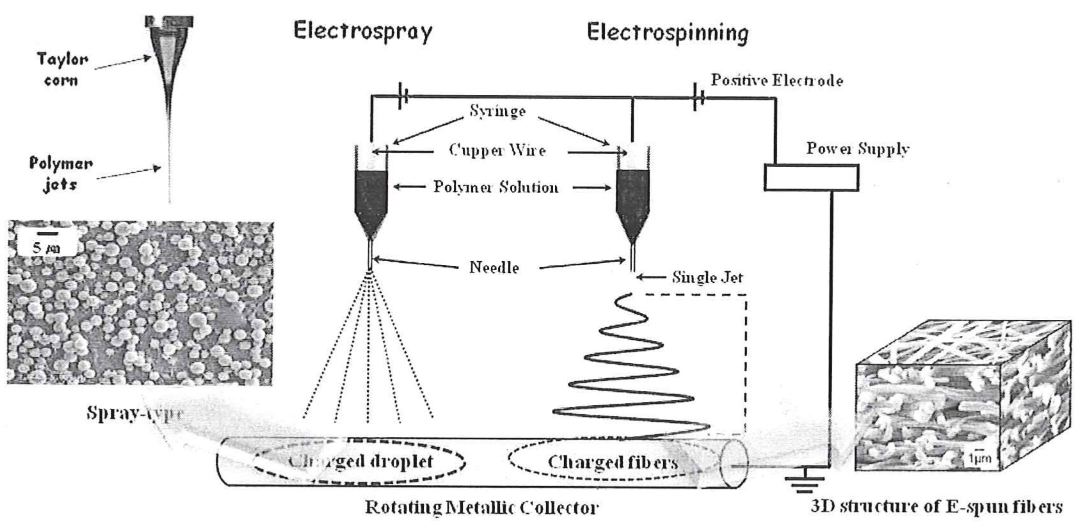

Figure 1. Schematic showing the electrospinning process

So far, several methods, for instance sea-island conjugated spinning, melt blowing, and solution electrospinning methods, have been developed to generate the nanofibers.[6-8] Among them, solution electrospinning is a simple, inexpensive and straightforward method for generating the polymer nanofibers, as compared with other spinning methods, and one of the technological innovations in nonwoven and textile industries. A number of polymers including both synthetic and natural polymers, as well as biopolymers have been successfully spun into the fibers with diameters ranging from tens of nanometers to a few micrometers via electrospinning.[9-13] The growing interest in the utilization of these nonwoven nanofiber membranes primarily stems from their unique physical, mechanical, and electrical properties associated with their very high surface area and small pore sizes in comparison with commercial textiles.[14] These properties make nanofibers suitable for the creation of numerous technologically excellent candidates for applications in filtration,[15,16] protective textiles,[17] reinforcement in composite materials,[18] catalysis,[19] sensors,[20] as well as biomaterials for wound devices[21] and drug delivery and scaffolds in tissue engineering.[22,23] During the last decade, the number of research activities resulting in patent applications and issued patents has increased rapidly, by almost a factor of more than 15, leading to the development of nanofiber mass-production system and a large variety of applications spanning many industrial sectors. Electrospun fibers were first commercialized for filter applications, as part of the nonwoven industry.[24] Many of nonwoven industries have tried to develop or search for the latest technologies that could have applications in the new performance products. Despite of the potential mentioned above, the application of nanofibers has been limited due to its poor mechanical properties and the difficulty for mass production because of its peculiarly low process throughput. The innovative modifications of the basic spinning apparatus and methodology used in electrospinning allow a wide range of fiber and mat morphologies to be produced, which include novel electrode arrangements, the use of AC voltage to drive the process, reactive electrospinning, unusual collector geometries, unique tip designs, vibrating tip designs and the use of different spinning environments. Although the full range of applications that best exploit these new developments are yet to be developed, the emerging innovative applications of nanofibers in biomedical, sensor, electronic, and other areas will likely to be enabled or enhanced by these recent advances in several key techniques.

In this special issue of *Polymer Reviews*, we present recent three articles that review distinct but interrelated of technical researches and developments, and possible applications for several industries in the polymer nanofiber arena. The first article contributes the promising high-performance nanofiber anodes, nanofiber cathodes, and nanofiber separators that can potentially replace currently-used lithium-ion battery materials. They demonstrate that lithium-ion batteries using electrospun nanofiber anodes, cathodes and separators have excellent overall performance including large capacity, high charge/discharge rate capability, and extended cycle life, which is a first review on the electrospinning of nanofibers of different materials, including polymers, carbons, and ceramics. The second contribution focuses on recently developed melt-electrospun fibers for advances in biomedical engineering, clean energy, filtration & separation. Here, it is worth to mention that the attempts were made to improve the design and development of melt electrospinning and fabricate fibrous materials using the set up during last few decades. On the other hand, even though melt-spinning has a great potential for the production of micro and nanofibers which can be an interesting alternative to the conventional solution electrospinning, the number of papers and research groups working in the application of melt electrospinning for novel applications is significantly lower than that of solution electrospinning. The last review emphasizes on the development of polypropylene (PP) nanofiber production system using three different methods, for instance, solution electrospinning, melt blown electrospinning, and novel handspinning. In general, solution electrospinning of polyolefins, including polyethylene and polypropylene, has been limited due to their high solvent resistance and very high electrical resistivity, while recently PP nanofibers were successfully prepared from the mixed and polar solvents for providing the electrical property with PP at room or slightly elevated temperature, which will offer potential opportunities for a wide variety of applications of the polypropylene nanofibers.

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