Chapter 5
Conclusions

> Piezoelectrics with electromechanical coupling, shape-memory materials that can "remember" their original shape, electrorheological fluids with adjustable viscosities, and chemical sensors which act as synthetic equivalents to the human nose are examples of smart electroceramics. "Very smart" materials, in addition to sensing and actuating, have the ability to "learn" by altering their property coefficients in response to the environment. Integration of these different technologies into compact, multifunction packages is the ultimate goal of research in the area of smart material.
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> R. E. Newnham

5.1 From Materials to Applications

The present monograph has been devoted to the performance of modern piezoelectric materials that can be applied as active elements of energy-harvesting devices or systems. In the last decade piezoelectric materials (mainly poled FCs and piezo-active composites based on either FCs or relaxor-ferroelectric SCs) have been the focus of many studies on energy-harvesting characteristics. The growing demand for effective energy-harvesting materials for the conversion of mechanical vibrations into electrical energy has motivated the production of this monograph to present the current state of knowledge in the field of piezoelectric materials, to discuss their performance and to develop concepts from previous monographs [1, 2] by the authors.

The high piezoelectric performance, strong electromechanical coupling, large figures of merit and considerable anisotropy enable us to regard the piezoelectric materials as an important group of energy harvesting materials that are suitable for effective conversion of mechanical energy into electrical energy. Based on these factors, one can select the appropriate piezoelectric materials for specific transducer, hydroacoustic, and related applications [3–5]. Piezoelectrics can also be selected for electromechanical and energy-harvesting systems [6–8] by taking into account

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modern energy-harvesting methods [9] and advanced technologies for processing novel materials [10–12].

As follows from numerous publications from the past decade, the overwhelming majority of piezoelectric energy harvesting materials are ferroelectrics or composites based on them. A unique charactristic of ferroelectric materials is the ability to combine ferroelectric, pyroelectric and electromechanical properties along with the opportunity to further improve these properties using the composite approach. These advantages make ferroelectric materials and their composites a promising and high-performance class of material for piezoelectric energy harvesting.

Our study enables us to conclude that the electromechanical properties of the piezoelectric materials and the optimistation of their properties (Fig. 5.1) open up new opportunities to use these materials for energy harvesting applications. Of particular interest are piezo-active composites with specific microgeometries and predictable effective properties [1, 2] that can be varied in wide ranges. These properties and related parameters have been determined for specific composite architectures, connectivity and components. In a number of cases, composites with 1−3, 2−2 or 0−3 connectivity patterns have the effective electromechanical properties and related parameters which can be improved by using relaxor-ferroelectric

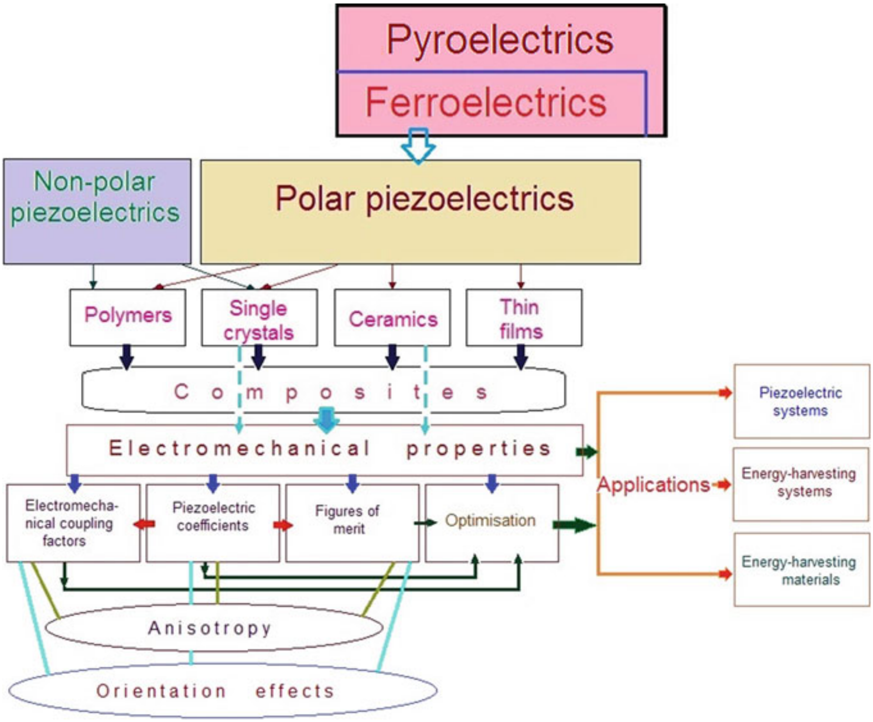

Fig. 5.1 Outline of directions of the study on piezo-active materials for energy harvesting applications

SCs with engineered-domain structures and very high piezoelectric activity, by an incorporation of porous or auxetic polymer matrices, etc. An additional stimulus to improve the electromechanical properties and parameters for piezoelectric energy harvesting is concerned with the third component and orientation effects [2] in modern piezo-active composites.

Undoubtedly, the diagram shown in Fig. 5.1 will be enlarged in the future due to new and pioneering work in the field of piezoelectric energy harvesting. It seems to be realistic that research in piezoelectric energy harvesting and related subjects (materials, properties and their optimisation) will continue to be actively carried out in the nearest future, and results from studies in physics, chemistry, mechanics, materials science, and engineering sciences will be taken into account and improved upon. It is believed that the FCs and composites based on ferroelectrics will attract interest for numerous piezotechnical and energy harvesting applications in the 21st century. In this context we would like to finish our monograph by the following words by Karl Ernst von Baer: "Die Wissenschaft ist ewig in ihrem Quell, unermesslich in ihrem Umfang, endlos in ihrer Aufgabe, unerreichbar in ihrem Ziel[1]".

References

1. Topolov VYu, Bowen CR (2009) Electromechanical properties in composites based on ferroelectrics. Springer, London
2. Topolov VYu, Bisegna P, Bowen CR (2014) Piezo-active composites. Orientation effects and anisotropy factors. Springer, Berlin
3. Safari A, Akdogan EK (eds) (2008) Piezoelectric and acoustic materials for transducer applications. Springer, New York
4. Sverdlin GM (1990) Applied hydroacoustics. Soodostroyeniye, Leningrad (in Russian)
5. Sherman CH, Butler JL (2007) Transducers and arrays for underwater sound. Springer, New York
6. Preumont A (2006) Mechatronics. Dynamics of electromechanical and piezoelectric systems. Springer, Dordrecht
7. Lenk A, Ballas RG, Werthschützky R, Pfeifer G (2011) Electromechanical systems in microtechnology and mechatronics. electrical, mechanical and acoustic networks, their interactions and applications. Springer, Berlin
8. Kaźmierski TJ, Beeby S (eds) (2011) Energy harvesting systems. Principles, modeling and applications. Springer, New York Dordrecht Heidelberg London
9. Elvin N, Erturk A (eds) (2013) Advances in energy harvesting methods. Springer, New York
10. Wang ZL, Wu W (2012) Nanotechnology-enabled energy harvesting for self-powered micro-/nanosystems. Angew Chem 51:11700–11721
11. Crossley S, Kar-Narayan S (2015) Energy harvesting performance of piezoelectric ceramic and polymer nanowires. Nanotechno 26:344001
12. Liu L, Lu K, Wang Y, Liao F, Peng M, Shao M (2015) Flexible piezoelectric nanogenerators based on silicon nanowire/α-quartz composites for mechanical energy harvesting. Mater Lett 160:222–226

[1]Science is eternal in its source, immeasurable in its scope, endless in its task, unattainable in its aim.