Organic Piezoelectric Biomaterials

Subjects: Nanotechnology | Electrical & Electronic Engineering | Energy & Fuel Technology

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Definition

The past decade has witnessed significant advances in medically implantable and wearable devices technologies as a promising personal healthcare platform. Organic piezoelectric biomaterials have attracted widespread attention as the functional materials in the biomedical devices due to their advantages of excellent biocompatibility and environmental friendliness. Biomedical devices featuring the biocompatible piezoelectric materials involve energy harvesting devices, sensors, and scaffolds for cell and tissue engineering. This paper offers a comprehensive review of the principles, properties, and applications of organic piezoelectric biomaterials. How to tackle issues relating to the better integration of the organic piezoelectric biomaterials into the biomedical devices is discussed. Further developments in biocompatible piezoelectric materials can spark a new age in the field of biomedical technologies.

1. Introduction

Piezoelectric materials are a class of solid materials that can accumulate an electric charge in response to applied mechanical agitation, facilitating the conversion from mechanical energy to electrical energy and vice versa. Piezoelectricity has been found in both organic and inorganic materials, where the physical principles of piezoelectricity are varied upon material classification. In inorganic piezoelectric materials, the piezoelectric effect arises from the rearrangement of ions in the dielectric materials that possess a lack of inversion symmetry in crystalline structure [1]. In contrast, the reorientation of molecular dipole mainly induces polarization in organic piezoelectric materials under applied mechanical stress [2],[3]. These materials have taken over the entire market of electromechanical devices, such as sensors [[4][5][6]], actuators[[7]] , energy harvesting [[8][9][10]] and storage [[11][12]] . Recently, medically implantable and mountable devices have attracted considerable attention [[13][14]], and are the newly emerging applications for piezoelectric materials.

2. Advances in Organic Piezoelectric Biomaterials for Energy and Biomedical Applications

Organic piezoelectric biomaterials offer several benefits over inorganic piezoelectric materials, which include a high biocompatibility, excellent flexibility, environmental friendliness, and a high level of processability. Ever since the discovery of polarization in asymmetric biological tissue in 1941 [[15]], many researchers have looked not only to unveil the primary principle underlying the piezoelectricity of those materials, but also to enhance its physical and chemical properties by designing a molecular structure, nanostructuring, and adding dopants [[2],[16]]. Although organic piezoelectric biomaterials exhibit weak piezoelectricity compared to inorganic counterparts, recent research suggests that biocompatible piezoelectric materials, which are interfaced with the biological system of human beings, can serve as the functional materials in the field of medically implantable and mountable applications when they are well-processed.

The rapid development in organic piezoelectric biomaterials calls for a comprehensive review that can provide a useful reference for researchers in relevant fields. Herein, we provide a thorough review of organic piezoelectric biomaterials that are used in energy and biomedical applications. We review the working principle and properties of the different types of organic piezoelectric biomaterials. Efforts to improve the piezoelectric performance of each materials are discussed. The applications of these materials are introduced in terms of energy harvesting, sensor, and cell and tissue regeneration. Meanwhile, the challenges that need to be addressed for practical application are also presented.

The present review has sought to offer the insight on the importance of the organic piezoelectric biomaterials in biomedical applications. We have reviewed the origin of the piezoelectricity in the organic piezoelectric biomaterials, including proteins, peptides, and biopolymers. The intrinsic piezoelectric property of those materials has been presented, and the engineering and scientific endeavors to enhance the properties has also been reported. In summary from current research, the organic piezoelectric biomaterials have been likely to impact three major fields across many disciplines. First, they can serve as the functional materials for power supply of implantable and mountable self-powered electronics because of their sensitivity to mechanical agitations and remarkable biocompatibility. Second, they have been utilized as platform materials for the pressure sensing in biomedical applications, which is likely due in large part to the high flexibility and high sensitivity to small force in tandem with their biodegradability. Lastly, in cases where the piezoelectric materials were integrated as the scaffolds for cell and tissue regenerations, those materials act as the tissue stimulator to promote the differentiation of the cells desired. An industry based on the organic piezoelectric biomaterials is anticipated for their variety of applications, but the further improvements are required to smoothly implement them into the practical biomedical devices.

We need to address several issues for better integration of the organic piezoelectric biomaterials in the biomedical devices. Here are listed a few: 1) Fundamental physics of piezoelectricity in biomaterials. Even though the researchers have focused on uncovering the biological piezoelectricity, the plenty of work remains to exploit the electromechanical behavior in terms of unit cell properties. Such studies are in progress by using not only single crystals of biomaterials but also calculations based on the first principle. 2) Relatively low piezoelectric constant compared to the piezoelectric inorganic materials. The output performances in the applications of energy harvesting and sensor are related to the piezoelectric constant. The constant of biomaterials has been found to be much smaller than that of the state-of-the-art piezoelectric inorganic materials (d_{33} = 593 pC/N and d_{31} = −274 pC/N), which has to be improved for achieving the maximized performance. This is possible by creating proper nanostructures, aligning biomaterials, or fabricating multilayer structure. 3) Biodegradability in the controlled manner. For biodegradable sensor and scaffold applications, the organic piezoelectric biomaterials must be decomposed in the desired time frame. The degradation rate of these materials can be engineered by the different experimental treatments, such as temperature, stretching ratio, or poling electrical fields. Although the researchers are still facing the challenging issues, the promising physical properties of organic piezoelectric biomaterials have suggested feasible biomedical applications in energy harvesting, sensor, and tissue regeneration. We truly believe that the organic piezoelectric biomaterials will continue their rapid growth in the next decade.

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Keywords

Piezoelectric materials;Organic materials;Biomaterials;Energy applications;Biomedical applications