Probing Multiferroic Order with Dichroic Soft X-ray Microscopy

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Soft X-ray microscopy is invaluable for the characterisation of ferroic materials due to the sensitivity to magnetism and ferroelectricity with strong dichroic contrasts. This is particularly useful for the study of multiferroic oxides in thin film or nanoparticles form. In the case of the room-temperature multiferroic bismuth ferrite (BFO), soft X-ray ptychography provides unprecedented insight into the multiferroic domain structure by resolving both the antiferromagnetic spin cycloid and ferroelectric domains in a single microscopy image [1].

Ptychographic imaging provides clear evidence of magnetoelectric coupling by separation of the antiferromagnetic and ferroelectric components even in the collinear case by employing X-rays at the Fe L-edge or O K-edge, respectively [2]. The X-ray linear dichroism (XLD) at the O K-edge that senses the ferroelectricity is due to the hybridisation of the O 2p and Fe 3d orbitals. Such XLD imaging of domains at the O K-edge can be applied to other ferroelectrics such as lead-free $K_{0.7}Na_{0.3}NbO_3$ (KNN), which forms stripe domains.

Freestanding thin films of BFO provide fertile ground for the study of strain effects, which was analysed by the step-wise application of tensile strain with a MEMS device and subsequent monitoring of the multiferroic domains by ptychography.

Another room-temperature single-phase multiferroic is ε-Fe_2O_3, which is ferroelectric and ferrimagnetic with high coercivity. It will be shown that multiferroic order of individual ε-Fe_2O_3 nanoparticles is amenable to ptychographic imaging with X-ray Circular Dichroism (XMCD) and XLD at the Fe L_3-edge.

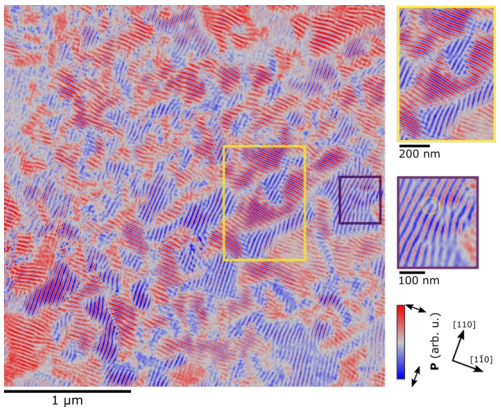

Figure 1. Multiferroic domains of a freestanding BFO film imaged by XLD soft X-ray ptychography at the Fe L_3-edge (from [1]).

References

[1] T. A. Butcher et al., Advanced Materials **36**, 2311157 (2024), https://doi.org/10.1002/adma.202311157.
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