PROBING TEMPERATURE EFFECT ON MAGNETIC DOMAIN STRUCTURE OF NOVEL MULTIFERROIC THIN FILMS

K. Prashanthi and V. R. Palkar
Centre for Nanoelectronics, EE-Dept. IIT Bombay, Powai, Mumbai -400076, INDIA.

Introduction

Mutiferroic systems, which exhibit coexistence of both ferroelectric and ferromagnetic ordering at room temperature, are of great importance for a variety of device applications, especially if there is significant coupling between the two order parameters. Hence, $BiFeO_3$ (BFO), which shows coexistence of antiferromagnetic and ferroelectric ordering at room temperature, has attracted a great deal of attention recently. However, to explore BFO for novel device applications, it is required to enhance its magnetic properties. We have been successful in inducing ferromagnetism in this system by doping with Dy at Bi sites [1, 2]. Moreover, the coupling between magnetic and ferroelectric ordering (ME coupling) at the macroscopic as well as microscopic level has also been demonstrated [3]. In this paper, we present the temperature dependence of the magnetic domain structure in $Bi_{0.7}Dy_{0.3}FeO_3$ (BDFO) thin films. We note that the as-grown film at room temperature shows irregular magnetic domain patterns, but as the temperature increases, the irregular pattern changes to a stripe-pattern at 200 °C. The phase image at 300 °C shows no clear magnetic domain structure as the magnetic transition occurs around 270 °C indicated by Differential Thermal Analysis (DSC) curve. Upon quenching the system back to room temperature, an irregular pattern is recovered albeit with larger magnetic domains. The observed changes in the domain structure with temperature suggest a strong thermal history dependence of the system related to the history-dependent internal strains in the sample.

Experiment

BDFO powder samples were prepared by wet chemical route to ensure controlled stoichiometry and chemical homogeneity. The details of synthesis process are reported earlier [4]. The reacted material was compacted into pellet and sintered at 800 °C for 2 hours. The dense pellet thus obtained was used as a target for growing films using pulsed laser deposition technique. The deposition conditions were optimized to get single phase thin films of BDFO on $Pt/TiO_2/SiO_2/Si$ substrate [2]. The films were deposited for 30 min. to achieve thickness of the order of 200 nm.

Apparatus and Procedures

The magnetic transition in these films is determined by studying the temperature dependence of the magnetizaton (M-T behavior) using a vibrating sample magnetometer (VSM) and also by differential scanning calorimetry (DSC). A Multimode Atomic Force Microscope (Nanoscope IV from Digital Instruments) configured to provide the magnetic domain structure has been used for the study. The images are obtained on a specific spatial area of the film spanning tens of microns on the lateral scale with a spatial resolution better than 50 nm. The magnetic force microscopy (MFM) images were obtained by using a tapping cantilever with a cobalt-coated tip that has been magnetized with a strong permanent magnet before installing on the AFM head. A tapping-mode topographic image was obtained during the main scan in order to investigate any correlation between the local order parameter and the sample morphology. During the interleave mode, the tip is raised above the sample surface, allowing the imaging of relatively weaker but long-range magnetic interactions while minimizing the influence of topography. The resulting images from the raw data for topography and magnetic structure are shown in Fig. 3 without any additional image processing.

Results and Discussion

XRD pattern obtained for BDFO thin film is shown in Fig.1.Thin films exhibit a perovskite structure and belong to the space group of $R3c$ similar to that of pure BFO. Fig. 2 shows the results of M-T plot on BDFO thin film. The magnetization vanishes at around 270 °C implying magnetic transition of these films. Inset shows the DSC measurements carried on these films. The magnetic ordering is observed at 265 °C. The temperature dependence of the magnetic domain structure has been studied on a temperature-controlled scanner. The results are shown in Fig.3. We note that the as-grown film at room temperature shows irregular magnetic domain patterns. But as the temperature increases, the irregular pattern changes to a stripe-pattern at 200 °C. As shown in Fig.2, the magnetic transition occurs around 270 °C. The phase image at 300 °C, accordingly, shows no clear magnetic domain structure. Upon quenching the system back to room temperature, an irregular pattern is recovered albeit with larger magnetic domains. It is well known that as-grown films are highly strained due to the growth process. It is likely that the annealing of the strains at elevated temperatures, but below the magnetic transition temperature, is responsible for the formation of the more ordered stripe pattern as seen at 200 °C. Hence, the observed changes in the domain structure with temperature suggest a strong thermal history dependence of the system related to the history-dependent internal strains in the sample.

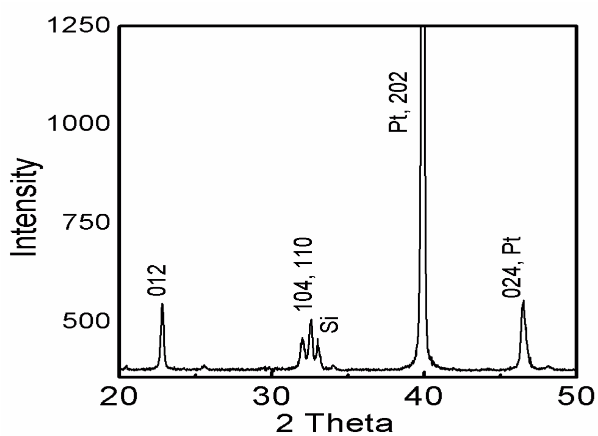

Fig. 1 XRD obtained for BDFO thin film

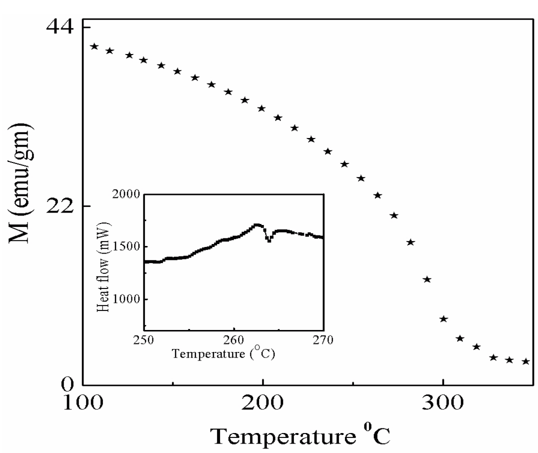

Fig. 2 M-T curve obtained for BDFO thin film indicating magnetic transition at ~ 270 ˚C. Inset shows DSC curve for the film

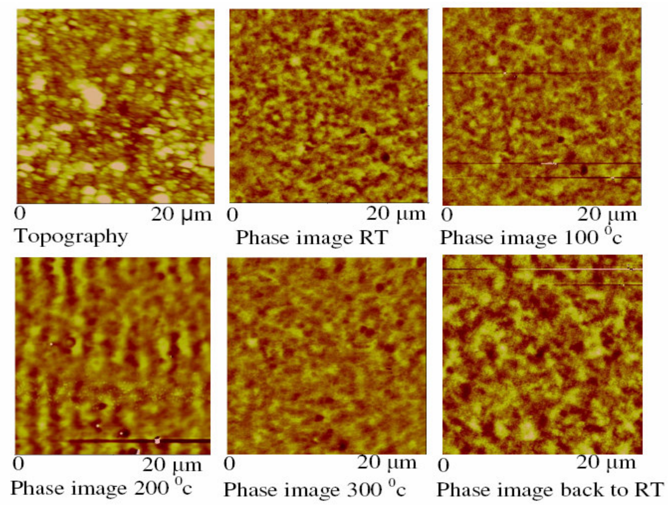

Fig 3 Topography at room temperature and magnetic domain phase imaging using MFM at different temperatures for BDFO thin film

Conclusion

In conclusion, the temperature dependence of BDFO thin films grown on $Pt/TiO_2/SiO_2/Si$ substrates by PLD technique has been established with the help of multimode atomic force microscopy (MAFM). More remarkably, the magnetic domain structure disturbs at magnetic transition. The observed changes in the domain structure with temperature suggest a strong thermal history dependence of the system related to the history-dependent internal strains in the sample.

References

1.V. R. Palkar, Prashanthi K. and S. P. Dattagupta, Influence of process-induced stress on multiferroic properties of pulse laser deposited $Bi_{0.7}Dy_{0.3}FeO_3$ thin film, *J. Phys. D: Appl. Phys*. 41, (2008) 045003

2. K Prashanthi, B.A. Chalke, K. C. Barick, A. Das, I. Dhiman, and V. R. Palkar, Enhancement in Multiferroic Properties of $Bi_{0.7-x}La_xDy_{0.3}FeO_3$ System with Removal of La, *Solid State Communications,* 149 (2009), 188-191.

3. V. R. Palkar, K. Prashanthi, Observation of magnetoelectric coupling in multiferroic $Bi_{0.7}Dy_{0.3}FeO_3$ thin films at room temperature, *Applied Physics Letters*, 93(2008), 132906.

4. V.R. Palkar, Darshan Kundaliya, S.K. Malik and S. Bhattacharya, Magnetoelectricity at room temperature in the Bi0.9-xTb xFeO3 systemPhys. Rev. B, 69 (2004) 212102.