EPS Structural Dynamics Afternoon Online Workshops **14h00 19th May 2022**

Stabilization of Polar Homochirality at $BiFeO_3$ Domain Walls

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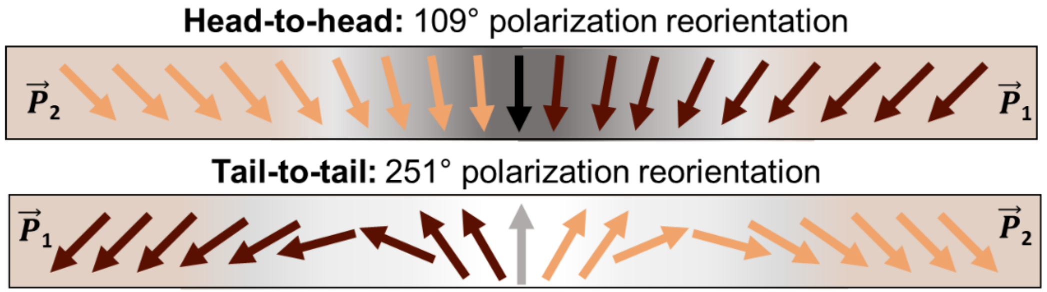
Chirality is a concept central to all molecular interactions in biological systems. In the last decade its importance was also highlighted in condensed matter physics, where spin texture at the homochiral ferromagnetic domain walls was shown to enable their deterministic current-driven motion. Nevertheless, only a few reports on polar chirality exist to this date, prompting the research efforts. Here, we report the stabilization of net chirality in $BiFeO_3$ ferroelectric films grown on a fully in-plane-polarized ferroelectric layer of Aurivillius phase. By introducing an in-plane-polarized epitaxial buffer we create polarization continuity and provide a symmetry breaking at the interface with the out-of-plane polarized $BiFeO_3$. Scanning probe microscopy uncovers the exclusive formation of rare in-plane 109° domain walls in $BiFeO_3$. Deterministic sense of polarization rotation is measured at these walls, establishing them as Néel-type domain walls with a net chirality extending across the film. Thus, we demonstrate a simple design combining perpendicular polar anisotropies for the effective stabilization of homochiral textures in ferroelectric thin films.



Head-to-head: 109° polarization reorientation

Tail-to-tail: 251° polarization reorientation

Figure: Homochiral ferroelectric domain walls in $BiFeO_3$.
E. Gradauskaite et al., under review (2022).

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14h30 19th May 2022

Highway to electrifying skyrmions

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Researchers have long wondered whether ferroelectric materials, characterized by a spontaneous and switchable electric polarization, may present topological textures akin to magnetic skyrmions and chiral bubbles. Experimental discovery of dipole vortices in PbTiO3/SrTiO3 superlattices [1,2] and earlier theoretical predictions of Bloch-like structures in ferroelectric domain walls [3] have boosted the search for electric Skyrmions.

In this lecture, I will show that, indeed, a simple multidomain configuration in PbTiO3 – namely, a columnar nanodomain with polarization opposed to that of its surrounding matrix – is sufficient to generate a dipole texture with the topology of a skyrmion. In this configuration, at the domain wall, between nanodomain and matrix, the polarization rotates forming a close loop around the nanodomain. This constitutes the first prediction of an electric skyrmion in a single-phase ferroelectric material [4]. Further, I will show that the properties and topology of the electric skyrmion can be tuned by external electric and elastic fields, as well as by temperature, obtaining novel effects such as topological and isotopological phase transitions.

In the second part of the lecture, I will present the first observation of a room-temperature electric skyrmion in PbTiO3/SrTiO3 superlattices [5]. In this study, S. Das and colleagues report the discovery of room-temperature polar skyrmions in a PbTiO3 layer confined by SrTiO3 layers using several experimental and theoretical methods. Lastly, I will discuss the most recent studies, in which it is demonstrated that the electric skyrmions observed in the PbTiO3/SrTiO3 superlattices display a strong enhancement of the dielectric permittivity when compared to the individual SrTiO3 and PbTiO3 layers [6]. In the same study, it is shown that, using external electric fields and temperature, a reversible phase transition from the skyrmion state to a trivial uniform ferroelectric state is observed, which is accompanied by a large tunability of the dielectric permittivity.

[1] Yadav, A.K., Nelson, C.T. et al., Observation of polar vortices in oxide superlattices. Nature 530, 198-201 (2016).
[2] Damodaran, A. R. et al., Phase coexistence and electric-field control of toroidal order in oxide superlattices. Nature Materials 16, 1003 (2017).
[3] Wojdel, J. C. et al., Ferroelectric Transitions at Ferroelectric Domain Walls Found from First Principles. Phys. Rev. Lett. 112, 247603 (2014).
[4] M.A.P. Gonçalves et al., Theoretical guidelines to create and tune electric skyrmion bubbles. Science Advances 5, no. 2, eaau7023 (2019).
[5] S. Das et al., Observation of room temperature polar skyrmions. Nature 568, 368-372 (2019).
[6] S. Das et al., Local negative permittivity and topological phase-transition in polar skyrmions. Nature Materials 20, 194–201 (2021)

EPS Structural Dynamics Afternoon Online Workshops 15h00 19th May 2022

Measuring and tailoring anisotropies in skyrmion and antiskyrmion hosts

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As known for long, in centrosymmetric crystals magnetic anisotropy plays a key role in the formation of magnetic bubbles, including topologically trivial and non-trivial ones. In contrast, in non-centrosymmetric crystals, where the Dzyaloshinskii-Moriya interaction is the key player in stabilizing magnetic skyrmions, systematic studies on the effect of anisotropy have been virtually non-existing. However, recent theoretical predictions and experimental observations show that the quantitative description of the (anti)skyrmion stability range, the formation of distinct high- and low-temperature skyrmion lattice phases and other emergent exotic mesoscale spin patterns all require the treatment of magnetic anisotropy on equal footing with the Dzyaloshinskii-Moriya interaction. Here we provide a short overview, from an experimental point of view, on the vital role of magnetic anisotropy in various skyrmion and antiskyrmion host materials, via the spectroscopic determination of relevant anisotropy terms in non-centrosymmetric cubic (O, T) and axial (C_{nv}, S_4) magnets as well as in centrosymmetric skyrmion hosts [1-6].

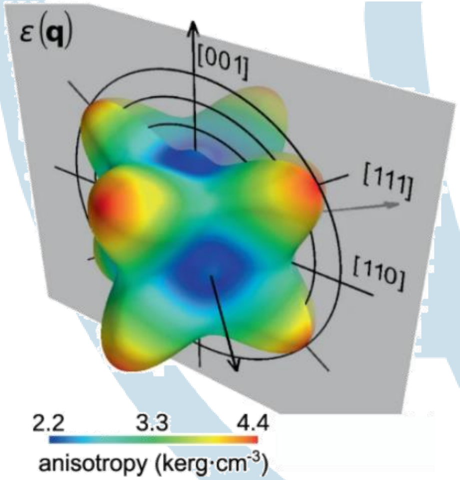

Figure: Anisotropy energy of the helical state versus the orientation of the q-vector in the cubic chiral magnet $Co_{10}Zn_{10}$.

[1] I. Kézsmárki et al., Nat. Mater. 14, 1116 (2015)
[2] D. Ehlers et al., J. Phys.: Condens. Matter 29, 065803 (2017)
[3] B. Gross et al., Phys. Rev. B 102, 104407 (2020)
[4] M. Preissinger et al., npj Quantum Mater. 6, 65 (2021)
[5] A. Butykai et al., npj Quantum Mater. 7, 26 (2022)
[6] K. Karube et al., Adv.Mater. 34, 2108770 (2022)