EDN: QPLYKO
УДК 666.655; 621.315.612 *2.2.6*

FERROELECTRETS BASED ON SPACE-CHARGE POLYMER ELECTRETS

Xiaoqing Zhang

School of Physics Science and Engineering, Tongji University, Shanghai, China
1239 Siping Road, Shanghai, P.R. China

Absrtact. Ferro/Piezoelectrets are cellular electrets exhibiting significant piezoelectric effect. The matrix of the piezoelectret may be space-charge electret made of nonpolar polymers or/and oriented-dipole electrets made of polar polymers with intrinsic dipoles. This article will delve into the physical principles of space-charge ferroelectrets, their fabrication techniques, and piezoelectric properties, as well as their applications in the field of flexible electronic devices.

Keywords: Ferro/Piezoelectrets, electrets, piezoelectric effect, polymer, flexible electronic devices.

Introduction

Ferro/piezoelectrets, are a novel class of lightweight, flexible electromechanical coupling materials with a cellular structure that exhibit piezoelectric effects. Their piezoelectric properties are derived from the synergistic interaction between the electret state and phase separation, which is significantly different from the physical mechanisms of traditional inorganic piezoelectric materials such as lead zirconate titanate (PZT) ceramics, and ferroelectric polymers such as ferroelectric polymer polyvinylidene fluoride (PVDF) [1]. Traditional piezoelectric materials must be composed of polar molecules, while nonpolar materials do not possess piezoelectric effects. However, the matrix polymer of ferroelectrets can be nonpolar.

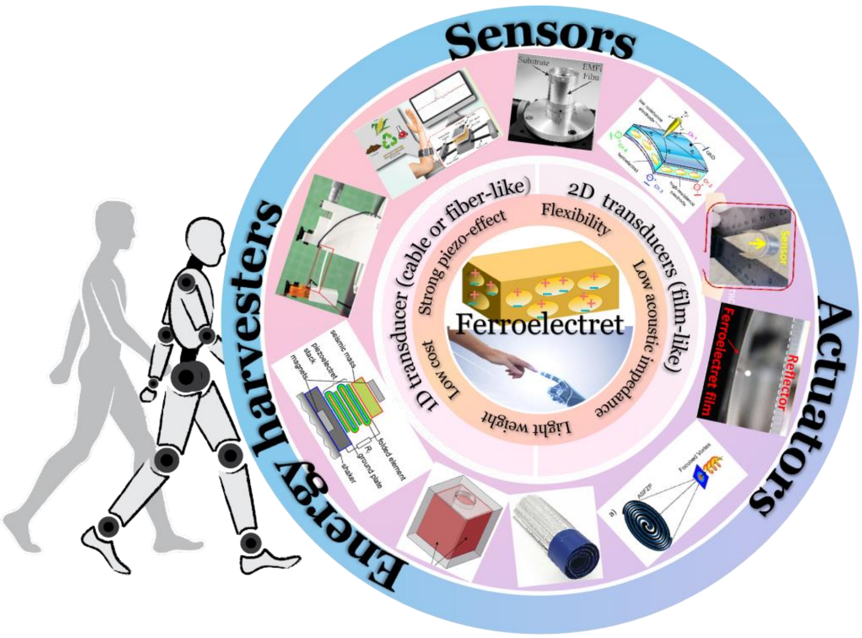

Fig. 1. Space-charge ferro/piezoelectret: microstructure, charge distribution, features and applications

Analogous to traditional ferroelectric materials, the microscopic functional units of ferroelectrets can be regarded as "ferroelectret domains", which are typically composed of elements with vastly different mechanical modules, such as gas and polymer phases, with trapped space charges regularly distributed at the interfaces between the two phases. Due to the significant difference in mechanical properties between the two phases, when subjected to external forces, mechanical deformation primarily occurs in the gas phase with lower modulus, leading to changes in the polarization strength of the material and thus exhibiting positive piezoelectric effects. When an external electric field is applied to the material, the elements deform under the influence of the electric field, demonstrating converse piezoelectric effects.

Physical model

An extension of classic theoretical model has been developed to express the longitudinal and transverse piezoelectric effects in ferroelectrets [2]. The longitudinal and transverse piezoelectric coefficients d_{33} and d_{31} are given by

$$d_{33} = \frac{\varepsilon_1 s}{Y_3} \frac{s_1 \sum_i s_{2i} \sigma_i}{s_2 (\varepsilon_2 s_1 + \varepsilon_1 s_2)^2}, \quad (1)$$

$$d_{31} = -\mu_{13} \frac{\varepsilon_1 s}{Y_1} \frac{s_1 \sum_i s_{2i} \sigma_i}{s_2 (\varepsilon_2 s_1 + \varepsilon_1 s_2)^2}, \quad (2)$$

where $\varepsilon_1$and ε_2 are relative permittivity of solid polymer and gas. s, s_1 and s_2 are total thickness of the film, thickness of solid polymer and gas, respectively. σ_i is the charge density on the ith layer of solid polymer. Y_1 and Y_3 are Young's module in lateral and thickness directions. μ_{13} is Poisson's ratio. As Poisson's ratio is negative, the material is a ferroelectret metamaterial.

Fabrication Techniques

Two key steps are involved in fabrication of ferroelectrets. One is formation of cellular films, and the other is polarization. General methods adopted to prepare cellular polymer films include supercritical foaming, template method, laser engraving, and 3D printing. Polarization techniques widely utilized are corona charging, contact charging and soft X-ray charging.

Features and Applications

Ferroelectrets combine the strong piezoelectricity of piezoelectric ceramics with the flexibility of ferroelectric polymers. Their piezoelectric effect has a frequency response range spanning eight orders of magnitude, including infrasound, audible sound, and ultrasound, making them ideal electromechanical coupling materials. They can serve as the core transducer materials for lightweight flexible film force sensors, acoustic-electric sensors, loudspeakers, air-coupled ultrasonic transducers, ultrasonic levitators, human motion energy harvesters, vibration energy harvesters, and acoustic energy harvesters. They are expected to play a vital role in various fields such as voice interaction, human health monitoring, intelligent sports equipment, gait analysis, robotic skin, structural health monitoring of buildings, intelligent transportation, and green energy.

Financing: This work was supported by the National Natural Science Foundation of China (NSFC) Grant No. 1237445.

Literature

1. Bauer S. Ferroelectrets: Soft electroactive foams for transducers / S. Bauer, R. Gerhard-Multhaupt, G. M. Sessler // Ferroelectrets: Physics Today. – 2004. – Vol. 57. – №. 2. – P. 37-43.
2. Hu Q. Longitudinal and transverse piezoelectric effects of ferroelectret metamaterials with positive and negative Poisson's ratios / Q. Hu et al. // Applied Physics Letters. – 2024. – Vol. 124. – №. 14.

ФЕРРОЭЛЕКТРЕТЫ НА ОСНОВЕ ПОЛИМЕРНЫХ ЭЛЕКТРЕТОВ С ПРОСТРАНСТВЕННЫМ ЗАРЯДОМ

Сяоцин Чжан

Школа физических наук и инженерии, Университет Тунцзи, Шанхай, Китай
1239 Сипинг-роуд, Шанхай, КНР

Аннотация. Ферро-/пьезоэлектреты - это ячеистые электреты, обладающие значительным пьезоэлектрическим эффектом. Матрицей пьезоэлектрета может быть электрет с пространственным зарядом, изготовленный из неполярных полимеров, или/и ориентированно-дипольные электреты, изготовленные из полярных полимеров с собственными диполями. В этой статье будут рассмотрены физические принципы работы ферроэлектретов с пространственным зарядом, технологии их изготовления и пьезоэлектрические свойства, а также их применение в области гибких электронных устройств.

Ключевые слова: сегнето- и пьезоэлектрики, элетреты, пьезоэлектрический эффект, полимер, гибкие электронные устройства.

Материалы представлены на Международной научно-практической конференции «Современные подходы и практические инициативы в инженерных науках» (г. Казань, 2-3 октября 2025 года).

Статья представлена в редакцию 15 августа 2025 г.