# Research Progress of Pressure Sensors: Structure, Principle, Application

Erli Zhang[a]
*School of Mechanical and Electrical Engineering, Guangdong University of Technology, Guangzhou, Guangdong Province, 510000, China*

Keywords: Piezoelectric Pressure Sensor, Capacitive Pressure Sensor, Piezoresistive Pressure Sensors.

Abstract: With the advancement of technology, the application of pressure sensors has gradually become more widespread. Flexible pressure sensors have attracted people's attention because they can adapt to more complex and changeable characteristics. The article reviews the structure, principle and application of piezoelectric pressure sensors, capacitive pressure sensors and piezoresistive pressure sensors, and the article provides researchers with relevant research materials for developing and improving flexible pressure sensors. In addition, this article briefly discusses the development challenges that will be faced in the transition from traditional rigid sensors to flexible pressure sensors in terms of future applications of pressure sensors. For example, materials will be selected based on the application environment and accuracy requirements of future sensors. The popularization and application of flexible sensors is bound to be the general trend. Therefore, studying novel flexible pressure sensors sensing mechanisms and finding new multifunctional materials to meet more application needs are major issues and challenges for future research.



## 1 INTRODUCTION

With the rapid innovation of the Internet of Things (IoT), artificial intelligence (AI), and the continuous development of the concept of intelligent manufacturing (Duan et al,2022). Pressure sensors are gradually being widely used in many fields. At the same time, with the diversification of application fields, the types of pressure sensors are gradually increasing to suit different tasks. Since traditional rigid pressure sensors cannot be applied to more complex environments, flexible sensors have become an important research field in recent years. Flexible sensors can be stretched, compressed, and folded, allowing them to change into different shapes to fit onto irregular surfaces, greatly expanding their application areas (Liu et al,2023).

Although flexible pressure sensors have made a lot of progress and development, they still face many challenges. One of the challenges is that as the pressure increases and exceeds a certain limit, the sensitivity of the flexible pressure sensor decreases. Under high pressure, the sensor material will affect sensitivity due to hyperelasticity and boundary limitations. In order to solve the problems are mentioned above, researchers need to constantly optimize the micro-geometry of the sensor and the elasticity, dielectric properties and other properties of the material (Yuan et al,2024).

The article will list the structure, principle and application of piezoelectric pressure sensors, capacitive pressure sensors and piezoresistive pressure sensors. Meanwhile, this article can provide research data and give some optimization suggestions for future pressure sensors for researchers who study pressure sensors mentioned above.

## 2 THE STRUCTURE, PRINCIPLE AND APPLICATION OF PRESSURE SENSORS

### 2.1 Piezoelectric Pressure Sensor

Piezoelectric sensors are composed of piezoelectric materials, and they are active sensors that do not need external energy to obtain output signals (Gautschi,

[a] https://orcid.org/0009-0001-6999-3990



Zhang, E.
Research Progress of Pressure Sensors: Structure, Principle, Application.
DOI: 10.5220/0014320700004718

In *Proceedings of the 2nd International Conference on Engineering Management, Information Technology and Intelligence (EMITI 2025)*, pages 79-83
ISBN: 978-989-758-792-4

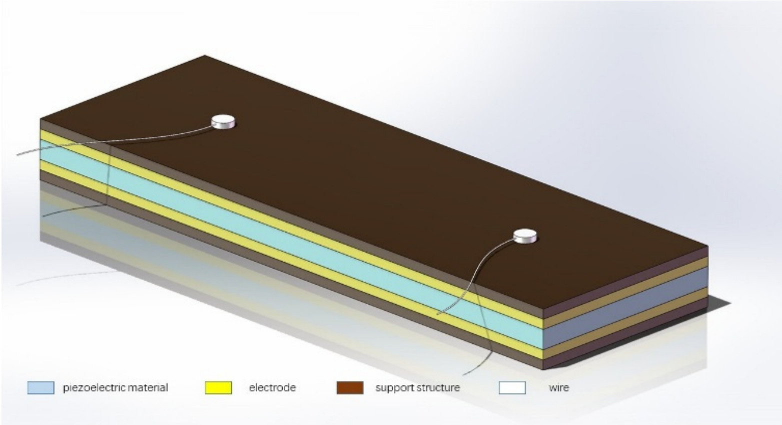


Figure 1: Piezoelectric pressure sensor device structure (Picture credit : Original).

2002). Flexible piezoelectric pressure sensors usually consist of four parts: piezoelectric material, electrode, support structure, and wire, as shown in Figure 1. The piezoelectric effect produced by piezoelectric materials is the working basis of piezoelectric sensors. Electrodes are the medium through which the sensor transfers charge. The support structure is the packaging protection structure of the sensor. It has a suitable Young's modulus and can provide a flexible environment. In addition, the support structure is usually made of some polymers, such as polyimide (PI), polydimethylsiloxane (PDMS), polyethylene terephthalate (PET), etc. Therefore, the supporting structure usually has the characteristics of insulation, stretchability and corrosion resistance, which makes the packaging structure better protect other components in the sensor. The wire is used to connect the piezoelectric pressure sensor to external instruments and transmit electrical signals (Ma,2024). Due to their exceptional stretchability and other characteristics that extend their service life, flexible piezoelectric pressure sensors are frequently utilized.

The working principle of the piezoelectric pressure sensor is the piezoelectric effect. The piezoelectric effect is that when a piezoelectric material is subjected to external pressure, alternating charges are generated on the surfaces of both ends of the piezoelectric material, thereby forming a voltage at both ends of the piezoelectric material (Wang et al, 2010). The voltage signal generated by the piezoelectric material will be exported by the electrode, and will be amplified, filtered, and processed by the signal conditioning circuit and transformed into a standard electrical signal output. The processed standard electrical signal is proportional to the externally applied pressure, so the pressure can be calculated by measuring the size of the standard electrical signal.

Piezoelectric pressure sensors have wide frequency and high dynamic performance, so they have significant advantages in measuring transient dynamic parameters (Tan et al,2006). The values that show how the system reacts and evolves in response to quickly shifting external stimuli are known as transient dynamic parameters. The parameter is very important when used to analyze and design the dynamic performance of the system to guarantee that the system is able to react steadily and quickly under transient conditions. Piezoelectric pressure sensors also have the characteristics of good stability. Because of the relatively stable nature of the piezoelectric effect of its working principle, it has a strong ability to resist external interference. Therefore, piezoelectric pressure sensors are usually used in long-term monitoring of the environment or the automation field. Stable data results can be obtained without frequent recalibration of the sensor. Furthermore, piezoelectric pressure sensors have a long service life because they use a design mechanism without moving parts, which greatly reduces the negative effects of mechanical wear or component fatigue. In some industrial environments and aerospace fields, piezoelectric pressure sensors have become their first choice due to the harsh application environment of sensors and the inability to frequently replace sensors. In addition, piezoelectric pressure sensors are universally utilized in mechanical mechanisms of industrial production and even in medical equipment such as ventilators.

## 2.2 Capacitive Pressure Sensor

Capacitive pressure sensors are typically consist of a dielectric layer and parallel plates with electrodes on both ends of the dielectric layer. Usually one of the two parallel plates will be fixed, and the other parallel

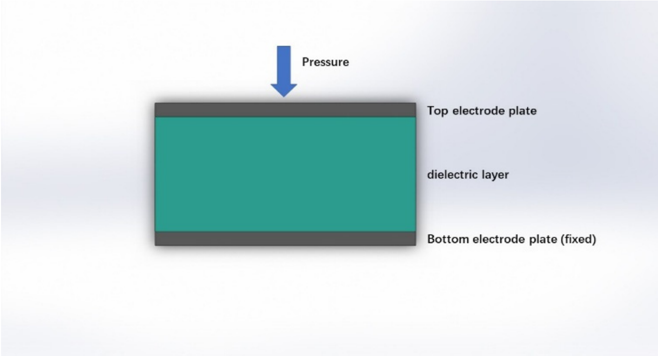


Figure 2: Capacitive pressure sensor device structure (Picture credit: Original).

plate will have the ability of mechanical sensing, as shown in Figure 2 (Mishra et al,2021). In the production and manufacturing of traditional capacitive pressure sensors, metal materials such as copper and silver are often selected as the manufacturing materials of electrodes. The electrodes of the flexible capacitive pressure sensor are required for good conformability so that the flexible sensor can bend, stretch and have other properties (Mishra et al,2021). With the advancement of science, it has become easier to manufacture electrodes that meet the performance requirements of soft sensors. Electrodes made of carbon nanotubes (CNTs) are flexible, stretchable and transparent (Mishra et al,2021). In addition, the electrode material can also choose some composite materials to satisfy the diverse needs of applications in practice.

The capacitive pressure sensor can be regarded as a parallel plate capacitor, and the data of sensor's detection is reflected by the capacitance change of the parallel plate capacitor. The value of capacitance depends mainly on the relative distance between the two parallel electrode plates and the dielectric constant. The relative distance between the two parallel plates changes with the external pressure, and the two are inversely proportional. The dielectric constant is usually associated with the material in the dielectric layer and the temperature.

Capacitive pressure sensors have excellent sensitivity and can remain stable to changes in ambient temperature. Therefore, capacitive pressure sensors are often used in the medical field. In the last few years, cuff electrodes have been frequently utilized to monitor neural signals. However, the radius of the nerve is much larger than that of the cuff electrode, so the cuff electrode may cause excessive pressure on the nerve tissue. Therefore, an elliptical electrode with the ability to flatten the nerve trunk and increase the contact zone between the nerve trunk and the electrode was proposed. Therefore, the capacitive pressure sensor with elliptical electrodes can better detect the pressure between the nerve stem and the electrodes, thereby detecting people's nerve health (Chiang et al,2007). The application of capacitive pressure sensors in the medical field often requires changing the material, shape and other characteristics of the electrode according to the situation to cope with different environments. Capacitive pressure sensors can be integrated into most medical devices because they can be made very small. During surgical operations, piezoelectric pressure sensors are integrated into minimally invasive catheter surgeries to monitor patients' blood pressure and other conditions. In addition, capacitive pressure sensors are used in environments that are in direct contact with medical drugs, such as infusion pumps and ventilators, because of their strong corrosion resistance. Many features of capacitive pressure sensors can satisfy their use in the medical field, and the development of flexible capacitive pressure sensors can further expand their application range.

## 2.3 Piezoresistive Pressure Sensors

Piezoresistive resistors and diaphragms are the core parts of the piezoresistive pressure sensor structure (Tran et al,2018). The structure diagram of the traditional piezoresistive pressure sensor is shown in Figure 3. The most important step in the manufacture of piezoresistive pressure sensors is the design of the sensing diaphragm. The design area of a conventional square flat diaphragm is typically separated into two levels, with the upper layer being variable and the bottom layer being fixed, as seen in Figure 4. In addition, the edges of the diaphragm will be fixed. Because of this double-layer sensing diaphragm structure, the sensitivity and linearity can be improved (Tran et al,2018). When manufacturing piezoresistive pressure sensors, different structures and material choices will affect the sensitivity and

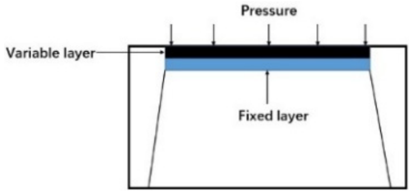


Figure 3: Piezoresistive pressure sensor device structure (Picture credit: Original).

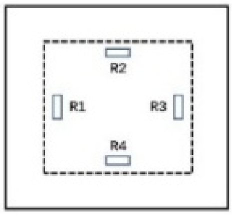


Figure 4: Traditional square flat diaphragm structure (Picture credit: Original).

linearity of the piezoresistive pressure sensors. A high-sensitivity pressure sensor with exceptional linearity in the 0–54 kPa range was predicted theoretically. It was constructed using a twin Wheatstone bridge architecture and a diaphragm that was 7 μm thick. In addition, a graphene-based resistive pressure sensor has a low linearity but a very high sensitivity across a broad pressure range (0~100 kPa) (Zhang et al,2018). Consequently, the performance of the piezoresistive pressure sensor is somewhat influenced by the choice of material and structure.

The working principle of piezoresistive pressure sensor is piezoresistive effect. The piezoresistive effect refers to the change in resistance when mechanical strain occurs due to external pressure (Meti et al,2016). When the piezoresistive pressure sensor is subjected to external pressure, the sensing diaphragm will deform and exert bending force on the piezoresistive resistors. For the varistor device, the piezoresistive action will cause the resistance value to fluctuate (Tran et al,2018). The piezoresistive effect of semiconductor materials is significant and has high sensitivity. Compared with semiconductor materials, the piezoresistive effect of metal materials is weaker, and it mainly causes changes in resistance through geometric deformation. The piezoresistive device connected to the upper diaphragm is connected in a Wheatstone bridge structure. An output voltage proportionate to the external pressure is produced from the resistance change brought on by the piezoresistive effect (Meti et al,2016). The method of applying an input voltage to a Wheatstone bridge structure and obtaining a linear output result has the characteristic of high sensitivity because small changes in resistance in the piezoresistive effect can be amplified.

Because of their high sensitivity, ease of preparation, and ability to provide linear signals, piezoresistive pressure sensors are widely used. Piezoresistive pressure sensors have been noticed by people due to their affordability and ease of preparation. Since the flexible electronic instruments are developing rapidly, the demand for piezoresistive pressure sensors with high sensitivity, long service life and wide data detection range is gradually increasing. Flexible electronic devices using piezoresistive pressure sensors can be used to detect a range of micro-movements such as heartbeat and breathing (Cao et al,2021). Detecting tiny movements requires very high sensitivity of the sensor, so the piezoresistive pressure sensor is suitable for this application, and its linearity characteristics can also clearly reflect the data of tiny changes. Driven by the rapid development of science and technology, electronic devices are gradually being integrated into the medical field. The possibility of using some piezoresistive graphene sensors with special sawtooth structures for invasive surgical procedures has been proposed (Szczerba,2022). For the application of piezoresistive pressure sensors in the medical field, the flexible sensor structure can better fit the patient's skin surface and better detect the patient's relevant data. Thus, the trend of future sensor advancement innovation will be the creation of flexible piezoresistive pressure sensors.

# 3 CONCLUSION

This article focuses on the structure, principle and application of piezoelectric pressure sensors, capacitive pressure sensors and piezoresistive pressure sensors. With the development and progress of technology, flexible mechanisms and pressure sensors are gradually integrated. Flexible pressure sensors have the characteristics of high sensitivity, long service life, and can be applied to more diversified environments. Therefore, the development of flexible pressure sensors has become the main trend of future sensor development.

There are several challenges in the way of the advancement of flexible sensors. The flexible structure of the flexible pressure sensor and the selected material often affect the final performance of the pressure sensor. Different application fields have different requirements for sensor accuracy and different application environments. Therefore, the application field needs to be considered when designing flexible mechanisms and finding new functional materials. In addition, the production and processing of sensors also need to keep up with the speed of technological development. Finding new sensing mechanisms is essential for future sensor development. The article suggests that in the future development of pressure sensors, attention should be paid to finding new pressure sensor sensing mechanisms. This can not only broaden the application range of sensors, but also provide options for applications that require higher accuracy, simpler preparation and lower cost. The advancement of pressure sensors should be associated with applications. Further research based on application requirements is a prerequisite for the advancement of pressure sensors.

# REFERENCES

Cao, M., Su, J., Fan, S., Qiu, H., Su, D., & Li, L. (2021). Wearable piezoresistive pressure sensors based on 3D graphene. Chemical Engineering Journal, 406, 126777.

Chiang, C. C., Lin, C. C. K., & Ju, M. S. (2007). An implantable capacitive pressure sensor for biomedical applications. Sensors and Actuators A: Physical, 134(2), 382-388.

Duan, Y., He, S., Wu, J., Su, B., & Wang, Y. (2022). Recent progress in flexible pressure sensor arrays. Nanomaterials, 12(14), 2495.

Gautschi, G. (2002). Piezoelectric sensors (pp. 73-91). Springer Berlin Heidelberg.

Liu, E., Cai, Z., Ye, Y., Zhou, M., Liao, H., & Yi, Y. (2023). An overview of flexible sensors: Development, application, and challenges. Sensors, 23(2), 817.

Ma, R. (2024). Research on flexible piezoelectric pressure sensor based on hybrid MAPbI3 pressure-sensitive material, Xidian University.

Meti, S., Balavald, K. B., & Sheeparmatti, B. G. (2016). MEMS piezoresistive pressure sensor: A survey. International Journal of Engineering Research and Applications, 6(4), 23-31.

Mishra, R. B., El-Atab, N., Hussain, A. M., & Hussain, M. M. (2021). Recent progress on flexible capacitive pressure sensors: From design and materials to applications. Advanced Materials Technologies, 6(4), 2001023.

Szczerba, Z., Szczerba, P., & Szczerba, K. (2022). Sensitivity of piezoresistive pressure sensors to acceleration. Energies, 15(2), 493.

Tian, H., Lin, Q., & Li, B. (2006). Research on the application of optical fiber transmission technology of piezoelectric pressure sensor. Sensors and Microsystems, 25(2), 3.

Tran, A. V., Zhang, X., & Zhu, B. (2018). Mechanical structural design of a piezoresistive pressure sensor for low-pressure measurement: A computational analysis by increases in the sensor sensitivity. Sensors, 18(7), 2023.

Wang, L., Qin, L., & Li, L. (2010). Piezoelectric dynamic pressure sensor. 2010 IEEE International Conference on Information and Automation (pp. 906-911). IEEE.

Yuan, H., Zhang, Q., Zhou, T., Wu, W., Li, H., Yin, Z., ... & Jiao, T. (2024). Progress and challenges in flexible capacitive pressure sensors: Microstructure designs and applications. Chemical Engineering Journal, 149926.

Zhang, J., Chen, J., Li, M., Ge, Y., Wang, T., Shan, P., & Mao, X. (2018). Design, fabrication, and implementation of an array-type MEMS piezoresistive intelligent pressure sensor system. Micromachines, 9(3), 104.