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Daining Fang
Jinxi Liu

压电与铁电体的断裂力学

Fracture Mechanics of Piezoelectric and Ferroelectric Solids

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With 209 figures

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内 容 简 介

本书是关于压电/铁电材料断裂力学的专著，从理论分析、数值计算和实验观察三个方面比较全面、系统地阐述了压电/铁电材料的电致断裂问题，强调静态、动态和界面断裂问题的力学提法以及力电耦合效应所导致的电致断裂的物理本质。本书的主要特色是：从晶体学的角度简要介绍了压电/铁电材料的基本特征；详细描述了压电材料的基本方程以及与断裂问题相关的一般解；以图的形式提供了大量的数值结果；给出了主题词和作者索引；用简洁的语言解释了复杂的电致断裂问题。本书可帮助固体力学、材料科学、应用物理和机械工程领域的读者很容易地抓住问题的物理本质并把握压电/铁电材料断裂力学的研究现状。

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Daining Fang
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Fracture Mechanics of Piezoelectric and Ferroelectric Solids

Foreword

Mechanical-electrical coupling and anisotropy of piezoelectric/ferroelectric solids complicate studies of their damage and fracture. Therefore, the solution of fracture mechanics problems for such materials is challenging. It has become an important subject in solid mechanics and materials physics to understand the physical mechanisms of fracture of piezoelectric/ferroelectric solids and improve the fracture resistance of such materials. This book discusses the characteristics and engineering background of piezoelectric/ferroelectric solids, the electromechanical coupling fracture behavior and failure modes from a systematic point of view, which combines solid mechanics and material physics. The establishment of fracture criteria is the embodiment of the research findings and theoretical system formed in recent years, which not only enriches the subject of studies in solid mechanics, but also underlies important academic values. This book is featured with the subject of “How Electromechanical Coupling Effect Influences Fracture Behavior of Piezoelectric/Ferroelectric Materials”, and addresses clear physical concepts and prudent mathematic mechanics, leverages theoretical approaches, experimental technology and actual materials as a valuable reference for postgraduates and researchers in solid mechanics and materials physics.

The authors of the book, Professors Daining Fang and Jinxi Liu are both young scholars with high academic accomplishments as well as solid and profound foundation in the mechanic theories of intelligent materials and expertise in materials physics. Their work has focused on theories and experimental research in deformation and fracture of piezoelectric/ferroelectric materials and ferromagnetic materials, where they made a series of important innovations with significant impact both at home and abroad. Based on their years of research and studies of relevant literature in China and abroad, they have systematically interpreted the fundamental theories and research approaches as applied to fracture of piezoelectric/ferroelectric solids in the form of a monograph with unique and rich content, wide coverage of literature, step-by-step discussion, clean and prudent structure and high academic standards. It is an excellent academic book and I hereby would highly recommend it to the readers.

黄克智

Kezhi Huang

At Tsinghua University

Preface

Rapid changes in the information technology have led to the development of mature technology for MEMS (microelectromechanical systems), microelectronics and packaging, sensing, actuation and the intelligent structure of control since the end of the 20th century. As a result, new scientific problems in multi-field coupling of functional materials and micro information structural mechanics are proposed. For stress, strain and strong interaction between heat and electromagnetic phenomena, mechanical rules become extremely important to the design of the above MEMS, microelectronics and intelligent structures. Therefore, the reliability of these devices is attracting increasing attention. Fragility of piezoelectric/ferroelectric ceramics and defect formation during their preparation, such as voids and cracks, generally lead to the loss of expected functions and even damage of piezoelectric/ferroelectric components or piezoelectric/ferroelectric intelligent structures in terms of the single or synergic functions of mechanical and electric loading. Such challenges urge us to understand the physical mechanisms of fracture of piezoelectric/ferroelectric materials in order to provide theoretical basis for the reliability analysis and life cycle prediction of piezoelectric/ferroelectric materials. The science of fracture mechanics of piezoelectric/ferroelectric solids has undergone significant development since the end of 1980s. In the second half of last century, researchers in mechanics, physics and materials both in China and abroad made wide and in-depth investigations, which resulted in major breakthroughs. Although there are still disputes on some problems, it is possible to say that the theoretical framework of fracture mechanics of piezoelectric/ferroelectric solids has been well established.

The author of the book has been engaged in the study of deformation and fracture mechanisms of piezoelectric/ferroelectric materials for over ten years and, as a result, gained significant experience and made distinct achievements in this area. This book attempts to give a systematic discussion on the fracture mechanics of piezoelectric/ferroelectric materials based on the research done by the author in combination with references to research done both at home and abroad. It explores some basic problems in mechanics of piezoelectric/ferroelectric solids under the topic of “How Electromechanical Coupling Effect Influences Fracture Behavior of Piezoelectric/Ferroelectric Materials”. There are 13 chapters in the book, of which the first four chapters introduce applications of piezoelectric/ferroelectric materials, experimental methods and findings related to piezoelectric/ferroelectric fracture, characteristics of electromechanical coupling and basic formulas of piezoelectrics. The fifth chapter discusses the general resolutions of electromechanical coupling formula of piezoelectric materials. The last eight chapters discuss fracture behavior of piezoelectric/ferroelectric materials, covering the nature of tip-field, interfacial fracture, dynamic fracture, non-linear fracture, electromechanical coupling numerical methods, electrically induced fatigue crack extension, electrode induced, electroelastic field concentration, and mechatronic coupling fracture criteria.

The main purpose of the book is to induce new thinking that would benefit future developments in this field. Therefore, this book attempts to describe fracture mechanics of piezoelectric/ferroelectric materials from several perspectives not only addressing theoretical analysis of fracture, but also the findings of numerical simulations and experiments. Electromechanical coupling effects and anisotropic fracture features of piezoelectric/ferroelectric solids complicate the study of the fracture characteristics. Therefore, it is challenging to solve the problems in electromechanical coupling fracture mechanics. The authors attempt to cover theories and experiments, principles and applications, and present critique and new thoughts at the same time. This book is not only a complete and systematic treatise, but it also relates theory to practice in order to reflect the latest progress in this field.

Although the literature cited by the authors covers wide-ranging field, it is far from exhaustive. Owing to the abundance and complicated nature of the literature on this subject, it is inevitable that some studies are not included in this book and we regret if we missed to cite some achievements in this field. The authors sincerely hope that the publication of the book shall facilitate the applications of piezoelectric/ferroelectric materials and the development of new functional materials in China. At the same time, it shall also serve as a high level reference book for teachers, graduates and professional technicians conducting research in solid mechanics, materials science, dielectric physics, mechanical and electrical engineering. Due to the limited theoretical capability and practical experience of the authors, there may be errors and inappropriateness in the book and the authors sincerely hope to receive corrections and critiques from specialists and readers.

The studies conducted by the authors themselves and described in this book have been awarded sponsorship as Key Project of “9th Five-Year-Plan”, Outstanding Youth Funding, Innovative Collective Project and International Cooperation Project under National Natural Science Foundation of China (NSFC) as well as the sponsorship for key project of Ministry of Education of China (MEC) and Doctorate Fund Projects of MEC. The authors are deeply grateful for such sponsorships, without which it would be difficult to complete such studies. The book also contains achievements made by the team members of the authors in post-doctorate/graduate programs over the last 12 years. The authors would like to

thank their team members for their diligence, talents, contributions and cooperation in these studies. In their research, the authors have been cooperating with Professor A.K. Soh from Hong Kong University, Professor C.T. Sun from Prudent University of USA, Professor J.Y. Li from Washington University. The author of this book has benefited tremendously from their profound expertise and extends his sincere gratitude to them. The author also sincerely thanks his dear colleagues, Huang Kezhi and Yang Wei, who are also Academicians of Chinese Academy of Sciences, for their encouragement, assistance and support over many years. Finally, the author is especially grateful to Mr. Mao Guanzhong, Mr. Wei Weiyi, Mr. He Huijing and Ms. Zhao Xiaofang for their great support in typing the manuscript, amending the graphs and charts, and setting up the literature index.

By the first author
At Beijing Tsinghua Park

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