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Stretchable Location Sensor Based on Transparent AgNWs Electrodes

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ABSTRACT

This paper presents a high-precision location sensor based on PDMS/AgNWs thin film, which enhances the transparency and stretchability of the device. It can be attached to human skin with conformal coverage, keeping the function under the elongation of 60%. The position and resistances have a good linear relationship which make the device can work as the analog mode of location theoretically. Particularly, this 2D panel sensor has potential applications such as wearable devices and E-skin for smart robots.

INTRODUCTION

In the recent years, the smart electronic skin (E-skin) has attracted extensive attention due to the human skin provides remarkable sensor networks such as touch, temperature, vibration and pressure sensors, etc[1-6]. There are many wearable electronic devices integrated with glasses and watches in the consumer electronics with the rapid development[7,8]. However, all of these devices face an important issue about the stretchability which could sustain complex deformation and conformal contact with irregular surfaces. The stretchable materials are mainly required as a substrate such as organic polymer in order to make the devices stretchable. Apart from these, nanomaterials, such as carbon nanotubes[9], graphene[10] and metal nanowires[10-13] have been utilized to realize stretchable electronics. And the special structure designs have also played a very important role in improving stretchability. Wave, island-bridge structure, porous structure and grid structure are widely applied in these novel designs[14].

Inspired by the human skin, recent demonstrations have shown the property of multiple functionalities such as the in-situ perspiration analysis integrated with chemical and biological sensing for healthcare monitoring while the conductor is essential in the work as the foundation of electronic devices [15,16]. There are many efforts attempted to mix carbon nanotubes with polydimethylsiloxane (PDMS) or other stretchable substrate materials to make conductive elastomers, in which the content of carbon nanotubes should be in well control. Furthermore, One dimensional nanowires /nanotubes and two dimensional nanomaterials have been spin-coated on stretchable substrate due to transparent electrodes are crucial for manufacturing displays, solar cells and touch screens[9-13].

Herein, we developed a transparent conductive membrane which is uniform and stable even under elongation through spin-coating AgNWs solution on the stretchable substrate. The motion detection and location is indispensable for human-machine interfaces. However, as most devices work in digital method, there has been limited progress in the resolution enhancement that may lead to an increase in the number of electrodes. Therefore, the stretchable analog devices play an essential role in wearable devices [17], which owns higher resolution with a few electrodes. we demonstrate these new properties by using PDMS/AgNWs thin film.

CONCEPT AND PRINCIPLE

The overall 3D structure schematic of the stretchable location sensor is illustrated in Figure 1a. Two pieces of conductive PDMS/AgNWs thin film are separated by the PDMS spacers, which make the total structure transparent. Thin films of AgNWs were used as top and bottom electrodes whose resistance varies with distance while the PDMS spacers separated the top and bottom AgNWs films. While a finger touched the device, closed circuits are formed as the top AgNWs film contacted with the bottom one at the press positon (Figure 1a). The resistance of the four pairs of electrodes are different as the distances from corners to the touch point varied and the corresponding circuit diagram is shown in Figure 1b. The location of the press point could be obtained from the relative value of the four resistors in the analog method. The sensor can still work even under the elongation as all the materials chosen to fabricate the device are stretchable. Figure 1c presents a photo of the real device.

FABRICATION

The fabrication process of the stretchable location sensor is diagramed in Figure 2. A 10:1 mixture of PDMS elastomer base (Sylgard 184, Dow Corning) to curing agent is mixed and stirred for 5 min. The mixture of PDMS is evacuated in a vacuum desiccator until the air bubbles were no longer visible and then dropped on the smooth glass surface, spin-coated at 500 rpm for 60 seconds and next heated on the hot plate at 100 ℃ for 10 minutes to solidify. Then 5 minutes oxygen plasma treatment is carried out to make the PDMS membrane surface hydrophilic by the inductively coupled plasma (ICP) etching process, for which the alcohol solution of silver nanowires (5 mg/ml) could disperse on the surface uniformly. After repeating dropping the solution on the membrane surface and then spin-coating at 1000 rpm for 25 seconds two times, the membrane is placed on the hot plate at 150 ℃ for 10 minutes to anneal, through which the electrode becomes more conductive and stable.

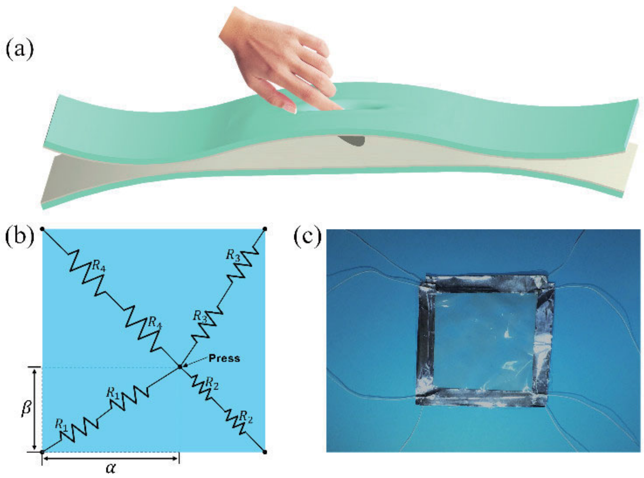

Fig.1: (a) The schematic and working mechanisms of the location sensor; The circuit schematic (b) and real photo (c) of the device.

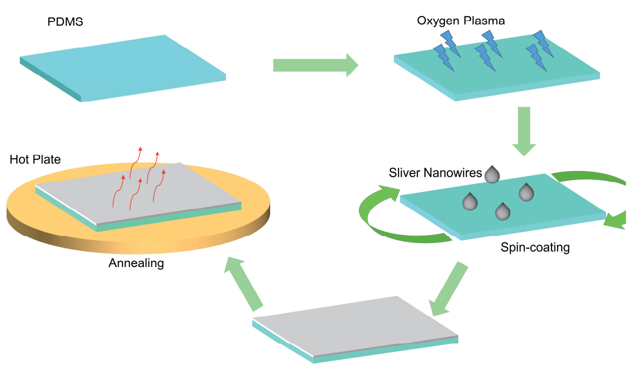

Fig.2: Schematic of the fabrication process of the PDMS/AgNWs film.

RESULTS AND DISCUSSION

Figure 3a and Figure 3b plot scanning electron microscopy (SEM) images of AgNWs coated on the PDMS substrate by spin-coating. As shown in the SEM images, AgNWs build a uniform interconnected conductive network on the PDMS surface. The diameter of the silver nanowire used here is about 30 ~ 50 nm and the length is about several microns. In order to improve transparency of the device, the thickness of the PDMS membrane coated with the AgNWs is only 150 um (Figure 3c). Figure 3d shows the transmittances of the PDMS/AgNWs film at the range of visible light, which shows the excellent transparency and potential applications in the touch screens.

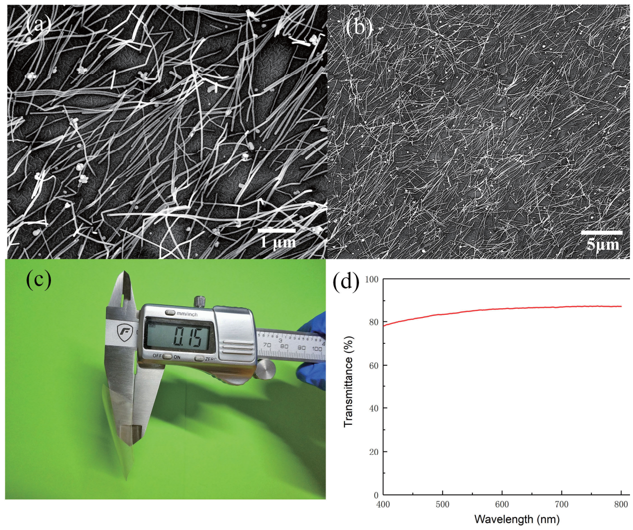

Fig.3: (a) and (b) SEM images of the AgNWs on the PDMS surface; (c) The thickness of the PDMS/AgNWs film; (d) Optical transmittance spectra of the PDMS/AgNWs film.

Figure 4a displays the normalized resistance as a function of the distance on the AgNWs/PDMS strip. With the increase of the distance, the resistance approximately linearly increases, which makes it suitable to be a sensor based on resistance changes. In this way, the sensor can work in the analog method and enhance the resolution without increasing in the number of electrodes. In order to study the effect of stretching on the performance of the conductivity, we make the stretchable membrane work as a part of a conductive loop. The conductivity and stretchability of the PDMS/AgNWs film are displayed in Figure 4b and Figure 4c. The LED bulb just turns darker when the film is stretched to 60%.

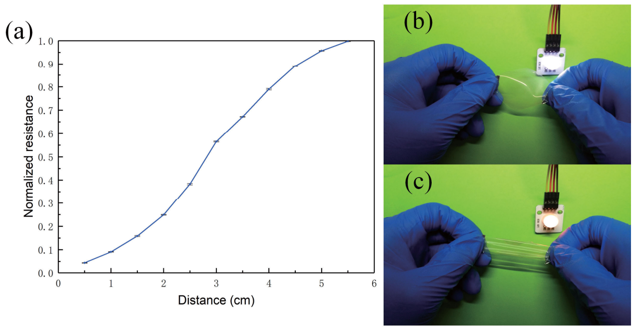

Fig.4: (a) The normalized resistances as a function of distance; The conductivity of the PDMS/AgNWs film under the (b) released and (c) stretched condition.

An 1D sensor was demonstrated in Figure 5a. The length and width of the strip is 6 cm and 1 cm, respectively. The strip was touched from the left electrodes (A1/A2) to the right (B1/B2) every 1 cm, and the resistances are measured from them. The Figure 5b displayed the relative resistance (R/R0, R0 is the sum of the top and bottom strip's resistance) for the position. The result shows that the relative value of resistance can well reflect the change of position.

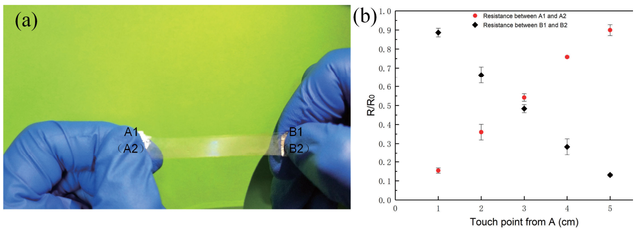

Fig.5: (a) Photograph of the 1D location sensor; (b) The relative resistance (R/R_0) as a function of the distance from electrode A.

Then a 2D plane device was shown in Figure 6a. Two normalized distances are described by α and β parameters. The bottom left corner of the plane corresponds to the origin. While the 2D device is pressed, closed circuits are formed as the top AgNWs film contacted with the bottom one at the press positon and the resistances of each corner between top and bottom electrodes can be acquired. The resistances of the four pairs of electrodes corresponds to four contact test points CP (contact point) 1 (0.17, 0.17), CP2 (0.83, 0.17), CP3 (0.17, 0.83) and CP4 (0.83, 0.83) are obtained, which reflect the distance between the contact point and each corner and demonstrating the location performance and potential in the field of wearable devices (shown in Figure 6b). The position of the contact point in the 2D plane has been clearly reflected by the relative resistance.

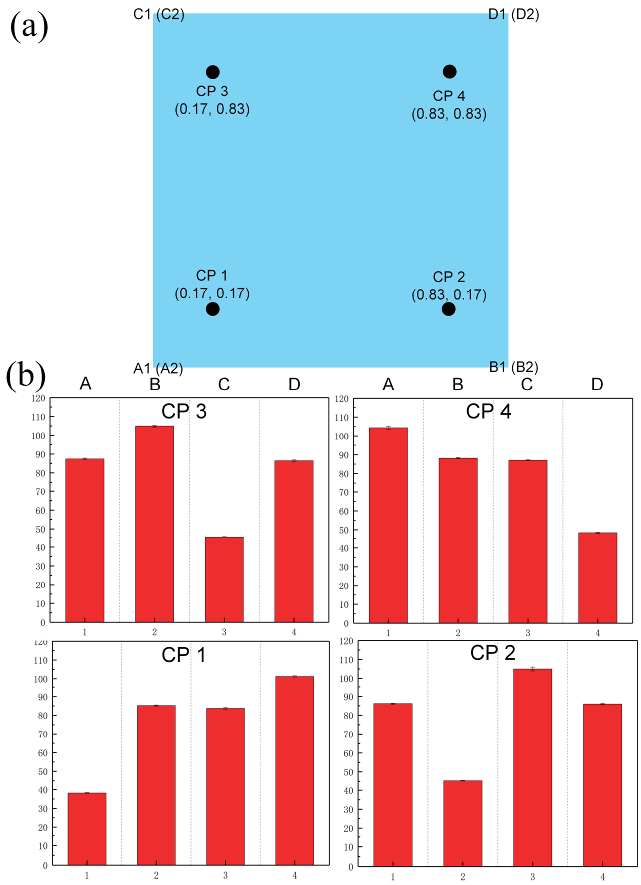

Fig.6: (a) The four contact points on the 2D location sensor; (b) The resistances of the four pairs of electrodes corresponds to four contact points were tested.

CONCLUSIONS

In summary, a novel stretchable, transparent location sensor has been demonstrated in this work. Through the spin-coating process, the AgNWs are deposited on the surface of the PDMS substrate, which enhances the transparency and stretchability of the device. It can be attached to the human skin with conformal coverage and keep the function under the elongation of 60%. When the sensor is pressed, the positon of the contact point can be acquired by the relative resistances in the analog method, which can enhance the resolution without increasing in the number of electrodes. All of the excellent properties makes the sensor have much potentials in the wearable devices and smart robots.

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