Phase Transitions and Morphotropic Phase Boundaries in Ferroelectric and Relaxor-Ferroelectrics

Ferroelectric solid-solutions have very large dielectric, piezoelectric and pyroelectric properties (up to two orders of magnitude higher than their non-ferroelectric polar counterparts), and therefore offer an opportunity for integrating multiple functionalities at the micrometer and nanometer scales, including sensing and actuation capabilities, integrated switches and filters for radio systems, energy harvesting for self-powered devices, miniaturized multilayer capacitors, and mechanical relays for low power embedded microcontrollers. This multi-functional nature presents a pathway towards a “More than Moore” (MtM) era.

Compositional and structural disorders in ferroelectric and relaxor-ferroelectrics solid solutions lie at the heart of the large enhancement of the dielectric and piezoelectric properties of these materials. However, characterization of these behaviors at the mesoscale remains mostly unprobed. Here, we use a piezoresponse force microscopy (PFM)-based dynamic acoustic, and multimodal relaxation spectroscopy techniques, enabling the study of field-induced phase transition, ferroelectric switching and polarization relaxation at mesoscopic length scales, and carry out measurements on a 0.72Pb(Mg1/3Nb2/3)O3-0.28PbTiO3 (PMN-PT) single crystal with minimal polishing.

Results indicate that beyond a threshold DC bias the average relaxation increases as the system attempts to relax to the previous state. Phenomenological fitting reveals the presence of mesoscale heterogeneity in relaxation amplitudes, and clearly suggests the presence of two distinct amplitudes. Independent component analysis reveals the presence of a disorder component of the relaxation, which is found to be strongly anti-correlated with the maximum piezoresponse at that location, suggesting smaller disorder effects where the polarization reversal is large, and vice versa. The disorder in the relaxation amplitudes is postulated to arise from rhombohedral and field-induced tetragonal phase in the crystal, with each phase associated with its own relaxation amplitude. Field-induced phase transition is consistent with an acoustic softening (reduction of the contact resonance) also observed through PFM measurements.

We subsequently leverage these phase transitions in superlattice-like, polycrystalline ferroelectric thin films of lead zirconate titanate, to enhance the effective piezoelectric and dielectric response of these films. The local electromechanical response of the films, with unusual amplitude of piezoresponse and an acoustic softening are consistent with presence of polar-glass-like phases, polarization rotation, and phase switching in the films. Dependence of the dielectric and piezoelectric response of the SL films on the stacking periodicity and the extent of the compositional gradient will be also discussed.

BIO:

Prof. Nazanin Bassiri-Gharb is an Associate Professor in the George W. Woodruff School of Mechanical Engineering at Georgia Tech, with a courtesy appointment in the School of Materials Science and Engineering. She obtained her Ph.D. in Materials Science from the Pennsylvania State University in 2005 and her laurea summa cum laude in Materials Engineering from University of Padua, Italy in 2001. She joined Georgia Tech in 2007. Prior to her academic position, she was a senior research engineer at the MEMS Research and Innovation Center (MRIC) of QUALCOMM MEMS Technology, Inc. in San Jose, CA.

She is a member of the editorial board of Scientific Reports, an associate editor of IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control (UFFC), and a guest editor for Journal of Applied Physics’ Focus Issues on PFM. In recognition of her technical contributions, she has received many awards, including the NSF CAREER Award, the IEEE UFFC-S Ferroelectrics Young Investigator Award, and the Society of Women Engineers’ General Motors Award. She is currently the President-Elect of IEEE UFFC-S, and a member of the Advisory Board for Piezoresponse Force Microscopy & Nanoscale Phenomena in Polar Materials (PFM Workshops).

Dr. Bassiri-Gharb’s research interests are in electro-active materials, specially ferroelectrics, and their application to nano- and micro-electromechanical systems as sensors, actuators and transducers, as well as novel approaches to high-response piezoelectric ceramics. Her research integrates micro and nanofabrication techniques and processes, with fundamental science. Contributions of domain walls and phase boundaries to the dielectric and piezoelectric properties, and size effects in thin films and nanostructures are some of the specific topics of focus.