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Multifunctional Composite Nanofibers

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Abstract

Multi-functional fibrous materials are a new family of fiber materials whose physical and chemical properties are sensitive to the change in the environment such as temperature, pressure, electric field, magnetic field, optical wavelength, adsorbed gas molecules and the pH value. This paper introduces a new approach to translate functions from nanoparticles to advanced fibrous structures by co-electrospinning of composite nanofibers. To illustrate this composite nanofiber concept an example of nanofibers that have tailorable, electrical and magnetic functions is shown.

Keywords: Functional Materials; Nanofibers; Co-electrospinning; Nanocomposite; Lignin Nanofiber

1 Introduction

Multi-functional materials are a new family of materials whose physical and chemical properties are sensitive to the change in the environment such as temperature, pressure, electric field, magnetic field, optical wavelength, adsorbed gas molecules and the pH value. The functional materials utilize the native properties and functions of their own to achieve an intelligent action [1]. Multi-functional materials in the form of fibers bring additional attribute as a carrier of the functions to higher order structures ranging from medical devices to clean water filters, to electrodes for rechargeable batteries and solar cells [2].

In the search for multi-functional material concepts one can find abundant of clues in nature. In fact multifunctionality is a norm rather than exception in living systems. Fibrous materials in nanometer scale are the fundamental building blocks of living systems. From the 1.5 nm double helix strand of DNA molecules, including cytoskeleton filaments with diameters around 30 nm, to sensory cells such as hair cells and rod cells of the eyes, nanoscale fibers form the Extra-cellular Matrices (ECM) or the multifunctional structural backbone for tissues and organs [2]. Specific junctions between these cells conduct electrical and chemical signals that result from various kinds of stimulation. The signals direct normal functions of the cells such as energy storage, information storage and retrieval, tissue regeneration, and sensing. Analogous to nature's design, nanofibers and their composites can provide fundamental building blocks for the construction of

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devices and structures that perform unique new functions. The areas expected to be impacted by the nanofiber based technology include drug delivery systems and scaffolds for tissue engineering, wires, super capacitors, transistors and diodes for information technology, systems for energy transport, conversion and storage, as well as smart structural composites for medical devices [2-3].

Some research studies have been done on multi-functional electrospun composite nanofiber fabrication and applied in different fields. In structural composite areas, for example, Carbon Nanotubes (CNT) reinforced Polyacrylonitrile (PAN) nanocomposite fiber has been fabricated by Ko *et al.* previously. It has been shown that co-electrospinning provides an excellent means for the translation of the mechanical properties of CNT to polymer fibril matrix by the inclusion of a small amount of CNT [4]. Multifunctional composite nanofibers can also be used in electrical and electronic application area. Lithium ion battery anode has been prepared by electrospinning of Poly(acrylonitrile-co-acrylamide) (PANAM) and silicon nanoparticles [5]. Using the process of electrospinning, nanofiber materials as a transparent conductor have been developed and their performance for applications in solar cell applications has been explored [5]. Electospun fiber could make soft magnetic materials with high saturation magnetization and high permeability for Electromagnetic Interference (EMI) shielding applications [6-8]. Bayat *et al.* developed electromagnetic nanofibers through incorporation of magnetic nanoparticles (Fe_3O_4) to PAN by electrospinning [6]. The electrical conductivity increased with the increase of carbonization temperature and Fe_3O_4 nanoparticles content in the carbon matrix. Chen *et al.* [7] fabricated cobalt ferrite ($CoFe_2O_4$)-embedded Polyacrylonitrile (PAN) carbon nanofibers. The saturation magnetization of this carbon fiber was 45 emu/g and it also demonstrated superparmagnetic behavior. Castillo *et al.* [8] designed a multifunctional core-shell fiber mat by co-electrospinning process. They used a fluorescent pH-sensitive copolymer (NP1(X)) as the outer fluid. Two different suspension, one is a polymethyl methacrylate (PMMA) melt magnetic nanoparticles (EDMA/MMA/-Fe_3O_4-OA-NP), and another is O_2 indicator (PtOEP) suspension, as the inner fluid. Thus, the core is magnetic and optically sensitive to O_2 and the shell is sensitive to pH. In biomedical area, multifunctional composite nanofibers have been tested out. An example of antibacterial fibers with silver nanoparticles has been studied [9]. It has been found that the Ag/PLLA fibrous membranes showed strong antibacterial properties. Thus, Ag/PLLA fibrous membrane can be used as an antibacterial scaffold for tissue engineering. Li *et al.* [10] developed a poly (L-lactic acid) (PLLA)/keratin composite nonwoven fibrous membrane as ECM for bone tissue engineering. Their testing results showed that the cell had higher viability and differentiation on PLLA/keratin membranes than on pure PLLA membranes. Li *et al.* further developed a keratin/hydroxyapatite (HA) nanocomposite then put it into electrospun PLLA fiberous membrane to mimic the natural mineralized nanofibrial counterparts. The result indicated that the keratin-HA could enhance the human osteoblast cell adhesion and formation on the PLLA-keratin-HA membranes [11-12]. Electrospun nanofibers are also an ideally scaffold for forming a hierarchically organized multi-functional components [13]. Bai *et al.* [14] assembled a TiO_2/PVP electrospun nanofiber/ZnO nanorod hierarchically multifunctional membrane for water filtration. It had several advantages such as high permeate flux and high antibacterial capacity. Lim *et al.* [15] combined sol-gel process and electrospinning technique to make Methyltriethoxysilane (MTES) organic-inorganic hybrid fabrics with thermally stable superhydrophobicity. The electrospun MTES fiber exhibited large water contact angle on surface and still maintained superhydrophobicity after heat treatment at high temperature. Summarily, multifunctional composite nanofibers preparation becomes very promising general method to transfer functions from nanoparticles to polymer and