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Preparation and application of polymer nano-fiber doped with nano-particles

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ABSTRACT

In recent years, the polymer nano-fiber behaves some novel optical properties by doping with some functional nano-particles, which prompts them to play an important role in the bio-chemical imaging and sensor areas. In this review, we have reviewed the preparation methods of the polymer nano-fibers, such as the electrospinning and one-step drawing technology, as well as the preparation processes and applications of the polymer nano-fibers doping systems containing different functional nano-particles. The low melting point of polymer nano-fiber leads to the easier preparation process. However, the susceptible corrosion to chemical and high temperature has limited its scope of application. In the future works, one should perfect the polymer nano-fibers devices by improving the production process and introducing new materials.

1. Introductions

Some properties of optical fiber can be improved and perfected by physically or chemically doping with other materials, such as rare earth elements [1–3] and various particles [4–8]. In recent decades years, the related studies have indicated that the nano-particles doped fiber possess many excellent properties and been used for the nano-lasers with high excitation efficiency [9–11], where the resonators (with the high energy convert efficiency, ultra-compact bending diameter and tight optical confinement) can be fabricated through micro-manipulating the flexible nano-fibers; the nano-sensors with high sensitivity [12–14], where the fast molecular diffusion and strong evanescent field near the nano-fibers can be used to sense the environment parameter change with a fast response time and high sensitivity; the energy storage with high capacitive performance [15–20], where the porous nano-fibers based electrodes can efficiently store the energy with a highly conductive, low density scaffold and high percent void space; as well as other optical devices [21,22]. Compare to the physical or chemical nanolithography techniques, the preparation method of polymer nano-fibers with nano-particles is more simple and economical and can be widely applied and promoted, especially in the experimental studies of nano-fiber devices [23,24].

The micro and nano-materials doped fiber is the typical main-object structure, where the object represents a dopant material (such as laser dyes, fluorescent particles, quantum dots, semiconductor particles, and metal particles), and the main is a fiber (such as polymer, quartz and ordinary glass) [25,26]. The object-material often determines the performance indicators and application of doped fiber devices; furthermore, the main-material will limit their operating wavelength and environment. In this review, we will introduce several typical doping systems (physical-type), as well as their optical properties and applications [27–30].

2. Preparation methods

In recent years, the polymer has been playing an important role as the main-materials for the fabrication of the nano-particles doped nano-fibers, that is the polymer big molecule materials prepared by the chemical synthesis method, which includes polymethyl methacrylate (PMMA), polyacrylamide (PAM), polystyrene (PS), polyvinyl pyrrolidone (PVP), polyvinyl alcohol (PVA), polycarbonate (PC), and deuterated polymer (DP), etc. These polymers have a number of advantages, such as low melting point results in the easily preparing; their light transmittance over 90% in a particular wavelength and can be used as a dielectric waveguide to guide light with a high efficiency; the gain medium and other particles can be

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doped in the polymer nano-fiber easily to facilitate the preparation of a number of specific fibers. One can prepare the transparent polymer optical nano-fiber from these polymer materials by many methods, such as electrospinning, phase separation, self-assembly, one-step drawing technology, and templating [31–36].

2.1. Electrospinning technology

The typical experimental setup for electrospinning technology is shown in Fig. 1(a), which includes a high voltage power supply, a metallic needle (connects to the anode), a collector substrate (connect to the cathode), and a syringe (pumps the viscous polymer or sol–gel into the needle to form a liquid droplet at its tip) [37,38].

Xia et al. have been studying and improving this technology [39–42]. They have successfully fabricated the core-sheath nano-fibers and hollow nano-fibers by centrally adding a silica capillary in the metallic needle and preparing a coaxial spinneret, as Fig. 1(b) indicates, where the silica capillary is filled with the mineral oil (it can be removed easily) [43–46]. Some functionalized hollow nano-fibers have been fabricated through the improved electrospinning system, as shown in Fig. 1(c). One can control the alignment of nano-fibers to prepare the nano-biomaterials with different geometry and functions by changing the driving forces and the geometry parameters of needles and substrate [47]. Fig. 1(d) presents a pair of electrodes (used as the collector substrate) [48]. The prepared nano-fibers are shown in Fig. 1(e and f) [49]. In one word, the electrospinning technology is the simple, effective and economic method for preparing the long and uniform polymer nano-fibers or nano-tubes, in which the functioned materials can also been doped easily.

2.2. One-step drawing technology

The most economic method for fabricating polymer nano-fibers is the one-step drawing technology. The polymer nano-fibers can be drew from the melt bulk polymer or the polymer solution [50]. Fig. 2(a) shows the polytrimethylene terephthalate (PTT) nano-fiber fabrication process by the one-step drawing technology [51]. The PTT pellets are melt firstly on a heating plate (the temperature is controlled near 250 °C, little higher than 225 °C, which is the melt temperature of PTT). The silica or iron rod is used here to dip and extend the PTT nano-fiber. The PTT nano-fiber can be obtained after being quenched quickly in air. Fig. 2(b–d) shows the optical microscope images of the PTT nano-fibers in different constructions (Fig. 2(b) racetrack-shaped resonator, Fig. 2(b)

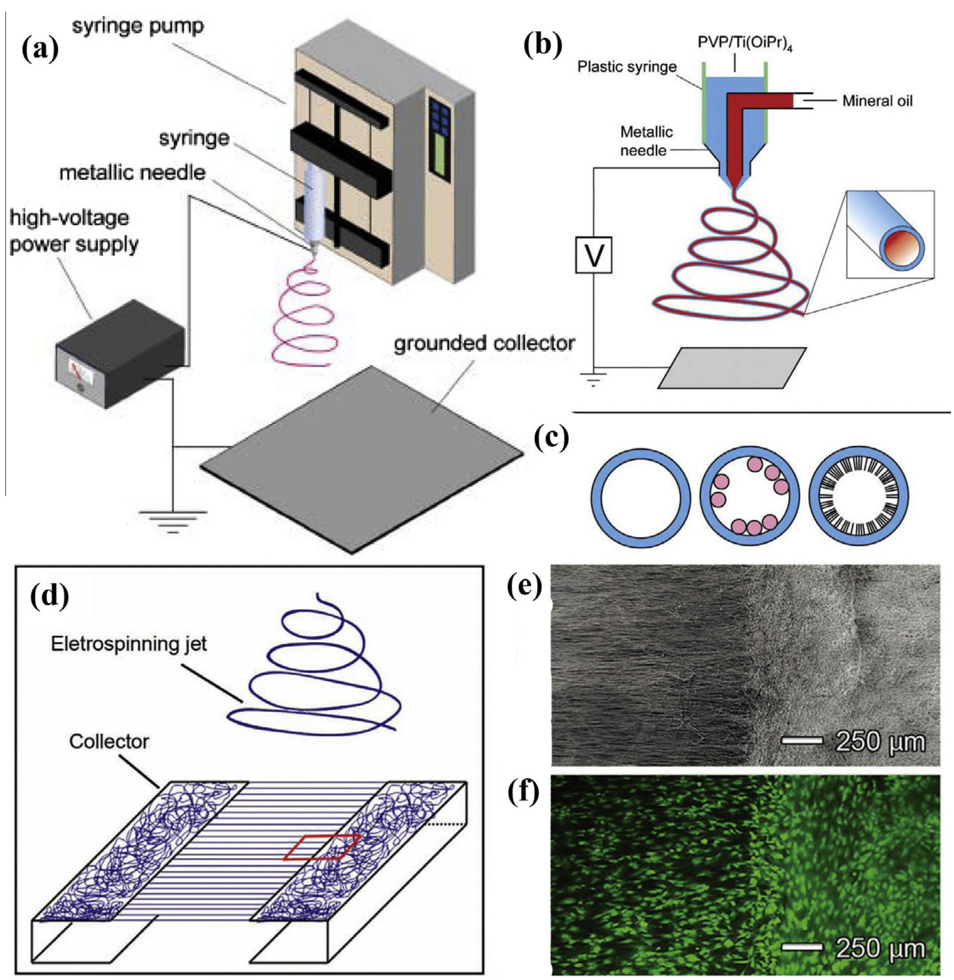

Fig. 1. (a) The schematic of a typical experimental setup for electrospinning technology (Fig. 1 in Ref. [37]). (b) The schematic for fabrication of core-sheath nano-fibers with a coaxial spinneret. The mineral oil is fed through a silica capillary, while the outer sheath layer contains a sol–gel precursor and poly(vinyl pyrrolidone) (Fig. 1(a) in Ref. [46]). (c) With subsequent removal of the oil core, hollow nano-fibers can be generated. In addition, colloidal particles and long-chain silanes can be added to the mineral oil to generate hollow nano-fibers with functionalized interiors (Fig. 1(b) in Ref. [47]). (d) Schematic for fabricating a scaffold with aligned-to-random transition for the nano-fibers. (e) SEM image showing the boundary between aligned and random fibers. (f) Fluorescence micrograph showing morphologies of tendon fibroblasts seeded on the aligned and random sides of the scaffold (Fig. 8 (F, G, H) in Ref. [49]).