Deterministic Control of Morphotropic Phase Boundary using Electric Field

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1. Introduction

A multiferroic refers to a material that is both ferromagnetic(or antiferromagnetic) and ferroelectric(or antiferroelectric). It has a spontaneous magnetization that can be switched by an applied magnetic field and a spontaneous polarization that can be switched by an applied electric field as a result of intercoupling between magnetism and electricity. Very few compounds exist in nature or have been synthesized in the laboratory. Bismuth ferrite is one of the multiferroic material which has ferroelectric and antiferromagnetic orders at room temperature. Moreover, morphotropic phase boundary (MPB) where tetragonal-like monoclinic phase and distorted rhombohedral phase coexist, has been found in $BiFeO_3$ (BFO) films grown on $LaAlO_3$ substrates. The MPB regions in the BFO films possess large piezoelectric response and non-zero spontaneous magnetic moments. We report that La substitution improves the formation of well-aligned MPB regions. Using piezoresponse force microscopy (PFM), MPB regions can be created or erased. By changing the scanning direction of tip, the MPB alignment angle can be controlled. Our work is focusing on how we can obtain more dense and uniform MPB area and control the MPB alignment angle in a deterministic way.

2. Experiment

We investigated inter-relations between the electrical writing angle of PFM and the MPB alignment direction. First, we obtained the surface image of films and then the sample surface was partially scanned with a tip voltage of -9V using PFM. After electrical poling, we could get the alignment of MPB. Finally, we tried electrical overwriting to check that the electrically-written regions could be rearranged as expected.

3. Experiment result

Changing the tip scanning direction, we can control the MPB alignment dirction. There are only 4 variant MPB alignment angles and the net in-plane polarization is not perpendicular to MPB alignment but tilted more by ~15 degrees (tilted by ~30 degrees with respect to a crystal axis). The formed MPB pattern can be overwritten by another electrical poling process.

4. Consideration

The MPB alignment angle is likely to be determined by interaction between in-plane electric field of the tip and the net polarization of MPBs. During tip scanning with a DC electric bias, the final in-plane electric field is parallel to the slow scan axis. By choosing a proper tip scan axis, we can create a MPB region to be aligned as we want.

5. Conclusion

We report that La-substituted BFO shows dense and uniform stripe MPB patterns with large scale continuity of the alignment. By changing the scanning direction of tip, we can control the direction of MPB alignment as well. We also determined the in-plane polarization direction in the region of MPB to be tilted by ~30 degrees with respect to a <100> substrate crystal axis. Moreover we demonstrated that the large scale MPB patterns can be repeatedly overwritten on the same area with different poling directions. Our findings provide pathways to deterministic control of high-quality MPBs in an electric way.

6. Reference

[1] R. J. Zeches et al., Science. 326, 977 (2009)