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Research of flexible sensor based on nanomaterial

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Abstract. A flexible sensor is a sensor made of flexible materials, generally composed of three layers: base layer, sensing layer, and packaging layer, can be widely used in medical electronics, biological monitoring, wearable electronics and other fields. Compared with traditional electronic devices, flexible electronics have cheap substrates and can be attached to curved surfaces to achieve sensing functions, which attract researchers in different fields. In recent years, the development of nanotechnology and polymer materials has greatly promoted the innovation of flexible electronics. This paper focuses on the application of nanotechnology in flexible sensing. Through horizontal induction and analysis of nanotechnologies in polymer -based sensors, hydrogel sensors, self-powered sensors and other sensors, suggestions for continuous detection and clinical treatment of sensors are put forward vertically. Achieving the structure and intrinsic flexibility of the flexible sensor substrate, deposition of the micro-circuit onto the substrate, encapsulation without breaking the ductility condition, maximizing its conductive, thermal and mechanical response, self-powered, degradability and other properties that meet human needs are all the focus of the flexible electronics discussion. In this paper, the structure, response and drug delivery of the flexible sensor will be analyzed and discussed from the Angle of material.

Keywords: Flexible Sensor, Nano Materials, Polymer.

1. Introduction

To achieve flexibility, the substrate can be intrinsically flexible materials can be selected, such as the selection of insulating, high-elastic polymer, while controlling the polymer strain below the yield strain to achieve repeated bending, folding, twisting, stretching and other activities of the substrate. In recent years, with the development of field -effect theory, people realize sensing through the arrangement of transistor matrix [1]. Therefore, people are trying to realize the intrinsic flexibility of the semiconductor material, an important part of the transistor. The coupling of conjugated polymers and rubber materials at the nanoscale allows electrons to be transported in the polymer chain, achieving the function of semiconductors, and also improving the stretchability of the polymer material [1, 2]. Nano confinement effect gives conductive properties to polymer materials, so more organic intrinsic semiconductor materials are discovered [2]. For example, hydrogel network can realize the coupling of conductive gel particles by doping nanoparticles, crosslinkers, surfactants, etc., so as to achieve the improvement of sensing and mechanical properties [3]. In addition, the circuit matrix can be designed into a stretchable structure to achieve flexibility. For example, topological networks, wave structures, snake structures and other high strain structures are designed [4].

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Flexible sensors can be divided into electronic skin and implantable devices. Implantable sensing puts forward higher requirements for flexible substrates and electronic devices, such as degradability, biocompatibility, affinity, self-powered, continuous monitoring and other characteristics. Triboelectric nanogenerators can use the charge generated by friction to generate electricity, and at the nanoscale, tiny mechanical movements can also be used to generate energy [5]. In order to achieve the flexibility of the device in nature, a regular array can be etched on the polymer surface to generate electrical energy through sufficient friction on the polymer surface, while ITO film replaces traditional copper as the electrode, thus achieving a flexible triboelectric generator [5]. However, for electronic skin that fits on the surface of the skin, the requirements for material power need not be so harsh. The appearance of flexible solar cells meets the needs of people. By using liquid phase epitaxy method to deposit electrodes on flexible substrates, semiconductor array integration is realized [6]. At the same time, in order to meet the flexibility and avoid affecting conductive properties or response functions, conductive fillers such as carbon nanotubes need to be appropriately embedded and flexible composite materials that can respond to physiological signals such as humidity, biomarkers, and blood pressure are introduced, so as to improve the conductive performance and physiological signal response of the sensor. Therefore, in order to design the intrinsic flexible sensing materials, the composite of a variety of polymers and the embedding of nano materials are essential. At the same time, we hope that the sensor can realize the function of treatment while monitoring.

2. Tensile properties of nanocomposite flexible sensors

Tensile properties are an important characteristic of flexible devices, and improving tensile properties can effectively avoid mechanical damage to electronic devices and improve their stability. This problem can be effectively solved by embedding an extrinsic structure or endowing the material with intrinsic flexibility.

2.1. Nanocomposite flexible transistor

The active layer of a flexible electronic product is composed of an array of transistors. The polymer transistor array essentially realizes the stretchability of the circuit and device [1]. SEBS with high elasticity and corrosion resistance is used as the substrate, the stretchable dielectric connecting the semiconductor consists of a polymer formed by cross-linking the aside group and the CH group in the elastomer, and the electrode is composed of carbon nanotubes, and the semiconductors are made by crosslinking conjugated polymers with elastomers [1]. SEBS is a linear triblock copolymer that does not contain unsaturated double bonds and is a polymer with good stability. Flexible organic intrinsic semiconductors replace inorganic silicon with poor stretchability. At the same time, the nanoarray structure makes the material softer and improves the density of the device integration. The transistor structure is completed through the interconnection of flexible organic and inorganic materials, which improves the compatibility of the electronic skin with the human body.

2.2. The nano-electrolyte in humidity sensor

A flexible sensor based on the cell structure of metal-air redox reaction realizes the detection of self-powered systems and physiological signals. The metal in the anode steadily loses electrons, these electrons are transferred to the cathode, and the oxygen dissolved in the electrolyte gains electrons, creating an electric field. The conversion of chemical energy into electrical energy is relatively smooth and efficient [7]. When the graphene oxide arranged in the silk fibroin gel adsorbs water molecules, the ion migration ability is significantly improved, showing a good humidity response function [7]. The high-performance metal-air battery reduces the dependence on the power supply mechanism to generate energy from external stimuli and improves sensing stability. Among them, silk fibroin and lithium bromide gel containing graphene oxide sheets as electrolytes have good hygroscopic and hydrophilic properties, making the sensor sensitive to humidity and realizing stable and continuous detection of physiological signals such as breathing [7]. At the same time, a graphene sheet is a two-dimensional nanostructure composed of a single layer of carbon atoms in the form of a bee nest, with a large specific

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surface area and good carrier conductivity, and will be widely used in highly sensitive and low-power room temperature biochemical sensors.

2.3. *Wearable nano-tooth sensor*

Graphene biosensors can also be used for tooth surface analysis and the activity of biological components in the mouth. Integrating sensors on graphene sheets and applying resin to the surface of the sensors, it helps to analyze biofluids and can act as water-repellent. To design a tooth sensor that can treat cavities and monitor them, we can cross-link glass cement with graphene sheets to attach the sensor to the tooth. Glass cement is a ceramic material widely used in dentistry, which has three basic components, namely polymerized water-soluble acid, alkaline glass and water [8]. They are based on the reaction products of weak polymeric acid with glass powder with alkaline characteristics. Curing occurs in a concentrated aqueous solution, and the final structure contains a large amount of unreacted glass that acts as a filler and strengthens the solidified cement. GIC binds well to tooth enamel and releases fluoride. Therefore, GICs not only have a tooth remineralization effect, but also have an antibacterial effect and can be used as a repair material or substrate [8].

2.4. *Nanocomposite conductive hydrogel*

Conductive hydrogels, which have good conductivity and tensile properties, are also widely used in flexible sensors. A polyacrylamide/montmorillonite/carbon nanotube hydrogel was shown to have good environmental stability, and mechanical and electrical properties [3]. To improve the environmental tolerance of conductive hydrogels, organic solvents can be added to the hydrogel network. The formation of hydrogen bonds can reduce the evaporation and crystallization of water molecules in the gel system, and improve the stability of the sensor in extreme environments. In order to avoid the decrease of electrical conductivity, carbon nanotubes coated with montmorillonite can be embedded into the gel system, and the surface active agent can stably disperse the conductive nanomaterials in the gel network to reduce the decrease of electrical properties caused by the entanglement of carbon nanotubes [3]. At the same time, the conductive hydrogel has the advantage of small resistance change during stretching, which effectively improves the stability of the sensor.

2.5. *Nanostrain engineering*

Strain engineering can make traditional electronic components obtain extrinsic stretchability. Release energy through buckling or creasing of various geometric structures. For example, a wavy elastomer formed by the buckling of a single crystal-thin silicon strip can be reversibly stretched to release strain without causing damage [9]. In addition, snake-like elastomers that allow for biaxial strain can be used to interconnect island electronic components [10]. Strain engineering effectively uses classical electronic materials such as metals and oxides, and also designs composite materials of elastomers and microelectronics, effectively developing the direction of stretchable semiconductors. Nano-polymers with nano-confinement effects can form semiconductor networks [1,2]. Because of the large specific surface area of nano-polymer fibers, the carrier transfer efficiency can be accelerated. The non-covalent cross-linking between polymer chains makes the material essentially stretchable. For example, when the phenylurea and isophorone diurea part is connected to the PDMS, the weak hydrogen bond can be re-formed after being broken during strain, which improves the stretchability of the nano-polymer [11]. Meanwhile, the fracture and recombination of weak hydrogen bond can release strain energy, and strong hydrogen bond can enhance polymer elasticity.

3. High sensitivity response

Achieving highly sensitive responses and continuous detection of biological indicators is the key to the diagnosis and prevention of diseases. The close contact of the gel sensor with the skin reduces the interface impedance and allows sensitive measurement of biophysical signals. A GelMA/PEGDA-CNT-PDA composite gel was shown to have good electrical conductivity and tensibility, because CNTs improved the mechanical properties and electrical conductivity of the composite hydrogel network, and the active groups in the PDA prepolymer formed thiourea structure with the surface of biological tissue, which made the material exhibit good adhesion and improved the stability and continuity of detection. The introduction of conductive polymer can effectively reduce the impedance between the electrode and the tissue surface [4]. At the same time, the topological structure of the crosslinking molecule can be designed to greatly improve the locking degree of the crosslinking agent, so as to improve its conductivity and response [4].

4. Nanoactive layer in aquatic layer

Aquatic sensing has also become a subject of great concern. Underwater detection needs to overcome visual difficulties such as poor light and turbidity, while water-based electronic skin can rely on multi-modal sensor including touch, pressure, temperature, to obtain biological information in water, such as biomechanical analysis of aquatic organisms and biological information detection of underwater workers. In addition, the sensor still has to avoid electrochemical corrosion, short circuits and other problems, and design a suitable package to adapt to the water pressure. The multi-modal flexible ion sensing mechanism can improve the sensitivity of environmental monitoring of waterborne skin. The sensor consists of three main stacked layers, namely the top ion-active layer, the stretchable electrode layer and the spacer connection layer. The ionic active layer of the sensor is composed of polyacrylonitrile bound alumina nanoparticles. Such porous films have good flexibility and water molecule trapping properties, while being able to form ion concentrations for water-volt power generation and ion monitoring. Ion sensor is a sensor that can convert the perceived amount of ions into an available output signal, and has the characteristics of high sensitivity and high resolution [12].

5. Nanomateials in continuity detection

In implantable flexible sensors, achieving self-power or degradability can effectively avoid the risk of secondary surgical infection or non-surgical excision and achieve the goal of continuous detection. The triboelectric nanogenerator uses triboelectrification to convert mechanical energy into electrical energy and realize a sustainable energy supply [5]. The E-DNA sensor realizes the specific detection of biological signals through the specific combination of probe and target, and can be used repeatedly after washing sodium perchlorate electrolyte to meet the needs of continuous monitoring [12]. But at present, integrating a power supply with a consistent and stable output into the sensor is still the mainstream and major problem. Through the integration of stretchable design and radio systems, continuous operation of the skin can be maintained. However, it is still necessary to pay attention to problems such as explosion, overheating, and charging time.

Flexible solar cells have many substrates, low cost, good stretchability, good surface contact and so on. Now, a stretchable gallium arsenide solar cell is a promising candidate for self-powered sensing, and its structure mainly consists of InGaP sub-cells and GaAs sub-cells, buffer layers, and substrates. As a semiconductor material, gallium arsenide is an ideal solar cell material, which has a direct band gap and can absorb sunlight efficiently [6]. The preparation method for the battery is generally to grow the epitaxial layer of the battery on the substrate, and then corrode the substrate with corrosive liquid, and finally complete the transfer of the battery epitaxial layer and graphics. Substrate corrosion is a key step in the process, and the over-corrosion of the epitaxial layer and the folding of epitaxial film should be reduced during corrosion [6]. Thin-film batteries can effectively reduce the mass of the battery itself, and have high-temperature resistance and radiation resistance, which can be applied to the harsh conditions of the aerospace field.

Electronic skin with a self-healing function can also achieve the continuity of monitoring. Through the use of intermolecular hydrogen bonds, metal coordination, n-n orbital conjugations, electrostatic interactions and other natural repeatable bond cooperation, the material has an endogenous self-healing system. Bonds of different strengths can respond to strain multiple times. For example, the double hydrogen bond system can make the material obtain high toughness, and the strong hydrogen bond can effectively improve the mechanical properties of the material. The weak hydrogen bond allows the material to dissipate energy to obtain stretchability [11].

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6. The biocompatibility nanomaterial

Biocompatibility is a necessary characteristic of implantable electronic devices that can effectively reduce the pain of rejection in patients. However, electronic components with high conductivity and insulators with good biocompatibility are often difficult to combine in one material at the same time. A material is crosslinked by silver nanowires coated with an Au layer and SBS. The Au layer can effectively reduce the oxidation and leaching of silver nanowires, thus obtaining high electrical conductivity and biocompatibility. In addition, the gold nanonetwork can effectively reduce the contact area with the skin and increase the breathability to obtain good compatibility. Au is first evaporated into the PVA nano frame, and then the PVA nanonetwork is attached to the skin by spraying water, resulting in a highly responsive and compatible breathable electronic device [12]. The good compatibility of the metal film with the organic material is still a problem to be solved, and the metal film needs to be fixed to stabilize its resistance in different tensile states. The silver nanowire film can be sprayed on the cured PDMS and coated on the surface with PEDOT: PSS. This double-layer structure can effectively stabilize the resistance of the film and improve its mechanical properties. For the graphene sensor, the graphene composite material modified by silver nanoparticles can be embedded into the PDMS sponge, and the silver particles effectively improve the electrical conductivity of the material, so that the contact resistance of the graphene nanosheet is reduced, so as to produce a flexible sensor [13].

7. Multifunctional nanosensor

To realize treatment based on monitoring function is the development direction of flexible medical sensors in the future. The function of diagnosis and repair can be realized by introducing functional hydrogel wound dressing into the sensor. An intelligent antibacterial MXene hydrogel is composed of a network of nanosheets coated with antibacterial silver nanoparticles and a polymer network substrate. The supramolecular interaction and the dynamic cross-linking of groups in the polymer network make the hydrogel network system self-healing, injectable and wound-healing. Conductive biomaterials can stimulate cell proliferation and differentiation, thus promoting muscle tissue regeneration. Cross-linking degradable conductive polymers such as polyaniline with other polymers to form conductive scaffolds can accelerate wound healing while reducing the risk of infection in secondary surgery [14]. The gel sensors could also be used to prevent heart disease. By detecting muscle force associated with heart muscle contraction, myoelectric and biophysical signals are associated with heart rate.

8. Conclusion

The biggest advantage of flexible sensors is that they are flexible, so we can apply them to the surface of organisms or in the body to detect and transmit signals. In order to ensure flexibility, it is important to design the packaging structure and realize the flexible nature of the substrate material. In recent years, high molecular polymers are often used as flexible substrates for sensors because of their good tensile properties. The sensing layer is usually composed of an interconnect between hard electronic components and inorganic silicon bands. The flexibility of such a traditional circuit structure can be improved by strain engineering, but it is still limited by traditional hard electronic components. With the development of semiconductors, it was found that the problem of electron transport could be solved by integrating transistor matrices. Thus, the emergence of flexible transistors solves the problem of material characteristics. In general, most polymers are insulators, but there are some polymers that have their own channels for electron transport, such as conjugated polymers. Or, after doping with nanomaterials, its electrical properties are greatly improved. Even conjugated polymers with nanostructures have excellent properties of tensile and electrical conductivity, but also show high sensitivity to other signals. On the basis of achieving good flexibility, we still need to ensure the conductivity, responsiveness, degradability and other characteristics of the material itself. However, one material is often unable to satisfy both at the same time, and we need to design more advanced composite materials to ensure excellent performance. Triboelectric nanogenerators are a good idea, etching nanoarrays on polymer surfaces, generating electricity through friction, achieving continuous monitoring, and playing a huge role in implantable sensors. In wearable sensors, using a metal-air battery, chemical energy can be

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converted into electricity. If nanomaterials, such as graphene, are introduced into the electrolyte, their capture of signaling molecules can be enhanced. If electrolytes can be designed into nanostructures, such as nanoactive layers, the perception of signals such as ions or pressure at higher sensitivity can be achieved. In the future, flexible sensors can be combined with nanomicroneedles to achieve painless drug delivery, intelligent drug delivery and other therapeutic functions and real-time monitoring functions. Therefore, the introduction of nanomaterials is a shining point in the field of flexible sensors, meeting people's expectations for a good and healthy life.

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