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Unveiling moiré-Induced topological polar structures by scanning transmission electron microscopy

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Complex correlated oxides are quantum materials characterized by unshielded d-electrons. Their interaction across competing energy scales leads to diverse functionalities, which can be altered by slight changes of their structure, composition, or boundary conditions [1]. In this context, recent studies on ferroelectric oxides have shown the formation of complex polar topologies, which are related to a delicate interplay between the intrinsic tendency of the material towards a uniform polarization and the electrical and mechanical constraints placed upon them [2]. However, the cube-on-cube epitaxial structure of these materials forces the use of single crystalline substrates for their growth, which restricts the possible mechanical boundary conditions and, therefore, the formation of new topological structures. To overcome this limitation, we have isolated the ferroelectric materials from their parent substrate by a selective chemical exfoliation method, thus obtaining freestanding layers of just a few unit cells in thickness. This new approach vastly increases the potential for novel hetero-integration approaches by stacking various freestanding layers and avoiding the chemical, structural, or thermal limitations of conventional synthesis and growth processes [3].

In this work, we show how a polar vortex pattern is induced by stacking twisted freestanding ferroelectric $BaTiO_3$ layers [4]. We study the formation of these topological polar structures in relation to the twisted angle and layer thickness by aberration-corrected scanning transmission electron microscopy and density-functional theory calculations.

These results show an exciting opportunity to create novel polar topologies using the unique modulations that are possible in moiré bilayers and pave the way for potential applications in future high-density ferroelectric memory devices.

References:
[1] Y. Tokura et al., *Nature* **13**, 1056 (2017)
[2] Yadav, A. K. et al., *Nature*, **530**, 198 (2016).
[3] S. Puebla et al., *Nano Letters* **22**, 18 (2022)
[4] G. Sánchez-Santolino, V. Rouco et al., *Nature*, **626**, 529 (2024)