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Investigating the Ferroelasticity Governing the Dynamics of Improper Ferroelectric Domain Walls by In-Situ Biasing 4D-STEM

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Dynamic conducting ferroelectric domain walls overturn the classical idea that our electronic circuits need to consist of fixed components of hardware [1]. Domain wall topologies in ferroelectrics are an emerging research focus in nano-electronics and potential quantum technologies [2, 3]. However, due to the high energetic cost of creating charged walls in conventional ferroelectrics they are not stable long term. Improper ferroelectrics circumvent this issue as their driving force is not a polar instability, but rather the critical dynamics of symmetry-breaking of the non-polar primary mode. With these benefits there has been a recent surge in improper ferroelectric topology research [4].

We focus our studies on the improper ferroelectric boracite material system, known for their stable conducting and insulating domain walls and anomalous motion associated with negative capacitance [5, 6]. Boracite is an improper ferroelectric material where the primary order parameter is the physical quantity spontaneous shear strain. As a ferroelastic material the conductivity of the charged walls is governed by the shear strain direction of the neighbouring domains. Thus, traditional atomic resolution STEM polarity mapping will not give a true picture of the ferroelectric properties. In order to understand the mechanism of the wall movement and the fundamental physics governing their formation, strain analysis was completed using four-dimensional scanning transmission electron microscopy (4D-STEM) [7, 8] strain mapping. This strain analysis was then compared to the atomic resolution STEM imaging and polarity mapping [9].

The dynamic nature of the topologies was first investigated by utilising the applied electric field of the STEM probe [10]. We show long-ranged re-ordering of shear strain during wall motion that is not present when the walls are stationary, and the complexity of the domain walls' local strain as they move through defects such as twin boundaries. Additionally we used an in-situ biasing holder set up in a parallel contact mode to compare to our previous device level work on negative capacitance measurements [5]. When mobile, the insulating domain walls have a very distinct local change in both strain and symmetry compared to the conducting walls. Finally, we explore the motion of higher order topology junctions such as vertices and vortices. Theoretical calculations confirm the shear strain to polarization vector relationship and charged topology energetics. We will present the benefits of 4D-STEM characterization for wall topologies governed by ferroelasticity, over the use of segmented detectors, where differential phase contrast mapping cannot detangle the strain and polar signals. The opportunities time-resolved 4D-STEM characterization methods can bring to the field of ferroelastic governed polar topology physics will be discussed in detail [11].

References:

[1] G Catalan et al., Reviews of Modern Physics **84** (2012). 10.1103/RevModPhys.84.119
[2] JPV McConville, et al. Advanced Functional Materials **30** (2020). 10.1002/adfm.202000109
[3] D Meier and SM Selbach, Nature Reviews Materials (2021). 10.1038/s41578-021-00375-z
[4] D Meier et al., Nature Materials **11** (2012). 10.1038/nmat3249
[5] JGM Guy et al., Advanced Materials **33** (2021). 10.1002/adma.202008068
[6] RGP McQuaid et al., Nature Communications **8** (2017). 10.1038/ncomms15105
[7] C Ophus, Microscopy and Microanalysis **25** (2019). 10.1017/S1431927619000497
[8] BH Savitzky et al., Microscopy and Microanalysis **27** (2020). 10.1017/S1431927621000477
[9] E O'Connell et al., (2021). arXiv:2110.00112
[10] M Conroy et al., Microscopy and Microanalysis **26** (2020). 10.1017/S1431927620023594
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