January 2004

Preface to *Nanoscale Characterization of Ferroelectric Materials: Scanning Probe Microscopy Approach*

Mann Alexe

Alexei Gruverman
University of Nebraska-Lincoln, agruverman2@unl.edu

From: *Nanoscale Characterization of Ferroelectric Materials: Scanning Probe Microscopy Approach,* ed. Mann Alexe and Alexei Gruverman (Berlin & Heidelberg: Springer-Verlag, 2004), pp. v–vi.

Preface

Among the main trends in our daily society is a drive for smaller, faster, cheaper, smarter computers with ever-increasing memories. To sustain this drive the computer industry is turning to nanotechnology as a source of new processes and functional materials, which can be used in high-performance high-density electronic systems. Researchers and engineers have been focusing on ferroelectric materials for a long time due to their unique combination of physical properties. The ability of ferroelectrics to transform electromagnetic, thermal, and mechanical energy into electrical charge has been used in a number of electronic applications, most recently in nonvolatile computer memories. Classical monographs, such as *Ferroelectricity* by E. Fatuzzo and W. J. Mertz, served as a comprehensive introduction into the field for several generations of scientists. However, to meet the challenges of the "nano-era," a solid knowledge of the ferroelectric properties at the nanoscale needs to be acquired. While the science of ferroelectrics from micro- to larger scale is well established, the science of nanoscale ferroelectrics is still terra incognita. The properties of materials at the nanoscale show strong size dependence, which makes it imperative to perform reliable characterization at this size range.

One of the most promising approaches is based on the use of scanning probe microscopy (SPM) which has revolutionized materials research over the last decade. SPM provides a unique opportunity to measure local properties of the matter, to tailor and engineer these properties and to characterize nanoscale devices while operating in ambient forbidden to traditional vacuum-based high-resolution techniques.

The aim of this book is to present recent advances in nanoscale characterization of electrical, mechanical and optical properties of ferroelectric materials made possible due to the use of the SPM techniques. As the field is not mature enough, this book is rather a collection of reviews written by the leading researchers in the field and not a textbook in a traditional sense. Along with the generally accepted concepts there are some new challenging ideas and experimental controversies reflected in the contributions. We hope that this book will make the readers aware of the tremendous developments in the field of nanoscale investigation of ferroelectric materials over the last decade. We also hope that it will inspire further scientific endeavors and will attract students and researchers from diverse disciplines such as chemistry, biology, material science, and electrical engineering.

The first five chapters address fundamentals of SPM methods used in nanoscale investigation of ferroelectrics, the first chapter presents a review of two of the most common SPM techniques used for ferroelectric imaging, electrostatic force microscopy (EFM) and piezoresponse force microscopy (PFM), analyzing domain contrast formation mechanism in PFM and relative magnitudes of electrostatic versus electromechanical contributions. The second chapter discusses in depth quantitative information about ferroelectric polarization by PFM. Chapter 3 focuses on direct electrical measurements of nanoscale ferroelectrics and chapter 6 presents applications of near-field scanning optical microscopy (NSOM) to probe optical of ferroelectrics at the nanoscale, begins after an overview of conventional optical microscopy techniques for characterization of ferroelectrics. Finally, chapter 5 includes the theory of polarization detection based on nonlinear dielectric response and reports the results of the imaging of the ferroelectric domains using scanning nonlinear dielectric microscopy (SNDM) as well as application of SNDM as a tool for high-density data storage with a density in the terabit range.

The next four chapters present remarkable applications of SPM methods in nanoscale characterizations of ferroelectrics. Chapter 6 shows one of the most successful application of PFM which was used along with a Ginzburg-Landau-Devonshire phenomenological theory to explain the dependence of longitudinal piezoelectric constant measured by PFM on the lateral size of nanoscale capacitors fabricated by focused ion beam milling. SPM studies of phase transitions in ferroelectric crystals via observation of domain structure evolution along with the dynamics of domain growth under the tip and local domain switching and hysteresis loop measurements are discussed in Chap. 7. Chapter 8 describes the nanodomain engineering in ferroelectric crystals using high voltage SPM. It presents a comprehensive experimental and theoretical description of a newly discovered effect of domain breakdown: domain growth under practically zero electric field in the crystal bulk. Issues related to nanodomain engineering, such as domain scaling, stability and writing speed, are also discussed. Chapter 9 applies a combination of scanning probe methods to investigate the local dielectric and polarization properties of the PZT film interfaces.

This book is intended to be useful for the undergraduate and graduate students interested in the SPM techniques, electrical engineering, materials science and information technology. Scientists at research centers, industrial engineers, specialists from the SPM community who wish to broaden their knowledge on the development in the related fields may also find this book practical.

We would like to thank our colleagues all over the world who contributed in many ways to the development of nanoscale science of ferroelectrics and particularly the contributing authors of this book.

Halle and Raleigh,
January 2004

Mann Alexe
Alexei Gruverman