Deterministic control of polarization switching in multiferroic materials using scanning probe microscopy

N. Balke,[1] S. Choudhury,[2] S. Jesse,[1] M. Huijben,[3,4] Y.H. Chu,[3,5] A.P. Baddorf,[1] L.Q. Chen,[2] R. Ramesh,[3] and S.V. Kalinin[1]

[1] Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831

[2] Dept. of Mat. Sci. Eng., Pennsylvania State University, University Park, PA 16802

[3] Department of Materials Science and Engineering and Department of Physics, University of California, Berkeley, California, 94720

[4] Faculty of Science and Technology, MESA+ Institute for Nanotechnology, University of Twente, P.O. BOX 217, 7500 AE, Enschede, The Netherlands

[5] Dept. of Materials Science and Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan

Proposal Title

Polarization measurements and switching spectroscopy on ferroelectric thin films as function of film thickness (CNMS2008-R07)

Research Achievement

Bias induced phase transitions in ferroelectric oxide materials are used as a functional basis for information storage. Realization of the next generation of magnetoelectric, strain-coupled, and domain-wall based devices necessitates the deterministic control of polarization switching in multiaxial multiferroics. In rhombohedral ferroelectrics, application of an electric field in the pseudocubic (001) direction can lead to 180° ferroelectric switching and 71° and 109° ferroelastic switching. While the electrostatic energy gain is equivalent, the properties of the final structures are remarkably different. In materials such as $BiFeO_3$ (BFO) enhanced conduction at 180° and 109° domain walls has been reported [1], raising the possibility for novel electronic and memory devices. Finally, given that magnetic ordering in BFO is ferromagnetic in (111) planes and antiferromagnetic between these planes, control of non-180° switching is crucial for the development of exchange-coupled magnetoelectric devices.

The goal of this proposal was to investigate and understand the domain switching process on the nanoscale using Scanning Probe Microscopy (SPM). It was found that ferroelectric switching underneath a SPM tip creates a flower like pattern of different domains with different sizes and penetration depths. Most domains were not stable and were not observed experimentally. In order to stabilize certain domains which form underneath a biased SPM tip, the symmetry of the rotationally invariant electric field around the tip has to be broken. Broken symmetry was created by moving the probe during the switching process. This enabled us to fabricate predefined domain patterns demonstrated through the creation of artificial ferroelectric closure domains which are believed to be the precursors to vortex domains (see Fig. 1). Vortex domains are highly discussed in the literature [2] although not yet observed in ferroelectric materials.

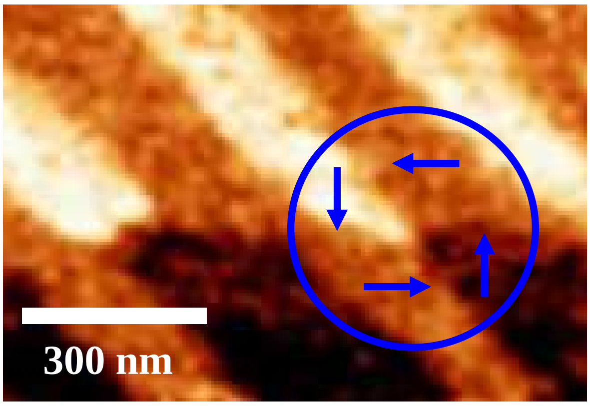

Figure 1 | Closure domains consisting of in-plane domains formed by motion of a scanning SPM tip.

In summary, the deterministic control of ferroelectric switching enables a reliable pathway for local control of non-ferroelectric order parameters, probing local strain and magnetic orderings, and design and creation of domain engineered magnetoelectric, domain-wall based and strain coupled devices.

Future Work

Future work will focus on two directions. The first is to explore the possibilities of local control of the ferroelectric switching at expanded length scales ranging from 20 nm to several μm. The goal is to understand and manipulate switching of macroscopic devices and to find new concepts for device structuring. The second direction will focus on the detailed investigation of artificially created closure domains. These measurements will show if a ferroelectric vortex state forms in the core of the closure domain and will clarify the coupling of this toroidal compared to the classical ferroid order parameters.

References

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Publications

[1] N. Balke, S. Choudhury, S. Jesse, M. Huijben, Y.H. Chu, A.P. Baddorf, L.Q. Chen, R. Ramesh, and S.V. Kalinin, "Deterministic control of ferroelastic switching in multiferroic materials", Nature Nanotechnology, *under review*