Application of AgNPs/rGO Modified Nylon Fabric in Strain Sensing

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Abstract. The graphene oxide slurry was printed on the pre-stretched and non-pre-stretched nylon fabric by screen printing, and immersed in silver ammonia solution of different concentrations, and then reduced to obtain silver nanoparticles/reduced graphene oxide (AgNPs/rGO) modified nylon fabric with excellent conductivity. The surface morphology of the fabric was observed, and the performances of the fabric sensor that was scraped with graphene oxide slurry between the pre-stretched and non-pre-stretched states were explored. The resistance responses of the nylon fabric finished with different concentrations of silver ammonia solution under different strains (1\%, 2\%, 3\%, 4\%, 5\%, 10\%, 15\%, 20\%) were investigated. The results showed that the nylon strain sensor was more sensitive and stable when the graphene oxide slurry was scraped in the pre-stretched state, and while the silver ammonia solution concentration was 10 mg/mL, the nylon fabric had maximum sensitivity and lowest hysteresis performance.

1. Introduction

In recent years, the market of smart wearable devices has grown rapidly\cite{1-3}. Wearable mechanical sensors can be directly integrated into textiles and garments for perception and response to the external environment. They have shown great application potential in the fields of artificial intelligence, health monitoring, and sports tracking\cite{4-7}.

The excellent electrical conductivity and mechanical properties of graphene make it an emerging research object in the filed of flexible wearable sensor devices. At the same, the light weight, high moisture absorption, high softness, and high comfort of textiles make it an ideal carrier for flexible wearable sensor\cite{9-11}. However, due to the poor affinity and interface bonding force of graphene, it is difficult to bond with the fabric. Usually, the adhesive adhesion method is used to make the graphene load on the fabric, but its washing resistance, softness and sensing properties are different to meet the application requirement.

In this paper, the graphene oxide slurry was printed on the surface of nylon fabrics using screen printing method, and the tensile sensing properties of the nylon fabrics was compared under the condition of unstretched and different pre-stretching stresses. And then the nylon fabrics were immersed in different concentrations of silver nitrate solution, and obtained AgNPs/rGO modified
nylon fabric. The influence of the concentration of silver nitrate on the tensile sensing performance was investigated.

2. Experimental section

2.1. Main materials
Graphene oxide slurry (DC (Suzhou) New materials and technology Co., Ltd.); Silver nitrate, L-ascorbic acid, and ammonia (AR, Sinopharm Chemical Reagent Co., Ltd.); nylon fabric (nylon/spandex 70/30, 220 g/m²), commercially available.

2.2. Preparation of nylon fabric sensor
The graphene oxide slurry is scraped onto the fabric by screen printing, dried, and then repeat once. Then the obtained fabric (0, 5, 10, 20, 40 mg/mL) is put into silver ammonia solution soaked for 15 min, and reduce with L-ascorbic acid (5 mg/mL) at 90°C for 12h.

In order to explore the effect of graphene oxide coating on fabric strain sensing performance under certain pre-stretching conditions. The fabric was scraped and dried under 5%, 10%, 15% and 20% strain, respectively. The fabric scraped with graphene oxide was immersed in different concentration silver ammonia solution (0, 5, 10, 20, 40 mg/mL), and reduced with L-ascorbic acid (5 mg/mL) at 90°C for 12h.

2.3. Characterizations
The morphologies of the samples were characterized by scanning electron microscopy (SEM, SU150, HITACHI, Japan). The crystal structure was confirmed by the X-ray diffractometer (XRD, D2 PHASER, Bruker, Germany). The conduction of the samples was tested by a digital multimeter (KEITHLEY, America) for ten times and the average value was taken. The sensing performance of the sensor was explored under different strain and tensile force by using a tensile machine (Mark-10, America).

3. Results and discussion

Figure 1. The morphology analysis of (a) control fabric, (b) rGO fabric, (c, d) 5 mg/mL silver nitrate treated AgNPs/rGO fabric, (e, f) 10 mg/mL silver nitrate treated AgNPs/rGO fabric

Using rGO as a conductive material, and depositing silver nanoparticles on the surface through the silver mirror reaction, a fabric-based sensor is formed. As shown in Figure 1(a), the surface of the nylon fabric fibers is smooth. When rGO was printed, a dense rGO layer appeared on the surface of
the fabric fibers (Figure 1b), and the gaps of the fibers were filled by rGO. Figure 1(c-f) shows the surface morphology of the AgNPs/rGO modified nylon fabric. When the concentration of the silver ammonia solution is low, a small amount of silver nanoparticles are scattered on the surface of rGO fabric, and a complete connection path state is not formed (Figure 1(c,d)). With the increase of the concentration of silver ammonia solution, the silver nanoparticles gradually increase and gradually accumulated, so that they cover and fill the surface and inside of the rGO fabric. A relatively complete and continuous path is formed (Figure 1(e,f)).

Figure 2. X-ray diffraction patterns of rGO fabric with AgNPs

In order to further verify the formation of silver nanoparticles on the surface of the fabric, XRD was used to analyze these fabrics. As shown in Figure 2, compared with the original fabric, there are obvious characteristic diffraction peaks at 2θ = 38.6°, 44.8°, 65.0° and 77.8° in the AgNPs/rGO fabric, corresponding to the (111), (200), (220) and (311) crystal planes of silver. Therefore, the silver nanoparticles were successfully reduced and adsorbed on the surface of fabric.

Figure 3. The resistance response performance of AgNPs/rGO nylon strain sensor blade coated with GO slurry in the non-pre-stretched state under different strains
Figure 3 shows the resistance response performance of AgNPs/rGO nylon strain sensor under different strains (1%, 2%, 3%, 4%, 5%, 10%, 15%, 20%) in the non-pre-stretched state. When the fabric sensor without silver nanoparticles, the resistance response of the sensor changes obviously when the strain is small, but the resistance response of the sensor changes slightly with the further increase of the strain, and there is no obvious distinction between the strain states. With the increase of the concentration of silver ammonia solution, the sensor showed obvious response to different strain states. The reason is the addition of silver nanoparticles improves the sensitivity of the device. However, when the concentration of the silver ammonia solution exceeds 10 mg/mL, the functional groups of the graphene oxide have fully absorbed the saturated silver ions, and the further increase the concentration of silver nitrate will not continue to be absorbed on the graphene oxide, forming a dynamic equilibrium process of adsorption-dissociation. This will affect the sensitivity of the sensor.

Figure 4 shows the resistance response performance of AgNPs/rGO nylon fabric strain sensor under different strains (1%, 2%, 3%, 4%, 5%, 10%, 15%, 20%) in the pre-stretched state. Compared with the performance of the fabric sensor in the non-pre-stretched state, the surface resistance of the fabric does not change much, but it has higher stability for resistance response signals of different strains. Similarly, when the concentration of the silver-ammonia solution is low, the response signal change of the sensor to strain is smaller, to strain is better than the non-pre-stretched state sensor. As the concentration increase, the sensor has an obvious and stable gradient response to different strain states.

Sensitivity reflects the resistance response of the fabric sensor to different strain states. Silver nanoparticles can be adsorbed and fixed in the gaps between the rGO sheets and fibers, increasing the sensitive response of the sensor. When the fabric is stretched, the gap between the fibers will increase, and when the fabric is printed with graphene oxide slurry in the pre-stretched state, the graphene oxide will enter the gaps of the fibers, filling the gaps in the stretched state between the fabric fibers. Therefore, specific morphologies will be formed under different stretched states. After being immersed in the silver ammonia solution, the silver nanoparticles are adsorbed on the rGO sheet, filling the gaps and surfaces of the fibers. Although the distance between rGO and silver nanoparticles will increase with the increase of fiber strain, there will be no obvious gully, which further improves the sensitivity of the sensor. Figure 5 shows the sensitivity of a fabric sensor printed with graphene...
oxide slurry in a pre-stretched state to different strains. When the concentration of silver ammonia solution is low, the silver nanoparticles attached to the rGO sheets are less, and the rGO sheets will be discontinuous when stretched, resulting in lower sensitivity of the sensor. When the concentration is 10 mg/mL, the sensitivity of the sensor increases greatly with the increase of the strain, showing a higher resistance response change. When the concentration continues to increase, the dynamic adsorption-desorption of silver nanoparticles on the rGO sheet will reduce the sensitivity of the sensor.

The hysteresis rate of the sensor is related to the speed of the sensor’s response. When the sensor’s response is slow, the response to the strain changes will be delayed. Figure 6 shows the hysteresis of AgNPs/rGO nylon fabric strain sensor in which the rGO nylon fabric is immersed in different concentrations of silver ammonia solution in the pre-stretched state. It is calculated that the hysteresis rate is the lowest 11.42% when the silver ammonia solution is 10 mg/mL.

![Figure 5. Sensitivity of AgNPs/rGO nylon fabric strain sensor blade coated with GO slurry in pre-stretched state](image)

![Figure 6. Hysteresis curve of AgNPs/rGO sensor in pre-stretched state](image)
In order to further study the durability and stability of the AgNPs/rGO nylon fabric strain sensor, the sensor was subjected to 2000 repeated stretch/recovery cycle tests under a strain of 10%. It can be seen from the Figure 7 that, the sensor has relatively stable response and recovery performance with repeated stretching and recovery. The reason of the weak fluctuation is that the slow recovery speed of the sensor fabric itself, which produces a very weak hysteresis recovery phenomenon. Overall, the AgNPs/rGO sensor shows good stability, reliability and durability.

![Figure 7. Stability of AgNPs/rGO sensor under repeated stretching/recovery for 2000 times](image)

**4. Conclusion**

In this paper, the sensing performance of a nylon fabric-based strain sensor that is scratch-coated with graphene oxide slurry in pre-stretched states and non-pre-stretched states and immersed in different concentrations of silver ammonia solution were compared. The results show that the nylon fabric strain sensor has better strain response ability when the graphene oxide is scraped-coated in the pre-stretched state; and when the silver ammonia solution concentration is 10 mg/mL, the sensor exhibits the highest sensitivity and the lowest hysteresis performance, and the AgNPs/rGO modified nylon fabric strain sensor has good durability and stable performance.

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