The Application and Progress of the Combination of Energy Technology and Bioelectronics in Wearable and Medical Fields

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Abstract. The combination of energy technology and bioelectronics can be said to be the most innovative and cutting-edge technology today. Enhance the versatility and sustainability of bioelectronic devices. This fusion technology can capture and collect energy directly from living organisms, the environment, and convert it into electricity. This technology focuses on the development of self-powered devices for health detection, implantable and therapeutic applications, and has a wide range of applications in wearable, medical and other fields. It is because of this technology that people reduce the reliance on battery power generation, some wearable, medical devices can operate continuously without frequent charging. The effective use and development of some new energy sources, such as solar energy, wind energy and bioenergy, has also greatly reduced the utilization rate of fossil fuels and reduced environmental pollution. This article will list three kinds of energy-based wearable technologies, namely solar, mechanical and bioenergy wearable technologies, focusing on their working principles, materials and applications. The combination of energy technology and bioelectronics has led to breakthrough developments in various fields.

Keywords: Energy technology; Bioelectronics; self-power; wearable technology; Medical devices.

1. Introduction

Benefiting from the rapid development of the Internet of Things and the launch of a series of high-performance, low-power chips. As an extension of mobile phones and other terminal devices, wearable devices have gradually moved from the laboratory to the market in recent years. These types of devices typically exist in the form of portable accessories that integrate sensing, computing, and connectivity functions, thereby expanding the device's range of use. With the increasing diversity of product features among users, the volume and size of wearable devices are gradually moving towards being compact and convenient to carry. However, the rapid development of wearable devices is limited by the limited battery life required for sensing and computing.

With the popularity of the concept of environmental protection and energy conservation, more and more products are using various types of energy in people's environment, such as solar energy, mechanical energy, and bioenergy. These energy sources have three major advantages: firstly, they are relatively environmentally friendly and pollution-free. In the process of converting them into solar energy, they do not produce greenhouse gases or other harmful substances; Recyclable, as a renewable energy source, there is no need to consider issues such as resource depletion; Three can be used anywhere, without geographical limitations, and the way to obtain energy is very convenient. Therefore, using these energy sources can effectively solve the problem of energy consumption and endurance of wearable device batteries [1].

2. Solar powered wearable devices

To ensure that solar cells can continuously provide energy to equipment, an efficient device is achieved based on the following five parts: distribution of electricity, collection of data, processing and display of information, durable casing, and comfortable and compatible materials. Solar cells typically use semiconductor materials (such as Si) to absorb photons and use their energy to direct the free electrons in the material to move, forming an electric current. Soft and lightweight materials ensure high sensitivity while being comfortable and not affecting aesthetics. (For example, thin films made of MoTe2 and MoS2).

2.1. Materials

In recent years, with the increasing attention of society to organic green energy, significant development and strategic breakthroughs have been made., The solar energy sector is developing rapidly. Based on the efficient electronic properties, conductivity, and flexibility of fullerene, it can effectively improve the economic efficiency of the device and provide a guarantee for its long-term use.

2.1.1 Fullerenes and their derivatives

The excellent electronic properties of fullerenes and their derivatives (such as PCBM) are widely used in the field of organic solar energy. Fullerenes have the advantages of high conductivity, flexible structure, lightweight and transparent, and can be combined with other materials. Good electrical conductivity. The molecular structure of fullerene enables it to provide high electron mobility. The rapid transition of electrons from the photovoltaic active layer to the electrode in the battery greatly improves efficiency [2]. Structural flexibility. The cage like molecular structure of fullerene molecules enables them to achieve softness, bendability, fit the curves of the human body, and good conductivity. Three lightweight and transparent. The low density and excellent transparency of fullerene make it suitable for lightweight wearable devices. Collecting energy without affecting usage and aesthetics, achieving compactness and lightness. Fullerenes can be well combined with organic semiconductor materials to form efficient organic photovoltaic systems. These hybrid materials typically have better flexibility and cost-effectiveness, making them suitable for large-scale manufacturing and wearable applications. However, the preparation process of fullerene is extremely complex and the production cost is high. Make it unable to be widely promoted; And it is difficult to control the size of the preparation results, which cannot achieve uniformity; Fullerenes cannot achieve stable performance in certain specific situations. (Specific metal catalysis, high temperature, high pressure) can easily trigger reactions such as decomposition or degradation.

2.2.2 polysilicon

The interior of polycrystalline silicon is composed of many small grains, all of which have a regular crystal structure and are interconnected to form polycrystalline silicon. Among them, the larger the grain size, the fewer grain boundaries, and the better the conductivity. Based on these characteristics, polycrystalline silicon has the advantages of high conversion rate, low cost, and simple manufacturing process, making it an excellent material for making wearable solar devices. Firstly, polycrystalline silicon does not require a long time to crystallize like monocrystalline silicon, and it wastes less material. Compared to monocrystalline silicon, the production cost of polycrystalline silicon is also lower. SolarWorld, a German company, has certain advantages in the solar cell market. Among them, the company uses polycrystalline silicon to produce batteries, which can reduce the cost of its products by 20% and has a price advantage in the market. Secondly, in recent years, the production process of polycrystalline silicon has become more mature and widely used around the world. In addition, polycrystalline silicon can adapt to various weather and environments. In such hot and dry environments, polycrystalline silicon cells exhibit good durability and stability, continuously providing renewable energy for the local area. This reliability demonstrates the advantages of polycrystalline silicon solar cells in harsh outdoor environments.

2.2. Application

In 2015, the A-D-A small molecule receptor ITIC developed by Zhan Xiaowei and others emerged, promoting the rapid development of organic solar cells. At the same time, solar energy equipment is becoming increasingly widely used. In healthcare, solar wearable devices are used for the detection of various chronic diseases. For heart disease patients, solar powered wearable devices can achieve 24-hour data collection of electrocardiograms and provide personalized services.

3. Mechanical energy in wearable

The core of the work of wearable devices is also to collect and convert energy, mainly by the movement of the human body such as running, walking, arm bending and swinging generated by mechanical energy through a series of energy conversion devices into electricity [1]. Some mechanical energy conversation technologies are also list below.

3.1. materials

3.1.1 Piezoelectric materials

Piezoelectric effect is a relatively classical energy conversation technology and method of converting energy is also relatively simple, and is generally used for low-power electronic power supply equipment [2], which is deformed by some kind of pressure to produce electric charge, as shown in figure 1. Materials with piezoelectric properties produce electrical energy when subjected to external forces and also exhibit inverse piezoelectric effects, which the applied electric field can be converted into mechanical stress [3].

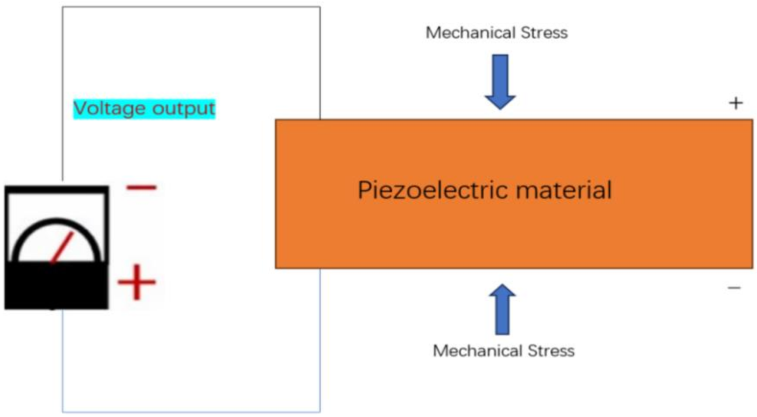

Fig. 1 The most basic working principle of materials with piezoelectric properties - the piezoelectric effect

For some good piezoelectric materials, barium titanate(BaTiO3) is an inorganic compound and also a piezoelectric ceramic. It shows different crystal structures at different temperatures, so that it shows excellent physical and chemical properties, the higher dielectric constant also makes it better able to store electric energy in an electric field. Polyvinylidene fluoride (PVDF) is a flexible polymer material, compared with the inorganic material BaTiO3, it has better durability and biocompatibility [2]. PVDF exhibits ferroelectric properties and strong piezoelectric properties in β crystals [2].

3.1.2 Triboelectric material

The energy harvesting technology, based on the triboelectric effect, mainly involves rubbing two different materials and converting them into electricity. This collection device is called a triboelectric nanogenerator, as shown in figure 2. When a material is rubbed against another material, the surface of the material will generate opposite charges, and the amount of opposite charges is proportional to the surface of the material [4].

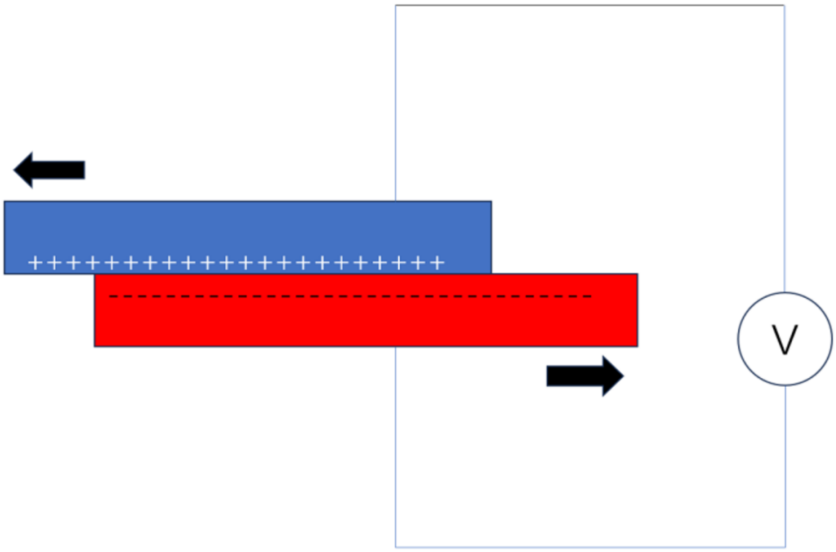

Fig. 2 The most basic working principle of materials with triboelectric properties - the triboelectric effect

The main material of tribogenerator nanomachines is polymer [4]. And polytetrafluoroethylene (PTFE) is considered to be a suitable material for the manufacture of triboelectric nanomachines because of its excellent properties, which is a highly electronegative material, and it is easier to capture electrons when it is rubbed to produce electricity. And it can also combine with metals to form a strong charge separation, resulting in a high voltage. Silicone has better flexibility and elasticity, and the durability is also very good, in extreme environments can also make the friction power generation device stable operation.

3.2. Application

Mechanical energy wearables have also found a wide range of applications, such as self-powered sensors, which can provide power for some health monitors that monitor blood sugar and heart rate, compare to traditional sensors, the TENG self-powered sensor can monitor multiple physiological health signals in real time, continuously and accurately [3], and can also be combined with wireless technology to transmit the captured data to the computer or mobile phone, In addition, implantable pacemakers can be converted into electrical output through the mechanical movement of the heart or blood flow, which also reduces the reliance on battery power and is more environmentally friendly.

4. Biological energy in wearable

The bioenergy conversion mechanism mainly relies on the metabolic process of the human body to convert chemical energy into electrical energy. In the human body, metabolites such as glucose release energy through redox reactions, which can be captured by a biofuel cell. Its use of enzyme catalysts, such as glucose oxidase, breaks down glucose to produce electrons and protons. The electrons will pass through an external circuit to generate an electric current, and the protons will pass through an electrolyte membrane and combine with oxygen to produce water. Another common metabolic pathway is lactate metabolism, which utilizes lactic acid to react with oxygen to produce energy through a similar mechanism. The bioenergy conversion method is naturally synchronized with the body's metabolism and is capable of generating electrical energy on a continuous basis, making it particularly suitable for long-term use in implantable or wearable devices.

4.1. Materials

4.1.1 Enzyme catalysts

The most significant advantage of glucose oxidase for use in biofuel cells is its ability to efficiently catalyze the oxidation reaction of glucose under physiological conditions [5]. Glucose oxidase is able to produce a stable current output when combined with glucose, and the high selectivity of the enzyme means that it reacts almost exclusively with glucose, avoiding the interference of other substances in the energy conversion process. At the same time, the enzyme, when combined with carbon nanomaterials, is able to further improve its catalytic activity and stability, enhancing the energy efficiency of the overall system. The above reasons make it one of the indispensable core materials in current biofuel cells.

4.1.2 Nanomaterials

Carbon nanotubes (CNTs), with their unique structure and physical properties, are one of the most effective nanomaterials in biofuel cells [6]. The high electrical conductivity of CNTs makes them an ideal electrode material for effectively transferring the electrons generated in the biofuel cell reaction. At the same time, the high specific surface area of CNTs means that they can load more enzyme catalysts and increase the reaction active sites, thus enhancing the overall energy output efficiency. CNTs also have good mechanical properties and chemical stability, so they can maintain their function for a long time in a variety of biological environments. By combining with enzymes, carbon nanotubes not only improve the conductivity of the electrode, but also increase the efficiency of the enzyme-catalyzed reaction.

4.1.3 Biocompatible Polymers

Polyethylene glycol (PEG) is a polymer material widely used in the biomedical field, with excellent biocompatibility and chemical stability.PEG can effectively coat the electrode surface, avoiding undesirable reactions such as inflammation or rejection between biological fluids and the electrodes, and thus improving the service life of the batteries in the in vivo environment.PEG also has a certain degree of flexibility, which is able to adapt to the requirements of wearable devices and does not cause mechanical damage to human tissues. By adding PEG coating on the electrodes, it can not only realize stable power output, but also ensure the safety of long-term compatibility with the human body.

4.2. Processing method

In order to integrate biofuel cells into wearable devices, micro- and nano-fabrication techniques shall be used. Micro and nano fabrication techniques enable the fabrication of the components of the biofuel cell (e.g., enzyme electrodes, nanomaterials, and biocompatible polymers) in sizes up to the nanometer scale, which is well controlled to comply with the size requirements of the wearable device and ensures a good energy output performance. At the same time, the flexible circuitry in the device enables it to fit snugly against the human skin or organs and continuously provide electrical energy without interfering with the body's natural activities.

4.3. Applications

An important application of biofuel cells is implantable medical devices such as pacemakers or brain nerve stimulators. While traditional implantable devices rely on external batteries for energy supply, biofuel cells can obtain energy directly from human metabolism to realize long-term and stable power supply, reducing the need for battery replacement. Another important application area is health monitoring devices, such as wearable blood glucose sensors, which utilize biofuel cells to obtain energy directly from body fluids and monitor glucose concentration in the body in real time. In addition, in patients with chronic diseases, especially diabetes, biofuel cells can supply energy for continuous monitoring systems, greatly improving the convenience of monitoring.

5. Conclusion

In summary, the substantial opportunity to counter battery life and sustainability issues exists within the integration of renewable energy resources, especially solar and mechanical energy, into wearable devices. Developments in flexible, lightweight materials such as fullerene-based materials, piezoelectric ceramics, and triboelectric polymer materials are enhancing energy harvester technology that will be more efficient, durable, and flexible for wearables. These methods will assure power independence while avoiding discomfort and usability, which are barriers to consumer adoption. Moreover, bioenergy transformation techniques, including glucose-based biofuel cells, offer a potential avenue for implantable medical devices and long-term wearables. These methods exploit the body's metabolism as a source of continuous and sustainable energy, limiting battery replacement requirements and improving the intelligence of health monitoring devices. As increasing demand for smaller, portable, and multifunctional wearables arises, employing the various energy-harvesting methods together is a unique avenue for the next set of devices, however, there are still limitations to scaling up manufacturing using these techniques, their commercialization, and long-term stability of certain materials (for example, fullerene). Future work should explore solutions to scaling the episodes of energy-harvesting techniques, while also continuing to advance integration of these technologies, to meet each of the varied needs of wearable applications.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Dong Daqun, Zhao Jisheng.Analysis of the Development Trends and Challenges of Solar Photovoltaic Power Generation. Light Source and Lighting, 2024, (05): 120-122.

[2] Wang Zijian, Zuo Huilin, Wang Meng, et al.Performance optimization of MoTe2/MoS2 heterojunction optoelectronic devices based on surface engineering control 2024, 1-8

[3] Maoying Zhou, Jun Zou, Weiting Liu, A review on heat and mechanical energy harvesting from human – Principles, prototypes and perspectives, Renewable and Sustainable Energy Reviews, 82, 2018, 3582-3609.

[4] Xiao Pan, Yuying Wu, Youfu Wang, Gang Zhou, Hongling Cai, Mechanical energy harvesting based on the piezoelectric materials: Recent advances and future perspectives, Chemical Engineering Journal, 497, 2024, 154249.

[5] Minglu Zhu, Zhiran Yi, Bin Yang, Chengkuo Lee, Making use of nanoenergy from human – Nanogenerator and self-powered sensor enabled sustainable wireless IoT sensory systems, Nano Today, 36, 2021,101016.

[6] Slabov, V., Kopyl, S., Soares dos Santos, M.P. et al. Natural and Eco-Friendly Materials for Triboelectric Energy Harvesting. Nano-Micro Lett. 12, 2020, 42.