Atomic Resolution Analysis of Single Atoms in 2D Materials using Transmission Electron Microscopy

Jamie H. Warner

Department of Materials, University of Oxford

Jamie.warner@materials.ox.ac.uk

Measuring a material atom-by-atom provides unrivalled insights into its structure and how this impacts its properties. Transmission electron microscopy is one of the leading approaches to probe individual atoms in solids to measure their position, elemental type, bond length, charge state, and local electric field. I will discuss our recent advances in sub-Angstrom resolution measurements of nanomaterials using aberration corrected transmission electron microscopy (TEM). I will show how state-of-the-art electron-optics provide electron probes that can interact with single atoms, using a combination of annular dark field scanning TEM with electron energy loss spectroscopy (EELS). The main materials of focus are 2D systems, such as graphene, MoS and WS2. I will show how we can measure the local electric field around single atoms in MoS2 using direct electron detectors to capture 4D data sets that are rich with information. Analysis around defects and dopants in 2D materials will be presented, with atom-by-atom EELS mapping and measurements of local perturbations to electric fields. In-situ TEM is also shown for nanoelectronic devices to understand the mechanisms of electrical breakdown in monolayer MoS2, and how high temperature transformations occur in 2D materials in real time. I will discuss grain boundaries, single atom dopants, vacancy defects, dislocations, buckling, edges, interlayer stacking structures, atomically sharp cracks, inversion domains, and nanopores in 2D materials at the atomic level.

Figures

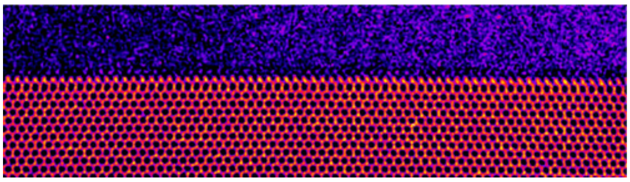

Figure 1: TEM image of atomically flat zigzag edges in MoS2