EPSRC
Engineering and Physical Sciences Research Council

Case Study

HERIOT WATT UNIVERSITY

Two-Dimensional Heterostructure Device Fabrication

Two-dimensional (2D) materials, formed from crystals in which the individual atomic layers are only weakly bonded, can produce a remarkably wide range of electronic and optical properties. An amazingly rich selection of 2D materials can be found: insulators, semi-conductors, metals, superconductors, and graphene (a semi-metal) are all possible. Beyond merely replacing conventional materials such as Si or GaAs in conventional electronic or photonic devices, 2D materials can have unique physical properties and can be stacked together in novel ways to make entirely new quantum materials.

Opportunities and Challenges:

Stacking individual layers of different 2D crystals leads to heterostructures which are not limited by lattice mismatch between adjacent layers, as is the case in conventional materials. This opens the door to unlimited possibilities to engineer materials with specific properties, which can be tailored towards new electronic/photonic technologies or investigating new quantum materials. There are however significant challenges in fabricating high quality pristine heterostructures. 2D materials are sensitive to adsorption, moisture and oxidation, making pristine interfaces and homogeneous interlayer contact difficult. Additionally, accurate identification, characterisation, and positioning of each layer to be stacked into a heterostructure is essential.

Solution:

Our facility provides the optimal conditions to fabricate state-of-the-art 2D heterostructures devices. Our world-leading facility hosts a wide-range of equipment for exfoliation, in-situ optical characterisation, and deterministic stacking of 2D materials into fully functional encapsulated heterostructure devices, all in an Argon atmosphere glovebox.

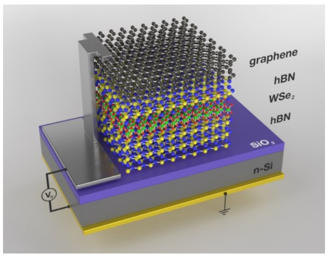
⇒ A spectroscopic imaging ellipsometer (EP4 from Accurion) enables automatic flake searching and in-depth optical characterization, achieving micron (Angstrom) lateral (vertical) resolution.

⇒ Two optical microscope systems to image and monitor the deterministic transfer of 2d samples.

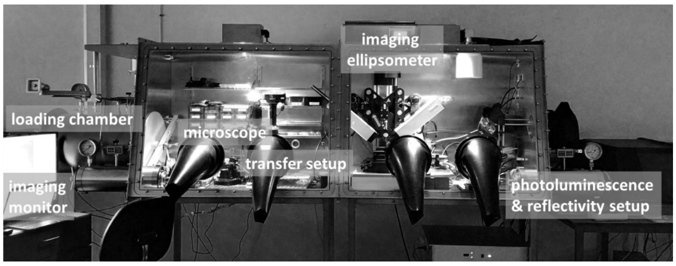
⇒ A ‘hot-pick-and-place’ transfer stage with integrated heater to ensure pristine heterostructure interfaces (which have never been exposed to polymer stamps).

⇒ An in-situ set-up for white-light reflectivity and photoluminescence spectroscopy.

A full suite of lithographic (e-beam lithography, direct laser writing, photolithography), plasma etching, metal deposition, and wire-bonding facilities are available to create fully functional electronic/photonic devices following assembly in the glovebox.



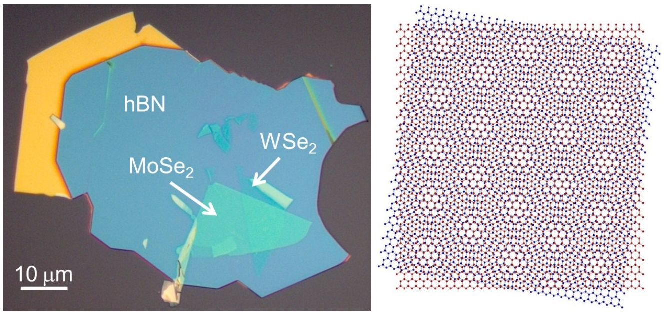
Example 2D Heterostructure device



Glovebox for 2D heterostructure fabrication and in-situ optical characterization

Notable achievements from the 2D Fabrication Facility:

- Coulomb blockade in an atomically thin quantum dot coupled to a tunable Fermi reservoir, Nature Nanotechnology **XX**, YYYY (2019)
- Atomically-thin quantum dots integrated with lithium niobate photonic chips, Optical Materials Express **9**, 441 (2019).
- Microcavity enhanced single photon emission from two-dimensional WSe2, Applied Physics Letters **112**, 191105 (2018)
- Towards spontaneous parametric down conversion from monolayer MoS2, Scientific reports **8**, 3862 (2018)
- Deterministic strain-induced arrays of quantum emitters in a two-dimensional semiconductor, Nature Communications **8**, 15053 (2017).



2D crystals with a twist: (Left) MoSe2 / WSe2 heterostructure encapsulated by hBN. (Right) The relative angle between the two monolayers creates a Moire superlattice period which determines the electronic and optical properties of the new material.

To expand our knowledge of the application domain, we are looking forward to the collaboration opportunity in new areas of optical metasurfaces and ultrathin optical devices built on our expertise.

HERIOT-WATT UNIVERSITY EDINBURGH EH14 4AS NANOFAB.HW.AC.UK