Materials Science and Engineering R 89 (2015) 1–48

Contents lists available at ScienceDirect

Materials Science and Engineering R

journal homepage: www.elsevier.com/locate/mser

Losses in ferroelectric materials

Gang Liu [a,b,c], Shujun Zhang [b], Wenhua Jiang [b], Wenwu Cao [a,b,*]

[a] Condensed Matter Science and Technology Institute, Harbin Institute of Technology, Harbin 150080, China
[b] Department of Mathematics and Materials Research Institute, The Pennsylvania State University, University Park, PA 16802, USA
[c] Center for High Pressure Science and Technology Advanced Research, Shanghai 201203, China

ARTICLE INFO

Article history:
Available online 14 February 2015
Guiding Editor: Paul Chu

Keywords:
Energy dissipation
Energy loss
Quality factor
Ferroelectrics
Piezoelectric
Dielectric

ABSTRACT

Ferroelectric materials are the best dielectric and piezoelectric materials known today. Since the discovery of barium titanate in the 1940s, lead zirconate titanate ceramics in the 1950s and relaxor-PT single crystals (such as lead magnesium niobate–lead titanate and lead zinc niobate–lead titanate) in the 1980s and 1990s, perovskite ferroelectric materials have been the dominating piezoelectric materials for electromechanical devices, and are widely used in sensors, actuators and ultrasonic transducers. Energy losses (or energy dissipation) in ferroelectrics are one of the most critical issues for high power devices, such as therapeutic ultrasonic transducers, large displacement actuators, SONAR projectors, and high frequency medical imaging transducers. The losses of ferroelectric materials have three distinct types, i.e., elastic, piezoelectric and dielectric losses. People have been investigating the mechanisms of these losses and are trying hard to control and minimize them so as to reduce performance degradation in electromechanical devices. There are impressive progresses made in the past several decades on this topic, but some confusions still exist. Therefore, a systematic review to define related concepts and clear up confusions is urgently in need. With this objective in mind, we provide here a comprehensive review on the energy losses in ferroelectrics, including related mechanisms, characterization techniques and collections of published data on many ferroelectric materials to provide a useful resource for interested scientists and engineers to design electromechanical devices and to gain a global perspective on the complex physical phenomena involved. More importantly, based on the analysis of available information, we proposed a general theoretical model to describe the inherent relationships among elastic, dielectric, piezoelectric and mechanical losses.

For multi-domain ferroelectric single crystals and ceramics, intrinsic and extrinsic energy loss mechanisms are discussed in terms of compositions, crystal structures, temperature, domain configurations, domain sizes and grain boundaries. The intrinsic and extrinsic contributions to the total energy dissipation are quantified. In domain engineered ferroelectric single crystals and ceramics, polarization rotations, domain wall motions and mechanical wave scatterings at grain boundaries are believed to control the mechanical quality factors of piezoelectric resonators. We show that a thorough understanding on the kinetic processes is critical in analyzing energy loss behavior and other time-dependent properties in ferroelectric materials. At the end of the review, existing challenges in the study and control of losses in ferroelectric materials are analyzed, and future perspective in resolving these issues is discussed.

* Corresponding author at: Materials Research Institute, The Pennsylvania State University, University Park, PA 16802, USA.
E-mail address: dzk@psu.edu (W. Cao).

http://dx.doi.org/10.1016/j.mser.2015.01.002

Contents