

Principle and Application of Flexible Pressure Sensors

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Abstract—Flexible pressure sensors are widely used in many ways, including health care and machine sensors. Compared with the traditional flexible pressure sensor, flexible pressure sensor has quality is light, easy to carry and deformation degree higher advantages are modern science and technology advanced has broad prospects for the development of technology products. In recent years, Remarkable progress has been made in the field of flexible pressure sensors. However, it is still a big challenge to realize the high resolution, high sensitivity, fast response, low-cost manufacturing and complex signal detection of flexible pressure sensors. This paper will introduce the mechanism of the flexible pressure sensor and improve the sensitivity by using the microstructure and the practical application. The research in this paper will have a very important value for the research and application of the flexible pressure sensor.

1 INTRODUCTION

Sensor is a tool used to detect and transmit information, using a certain order and mode, to transform the measured information into electrical signals or other signal output, to achieve information collection, delivery, testing, interpretation, performance and so on. The pressure sensor changes the non-internal pressure signal into other physical signals that can be detected (such as resistance, voltage, capacitance, etc.) to detect the change of absolute pressure or pressure. Pressure sensors have broad application prospects in tactile perception, fingerprint recognition, medical monitoring, human-computer interface, the Internet of things and other fields. General pressure sensors are basically composed of metals, materials with electrical conductivity between conductors and insulators at room temperature, and piezoelectric crystals, and most of these materials are hard.

Although the method of using these materials to prepare pressure sensors has been very successful, the pressure value can be measured accurately within a large standard, but due to the progress of science and technology and the enhancement of human demand, we can see its shortcomings more and more. For example, the weight of the device is too large, the volume is too large, and the deformation ability is too weak.

These bad aspects make it difficult to use them in scenarios such as flexible human-computer interaction, portable detection and intelligent robots. Flexibility and rigidity are relative concepts. Generally speaking, flexible materials are bendable and deformable. Among them, some soft, flexible materials also have the characteristics of low elastic modulus, good stretchability and good conformal ability. In the main performance

indicators of flexible pressure sensors, Not including flexibility, in the past few years, those who have done research have generally focused on agility, responsiveness, detection, stability, etc. However, as we delve deeper into flexible pressure sensors, the response range of pressure, stretchability, pressure resolution, and spatial resolution have become important parameters to evaluate performance in recent years. There have been many reviews on the principle, types, preparation materials, properties, and application fields of flexible pressure sensors in a very clear and systematic way.

However, in terms of performance, most research and review papers mainly focus on the device's sensitivity, linearity, response speed, stability, and tensile properties. However, the pressure response range, pressure resolution and spatial resolution are mentioned less. The research on these new performance metrics will be presented in this review. Flexible pressure sensor is widely used in many fields. For example, it can be used in electronic components that can be worn on the body to control human signals, such as heart beats and heartbeats that can be touched by the human body surface. At the same time, it is also an important component for the robot to have the ability of tactile perception. By strictly installing flexible pressure sensors on non-internal external surfaces of non-real limbs, we hope to restore physical touch sensation to people with physical disabilities. Sensors can also be combined with the clothes people wear on the body to monitor human health and movement signals anytime, anywhere, at any time, simplifying the process of use [1]. This paper will describe the mechanism introduction, the use of microstructure to improve sensitivity and practical application. The research of this paper will have a very important value for the research and using of flexible pressure sensors.

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2 THE BASIC SENSING MECHANISM OF THE FLEXIBLE PRESSURE SENSOR

According to the mechanism of action during this period, flexible pressure sensors can be divided into four types: 1) capacitive type, 2) resistive type, 3) piezoelectric type, 4) triboelectric type. These detection devices are usually composed of two layers of flexible electrodes and functional soft materials in the middle [1]. A capacitive pressure sensor comprises an electrode and a dielectric layer. It is a kind of parallel plate capacitor. A capacitive pressure sensor can detect static force. The common flexible capacitive pressure sensor has the advantages of less energy, small signal error and high repeatability of response. Dielectric layer is an important optimization object for capacitive pressure sensor to improve sensitivity and pressure response range. Because the soft material can not be compressed, if we do not use a new structure, the sensitivity of the device will be very low, so by forming a special microstructure, such as sphere, cylinder, cone, using another phase, using a very elastic material and using air gap, the accuracy of the capacitive pressure sensor can be improved [1]. Resistive pressure sensors convert pressure changes into changes in resistance or current. Resistive pressure sensors are generally composed of substrates and conductive materials. In order to obtain good flexibility and extensibility, the substrate will generally be an elastomer, conductive material in addition to a certain ability to conduct electricity. However, it also needs to be sensitive to pressure changes. Resistive and capacitive pressure sensors have similar design strategies.

For example, a very soft substrate or conductive layer with a tiny structure is used to achieve high precision. The micro-structures such as conical array, spherical array, cylindrical array and interlocking structure are used to improve the accuracy of the sensor. The piezoelectric pressure sensor can convert the external compression information into the physical quantity of information that measures the energy difference generated by the different electric potential of the unit charge in the electrostatic field. The principle of this sensor is the piezoelectric effect of the piezoelectric material. The most important parameter that refers to the piezoelectric properties of piezoelectric materials is called the piezoelectric constant, which represents the ability of piezoelectric materials to convert mechanical energy into electrical energy, or vice versa. Generally speaking, the larger the piezoelectric body, the better the piezoelectric performance. This kind of sensor can generate internal voltage under pressure. The magnitude of voltage is related to strain and has great potential in the field of passive pressure sensor [1]. The triboelectric pressure sensor appeared later than the first three sensors. Compared with the resistance-capacitance sensor, it does not need to provide power; the piezoelectric sensor can be selected from a wider range of materials.

The triboelectric pressure sensor adopts the triboelectric principle, which has the advantages of not too much money, low difficulty in manufacturing method and high output voltage. This sensor, which typically

consists of a first and second electrode and different materials in between, generates electricity by friction. There is a thin layer of gas in the space between the first and second layers of material. If we apply pressure, these two different materials with different orders of charge come closer to each other little by little, generating triboelectricity, generating electrically different charges on the first and second surfaces of the contact interface. When the force acting vertically on the surface of the object is released due to the extrusion between the objects, the separation of the two equal and opposite appearances does not require external interference, due to electrostatic induction, the compensation charge is generated on the electrode surface respectively. The air layer between the two surfaces of the material prevents the charges on the two surfaces from being completely neutralized, resulting in a potential difference. This mechanism enables the triboelectric pressure sensor to generate electrical signals when pressure is applied and released [1].

3 USING MICROSTRUCTURES TO IMPROVE SENSITIVITY

Many studies have shown that the flexible electrode layer or dielectric layer is one of the effective methods to improve the sensitivity of the flexible pressure sensor. There are many microstructures, such as pyramidal, wavy, cylindrical, bionic, and porous foam. Most of the microstructures are on the surface of the flexible matrix. Under pressure, deformation occurs, which is the change of the surface's dielectric layer constant/dielectric constant, causing the change of capacitance and realizing the perception and detection of the external pressure. In this paper, a micropyramidal structure is designed. The conductive material is printed, and the electrode layer is prepared by adding microstructures on the flexible substrate [2].

In a study by the Shandong University of Science and Technology, the performance of the double-layer microstructure electrode sensor was tested. The pressure sensor has high sensitivity and the advantages of dynamic response-ability to detect different pressures, fast response time and reliable repeatability. Firstly, weights of different masses were loaded on the sensor's surface, and the sensor's dynamic response at different pressure strengths (20 Pa, 100 Pa, 500 Pa, 1 kPa) was tested. The minimum detection pressure of this sensor is 20 Pa, which can quickly detect the dynamic response of different pressures. When the sensor is subjected to 20 Pa, the sensor's response time is 200 ms, and the response speed is relatively fast. Finally, the stable repeatability of the sensor was verified by repeatedly loading/unloading a force of 1 kPa 50 times [3].

The influence of the microstructure of silver nanowires electrode on the sensitivity of the flexible pressure sensor has been studied by the Beijing Institute of Printing and Technology. Usually, the scale of the skew rate of the special curved line of the transducer is used to show its spirit sensitivity. The characteristic curve of the sensor made by in-situ curing of

photographic paper has a higher slope, while the sensor is secured by pumping and filtration transfer. The characteristic curve of the sensor is gentle. It shows a great difference in the spirit sensitivity of the transducers constructed with two electrodes. When the pressure is less than 400Pa, the sensitivity of the sensor made by the in-situ curing method of photo paper is $S_{11}=0.651 \text{ kPa}^{-1}$, and when the pressure is more than 400 Pa, the sensitivity decreases to $S_{12}=0.33 \text{ kPa}^{-1}$. When the pressure is less than 80Pa, the transducer's spirit sensitivity prepared by extraction, filtration, transfer and reconsolidation method is $S_{21}=0.43 \text{ kPa}^{-1}$. When the pressure exceeds 80Pa, the sensitivity is $S_{22}=0.06 \text{ kPa}^{-1}$. The overall sensitivity of the flexible sensor made by in-situ curing is better than that of the sensor made by filtration transfer recurring [4].

In order to investigate the cause of the influence of the above two electrode fabrication methods on the spirit sensitivity of the device, the manifestation and comparison of the electrode micro-structure were performed. The surface roughness of the Ag nanowire electrode obtained by the extraction filtration, transfer and recementing method is smaller, about $0.4 \mu\text{m}$. The coarse-surface roughness of the photo paper template is $0.7\mu\text{m}$. Further, the microstructure of the electrode surface was observed by scanning electron microscope. The silver nanowires on the electrode surface prepared by extraction, filtration, transfer and reconsolidation were in more than one position inside Plasma Desorption Mass Spectrometry and relatively dense.

On the other hand, the silver nanowires on the electrode surface obtained by using the void type photographic paper as the template are mostly exposed to the outside of the PDMS. They are in a fluffy and porous state. The reasons for the differences in the electrode mentioned above morphology may come from: (1) The dense accumulation of silver nanowires brought by the negative pressure in the filter state, (2) The surface of the high light photographic paper has a porous and loose structure formed by nano-alumina coating. This porous structure induces the silver nanowires and PDMS to penetrate into the surface at different depths and at random. The silver nanowires are distributed on the surface of PDMS in a fluffy state [4].

4 PRACTICAL APPLICATIONS

We have seen the birth of the HP-150, the first touch-screen computer 40 years ago, and the rapid development of electronic materials in Smart is a portable phone terminal that can be used in a wide range. Smart refers to the instrument worn on the wrist to time and display time, intelligent equipment used to display images and colors or electrical appliances and other electronic products. Artificial intelligence has been very hot in recent years. In the process of realizing the interaction between intelligent machines capable of semi-autonomous or fully autonomous work and the space in which human beings live and various natural factors that can directly or indirectly affect human life and development, intelligent machines and human beings

capable of semi-autonomous or fully autonomous work, tactile perception is a topic of great importance that has to be solved. In addition, wearable and flexible pressure sensors used in the medical field to detect the arterial pulse, heartbeat, blood pressure and other human bodies that can be felt on the human surface will provide a faster and more efficient way for the examination and treatment of diseases. Although flexible pressure sensors are not yet used on a large scale, such devices will certainly change the way we live in the future [1].

Flexible sensor is made of flexible substrate materials with soft, easy deformation and low modulus characteristics, such as polyvinyl alcohol, polyester, polyimide, polynaphthalene dimethyl glycol ester, paper and textile materials, which are not easy to deformation, corrosion resistance and soft properties [5]. For flexible tactile sensors, it is required that the electrode and dielectric layer can be stretched [6]. The ultra-soft Ecoflex is a polymer with the same high tensile properties as human skin and is environmentally stable, making it suitable for use in electronic skin [7]. Many tactile receptors are distributed on the fingertips of human fingers, through which we can feel the shape, size, hardness, surface texture and roughness of objects. Pressure sensors are an integral part of machines' tactile sensing systems. Flexible devices can further make it safer and can stretch to a higher degree and apply to curved surfaces. Currently, most of the research on tactile perception focuses on the sensor's response to positive compressive stress. However, the force's direction is often random in the virtual environment. Our ability to feel forces from different directions (such as pressure and friction) and to judge the texture of surfaces stems from the intricate structure of our fingertips. Inspired by the structure of fingertips, Chen et al. used a mixture of carbon nanotube-polydimethylsiloxane to simulate the three-layer structure of fingertips to design the sensor. The outer double helix is an electrode and a friction nanogenerator. As an object slides across the surface of the device, electrons are transferred between the interfaces, generating an alternating voltage, and the spikes' frequency can reflect the object's roughness. The porous carbon nanotube-polydimethylsiloxane layered structure located on the innermost side can sense pressure changes, but the sensitivity of this device decreases rapidly after the pressure exceeds 1 N. Robots use sensors that can sense surface roughness, texture, grip, and loosen objects. Liang et al. attached 3×3 tactile sensor arrays to the surface of the robot's fingers and then touched the plates with different surface textures to generate a series of wave crest signals. By analyzing these crest signals and comparing them with the standard values, the recognition accuracy rate is up to 99% [1].

Li et al. used silver nanowires, graphene and polyamide nanofibers to form a nanonetwork structure. The Ag nanowires were uniformly dispersed in the polyamide nanofiber network to form a conductive path. Graphene acts as a bridge between silver nanowires. The pressure sensor has ultra-high sensitivity, can detect pressure up to 3.7 Pa, and operate normally in the pressure range of 75 kPa. It can be used to detect information such as the human pulse and the vibration of

vocal cords when speaking 450 μm) polydimethylsiloxane film and bulk polytetrafluoroethylene film combined with different heights of microstructure to ensure a certain sensitivity at the same time increase the pressure response range, porous, low density and high toughness of bulk polytetrafluoroethylene membrane to enhance its mechanical strength and toughness of the composite material. On this basis, the preparation of triboelectric type pressure sensor for sensitivity, in Signal response in the range of 0.1-60 kPa, with high stability and high signal-to-noise ratio (38 dB). These advantages enable it to meet various pulse, heartbeat and blood pressure monitoring requirements [1]. The proposed sensor consists of two soft electrode plates and a dielectric layer with an array of tilted microcolumns. The dielectric layer is tightly bonded to the electrode by attaching the dielectric microcolumn array tightly to the PDMS-coated counter electrode [8].

5 DISCUSSION

Cellulose nanofibers with interwoven network structure were prepared by electrospinning technology, and then cellulose/polypyrrole composite conductive nanofibers were constructed by in-situ surface polymerization technology. The cellulose paper-based cross-finger electrodes were combined with lightweight, Flexible and environmentally friendly cellulosic paper based flexible pressure sensor [9]. Flexible pressure can feel the measured information, and can feel the information, according to certain rules into electrical signals or other required forms of information output, in order to meet the requirements of information transmission, processing, storage, display, recording and control, etc. Equipment, mainly divided into capacitive pressure can feel the measured information, and can feel the information, Equipment, resistive pressure sensor, piezoelectric pressure sensor and frictional pressure sensor that is transformed into electrical signal or other required form of information output according to certain laws to meet the requirements of information transmission, processing, storage, display, recording and control. We can see that the capacitive force sensor that occurs on the contact surface of two objects usually consists of an electrode and a dielectric layer, belonging to the parallel plate capacitor. Resistive pressure sensors convert pressure changes into changes in resistance or a change in the amount of electricity that passes through any cross section of the conductor per unit of time. Piezoelectric pressure sensors convert pressure signals into voltage signals. The principle of this sensor comes from the piezoelectric effect of piezoelectric materials. In contrast to resistive and capacitive pressure sensors, triboelectric pressure sensors actually emerged later than the first three types of sensors. Compared to piezoelectric sensors, it can choose more materials. The triboelectric pressure sensor adopts the triboelectric principle and has the advantages of low cost, simple manufacturing method and high output voltage [1]. The sensitivity of the flexible pressure sensor can be positively influenced by

the microstructure of the silver nanowire electrode, which can be combined with polydimethylsiloxane into a tension-extender electrode by a simple, fast and low-cost fabrication method. Finally, a new type of capacitive flexible pressure sensor is prepared. The results show that the sensor's sensitivity is greatly influenced by the micro-shape of the silver nanowires on the electrode surface. When the silver nanowires on the electrode surface are random and loose, and the electrode roughness is relatively large, the spirit sensitivity of the sensor is high [4]. The dynamic durability of the sensors can be evaluated through the stable electrical functionality and mechanical integrity during its loading/unloading cycles [10]. However, at present, the technical difficulty of this technology is still relatively high, and further development is needed in the future. The flexible pressure sensor is widely used in medical devices, robot interaction and human body wear, and it still has a broad development prospect and research value in future development.

6 CONCLUSION

In this paper, the principle of a flexible pressure sensor adjusts the sensitivity and introduces the application scenario microstructure. Compared with the traditional pressure sensor, flexible pressure sensor has the advantages of being lightweight and deformable but also higher technical requirements. However, for now, the technology is not high enough, and the maturity of the flexible pressure sensor to complete the market is still some distance. In the future, the research of flexible pressure sensors is still an important topic, but its development prospect and market potential are still great. We can predict that in the future, flexible pressure sensors will be used more widely and bring more benefits to humankind.

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