Domain Stability in Ferroelectric Thin Films

Grady S. White, John E. Blendell

Ferroelectric thin films have the potential for making major impacts in applications as diverse as non-volatile RAM, uncooled detectors, and MEMs. The material properties required for these applications, switchable electric dipoles, large pyroelectric coefficients, and piezoelectric response, are all controlled by the domain stability in the films. The relationship between microstructure and the physics of domain stability has never been established. We are developing measurement techniques which allow real time determination of the domain behavior.

We are measuring domain stability in $Pb(Zr,Ti)O_3$ (PZT) thin films as a function of film microstructure and electric history. Although domain stability issues, i.e. pinning, aging, fatigue and retention, limit the use of ferroelectric films in nonvolatile memory and micro-actuator applications, the physics and materials science that affect them are not understood. We have demonstrated that domain pinning in a PZT film appears to be associated with specific grain boundary sites; different sites pin domains either up or down. These sites can occur at different locations along the grain boundary. We are currently examining these sites to ascertain what features of the grain boundary control pinning.

The technique used to monitor domain motion is based on the piezoelectric response of a film to an applied electric field (J. Vac. Sci. Tech. B, **14**[2], 602 (1996)). In the measurements, an applied AC electric field (≈1 MV/m) changes the thickness of the ferroelectric film due to piezoelectric response. Such changes are observed by atomic force microscopy (AFM) and the phase shift of the response is related to the orientation of the polarization of the sample. The spatial resolution of the technique is limited to ≈20 nm due to the contact area of the tip and spreading of the electric field. The response varies from in-phase response (polarization in the direction of the applied field) to response which is 180° out of phase (polarization in the opposite direction to the applied field). Figure 1 illustrates the measurement method.

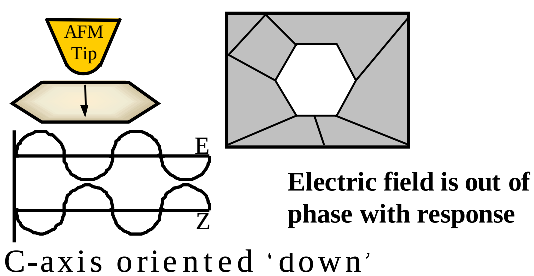
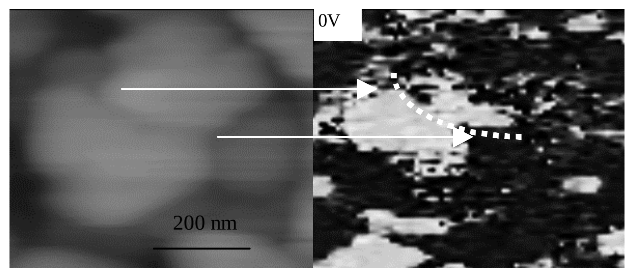


Figure 1. Schematic of AFM domain imaging. A conductive AFM tip is scanned over the film and the center region (bright) indicates that the domain orientation is opposite that of the surrounding regions (dark). Designations of "down" or "up" represent 180° phase changes and are not aligned with the laboratory coordinate system.

As shown below, grain boundaries are the strongest pinning sites, with the adjacent regions resisting 180° polarization changes. The grain boundary regions also initiate the rapid relaxation of the domains back to their original orientation. Modeling of the stresses which may drive this reversal are being carried out using an object oriented finite element technique (OOF) developed at NIST.



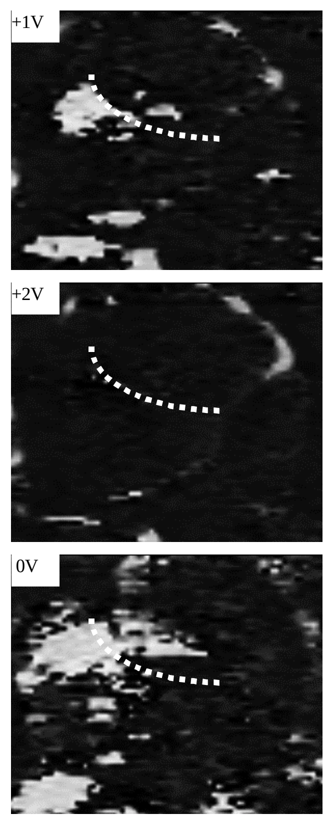


Figure 2: Top left image is AFM topograph of a portion of a PZT thin film. Images in the right column show the phase response of the film to 1 V_{rms} driving voltage as a function of a applied bias V_{DC}. From top to bottom, V_{DC} = 0 V, +1 V, +2 V, and 0 V. The dotted line indicates the location of the grain boundary observed in the topograph image. The out-of-phase response (bright region) around the grain boundary shrinks as V_{DC} increases but reemerges when V_{DC} is removed. Note that the domain behavior is not uniform along the length of the grain boundary.

Contributors and Collaborators

Edwin R. Fuller, Jr., Ceramics Division
Qing Jiang (University of California, Riverside)
Yong-Eui Lee (Seoul National University)