Reconfigurable Topological Polar Textures in Freestanding Ferroelectric Nanolayers

Franco N. Di Rino
Tim Verhagen
Institute of Physics, Czech Academy of Sciences, Na Slovance 2, Prague 8, 182 00, Czech Republic
dirino@fzu.cz

The emergence of two-dimensional materials has recently expanded toward freestanding complex oxides, opening a new route to engineer ferroic functionalities beyond substrate constraints. In this work, we demonstrate that ultrathin freestanding ferroelectric layers host a rich landscape of topological polarization textures, even in the absence of interfaces, strain engineering, or moiré reconstruction.

Using first-principles-based atomistic simulations, we investigate the evolution of polarization patterns in freestanding $BaTiO_3$ nanolayers as a function of temperature and thickness. We find that above a critical thickness, electrostatic confinement stabilizes a dynamic vortex–labyrinthine regime characterized by fluctuating out-of-plane domains with long-range orientational order. Upon cooling, this state freezes into two nearly degenerate topological phases: a wave–helix texture, consisting of stripe-like domains with helical polarization rotation, and a chiral bubbles phase, formed by closed toroidal polarization loops.

These configurations differ in their domain morphology and topological organization but remain separated by an exceptionally small energy barrier, enabling reversible switching. We show that static electric fields can deterministically drive the system into the wave–helix state, while time-dependent THz fields induce the reverse transition, restoring chiral bubble textures. This demonstrates ultrafast electrical control of topological states in a minimal system.

Importantly, the observed behavior emerges without the need for multilayer stacking, twisting, or interfacial engineering, in contrast to current approaches in oxide heterostructures and moiré materials. Instead, the competition between electrostatic, elastic, and surface energies in a freestanding geometry is sufficient to generate a programmable energy landscape with multiple accessible topological states.

Our results establish freestanding ferroelectric nanolayers as a simple yet powerful platform for reconfigurable topological nanoelectronics, bridging concepts from ferroelectrics, soft matter, and two-dimensional systems[1].

References

1. Franco N. Di Rino, Tim Verhagen, Topological Polar Textures in Freestanding Ultrathin Ferroelectric Oxides, arXiv:2601.20534 DOI: 10.48550/arXiv.2601.20534

Figures

Figure 1: (a) Phase diagram and representative polarization textures in freestanding $BaTiO_3$ ultrathin layers. A vortex–labyrinthine regime emerges (b) at high temperature and evolves into two nearly degenerate low-temperature topological states: wave–helix (c) and chiral bubbles (d)[1].