Probing two-dimensional ferroic heterostructures.

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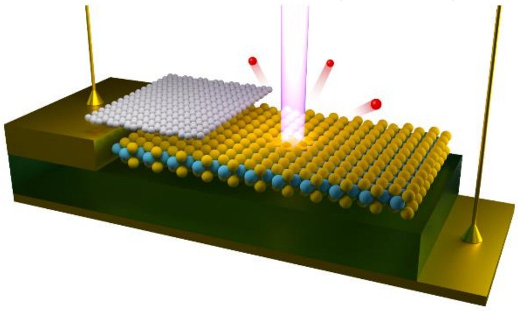
This project will probe electronic structure changes in two-dimensional ferroic heterostructures through angle resolved photoemission spectroscopy (ARPES) and tunnelling spectroscopy.

Ferroics exhibit phase transitions where spontaneous symmetry breaking occurs and have order parameters that can switch in response to external stimuli: for example, in ferroelectrics the electric polarization can be switched by the application of an electric field, and the magnetization can be switched by a magnetic field in ferromagnets. Understanding these materials is a core part of condensed matter Physics and has led to their widespread application in the electronics industry and beyond.

The advent of two-dimensional materials (2DMs) has opened fascinating new avenues of research in this field [1,2]. A large family of different 2D materials have been isolated in thin-layers, down to monolayers, including semi-metals like graphene, semiconductors, superconductors, magnetic materials, ferroelectrics and more. Without dangling bonds, these 2DMs can be simply stacked into atomically precise 2D heterostructures with atomically perfect interfaces. For ferroic materials, this has offered opportunities to probe truly two-dimensional Physics. The nature of the 2D platform also opens control parameters that are difficult to access in 3D: it simplifies electrostatic doping, modulation of strain, and the application of proximity effects. Interlayer interactions allow coupling of ferroic ordering to direct electrical and optical readout, giving greater flexibility in studying these materials and opening new device designs for applications. All of these are underpinned by the electronic structures of the constituent layers and of their changes when stacked and in response to variations in control parameters. These changes in electronic structure (band alignment, proximity effects etc.) are fundamental to the understanding and development of 2D ferroics and 2D heterostructures in general.



Through this project, we will gain new insight into 2D ferroic heterostructures by direct electronic structure measurements using ARPES, and by a new form of spatially resolved tunnelling spectroscopy. We will probe, in situ and for the first time, the effects of electric field on 2D ferroelectric and ferromagnetic heterostructures using techniques pioneered by our group at the University of Warwick [3]. Our preliminary temperature dependent electronic structure measurements on a magnetic 2D material have shown strong magneto-electronic coupling, with clear electronic structure changes through the magnetic phase transition. In ferroelectrics, large band shifts with changing polarization have been predicted, but not yet measured.

Applicants with an interest in condensed matter Physics and aptitude for experiment and data-analysis are encouraged to apply. In addition to the experimental work at the University of Warwick (sample fabrication and testing, scanning probe microscopy, optical spectroscopy measurements etc.), many of the results will be acquired at international ARPES facilities such as Diamond Light Source (UK, we have a long-standing collaboration with Dr Cephise Cacho and Dr Matthew Watson of the I05 ARPES beamline) and the ELETTRA synchrotron light source (Italy).

References:

[1] W. Li, X. Qian, and J. Li, Nat. Rev. Mater. **6**, 829 (2021).
[2] P. Man, L. Huang, J. Zhao, and T. H. Ly, Chem. Rev. **123**, 10990 (2023).
[3] P. V. Nguyen, …. and N. R. Wilson, Nature **572**, 220 (2019).