Flexible Pressure Sensors and Their Applications

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Abstract. The application of flexible pressure sensor is a new type of pressure sensor based on new materials prepared by a nano process. It differs from conventional pressure sensors due to its good flexibility, free bending, small thickness, high sensitivity, and ease of mass production, and is particularly suited for measuring soft surface contact stress. It has several potential applications in smart homes, smart medicine, wearable gadgets, and other domains. The microstructure can not only increase the sensor's sensitivity, but it can also recover the sensor's elastic deformation more quickly, so it has a swift duty. The capacitive flexible pressure sensor will be introduced first, followed by the resistive pressure sensor, and then their practical applications will be discussed. This paper's research will contribute significantly to the study and implementation of flexible pressure sensors. It will contribute significantly to the study and application of flexible pressure sensors.

Keywords: Capacitive Sensor, Resistive Sensor, Flexible.

1. Introduction

As a unique electronic device, the flexible pressure sensor offers greater advantages than the rigid sensor in human-computer interface, medical health, robot touch, and other applications, but it has stricter material requirements [1]. For instance, the device's material must be thin and flexible, and in some circumstances, it must be able to fit on the surface of human skin or be implanted inside the body. In addition, the material must be biocompatible and mechanically compatible with the organic tissue. Flexible pressure sensors are intended mainly to enhance their sensitivity, response time, detection limit, stability, and other performance aspects. There are a variety of applications for flexible pressure sensors. In wearable electronic devices, it may be used to monitor the pulse, heart rate, and other physiological signals. Furthermore, it is crucial to the robot's capacity to detect touch [2]. It is hoped that flexible pressure sensors mounted to the surfaces of prosthetic limbs would restore the sensation of touch in those with physical limitations. Moreover, sensors may be embedded into clothing to monitor human health and activity signals in real-time while simplifying usage [3]. This study will first examine the capacitive flexible sensor (capacitive flexible pressure sensor is a device based on the principle of parallel plate capacitance, with high sensitivity, fast response, wide dynamic range, and other advantages). Second, the resistive flexible sensor is shown, which is an important branch of the flexible pressure sensor with a simple construction, high sensitivity, broad operating range, rapid response speed, and high stability. Finally, their practical applications are examined. This study analyzes current advances in flexible pressure sensor research, including the sensing principle, sensing performance, and prospective applications of flexible pressure sensors [4].

2. Capacitive flexible pressure sensor

Through voltage changes, capacitive force sensors can respond to external force changes. Flexible capacitive force sensors often employ carbon nanotubes, Ag nanowires, and conductive ionic materials for their electrodes. As dielectric layers, low-modulus elastic polymers such as polydimethylsiloxane (PDMS), Styrene-Ethylene-Butylene-Styrene (SEBS), and Ecoflex are excellent. The combination of capacitive sensors with field-effect transistors to enhance sensitivity is also a significant area of research. The source-drain current in field-effect transistors devices is exactly proportional to the gate dielectric capacitance. The usage of a microstructured PDMS film as a dielectric layer was reported by Schwartz et al.

This article illustrates the quick and straightforward construction of flexible capacitive pressures. The wearable electrical force sensor consists of a conductive fabric electrode and a microstructured silicon dielectric layer. This is accomplished by mixing solid sacrificial particles with silicone elastomers. When liquid is put into a 3D printing mold, a thin dielectric layer is produced (less than 1 mm thick). This article illustrates the quick and straightforward construction of flexible capacitive pressures. The wearable electrical force sensor consists of a conductive fabric electrode and a microstructured silicon dielectric layer. This is accomplished by mixing solid sacrificial particles with silicone elastomers. When liquid is put into a 3D printing mold, a thin dielectric layer is produced (less than 1 mm thick). The thin dielectric layer increases the sensor's baseline capacitance, making it readable. The robustness of the parasitic capacitance in the output circuit raises the signal-to-noise ratio. While the microstructure is moderate. The dielectric boosts sensitivity, while conductive fabric electrodes guarantee the grid's safe conduction. Using hot pressing and membrane-bonding technologies, collaterals can make durable and adaptable electrical connections. This is essential for real-world applications that demand secure, adaptable, and low-key connectivity. Gas also forms between the dielectric layer and the electrode layer due to the intrinsic structural features of conductive textiles. This gap works as an extra dielectric layer to boost sensitivity. To understand. The proposed sensor is used to several types of textiles, including knitwear and textiles. To fulfill the customization needs of the final application, it is crucial to consider the sensing mechanism's effect. Consequently, the article also investigates the soft pressure of various conductive fabrics (knitted and woven). The force sensor is affected by pressure sensitivity and is comprised of two distinct materials (sugar granule particles and salt crystals) to build micropores in a silicon elastomer dielectric layer in order to comprehend the pore size small, which also influences sensor performance [5].

A sensitive, flexible piezoresistive pressure sensor has been designed. Utilization of biomimicry-inspired porous materials A conventional piezoresistive pressure sensor consists of two diametrically opposed elastomer bottoms. A flexible piezoresistive pressure sensor with high sensitivity has been created. Utilization of biomimicry-inspired porous materials Traditional piezoresistive pressure sensors consist of two diametrically opposed elastomer bottoms. The bottom is coated with an active conducting electrode. Two elastomers, stimulated by external pressure. Contacts provide conductive paths, a mechanism that transfers pressure into resistance Change. Therefore, the performance of flexible piezoresistive pressure sensors is based on the pressure-dependent change of the conductive channel, which consists of conductive electrodes and elastomer substrates. Pressure sensors frequently incorporate mechanical pliability, compatibility, and optical qualities. This material's elastomer. To enhance the conductivity of the pressure sensor even further. Path alterations, PDMS have adopted numerous forms of surface microstructure, flexible pressure based on the bio-inspired and inexpensive Resistance pressure sensor. In imitation of the natural. Developing a porous structure using sugar as a template. This increases the permeability resistance. Therefore, the pressure sensor has great sensitivity and a low limit of detection [6].

3. Resistance-type flexible pressure sensor

Resistive pressure sensors translate changes in pressure to variations in resistance or current. Due to its simple sensing mechanism, simple structure and manufacturing technique, and low energy consumption, it is frequently used by researchers. As pressure rises, fibers come into closer contact, causing resistance to decrease. These sensors suffer from the disadvantages of signal drift and delay.

The phase separation of the composite's internal conductivity varies. As the second step, the conductive filler is applied to the polymer material with relatively poor conductivity. When the penetration threshold is attained, the conductive phase will form a conductive network, indicating a considerable reduction in resistance. The creation of a conductive network is governed by two fundamental concepts. The osmotic theory is the first. The present tunnel effect is the second effect. Design methodologies for resistive and capacitive pressure sensors are comparable. For example, a microstructured flexible substrate or conductive layer is applied for enhanced sensitivity. To increase

the sensitivity of sensors, microstructures such as apical array, spherical array, columnar array, and interlocking structure are used. Park et al. inserted carbon nanotubes into PDMS and using the template approach to create two layers of thin films with microsphere shapes on the top and bottom surfaces. The structure is interconnected. The resistance between the conductive fillers and the PDMS substrate reduces as the microsphere structure deforms and the contact area rises. Compared to traditional lithography, this method significantly simplifies the preparation process.

Emerging technology in the field of health monitors; these applications necessitate sensors Record human pulse pulses while fostering conformal attachment to a soft, curved surface and sensitivity sufficient to "feel" an irritation (such as the impact of a fly landing) (human skin). To achieve certain at low pressure (10 kPa), Highly sensitive, unconventional technologies such as microstructured PDMS in capacitors and triboelectric sensors, piezoelectric sensors in the pt coating Interlocking nanofibers, or electrospun poly (vinylidene difluoride) in piezoelectric sensors are utilized. Due to the small size of the pyramid, PDMS with miniature pyramid designs are shown at low pressure and show tremendous potential in this area. The form factor quantifies the effect of the elastomer's shape on its compressibility under external pressure; it is composed of compression. The area ratio is determined by the pyramid's apex relative to the total area that can be increased freely. Discharging surface (four triangular walls). Due to its high sensitivity at low pressures and rapid response time, it can noninvasively measure the primary parameters of the human pulse waveform. 0.2V detecting the device's working voltage is low enough to allow power to be supplied by an energy harvesting device, such as a friction generator. Motor, allowing for the incorporation of self-powered green hybrid devices into wearable applications [7].

For specific applications, there is an increasing demand for correctly engineered pressure sensors. Microstructured capacitive pressure sensors are commonly accessible. Through manipulation of dielectric layer materials and microstructure shape, demonstrated a high capacity to meet this need in terms of functionality and adaptability. Nonetheless, for sake of simplification. When designing and fabricating sensors, it is essential to comprehend how the microstructure of materials and the characteristics of dielectric layers affect performance. Set of predictive sensors. The ability to assess and track performance trends simplifies the design and production of sensors for several applications. The length of the base and the junction are determined by the dielectric constant and compression modulus of the dielectric material, respectively. Using a set of equations, starting capacitance, capacitance change, and sensitivity trends for infrastructure separation and dielectric layer microstructure height may be estimated based on experiments and calculations. The length of the base and the junction are determined by the dielectric constant and compression modulus of the dielectric material, respectively. Using a set of equations, starting capacitance, capacitance change, and sensitivity trends for infrastructure separation and dielectric layer microstructure height may be estimated based on experiments and calculations. The accuracy of the model is checked by computation.

The model is then used to elucidate subjectively and quantitatively the qualitative and quantitative link between the characteristics of these crucial materials and their microscopic geometry. Lastly, the model displays a high degree of adaptability and a straightforward implementation for predicting sensor performance in order to help fulfill the growing need for highly specialized sensors. A sensor's rational design is aided by its transparent microstructure. The effect of structural design and geometric differences on sensitivity has been emphasized. The majority are performed experimentally or through finite element modeling Nonetheless, basic computational modeling. It is possible to make comparisons that are more precise and performance forecasts that are more straightforward. Through the quantization of electricity, the interaction between the geometry of the medium, the intrinsic qualities of the material, and the performance of the sensor, custom pressure sensors can be built and even extended to interesting new application areas. A method for simulating the performance of microstructured sensors is proposed in order to facilitate the design of a capacitive pressure sensor sensitive enough for the intended application. The model's construction is intended to facilitate the comparison of five distinct variations in geometry and material attributes. Pattern design for

microstructures. In this study, the article is integrated with earlier experimental results and the pyramid structural model's finite element modeling. The dome structure and pyramid structure have been validated more thoroughly. A model of a multi-column structure. This method permits the prediction of a range of sensors. Designed sensor performance, including sensors made by other organizations. Future research will concentrate on applying this model and analysis to the construction of Special High-Efficiency Capacitive Pressure Sensors for certain applications [8].

4. Practical Applications

Utilizing single-wall carbon nanotubes (SWCNT), flexible silver inks, encapsulation ointment, and thin spacer fabrics, a technique for generating textile sensors is developed. In applications involving wearable devices, silver paste renders Sensors flexible, stretchy, and conductive. Moreover, the SWCNT layer will expedite the restoration of electrical conductivity throughout the working cycle. In addition, the encapsulation/PET yarn layer will ensure the functioning of the sensor. The consistency and resilience of a structure's elasticity amid considerable deformation. In addition, the characteristics of the sensor are analyzed in this research. This article also highlighted the use of this sensor to monitor finger motions in gloves. The research creates a monitoring adaptable nerve fuzzy network (ANF) to accelerate the convergence of intelligent textiles and machine learning algorithms. A capacitive pressure sensor-based spacer material that is very elastic and sensitive. In addition to a quick reaction time. Printing SWCNT/silver ink on the electrode layer yields excellent conductivity in order to strengthen its resistance to large deformation. To provide strong resistance, the dielectric is a network of PET fibers and encapsulating paste. In this article, intelligent textile gloves are recommended for sensitive applications. Using a mix of techniques, the phases of walking gait are analyzed with precision. These applications illustrate the feasibility of the sensors. To a variety of wearable applications in robot control and human motion recognition [9].

In the automotive industry, micro-electromechanical systems (MEMS)-based capacitive pressure sensors have made significant development; MEMS has also made significant strides. The automotive sector relies on capacitive pressure sensor technology. Emerging technologies based on flexible pressure/strain sensors are, however, a multifaceted development. Things such as tire inflation, exhaust, and airbags

For monitoring the deep-sea environment, this sensor has a freestanding, lightweight, low-cost, multi-sensor Marine skin compatible with complementary metal-oxide-semiconductor transistor (CMOS). When applied to diverse marine animals, the ocean skin can monitor the marine environment, including pressure, depth, temperature, and salinity.

Sensors and artificial skin for robots are largely used for tactile sensing, a critical and innovative research field. This article will investigate some essential approaches to this underdisciplined area of inquiry. In order to meet the projected demands of the most promising applications in the automation and medical sectors, the monitoring and management of excellent organization and control rely heavily on robotic electronic skin. For pressure monitoring, the researchers created smart e-skins that can be tagged/deployed/placed on flat surfaces [10].

5. Discussion

5.1. Advantages of capacitive flexible pressure sensor

The capacitance value of the sensor is generally unrelated to the electrode material and only depends on the electrode's geometric size, and the loss of air and other medium is very small, so if from the strength, temperature coefficient, and other mechanical characteristics of consideration, reasonable selection of materials and geometric size can be made, other factors (due to the minimal heating of the sensor itself) have little impact. The inductance sensor contains copper loss and eddy current loss, which induces its own heating and results in zero drift.

Capacitive sensors have a basic design and are easy to produce. It can function in high and low temperatures, intense radiation, and a strong magnetic field, as well as other hard environmental circumstances, has a high degree of adaptation, and can tolerate big temperature swings, high pressure, high impact, and other scenarios. In addition to measuring the difference between ultra-high and low pressure, it can also monitor magnetic fields on the workpiece. In addition, the sensor may be made diminutive to satisfy certain measurement needs.

Between the two plates of the capacitor sensor is an electrostatic field, therefore the electrostatic force or electrostatic moment acts on the plate. The strength of electrostatic attraction is proportional to the operating voltage, dielectric constant, and plate separation. This electrostatic attraction is relatively weak, so only the elastically sensitive element with a small driving force must be accounted for when calculating measurement error.

5.2. Disadvantages of capacitive flexible pressure sensor

The geometric size of the electrode, which is normally tens to hundreds of picofarads (pF), limits the capacitance of capacitive sensors, therefore the output impedance of the sensor is very high; when the AC power supply is utilized in the audio range, the output impedance is as high as 106 108. Therefore, the sensor's load capacity is inadequate, it is susceptible to external interference and instability phenomena, and it cannot function in extreme circumstances. Shielding measures must be implemented, which complicates the design and operation. High capacitive resistance also necessitates a very high resistance value of the sensor's insulation (more than tens of M). Otherwise, the insulating component will be employed as a bypass resistance and affect the sensor's performance (such as sensitivity reduction), therefore pay great attention to the effect of the surrounding environment, such as temperature and humidity, cleanliness, etc., on the insulation performance. Even though the high-frequency power supply can reduce the output impedance of the sensor, the amplification and transmission are significantly more complicated than with the low-frequency power supply, and the influence of parasitic capacitance is increased, making stable operation difficult to achieve.

The initial capacitance of the sensor is small, but the capacitance of the lead cable, the stray capacitance of the measurement circuit, the capacitance of the sensor plate, and the capacitance of the surrounding conductor are all large, reducing the sensitivity of the sensor. (2) These capacitors (such as cable capacitors) frequently undergo random fluctuations, rendering the sensor unstable and impacting measurement precision. The amount of change exceeds the observed capacitance change, hence rendering the sensor inoperable. Consequently, there exist specifications for the selection, installation, and connecting of cables.

Capacitance sensors with changing pole distance have nonlinear output characteristics, which can be enhanced by differential structure but cannot be abolished. Other types of capacitive sensors only exhibit linear output characteristics when the electric field's edge effect is disregarded. Otherwise, the additional capacitance generated by the edge effect will be overlaid directly with the capacitance of the sensor, resulting in nonlinear output characteristics.

5.3. Advantages of resistive flexible pressure sensor

(1) The approach is nonlinear and the output signal is weak, but there are ways to compensate for this. As a result, its application in automatic measurement and control technologies has been extensive.

(2) The strain effect of metal is exhibited by the resistance strain gauge in the resistance strain sensor. Thus, mechanical deformation happens under the influence of an external force, causing a corresponding change in the resistance value.

5.4. Disadvantages of resistive flexible pressure sensor

(1) Significant nonlinearity for high strain, but a weak output signal.

(2) As time and environment change, so will the material and device performance of the sensor. Due to the substantial time drift and temperature drift, it is unsuitable for long-term monitoring, since it may not be able to acquire accurate and reliable data if observed for an extended period.

(3) Highly susceptible to the effects of electric field, magnetic field, vibration, radiation, air pressure, sound pressure, air movement, etc.

6. Conclusions

A pressure sensor is an electronic device that monitors the force of contact between two surfaces. With the rapid advancement of science and technology, people's working environments tend to become more complex and diverse, and the flexibility, portability, and wearability requirements placed on electronic devices increase. Since conventional pressure sensors are predominantly comprised of inflexible semiconductor materials, it has been challenging to adapt them to the flexibility and convenience requirements of the next generation of sensors, thereby limiting their applicability. The flexible pressure sensor overcomes the traditional pressure sensor's fragility and has the advantages of a compact size, light weight, low power consumption, simple integration, and durability to tough working circumstances. Health monitoring, electronic skin, biomedicine, wearable electronic devices, etc., are just a few of the many domains in which it has become a study focus point. With the development of a new generation of flexible materials and sensing technologies, the overall trend in the development of flexible pressure sensors is toward flexibility, portability, sensitivity, stability, responsiveness, and cheap cost.

The fundamental operating principle of a resistance sensor is to convert the observed change into a change in the sensor's resistance value. Strain-type and piezoresistive-type sensors dominate the classification of flexible resistance sensors. The strain-type sensor measures strain primarily through the stretching of an elastic conductor. When pressure is applied, the conductor's conductive channel changes, causing a change in resistance value.

By applying tension or pressure to change the capacitance value of the change, usually for the variable pole distance type, through the distance between the plate caused by the change of capacitance, usually choose high elastic dielectric layer or the dielectric layer is designed into a microstructure, so it has very good elasticity and recovery ability, thereby increasing the sensitivity of the sensor. The key to achieving capacitive sensors is the production of flexible electrode materials. Carbon nanotubes and silver nanowires may be utilized to generate stretchable, high-performance conductors.

References

[1] HUANG Y, FAN X, CHEN S, et al. Emerging Technologies of Flexible Pressure Sensors: Materials, Modeling, Devices, and Manufacturing [J/OL]. Advanced Functional Materials, 2019, 29(12): 1808509. https://doi.org/10.1002/adfm.201808509.

[2] LI R, ZHOU Q, BI Y, et al. Research progress of flexible capacitive pressure sensor for sensitivity enhancement approaches [J/OL]. Sensors and Actuators A: Physical, 2021, 321: 112425. https://doi.org/10.1016/j.sna.2020.112425.

[3] RUTH S R A, BEKER L, TRAN H, et al. Rational Design of Capacitive Pressure Sensors Based on Pyramidal Microstructures for Specialized Monitoring of Biosignals[J/OL]. Advanced Functional Materials, 2020, 30(29): 1903100. https://doi.org/10.1002/adfm.201903100.

[4] MISHRA R B, EL‐ATAB N, HUSSAIN A M, et al. Recent Progress on Flexible Capacitive Pressure Sensors: From Design and Materials to Applications[J/OL]. Advanced Materials Technologies, 2021, 6(4): 2001023. https://doi.org/10.1002/admt.202001023.

[5] RUTH S R A, BAO Z. Designing Tunable Capacitive Pressure Sensors Based on Material Properties and Microstructure Geometry [J/OL]. ACS Applied Materials & Interfaces, 2020, 12(52): 58301-58316. https://doi.org/10.1021/acsami.0c19196.

[6] ATALAY O, ATALAY A, GAFFORD J, et al. A Highly Sensitive Capacitive‐Based Soft Pressure Sensor Based on a Conductive Fabric and a Microporous Dielectric Layer[J/OL]. Advanced Materials Technologies, 2018, 3(1): 1700237. https://doi.org/10.1002/admt.201700237.

[7] RUTH S R A, BAO Z. Designing Tunable Capacitive Pressure Sensors Based on Material Properties and Microstructure Geometry [J/OL]. ACS Applied Materials & Interfaces, 2020, 12(52): 58301-58316. https://doi.org/10.1021/acsami.0c19196.

[8] ZHAO T, LI T, CHEN L, et al. Highly Sensitive Flexible Piezoresistive Pressure Sensor Developed Using Biomimetically Textured Porous Materials [J/OL]. ACS Applied Materials & Interfaces, 2019, 11(32): 29466-29473. https://doi.org/10.1021/acsami.9b09265.

[9] YAGHOOBI A, ABIRI R, ALVANDI A, et al. A novel and highly selective aptamer-based sandwich-type biosensor assisted by second-order calibration methods for efficient biosensing of Streptococcus pneumoniae[J/OL]. Sensors International, 2022, 3: 100203. https://doi.org/10.1016/j.sintl.2022.100203.

[10] VU C C, KIM J. Highly elastic capacitive pressure sensor based on smart textiles for full-range human motion monitoring [J/OL]. Sensors and Actuators A: Physical, 2020, 314: 112029. https://doi.org/10.1016/j.sna.2020.112029.