Electrospun Nanofibers: Technology Status, Applications, and Market

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1. Technology Status

Interest in producing smaller diameter textile fibers came about by late 1980's when first microfibers were spun. Several innovative textile techniques such as the spinning of bicomponent polymer fibers through islands-in-the-sea dies followed by extraction of the soluble component, melt-spinning, and melt-blowing have since been used to obtain fibers with average diameters in the range of hundreds of nanometers. Electrospinning, however, introduces a new level of versatility and a wider range of materials into the micro/nanofiber range. An old technology rediscovered, refined, and expanded into non-textile applications in recent years. Electrospinning is unique among nanofiber fabrication techniques in terms of process control, materials combinations, and the potential for scale-up. In the electrospinning process, a high voltage is used to create an electrically charged jet of polymer solution or melt out of the pipette, and before reaching the collecting screen, the solution jet evaporates or solidifies, and is collected as an interconnected web of small fibers. The first description of the process recognizable as electrospinning was in 1902 when J. F. Cooley filed a United States patent, where he describes a method of using high voltage power supplies to generate yarn. The next significant academic development was achieved by John Zeleny, who published work on the behavior of fluid droplets at the end of metal capillaries in 1914. In the 1990's Reneker and co-workers drew attention to electrospinning as a means to produce small diameter, continuous filaments. Since then, the electrospinning has attracted increasing attention, as seen from the number of publications and patents per year (Figure 1). In contrast to conventional synthetic fiber forming processes where continuous fibers ranging from 10 to 500μm are produced, electrospinning readily leads to the formation of continuous fibers with diameters ranging from 0.01 to 10μm. When the diameters of fibers are reduced from micrometers to nanometers there appear several superior characteristics such as very large surface area to volume ratio, flexibility in surface functionalities, and superior mechanical performance. This has led to it being recognized as a key platform technology that will yield products for a broad range of uses including electronics, drug delivery, chemical sensors, tissue scaffolding, filtration, solid-state lighting applications. nanocatalysis, protective clothing, pharmaceutical, healthcare, biotechnology, defense and security, and environmental engineering [1-3].

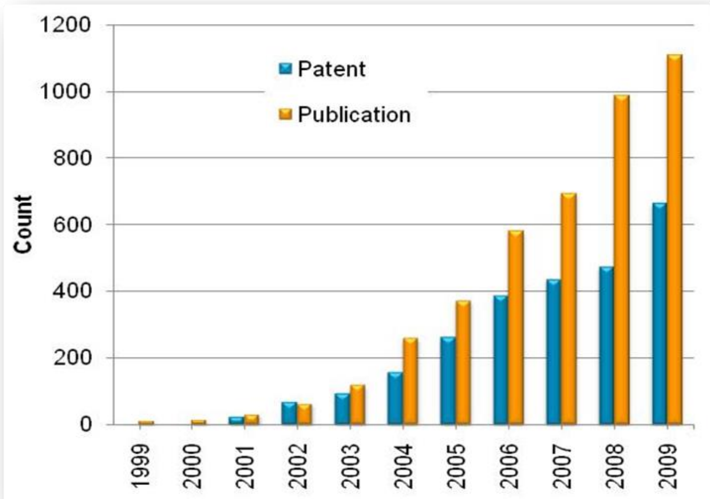

Figure 1. Number of electrospinning related publications and patents per year (Source: Scopus)

Innovative modifications of the basic spinning apparatus and methodology used in electrospinning allow a wide range of fiber and mat morphologies to be produced. Many interesting variations of the basic electrospinning process have been described in the literature over recent years. These innovations include coaxial electrospinning, mixing and multiple electrospinning, core-shell electrospinning, blow assisted electrospinning and others. Coaxial electrospinning includes fabrication of nanofibers from two polymers which utilizes coaxial capillary spinneret and as a result a core of one polymer and shell of the other are formed. With this technology, some polymers which are difficult to process are co-electrospun and form a core inside the shell of other polymer. This method gains attention as it provides novel properties and functionalities of nanoscale devices through the combination of polymeric materials in the axial and radial direction. Blowing-assisted electrospinning helps in spinning of high molecular weight polymers which was otherwise difficult to spin by solution electrospinning. A recent research has demonstrated the use of nanofibers in making nanowires as the incorporation of carbon nanotubes within the fibrous structure provides anisotropic properties such as electrical and thermal conductivity. Also, changing the surface morphology of individual fibers either by creating pits, pores, or bumps on their surface or by altering their circular cross-section by regular or irregular patterning of the surface offers an alternative or complementary method of increasing the specific surface area of nanofibers. In future, electrospun nanofibers will prove to be a promising candidate for a wider range of applications [4, 5].

2. Applications

Recently, researchers have begun to look into various applications (Figure 2) of electrospun fibers and mats as these provide several advantages such as high surface to volume ratio, high porosity and enhanced physico-mechanical properties. While the potential for nanofibers is enormous, there are also considerable challenges ahead for many of these applications. Most of the studies in this area have been conducted on fibers produced on a very small scale, using a needle based system to electrospin nanofibers from a polymer solution. Since large scale production of nanofibers using pilot or industrial scale equipment, such as the Nanospider™ system from Elmarco, is now possible, nanofibers are one-step closer to commercializing [6-8]. On the other hand, Donaldson Company, Inc. has been using electrospinning technology to make fine fibers for more than two decades. Donaldson produces Ultra-Web™ nanofibers with sub-half-micron diameters for air filtration in commercial, industrial and defense applications. Nanofibrous filter media make new levels of filtration performance possible in several transportation applications including internal combustion engines, fuel cells and cabin air filtration. Today, there are more 60 companies involved in nanofiber business, with the increase in the number of start-up and spin-off companies every year.

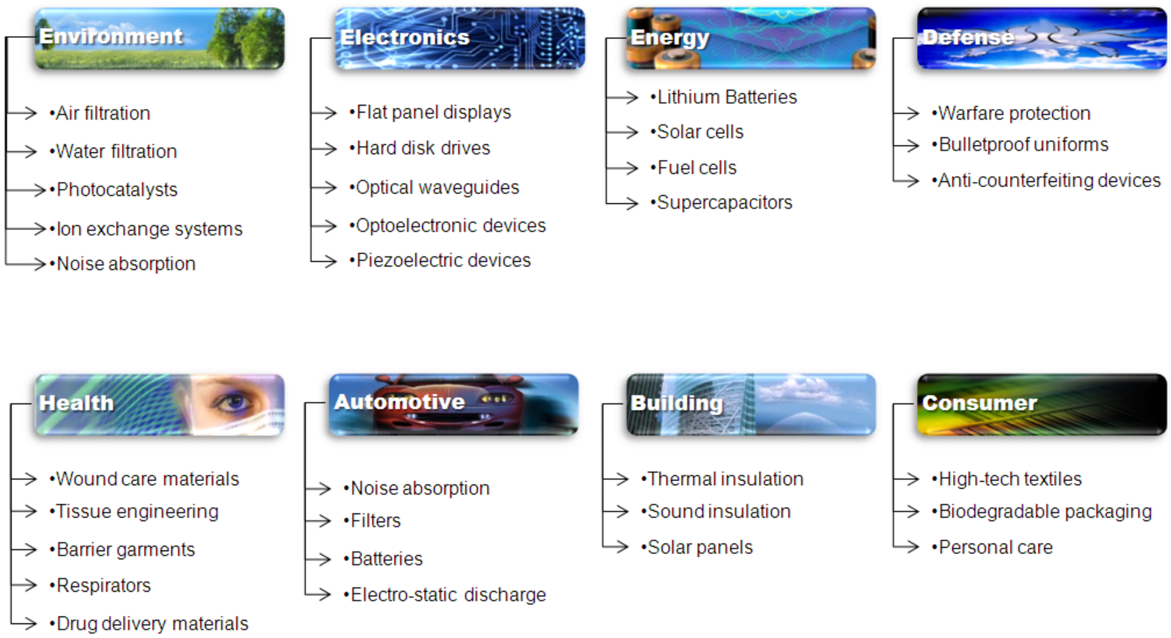

Figure 2. Potential applications of electropsun nanofibers

3. Market

According to BBC market report, the global market for nanofiber based products increased from $51.8 million in 2007 to $67.1 million in 2008 and $80.7 million in 2009, and is estimated to reach $101.5 million by the end of 2010. Despite the global economic downturn that started in December 2007, sales of nanofiber products have experienced very healthy growth during the past 3 years, with an estimated CAGR of 25.1% for the period 2007 through 2010. Sales growth has actually accelerated compared to previous years. Revenue growth for nanofibers is being driven primarily by the utilization of these materials in the mechanical/chemical sector for manufacturing filtration media and catalysts. The mechanical/chemical sector is estimated to account for 73.2% of all revenues in 2010. The other two main sectors are energy and electronics, which combined account for 22.8% of the total market. Sales of nanofiber-based products are projected to continue growing at a very healthy rate during the next 5 years, driven by further penetration of nanofibers in the above sectors and by various newer, high-tech applications that are entering mainstream commercialization in other fields such as the consumer and medical/biological/pharmaceutical sectors. The total market for nanofiber products is forecast to grow at a compound annual growth rate (CAGR) of 34.3% through 2015, and at a 37.2% CAGR from 2015 through 2020, reaching nearly $2.2 billion in total revenues by 2020 [9].

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