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Modern Piezoelectric Energy- Harvesting Materials

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Modern Piezoelectric Energy-Harvesting Materials

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To our colleagues, friends and pupils

Preface

Energy is the capacity for doing work. It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms... Energy can be converted from one form to another in various ways. Usable mechanical or electrical energy is, for instance, produced by many kinds of devices, including fuel-burning heat engines, generators, batteries, fuel cells, and magnetohydrodynamic systems.

Encyclopædia Britannica

But do not try to keep what Providence
Has given you, for your own use alone:
We're doomed—and we all know it perfectly
To squander not hoard the wealth we own.

A. Akhmatova

An increasing interest in autonomous devices and electrical accumulators promoted by industrial and domestic applications has raised the issue of powering these systems. In the past decade, the important trend to address this problem consists in using ambient energy from the environment to supply autonomous devices and to make them self-powered with sufficient energetic concentration for various applications. Among the ambient-energy sources to be of interest, one can mention solar, thermal and mechanical sources. Despite this variety, much attention is paid to using mechanical energy, whose sources are available for small-size piezoelectric systems. Mechanical ambient energy to be taken from nature and converted into electrical energy is usually associated with strong winds, sea waves, sounds (acoustic waves) and earthquakes. A conversion of the mechanical form of energy into the electrical form implies using piezoelectric materials due to their sufficiently high energy densities, various electromechanical properties and performance in piezoelectric transducers, sensors, self-powered small-scale devices, hydrophones, etc.

In the past decade, rapid growth in the energy-harvesting field has been obvious, and thereafter the term '*piezoelectric energy harvesting*' has become widespread in the society of scientists and engineers. Piezoelectric energy harvesting is based on the direct piezoelectric effect at which electrical charge (or polarisation of a piezoelectric element) is generated from an external mechanical stress, strain, acoustic wave, vibration sources and so on. It should be added that the piezoelectric

effect is concerned with one of three physical mechanisms of vibration-to-electric energy conversion. Along with the piezoelectric effect, electrostatic and electromagnetic transduction may be effective at this conversion, but to a lesser degree. A piezoelectric harvester can transform kinetic energy from mechanical vibrations into electrical energy due to the piezoelectric effect, and therefore, piezoelectric coefficients concerned with this effect should influence energy-harvesting characteristics of every piezoelectric harvester. Its important feature is that the geometric configuration and sizes of the piezoelectric harvester can be varied in wide ranges, and therefore, the system can be exploited on either a macro-scale or micro-scale level.

Among materials that meet conditions for piezoelectric energy-harvesting applications, in the first line we should highlight poled ferroelectric ceramics and composites based on either ferroelectric ceramics or relaxor-ferroelectric single crystals with high piezoelectric activity. Due to various adaptive characteristics, high piezoelectric performance and possibilities to vary and tailor their electromechanical properties in external fields, the aforementioned composites have been regarded as an important group of smart materials. Undoubtedly, complex and intricate interconnections between microstructure, composition and physical properties of the composites stimulate studies to predict and interpret the properties and related parameters of these materials under various conditions.

In the present monograph we discuss the piezoelectric performance and related parameters that are to be taken into consideration at piezoelectric energy harvesting. In particular, it provides a complex analysis of the *microgeometry-properties* relations in modern piezo-active composites, and this analysis broadens the traditional material-science concepts on the *composition-structure-property* relations and may be a stimulus to create novel high-effective materials with the predictable properties. Important examples of the piezoelectric performance of the composites or ceramics are discussed in the context of their anisotropy, piezoelectric sensitivity, electromechanical coupling, figures of merit and so on. The novelty of the monograph consists in the first systematisation of many authors' results on the performance of modern piezoelectric materials in the context of energy-harvesting applications.

The present monograph has been written on the basis of the authors' research results obtained at the Southern Federal University (Russia) and University of Bath (United Kingdom). The academic style of presentation of the research results and the discussion about these results indicate that this monograph would be useful to engineers, postgraduate students, researchers, and lecturers, i.e., to many specialists working in the field of smart materials, dealing with their effective electromechanical properties and applications. This monograph will be of benefit to all specialists looking to understand the anisotropic electromechanical properties and their links to piezoelectric energy harvesting, its parameters and applications. Some chapters and sections of the monograph may be a basis for a university course devoted to piezoelectric (or ferroelectric and related) materials and their energy-harvesting characteristics. Introducing this new monograph, we would like to mention lines from '*The Reader*' by A. Akhmatova as follows:

Each reader's a treasure-trove hidden
In fathoms of earth—even if
He is undistinguished, unbidden,
And has been mute all of his life.
And buried there, everything lies
That nature deems best to conceal...

Based on our knowledge, experience and new research results, we hope that the twenty-first century termed *The Century of New Materials and Technologies*, will lead to the fruitful development of new scientific directions in the field of piezo-electric energy harvesting and will promote creation of novel high-effective piezoelectric materials for energy-harvesting and related applications.

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