Flexible Strain Sensor based on Artificial Skin for Human Sports Health Monitoring

Shiyu He

School of Logistics Engineering, Shanghai Maritime University, Shanghai 201306, China.

h17521797507@163.com

Abstract

The exploration of wearable strain sensors with new features and functions may promote the rapid development of Internet of Things (IoT) technology in the healthcare industry. In this article, we propose a flexible and highly sensitive strain sensor. The sensor uses artificial skin (AS) as a flexible substrate and graphene nanosheets (GNP) as conductive sensing elements, which are prepared by a direct coating method. GNP/AS flexible strain sensor shows good flexibility, high sensitivity and long-term stability. The GNP/AS strain sensor is used for the full range of human body condition monitoring, and the results show that the GNP/AS strain sensor can monitor large-scale human movements in real time, such as wrist rotation, finger rotation, and knee joint rotation, and can be safely used to monitor the human body Sports situation. GNP/AS strain sensor has flexibility and high sensitivity, and has broad application prospects in medical health management and human sports health monitoring.

Keywords

Graphene Nanosheets; Artificial Skin; Flexible Strain Sensor; Human Body Monitoring.

1. Introduction

Nowadays, the development of electronic equipment has aroused great interest. As an important branch of wearable electronic products, flexible strain sensors have received extensive attention due to their potential applications in smart clothing, electronic skin, healthcare monitoring, and human-computer interaction systems [1-3]. At present, researchers have developed many methods to prepare flexible stress sensors [4], using conductive materials (graphene [5], carbon black, metal particles [6], carbon nanotubes, nanowires [7], etc.) and flexible The strategy of combining elastomers makes flexible strain sensors [8-11]. However, current sensors cannot have both large stretch and high sensitivity performance, which largely limits their application in large-scale motion detection [12]. For example, a super-elastic strain sensor is made of silicone rubber. The composition of nanocomposite materials has excellent tensile properties (500% strain), but the sensitivity is less than 2.5 at 100% strain [13]. Recently, by pre-stretching a composite film of reduced graphene (rGO) and elastic bands, a strain sensor has been prepared with a wide strain range (82% strain) and high sensitivity (16-150), but the sensor cannot meet the requirements of multiple joints. The needs of motion monitoring cannot meet the strain monitoring of smart machines [14].

In recent years, rational design of sensor structure and control of the connection type of sensitive materials have been the main strategies for many researchers to achieve sensing goals [15]. Shen et al. [17] studied a pressure sensor based on RGO/polyvinylidene fluoride (PVDF) elastic band composite film, which has high sensitivity and fast response speed. Cui et al. [18] reported an infiltration drying process that uses single-walled carbon nanotubes to prepare a conductive fiber network, which has excellent conductivity, flexibility and stretchability. Graphene nanoplatelets (GNP, graphene nanoplatelets) have become an excellent sensor conductive element due to their excellent mechanical, electrical, thermal conductivity and chemical properties [16]. Artificial skin (AS, artificial skin) is a silicone rubber material developed by imitating mammalian skin. It has excellent flexibility, tensile toughness, biocompatibility and improved friction. Equipment without causing skin irritation or discomfort [19-21].

In this paper, artificial skin (AS) is used as the flexible substrate, graphene nanosheet (GNP) is used as the conductive sensing element, and the GNP/AS flexible strain sensor is prepared by the direct coating method. The GNP/AS strain sensor has ultra-high stretchability. And sensitivity, the highest sensitivity in the normal working range reaches 866.3. The GNP/AS strain sensor is used for the full range of human body condition monitoring. The results show that the GNP/AS strain sensor can monitor large-scale human movements in real time, such as wrist rotation. , Finger rotation and knee joint rotation confirm the high sensitivity and stretchability of the sensor. In summary, the GNP/AS flexible strain sensor achieves the optimization of sensitivity and working range at the same time, and realizes comprehensive human body condition monitoring, which opens up a new way for the design of wearable electronic products.

2. Experimental Section

2.1 Chemical Materials

Graphene Nanosheets (GNP) were purchased from Pioneer Nano Material Technology Co., Ltd.

2.2 Fabrication of GNP/AS flexible strain sensor

First, prepare several AS colloids with a size of 10mm*30mm*5mm, and weigh an appropriate amount of GNP material. Then tear off the AS protective film, put the AS gel face up, and naturally flatten it on the flat-nose pliers, fix the joints with the flat-nose pliers at both ends with tape, keep the joints 5mm, leave a 20mm coating area in the center, and then pass the flat-nose pliers The AS is pre-stretched by 50% to extend the central coating area to 30mm, and the GNP material is evenly coated on the front of the AS with a paint brush and coated with multiple layers until the GNP is completely and evenly covered the entire surface of the AS. Use flat-nose pliers to restore the AS colloid to its original length, and remove the coated GNP/AS colloid to obtain a GNP/AS flexible sensor film. Each end of the sensor film is 5mm long as the sensitive grid at the sensitive grid. Connect the copper wire with a double-lead copper foil tape, and the GNP/AS flexible strain sensor is prepared.

2.3 Characterization

A JSM 7500F scanning electron microscope was used to characterize the microscopic morphology of the GNP/AS flexible strain sensor, and the samples were scanned by energy dispersive spectroscopy (EDS).

2.4 Electromechanical measurement

The mechanical stress-strain measurement of the strain sensor is carried out using the WDW-0.1 electronic universal testing machine (Shanghai Bairuo Testing Instrument Co., Ltd.). The strain sensing experiment uses a WDW-0.1 testing machine to apply strain and fix the strain sensor on the machine tool fixture. The electrical signal of the strain sensor is recorded on the Keysight B2901A multimeter, which is used to define the sensitivity of the strain sensor GF, which can be calculated according to formula (1)

$$GF=(\Delta R/R0)/\varepsilon \tag{1}$$

Where ε is the strain of the strain sensor, and R and R0 are the relative resistance change rate and the initial resistance of the strain sensor, respectively.

3. Results and discussion

The preparation of the GNP/AS flexible strain sensor is divided into two main steps, as shown in Figure 1. First, the AS colloid is face-up, naturally flattened on the flat-nose pliers, and fixed, and the AS is 50% pre-processed through the flat-nose pliers. Stretch. Secondly, evenly coat the GNP material on the front of the AS with a paint brush and coat it in multiple layers until the GNP is completely and evenly on the entire surface of the AS. Use flat-nose pliers to restore the AS colloid to its original length, and remove the coated GNP/AS colloid to obtain a GNP/AS flexible sensor film. Because the mass of GNP used in the experiment is 3mg, the flexible sensor is named GNP/AS -3.

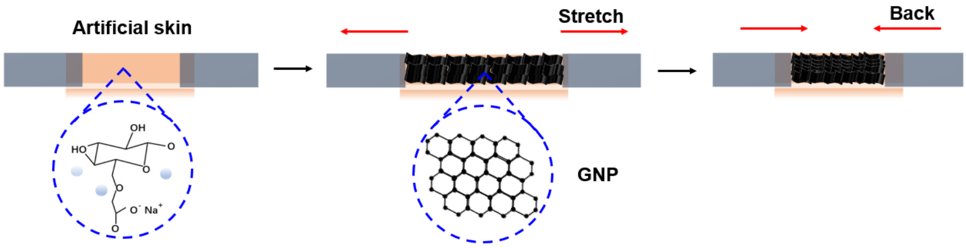

Figure 1. Schematic diagram of the preparation process of GNP/AS flexible strain sensor

The microscopic morphology of the GNP/AS-3 flexible sensor film was characterized by scanning electron microscopy. Figure 2 (a-e) shows the strain state of the GNP/AS-3 strain sensor at 0%, 20%, 40%, 60%, and 80% in sequence. The scanning electron micrograph of the SEM, the picture clearly and intuitively reflects the topographic structure and stretching effect of the GNP/AS-3 strain sensor. Analyzing the scanning electron micrograph of the sensor in the original length state in Figure 2 (a), it is found that the dark gray GNP powder is evenly and fully distributed on the AS flexible substrate, and the surface of the sensor is very flat, which can form a large-scale continuous conductive network. Good, but there are very few cracks in the figure, indicating that the prepared sensor is not completely ideal, and the existence of such cracks is within the normal range. A comparative analysis of the scanning electron microscope images of the sensor in different tensile strain states in Figure 2 (ae) shows that as the tensile strain increases, the original cracks in the sensor gradually elongate, and the GNP attached to the AS substrate will gradually disperse. This leads to the expansion and increase of sensor cracks and the deterioration of sensor conductivity.

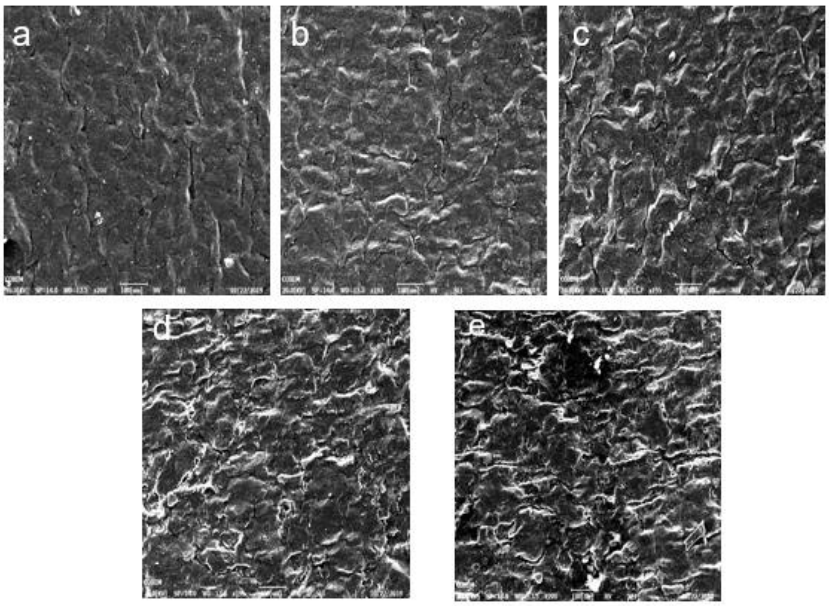

Figure 2. GNP/AS-3 strain sensor tensile (a) 0%, (b) 20%, (c) 40%, (d) 60%, (e) 80% strain SEM images

The electrical performance test of the GNP/AS flexible sensor is carried out. Figure 3(a) shows the comparison diagram of the resistance change rate of the GNP/AS-3 strain sensor in the tensile test in the 0-100% pre-tension range. It can be clearly found that for all the tested tensile sensors, the resistance change rate increases continuously with the increase of the tensile strain. Among them, the pre-stretched 50% strain GNP/AS-3 strain sensor has the largest tensile strain range up to 96% and the highest resistance change rate as high as 831.6, and its resistance changes The rate increases fastest in the strain range of 88%-96% stretch. Figure 3(b) shows the comparison of the tensile test sensitivity of the GNP/AS-3 strain sensor in the 0-100% pre-stretch range. Among them, the 50% pre-stretched GNP/AS-3 strain sensor is compared to other strain sensors. The pre-stretched device has the largest tensile strain range up to 96% and the highest sensitivity as high as 866.3, and its resistance change rate increases fastest in the tensile strain range of 88%-96%, indicating that for GNP For the /AS-3 strain sensor, pre-stretching 50% strain can maximize the sensitivity of the device and the maximum tensile strain range.

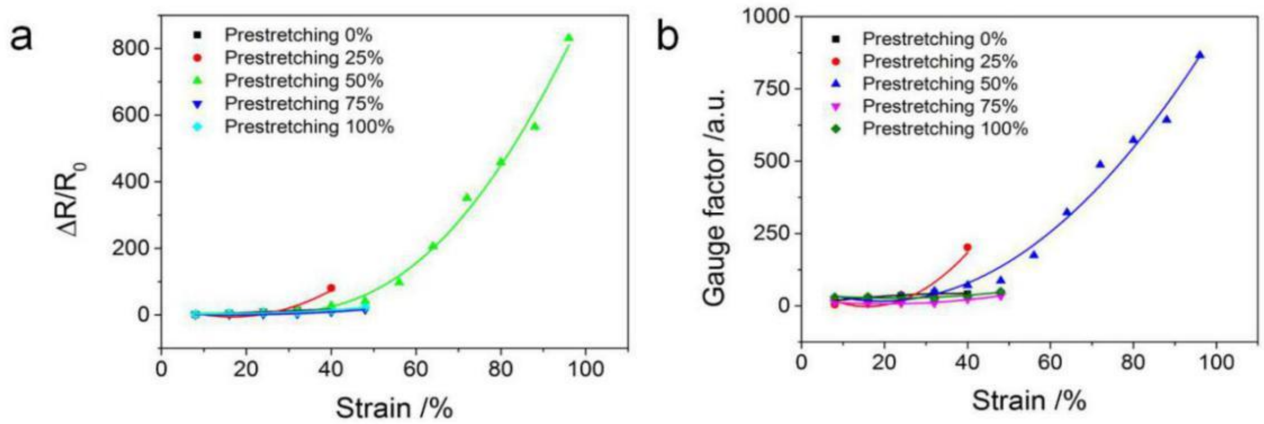

Figure 3. Tensile test of GNP/AS-3 strain sensor in the range of 0-100% pre-tension (a) Resistance change rate comparison chart and (b) Sensitivity comparison chart

Figure 4 is a test diagram of the 0-10% strain resistance change rate of the pre-stretched GNP/AS-3 strain sensor with 50% cyclic extension. This experiment was carried out by loading and unloading tensile stress under 10% tensile strain. Ten cycles of tensile testing. It can be observed from the figure that in the range of 1000 cycles of the stretching cycle, when the device is stretched to 10% strain, the resistance change rate maintains a small fluctuation around 60. Within the range of 1000 cycles of the cycle test, select 10- The response curves of the resistance change rate of the three stages of 20 cycles, 490-500 cycles and 980-990 cycles are amplified, and the comparison shows that although the three time periods are separated for a long time, the resistance change rate still does not change much, and A response curve of the resistance change rate that remains basically unchanged during successive cycles. During the 1000 stretch cycles, the overall signal of the resistance change rate maintains high stability, and the sensor exhibits consistent responsiveness throughout the cycle repeat process, which proves that the sensor has high stability and long service life.

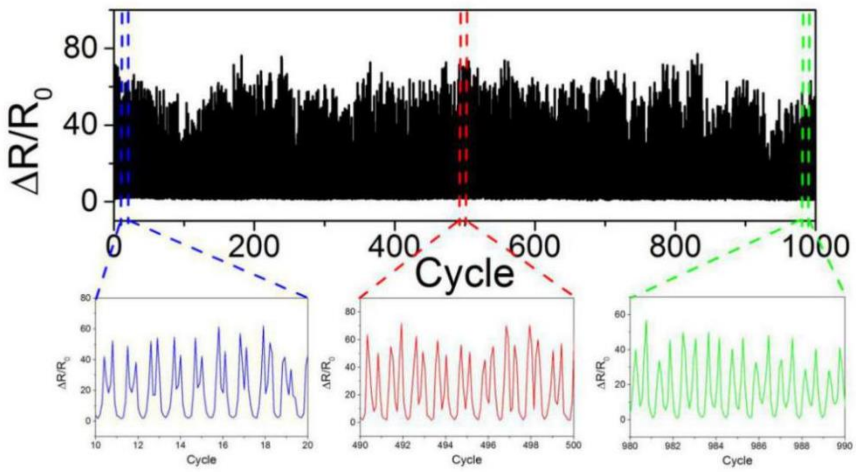

Figure 4. Test of 0-10% strain resistance change rate of pre-stretched 50% GNP/AS-3 strain sensor

Figure 5 shows the test graph of the resistance change rate of the GNP/AS strain sensor to human hand movement. Among them, Figure 5 (a) is the response graph of the resistance change rate of the index finger joint rotation repetitive action. The GNP/AS strain sensor is fixed on the surface of the first knuckle of the index finger, and the sensor rotates with the knuckle through the repetitive rotation of the index finger joint. When strain occurs, a cycle of finger rotation corresponds to a peak and trough of the resistance change rate response curve, and the peak resistance change rate is about 0.7. Figure 5(b) is the response diagram of the resistance change rate of the wrist joint rotation repetitive action. The GNP/AS strain sensor is fixed on the surface of the wrist joint. By repetitively rotating the wrist joint, the sensor is tight and loose with the skin surface of the wrist. Each period of action corresponds to a peak and trough of the response curve of the resistance change rate, and the peak resistance change rate is about 1.0. Figure 5(c) is the response graph of the resistance change rate of the index finger swinging repetitive action. The GNP/AS strain sensor is fixed on the surface of the first knuckle of the index finger. The repetitive swinging action of the index finger causes the sensor to strain with the swing of the finger, and the finger goes back and forth. A period of swinging action corresponds to a peak and trough of the response curve of the resistance change rate, and the peak resistance change rate is about 0.5. The figure shows that all repetitive movements have a cyclic electrical response, and the corresponding resistance change rate response has its own uniqueness.

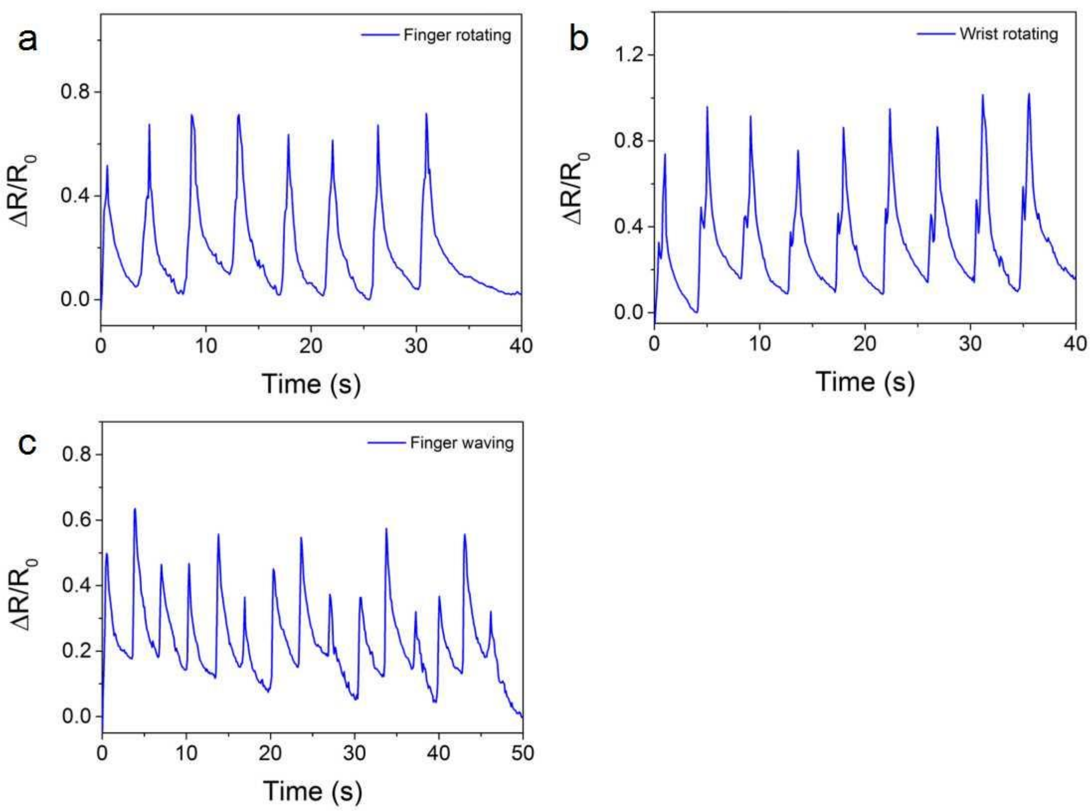

Figure 5. GNP/AS strain sensor (a) finger joint rotation, (b) wrist joint rotation, (c) finger swing repetitive action resistance change rate response graph

4. Conclusions

In summary, the GNP/AS-3 flexible strain sensor is prepared by attaching GNP to the surface of AS. The sensor has a working range of up to 0-96%, a sensitivity of up to 866.3 sensitivity coefficient, long-term stability and durability that can be cycled for more than 1000 cycles. In addition, the sensor has a maximum fracture strain of 692.1%, and has excellent mechanical fatigue resistance and recoverability. The 3mg GNP mass ratio is the optimal ratio, and the pre-stretched 50% strain is beneficial to promote its tensile properties. The sensor has ultra-high flexibility, high sensitivity, long-term stability and durability. The GNP/AS-3 flexible strain sensor can be used to monitor a full range of various human movements, including finger joint bending test, finger joint shaking test, finger joint rotation test, wrist joint bending test, and wrist joint rotation. Therefore, it has great application potential for reliable wearable devices.

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