Electrospun Nanofibrous Membranes

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1. Introduction

Membranes comprised of randomly oriented fibers ranging from microns to nanometers in diameter combine small pore size with high porosity. This porous structure has been shown to improve performance in many applications including filtration, catalysis, sensing and tissue engineering. The open porous structure of nanofiber membranes plays an essential role in enhancing the performance of the nanofiber-based materials in these applications. The porous structure of nanofiber membranes is also a determining factor in biological sensors, which require wicking of liquid analytes through the membrane to the detection point. The usage of electrospun nanofibrous scaffolds for biomedical applications has attracted a great deal of attention in the past several years. For examples, nanofibrous scaffolds have been demonstrated as suitable substrates for tissue engineering, immobilized enzymes and catalyst, wound dressing and artificial blood vessels. They have also been used as barriers for the prevention of post-operative induced adhesion and vehicles for controlled drug delivery [1]. For example, tumor-targeting nano-scale carrier from electrospun PLGA membranes through surface modification can convey the radio-active nuclide quantitatively to the tumor tissue by directly embedded at the lesions and can also play an anti-adhesion function at where surgical procedures have been made [2]. Nanofiber membranes are ideal for this application because the highly porous network of interconnected pores provides the necessary pathways for transport of oxygen and nutrients that are crucial for cellular growth, and tissue regeneration [3].

One principle of nanotechnology is that the reduction in the dimensions of a material leads to new properties, so called surface effect and quantum effect. Therefore, because of the unique properties and potential applications, especially one-dimensional (1D) nanostructures have been subject of research and mostly generated in the form of fiber, rod, belt, tube and spiral. Among these methods electrospinning seems to be the simplest technique for fabrication nanofibers which are exceptionally long in length, uniform in diameter and diversified in composition.

Furthermore, electrospinnnig is currently the only technique that allows the fabrication of continuous fibers with diameters ranging from several micrometers down to a few nanometers. This method is applicable to synthetic and natural polymers, polymer alloys, polymers loaded with nanoparticles or active agents, as well as to metals and ceramics [4].

2. Applications of Nanofibrous Membranes

2.1. Filtration and Separation

Nanofibrous membrane which possesses high porosity, interconnectivity and microscale interstitial space, is an attractive candidate for membrane preparation. Generally speaking, to obtain high filtration efficiency, it is necessary that the sizes of the channels and pores in the filter material be adjusted to the sizes of the particles to be filtered. Water filtration studies revealed that the electrospun nanofibers membrane possessed a better flux throughput than the commercial PVDF membrane with the same pore size [5]. Filtration efficiency can be further enhanced after incorporation some active substances into the nanofibers. In one study, a new class of thin film nanofibrous composite (TFNC) membrane containing a cross-linked PVA barrier layer and electrospun PAN nanofibrous scaffold demonstrated high flux and low fouling properties, suitable for ultrafiltration applications such as separation of oil and water [6]. Nanofibrous membranes had been extensively explored in air filters. Even though an extremely thin layer of electrospun nanofibrous membrane is used in air filters a significant increase in filtration efficiency can be achieved with a very low increase in pressure drop.

2.2. Biosensor

Outbreaks in food-borne illness bring rapid sensing diagnostics of biological pathogens to the forefront as a necessity to keep the food supply safe. The association of molecular recognition elements with high surface area electrospun nanofibrous membranes presents the opportunity for developing both novel sampling devices that can also be tailored to fit biosensor detection platforms. Because the capture and detection platform are the same, these nanofibrous membranes will not require flow devices or pumps allowing for the development of smaller biosensor foot prints. Functionalizing the surface of electrospun fibers provides extensive possibilities in designing the high surface membranes with a variety biological capture and detection possibilities to include multiplexing capabilities by arranging multiple molecular recognition elements on a single electrospun membrane. Exposure of electrospun capture membranes to larger sample volumes provides potential for increasing the sensitivity for detection of biological agents when present in very low or dilute concentrations as might be found in environmental and/or food detection scenarios. The electrospinning method provides a process for developing both capture and detection methods within the same platform. [7].

2.3. Tissue Engineering

Tissue engineering scaffolds produced by electrospinning feature a structural similarity to the natural extracellular matrix. The main advantages of nonwoven nanofibrous membrane mats for wound dressing are their pore size, usually from 500 nm to 1 µm, which is small enough to protect the wound from bacterial penetration, and the high total nanofiber surface area of 5 to 100 $m^2 g^{-1}$, which is extremely efficient for fluid absorption and dermal delivery. It has been shown that, electrospun nanofibrous membrane showed excellent and immediate adherence to wet wound surface. The electrospun membrane is also important for cell attachment and proliferation in wound healing. Chitosan has been considered to be one of the most promising biopolymers as tissue engineered scaffolds and wound dressing because of its excellent biological properties such as biodegradability, biocompatibility, antibacterial and wound-healing activity [8].

2.4. Fuel Cell

The proton exchange membrane fuel cell converts chemical energy directly into electrical energy with a high efficiency and low emission of pollutants. The proton exchange membrane is one of the key components in fuel cell systems. To improve the power density and efficiency of polymer electrolyte membrane, the polymers with high proton conductivity and low gas permeability or cross-over are desired. In addition, the polymer membranes are required to achieve a sufficient thermal stability and long-term durability. The perfluorosulfonated membranes such as Nafion have been widely used because of their excellent oxidative and chemical stability as well as high proton conductivity. However, there are several drawbacks of Nafion, such as high cost, low thermal stability, and high gas permeability. In one study, novel blend membranes containing sulfonated polyimide nanofibers for proton exchange membrane fuel cell demonstrated that the proton conductivity of the nanofibrous blend membrane indicated a higher value when compared to that determined for the blend membrane without nanofibers prepared with conventional solvent-casting method [9].

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