

Preface

“Mesoscopic Phenomena in Multifunctional Materials” is at the heart of many current technologies and entails a fundamental need to control various materials functionalities such as magnetoelectricity and piezo-response at the mesoscale. The book brings out the state of the art on the present understanding and potential applications of complex multifunctional materials. The main emphasis is on the multiscale bridging of properties from nano- to macroscopic scales in this class of (multiferroic and multifunctional) materials with the aim of discovering novel properties and applications in the context of Materials by Design. The book is expected to be broadly accessible and caters to graduate students, beginning researchers as well as experts.

The twelve chapters in the book are partly a review with a broad perspective and partly original research that delineates open issues in the field. The scope of the book is as follows. “A highly desirable feature of modern materials science is to optimize multiple functionalities in the same single phase material and control these via cross-response in multiple external fields. Magnetoelastic and multiferroic materials are representative examples of this paradigm. Now that the nano- and continuum length (and time) scales have been understood in great detail, the next important frontier is to connect these two limiting scales by probing and modeling the mesoscale physics of these materials. Seamless integration across the scales and information flow between different length (and time) scales are key features. Clearly these concepts can also be extended to composites of materials with complementary properties.”

The first two chapters provide a description of nanoscale characterization of and nanoscale phase transformations in multifunctional materials. Chapter 3 focusses on the relevance of modelling of microstructure, heterogeneities and discusses the importance of using large computational capabilities in designing materials with desired properties. A special emphasis is placed on information theoretic and co-design aspects of materials modeling strategies. The thermodynamics of multiferroic materials is developed in detail in the next chapter including technologically important multicaloric effects. Examples for prototypical multiferroic systems are also provided. Chapters 5 and 6 provide an in-depth description of high resolution imaging techniques for both real-space and k-space imaging of mesoscopic phenomena, in particular domains, anti-phase boundaries, magnetic flux lines and magnetic vortices in magnetic shape memory and related materials.

Some examples of the techniques include energy-filtered transmission electron microscopy, phase reconstructed Lorentz transmission electron microscopy and electron holography.

Chapter 7 is an extensive review of combinatorial and other synthesis strategies for technologically important (e.g. in magnetic recording, data storage and mobile communications) magnetoelectric hexagonal ferrites, in particular single phase cryogenic as well as room temperature materials. Chapter 8 deals with domain boundary engineering by functionalizing them, examples being conductive twin boundaries and chiral twin walls. It also delineates how to achieve high domain wall densities to optimize functionality. Chapter 9 further emphasizes the physics of ferroic and multiferroic domain walls including their dynamics and octahedral tilts. Chapters 10 and 11 focus on the role of disorder in relaxor ferroelectrics and ferroelastics, respectively, with an emphasis on glassy phenomena: polar glass and strain glass (as ferroic extensions of spin glass). The notions of polar nanoregions and strain nanodomains are specifically emphasized in this context. Finally, the last chapter elucidates two important applications of shape memory materials in power generation and refrigeration technologies based on entropy change during the transformation and reversible changes in their physical properties. The roles of hysteresis, fatigue, magnetocrystalline anisotropy and combinatorial synthesis are underscored.

These chapters discuss many open questions and set the stage for future research in this still evolving field. A close integration of various synthesis, characterization, modeling, simulation and data-aware strategies (that use techniques from information science, e.g. data mining and machine learning) is urgently needed to fully harness the potential of multifunctional materials. In addition to researchers, the book will serve as a valuable resource for graduate students in materials science and engineering, condensed matter physics and other related disciplines.

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