

# Fabrication and Characterization of Electrospun Silver Nanofibers with Unmatched Porosity

Fathima Shahitha Jahir Hussain and Mashitah Binti Mohd Yusoff, *Faculty of Industrial Science and Technology, Universiti Malaysia Pahang*

**Abstract—** Herein we describe the fabrication and characterization of free standing silver nanofibers with very high porosity using electrospun polymer nanofibers as template. Silver (Ag) metal was deposited on these porous nanofibers using thermal evaporator. The polymer nanofibers (template) and silver nanofibers were characterized using scanning electron microscopy, XRD and cyclic voltammetry. The Ag nanofibers showed high electrical conductivity.

## I. INTRODUCTION

Recently designing of noble metals in micro and nanometer scale have received much attention in the field of material science. Intense research is being carried out on one-dimensional (1D) micro and nanostructures of noble metal due to their special properties and potential applications in various fields which includes biomedical monitoring, catalysis, optical devices, chemical and biological sensing, optoelectronics, microfluidics, microanalytical and microelectromechanical devices, barcodes in biondiagnostics and information technology [1].

Significant efforts are devoted to the development of 1D silver micro and nanostructures because of its extraordinary properties such as high thermal and electrical conductivities, chemical inertness and ductility [2].

A number of approaches have been employed to fabricate silver nanostructures, which includes electrophoretic deposition [3], self-assembly [4], Langmuir Blodgett method [5], and template synthesis [6] involving DNA strands, bacteria and virus, linear polymers and lithography.

Electrospinning is a low cost technique, which produces polymer nanofibers in the range of 30-2000 nm, from polymer solutions or melts. In electrospinning, an electric field is used to draw the positively charged polymer solution from an orifice to the collector. The morphology and properties of the nanofibers can be varied by changing the process parameters, such as solution viscosity and conductivity, applied voltage, average molecular weight of the polymer and the distance between the needle and the collector plate [7]. Electrospinning is the most advantageous of all the fabrication techniques for nanofibers.

J. H. Fathima Shahitha, Faculty of Industrial Science and Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Kuantan, Pahang, (e-mail: [fathima@ump.edu.my](mailto:fathima@ump.edu.my))

Mashitah Binti Mohd Yusoff, Faculty of Industrial Science and Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Kuantan, Pahang. (e-mail: [mashitah@ump.edu.my](mailto:mashitah@ump.edu.my))

So far various methods have been discussed to fabricate 1-D nanostructures, but to the best of our knowledge there is no report on the fabrication of 1-D nanostructures of silver using electrospun polymer fibers as templates. In this report we describe a method to fabricate highly porous, free-standing and pure Ag nano and micro fibers using electrospun poly(vinyl chloride) (PVC) nanofibers..

## II. EXPERIMENTAL

### A. Electrospinning

Poly (vinyl chloride) (PVC) was purchased from Aldrich. The PVC solution (15 wt %) was obtained using tetrahydrofuran (THF) as the solvent. To dissolve the PVC, mild heating of about 60 to 70 °C using a hot plate was required. The PVC solution was taken in a syringe (5 ml) with a hypodermic needle with a flat-filed tip, with ID of 0.8 mm. The positive electrode of the high voltage power supply was connected to the needle using copper wires. The negative electrode was connected to the Al foil covered copper plate which served as the collector. The schematic of the electrospinning process is shown in fig.1. The polymer (PVC) solution was electrospun at 20 kV, with a tip-to-collector distance of 10cm and 75 $\mu$ l / min solution flow rate. The whole process was carried out at 25 °C. The electrospun nanofibers were collected on the Al foil.

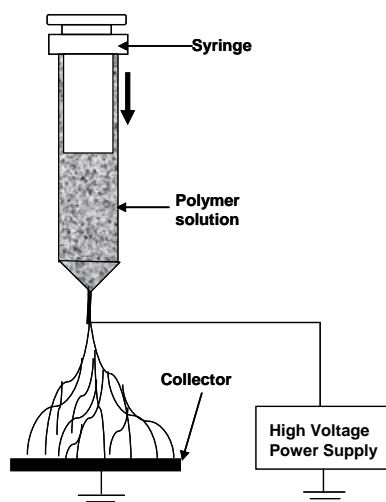


Fig. 1. Experimental set-up for electrospinning.

The electrospun PVC nanofibers were used as the template. The PVC nanofibers were cut into 3 cm by 5 cm size. Silver metal was allowed to deposit on these fibers by thermal evaporation. After the coating was complete, PVC together

with the silver was immersed in THF to remove the PVC. The fibers were washed with THF several times to make sure that the silver nanofibers were free from the polymer.

### B. Characterization

The morphology of the PVC and the silver nanofibers were observed on a JEOL JSM 6700 scanning electron microscope (SEM). The transmission electron microscopy (TEM) images were obtained with a JEOL JEM 3010 with 300 kV accelerating voltage with samples were deposited on carbon coated copper grids. X-ray diffraction measurements were carried out using a D5005 Siemens X-ray diffractometer with Cu-K $\alpha$  ( $\lambda = 1.54 \text{ \AA}$ ) radiation at 40 kV and 40 mA. All samples were scanned over a  $2\theta$  range of  $30 - 80^\circ$  at a step size of  $0.02^\circ$ .

## III. RESULTS AND DISCUSSION

Electrospinning of 15-wt% PVC solution produced nanofibers together with microfibrils. The fibers were crinkled and dimpled structures were observed on them. The rapid evaporation of THF is the cause for the porous structure on the fibers. The diameter of the PVC fibers varied in size ranging from  $0.35 \mu\text{m}$  -  $3.5 \mu\text{m}$ . All the fibers had dimples on it. The size of one such dimple varies from 200-350 nm. The SEM microscopy image of the PVC fibers is shown in Fig. 2.

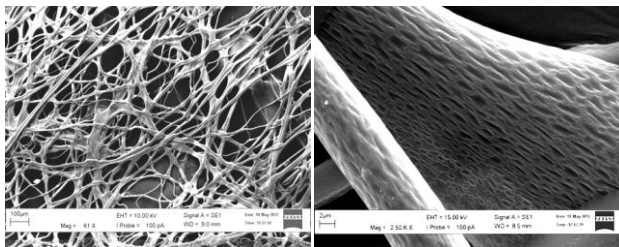


Fig. 2. (Left) SEM microscopy image of the PVC fibers and (right) the magnified image of the fibers.

These PVC fibers were used as template to form the silver fibers. The porous morphology of the PVC fibers was replicated on the silver fibers. The photograph of the Ag nanofibers is shown in fig. 3.

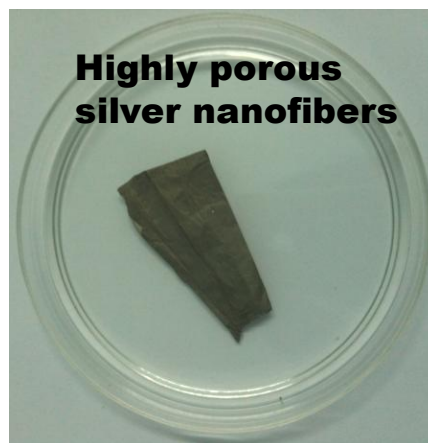


Fig. 3. Photograph of the silver nanofibers.

The SEM image of the Ag nanofibers is shown in fig. 4. The morphology of the fibers was exactly the same as that of the PVC fibers, with diameter ranging from  $0.35 \mu\text{m}$  -  $3.5 \mu\text{m}$  and the pores ranging from 200-350 nm.

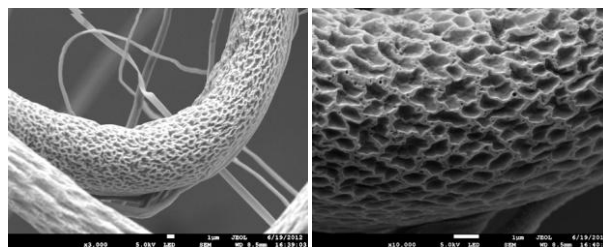


Fig. 3 (Left) SEM microscopy image of the silver fibers and (right) the magnified image of the silver fibers.

The high resolution transmission electron microscopy (HRTEM) images of the Ag fibers were taken. The interplanar distance was 0.24 nm, which indicated the (111) plane. The SAED pattern showed bright rings that can be indexed to (111), (200), (220) and (311) reflections of crystallized silver.

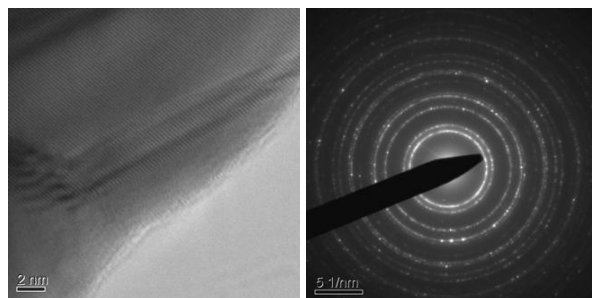


Fig. 4 (Left) HRTEM image of the silver fiber and (right) the SAED pattern.

It is observed that the intensity of the diffraction peak (111) is slightly stronger than the other peaks, indicating that the silver nanofibers are mainly dominated by the crystal

facet (111) and thus the growth direction is mostly oriented parallel to the [111] direction.

Fig. 5 shows the XRD pattern of the silver nanofibers. All the diffraction peaks can be indexed to the (111), (200), (220) and (311) planes of the face-centered cubic (fcc) silver. It is observed that the intensity of the diffraction peak (111) is slightly stronger than the other peaks, indicating that the silver fibers are mainly dominated by the crystal facet (111) and thus the growth direction is mostly oriented parallel to the [111] direction, as can be seen clearly from the HRTEM of the Au nanofibers. The lattice constant ( $a$ ) calculated from (111) patterns according to the crystal fringe distance is 4.066, which is in excellent agreement with the standard value of 4.07 Å in JCPDS.

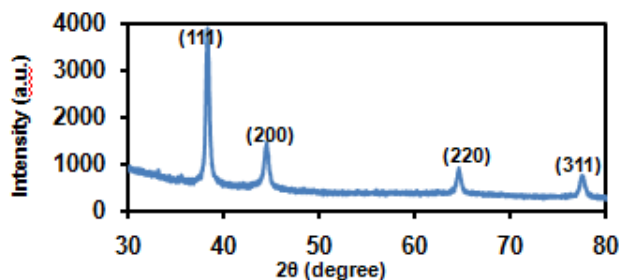


Fig. 5. XRD pattern of the silver nanofibers, indicating face-centered cubic (fcc) silver.

The cyclic voltammogram of the silver nanofibers indicating the oxidation and the reduction peaks is shown in Fig. 5.

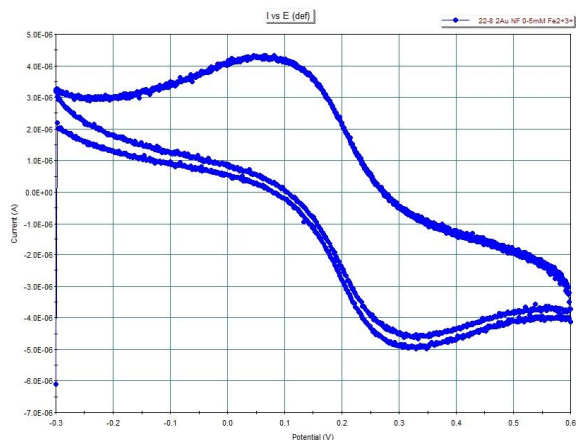


Fig. 5. Cyclic voltammogram of the silver nanofibers.

The electrical conductivity of the silver nanofibers was measured using a probe station and semiconductor parameter analyzer at room temperature in air. The curve showed a low resistance of ohmic behavior, Fig. 6. The electrical conductivity of the silver nanofibers was found to be comparable to that of the bulk value of silver materials.

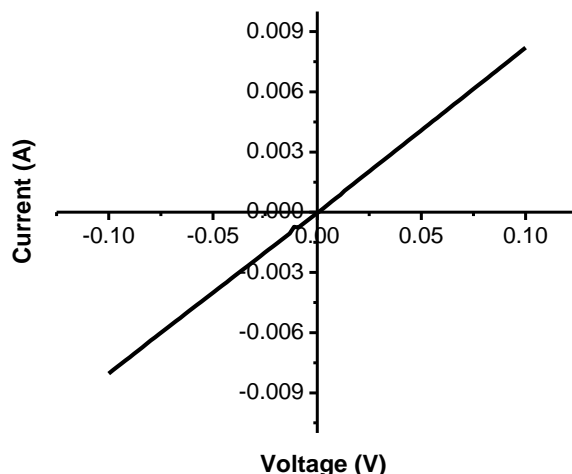


Fig. 6. Current-voltage (I-V) characteristics of the gold nanofibers measured at room temperature.

#### IV. CONCLUSION

In conclusion we have successfully demonstrated the fabrication of Ag fibers by using the electrospun PVC as the template. The nanofibers vary in diameter from 0.35  $\mu\text{m}$  – 3.5  $\mu\text{m}$ . The fibers have uniformly distributed pores on it, with sizes ranging from 200-350 nm. These pores increase the surface to volume ratio tremendously. The Ag nanofibers will prove technologically imperative and can benefit diverse areas like catalysis, chemical sensing, information technology, microfluidics, medical diagnostics etc. These can be widely used in electronic industry. These structures have large vacancy that makes it possible to immobilize biological molecules that have high affinity to gold, such as DNA, and protein, and make their detection easy. The method is very simple and produces excellent quality free standing fibers.

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#### REFERENCES

- [1] M. Geissler, H. Wolf, R. Stutz, E. Delamar, U. W. Grummt, B. Michel, A. Bietsch and Wm, *Langmuir*, vol. 19, pp. 6301-6311, 2003. S. I. Khondaker, Z. Yao and Vm, *Applied Physics Letters*, vol. 81, pp. 4613-4615, 2002. A. Bietsch, B. Michel and We, *Applied Physics Letters*, vol. 80, pp. 3346-3348, 2002. P. M. Ajayan and Th, *Chemical Reviews*, vol. 99, pp. 1787-1799, 1999. C. C. Chen, C. C. Yeh and Bf, *Advanced Materials*, vol. 12, pp. 738, 2000.
- [2] K. Vasilev, T. Zhu, M. Wilms, G. Gillies, I. Lieberwirth, S. Mittler, W. Knoll, M. Kreiter and Wx, *Langmuir*, vol. 21, pp. 12399-12403, 2005.
- [3] T. Teranishi, M. Hosoe, T. Tanaka and M. Miyake, *Journal of Physical Chemistry B*, vol. 103, pp. 3818, 1999.
- [4] N. Lu, X. D. Chen, D. Molenda, A. Naber, H. Fuchs, D. V. Talapin, H. Weller, J. Müller, J. M. Lupton, J. Feldmann, A. L. Rogach and L. F. Chi, *Nano Letters*, vol. 4, pp. 885, 2004.

- [5] F. Kim, S. Kwan, J. Akana and P. D. Yang, *Journal of the American Chemical Society*, vol. 123, pp. 4360, 2001.
- [6] C. A. Mirkin, R. L. Letsinger, R. C. Mucic and J. J. Storhoff, *Nature*, vol. 382, pp. 607, 1996. S. R. Hall, W. Shenton, H. Engelhardt and S. Mann, *Chemphyschem*, vol. 2, pp. 184, 2001. C. R. Martin, *Science*, vol. 266, pp. 1961, 1994.
- [7] D. H. Reneker and I. Chun, *Nanotechnology*, vol. 7, pp. 216-223, 1996. H. Fong, I. Chun and D. H. Reneker, *Polymer*, vol. 40, pp. 4585-4592, 1999.