Deterministic Control over Conducting States in Morphotropic $BiFeO_3$ using Electrical Bias and Uniaxial Stress: towards Piezoresistive Applications

N. Browne[1*], D. Edwards[1], K. Holsgrove[1], A.B. Naden[1], S.O. Sayedaghaee[2], B. Xu[3], S. Prosandeev[3], D. Wang[4], D. Mazumdar[5], A. Gupta[6], S.V. Kalinin[7], M.A. Arredondo[1], R.G.P. McQuaid[1], L. Bellaiche[3], J.M. Gregg[1], A. Kumar[1]

[1]School of Mathematics and Physics, Queen's University Belfast, Belfast, BT7 1NN, United Kingdom
[2]Microelectronics-Photonics Program, University of Arkansas, Fayetteville, Arkansas 72701, USA
[3]Physics Department and Institute for Nanoscience and Engineering, University of Arkansas, Fayetteville, Arkansas 72701, USA
[4]Electronic Materials Research Laboratory, Key Laboratory of the Ministry of Education and International Center for Dielectric Research, Xi'an Jiaotong University, Xi'an 710049, China
[5]Department of Physics, Southern Illinois University, Carbondale, Illinois 62901, USA
[6]Center for Materials for Information Technology, University of Alabama, Tuscaloosa, Alabama 35487, USA
[7]Center for Nanophase Material Sciences, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 37831, USA
*Niall Brown: nbrowne07@qub.ac.uk

The potential for active nano-electronic devices based on the creation and manipulation of pseudo-2d electrically conducting boundaries in ferroelectric materials is now well established [1, 2]. However, an accepted consensus on the microscopic origins of transport is not clear and careful de-convolution of contributing factors arising from crystal, electronic, and defect structures remains a challenge. [2] Furthermore, attempts to realise prototype devices based on controlled deployment and repositioning of conducting interfaces has so far relied on non-trivial electric-field poling regimes that are technically challenging to implement. [3, 4]

Here we investigate the behaviour of conductive interfaces in thin films of morphotropic Bismuth Ferrite ($BiFeO_3$) written using a combination of locally applied bias and uniaxial stress, facilitated by a metallic scan probe. Clear changes in local mixed-phase structure are mapped and directly correlated to the level of applied bias or stress stimuli. In particular, we note that such structural changes correspond to significant enhanced current and utilise this to demonstrate a pressure-write, voltage-read piezoresistance device based on manipulation of the conducting-interface density with a 10^6 on/off current ratio. We used scanning transmission electron microscopy (STEM), along with nano-beam electron diffraction (NBED), to perform strain gradient mapping which revealed the pressure-written transport-active boundaries where more strained than natively occurring interfaces. Combined with local current-voltage measurements, our results indicate the observed conduction and large piezoresistive response within morphotropic $BiFeO_3$ to be linked to a strain-induced band-gap alteration.

[1] Seidel, J. *et al.* Conduction at domain walls in oxide multiferroics. *Nat. Mater.* **8,** 229–234 (2009).
[2] Guyonnet, J., Gaponenko, I., Gariglio, S. & Paruch, P. Conduction at Domain Walls in Insulating $Pb(Zr_{0.2}Ti_{0.8})O_3$ Thin Films. *Adv. Mater.* **23,** 5377–5382 (2011)
[3] Catalan, G., Seidel, J., Ramesh, R. & Scott, J. F. Domain wall nanoelectronics. Rev. Mod. Phys. **84**, 119–156 (2012).
[4] Chanthbouala, A. et al. A ferroelectric memristor. Nat. Mater. **11**, 860–864 (2012)