Fabrication of Micro/Nano optical Fiber by Electrospinning Direct-writing

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Abstract. Because of the excellent performance, Micro/Nano optical fiber has been more and more widely applied in passive photonic devices, micro-optical sensors, field of atomic manipulation, etc. Currently the main manufacturing mode of Micro/Nano optical fiber is the stretching method which is susceptible to air impact, vulnerable to contaminant and has poor reproducibility. In order to solve these problems, the fabrication of the Micro/Nano optical fiber by electrospinning direct-writing is researched in this article. The experimental platform is set up after the scheme of electrospinning direct-writing is designed. A series of comparative experiments are carried out with changing three experimental variables. The PMMA Micro/Nano optical fiber of controllable diameter is fabricated by regulating the distance between the sprinkler head and collecting plate, flow rate and concentration of PMMA solution. The testing results indicate that the light transmission power loss rate of the PMMA Micro/Nano optical fiber is 0.41dB/mm excited by a 633-nm-wavelength light. The problem is expected to be solved by further optimization of the experimental process and parameters.

1. Introduction
Because of the low optical waveguiding losses, tight optical confinement, strong evanescent fields, small mass or weight, Micro/Nano optical fibers[1] will be the one of best optical waveguide. They can be used as air-clad wire-waveguides with subwavelength-diameter cores, and in building blocks in the future Micro/Nano photonic devices. They renewed research interests in optical MNFs as potential building blocks for applications in high density and miniaturized PICs[2-5]. So far, Micro/Nano optical fibers are mostly fabricated from amorphous materials including glasses and polymers. For these materials, the top-down physical drawing techniques[6-8] include flame-heated taper drawing of glass fibers, laser-heated taper drawing of glass fibers, flame-heated drawing of bulk glass and electrically heated taper drawing of glass fibers are researched. Though the fibers fabricated by these drawing techniques have uniform diameter, smooth surface, large length and low cost, they are vulnerable to air pollution and poor to repeat.

Electrospinning is a popular technique for fabricating polymer Micro/Nano optical fibers from a wide range of polymer materials[9-10]. Electrospinning direct-writing is a near-field electrospinning system, in which the distance between the spray-head and collector is a few millimeters. The near field will make the jet stability to obtain orderly Micro/Nano fiber. The precisely and orderly positioning of the Micro/Nano fiber will be implemented by controlling the trajectory and velocity of the collector. And the collection of single Micro/Nano fiber will be realized by the stability of the jet in the direct-writing system. Both these two characters provide the feasibility for the preparation of Micro/Nano optical fiber.

2. The design of the electrospinning direct-writing scheme
The electrospinning direct-writing platform is shown in Fig.1, including high-voltage DC power supply, solution storage device, solution injection mechanism and fiber collection system. The solution is poured into the transparent plastic tube between injection syringe and needle. The generation of air bubbles must be avoided in the solution injection process. The collector is silicon or tin foil which is placed on the X-Y motion stage. The anode of the dc high voltage power supply is connected to the syringe, and the ground wire is connected to the collector. By setting the voltage and the velocity of the fluid for predetermined value...
and controlling the X-Y motion stage to move along the default path, the Micro/Nano optical fiber is collected to be inspected and measured by electron microscope and SEM.

![Image](image.png)

**Figure 1.** The electrospinning direct-writing platform

### 3. Experimental details

In the experimental process, multiple sets of experimental results are compared by changing one of the three experimental parameters (the distance between the nozzle and collector, PMMA solution concentration and flow rate). And the influence of the morphology and diameter of the Micro/Nano optical fiber by the experimental variables is analyzed qualitatively and quantitatively. By analyzing the mechanism of the Micro/Nano optical fiber surface defects such as porosity, distortion, and flatness, the universal laws of fabricating Micro/Nano optical fiber by electrospinning direct-writing from PMMA solution is summarized.

Firstly, PMMA is dissolved in mixed solvent (CHCl3: DMF =2:1) and solution concentration is 25%. Flow rate and the diameter of the spinning nozzle are 200 μl/h and 0.21mm, respectively. The different samples have been prepared, changing the spinneret-collector distance: (a) 2 mm, (b) 3 mm, (c) 4 mm, (d) 5 mm, and (e) 6 mm. The applied voltage is the one which just can form stable jet. The morphology and varying tendency of the diameter of Micro/Nano optical fibers are attained in Fig.2. and Fig.3, respectively.

![Image](image2.png)

**Figure 2.** The morphology of Micro/Nano optical fibers at the different spinneret-collector distance: (a) 2 mm; (b) 3 mm; (c) 4mm; (d) 5 mm; (e) 6 mm;

![Image](image3.png)

**Figure 3.** The varying tendency of the diameter of optical fibers with the spinneret-collector distance
From Fig.2 and Fig.3 we can attain that the diameter of the PMMA optical fiber decreases with the increasing of the spinneret-collector distance. The reason is that the flight time in space of spinning jet gets longer because of the larger spinneret-collector distance to make the volatilization of the solvent in the jet more fully.

Secondly, the flow rate, the diameter of the spinning nozzle and the spinneret-collector distance are 200 μl/h, 0.21mm and 2 mm, respectively. The mixed solvent is CHCl3 : DMF =2:1. The different samples have been prepared, changing the PMMA concentration (a) 8%, (b) 12%, and (c) 16%. The applied voltage is the one which just can form stable jet. The morphology of Micro/Nano optical fibers is attained in Fig.4. It can be deduced that though the solution concentration gradient is large, all the optical fibers are continuous. The optical fiber electrospun from 8% PMMA concentration is finer than the ones from 12% and 16% PMMA concentration, because the more volatile solvent makes the fiber volatile fully in the electrospinning process.

Thirdly, the PMMA concentration, the diameter of the spinning nozzle and the spinneret-collector distance is 16%, 0.21mm and 2 mm, respectively. The mixed solvent is CHCl3 : DMF =2:1. The

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Figure 4. The morphology of fibers at the different solution concentration: (a) 8%; (b) 12%; (c) 16%.

Figure 5. The morphology of fibers at the different flow rate: (a) 100 μl/h; (b) 200 μl/h; (c) 300 μl/h; (d) 400 μl/h
different samples have been prepared, changing the flow rate (a) 100μl/h, (b) 200μl/h, (c) 300μl/h, and (d) 400μl/h. The morphology of Micro/Nano optical fibers is attained in Fig.5. It can be observed that the flow rate does a little influence on the diameter of the optical fiber, but significantly affect the distribution of the fiber. When the flow rate is 100μl/h, the straightness and parallelism of fiber is good. With the increasing of the flow rate, fibers become distorted to form an angle. The extrusion speed of the solution from the needlepoint is controlled by the flow rate. So the greater the feed flow rate, the faster the solution out of needlepoint and the faster the jet scream to the collector which makes the deviation between the position of fiber deposition and the pre-set position.

4. Light loss tests and discussion
The light loss is one of the main parameters of characterization of optical fiber transmission performance. We test the optical power loss of the PMMA Micro/Nano optical fiber for two times, which is shown in the Fig.6. It can be calculated that the optical power loss of the PMMA fiber is 0.41dB/mm excited by a 633-nm-wavelength light, which is much greater than the common optical fiber in the market. The reason is that PMMA fiber has poor morphology, rough surface, sparse holes in the surface and inside the fiber, flat rather than round cross section, etc.

5. Conclusions
The manufacturing of Minco/Nano optical fibers by electrospinning direct-writing using PMMA solution is feasible. The optimal design of the experimental scheme guarantees the collection of single and ordered fibers, which satisfies the basic requirements of Micro/Nano fiber. By controlling the distance between the sprinkler head and collecting plate, flow rate and concentration of PMMA solution, the spinning voltage, the PMMA Micro/Nano fiber with controllable diameter can be obtained. The controllable range of diameter is from ten to several hundred micrometers. At the same time, we know that the PMMA fiber made by electrospinning has the function of basic optical transmission.

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