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Preparation of Electrospun Polymer Fibers Using a Copper Wire Electrode in a Capillary Tube

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1. Introduction

Electrospinning method has been receiving more and more interests as a powerful technique for preparation of fine polymer fibers.[1-4] A high voltage supplier, a metal capillary tube with a pipette, and a metal collecting screen are used in conventional electrospinning technique. The metal capillary tube and collecting screen work as electrodes, and high voltage is applied between the electrodes. Some polymer in solution or polymer in melt form is filled in the pipette, and the high voltage produce polymer jet. Fine fiber of the polymer can be formed from the jet and can be deposited on the collecting screen. Such polymer fibers exhibit useful characteristics, e.g. quite large surface area to volume ratio,[5] facility in surface modifications,[6] and excellent mechanical characteristics compared with usual thin film of the material.[7] Therefore, many applications of electrospun fibers, such as medical science, filtration, nano-sensors and nano-electronic devices, have been proposed.[8-10] The performances should depend on the fiber size which can be controlled by the preparation condition (the viscosity of the polymer solution, applied voltage, electrode distance etc.). Furthermore, electrode shape and hydrostatic pressure are crucial for preparation of fine fibers.[1] In this study, a copper wire in capillary tube was used as an electrode and electrospun fibers were prepared for various polymers. Fine fibers were obtained, and needed solution volume and electrode distance could be reduced compared to conventional method.

2. Experimental Details

Our experimental setup is shown in Fig.1. Polymer solutions were filled in a Teflon capillary tube (inner diameter is 1 mm) and copper wire (diameter: 0.2 mm) was also set in the tube. High voltage was applied between the copper wire and colleting electrode. In conventional electrospinning method, certain hydrostatic pressure is given to polymer solution. However, such pressure was not applied to polymer solution in our setup, and only the attraction by electric field was applied to the polymer solution in the tube. Dependences on applied voltage, distance between the electrodes (D in Fig. 1), polymer specie, concentration of the polymer solution were observed for electrospun fibers. Furthermore, dependence on the position of the copper wire tip in the Teflon capillary tube was also investigated. The position of the wire tip (x in Fig. 1) is defined against the tip of the Teflon tube, and the position is negative when the wire tip is withdrawn in the Teflon tube, as shown in Fig.1. Even if the position is positive, the wire tip was set inside of the hemispherical surface of the polymer solution formed due to surface tension. The tip position x was set as 0 mm, except for cases specially mentioned.

For comparison, polymer fibers were also prepared by conventional electrospinning method. In this case, laboratory made stepping-motor setup was used to apply hydrostatic pressure to the polymer solution. The polymer solution was filled in a pipette with metal capillary tube and polymer solution was supplied at the rate of 64 μl/s by the hydrostatic pressure. The inner diameter of the capillary tube was 1 mm.

All the polymers used in this study were commercially available and were used without further purification. Poly(vinylalcohol) (PVA) and poly(vinylcarbazole) (PVK) were purchased from Kanto Chem. and Poly(3-hexylthiophene) (P3HT) was purchased from Aldrich. Towa Keisoku AKT-030K0, 33PS was used as a high voltage appliance. The morphologies of the prepared fibers were observed from SEM images. Furthermore, field-effect transistors (FETs) were prepared using P3HT fiber films and the FET characteristics were investigated.

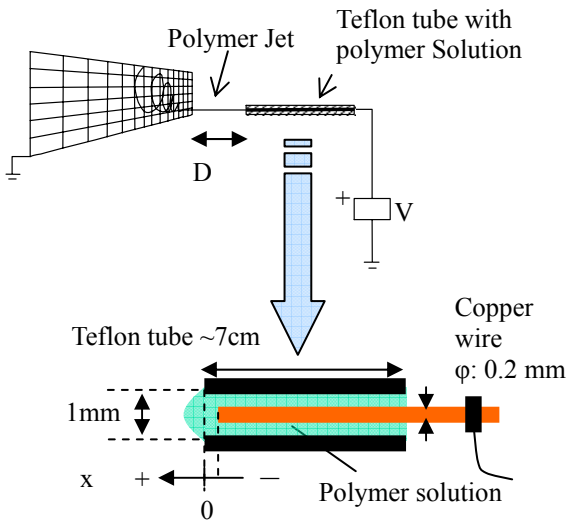
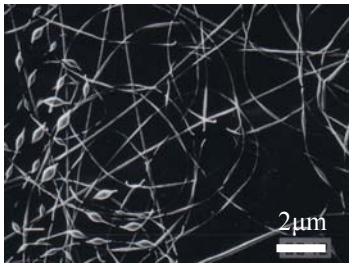


Figure 1. Experimental Setup

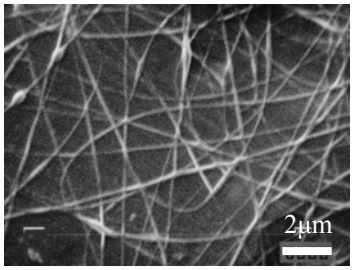
3. Results and Discussion

PVA Fiber preparations were attempted using 12 wt%

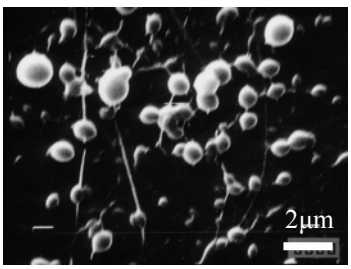
aqueous solution. The applied voltage was 20 kV and the distance D between the electrodes was 10 cm. Figure 2(a) shows the SEM image of the fiber prepared by conventional method, and polymer beads, as well as fibers, were observed. By using the wire electrode in capillary tube (tip position x = 0 mm), uniform fibers without beads were observed (Fig. 2(b)). However, when the tip position x was set as -10 mm, fibers could not be obtained, as shown in Fig. 2 (c). Polymer fibers were formed when the wire tip was close to (a few millimeters) the surface of polymer solution. Preparations of electrospun fibers with non-conductive capillary and metal wire were reported previously.[11] However, in such study the wire electrode tip was deeply withdrawn and far from the capillary tip (surface of polymer solution). In our method, the wire tip was close to the surface of polymer solution and intense effective electric field at the polymer solution should be applied. Moreover, hydrostatic pressure was not applied in this method, and the polymer jet was formed by the solution which was supplied only due to the attraction of electric field, so that the volume of the supplied polymer should be reduced. This also resulted in sufficient solvent evaporation and formation of fine fibers.



(a)



(b)



(c)

Figure 2. SEM images of PVA electrospun fibers prepared using (a) metal capillary electrode, (b) and (c) Teflon capillary and copper wire electrodes. The wire tip positions x = 0 mm and -10 mm for Fig. (b) and (c), respectively.

The distance between the electrodes could be reduced by using a wire electrode in capillary. Figure 3 shows the SEM image of PVA fiber film which was prepared in condition of applied voltage of 6 kV and electrode distance of 1 cm. Higher voltage was needed for longer electrode distance, e.g. applied voltages of 20 and 10 kV were needed for electrode distances of 10 and 5 cm, respectively. The shortest electrode distance was 1 cm for PVA fiber preparation in this study.

Furthermore, preparation and observation of PVK fibers, orientation control of PVA fibers and preparation of field-effect transistors of P3HT fiber film were carried out.

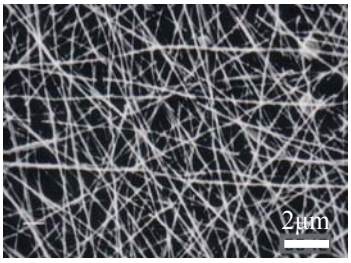


Figure 3. SEM image of PVA electrospun fibers.

We prepared electrospun polymer fibers using a copper wire electrode in Teflon capillary tube. In this method, fiber diameter, volume of polymer solution, applied voltage, distance between the electrodes were largely reduced compared to the conventional one. This method should be quite useful for study of electrospinning method and developing electronic devices using electrospun fibers.

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