Domain Structures in Fatigue-Free $SrBi_2Nb_2O_9$

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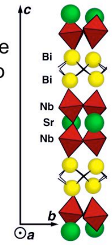
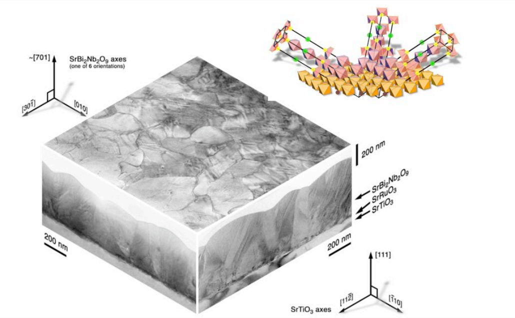
Motivation and Major Accomplishments

This work focuses on the study of domain structures in ferroelectric materials, as film and interface geometry play a significant role in determining the domain structure in ferroelectric films. Little experimental or theoretical evidence exists for the relative importance of the various energetic contributions to ferroelectric domain morphology. Ferroelectric domain maps obtained in this investigation allow us to formulate a better understanding of these various components of the free energy balance used to describe domain structure. We have succeeded in the first experimental observation of the domain structure in thin films of $SrBi_2Nb_2O_9$ (right), a ferroelectric material that is fatigue-free, i.e. does not show a loss of switched polarization with increasing number of switching cycles. Substrate orientation determines what growth twin variants will exist in a ferroelectric complex-oxide film, and thereby the orientation of the polarizable axes, which influences the ferroelectric behavior of ferroelectric structures.

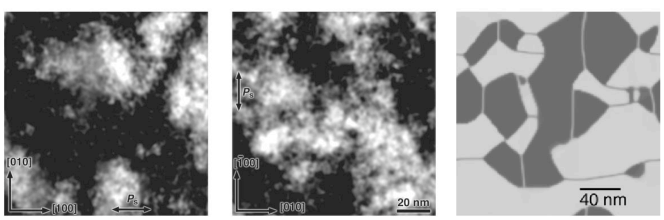


Results

Because of the absence of ferroelastic distortion, standard strain-based techniques for imaging ferroelectric domains are not feasible with this material. Instead, we utilized Fourier processing of high-resolution transmission electron microscopy (HRTEM) images to form a series of orthogonal polar-domain maps, generated from unique superlattice reflections associated with individual domains. Domain walls in $SrBi_2Nb_2O_9$ are found to be highly curved, indicating that the faceted 90° domain morphology found in typical oxide ferroelectrics is dominated by strain energy. The curved walls also indicate that $SrBi_2Nb_2O_9$ is fairly tolerant of the space charge associated with divergence of the normal component of the polarization at such walls.

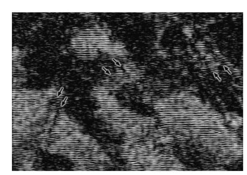


Films grown on differently-oriented substrate surfaces adopt non-*c*-axis orientations. Epitaxy results from local continuation of the perovskite sublattice, shown schematically to the left. The image to the left shows the growth twin domain structure of a $SrBi_2Nb_2O_9$ / (111) $SrTiO_3$ film, as viewed along three directions. This film has three orientational variants, each identically-oriented with respect to the cubic perovskite sublattice of the substrate.



Imaging ferroelectric domains along the non-polar *c*-axis (left and center) reveals a 90° domain morphology with highly curved domain walls. Both images are from the same area the film. Bright areas in each image have remnant polarization axes as indicated by P_s. Phase-field simulations (right) show excellent agreement with the experimentally observed domain structure (above right). Strain energy in $SrBi_2Nb_2O_9$ is shown to have essentially no effect on the domain structure.

Imaging ferroelectric domains along the polar *a*/*b*-axis (right) reveals a 90° domain morphology controlled by electrostatic interactions alone (in *c* direction). Bright areas correspond to regions with a spontaneous polarization vector perpendicular to the plane of the image. $SrBi_2Nb_2O_9$ appears to be very tolerant of the presence of space charge.



Impact

Experiment and simulation agree, and indicate that electrostatic interactions in $SrBi_2Nb_2O_9$ are sufficiently weak to allow curved domain walls. These findings stand in contrast to the accepted theory that an intolerance of space charge at domain walls leads to the faceting of domain walls in oxide ferroelectrics.

Future Directions

Our goal is now to correlate the observed domain structures with the lack of fatigue in this system. Of particular interest is the extent to which space-charge and its compensation influence domain wall mobility. Experiments will utilize electron microscopy, as well as x-ray microprobe/nanoprobe techniques under development at the Advanced Photon Source. Simulations of high-strain oxide ferroelectrics should prove enlightening regarding the degree to which strain versus space charge affects domain wall orientations and morphology.

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