

Ferroelectricity and Domain Dynamics in One Dimensional Single Crystalline BaTiO₃ Nanowire: a Piezoresponse Force Microscopy (PFM) Study

Min-Feng Yu*, Zhaoyu Wang, Jie Hu, Abhijit Suryavanshi

Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801. Email: mfyu@uiuc.edu

The recent success in the synthesis of varieties of low dimensional nanomaterials has brought in a new field for the exploration of new science at low dimensionality and at the nanoscale. However, the study of piezoelectricity or ferroelectricity in nanomaterials, which could form the basis for their applications in nanoscale sensor/actuator and high density memory device, is still lacking. The materials behaviors at the nanoscale are expected to be very different from its bulk. A couple of recent studies [1-2] on piezoelectric and ferroelectric behavior of crystalline thin film (20 nm thick or less) have shown the length scale effect, such as enhanced surface polarization and periodic surface domain formation. Gruverman et al. have extensively studied the ferroelectricity of individual domain in polycrystalline ferroelectric film using piezoresponse force microscopy (PFM). Imprint behavior in ferroelectric film, which is the result of preferable existence of one polarization state over the other, was argued to originate from the surface charge at the boundary interfaces and/or the mechanical stress within the materials. Scaling effects on the hysteresis behavior in ferroelectric materials was found to result in the decrease of the switching polarization and the redistribution and even the inversion of the original spontaneous polarization [3-4]. However, owing to the complex nature of ferroelectricity, and the difficulty of experimental studies at the nanoscale, a conclusive picture on nanoscale ferroelectricity is still yet to emerge.

We report the study of ferroelectricity in one dimensional BaTiO₃ nanowire. We use chemical synthesis method to produce BaTiO₃ nanowires having precisely defined chemical composition, high crystallinity and uniform geometry. Such properties are essential for the systematic and parametric study of nanoscale ferroelectricity, as the electromechanical effect in piezo/ferro electric materials at the nanoscale could be very sensitive to many variables in materials, such as internal stress, surface charge, surface imperfection, mechanical deformation, chemical stoichiometry (Nanostructures made by traditional lithography are inherently susceptible to those variables). Piezoresponse force microscopy is applied to characterize the piezoelectric and ferroelectric properties of such nanowires, and to study the domain formation and polarization switching dynamics in such nanowires. Our preliminary data presented in the following page indicates that there exists complex and unusual behavior of polarization in one dimensional ferroelectric nanostructure, especially on the state and switching properties of polarization. We will further detail our findings in this conference.

References

- [1] M. Dawber, D. J. Jung, and J. F. Scott, *Appl. Phys. Lett.* **82**, 436 (2003).
- [2] P. Ghosez and K. M. Rabe, *Appl. Phys. Lett.* **76**, 2767 (2000).
- [3] M. Alexe, A. Gruverman, C. Harnagea, N. D. Zakharov, A. Pignolet, and D. Hesse, *Appl. Phys. Lett.* **75**, 1158 (1999).
- [4] M. Alexe, C. Harnagea, D. Hasse, and U. Gösele, *Appl. Phys. Lett.* **79**, 242 (2001).
- [5] The work is supported by a grant from NSF: CMS-0324643

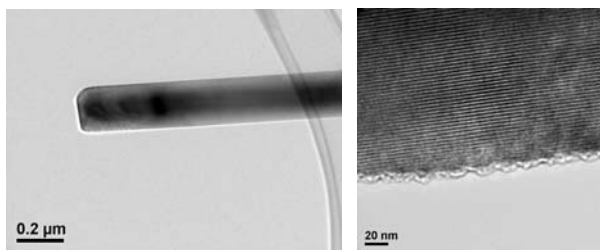


Fig. 1. Representative transmission electron microscope (TEM) image of BaTiO₃ nanowire used for PFM study showing its high crystallinity.

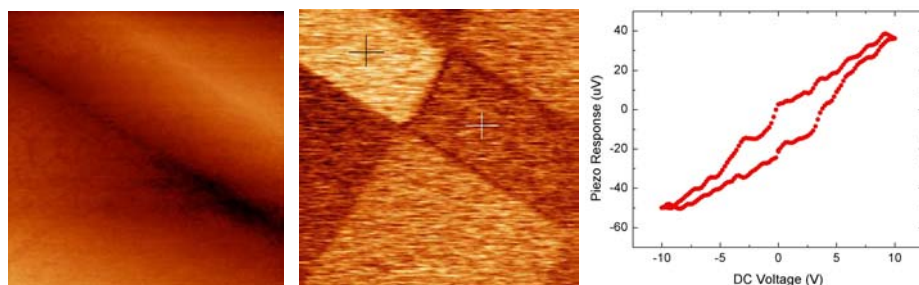


Fig. 2: Topography and PFM images taken from the same area in bulk BaTiO₃ crystal surface showing the step structure and the domain structures (scan size: 5 μm); and the acquired P-E loop.

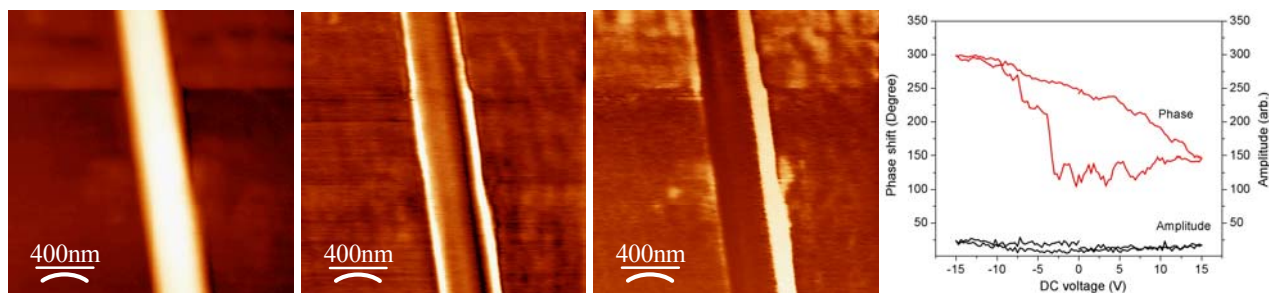


Fig. 3: Topography, PFM amplitude and PFM phase images of an individual BaTiO₃ nanowire (80 nm in diameter) with a constant dc bias of -10 V; and representative PFM amplitude and phase loops taken from BaTiO₃ nanowire.

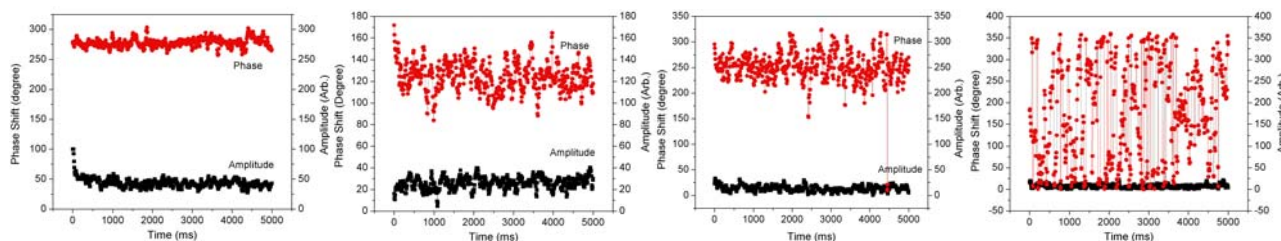


Fig. 4: Plots from left to right showing the dynamic response of polarization in BaTiO₃ nanowire after applying -20V step voltage, +20 V step voltage, -20 V/0.5 s voltage pulse, and +20 V/0.5 s voltage pulse.