Proceedings of CONF-FMCE 2025 Symposium: Semantic Communication for Media Compression and Transmission
DOI: 10.54254/2755-2721/2025.GL27349

# *Material Demand Analysis and Application Research for Human Body Flexible Electronic Device*

**Zichuan Wang**

*Yangzhou High School of Jiangsu Province, Yangzhou, China*
*Princelovegood@outlook.com*

***Abstract.*** This article focuses on the core materials of human body flexible electronic devices and analyzes their performance requirements and application research in human body scenarios. First, elaborate on the market prospects of flexible electronic devices, including their growth potential in fields such as wearable devices, medical health, and smart homes; Subsequently, the key requirements that the material needs to meet, such as biocompatibility, electrical conductivity, cost, flexibility, and stability, are analyzed in detail. Then, taking Poly (3,4-ethylenedioxythiophene) /poly (styrenesulfonate), carbon nanotubes, and graphene as examples, this paper explores their specific applications in human-related devices such as flexible electroencephalogram electrodes. Finally, it points out the challenges currently faced by materials, such as performance optimization, large-scale preparation, reliability and biosafety, and looks forward to the development trends of material composite and hybridization, application of degradable materials, integration with artificial intelligence/Internet of Things and multi-functional integration. Research shows that optimizing materials and promoting technological innovation are crucial for the sustainable development of flexible electronic devices.

***Keywords:*** Flexible electronic devices, conductive materials, polymer.

## 1. Introduction

Flexible materials have developed rapidly in recent years and achieved significant breakthroughs in many aspects, with advantages that traditional electronic devices cannot match. Due to the complex manufacturing process, rigidity, and poor fit with the human body of traditional electronic devices, they are difficult to meet the flexible requirements such as stretching, bending, and twisting, thus being greatly restricted in the field of human factors engineering. The development of flexible conductive materials has provided strong support for the development of flexible electronic devices and promoted the rapid progress of flexible electronic equipment [1].

The research and development of materials for flexible electronic devices have opened new opportunities and growth points for the electronics industry, with a very promising market outlook. In the wearable device market, as people's demand for health monitoring and medical care continues to grow, flexible electronic devices have become the core technology for future wearable devices. According to data from market research institutions, the global market size of flexible sensors has shown a strong growth trend in recent years and is expected to reach 12 billion US dollars by 2030,

DOI: 10.54254/2755-2721/2025.GL27349

with a compound annual growth rate (CAGR) of approximately 14%. Take smartwatches as an example; in 2022, the global shipment of smartwatches exceeded 150 million units, and most of these products are equipped with at least one type of flexible sensor. The future market demand is expected to continue to rise. In the medical field, the application of flexible electronic devices in various stages of disease is constantly expanding. For instance, in health monitoring devices, flexible sensors used for heart rate monitoring can collect heart rate data in real-time and accurately, and transmit the data to mobile phone apps or medical cloud platforms via wireless communication technology, providing users with health analysis and early warnings. The wearable flexible blood glucose sensor currently under development is expected to achieve non-invasive and real-time blood glucose monitoring, bringing great convenience to diabetic patients. It is estimated that by 2025, the market share of flexible sensors in the medical and health field will approach that of the consumer electronics field, reaching about 28%, which is expected to drive medical equipment to make significant strides towards intelligence and personalization, significantly improving the quality and efficiency of medical services. In fields such as smart packaging, smart home, and smart transportation, flexible electronic devices also play a key role. In smart homes, temperature control systems use flexible temperature sensors to monitor indoor temperature changes in real-time and precisely control the operation of air conditioners, heaters, and other equipment, creating a comfortable indoor environment. Currently, its market share is about 7%, with huge growth potential in the future. In the automotive electronics field, pressure sensors on the steering wheel can monitor the driver's grip strength and posture in real-time and issue warnings when the driver is fatigued or inattentive, ensuring driving safety. It is expected that by 2030, its market share will reach about 15%, providing a solid technical guarantee for the innovative development of these fields [2].

This article will focus on the core materials used in flexible electronic devices, and will analyze in detail the performance requirements and practical application research of these materials in human-related scenarios. Currently, flexible electronic devices, with their unique advantages, have seen a continuous expansion of their market scale and rapid technological iteration, and have gradually become one of the core industries in the international market. Their technological innovation level has also ranked among the forefront and hotspots of world science and technology. However, in the complex application environment of interaction with the human body, materials need to simultaneously meet multi-dimensional performance requirements such as biocompatibility, conductivity, cost, flexibility, and stability.

## 2. Analysis of material requirements for flexible electronic devices

The materials required for flexible devices should possess multiple material characteristics simultaneously to meet the usage requirements in practical applications.

Biocompatibility. For flexible electronic devices that are in direct contact with the human body or implanted inside the human body, such as those used in medical monitoring and electroencephalogram monitoring equipment, biocompatibility is a crucial performance indicator. The materials must not cause adverse biological reactions such as immune responses or allergic reactions in the human body, ensuring their long-term stable operation in the human environment and safeguarding human health and safety.

Conductive properties. Good conductive properties are the foundation for flexible electronic devices to achieve their functions. Whether it is for transmitting electrical signals, driving electronic components, or achieving energy storage and conversion, the materials need to have good conductivity to ensure efficient transmission of electrons.

DOI: 10.54254/2755-2721/2025.GL27349

Cost. In large-scale production and practical applications, the cost of materials is a key factor. If the material cost is too high, it will limit the popularization and market promotion of flexible electronic devices. Therefore, under the premise of meeting performance requirements, materials with low cost and wide availability should be preferred.

Flexibility. Flexibility is the core characteristic of flexible electronic devices. The materials need to have good flexibility and extensibility, and be able to maintain their structural integrity and performance stability under certain deformations such as bending, stretching, and twisting.

Stability. The materials should remain stable under different environmental conditions, such as temperature, humidity, light, and chemical substances, to avoid performance degradation or failure due to environmental factors.

In addition to the above main performance requirements, flexible electronic devices may have other special requirements for materials depending on different application scenarios, such as comfort, lightness, photo-sensitivity, and other requirements.

## 3. Research on the application of materials in flexible electronic devices

### 3.1. Poly (3,4-ethylenedioxythiophene): application of poly(styrene sulfonate) (PEDOT:PSS) in flexible electroencephalogram electrodes

Due to its unique performance advantages, PEDOT:PSS has become the most commonly used conductive polymer material for flexible electroencephalogram (EEG) electrodes [3]. Studies have shown that PEDOT:PSS has excellent biocompatibility, low contact resistance, high flexibility, and mechanical stability.

Clinical trials have demonstrated that compared with other materials, PEDOT:PSS stands out due to its outstanding biocompatibility, electrochemical performance, and adjustable conductivity. By optimizing the preparation process, PEDOT:PSS electrodes can achieve low-resistance contact with the skin. The researchers developed a PEDOT:PSS-modified tricarbazone flexible conductive sponge (PMA) scalp EEG electrode, which can simultaneously collect multi-channel EEG waves in both hairless areas and hair-covered areas. Through special processing methods, the flexibility and mechanical stability of PEDOT:PSS can be significantly improved. Based on the strategy of semi-permeable membrane-mediated hydrogen bond interface, the high-performance pure PEDOT:PSS hydrogel (HEP) prepared by ethanol dialysis and subsequent sulfuric acid treatment remains stable in PBS for 3 months and has been successfully applied to monitor the brain electrical signals of rats. Ahmed et al. developed a Joule heating device with certain tensile properties and stable heating performance using cotton fabric as a flexible carrier, by coating reduced graphene oxide and (3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS). This device responds rapidly to heat and can achieve rapid heating, heating to approximately 30 ℃ within 15 seconds at a 10 V voltage, and remains stable [4].

### 3.2. Application of carbon nanotubes in flexible electroencephalogram electrodes

Carbon nanotubes have become an important candidate material for flexible brain electrical electrodes due to their excellent electrical and mechanical properties [3].

Carbon nanotubes possess extremely high electrical conductivity and outstanding electrical performance, enabling high-quality brain electrical signal acquisition. Studies have shown that pure carbon nanotube fibers can serve as effective tools for stimulating neurons and recording single neuron activities, without the need for additional surface treatment. Carbon nanotubes have good

DOI: 10.54254/2755-2721/2025.GL27349

biocompatibility and can form good interfaces with biological tissues. The flexible microelectrodes based on carbon nanotube fibers developed by researchers performed well in biocompatibility tests and can be used for long-term neural signal recording [5]. Wang et al. prepared porous carbon nanotube/PU foam strain sensors through template methods. These sensors have a high sensing coefficient (GF = 363) and a high working range (100%), and can effectively adhere to human skin and effectively recognize subtle movements and large-scale human activities [6].

### 3.3. Application of graphene in flexible electroencephalogram electrodes

Graphene, as an emerging two-dimensional carbon material, demonstrates great potential in the field of flexible electroencephalogram (EEG) electrodes due to its extremely high electron mobility, excellent flexibility and mechanical properties, high specific surface area, and biocompatibility [7].

Firstly, graphene has an extremely high electron mobility, enabling rapid electron transmission, which is beneficial for improving the speed and quality of signal acquisition. In terms of physical mechanical properties, graphene has excellent flexibility and mechanical strength, capable of withstanding repeated bending and stretching without damage. Secondly, in the process of contact between flexible devices and the skin, the contact area is a very important parameter. The extremely large specific surface area of graphene is conducive to increasing the contact area between the electrode and the skin, reducing contact resistance. Finally, studies have shown that graphene has good biocompatibility, suitable for long-term biomedical monitoring. Huang et al. constructed porous graphene/PVDF/PU fibers by adding PVDF nanospheres between graphene nanosheets. Due to the addition of PVDF microspheres, the connection between graphene nanosheets and PU was reduced, significantly improving the sensitivity of graphene fibers (0-5% GF = 51, 5-8% GF = 87) [8].

## 4. Challenges of flexible device materials

Although significant progress has been made in the materials of flexible electronic devices, many challenges still remain. The performance optimization of the materials still needs to be further strengthened. For instance, while improving the conductivity, flexibility, and stability of the materials, the compatibility issues between the materials also need to be addressed to achieve a comprehensive improvement in the material performance. The large-scale production technology of the materials needs to be improved. Currently, the preparation processes of some high-performance materials are complex and costly, making it difficult to meet the requirements of large-scale industrial production. It is necessary to develop efficient and low-cost production technologies to achieve large-scale production of the materials. Moreover, the reliability and stability of flexible electronic devices have not been deeply studied enough. In complex practical application environments, how to ensure that the devices work stably for a long time is a key issue that needs to be addressed. At the same time, as the applications of flexible electronic devices in fields such as biomedicine become increasingly widespread, related issues of biological safety and ethics also require sufficient attention. A complete evaluation system and regulatory mechanism should be established to ensure the health and safety of the public.

DOI: 10.54254/2755-2721/2025.GL27349

## 5. Development trends

### 5.1. Material composites and hybridization

In order to integrate the advantages of various materials and meet the diverse material performance requirements of flexible electronic devices, material composites and hybridization have become an important development trend. For example, carbon-based materials can be combined with other materials, and researchers have developed various carbon-based composite materials [9]. It provides core material support for the performance breakthroughs of key devices such as flexible sensors and wearable energy storage equipment.

### 5.2. Application of biodegradable and environmentally friendly materials

As people's awareness of environmental protection has increased, the application of degradable and environmentally friendly materials in flexible electronic devices has gradually attracted attention. Developing flexible electronic materials that can degrade in the natural environment can reduce the pollution of electronic waste to the environment and meet the requirements of sustainable development.

### 5.3. Integration with artificial intelligence and the internet of things

With the rapid development of artificial intelligence and Internet of Things technologies, the integration of flexible electronic devices with these technologies will bring them broader application prospects. As the sensing terminals of the Internet of Things, flexible electronic devices can collect various environmental and biological information in real time. By combining with artificial intelligence algorithms, they can achieve intelligent analysis and processing of data, providing users with more intelligent services.

### 5.4. Research and development of multi-functional integrated materials

Future flexible electronic devices tend to integrate multiple functions, so the research and development of multi-functional integrated materials is of great significance. Developing materials that possess multiple functions such as sensing, energy storage, and display is crucial. Such materials can simplify the device structure, enhance the integration degree and performance of the device. Preparing multi-functional materials that can serve as both sensors to detect environmental parameters and energy storage elements to store energy can be used in wearable devices to achieve miniaturization and multi-functionality of the devices.

## 6. Conclusion

The selection of flexible electronic device materials is of vital importance for promoting the development and application of flexible electronic technology. By meeting various requirements such as biocompatibility, conductivity, cost, flexibility, and stability, choosing appropriate materials and conducting in-depth research on their applications, such as PEDOT:PSS, graphene, carbon nanomaterials, etc., can provide strong support for the performance improvement and functional expansion of flexible electronic devices. With the advancement of trends such as material composites and hybridization, the application of degradable and environmentally friendly materials, the research and development of multi-functional integrated materials, and the integration with

DOI: 10.54254/2755-2721/2025.GL27349

artificial intelligence and the Internet of Things, the materials for flexible electronic devices will have a broader development space. However, it is also necessary to be soberly recognize the current challenges, through continuous research and innovation, to solve problems such as material performance optimization, large-scale production, reliability and stability, and biological safety, to lay a solid foundation for the wide application of flexible electronic devices in various fields, achieve the sustainable development of flexible electronic technology, and bring more convenience and innovation to people's lives and social development.

## References

[1] Huang, S., Liu, Y., Zhao, Y., Ren, Z., & Guo, C. F. (2019). Flexible electronics: stretchable electrodes and their future. Advanced Functional Materials, 29(6), 1805924.
[2] Deepdata_cn (2025). The current market situation and future development trends of the flexible sensor industry - The current development status of wearable flexible sensors worldwide. Retrieved from https: //blog.csdn.net/weixin_43156294/article/details/146933036?f_link_type=f_linkinlinenote& flow_extra=eyJkb2NfcG9zaXRpb24iOjEsImRvY19pZCI6IjNjNmQ3YjRiZWRkZDI5ZTktYTMzODZkYTg0YzM2ZmU4ZiIsImlubGluZV9kaXNwbGF5X3Bvc2l0aW9uIjowfQ%3D%3D
[3] He, S., Hong, Y., Liao, M., Li, Y., Qiu, L., & Peng, H. (2021). Flexible sensors based on assembled carbon nanotubes. Aggregate, 2(6), e143.
[4] Ahmed A, Jalil MA, Hossain MM, et al. (2020). A PEDOT: PSS and graphene-clad smart textile-based wearable electronic Joule heater with high thermal stability. Journal of Materials Chemistry C, 8(45), 16204-16215.
[5] Muqaddas, S., Javed, M., Nadeem, S., et al. (2023). Carbon nanotube fiber-based flexible microelectrode for electrochemical glucose sensors. ACS omega, 8(2), 2272-2280.
[6] Wang, H., Zhou, R., Li, D.et al. (2021). High-performance foam-shaped strain sensor based on carbon nanotubes and Ti3C2T x MXene for the monitoring of human activities. ACS nano, 15(6), 9690-9700.
[7] Docin(2025). 2025-2030 Commercialization Prospects and Ethical Considerations of Brain-Computer Interface Technology in China. Retrieved from https: //m.book118.com/html/2025/0628/6051012233011151.shtm
[8] Huang, T., He, P., Wang, R., Yang, S., Sun, J., Xie, X., & Ding, G. (2019). Porous fibers composed of polymer nanoball decorated graphene for wearable and highly sensitive strain sensors. Advanced Functional Materials, 29(45), 1903732.
[9] Wang, X., Lim, E. G., Hoettges, K., & Song, P. (2023). A review of carbon nanotubes, graphene and nanodiamond based strain sensor in harsh environments. C, 9(4), 108.