Direct Observation and Quantitative Analysis of Ferroelectric Domain Switching Behavior Using *In Situ* TEM

Mitra L. Taheri[1], Christopher R. Winkler[1], Lane W. Martin[2], Andrew, Steven R. Spurgeon[1], and Jennifer D. Sloppy[1]

[1]Drexel University, Materials Science & Engineering, 3141 Chestnut Street, Philadelphia, PA 19104
[2]University of Illinois-Urbana-Champaign, Urbana, IL 61820

Dynamic microscopy can potentially fill in gaps in the current understanding interfacial phenomena in a wide variety of materials, ranging from metals to complex oxides. Select multiferroic oxide materials, such as $BiFeO_3$ (BFO), exhibit ferroelectric and magnetic order, and the two order parameters are coupled through a quantum-mechanical exchange interaction. The magneto-electric coupling in BFO allows control of the ferroelectric and magnetic domain structures via applied electric fields. Because of these unique properties, BFO and other magneto-electric multiferroics constitute a promising class of materials for incorporation into devices such as high-density ferroelectric and magnetoresistive memories, spin valves, and magnetic field sensors. However, the magneto-electric coupling in BFO is mediated by volatile ferroelastically switched domains that make it difficult to incorporate this material into devices.

To facilitate device integration, an understanding of the microstructural factors that affect ferroelastic relaxation and ferroelectric domain switching must be developed. Using *in situ* biasing in TEM, the evolution of ferroelastically switched ferroelectric domains in BFO thin films during many switching cycles is investigated. Evidence of domain nucleation, propagation, and switching even at applied electric fields below the coercive field is presented. Quantitative kinetic data is extracted from these *in situ* videos. These observations indicate that the occurrence of ferroelastic relaxation in switched domains and the stability of these domains is influenced by the local microstructure of the BFO film. These biasing experiments provide a real-time view of the complex dynamics of domain switching and complement scanning probe techniques.