Probing Structure and Dynamic Behaviors of Topological Polar Solitons by Electron Microscopy

Xiaoqing Pan

Department of Materials Science and Engineering,
Department of Physics and Astronomy,
Irvine Materials Research Institute (IMRI),
University of California, Irvine, CA 92697, USA

Topological polar solitions such as domain walls, polar voritices, skyrmions, etc, in ferroelectrics have received much attention owing to their unique functionalities and potential applications in electronic devices. Recent advances in transmission electron microscopy (TEM) and electron energy-loss spectroscopy (EELS) provides powerful tools to study the structure, properties, and dynamic behaviors of these nanostructures with atomic resolution. In this talk, I will demonstrate the nucleation, growth and evolution of polar domains, dynamics of domain wall motion by *in situ* TEM.[1] The electric polarization of nanodomains, vortices and other polar solitons can be mapped by quantitative TEM with the atomic resolution.[2] Recently, we have developed a novel four-dimensional STEM (4D STEM) method that can directly map the local electric field and charge density of crystalline materials in real space with sub-angstrom resolution.[3] Our results provide fundamental understanding of the origins of ferroelectricity and the mechnisms of charge transfer across ferroelectric interfaces. So far, topological polar structures reported in literature, have been observed only in superlattices grown on oxide substrates. We have recently found that two types of skyrmion-like polar nanodomains can be created in lead titanate/strontium titanate bilayers transferred onto silicon and can be switched from one type to another by an applied electric field, which substantially modifies their resistive behaviours.[4] The polar-configuration-modulated resistance is ascribed to the distinct band bending and charge carrier distribution in the core of the two types of polar texture. The integration of high-density (more than 200 gigabits per square inch) switchable skyrmion-like polar nanodomains on silicon may enable non-volatile memory applications using topological polar structures in oxides.

[1] C. T. Nelson et al., *Science* **224**, 968 (2011)
[2] C. T. Nelson et al., *Nano Letters* **11***,* 828 (2011)
[3] W. P. Gao et al., *Nature* **575**, 490 (2019)
[4] L. Han et al., *Nature* **603,** 63 (2022).