2D Quantum Straintronics

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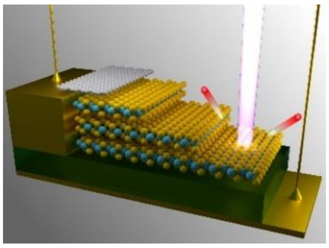
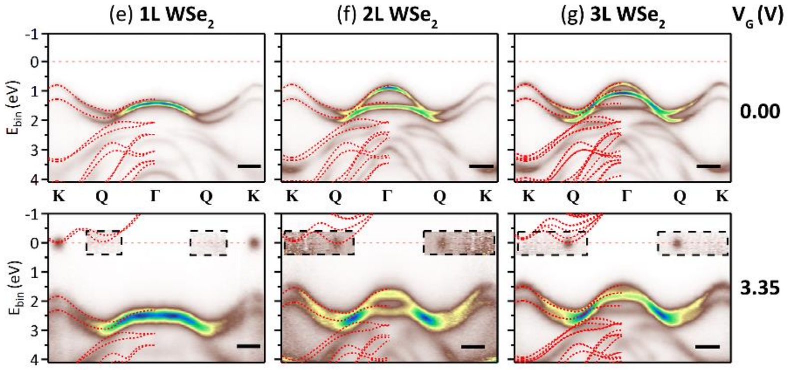
Strain plays a crucial role in modern electronics, with strain engineering a cornerstone of band engineering, essential for high-speed electronics. However, strain has the potential to play an even more transformational role in the field of 2D electronics. Amongst the extraordinary mechanical properties of 2D materials, their ability to tolerate large strains before breaking is noteworthy, with reports of strain in graphene exceeding 10%. Strain changes the length of atomic bonds and changes bond angles, tuning electronic coupling and hence altering band gaps, band alignments and effective masses. Uniaxial strain can break crystal symmetry and induce anisotropy, and in strongly correlated systems, strain can drive phase transitions.

This has led to the concept of 2D straintronics [1]: engineering the electronic and optical properties of 2D devices through the introduction of mechanical deformations. Some of this is inadvertent. For nearly commensurate layers, for example in small angle twisted bilayers of graphene, commensurate domains can form with strain localised at the nanoscale into domain walls. But strain can also be used as a control parameter. For example, optical spectroscopy measurements of increasing tensile strain on monolayers of semiconducting MoS_2 initially indicate a reducing band gap, until at around 2% strain a transition from direct to indirect band gap is inferred. Strain can also drive magnetic phase changes in 2D materials: in recent work [2], uniaxial strain was used to reversibly induce an anti-ferromagnetic to ferromagnetic transition in the 2D magnetic semiconductor, CrSBr. In all cases, strain induced changes to the electronic structure drive changes to the functional properties. But, so far, the underlying electronic structure changes have only been indirectly inferred.

We see an exciting opportunity to gain new insight into 2D straintronics through direct in situ electronic structure measurements using angle resolved photoemission spectroscopy with micrometre scale spatial resolution (μARPES). The project combines the world-leading expertise in μARPES at the I05 beamline of the Diamond Light Source with the experience of Professor Neil Wilson's group at the University of Warwick, pioneers of in-operando ARPES measurements of 2D heterostructures [3]. The aim of the project will be to develop the strain rigs and sample designs necessary to make in situ strain dependent electronic structure measurements. By delivering proof-of-principle experiments, demonstrating band structure changes and strain driven phase transitions, we will open the field of 2D straintronics to ARPES.

Funding (stipend plus fees) is available for exceptional candidates for 3.5 years, with an enhanced stipend above the standard research council rate (see here). Applicants with interest in condensed matter Physics and aptitude for experiment and data-analysis are encouraged to apply. The student will spend part of the project at the University of Warwick and part at Diamond Light Source, benefitting from exceptional facilities and collaborations at both. A broad education in Materials Physics will be provided through dedicated modules at Warwick, Diamond, and external courses.





(left) Schematic of 2D heterostructure for μARPES ; (right) example nanoARPES results from a 2D heterostructure, showing layer-dependent band structure in the 2D semiconductor WSe_2, adapted from [3].

References:

[1] F. Miao et al., Npj Quantum Mater. **6**, 2 (2021).
[2] J. Cenker et al., Nat. Nanotechnol. **17**, 256 (2022).
[3] P. V. Nguyen et al., Nature **572**, 220 (2019).