Imaging of ferroelectric vortices in complex oxides

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Physical properties of materials can be significantly changed when the materials dimension is reduced and with collective behavior of atoms or charge carriers in these low-dimensional systems properly modulated. Topological defects are emergent phenomena in which the balance between competing energies leads to stable configurations in material structure with characteristic long ordering. Understanding of topological structures hence can lead to variety of applications in modern materials science as well as in quests of fundamental physics [1].

Ferroelectric vortices present one of challenging topics with direct application into electronics, energy storage and signal generation and processing. Until recently high-resolution experimental studies of complex topological structures of ferroelectric polarizations have been bound to the surface phenomena [2]. This posed severe limitations on probing of the whole-volume morphologies with rich dynamics under external perturbations. If the useful properties of the topological defects to be harnessed, then the three-dimensional structural information must be accessed while variable external perturbations are applied to the sample.

Using synchrotron-based Bragg coherent diffraction imaging technique our group has successfully imaged a topological vortex in a volume of individual nanoparticle of barium titanate while the nanoparticle was undergoing phase transitions under applied electric field [3]. This was possible through optimization of reconstruction algorithms, thorough theoretical modelling, design and implementation of functional ferroelectric capacitors, and development of electric field application system with programmable control.

Results of our study show rich structural phase transitions modulated by ferroelectric vortex, mobility and controllability of the vortex core, and chirality of the vortex structure that changes at different electric field states. The behavior of the core as well as changes in the chirality of the topological vortex under external electric field suggest that it can be used in the designs of nanomotors, nanosensors, three-dimensional MOSFETs, and NVRAM [3]. Our findings open new avenues for studies of vortex dynamics that are crucial for future applications of the polar vortices for quantum, integrated and reconfigurable electronic devices, as well as for studies of fundamental physics through creation of artificial states of matter and manipulation of related phase transitions.

This work was supported by the Air Force Office of Scientific Research under Award No FA9550-14-1-0363 (Program Manager: Dr. Ali Sayir) and by LDRD program at LANL. We also acknowledge support, in part, from the LANSCE Professorship sponsored by the NSEC at LANL under subcontract No 257827.

References

[1] J. Mangeri et al., Topological phase transformations and intrinsic size effects in ferroelectric nanoparticles. Nanoscale 9, 1616 (2017).
[2] A. K. Yadav et al., Observation of polar vortices in oxide superlattices. Nature 530, 198–201 (2016).
[3] D. Karpov et al., Three-dimensional imaging of vortex structure in a ferroelectric nanoparticle driven by an electric field. Nature Communications 8, 280 (2017).
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