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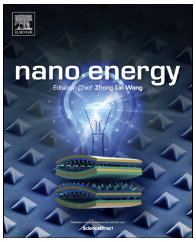

REVIEW

Flexoelectric nano-generator: Materials, structures and devices

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Abstract
Flexoelectricity, as a fundamental electromechanical coupling effect between electric polarization and mechanical strain gradient, or vice versa between electric polarization gradient and mechanical gradient, exists in various categories of materials including solid materials, liquid crystals, polymers, and biomembranes. Dependence of electric or mechanical gradients on geometry requires the adoption of specific structures for different flexoelectric mode applications. Scaling effect associated with gradient suggests that flexoelectric effect can be more significant in micro/nano systems, comparable to or even exceed piezoelectricity. In this review, flexoelectricity in those studied materials will be summarized and compared. Applications in sensors, actuators, capability of tuning the ferroelectric thin film properties, and roles in bio-system mechanosensitivity and mechanotranduction of flexoelectricity will be introduced respectively. Especially, flexoelectricity nano-generator enlightens a new technique for energy harvesting. Comparison with piezoelectric nano-generator suggests that flexoelectric counterpart can yield enhanced performance with specific nanostructures and provide a wider materials choice.

Contents

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Flexoelectricity

Flexoelectric effect

The flexoelectric effect describes the generation of an electric polarization response under a mechanical strain gradient (direct flexoelectric effect) [1] or the mechanical response under an electric field gradient (converse flexoelectric effect). In 1964, Kogan firstly discussed the electric polarization induced in a symmetric crystal by inhomogeneous deformation and introduced the concept of flexoelectricity [2]. The effect is schematically illustrated in Figure 1. As shown in Figure 1a, the material is center symmetric in free status, showing zero polarization. When the unit cell is under uniform strain (Figure 1b), the centers of the negative and positive charges coincide again, thereby resulting in macroscopic zero net polarization. Consider the application of inhomogenous strain depicted in Figure 1c, the displacement of the centers of the negative charge and positive charge differs from each other, creating a dipole moment in the direction opposite to the strain gradient.

In solid dielectrics, the flexoelectric effect can be written as

$$P_l = \mu_{ijkl} \frac{\partial \varepsilon_{ij}}{\partial x_k} \tag{1}$$

where P_l, μ_{ijkl}, ε_{ij} and x_k are flexoelectric polarization, flexoelectric coefficient, elastic strain, and position coordinate, respectively. In a paper published in 1986, [3] Tagantsev suggested that the flexoelectric coefficient (μ_{ijkl}) is linearly proportional to the dielectric susceptibility, which is given as

$$\mu_{ijkl} = \chi_{ij}\gamma_{kl}\frac{e}{a} \tag{2}$$

where χ_{ij} is the susceptibility of the dielectric, γ_{kl} is a constant material parameter tensor, e is the charge of the electron, and a is the atomic dimension of the unit cell of the dielectric. Based on rigid ion model, Tagantsev predicted four contributors

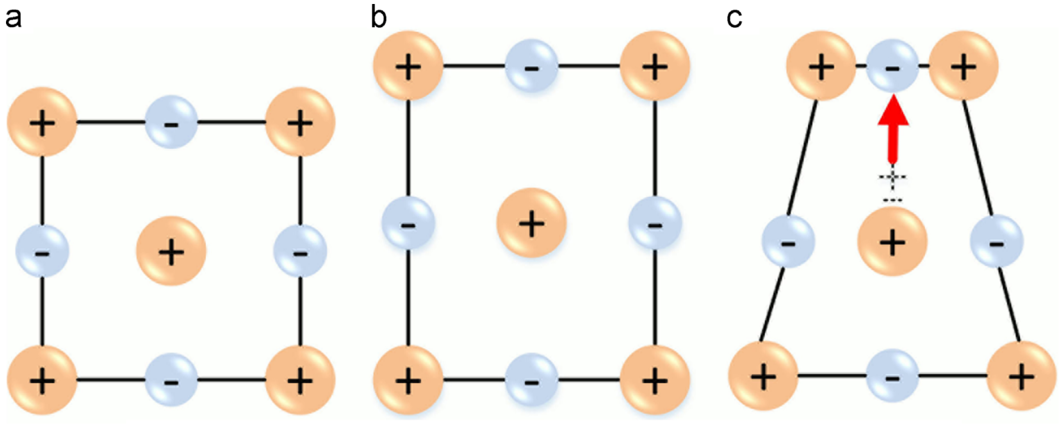

Figure 1 Schematic illustration of flexoelectric effect based on an ionic crystal. (a) Free status without polarization. (b) Zero net polarization under homogeneous deformation due to the overlap of positive and negative charge centers. (c) When experienced an inhomogenous strain, centers of positive and negative charge would mismatch thus creating a non-zero polarization (red arrow) due to the strain gradient.