Arc Discharge Drawing Silica Nanowires

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Abstract

We propose a new approach, the Arc Discharge Drawing (ADD) technique, to fabricate silica fibers with diameters less than the wavelength of commercial available lasers. With this single-step technique, silica wires with diameters as small as 50 nm were demonstrated. This technique would provide an attractive alternative to current approaches to fabricate the silica nanowires. For ADD technique, a standard optical fiber is placed in two fiber mounts. One of the fiber mount performs as the computer-controlled stage that pulls the fiber at various speeds in the range of 2 mm/s to 15 mm/s. During this computer-controlled fiber drawing process, the fiber is heated by the arc discharge serving as the heat source. The arc discharge is supplied with a D.C. current from a rectifier with a controlled voltage to 20 kV. The nanowires can be fabricated by varying the voltage in the range of 4 kV to 5 kV. The optimum operational voltage is determined by the scanning electron microscope (SEM) images of the fabricated silica nanowires. Based on the SEM images, it is evident that nanowires obtained by the ADD technique exhibit great diameter uniformity and large length. In addition, the fabricated silica nanowires are flexible due to their large aspect ratio between the diameter and the length. Furthermore, the nanowires can be bent and twisted without breaking. The bent and twisted silica nanowires are extremely useful to guide laser light for small scale photonic devices. In this study, the nanowires obtained by ADD technique were also investigated in the aspect of guiding 633-nm wavelength light. The results reveal the high transmission losses thus providing the greater evanescent field. This represents a significant advancement in the field of nanophotonics. Due to their extraordinary compactness and excellent optical properties, nanowires will find a whole range of nanoscale photonic devices.

Keywords: Nanowire, Silica nanowire, Optical fiber drawing

Introduction

Silica nanowire has been considered as a new building block for nano-and microphotonics applications [1-7]. The past ten years have seen much attention in the drawing methods to obtain the silica nanowires [8-9]. Several fabrication methods have been introduced. For example, the flame heating method [10-11] has been able to achieve the minimum diameters as small as 90 nm. However, flames with low carbon content are critical importance to circumvent the contamination of the fiber surface. For laser heating method, CO_2 laser provides sufficient heat to above soften point temperature (1600 C°) [12]. However, the diffraction limited laser beam prevents the achievable nanosize of silica wires. Drawing from a piece of bulk glasses has been introduced to fabricate nanowires using flame or laser as the heat source [13-15].

Despite these successes, it still remains a challenge in the production of silica nanowires with an alternative approach to implement a simple and inexpensive setup. Such a production would be a breakthrough for application in nanophotonics. In this contribution, we propose the Arc Discharge Drawing (ADD) technique to fabricate silica nanofibers. This technique is inspired by the adaptation of the fusion splicers [16]. The drawing system based on ADD technique is simple in construction. This affordable system is capable of producing silica nanowires with simplicity of operation.

Materials and Methods

The schematic diagram shown in Figure 1 illustrates the computer-controlled fiber drawing process. Such a configuration is chosen to produce high-quality nanowires. A standard "step index" optical fiber is placed in two fiber mounts (Stage 1 and Stage 3). The stage 3 serves as the computer-controlled stage that pulls the optical fiber at various speeds. The computer-controlled stage is capable of pulling the fiber at the speed in the range of 1 mm/s to 20 mm/s.

The stage 2 provides the electrical discharge to generate the arc plasma. The arc discharge is supplied with a D.C. current from a rectifier with a controlled voltage to 20 kV. Appropriately designed, the generated plasma performs as the heat source for silica wires.

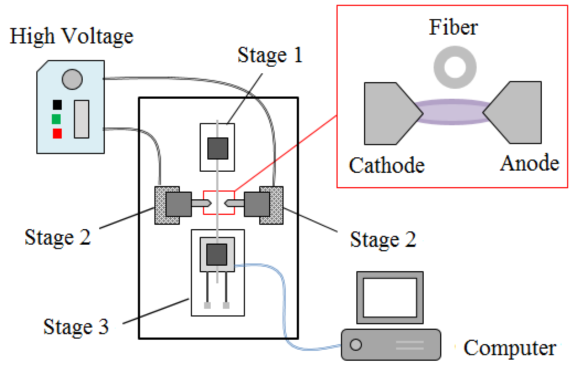


Figure 1. Experimental setup for ADD technique

The drawing steps of ADD approach can be shown in Figure 2. The protective polymer coating around a standard optical fiber is removed by the fiber stripper. The prepared fiber is then placed on the top of the arc plasma. The computer-controlled stage is moving perpendicularly respected to the plasma source.

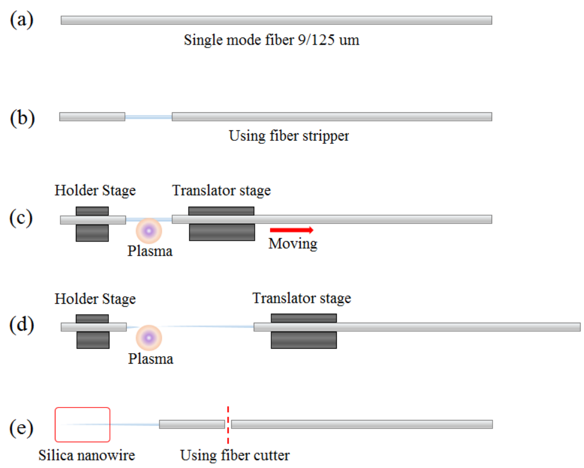


Figure 2. Illusion of the steps for drawing nanowires using ADD technique

The nanowires can be fabricated by adjusting the voltage in the range of 4 kV to 5 kV. To this end, the fabricated nanowire is cut and meant to be investigated by the scanning electron microscope (SEM).

Results and Discussion

Nanowires fabricated by this technique exhibit diameter uniformity and large length. The diameter of the fabricated nanowire ranges from hundreds of nanometers to one micrometer (Figure 3). This depends on the drawing conditions such as the voltage supply, moving speed and heating position.

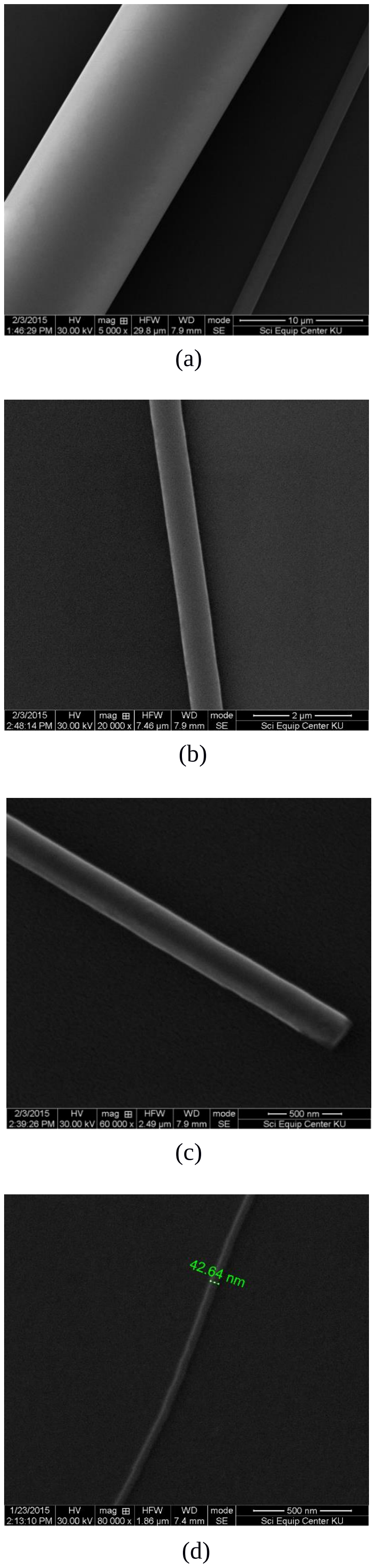
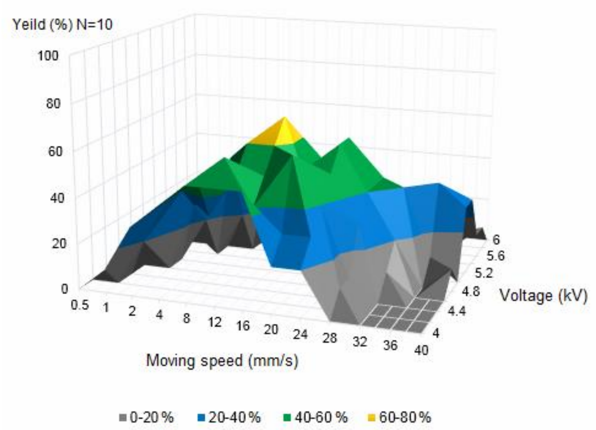


Figure 3. Examples of SEM images of fabricated nanowires (a) A 960 nm-diameter nanowire with a 12 micron-fiber. (b) 600 nm-diameter nanowire (c) 250 nm-diameter nanowire (d) A 50 nm-diameter nanowire.

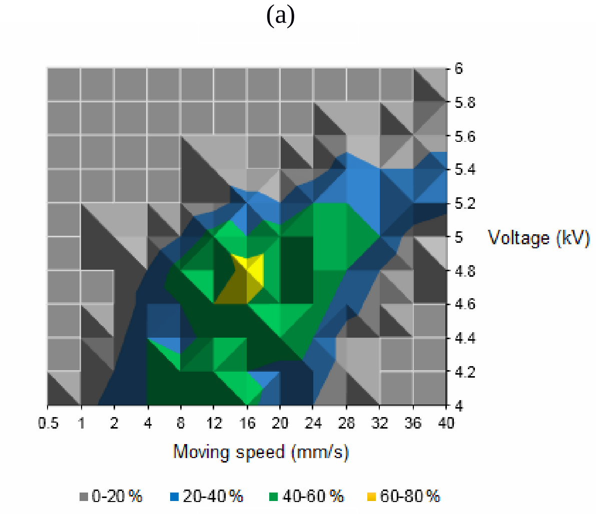
Using ADD technique, we produced silica wires with diameters as small as 50 nm (Figure 3d). This is significance and it can be suggested that ADD technique would provide an attractive alternative to current approaches to fabricate the silica nanowires.

In addition, the throughput yield of the fabrication was also investigated. Silica wires diameter less than 2 µm, N = 10 samples were evaluated (Figure 4).

It can be realized that the optimal parameters in the applied voltage falling in between 4.6 and 4.8 kV along with the moving speed 12- 16 mm/s.



(a)

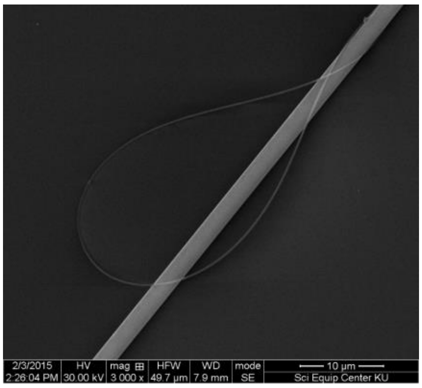


(b)

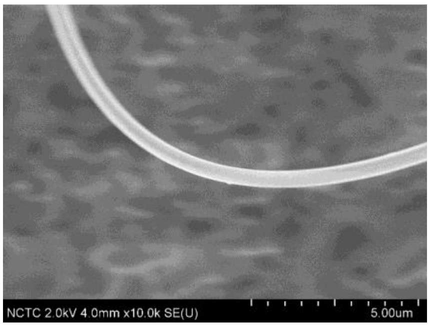
Figure 4. The throughput yield of the fabrication of nanowires. (a) Side view. (b) Top view.

It is desirable to shape the silica nanowires into complex forms. Figure 5a shows a micro-loop nanowire getting along with a subwavelength wire. Figure 5b shows the bending property of the nanowires. In addition, twisted nanowires are achievable (Figure 5b). It is evident that the fabricated silica nanowires are flexible due to their large aspect ratio between the diameter and the length. Furthermore, the nanowires can be bent and twisted without breaking.

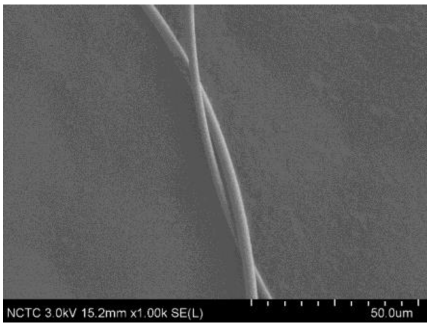
It is tempting to explore a natural behavior of the nanowires to adhere to one another due to van der Waals forces. Such a performance is observed as shown in Figure 6.



(a)



(b)



(c)

Figure 5. SEM images of fabricated nanowires which were shaped into complex forms. (a) Micro-Loop nanowire. (b) Bending nanowire (c) Twisted nanowires.

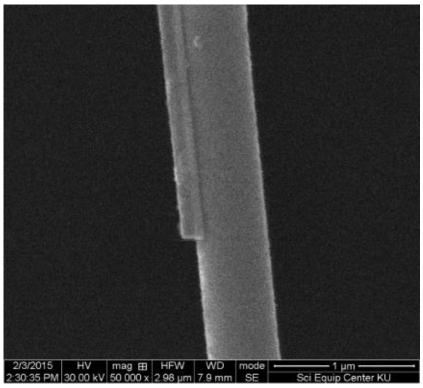


Figure 6. SEM image of nanowires with van der Waals forces.

This study is also aimed to investigate the optical and guiding properties of the nanowires. To achieve this task, a weak HeNe laser was seeded into the nanowires. The leakage of the seed beam is presented in the form of the evanescent field.

Conclusions

We demonstrate the fist nanowire drawing based on arc discharge. This technique is capable of producing the silica nanowires diameter ranging from 50nm to1000 nm and lengths from 0.2 to 2 mm. ADD technique combines the advantages of the arc discharge and the economic computer-controlled stage**.** We have accomplished many aspects of the fabrication of nanowires. The drawing conditions were examined. The twisted manners were investigated. ADD technique is potential to serve as an approach of mass production of the silica nanowires.

Acknowledgments

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