STRETCHABLE AND CONDUCTIVE TEXTILE MATERIALS FOR WEARABLE ELECTRONICS

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ABSTRACT

Wearable electronics industry is growing exponentially as well as the demand for conductive textile materials. Ideally, conductive textile materials should be washable, breathable, and easily convertible into textile product using conventional textile machinery. These requirements are critical for creating comfortable wearable electronics products in a facile way. In this study we have developed conductive knitted and nonwoven textile materials using AgNWs. AgNWs were synthesized according to the polyol method and coated on aforementioned textile materials. Both synthesized AgNWs and coated samples were characterized with SEM. Moreover, samples' electrical conductivity was investigated under stretching conditions. Results show that knitted samples perform higher stretchability than nonwoven samples. Nonwoven sample was employed as a touched based sensor which can be converted into wearable electronics products in the future. In conclusion, our results indicate that both fabrics might be used in wearable electronic industry.

Key Words: CONDUCTIVE TEXTILES, SILVER NANOWIRES, WEARABLE ELECTRONICS, STRETCAHBLE ELECTRONICS

1. INTRODUCTION

Textile materials such as yarns and fabrics are the basic counterparts of our clothing. Natural fibers such as flax, wool, cotton and silk have been used to create yarns and fabrics for ages. In our modern era, scientist have developed synthetic fibers with some spectacular physical properties such as nylon and polyester which are widely used in textile industry. These fibers can be used to produce very comfortable and light clothes which do not restrict our body motions [1]. However, these basic functions are not enough for modern people. In our current world, mobile phones and smart devices become an indispensable part of our daily life. We are carrying these devices with us all the time just like our cloths. As a natural result, scientists have been seeking ways to integrate these smart devices with our clothing.

Since we are wearing clothes almost all day long, they become a perfect platform to unite our smart devices. They can be used for generating energy, charging our devices, measuring body function, monitoring joint movements or as a display area [2, 3, 4]. For these type of applications; flexible, stretchable and electrically conductive textile materials which can be turn into breathable and washable fabrics are required. Neither natural fibers nor the man-made fibers can response to this demand at their current state. Textile materials have to be functionalized to be used in wearable electronic applications [5].

In this study, silver nanowires were synthesized according to the polyol method and coated on the flexible nonwoven fabrics. These nonwoven fabrics demonstrates excellent flexibility but limited stretchability. Knitted fabrics on the other hand, provide excellent stretchability. These properties make these materials excellent candidates for wearable electronic applications.

2. MATERIALS AND METHOD

Silver nitrate, polyvinyl pyrrolidone (PVP), ethylene glycol (EG), and sodium chloride (NaCl) were purchased from Merck. All chemicals were used without any further purification. PVP

was dissolved in ethylene glycol at 180 ˚C for 40 minutes and then 0.1 ml NaCl solution was added into the PVP solution. After 10 minutes, silver nitrate-EG solution was injected inside the PVP solution. After completion of the injection process, solution was stirred at 180 ˚C for additional 20 minutes and then left for cooling. AgNWs were precipitated in a centrifugal equipment. Finally, AgNWs were diluted in ethyl alcohol and coated on nonwoven and knitted samples with a Pasture pipette.
Knitted fabric was produced with a commercial yarn in a laboratory type knitting machine. Thermoplastic polyurethane (TPU) nonwoven sample was donated by a local company.
Samples were stretched using a homemade equipment. Initial length, final length, and stretching duration of the samples were reported. Samples were attached to the stretching apparatus with conductive copper tapes and resistivity was measured constantly using Fluke 8845A 6.5 Digit Precision Multimeter. SEM images of the samples were captured using TESCAN VEGA3 Scanning Electron Microscope.

3. RESULTS and DISCUSSION

Figure 1 shows SEM image of synthesized silver nanowires according to polyol method. The length of the synthesized silver nanowires is in the range of 8 to 80 µm and their thickness is less than 100 nm.

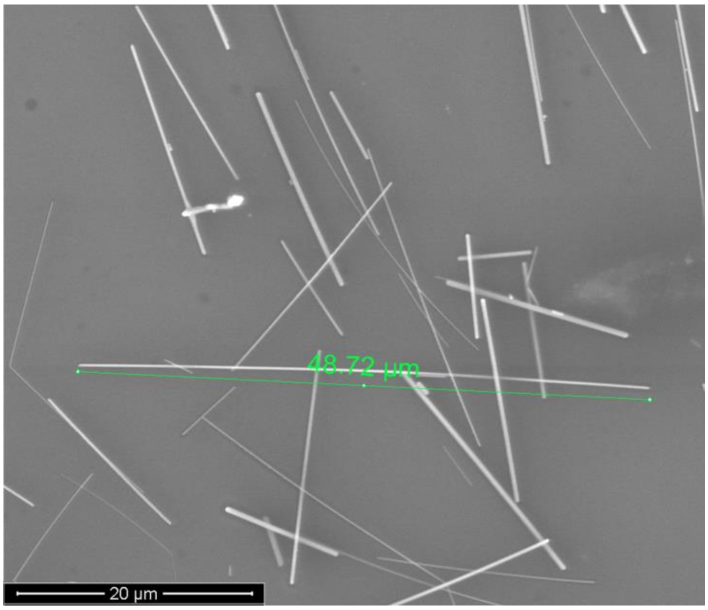

Figure 1. SEM image of AgNWs under 5000 magnifications. Scale bar is given on the lower left corner of the image.

Synthesized silver nanowires were coated on textile samples using a Pasture pipette. Although both samples became highly conductive after this coating process, knitted fabric had lower resistance value. While the resistance of knitted sample was 2.3 Ω/cm, it was 6 Ω for nonwoven sample. This difference rise from lower affinity of the TPU used in nonwoven sample. SEM images in Figure 2 shows that AgNWs can for highly packed network on both knitted and nonwoven samples.

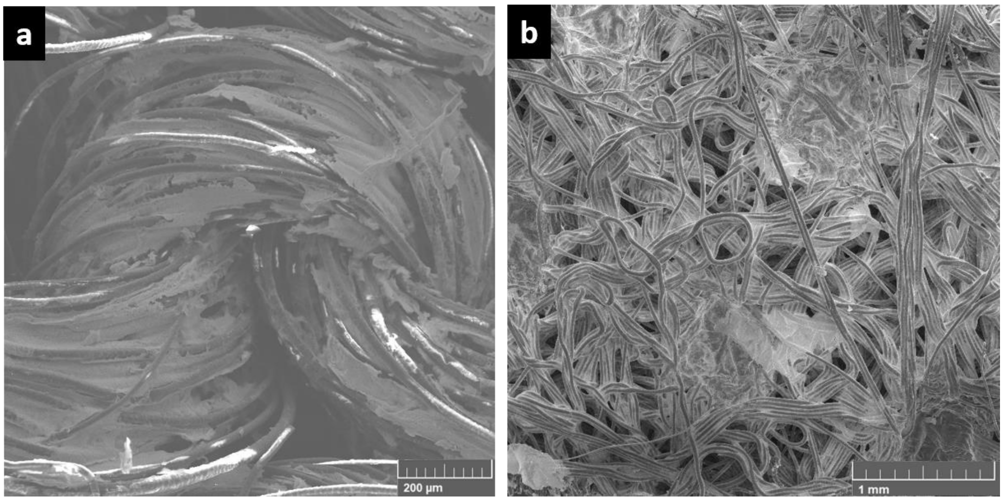

Figure 2. SEM image of AgNW coated knitted fabric (a) and nonwoven sample (b). Scale bars are given on the lower right corner of the images.

In our previous study, we have developed conductive knitted fabrics and performed bending tests [6]. Our knitted samples can preserve their initial resistance even after 150 continuous bending cycles. In this study we have performed stretching on knitted and nonwoven samples while continuously monitoring their electrical resistance.

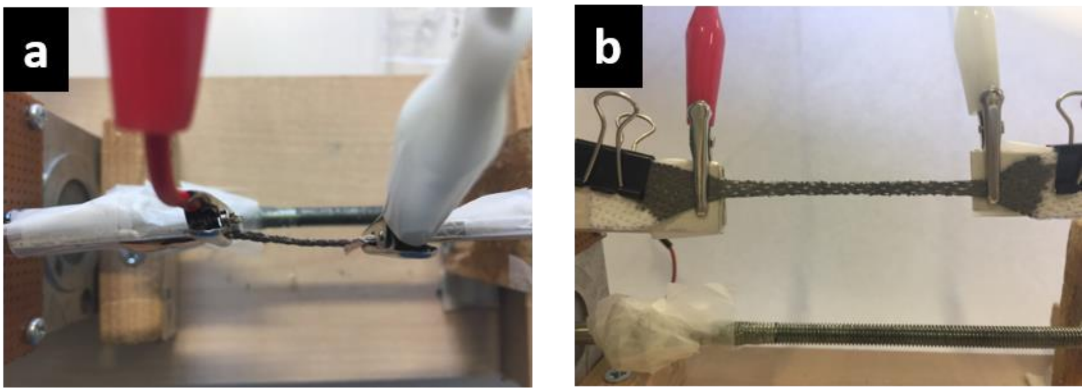

Figure 3. SEM image of synthesized AgNWs under 5000 magnifications. Distance between the gauges are 3 cm on image (a) and 3.5 cm on image (b).

As seen in Figure 3, nonwoven sample was stretched using a homemade stretching apparatus. Initial length of the nonwoven sample was 3 cm and stretched to 3.5 cm in 22.46 seconds. As seen in Figure 4, sample's resistance is increasing exponentially. This kind of sample can be used under 10% of strain if high conductivity is required. Since samples conductivity is increasing constantly with applied strain, conductive nonwoven sample can be an ideal candidate for wearable strain sensors.

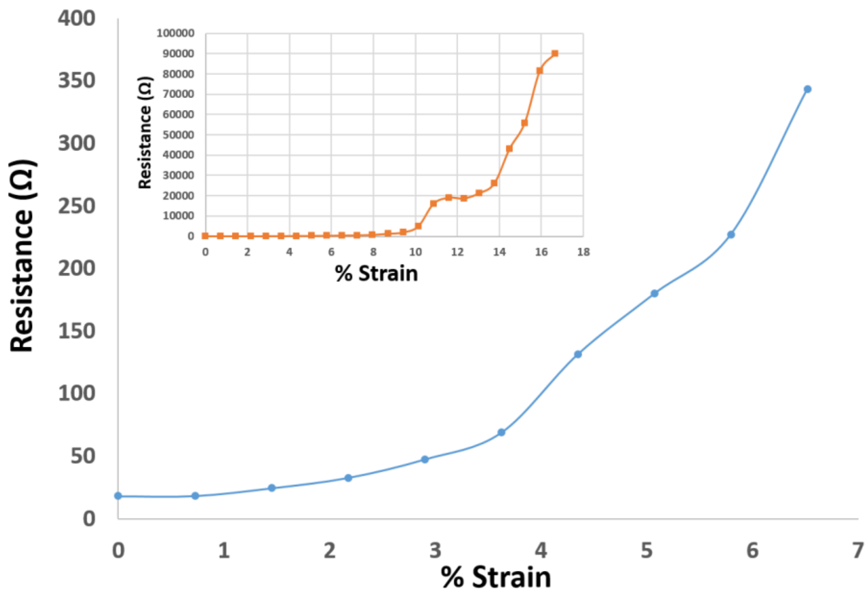

Figure 4. SEM image of synthesized AgNWs under 5000 magnification

Electrical resistance of knitted fabric sample was also investigated under stretching condition. Initial sample length was 3.5 cm and sample was stretched to 5.25 cm, corresponding to 50 % strain. As seen in Figure 5a, sample's resistance value almost constant till 20% strain. Resistance increase 40 % under 50 % applied strain. Our apparatus was not suitable for further stretching. Based on these results, we can claim that knitted conductive fabrics are not only flexible but also stretchable. Thus, they can be used in various wearable electronic applications.

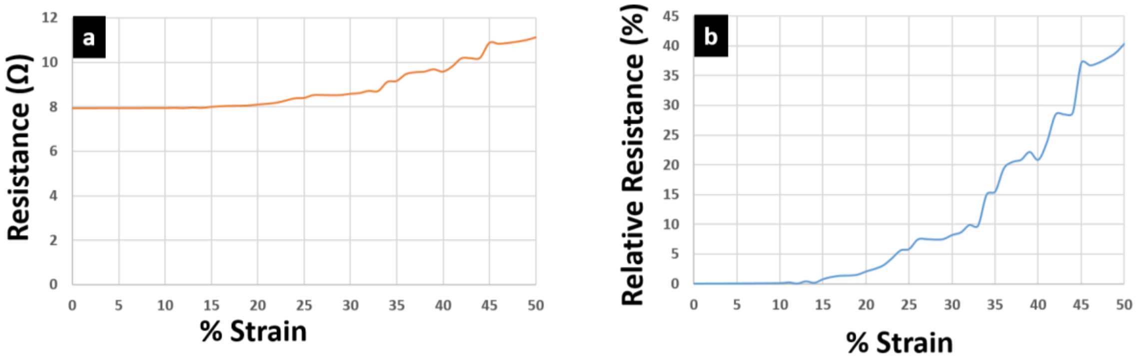

Figure 5. (a) Resistance versus % strain plot (a) and % increase in resistance versus % strain plot for conductive knitted sample. Distance between the two gauges was 3.5 cm. Thus, initial resistance of the sample was 2.3 Ω/cm.

In order to demonstrate a simple application of conductive textile materials, conductive nonwoven sample was used as a touched based capacitive sensor. Two conductive nonwoven sample was separated with a thin layer of an inductive Ecoflex. This simple capacitance was mounted to an Arduino microprocessor. Touching on the nonwoven sample results a change in the capacitance value and microprocessor use this change as a command to light up the LED as seen in Figure 6.

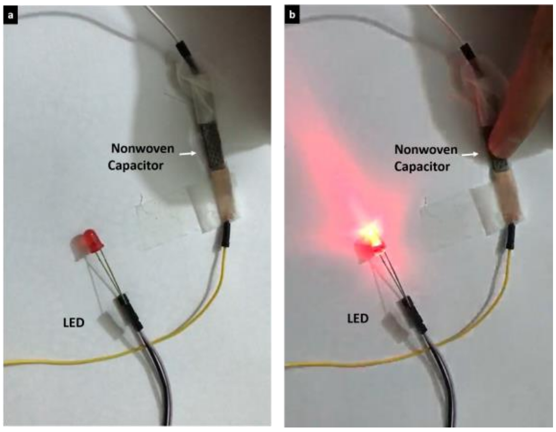

Figure 6. Conductive nonwoven sample was used as a capacitive sensor to light up an LED.

4. CONCLUSION

In conclusion, we have created conductive nonwoven and knitted fabrics. Both samples had high conductivity after coating with AgNWs. Nonwoven samples have slightly less affinity to AgNWs than knitted fabric. Both samples were flexible. Nonwoven samples had increasing resistance under stretching conditions, while knitted sample preserved its initial resistance value up to 20% strain. Nonwoven samples can be used as a strain sensor and knitted fabric has great potential in wearable electronics applications when flexibility and stretchability is required.

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