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Synthesis and fabrication of silver nanowires embedded in PVP fibers by near-field electrospinning process

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ABSTRACT

In this study, polyol process was used to synthesize anisotropic silver nanowires (AgNWs). The ranges of synthesis temperature from 100 to 200 degrees were explored, and the ranges from 4.53 to 13.75 wt% Polyvinylpyrrolidone (PVP) were investigated. The lengths and diameters of AgNWs from 15 to 30 μm and from 10 to 50 nm can be obtained, respectively. Then, the AgNWs embedded in PVP fibers (PVP/AgNWs) were fabricated by the near-field electrospinning (NFES) process. The AgNWs were broken down into nanoparticles when the applied electric field was over 1.4×10^7 V/m. However, the AgNWs could remain undamaged when the electric field was controlled between 8×10^6 and 1.2×10^7 V/m. Therefore, the threshold electric field can be determined and the diameter of the PVP/AgNWs fibers from 500 nm to 10 μm can be obtained. Next, the characteristics of the PVP/AgNWs were examined by N&K analyzer, four-point probe, EDS and FTIR. The transmittance of PVP/AgNWs films was 51.29–68.97% and the sheet resistance of purified AgNWs was 0.125 Ω/sq which was superior to that of commercial ITO. In addition, the haze of PVP/AgNWs with 30–90 nm thick was from 11.5% to 13.3%. In the near future, the PVP/AgNWs fibers can be used as transparent conductive electrodes.

1. Introduction

Recently, as the smart display technology has been developing rapidly, lots of attention are focused on the application of the transparent electrodes [1,2], which can be widely applied to the smart phones [3,4], touch screen [2,5], organic light-emitting diode (OLED) [4], liquid crystal display (LCD) [6], and thin-film silicon solar cells. Currently, the important material of the current transparent electrodes was indium tin oxide (ITO) [7], but the indium was scarce on earth. Moreover, the disadvantages of ITO including expensive price, brittle material, and complicated process needed in the vacuum environment [8] resulted in extremely energy-intensive and economically expensive fabrication process. Therefore, the new materials for transparent conductive electrodes should be developed to replace the ITO [9].

There are many drawbacks of the ITO transparent electrodes. Therefore, some emerging alternatives, such as carbon nanotubes [10], graphene [11] and silver nanowires (AgNWs) [12] with high conductivity and transmittance were studied to replace the ITO. AgNWs are a promising alternative, which have been reported as the potential candidate to replace ITO. This material was pioneered by Lee et al [13] and showed that the transparent electrodes fabricated by casting AgNWs thin film exhibited comparable and even better than that fabricated by sputter-coated ITO. Now, several methods for the syntheses of AgNWs have been developed such as chemical synthesis, electrochemical process, hydrothermal method, ultraviolet irradiation photodetection technique, DNA template, porous materials template, and polyol process [14,15]. In addition, far-field electrostatic spraying system was used to obtain AgNWs electrodes [14]. However, a high voltage at the tip was required.

The electrospinning is a technology where a high electric field is used to produce nonwoven materials which are excellent in the characteristics such as controllable porosity, high surface area, and uniformity of the fibers [16]. In this process, a high voltage

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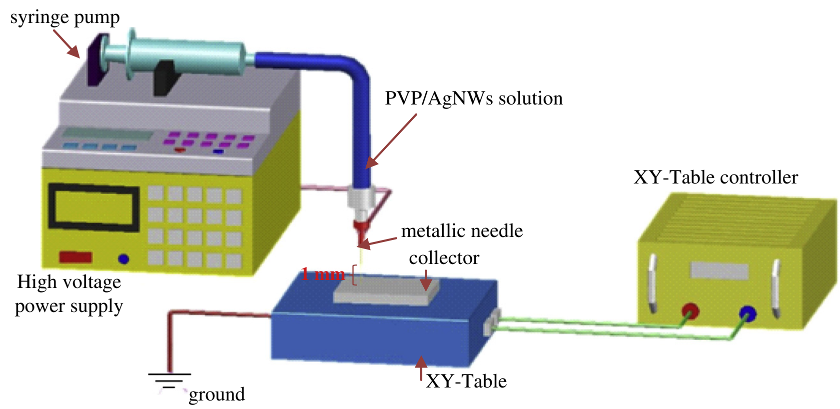

Fig. 1. The experimental set-up of near-field electrospinning system.

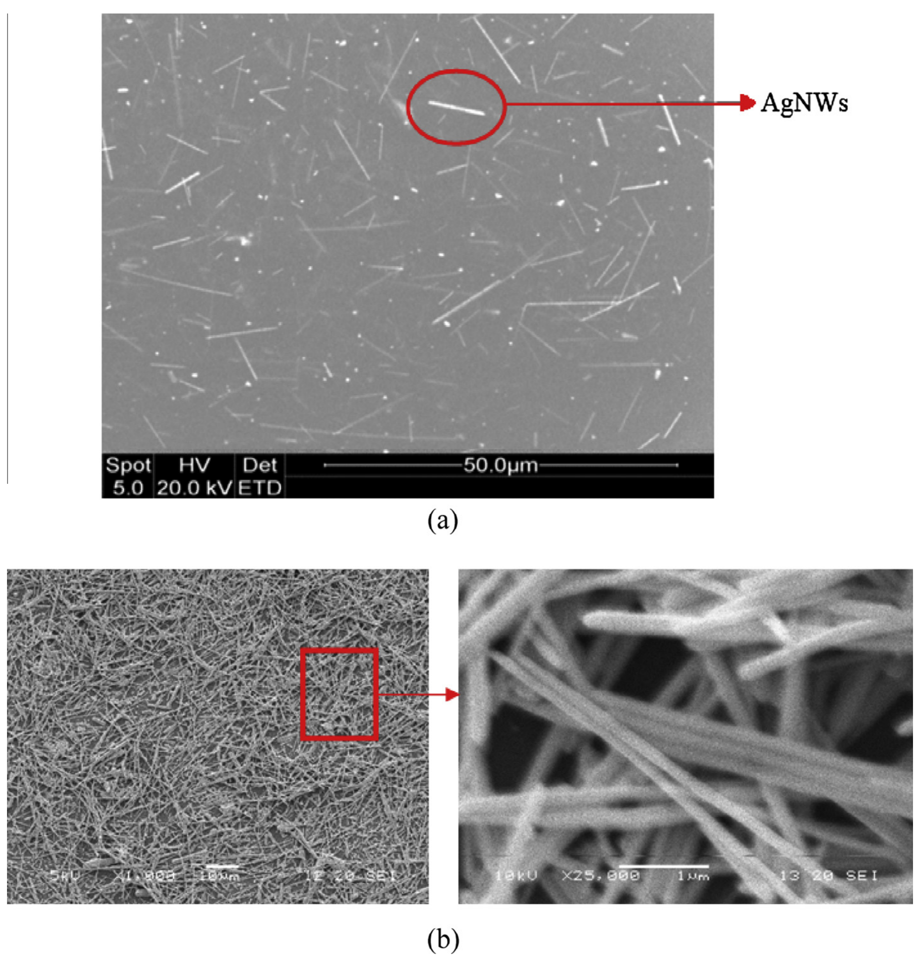

Fig. 2. The images of, (a) PVP/AgNWs and, (b) centrifuged AgNWs.

was applied to a metallic capillary which was connected to a reservoir holding a polymer solution with the proper viscosity, conductivity and surface tension [17]. A positive potential was applied to a metal wire which was connected with the glass pipette filled with polymer solution. Thus, the polymer solution can be electrospun (electric field strength was 100 kV/m) [18]. In another study, the fibers could be direct-written Polyethylene oxide (PEO) fibers in a special pattern by using near-field electrospinning (NFES) with a programmable collector [19,20]. To achieve continuous NFES process, a critical voltage was applied to deform a polymer meniscus by electrospinning process [21]. In the energy scavenging applications, the NFES was used to polarize PVDF fibers in situ and transform non-polar α phase into polar β phase [22]. When a DC voltage bias was set at 14 kV and the tube rotation velocity was set at 1900 rpm, piezoelectric PVDF fibers with small diameters and smooth surface morphology can be obtained [23]. The PVDF fibers showed a downward center displacement of 23 μm and upward center displacement of 16 μm under a high electric field [24]. D. Di Camillo et al adopted NFES process at 1.1 kV and PEO-TiO_2 polymer solution to make NO_2 nanofibers sensor which can detect limits as low as 1 ppm [25]. Min et al fabricated organic FET nanofibers with a low contact resistance (<5.53 Ω/cm) by using