Title: Transparent Electronic Skin Based on Microstructured Silver Nanowire Electrode

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ABSTRACT: Transparent and flexible electronic skin holds a wide range of applications in robotics, artificial intelligence, prosthetics, health monitoring, and human-machine interfaces. Silver nanowires are mechanically flexible and robust, and show great potential in transparent and electric-conducting thin film. Herein, we report on a nanowire-spray-coating and electrode-microstructure replicating fabrication strategy to construct a highly sensitive and flexible electronic skin device. The device was fabricated by sandwiching thin dielectric film between two transparent and conducting polyurethane (PU) elastomer substrates pre-coated with silver nanowire conducting layer. The ultrathin (45~65 nm) silver nanowire layer was produced by spraying ultralong (>100 μm) silver nanowires on the PU substrates. The electronic skin device shows sensitive piezo-capacitance response to pressure. It is found that micropatterning the surface of PU elastomer by replicating natural surfaces such as lotus leaf, silk, and frosted glass can greatly enhance the piezo-capacitance performance of the device. The fabrication process is so simple that the entire device can be produced in a high school chemistry laboratory. The microstructured pressure sensors based on silver nanowires exhibit good transparency, excellent flexibility, wide pressure detection range (0-150 kPa), and high sensitivity (up to 1.28 kPa^{-1}). Moreover, our sensor can detect very small pressure and enable real-time monitoring of human pulse, and show great potential for health monitoring.

Key words: Electronic skin, pressure sensor, transparent electrode, silver nanowires, microstructure replica, polyurethane

SYMBOL DEFINITION

Abbreviations	Definition
AgNW	Silver nanowires
CNT	Carbon nanotubes
PDMS	Polydimethylsiloxane
PU	Polyurethane
C	Capacitance
F	Total normal pressure and total shear force, unit N
p	Interface stress, unit Pa
p_z	Normal pressure perpendicular to the interface
p_x,p_y	The shear force parallel to the interface, obtained by orthogonal decomposition

CONTENTS

Transparent Electronic Skin Based on Microstructured Silver Nanowire Electrode

1. Introduction

1.1 Electronic skin

In 21st Century, with the rapid development of science and technology, biomechanics and medical engineering are rising as a new multidisciplinary field with fast development, high potential and wide applications. Electronic skin is the product of the application of new materials technology in biomechanics and medical engineering. For the widely used manipulator, electronic devices named as electronic skin composed by the collections of pressure sensors and other sensors will play important roles. To meet the demands of these applications, the pressure sensor devices featured of high flexibility, transparent, large scale integration, and high spatial resolution has become an important development direction of electronic skin.

Note that (Electronic Skin) electronic skin and artificial skin (Artificial Skin) are two different concepts, the latter contains only for medical skin substitutes, while the former contains more electronic components with similar properties with the skin. In this paper, the electronic skin devices as a kind of electronic components or integrated circuit which can imitate the function of human skin protection and perception are made by integrating sensor technology with new material technology.

Electronic skin needs to detect the surface force, that is, the interface stress. This function is equivalent to the human skin touch. The "touch" of electronic skin should include the internal force on the surface which is in contact with the object. It can be divided into normal stress and the vertical interface (Compressive Pressure) and the interface tangential shear force (Shearing Stress). Both of these two kinds of force should be important for electronic skin device to detect and identify. In this paper, the normal stress is expressed by Z, and the shear force and the shear force of Y are expressed by X.

In the past thirty years, there are a lot of new designs of the electronic skin which can measure the pressure. The electronic skin has the characteristics of small area, thin thickness, and can measure the positive pressure on the surface.

As early as in 1991, T.R.Jensen [1] and E.S.Kolesar [2] et al. have developed electronic skin devices with tactile function for the robot. The sensor array is used to measure the pressure, but its reliability and stability are not satisfied with the use of the electronic skin.

In 2004, the T. Someya research group of University of Tokyo in Japan reported a flexible electronic skin with tactile function [3]. The electronic skin composed of micro rubber resistance sensor is drawn into the molecular size and the production of semiconductor crystal to the substrate, the sensor array made of flexible electronics can change the shape of the robot, and can be used for simultaneous measurement of temperature and pressure [4]. Due to the adoption of organic electronic technology, the electronic skin is very thin, and bending does not significantly affect its performance. The disadvantage of the electronic skin is due to the use of a resistance type pressure sensor, and expense of the response level to achieve the effect of bending.

In 2010, Professor Zhenan Bao of the Stanford University published on Nature Materials to report a flexible capacitive pressure sensor design of electronic skin [5]. The electronic skin is coated with indium tin oxide film as electrode, and microstructured PDMS as the dielectric layer. The surface of the PDMS is shaped to form a column or Pyramid shape, which increases the sensitivity of the pressure. This electronic skin also has a high level of response and flexibility, but the spatial resolution is low, and because of the production process of PDMS thin film, the device is difficult to calibrate, which is not suitable for mass production.

In the following year, the research team reported a capacitive pressure sensor based on carbon nanotube film [6]. The carbon nanotubes (CNT) was attached to the flexible base plate, and the thin film of metal oxide was replaced by the sensor. Response levels have been greatly improved, but the short back of low spatial resolution and difficult to calibrate the shortcomings still exist, need to be further optimized.

Although the use of nano materials in the attempt failed to solve all the problems, but this will undoubtedly give us inspiration that in the traditional design of the use of new materials, and sometimes can achieve unexpected results. In the capacitive pressure sensor, the concentration of nano material on the electrode surface changes with the pressure, and the size of the electrode surface is related to the initial concentration. At the same time, due to the properties of nano materials (carbon nanotubes), the electronic skin also has a better tensile property, and the electrode conductivity will not weaken or even increase after stretching. This change in performance can be extended by the use of the pressure sensor integrated components of the electronic skin.

The current electronic skin can be divided into three types according to the mechanisms of work, the resistance type, the capacitance type, and the piezoelectric type.

Resistance type pressure sensor is divided into strain and piezoresistive pressure sensor, strain type structure generally consists of a spring type body, when the structure is deformed when the cross-sectional area of the decrease of the conductive area length becomes longer, leading to its resistance value changes, Kyoichi Ikeda reported a resistance pressure sensor in Ref [7]. The pressure sensor is a kind of typical strain sensor; and the piezoresistive pressure sensor is worked by resistance values changing under pressure. For preparing piezoresistive materials, Lijia Pan describes a piezoresistive pressure sensor based on conductive polymer materials in Ref [8].

The capacitive pressure sensor detects the pressure value by applying the change of the capacitance value, and the distance between the two electrodes under the pressure is changed to change the capacitance value. For example, a kind of capacitive pressure sensor based on PDMS as dielectric layer as described in Ref [5]. Capacitive pressure sensor is a kind of sensing technology which has high response to micro pressure.

Piezoelectric pressure transducer is used with piezoelectric materials: piezoelectric material subjected to external force, will cause the internal negative charge center and the relative displacement of the electrode, and the two relative appeared on the surface of positive and negative charges on the contrary, it will produce a current connection when the detected pressure value what size by size or charge the current detection. Poly [vinylidene (fluoride) PVDF] is one of the most widely used piezoelectric materials. PVDF piezoelectric film has a wide frequency response range, strong flexibility, high level response, strong impact resistance, small noise, soft texture and small influence on the mechanical properties of the structure, high mechanical strength and good impedance matching characteristics. A piezoelectric type pressure transducer is described in the literature [9].

Based on these three mechanisms, pressure sensors have some common characteristics, the advantages and disadvantages of the three mechanism of the pressure sensor are compared [10] in Table 1-1.

Table 1-1 Comparison of advantages and disadvantages of various sensor technologies

Type	Piezoresistive type	Capacitive type	Piezoelectric type
Advantages	Easy integration with peripheral circuits High spatial resolution Easy to realize three dimensional pressure sensing technology Strong anti-interference ability Easy to miniature	High sensitivity Not easily affected by temperature High spatial resolution can be achieved. Easily applied to large scale applications Transparent	High sensitivity High output signal Flexible, thin and light Resistance to chemicals
Disadvantages	Response level is low high cost Complex preparation process The materials are brittle	the peripheral circuit is not convenient to integrate Rely on complex circuits Influence of parasitic capacitance Susceptible to electromagnetic interference crosstalk	dependent on charge amplifier Output drift Not applicable to the application of dynamic force

However, most of the devices can only measure Z to normal stress, and can not measure shearing stress in the X direction and the Y direction. Some reports try to set up a mathematical model according to the normal stress to predict shear force [11], but the latest report found that these mathematical models are not accurate [12]. In addition, these devices are not only vulnerable to interference, and it is difficult to calibrate. In order to obtain the electronic skin which can measure the 3D interface stress at the same time, a new type of sensor which can measure the stress of 3D interface is designed.

Several examples of the electronic skin listed above can explain the research direction of electronic skin: first of all, the electronic skin should be the same as human skin, for example flexible, which can be arbitrary bending deformation and the performance is not significantly influenced, and the thickness should be in the ideal range (less than 1cm); secondly, electronic skin should have the flexibility, which not only can detect the pressure change the tiny, spatial resolution of pressure should be high enough; finally, the electronic skin should also have certain mechanical strength, can protect the internal structure of the same as human skin.

1.2 Microstructures of the capacitance type pressure sensors

The results show that the sensitivity dependence on the microstructure of the flexible sensor has become a hot research topic in recent 5 years. Stanford University Professor Zhenan Bao reported in Nature Materials 2010 [5], Nature Communications 2014 [8], for the micro structured dielectric layer material and conductive polymer materials as the sensor components to making the capacitive and resistive electronic skin. Changhyun Pang, South Korea Seoul University reported in 2012 Nature Materials for the use of nano fibers with interlocking microstructure to prepare the resistance type stress sensor [13]. The team led by Professor Javey Ali of the University of California, Berkeley, used a lithography based micro nano processing technology to prepare the electronic skin sensor [14]. In 2013, Hongbin Yao [15] at University of Science and Technology of China, prepared the resistance stress sensor based on the graphene coated micro structured sponge fiber.

Although the research on the micro structure of the device has made great progress, the structure of micro structure is based on the technology of silicon based micro electronics, such as deposition, lithography, with high cost, high energy consumption, and high access threshold. Therefore, it is necessary to find a new technology to prepare the flexible pressure sensor, which is suitable for the production of low energy consumption, large area and high efficiency. In this paper, the micro structure of the silk, lotus leaf and the ground glass is used as the template to shape the polyurethane elastomer (PU), which replaces the traditional micro nano processing technology, and the electronic skin with excellent performance is prepared.

Silk textiles have been used as a tool for templating capacitive pressure sensor substrate microstructure processing in 2014. Suzhou Institute of nanotechnology and nano bionics Institute researcher Zhang Ting project group in 2014 with two polydimethylsiloxane (PDMS) micro structure silicon rubber copy of silk, and making electrodes using carbon nanotubes, prepared a resistance type stress sensor [16]. In this paper, the surface microstructure of the silk has been proved to be a control to reflect the effectiveness of the other two micro structures for optimizing the electronic skin response.

The surface microstructure of the lotus leaf has been used as the design of the super hydrophobic material. Due to the tiny particles of the surface of the surface, the liquid will converge to a trickle down, so the lotus leaf has a strong hydrophobic property. The microstructure can also be replicated to the preparation of electronic skin substrate in our work, and the design effectively improved the response level of our devices.

In the field of electronic skin, another focus of research is how to obtain flexible transparent electrode. In 2011, a research group at the Stanford University Bao Zhenan published in the Nature Nanotechnology indicates that the carbon nanotubes sprayed on the surface of PDMS to form a conductive network effectively, and has a high degree of transparency. The transparent electrode based on their preparation can be used to fabricate transparent, flexible, and stretchable electronic skin devices system. This prerequisite is the use of carbon nanotubes with extremely fine diameter of only a few nanometers, and has a length of tens of microns. The carbon nanotubes spray coated on the surface of PDMS were distributed to form a snake-like conductive network. However, the fabrication process relies on high quality carbon nanotubes, and the adhesion between carbon nanotubes and PDMS substrate is weak, where the CNTS easy to fall off, and finally resulted in the low sensitivity of skin. Considering the limitations of spraying carbon nanotube transparent electrode, we adopt an alternative process to use scalable synthesis with high aspect ratio of silver nanowires, and use polyurethane (PU) elastomer as substrate to replace the PDMS. Similar to PDMS's flexibility and mechanical properties, polyurethane owns the advantages of the rich surface functional groups, which form strong interaction with metal material by strong hydrogen bonding and Van der Waals' force. Thus the silver nanowires were firmly fixed on the surface of polyurethane.

2. Basic structure and working mechanism

From the formula, we can know that the capacitance of the flat plate capacitor is proportional to the area of the electrode, and is inversely proportional to the distance between the electrodes. When the area or distance between the electrodes is changed, the output capacitance can be changed. The change of output capacitance caused by the change of the output capacitance of the sensor is determined by changing the area or distance between the plate electrodes.

The new electronic skin uses the traditional "sandwich" structure, which is divided into: the surface layer, the middle layer and the bottom layer, as shown in Figure 2.1 and 2.2 (the top and bottom of the substrate has been omitted). The bottom layer is a driving electrode, the bottom layer is an induction electrode, and the middle layer is made of elastic material. When the surface loading force, strain the middle layer of the elastoplastic material, cause the driving distance between the electrode and the sensing electrode and the overlapping area changes according to the change of the output capacitor, to measure the size of the loading pressure.

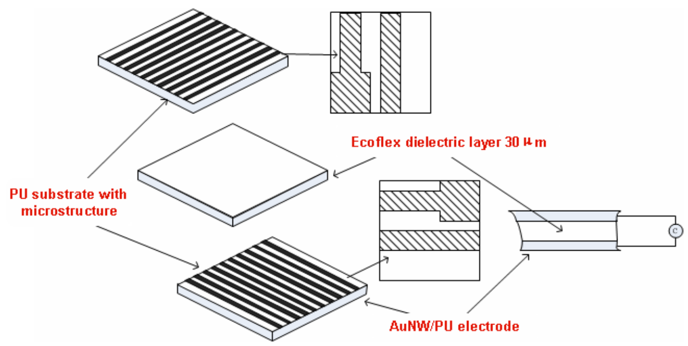

Figure 2.1 Schematic diagram of the basic structure of the new type of pressure sensor

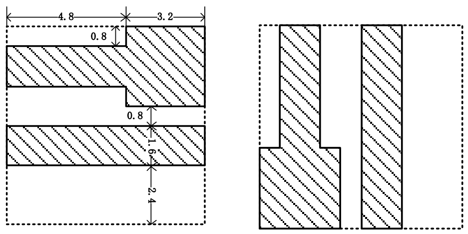

Figure 2.2 Top down (unit mm) of the drive electrode (right) and the inductive electrode (left).

When discussing the working mechanism of electronic skin, the edge effect is not considered.

$C_{i,j}$ is the capacitance between the *i*th strip electrode and *j*th strip electrode. (where $1 \le i < j \le 4$).

For the new flat capacitance pressure sensor, the initial inter-electrode distance, the overlapped area of electrodes, the dielectric constant of the middle layer of elastic material, and the initial value of the output capacitor satisfy the following equation:

$$C_{z0} = \frac{\varepsilon S}{d_0} \tag{2.1}$$

When the interfacial stress is applied on the surface of a new type of pressure sensor, the distance between the driving electrode and the sensing electrode is reduced by Z to the positive pressure, which causes the output capacitance to change:

$$C_{zo} = \frac{\varepsilon S}{d_0 - \Delta d} = C_{z0} \frac{1}{1 - \frac{\Delta d}{d_0}} \tag{2.2}$$

Because $d_0 / \Delta d$ the equation (2.2) is expanded to

$$\frac{\Delta C_z}{C_{z0}} = \frac{\Delta d}{d_0}[1 + \frac{\Delta d}{d_0} + (\frac{\Delta d}{d_0})^2 + (\frac{\Delta d}{d_0})^3 + ...] \tag{2.3}$$

It can be known that there is no linear relationship between the variation of output capacitance and the distance between electrodes. In the above formula, the higher order infinitesimal is ignored, and resulted in:

$$\frac{\Delta C_z}{C_{z0}} \approx \frac{\Delta d}{d_0} \tag{2.4}$$

By the formula (2.4) shows that when the interfacial pressure acting on the plate capacitance sensor, the C output capacitance increases with the electrode spacing of D decreases, which can be used to measure changes in the role of output capacitance sensor Z to the size of the positive pressure.

When the interface pressure loaded on the surface of the novel plate capacitor sensor, X and Y trending shear force changes the sensor overlap area between the drive electrode and the sensing electrode. If the moving distance of induction electrode along X and Y direction is defined as A_x and A_y. a is defined as the increased width of the induction electrode 3 in the X direction. b is defined as the increased width of the drive electrodes in the direction of Y. w is the width of the other part. ε is the dielectric layer dielectric constant. C_x is defined as the value of electrode output capacitance of the electrode $C_{2,3}$, C_{x0} is the initial value; C_y is defined as the value of the output capacitance of the electrode $C_{1,4}$, and C_{y0} is the initial value. Then C_x and C_y are:

$$C_x = \frac{\varepsilon(w^2 + b(\frac{w}{2} - A_x))}{d} = C_{x0} - \frac{\varepsilon b}{d} A_x$$
$$C_y = \frac{\varepsilon(w^2 + a(\frac{w}{2} - A_y))}{d} = C_{y0} - \frac{\varepsilon a}{d} A_y \tag{2.5}$$

Thus obtained:

$$\Delta C_x = C_x - C_{x0} = -\frac{\varepsilon b}{d} A_x$$
$$\Delta C_y = C_y - C_{y0} = -\frac{\varepsilon a}{d} A_y \tag{2.6}$$

Thus, the output capacitor plate capacitive pressure sensor and the size of the drive electrode and an inductive electrode relative to X and Y to the displacement between the linear relationship. But since the value will be affected by the positive pressure, it is necessary to eliminate the interference of the positive pressure, Substitution $C_z = \frac{\varepsilon w^2}{d}$, got:

$$\frac{\Delta C_x}{C_z} = -\frac{bA_x}{w^2}$$
$$\frac{\Delta C_y}{C_z} = -\frac{aA_y}{w^2} \tag{2.7}$$

The change of the output capacitance A and B can be used to measure the X direction and the Y direction shear force of the sensor.

3. Optimization of the response level of the positive pressure

3.1 Effect of electrode material on the response of positive pressure

Known by $\frac{\Delta C_z}{C_{z0}} \approx \frac{\Delta d}{d_0}$, The response level of the positive pressure is determined by the change of the distance between the electrodes under the change of the unit positive pressure. Therefore, in the design and manufacture of electronic skin preparation process, the electrode material of silver nanowires and the characteristics of concentration, substrate surface microstructure, the thickness of the dielectric layer and the pumping degree will affect the positive pressure of the device's response level. The following from many aspects of the analysis of the factors affecting the level of positive pressure response and make the program optimization.

Because our research is based on the response level of the positive pressure, the structure of the device is simplified in this chapter. Use only a single electronic skin of square electrodes in test positive pressure sensor instead of the whole, and in the study of dielectric layer, the thickness of polyimide stable (PI) film as the dielectric material to prevent the effects of different thickness of the dielectric layer caused by. These methods simplify the operation and reduce the interference of other factors.

Silver nanowires (AgNWs), is a nano scale one dimensional material with the diameter lower than 100 nm, as shown in Figure 3.1. It has excellent and unique electrical, mechanical, thermal, chemical and electronic properties.

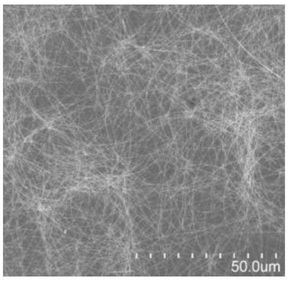

Figure 3.1 SEM image show the microstructure of silver nanowires.

When the AgNWs/PU electrode is subjected to pressure, the electrode surface is deformed due to the uneven distribution of the force, which leads to the tensile or shrinkage of the silver nanowires in the local area. The density of silver nanowires in these areas will change, and the ability to store charge has also changed. This change is reflected in the output capacitance value, so that the amount of change in the amount of capacitance. Thus, the electronic skin of the silver nanowire electrode has a higher positive pressure response level than the conventional metal foil.

Carbon nanotubes (SCNTs) have demonstrated the potential of its application in many fields. In recent years, SCNTs has become one of the research focuses in the field of pressure sensors. Carbon nanotube electrode and silver nanowire electrode also have the same nano scale effect.

To compare the two electrode response level influence on the electronic skin, as shown in Figure 3.2 As shown as the SEM images, the surface of AgNWs/PU electrode is more fluffy and there irregular fold structure obviously, while the SCNTs/PU electrode surface is relatively flat. From the point of view of the distribution of the nano materials, the silver nanowires were dispersed well, and the direction of nanowires is disorder, covering the surface of the substrate, while the carbon nanotube dispersion was poor. Because the change of electrode surface structure more irregular to sensor in micro pressure under two electrode spacing, electrode and dispersed more evenly is conducive to change the local concentration of the electronic skin so AgNWs/PU electrodes are made compared with SCNTs/PU, with higher water flat response.

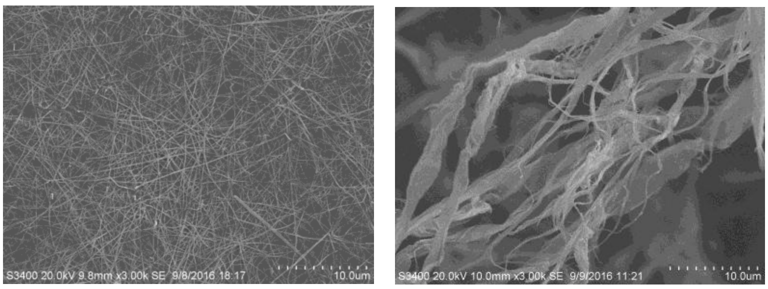

Figure 3.2 Microstructure of AgNWs (left) and SCNTs (right) on the substrate

As compared with traditional metal nano materials, carbon nanotubes and silver nanowires electrodes enhance response level of electronic skin, which verified the above analysis, we conducted a comparative test: using carbon nanotubes, silver nanowires and nano scale effect no ordinary metal electrode as the pressure sensing device to the level of contrast their response to stress. Here we use the common silver mirror reaction to prepare silver foil as ordinary metal electrode. The test results are shown in Figure 3.3

Therefore, a new type of electrode materials for electronic skin selection of silver nanowires comes out.

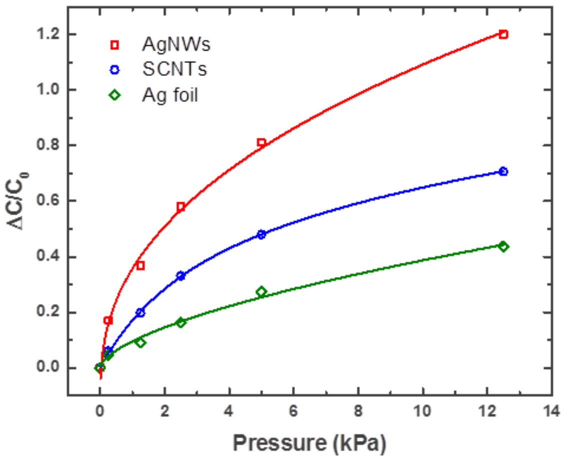

Figure 3.3 Effect of different electrode materials on the level of positive pressure response

3.2 Effect of silver nanowire density on the response of positive pressure

The above analysis shows that the sensitivity of the silver nanowires as electrode to improve the pressure sensor is dependent on the nano scale effect, that is, the density of the silver nanowires changes in local area when the pressure is applied. At the same time, the density of the silver nanowires can change the range of the density of the silver nanowires in the local area, so it can affect the sensitivity of the electronic skin to the pressure. The high density of silver nanowires with dense distribution, electrode during compression of silver nanowires distribution with weak charge storage capacity is less affected; on the contrary, very thin silver nanowire electrode when compressed easily opened, resulting in a substantial charge storage capacity decreased. Therefore, the optimization of the response level required to maintain a certain surface specific density of silver nanowires.

To explore the effective optimization of the level of response of silver nanowires density range, verify the above analysis and concentration by changing the preparation procedure used in silver nanowires quantitatively spraying, further testing, the test results are shown in Figure 3.4.

The experimental results show that the sensitivity of the capacitive pressure sensor to the pressure is increased with the increase of the surface specific density of the silver nanowires in a certain range. When the density of the silver nanowires is increased beyond the optimum range, the sensitivity of the capacitive pressure sensor to the pressure is decreased.

Therefore, the new electronic skin electrode material concentration is controlled in 1.6mg/cm2, that is, for each square centimeter of the floor, spraying 8 ml of silver nano wire solution (0.2mg/mL)

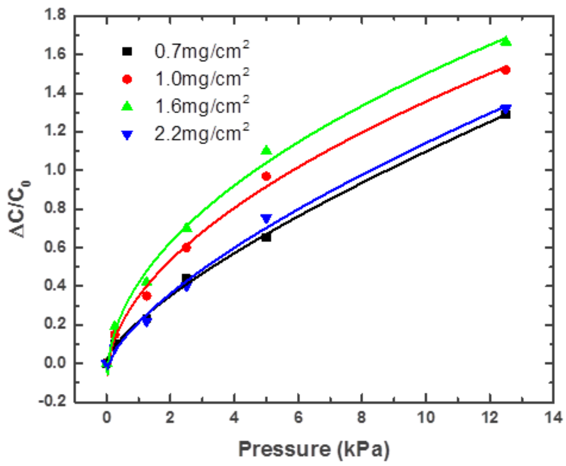

Figure 3.4 Effect of different concentrations of electrode materials on the response of normal pressure

3.3 Effect of microstructure of substrate surface on the response level of positive pressure

The quantitative characterization and measurement of positive pressure need to reflect the change of the positive pressure through the distance between electrodes. When the same size of the positive pressure is applied on the interface, it is assumed that the surface stress is uniform, the change of electrode spacing is larger, and the response level of the electronic skin to the positive pressure is higher. One of the effects of the substrate with a surface micro structure on the electronic skin response level is to amplify the distance variation. If the substrate surface with a microstructure is equivalent to a regular, repetitive Pyramid shape, the Pyramid shaped support material is extruded and the shape is closer to the column, so the height change is obvious. The surface structure of the substrate with surface micro structure under pressure is more obvious than that of the flat surface under the same conditions. Because of the nano scale effect, the surface structure changes can lead to the local silver nanowire stretching or shrinking, which changes the output capacitance value.

The polyurethane elastomer is obtained by mixing the liquid component, which determines that the substrate can be solidified on a template having a surface microstructure, thereby replicating the surface microstructure of the template.

The micro structure of bionics and common material replication is innovative method nowadays making the surface micro structure. In this paper, the microstructure of the three kinds of materials, such as silk, lotus leaf and ground glass, were selected.

Copy operation for substrate step in the fabrication process, the first to be copied material textile and fixed on the bottom of culture dish, and then injected into the uncured polyurethane liquid. After curing, we cut out the required parts and peeling off the material, the surface of the substrate replicated the microstructure of the template as shown in the SEM images in Figure 3.5.

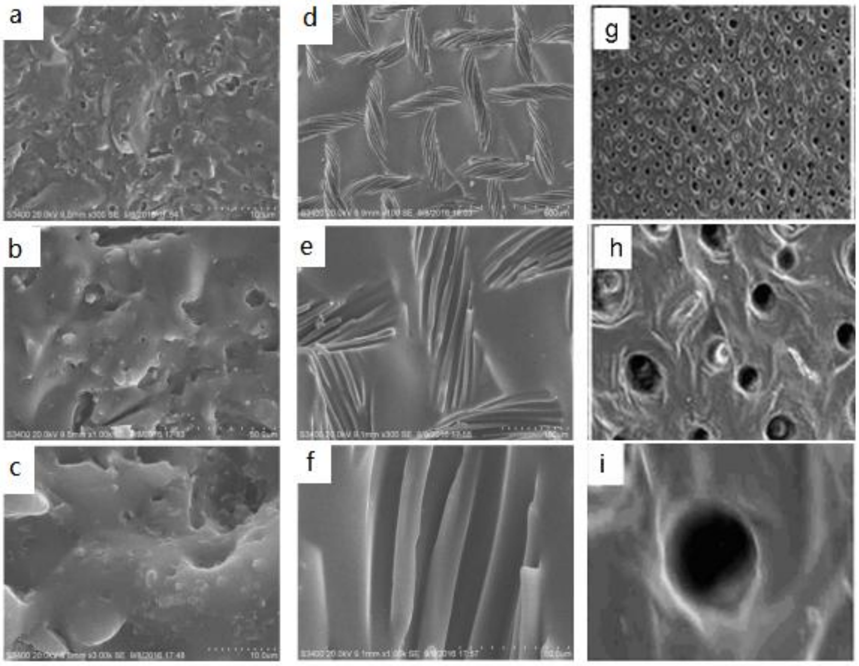

Figure 3.5 Substrate surface microstructure (a-c) imitation glass negative structure (d-f) imitation silk negative structure (g-i) imitation lotus leaf negative structure

Compared with the substrate prepared by the replicated microstructure of the substrate and the non-structured substrate, the silver nanowire solution were sprayed with 8ml is prepared and separated by the PI film. The test data are shown in Figure 3.6.

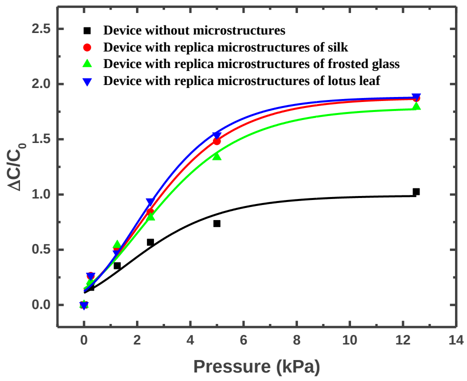

Figure 3.6 Effect of substrate with different surface microstructure on the response of normal pressure

Experiments show that the electronic skin based on the substrate has a higher positive pressure response level in the micro pressure range within the 5000Pa. This may be because the surface microstructure is greatly changed when the pressure is small; when a larger pressure is applied, the surface structure has been close to the column, and is is not sensitive to the pressure.

Therefore, the electronic skin substrate needs to be processed by microstructure. The above data area to indexing structure for the comparison of three kinds of micro positive pressure response levels, in the production of electronic skin large-scale integration, due to size of the material itself, the best selection of silk as a tool for preparing surface micro structure.

3.4 Effects of dielectric layer dependent parameters on the response of positive pressure

The dielectric layer is made of Ecoflex material, which is prepared by the processes of liquid mixing, degassing, spin coating and solidification. The thickness of the dielectric layer directly affects the mechanical properties and thickness of the dielectric layer, which is different from the shape of the same size, which influences the normal pressure response of the device. On the other hand, there will be micro bubbles in the dielectric layer, the gas content is related to the gas removal process, and some of the bubbles in the compressed gas will be squeezed out of [17]. Because the dielectric constant of the air (denoted as 1) is less than the dielectric constant of Ecoflex plastic (about 2.8), the effective dielectric constant increases and the output capacitance value also increases. So the bubble content will also affect the level of the device's positive pressure response.

The change of dielectric constant of the material is inversely proportional to the force. When D is large, the output capacitance value is small, measurement error increases, and the device is affected by other factors (such as parasitic capacitance and electromagnetic interference) influence increased, while other factors (increase the sensitivity of the distribution of surface micro structure and deformation of silver nanowires decreases influence). When the D is smaller, the output capacitance is larger, easy to measure, and is more sensitive to other factors.

Ecoflex silicon rubbler film itself as a mechanical elastic film with excellent performance, when there is pressure on the surface, Ecoflex will be deformed, because there are many pores within the Ecoflex plastic film, deformation occurs, the pore air will be discharged, the effective dielectric constant increased.

In addition to the low degree of degas, the bubble resist for a long time, the effective dielectric constant change, and vice versa. However, when the bubble is too large, the electrode may be directly exposed, resulting in short circuit and the electronic skin failure.

In order to determine the optimum thickness of dielectric layer and the gas removal time, to verify the above analysis, using AgNW/PU as electrode, Ecoflex plastic film with different parameters as the dielectric layer was compared. Ecoflex plastic film is prepared by spin coating method, and the thickness of the film prepared by spin coating can be expressed as follows: [18]

$$d = k\omega^{\alpha}$$

Which represents the thickness of the film, said the rotation speed of the substrate, and the solution is K and the physical properties of the substrate, the solute and the related empirical constants, where the value of -0.5, K 0.0023, by pre testing the effective formula. In the experiment, two kinds of thickness of the film, the film thickness is about 30, the film thickness is about 120, two kinds of thin film by spin coating and lamination, are more uniform 6000rpm. Fully in addition to the need to solidify the gas before the liquid Ecoflex in the test environment, the extraction of 20 mins, partly in addition to gas exhaust 2min. In the process of heating and curing, the bubble rise Ambassador effect is more obvious.

The test results are shown in Figure 3.7.

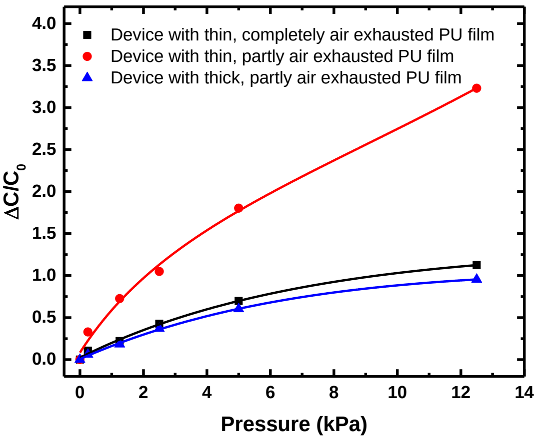

Figure 3.7 Effect of different parameters on the response level of the positive pressure

The experimental results show that the dielectric layer is thinner, and the electronic skin prepared by partial removal of the gas has a significantly higher level of positive pressure response.

3.5 Optimization of electronic skin design

According to the above discussion, the design of the new electronic skin is optimized from two angles of the material and the structure. On the selection of materials, silver nanowires as electrode material and concentration control in 1.6mg/cm2; the structure, using the synthesis characteristics of polyurethane and Ecoflex, before the polymerization occurs in the composition, appropriate treatment is still liquid when the substrate surface micro structure and dielectric layer of bubble preparation. The experiment proved that the above operation can effectively improve the positive pressure response level of electronic skin. The fabrication process and final test of the device will be completed in 5 and 6 sections.

4. Protection performance optimization

Electronic skin in the skin to achieve a sense of touch, but also should be able to achieve a protective effect, that can be isolated inside and outside space, protecting the internal structure from the outside world. In order to optimize the performance, it is needed to enhance the structural strength, chemical stability and thermal insulation properties of the new electronic skin. This section compares the effects of flexible polymer material PDMS and polyurethane elastomers on the pressure response level of the substrate.

4.1 The protective effect of the substrate itself

PDMS is a kind of polymer with high transparency, chemical inertia, non-toxic and non-flammable and so on. PDMS is a viscous liquid, heated to a solid state when it is a silica gel, so widely used in the electronic skin of the substrate.

Polyurethane (PU) is a kind of polymer, which is a kind of polymer with NHCOO repeating structure unit in the main chain. It is formed by the polymerization of isocyanate and hydroxyl compound, and its elastomer is a polymer which is a kind of polymer which is between plastic and rubber. Through the reaction of low molecular weight diols and excess aromatic isocyanate synthetic elastomer, generate isocyanate terminated prepolymer, and butylene glycol chain extender, thermoplastic elastomer; with two aromatic diamine chain extender and further cross-linking, this test is obtained for use in casting polyurethane elastomer (CPU Elastomers). Two groups of cast elastomers are mixed, heated and solidified to obtain solid materials. The solid material with strong carbamate polar, insoluble in nonpolar groups, with good oil resistance, aging resistance and adhesion, in the pretest in 200 thick film stretching as the original 2 times longer without fracture, illustrates its flexible stretch characteristics. At the same time, its wear resistance is 3-10 times of ordinary rubber. The tensile strength, elongation at break, tear is far stronger than ordinary rubber, shows its strong wear resistance and excellent mechanical properties of [19]. Polyurethane elastomers can also be resistant to low temperature, but also the world's best performance of thermal insulation materials. Although the polyurethane elastomer at high temperature is not resistant to acid and alkali, but its best working range of -50 ~ 150 ˚C, can meet the needs of the general electronic skin.

4.2 Strength of substrate and electrode interaction

The role of the substrate is to protect the nano electrode in the use of non-shedding, not to be worn. If the substrate is not effectively adhered to the electrode, it is easy to cause the overall disconnection, the device is broken up, or the local circuit breaker, and the device failure. The previous chapters have been identified using silver nanowires as electrode materials, this part compares the effect is often used in electronic skin in commonly used engineering materials PDMS and polyurethane on the performance of electronic skin protection.

PDMS and carbon nanotubes have good interacting effect, but the interaction with the metal is not strong. In the spraying of silver nanowires when the surface treatment is required: [20] The Tris-HCl buffer solution to dopamine hydrochloride dissolved in PH=8, 1g/L solution. The PDMS thin film can be adsorbed on the surface of PDMS with a solution of 24 h, which is needed to be treated. This is because in the PH=8 environment after the polymerization of dopamine oxidation reaction, the PDMS surface formed a layer of polymer film, as shown in Figure 4.1.

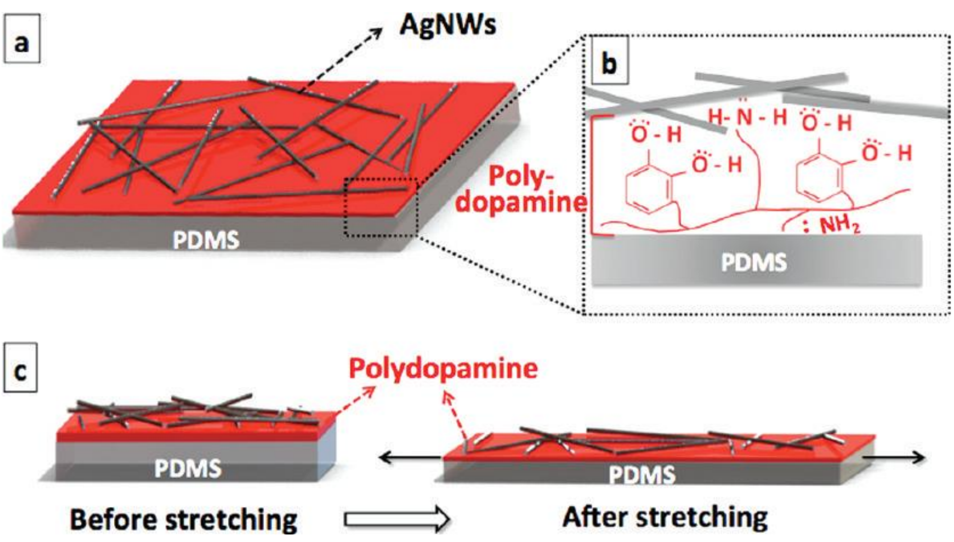

Figure 4.1 PDMS surface treatment

The group (-OH, -NH2) on the polymer layer has a pair of electrons, which can coordinate with the silver nanowire to prevent the silver nanowire from falling off. In the experiment, the surface treated PDMS and silver nanowires still did not show good adhesion. Although the surface treatment can not completely solve the problem, but the lone electron groups on easily and silver nanowires, while electron donating -NH2>-OH, electronegativity of O>N, so the -NH2 lone pair electrons on a higher degree of freedom, the thought of using surface containing -NH2 polymer instead of PDMS.

Polyurethane and metal silver have a strong effect. In the literature [21], the water purifying device, which is based on polyurethane, is introduced. It reflects the strong adhesion of polyurethane and silver nanoparticles. The similar phenomenon of silver nanowires was also found in the experiment. This is because the surface of polyurethane (-NH2) a large number of primary amine and secondary amino (-NH-) the existence of a lone electron atom in N, with the silver nanowires of silver atoms, so that the silver nanowire is firmly attached on the surface of polyurethane.

4.3 General comparison

As can be seen from the above analysis, compared with PDMS polyurethane elastomer, with a stronger mechanical properties and thermal insulation, and with the electrode material silver nanowire adhesion force is stronger, more suitable for the general use of electronic skin. PDMS has a stronger chemical stability and heat resistance, more suitable for the special conditions of the sensor. Therefore, in order to optimize the protective performance of the electronic skin, the polyurethane elastomer material is selected as the substrate.

5. Simple preparation method of electronic skin

This section describes the preparation process of the new electronic skin. First, using standard cast polymer material preparation technology of polyurethane finish substrate preparation, surface treatment and curing, and complete the silver nanowire spraying solution and mask preparation; then cover the substrate with mask, coating silver nanowire films. The intermediate separation layer and the signal of the signal are produced on the electrode, and the electrode is pressed to form and solidified. The specific process for the preparation of a repeating unit of electronic skin is shown in Figure 5.1.

5.1 Preparation equipment

Instrument: spin coating machine, analytical balance, gas, heat, spray gun and air pumping device group, capacitance meter, multimeter, measuring tools, utensils, appliances, bearing clamping cutting tool, fixture, solution preparation equipment.

Material: silver nitrate, D+ glucose, poly(vinylpyrrolidone) and sodium chloride, polyurethane (component AB and release agent), Ecoflex (group AB), Tris, hydrochloric acid, dopamine hydrochloride, copper tape.

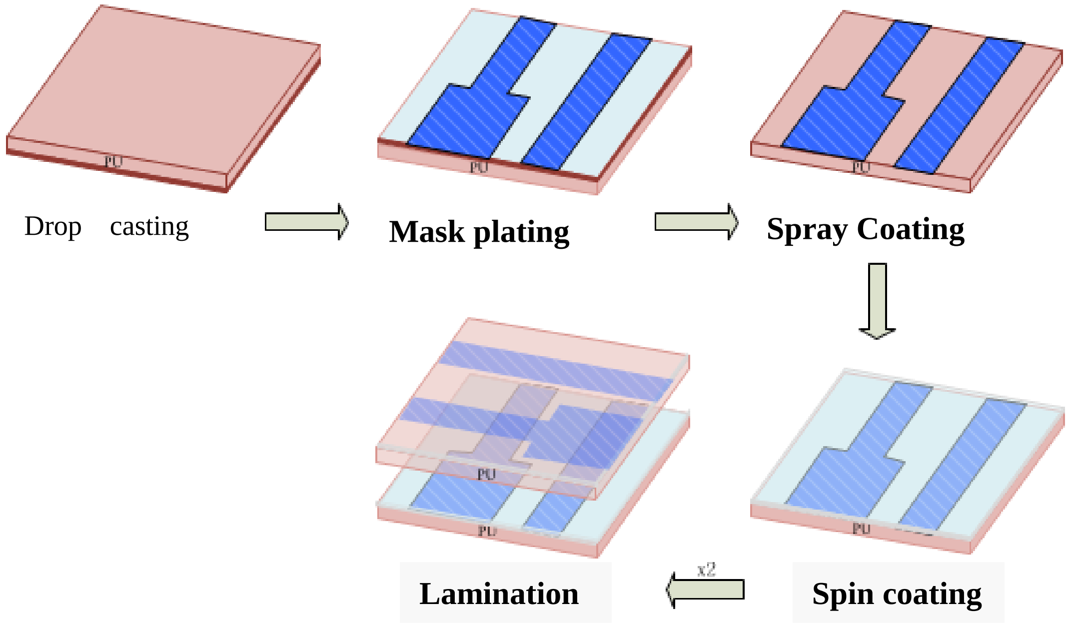

Figure 5.1 The preparation process of the new electronic skin structure unit

5.2 Preparation of Silver Nanowire

Ultra-long silver nanowires of an average diameter of 45–65 nm and length greater than 200 μm were synthesized by a simple hydrothermal route. In a typical synthesis procedure, silver nitrate (0.02 M, 15 ml) (Sigma-Aldrich, 10220), D+ glucose (0.12 g, 5 ml) (Sigma-Aldrich, G8270), poly(vinylpyrrolidone) (PVP, Mw z 40 000) (1 g, 5 ml) (Fisher Sci, BP431) and sodium chloride (0.04 M, 15 ml) (Fisher Sci, S93361) were prepared in deionized water (DI) as four separate solutions, in a well dissolved form. PVP solution was prepared at 65 C while the rest of the solutions were prepared at normal room temperature. Glucose solution was added to silver nitrate solution with continuous stirring. After 5 to 10 minutes, PVP solution was added and stirred for 20 minutes until it mixed well. Afterwards, sodium chloride solution was injected drop-wise into the above solution with continuous stirring until it fully dissolved. This turbid hydrosol was added to a 50 ml Teflon-lined stainless steel autoclave and heated in an oven at 160 C for 22 hours. After that, the autoclave was air cooled to room temperature unaided and the final product in the form of a fluffy gray white precipitate was collected by centrifugation at a speed of 2500 rpm for 60 minutes and washed thrice with distilled water and 3 to 4 times with isopropanol. The final product was dispersed in isopropanol for further use. Every time before centrifugation to remove the PVP layer, wires were shaken gently to prevent them from breaking down. The process above is shown in Figure 5.2

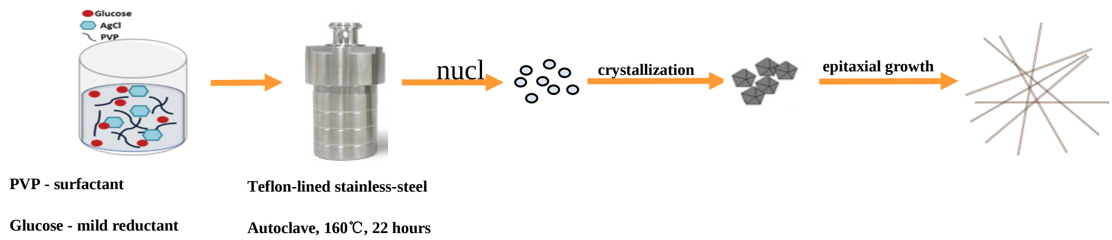

Figure 5.2 Synthesis of Ag nanowire

5.3 Preparation of polyurethane substrate

To replicate the microstructure of silk, the silk texture was bonded to the bottom of culture dish, the liquid precursor of PU were cast in analytical balance. Shake the culture dish to make polyurethane cover the bottom surface, and flow flat. Then, the culture dish is placed in an oven for two hours to cure PU, and the flexible substrate with surface microstructure is obtained by peel off the silk mold and cutting for the required size.

5.4 Preparation of Electrode

With 1mL silver nanowires (40 mg/mL in isopropyl alcohol) were measured and mixed with 20 mL solution in isopropyl alcohol, and ultrasonic dispersing for 5 min. The obtained silver nanowires dispersed solution can be used for spray coating on the substrate. Required amount of solution was calculated and loaded in the spray gun. At the same time, the microstructured PU substrate was placed on a glass sheet. The silver nanowires were sprayed on a hot stage of a constant temperature 80 ˚C. The consumption volume of the solution after the resistance of the film measure is less than 100 Ω. After that, the substrate was heat treated at temperature of 200 ˚C for 20 min. The electrode was connected with a thin copper foil tape at the edge of the conducting PU substred to obtain a complete electrode. Figure 5.3 illustrates the spray coating process.

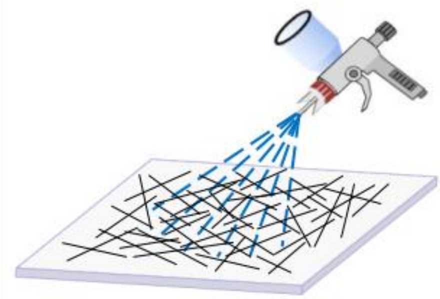

Figure 5.3 Spray coating Ag nanowire

5.5 Preparation of Ecoflex dielectric layer

To prepare the dielectric layer, 1 g Ecoflex component A and 1 g Ecoflex component B were mixed in a small plastic cup, and degassed by pumping for 2min. The substrate was dip coated in Ecoflex precursor, and spun at 600r/min for 20s and 8000r/min for 40s. The dielectric layers of the electrode were cured in the oven at 70 ˚C for 5min, and sandwithed between two conducting PU electrode to form the device. And the device was treated in the oven to complete curing (15min)

At this point, the electronic skin repeating unit is prepared, and the whole electronic skin preparation process is same as the said process.

5.6 Key problems in the process of preparation

The above process has realized the new electronic skin with the economical and simple way. In the process of manufacturing, the following problems will affect the success rate or device performance.

The substrate by casting polyurethane elastomer made of liquid components after mixing gas in addition to the time should be controlled within 5min, otherwise it will lead to casting liquid components not being able to flow; with alcohol cleaning can not polyurethane substrate, because solid polyurethane in alcohol contraction, due to the uneven shrinkage of the substrate surface two rolled up. We can use deionized water to clean; general polyurethane and silk effect is not strong, can be easily torn off from silk, if there are difficulties in this step, silk surface before coating a layer of polyurethane release agent; surface micro structure processing can also be used for processing silk lotus leaf, taking into account the bulk substrate and the limited area of lotus leaf that has made the current selection.

The electrode is composed of a set of silver nanowires, and the spraying method is adopted. Because the solvent is easy to evaporate, the solvent is sprayed onto the surface and the solvent is immediately evaporated, leaving a small liquid drop in the solution of the silver nanowires. Spraying liquid injection rate cannot be too fast, or solvent for a moment cannot be evaporated, poly into droplets, resulting in the silver nanowire into a lump, is not conducive to the conductivity of the electrode and the sensitivity of electronic skin. After the solution needs to be tested, the resistance at both ends of the strip electrode should be tested, and no more than 100. When the coating is finished, the silver nano wire can be dispersed better with the heavy load, and the accumulation of the silver wire can be prevented. Thin copper foil used for signal extraction, to minimize the impact on the area, measurement devices can be ignored.

The dielectric layer is made of Ecoflex plastic. The parameters are selected according to the results of section third. Need to pay attention to the first time the curing time must be moderate. When the time is too short, the upper and lower electrodes of the upper and lower electrodes are short circuit, which leads to the lamination unsuccessful.

6. Test and error analysis

Based on the third and 4 sections of the optimal design and the fifth section of the preparation method, a new type of electronic skin repeating unit was prepared and tested. The length of the experiment, the repeat unit is enlarged to four times, the 32mm side, to verify the new electronic skin of normal pressure and shear force response ability and the uncertainty analysis.

6.1 Test apparatus and program

For the capacitor using a direct measurement method, we used the E4980A LCR Agilent table connected to the computer for real-time data recording. The output capacitance value fluctuates within a certain range, the measurement is set in the program, and the average value of the output capacitance value of ten consecutive time points is taken as the output value of the specified time point in the time interval of 0.1s.

For the indirect measurement method of the pressure, we used Mark-10's M5-5 models of real-time pressure sensor with Z axis measuring interface to the mobile device group is the total pressure, as shown in Figure 6.1, in accordance with the calculated pressure repeating unit area.

The shear force was measured by an indirect method, using the same set of devices to measure the total shear force, according to the area of the repeating unit.

Figure 6.1 LCR type E4980A table (left) and test device group (right)

6.2 Test results and analysis of positive pressure

The data obtained from the experiment are shown in table 6-1, scattered points and fitting curves are shown in Figure 6.2.

Table 6-1 Positive pressure and capacitance test data

Pressure （kPa）	0	0.5	2.5	5	7.5
Capcitance （pF）	44.833	73.619	99.312	116.414	134.546
Pressure （kPa）	10	12.5	15	17.5	20
Capacitance （pF）	142.907	154.749	164.355	174.307	183.299

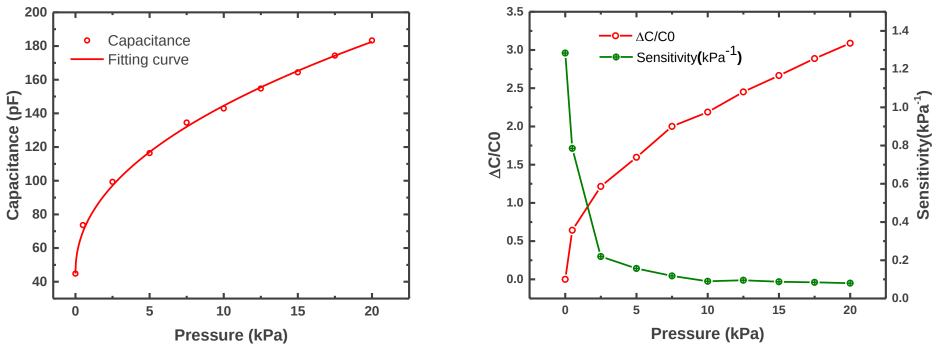

Figure 6.2 Positive pressure test points and fitting curves

By calculation, the new electronic skin has a sensitivity of 1.280 kPa-1 at 500Pa under pressure, with the sensitivity of 0.486kPa-1 at 2.5kPa under pressure, also has the sensitivity of 0.178 kPa-1 at 15kPa below the pressure higher than the use of electronic skin PDMS substrate and CNT most of the traditional electrode.

Using the data in table 6-4 for the uncertainty analysis, the maximum linear error of the new electronic skin pressure measurement is 4.7%.

6.3 Test results and analysis of shear force

The data obtained from the experiment are shown in table 6-2, scattered points and fitting curves are shown in Figure 6.3.

Table 6-2 Test data of shear force and capacitance change rate under different positive pressure

PX \ PZ	5（KPa）	10（KPa）	15（KPa）	20（KPa）
10（KPa）	0.056	0.054	0.047	0.051
20（KPa）	0.116	0.112	0.103	0.106
30（KPa）	0.170	0.168	0.162	0.154
40（KPa）	0.233	0.225	0.218	0.215
50（KPa）	0.283	0.277	0.267	0.256
60（KPa）	0.337	0.328	0.312	0.299

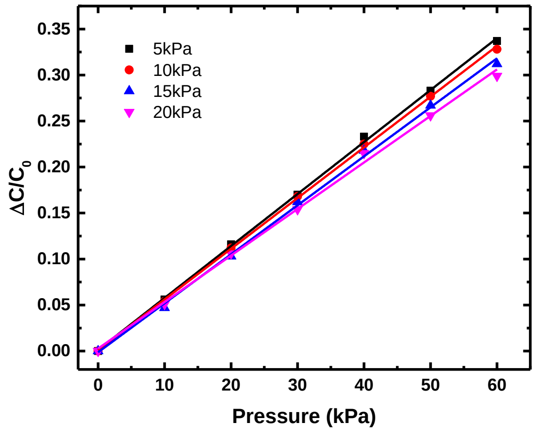

Figure 6.3 Scattered points and fitting curves of shear force test

After calculation, the new electronic skin at 60kPa shear force has sensitivity as0.006kPa-1, positive pressure is greater than 20kPa when the shear force also has 0.005 kPa-1 sensitivity, the response level still needs to be improved.

The linear error data obtained from the tests are small, the maximum linear error is 2.5%, but the positive pressure exceeds 25kPa, the data curve deviated from the linear, so that the accurate measurement of shear force to ensure positive pressure within 25kPa.

6.4 Determination and analysis of measuring range

The positive pressure range of the output capacitance value can be more sensitive than the positive pressure change when the new electronic skin positive pressure measurement range is approximately equal to the positive pressure. In the experiment, through the heavy weight test, the electronic skin can be sensitive to the positive pressure of 0-150kPa. The device will not be damaged beyond this range, but the capacitance value changing with pressure is not obvious.

The shear force measurement range is approximately equal to the electronic skin can withstand the shear force range, the test of electronic skin can withstand the shear force of 0-60kPa, the electronic skin will be damaged beyond this shearing force range.

The new electronic skin prepared by this experiment has a high level of response and the detecting range is small. The range of normal pressure and shear force can be effectively increased by increasing the thickness of the dielectric layer, but the response level will decrease. Therefore, the thickness of the dielectric layer should be determined by the required response level and range.

6.5 Uncertainty analysis of test results

Uncertainty is a concept that is widely used in mathematics and engineering, and it is the randomness, fuzziness and uncertainty when describing the characteristics of objects and processes. "Guide to Expression of Uncertainly of in Measurement, the definition of [22] GUM", the output capacitance measurement uncertainty is defined as the extent which can't be determined by the measured value. Its mathematical expression is:

$$\mu(C_m) = C_m - E(C)$$

The positive pressure and the shear force uncertainty are defined as the degree of the three-dimensional interface stress calculation value cannot be determined: $u(p_n) = p_n - E(p)$

Type: the M capacitance measurement uncertainty; uncertainty for the n pressure calculation for the m; capacitance measurement values; the calculated value of the n pressure; and respectively capacitance and pressure of the true value, namely mathematical expectation

The uncertainty of output capacitance value is analyzed first:

Uncertainty of LCR meter:

Measurement of the use of digital meters, the level of 0.05, the maximum allowed difference

$$\Delta = C * 0.05\% + 0.0004$$

Among them, C is the measured value, and the 0.0004 is the effective number. According to the triangular distribution, LCR meter brings the standard uncertainty:

$$u_B = \frac{\Delta}{\sqrt{6}} = 0.0002C + 0.0002 \tag{6.1}$$

According to the triangular distribution, the expanded uncertainty is:

$$u_B = k_p \cdot u_B = 1.064 u_B \tag{6.2}$$

Uncertainty of measurement:

$$u_A = \sqrt{\frac{\sum_{i=1}^{n}(C_i - \bar{C})^2}{n(n-1)}} = \frac{\sigma}{\sqrt{n}} \tag{6.3}$$

According to the data acquisition setting (continuous acquisition of ten capacitors), the number of measurements for the 10 time, check the table (p=0.683), the formula (6.3) is amended as:

$$u_A = t_p u_A = 1.06 u_A \tag{6.4}$$

Data into a positive pressure sensing group on the 134.443pF output capacitance 7.5kPa positive pressure as an example, the 10 results are shown in table 6-3.

Table 6-3 10 measurement of 7.5kPa positive pressure output capacitance data

No.	1	2	3	4	5
Capacitance(pF)	134.430	134.451	134.448	134.443	134.431
No.	6	7	8	9	10
Capacitance(pF)	134.441	134.452	134.455	134.442	134.437

Standard deviation and expanded uncertainty (unit pF) calculated by the formula (6.2) and (6.4):

$$\sigma = 0.0082 \qquad u_A = 0.0029 \qquad u_B = 0.0293 \tag{6.5}$$

The degree of uncertainty is satisfied: the other group data is the same as this group, so it is ignored:

$$u_C \approx u_B = 0.0293 \tag{6.6}$$

The following shows the analysis of the uncertainty of the pressure.

The measured total pressure applied on the surface of F, the measured length of pressure sensing area modeling was a:

$$p = f(F, a) = \frac{F}{a^2} \tag{6.7}$$

The uncertainty of total pressure measurement is calculated as follows:

Measured using a digital dynamometer, the relative allowable error, according to the normal distribution, the standard of the force measurement device to bring the relative uncertainty of:

$$u_{Brel} = \frac{\Delta_{rel}}{3} = \frac{0.1\%}{3} = 0.033\% \tag{6.8}$$

According to the normal distribution, =1, P=0.683, the extended uncertainty:

$$u_C = u_B \tag{6.9}$$

In order to get the P=7.5kPa F=0.48N for example, substituting the data:

$$u_C(F) = u_{Brel} \cdot F = 0.001 \tag{6.10}$$

Expressed as:

$$F = 0.48 \pm 0.001N \tag{6.11}$$

The length of the measurement uncertainty is calculated as follows:

When measuring using vernier caliper, the maximum permissible error, according to the uniform distribution, the vernier caliper standard uncertainty is:

$$u_B = \frac{0.02}{\sqrt{3}} = 0.012mm \tag{6.12}$$

According to the uniform distribution, the expanded uncertainty is:

$$u_C = 1.183u_B = 0.014mm \tag{6.13}$$

Expressed as:

$$a = 8.00 \pm 0.01 \tag{6.14}$$

Positive pressure is calculated by the formula (6.7) and (6.10):

According to the mathematical model of the pressure (6.5):

$$p = \frac{0.48N}{(8mm)^2} = 7.5kPa \tag{6.15}$$

Uncertainty of calculation for pressure measurement:

$$u(p) = \sqrt{\left(\frac{1}{F}\right)^2 \cdot u_c^{\,2}(F) + (\frac{2}{a})^2 \cdot u_c^{\,2}(a)} = 0.0044 \tag{6.16}$$

Expression as:

$$p = \bar{p} \cdot (1 \pm u(p)) \tag{6.17}$$

Table 6-4 The pressure test data with the consideration of uncertainty

Pressure(kPa)	0	0.5 ± 0.002	2.5 ± 0.011	5 ± 0.022	7.5 ± 0.033
Capcitance(pF)	44.833 ± 0.009	73.619 ± 0.015	99.312 ± 0.021	116.414 ± 0.025	134.546 ± 0.029
Pressure(kPa)	10 ± 0.044	12.5 ± 0.055	15 ± 0.066	17.5 ± 0.077	20 ± 0.088
Capcitance(pF)	142.907 ± 0.031	154.749 ± 0.033	164.355 ± 0.035	174.307 ± 0.038	183.299 ± 0.043

The above analysis, the output capacitance of the relative expanded uncertainty of =0.0293%, measuring the pressure of the relative expanded uncertainty of =0.44% was generally reasonable, reflected in test system with high reliability.

7. Innovation

The aim of this paper is to design a flexible, transparent, highly sensitive electronic skin device. Using a high aspect silver nanowire layer as the conductive material, and a polyurethane as a flexible substrate with a strong adhesion to the silver nanowire, a flexible transparent electrode is formed. In the device design, we used the micro structure of the silk, grinding glass and lotus leaf as the electrode substrate, which can effectively improve the sensitivity of the device. The main innovation of this paper is presented as following:

1) High quality silver nanowires with high aspect ratio were used as the electrode material of electronic skin. And a spray coating method was used to coat the silver nano wires layer on the

substrated, which forms a conductive network and has high conductivity;

2) Polyurethane was used as flexible transparent substrate. Due to the strong adhesion between the polyurethane and the silver nanowire, the electrode is transparent, flexible and robust;

3) Easy access materials, such as silk, matte glass and lotus leaf, were used to microstructure the electrode surface, which effectively improve the sensitivity of electronic skin devices.

8. Conclusion and Prospect

8.1 Conclusion

The development and application of new materials is one of the important directions of the development of science and technology in 21st Century. New material research is to understand relationship of the nature of the material and the application deeper. In recent years, biomechanics and medical engineering, as a new multidiscipline subject, have caused wide and deep research in the world. Electronic skin is a new research hotspot in the fields of biomechanics and medical engineering. In this paper, a new type of electronic skin for pressure sensing is introduced, which is compared and used in a variety of new materials. The electronic skin can measure the 3D interface stress distribution in real time and has the advantages of high flexibility, high transparency, high response level and high mechanical strength. Are summarized as follows:

In order to measure the three-dimensional interface stress (including vertical and interface Z to the normal pressure and tangential to the X interface and Y to the shear force and shear force), design a new type of electronic skin, the skin is based on the principle of electronic plate capacitor, applied with the local electrode width changes, real-time measurement of three-dimensional interface stress distribution. The working mechanism of the measurement of the positive pressure and the change of the overlap area of the plate with the change of the distance between the plate and the plate is derived and proved.

In order to improve the performance of the new electronic skin, optimization scheme proposed and confirmed in many aspects: because the interaction of substrate, electrode and dielectric layer material, the electronic skin has a very high level of response in the low pressure region; the substrate, electrode and dielectric layer used in this work are transparent and flexible material, so the electronic skin also has transparency flexible, extensible and high strength properties; the preparation process is simple, which show the advantages of low cost, and fully meet the requirements of electronic skin and touch screen application. The method to optimizing the protective properties of electronic skin is studied from the aspect of the micropatterning the substrate, and highly sensitive devices were obtained.

In order to ensure the applicability of the new electronic skin, the precise performance of the electronic skin is important. The experiments were carried out to verify the experimental results and the uncertainty analysis was carried out. The test results show that the electronic skin can shear force measurement in the range of 0-150 kPa and 0-60 kPa positive pressure range, sensitivity to smaller stress were 1.280 kPa-1 and 0.006 kPa-1, and the maximum linear error are 4.7% and 2.5%.

8.2 Prospect

Electronic skin, as a new research hotspot in the joint fields of physics, chemistry and material science, has been widely used in the fields of rehabilitation medicine, mechanical manufacturing, electronic equipment manufacturing and so on. Research on new electronic skin is still in its infancy, there are a lot of problems to be studied and resolved. To further improve its performance, so that it can simulate, restore or even replace the body skin, but also need to have a breakthrough in the field of chemistry. We need to quantitatively characterize the mechanical properties of self repair system in the follow-up study, study the DA reaction kinetics, and test the content of different pre polymer and DA bond, the pursuit of higher self healing efficiency.

At the same time, the design of the electronic skin output is the capacitance signal, how to synthesize the field effect transistor or thin film integrated circuit which can be integrated with the electrical signal output will constitute the next step in this paper.

In addition, how to enhance the dynamic response of the sensor array by changing the structure of the substrate and to solve the problem of the hysteresis effect will form the next step of the research content.

Finally, this paper designed the electronic skin can only measure the pressure, simulated the human skin tactile function, but does not have the function of simulating the skin of other senses. Therefore, the design has the ability to simultaneously measure the pressure, temperature and humidity and other functions of the intelligent electronic skin is our long-term research objectives.

9. Acknowledgment

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