Invited talk
April 5, 2005
Drexel University
Philadelphia, PA

Nanoelectromechanics of Scanning Probe Microscopy: From Perovskites to Proteins and Back

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Functional properties of ferroelectric materials and biological systems alike are determined by complex set of mechanical, electrical and electromechanical interactions on the length scales from macroscopic to molecular. Understanding these systems requires capability to probe these interactions on these length scales – the goal that can be achieved by advanced Scanning Probe Microscopy techniques. We present an approach for three-dimensional electromechanical imaging, referred to as Vector Piezoresponse Force Microscopy (PFM). The image formation mechanism in PFM and mechanical SPMs is ultimately controlled by the contact mechanics of the tip-surface junction. Nanoelectromechanics of piezoelectric indentation, including the structure of coupled electroelastic fields and stiffness relations, is analyzed for several tip geometries. The results of Hertzian mechanics are extended to piezoelectric materials, relating indentation depth, force and bias to the relevant material properties. The structure of the electroelastic field yields a quantitative measure of the signal generation volume in electromechanical SPMs and also provides a quantitative basis for the analysis of tip-induced polarization switching and local hysteresis loop measurements. An approach for combined imaging of elastic and electromechanical properties of materials is presented, extending vector PFM to four dimensions. This combination of techniques is used to address a broad set of phenomena – from three dimensional polarization imaging in perovskite oxides to quantitative description of PFM hysteresis loop and switching phenomena. Going beyond perovskites, the applicability of these techniques to the local elastic and electromechanical imaging of biological systems is demonstrated for a range of biological objects, and future prospects for imaging on a single molecule level are discussed. Finally, an approach for imaging local polarization orientation from vector PFM data is demonstrated for PZT thin films and is further explored to study nanoscale phase separation in relaxor ferroelectric materials, yielding information on polarization orientation, crystallographic structure, and local elasticity in the single nanodomain and providing a new paradigm for the local probing of strongly correlated materials.

Research performed as a Eugene P. Wigner Fellow (SVK) at ORNL, managed by UT-Battelle, LLC under DOE contract DCE-AC05-00OR22725.

Bio:

Sergei Kalinin is currently a research staff member at the Oak Ridge National Laboratory. He completed his Ph.D. in Materials Science at the University of Pennsylvania in 2002 (with Dawn Bonnell). His previous undergraduate and graduate work in Materials Science was conducted at Moscow State University, Moscow, Russia. His research focuses on the development and quantitative interpretation of electromechanical and electrical scanning probe microscopy techniques, including nanoelectromechanics of ferroelectric materials, transport measurements in nanotubes, nanowires, and polycrystalline materials, and recently on atomic resolution imaging by STM and non-contact AFM. He has served as a member of NSF MRI panel, a symposium organizer for MRS meeting, an instructor for Lehigh Microscopy course (2005), and is currently a member of American Vacuum Society NSTD board. As a student, he earned multiple research awards including AVS Graduate Student Award and several MRS Graduate Student Awards. Sergei was recognized with the Ross Coffin Purdy Award of American Ceramics Society (2003) for the development of Scanning Impedance Microscopy, a novel SPM technique for the characterization of frequency-dependent transport on the nanoscale. He is also a recipient of Wigner Fellowship of Oak Ridge National Laboratory. He has authored more than 50 scientific papers, 6 book chapters and several patents.