

# Microstructures of Nanoscale Mixed Phase BiFeO<sub>3</sub> Thin Film with Electrically Controllable Spontaneous Magnetism

R. Huang<sup>1,3</sup>, C.-G. Duan<sup>1</sup>, Y. -H. Chu<sup>2</sup>, Y. Ikuhara<sup>3,4</sup>

<sup>1</sup>Key Laboratory of Polar Materials and Devices, Ministry of Education, East China Normal University, Shanghai 200062, China

<sup>2</sup>Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan

<sup>3</sup>Nanostructures Research Laboratory, Japan Fine Ceramics Center, Nagoya 456-8587, Japan

<sup>4</sup>Institute of Engineering Innovation, the University of Tokyo, Tokyo 113-8656, Japan

BiFeO<sub>3</sub> (BFO) is a promising multiferroic for technological applications because its electric polarization is coupled to antiferromagnetic ordering at room temperature. Recently, a strain-driven rhombohedral (R phase) and super-tetragonal (T phase) mixed phase in BFO thin films grown on LAO substrates has also been reported to exhibit electrically controllable spontaneous magnetism[1]. To reveal the stability of both T-BFO and R-BFO, the detailed local structures of the BFO/LAO interfaces and the T/R morphotropic phase boundary were investigated by means of state-of-the-art Cs-corrected scanning transmission electron microscopy (STEM) techniques.

Figure 1(a) shows the detailed atomic structure of the R-BFO/LAO interface observed by the high angle annular dark-field (HAADF) STEM. A continuous expansion of the BFO crystal lattice, and displacement of Fe ions occur at coherent super-tetragonal BFO/LAO and rhombohedral BFO/LAO heterointerfaces, measured as  $c/a$  ratios given in Fig 1(b). A similar pinned interface transition layer about two unit cells thick was directly observed at both interfaces. The continuous ferroelectric polarization relaxations observed at both T-BFO/LAO and R-BFO/LAO interfaces show different features, which are the result of competition between the tilting of Fe-O<sub>6</sub> octahedra and the displacement of Fe ions, depending on the strain state of BFO thin film [2]. However, the phase boundary between T-BFO and R-BFO is very sharp. The lattice relaxed within 1-2 unit cells and no defects can be observed, as shown in Fig. 2. Such information is important for rationalizing the varied and complex phenomena of BFO, and adds to our rapidly growing understanding of the ferroelectric behavior of complex oxide heterointerfaces.

References:

- [1] Q. He et al., Nat. Commun., 2(2011) 255.
- [2] R. Huang et al., Adv. Func. Mater., 24 (2014) 793.

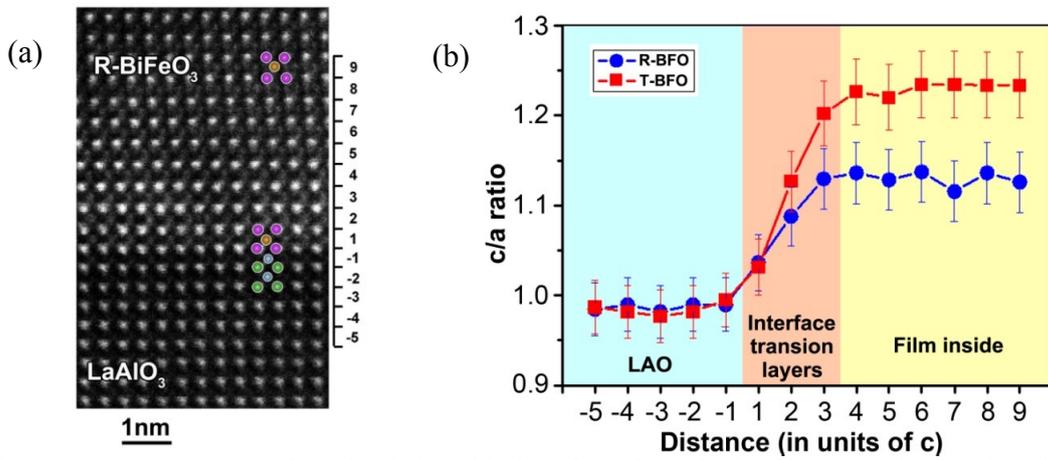


FIG. 1. (a) HAADF image of R-BiFeO<sub>3</sub>/LaAlO<sub>3</sub> interface along the [010]<sub>c</sub> zone axis. (b) *c/a* ratios of T-BFO and R-BFO as a function of distance from the interface.

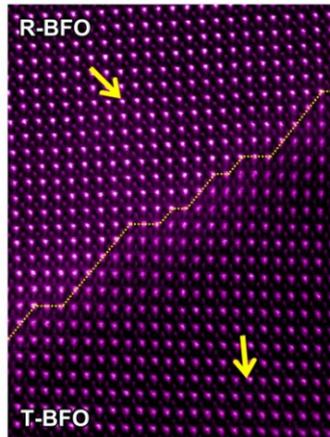


FIG. 2. Atomic structure of T/ R phase boundary.