

Mechanical and piezoelectric analysis of ferroelectric domains in BFO thin films

F. Dinelli,¹ C.-E. Cheng,^{2,3} C.-S. Chang,² F. Chien,³ Y.-C. Chen⁴

¹*Istituto Nazionale di Ottica, CNR, Pisa, Italy*

²*Department of Photonics, National Chiao Tung University, Hsinchu, Taiwan*

³*Department of Physics, Tunghai University, Taichung, Taiwan*

⁴*Department of Physics, National Cheng Kung University, Tainan, Taiwan*

Corresponding author: F. Dinelli

E-mail: franco.dinelli@ino.it

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Introduction

Recent advances in thin-film engineering have led to the realization of BiFeO₃ (BFO) epitaxial films, a new type of mixed-phase system driven by the substrate strain. [1] Under a strong compressive strain (>4%), the most stable crystalline structure can be transformed from the rhombohedral-like monoclinics (R) to tetragonal-like monoclinics (T). Additionally, the coexistence of R- and T-phase can be obtained in the same film with an appropriate strain relaxation through the film thickness.

This mixed-phase system can provide a template to reveal the origins of physical properties in relaxor and morphotropic phase boundary materials, such as large piezoelectric response and enhanced ferroelectric polarization. [2] In this work, we present a study of the piezoelectric and mechanical properties of T-R mixed-phase stripes by means of piezoresponse and ultrasonic force microscopies (PFM, UFM).

Materials and Methods

Our microscope is a homemade system. In particular the head is a commercial NT-MDT Smena suitable for electrical measurements; the electronics and the software used for control and acquisition are both developed in house. For both UFM and PFM, we use a function generator (Agilent 33220A) and a double lock-in amplifier (Zurich, HF2LI). The color codes of the images are the following: topography, whiter for higher regions; UFM, whiter for higher elastic moduli; PFM, whiter for larger out-of-plane response.

The tip employed is a diamond coated one (DCP11, NT-MDT). PFM [3] is generally operated at 20 kHz and 5V. UFM [4] is operated at around 4MHz with an amplitude modulation of around 1 nm at 4kHz. The two techniques can be performed in the same place, with no need to withdraw the tip. This can be simply obtained by switching the electrical connection to the top electrode of a piezo-plate located directly under the sample.

The sample herein reported is a mixed-phase BiFeO₃ (BFO) film with a thickness of 150 nm, grown by pulsed laser deposition on conducting LaNiO₃ (LNO) buffered (001) LaAlO₃ (LAO) substrates.

Results and Conclusions

In the Figure 1, we show some of the results obtained. The topography of flat (T-phase) and stepped regions (mixed R- and T-phase) is presented along with the PFM and UFM signals obtained. From the topography profile shown in the graph, it is possible to verify that the vertical scale of the mixed phase regions is around 1 nm, whereas the lateral dimension of the stepped regions ranges around 50 and 100 nm. Therefore, though the R-phase steps in the graph appear very steep, in reality they are quite flat.

In order to help the reader to visualize the data obtained, we have superposed stripes of UFM and PFM signals on the corresponding morphology. Starting with the PFM data, it is possible to identify the different ferroelectric domains: the whiter regions are those where it has been measured a larger out-of-plane response for a constant oscillating voltage applied.

In addition to the topography profile of a mixed-phase region, in the graph we show the corresponding UFM signal (light grey). It can be clearly seen that the regions with larger UFM signal correspond to the less steep regions, identified with the T-phase. It is thus possible to state that the R-phase regions are more compliant than the T-phase ones. This is for the first time established, according to the literature published up to now.

Finally, not reported here in details, we have also applied a DC vertical bias in order to switch the piezoelectric domains in square areas of the flat T-phase regions. PFM shows that depending on the bias amplitude partial or full inversion can be obtained. UFM indicates that the mechanical properties of the fully inverted domains do not change.

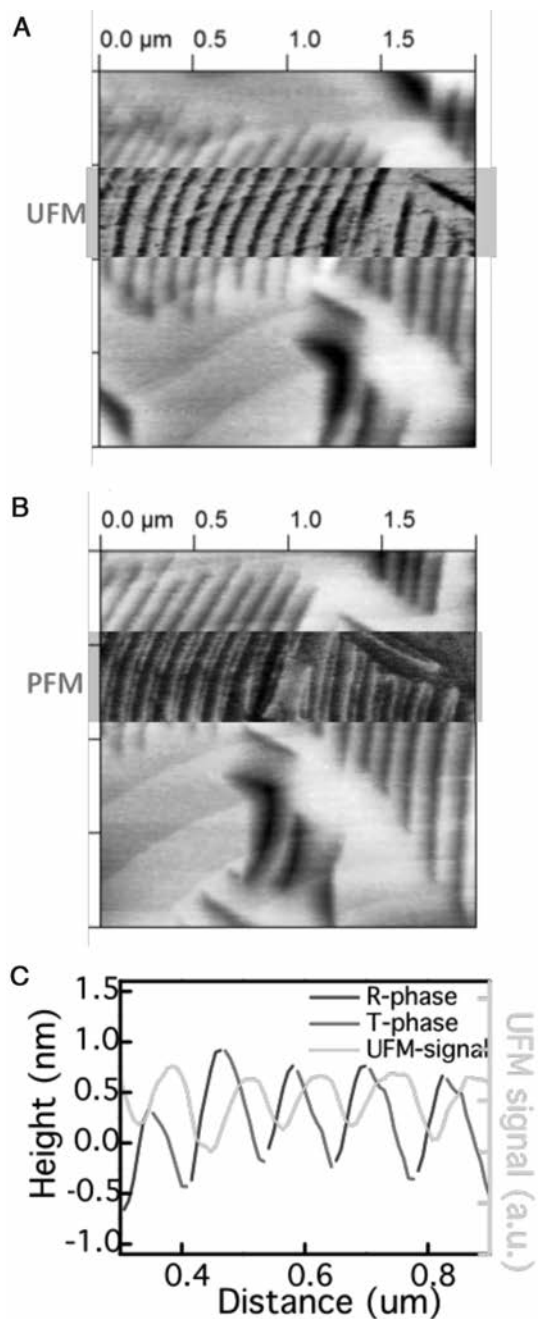


Figure 1. A. The grey-scale stripe represents the UFM signal superposed to the topography (white-black scale). B. The grey-scale stripe represents the PFM signal superposed to the topography. C. Line profiles of UFM (light grey) and topography.

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