Understanding nanoparticle catalysts and 'beyond-graphene' heterostructures using advanced analytical scanning transmission electron microscopy

S. J. Haigh[1]

[1]University of Manchester, School of Materials

The current generation of aberration corrected scanning transmission electron microscope (STEM) instruments optimized for high spatial resolution energy dispersive x-ray (EDX) spectroscopy provide exciting opportunities for structural and elemental analysis of nanoscale objects. Here I will discuss recent example applications from our studies of nanoparticle catalysts and 2D device heterostructures where these analytical capabilities have provided new insights to interpret the optical, electronic and catalytic properties of such systems.

The emerging area of 2D materials has attracted a great deal of attention in recent years. Like graphene, these materials can be exfoliated to single atom thickness and can then be layered together to create new van der Waals crystals with bespoke properties. We have been developing methods for investigating the structure of these novel materials at the atomic scale. I will present work demonstrating that cross sectional STEM-EDX spectrum imaging can be used to reveal the internal atomic structure of van der Waals heterostructure devices[1,2]. For example, we have studied light emitting diode (LED) devices, produced by mechanical exfoliation and subsequent stacking of 13 different 2D crystals, including four MoS2 monolayer quantum wells3. Using cross sectional STEM spectrum imaging we reveal that the crystal interfaces of such devices are atomically flat and provide detailed structural information to help to explain the photoluminescence results obtained. Other 2D crystal het erostructures will also be discussed including those incorporating air sensitive 2D crystals, such as black phosphorus and NbSe2, which are fabricated under an argon atmosphere to preserve the structure of the material.[4] Recent results where heterostructures containing atomically engineered nanoscale channels have been used to study water transport will also be discussed.[5]

Most (S)TEM imaging and analysis gives only a 2D projection of the structure in vacuum. I will discuss the application of elementally sensitive STEM EDX electron tomography to provide a route to understanding the full 3D morphology and chemistry with nanometre resolution.[6] I will also discuss current progress and using customised modification of an in situ STEM holder system has allowed us to perform high spatial resolution STEM-EDX spectrum imaging during in-situ gas and liquid phase experiments and at elevated temperature.[7]

[1] Haigh et al, , *Nature Materials* **11**, 764 (2012).

[2] Georgiou et al , *Nature Nanotechnology* **8**, 100 (2013).
[3] Withers et al, *Nature Materials* **14**, 301 (2015).
[4] Cao et al , *Nano Letters* **15**, 4914 (2015).
[5] Boya et al, *Nature* **in press**, - (2016).
[6] Slater et al, *Nano Letters* **14**, 1921 (2014).
[7] Lewis et al, *Chemical Communications* **50**, 10019 (2014).