Preface

This book is a natural continuation of the author's previous book, "*An Introduction to the Theory of Piezoelectricity*" (Springer, New York, 2005), which discusses the three-dimensional theory of piezoelectricity. Three-dimensional theory presents complicated mathematical problems due to the anisotropy of piezoelectric crystals and electromechanical coupling. Very few problems in piezoelectric devices can be directly analyzed by the three-dimensional theory. To obtain results useful for device applications, usually numerical methods have to be used or structural theories have to be developed to simplify the problems so that theoretical analyses are possible. These two approaches are both very effective in the modeling and design of piezoelectric devices.

For piezoelectric devices, dynamic problems are frequently encountered. This is because many piezoelectric devices are resonant devices operating at a particular resonant frequency and mode of a structure. Both surface acoustic waves (SAW) and bulk acoustic waves (BAW) are used. In the analysis of resonant piezoelectric devices, usually vibration characteristics like frequency and wave speed are of primary interest, not the stress and strain for strength and failure consideration as in traditional structural engineering.

Another rather unique feature of the analysis of resonant piezoelectric devices is that BAW devices often operate with the so-called high-frequency modes. Take a plate as an example. The high frequency modes, e.g., thickness-shear and thickness-stretch, are modes whose frequencies are determined by the plate thickness, the smallest dimension. This is in contrast to the low frequency modes of extension and flexure in traditional structural engineering, whose frequencies depend strongly on the length and/or width of the plate. Another characteristic of the high frequency modes is that for long waves their frequencies do not go to zero but have finite cutoff frequencies. This has implications in certain unique behaviors of the high frequency modes such as the useful energy trapping phenomenon.

THE MECHANICS OF PIEZOELECTRIC STRUCTURES

In applications to high-frequency, dynamic problems of piezoelectric devices, the accuracy of a structural theory is judged by its dispersion relation of the wave solution of the operating mode of a device in the frequency range and wave number range of interest. This is different from traditional structural engineering where, for example, the stress distribution over the cross section of a beam or plate is often of main interest.

The study of high frequency modes in piezoelectric plates by structural theories was initiated by R. D. Mindlin. Mindlin's effort in the shear deformation plate theory was mainly for the analysis of thickness-shear vibrations of crystal plates, a problem motivated by the study of piezoelectric resonators. Under the influence of the pioneering work of Cauchy, Poisson and Kirchhoff, Mindlin systematically derived equations for high-frequency vibrations of piezoelectric plates based on expansions and approximations in the variational formulation of the three-dimensional theory, and studied behaviors of the high-frequency modes using plate equations. A systematic treatment of high frequency vibrations of crystal plates was given by Mindlin in "An Introduction to the Mathematical Theory of Vibrations of Plates" (the U.S. Army Signal Corps Engineering Laboratories, Fort Monmouth, NJ, 1955), which was not formally published.

This book focuses on high-frequency, dynamic theories of piezoelectric structures for device applications. It emphasizes the development of theories and the determination of the frequency ranges and wave number ranges in which the theories are good approximations of the three-dimensional theory. Following a brief summary of the three-dimensional theories of electroelastic bodies in Chapter 1, the development of two-, one- and zero-dimensional theories for high-frequency vibrations of piezoelectric plates, shells, beams, rings and parallelepipeds is systematically presented in subsequent chapters. The range of applicability of the structural theories obtained is examined by comparing dispersion relations of simple wave solutions from the structural theories to the dispersion relations of the exact solutions of the same waves from the three-dimensional theories. In addition to linear piezoelectricity, certain nonlinear effects are also considered. As examples of applications, simple vibrations of piezoelectric plates, shells, beams and rings are analyzed. A few piezoelectric devices including resonators, actuators, a mass sensor, a fluid sensor, a transformer, a gyroscope and buckling of thin structures are also studied using structural theories.

The main purpose of the book is to present a procedure systemized by Mindlin for developing structural theories, rather than collecting all theories for piezoelectric structures. It is hoped that, having read a book like this, one can develop various structural theories needed when facing different device problems.

Due to the use of quite a few stress tensors and electric fields in nonlinear electroelasticity, a list of notation is provided in Appendix 1. Material constants of some common piezoelectric materials are given in Appendix 2.

I would like to take this opportunity to thank Ms. Deborah Derrick of the College of Engineering and Technology at UNL for editing assistance with the book, and Mr. Honggang Zhou, my graduate student, for plotting Figures 2.5.2 and 2.5.3.

JSY
Lincoln, NE
September, 2005