

Preface

Piezoelectricity — a phenomenon of the direct conversion of electrical and mechanical energy — has been discovered by Pierre and Jacques Curie about 135 years ago. Since that time, it is an excellent example of coupled field phenomena in physics. It attracted a lot of interest from the application point of view not only in its static (or quasistatic) form, but also in the properties of mechanically resonating bodies excited piezoelectrically, i.e. piezoelectric resonators. Such elements are nowadays used as resonant sensors, in electronic circuits, acoustical systems, actuators and ultrasonic motors or in energy harvesting devices. Piezoelectric resonators were treated in the literature as you can see from the comprehensive, although not exhaustive, list of books published within the last three decades. Although many literature sources cover various aspects of piezoelectric resonators and their applications, the fundamental literature is more than five decades old. Comprehensive textbook covering all fundamental properties of piezoelectric resonators for ceramic materials is not easily available. Specialized monography published on piezoelectric resonators — J. Zelenka: *Piezoelectric resonators and their applications*, Elsevier, Amsterdam 1986 — is also 30 years old already. Moreover, it is devoted specifically to quartz resonators, but not to piezoelectric resonators made from ferroelectric ceramics.

The authors would like to bridge this gap in specialized literature by this textbook focused specifically on the fundamentals of piezoelectric resonators based on crystallographically highly symmetrical material, i.e., ferroelectric ceramics. Its piezoelectricity is a result of material anisotropy imposed by poling in ceramic material. We can profit from the basic piezoelectricity and ferroelectricity phenomena explanations and descriptions published in the previous book — J. Tichý, J. Erhart, E. Kitinger, J. Přivratská: *Fundamentals of piezoelectric sensors: Mechanical, dielectric, and thermodynamical properties of piezoelectric materials*, Springer Verlag, Berlin, Heidelberg 2010. Therefore we can recommend this book for the basic reading on piezoelectricity phenomena and materials and to cover and explain piezoelectric ceramic resonators only. The textbook and the above-mentioned book are complementary in this sense. Piezoelectricity phenomena and

materials are also briefly treated in the textbook, but with simplifications and an emphasis on ceramic materials. Description of tensors, crystallographic symmetry and coupled field thermodynamics is however referenced to some of the specialized books. Linear piezoelectricity is used for all resonators and their property derivations. The textbook could help the reader not only in finding answers to the resonance parameters of piezoelectric ceramic resonators in comprehensive tables, but also to profit from the detailed derivations for each resonator and to learn methods useful in reader's own research. The textbook is based mainly on authors' experience with piezoelectric resonator research and teaching gained at the Piezoelectricity Research Laboratory at the Technical University of Liberec. Literature sources dealing with piezoelectric resonators are carefully reviewed, although fully exhaustive list of all applications and resonator types could not be included. We therefore limited this textbook to the basic resonator shapes and vibration modes, and application of resonators for the material property measurement and the piezoelectric transformer modeling, which two of the authors (J.E. and P.P.) studied theoretically as well as experimentally during last decade. List of references related to piezoelectric resonators is provided for the reader's convenience.

Authors completed the manuscript according to their own specialization in the field of piezoelectric resonators — i.e. J. Erhart prepared Chaps. 1, 2, 4, 5 (together with P. Půlpán) and Appendix A, M. Pustka completed Chap. 3 (with examples of measured resonators prepared by J. Erhart), Appendices B, C, D and prepared drawings of resonator figures and schemes. Finally, P. Půlpán contributed to Chap. 5 and edited all graphs for the manuscript. Final edition of the whole manuscript was prepared by all authors in cooperation.

Textbook content is organized in five chapters and four Appendices. Chap. 1 is devoted to the fundamentals of piezoelectricity, history of the phenomenon discovery, its basic description by tensors, crystallography and thermodynamics of coupled fields. Properties of the main piezoelectric ceramic materials are briefly reviewed in Chap. 2, serving also as the property tables for the reader's own material application research. An example of mechanically textured ceramic material and related calculation of the effective symmetry is included. Chap. 3 is focused on the properties of piezoelectric resonators in detailed derivations. General method of immittance (i.e. impedance or admittance) complex function is presented and applied for each calculated resonator. Resonators in the form of bars, plates, discs, rings or tubes are described for various vibration modes. Immittance and equivalent electrical circuit parameters are derived for each resonator. Comprehensive table of all calculated resonators is given for the reader's convenience in Appendix D. The applications of piezoelectric resonators for the material property measurement according to piezoelectric standard procedures are presented in Chap. 4. The resonators needed to measure all coefficients for full tensors of electromechanical properties are covered including Poisson's ratio measurement and experimental error analysis. Chapter 4 is completed by derivations of thermal stability for the resonance frequency for bar, plate or disc shaped resonators. Finally, Chapter 5 serves as an example of piezoelectric ceramic resonator

application in more advanced structures — piezoelectric transformers. It describes mathematical modeling for the various shapes of piezoelectric transformers working in different vibration modes (bar, plate, disc and ring) by immittance method. Numerical examples of transformer parameter optimization are included, experimental data are however referenced to the previously published literature only. Appendices A, B and C contain material tensors and equations in Cartesian or cylindrical coordinates, respectively.

The authors are very much indebted to Springer Verlag publisher for selecting piezoelectricity and piezoelectric resonators as a textbook topic and for the help with careful textbook print preparation. We also would like to thank to all colleagues at VÚTS, who stimulated our effort to prepare textbook manuscript and contributed to our work through their advise. Authors are very much indebted to Profs. Jiří Zelenka (†2001) and Jan Tichý (†2012), our great colleagues and teachers, who started our interest in piezoelectricity and piezoelectric resonators. Continuing support from PZT ceramics manufacturers — APC International, Ltd., Mackeyville, PA, USA and Noliac Ceramics, s.r.o., Hradec Králové, Czech Republic — is highly acknowledged. Authors' knowledge and expertise in the field of piezoelectricity literally grew up on their PZT ceramics products. Financial support from the Czech Ministry of Education under the project LO1213 is also highly acknowledged. Last but not least, the authors would like to thank to their wives and families for their patience and kind understanding during preparation of the manuscript.

April 2016

Jiří Erhart
Martin Pustka
Petr Půlpán
Liberec, Czech Republic

References

Piezoelectricity - fundamentals and special topics

- Ikeda T (1990) Fundamentals of piezoelectricity, Oxford University Press
 Rosen CZ, Hiremath BV, Newnham R (1992) Piezoelectricity. Key papers in Physics, AIP
 Yang J (2005) An introduction to the theory of piezoelectricity, Springer, New York
 Yang J (ed.) (2009) Special topics in the theory of piezoelectricity, Springer, New York
 Tichý J, Erhart J, Kittinger E, Přivratská J (2010) Fundamentals of piezoelectric sensorics: Mechanical, dielectric, and thermodynamical properties of piezoelectric materials, Springer
 Qin QH (2013) Advanced mechanics of piezoelectricity, Higher Education Press, Beijing and Springer, Berlin, Heidelberg

Ferroelectricity, ferroelectric crystals, domains

- Xu Y (1991) Ferroelectric materials and their applications, North-Holland
 Jona F, Shirane G (1993) Ferroelectric crystals, Dover
 Strukov BA, Levanyuk AP (1998) Ferroelectric phenomena in crystals, Springer
 Lines ME, Glass AM (2001) Principles and applications of ferroelectrics and related materials, Oxford University Press

- Newnham RE (2005) Properties of materials — Anisotropy, symmetry, structure, Oxford University Press
- Gonzalo JA, Jimenez B (eds) (2005) Ferroelectricity, The fundamentals collection, J Wiley & Sons
- Fujimoto M (2005) The physics of structural phase transitions, Springer
- Haussühl S (2007) Physical properties of crystals, An introduction, J Wiley & Sons-VCH
- Tagantsev AK, Cross LE, Fousek J (2010) Domains in ferroic crystals and thin films, Springer, New York

Materials, ferroelectric ceramics

- Setter N, Colla EL (1993) Ferroelectric ceramics, Birkhauser
- Bengisu M (ed) (2001) Engineering ceramics, Springer
- Setter N (ed) (2002) Piezoelectric materials in devices, EPFL
- Moulson AJ, Herbert JM (2003) Electroceramics — Material, properties, applications, J Wiley & Sons
- Buchanan RC (ed) (2004) Ceramic materials for electronics, 3rd edition, Marcel Dekker
- Safari A, Akdogan EK (2008) Piezoelectric and acoustic materials for transducer applications, Springer
- Ye ZG (ed) (2008) Handbook of advanced dielectric, piezoelectric and ferroelectric materials: Synthesis, properties and applications, Woodhead Publishing Ltd.
- Heywang W, Lubitz K, Wersing W (eds) (2008) Springer Series in Materials Science 114, Piezoelectricity Evolution and future of a technology, Springer, Berlin, Heidelberg
- Akopyan VA, Soloviev A, Parinov IA, Shevtsov SN (2010) Definition of constants for piezoceramic materials, Nova Science Publishers
- Uchino K (ed) (2010) Advanced piezoelectric materials: Science and technology, Woodhead Publishing Ltd.
- Pardo L, Ricote J (eds) (2011) Springer Series in Materials Science, Vol. 140, Multifunctional polycrystalline ferroelectric materials, processing and properties, Springer
- Priya S, Nahm S (eds) (2012) Lead-free piezoelectrics, Springer
- Somiya S (ed) (2013) Handbook of advanced ceramics, 2nd edition, Materials, applications, processing, and properties, Elsevier
- Parinov IA (ed) (2014) Advanced nano- and piezoelectric materials and their applications, Nova Science Publishers
- Parinov IA (ed) (2015) Piezoelectrics and nanomaterials: Fundamentals, developments and applications, Nova Science Publishers

Resonators

- Zelenka J (1986) Piezoelectric resonators and their applications, Elsevier
- Royer D, Dieulesaint E (2000) Elastic waves in solids I., Springer
- Royer D, Dieulesaint E (2000) Elastic waves in solids II., Springer
- Yang J (2006) The mechanics of piezoelectric structures, World Scientific
- Yang J (2006) Analysis of piezoelectric devices, World Scientific
- Yang J (2010) Antiplane motions of piezoceramics and acoustic wave devices, World Scientific

Applications — devices and structures, energy harvesting

- Uchino K (1997) Piezoelectric actuators and ultrasonic motors, Kluwer
- Tabib-Azar M (1998) Microactuators, electrical, magnetic, thermal, optical, mechanical, chemical and smart structures, Kluwer
- Bush-Vishniac IJ (1999) Electromechanical sensors and actuators, Springer
- Uchino K (2000) Ferroelectric devices, Marcel Dekker
- Galassi et al. (2000) Piezoelectric materials: Advances in science, technology and applications, NATO Science Series, Vol. 76, Kluwer
- Gautschi G (2002) Piezoelectric sensorics, Springer
- Arnau A (ed.) (2004) Piezoelectric transducers and applications, Springer

- Preumont A (2006) *Mechatronics: Dynamics of electromechanical and piezoelectric systems*, Springer
- Wang KW, Tang J (2008) *Adaptive structural systems with piezoelectric transducer circuitry*, Springer, New York
- Vives AA (2008) *Piezoelectric transducers and applications*, Springer, Berlin, Heidelberg
- Priya S, Inman DJ (eds.) (2009) *Energy harvesting technologies*, Springer, New York
- Jalili N (2010) *Piezoelectric-based vibration control*, Springer
- Sharapov V (2011) *Piezoceramic sensors*, Series: Microtechnology and MEMS, Springer
- Segel JE (2011) *Piezoelectric actuators*, Nova Science Publishers
- Erturk A, Inman DJ (2011) *Piezoelectric energy harvesting*, J Wiley & Sons
- Xu Q, Tan KK (2015) *Advanced control of piezoelectric micro-/nano-positioning systems*, Springer
- Levinzon F (2015) *Piezoelectric accelerometers with integral electronics*, Springer

History

- Katzir S (2006) *The beginnings of piezoelectricity, A Study in Mundane Physics*, Vol. 246 Boston studies in the philosophy of science, Springer

Piezoelectric Ceramic Resonators

Erhart, J.; PŰlpán, P.; Pustka, M.

2017, XVII, 251 p. 111 illus., 43 illus. in color.,

Hardcover

ISBN: 978-3-319-42480-4