Imaging interfaces in van der Waals heterostructures

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The advent of van der Waals heterostructures has led to a spate of advances in condensed matter physics thanks to the novel properties of 2D materials and the design flexibility these structures afford. Nevertheless they pose an interesting conundrum for materials characterisation. Sheets only 1-3 atoms thick stacked through van der Waals bonds are now routinely characterised by Raman spectroscopy and scanning probe techniques[1], however the nature and cleanliness of the atomic-scale interfaces remain uncharacterised despite directly influencing device performance[2]. Here we present cross sectional scanning transmission electron microscope (STEM) analysis of van der Waals heterostructures, providing direct imaging of the interfaces within these unique systems. We demonstrate the diversity of this technique by showing its successful application to a variety of heterostructures ranging from air sensitive crystals[3] (see Figure 2), to nanocapillaries formed in graphite with bespoke dimensions[4].

Cross sectional STEM analysis of van der Waals heterostructures allows the interfaces between atomically thin crystals to be characterised in unprecedented detail using the latest aberration corrected microscopes, leading to a better understanding of fabrication methods and device behaviour.

References

[1] Woods *et al.*, Nature Physics, 6 (2014)
[2] Chari *et al.*, Nano Letters, 7 (2016) 4477
[3] Cao *et al.*, Nano Letters, 8 (2015) 4914
[4] Radha et al., Nature, 7624 (2016) 222

Figures

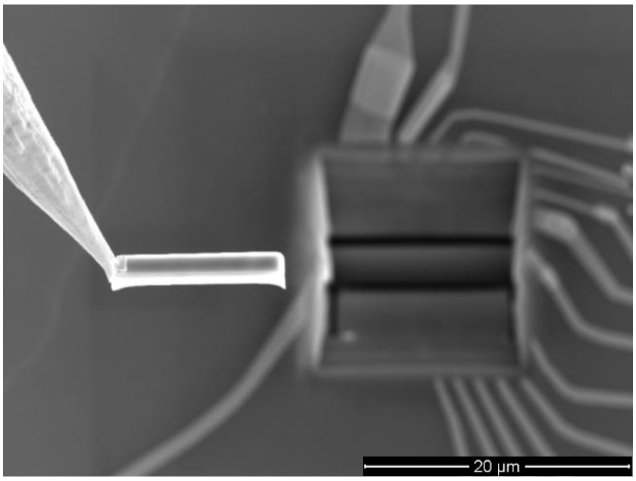

Figure 1: 'Lift out' of a cross section from a device for focussed ion beam polishing and high resolution STEM analysis. This thin window has been milled from the substrate in the image background.

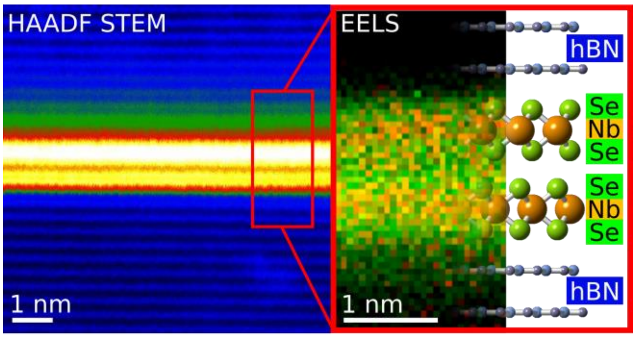

Figure 2: STEM analysis reveals the nature of buried interfaces in these unique structures. **Left**: The distance between components can be measured within 0.5Å using HAADF dark field imaging (false coloured to enhance contrast). The yellow stripes show the position of the $NbSe_2$ planes. The light blue stripes show the planes of hBN which encapsulate the niobium diselenide bilayer. **Right**: The atomic structure can be characterised using electron energy loss spectroscopy. Selenium atomic planes are shown green and lie either side of an atomic plane of niobium, shown orange. Direct imaging of these interfaces not only leads to improved device fabrication but allows us to determine the type of interaction present between atomically thin components and their adhesion.