Probing Defects and Dynamics in 2D Heterostructures by Scanning Transmission Electron Microscopy

Sarah J Haigh[1,]
D. J. Kelly[1] D. Hopkinson[1], A P Rooney[1] N. Clark[1] W. Zhao[2] F Ding[2] R Gorbachev[2] K. Novoselov,[1] A Geim[1], V. Falko[1], R Young[1]

1. National Graphene Institute, University of Manchester, Manchester, M13 9PL, UK
2. Institute of Textiles and Clothing, Hong Kong Polytechnic University, Hung Hom, Hong Kong

Sarah.haigh@manchester.ac.uk

Scanning Transmission Electron Microscopy (STEM) is a powerful tool to probe the structure and chemistry of 2D materials vertical heterostructures stacks. For example, using advanced STEM we have shown that protruding defects prevent the realisation of pristine interfaces between transition metal selenides (MoSe2, WSe2, NbSe2) and boron nitride, unless exfoliation is performed in an inert environment.[1] We also report cross sectional STEM analysis of microstructures produced when 2D van der Waals materials (graphite, boron nitride, $MoSe_2$) are subjected to mechanical deformation. We find that the types of defect can be predicted from just the bend angle and thickness of the materials.[2] Above a critical thickness the materials exhibit numerous twin boundaries and for large bend angles these can contain nanoscale regions of local delamination (Fig.1). Such features are proposed to be important in determining how easily the material can be thinned by mechanical or liquid exfoliation.[2]

2D material heterostructures are also enabling new STEM imaging capabilities. We show they can be used as a platform to study real time reactions in liquid environments with unprecedented spatial resolution and spectroscopic capabilities [3]. We further demonstrate that graphene encapsulation allows imaging of point defect dynamics in monochalcogenides, GaSe and InSe (Fig. 2) [4].

References

[1] A P Rooney et al. Nano Letters, (2017) 17, 5222.
[2] A P Rooney et al. Nature Communications (2018) 9, 3597
[3] D J Kelly et al Nano Letters, (2018) 18, 2, 1168
[4] D G Hopkinson et al, ACS Nano, (2019) 10.1021/acsnano.8b08253

Figures

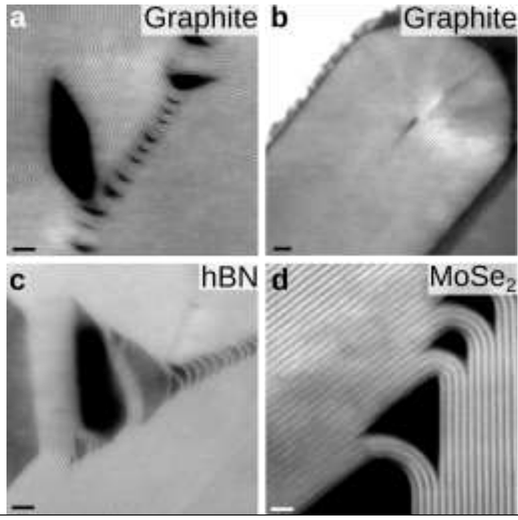

Figure 1: Defects induced by mechanical deformation in van der Waals materials [2]

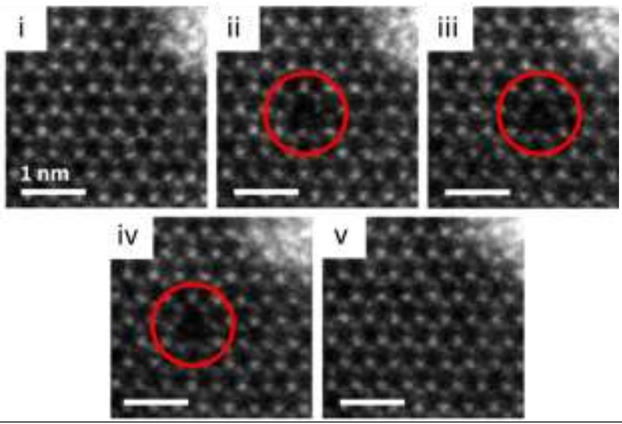

Figure 2: Formation and healing of defects in monolayer InSe.