Type of presentation: Invited

IT-2-IN-2893 Extending the capabilities of high-resolution STEM:measuring depth dependent strain using optical sectioning and aberration-free phase contrast imaging of low-Z materials

Nellist P. D.[1,2], Yang H.[1], Lozano J. G.[1], Hirsch P. B.[1], Pennycook T. J.[1,2]

[1]Department of Materials, University of Oxford, UK, [2]SuperSTEM Laboratory, Daresbury, UK

Email of the presenting author: peter.nellist@materials.ox.ac.uk

The development of aberration correction in scanning transmission electron microscopy (STEM) has had a major impact on spatial resolution and analytical capability. Unsurprisingly, alongside these developments come further complications but also opportunities. The increased numerical aperture allowed by aberration correction leads to a reduced depth of focus (DOF), which in a modern instrument may be just a few nanometres, and typically less than the sample thickness. The increased numerical aperture of the probe converging optics also leads to a larger bright-field (BF) disc in the detector plane, and as a result much of the scattering by the sample remains in the BF disc. In this presentation we will two explore STEM imaging modes that make use of each of these effects to provide aberration-corrected STEM with new capabilities.

The reduced DOF means that in principle a three-dimensional (3D) data-set can be recorded as a focal series of images. In practice, a confocal configuration is generally required. At atomic resolution, however, nanometre-scale depth resolution is also available in the conventional STEM configuration [1]. For dislocations in GaN viewed end-on we show the detection of depth-dependent Eshelby twist displacements associated with screw dislocations. We also show that ADF STEM optical sectioning can be used to measure the screw displacements parallel to the dislocation line for dislocations lying in the plane of the TEM sample, and we use this effect to measure the dissociation reaction of mixed dislocations in GaN. Despite the channelling of the probe, the depth sensitivity persists, and Fig. 1 shows how a simple weighted potential model is a reasonable approximation to a full channelling simulation.

Use of a pixelated detector to record the entire BF disc in the detector plane as a function of probe position results in a 4D data set. A phase contrast image can be retrieved from this data set using a processing method proposed by Rodenburg et al [2]. Interference between the BF disc and a diffracted disc leads to intensity in the overlap region that oscillates with respect to probe position. Figure 2 shows the magnitude and phase of that oscillation for a bilayer graphene sample. From such data a full phase contrast image can be retrieved and we compare the sensitivity of this imaging mode with alternative techniques such as annular bright-field and differential phase contrast. The data is also an excellent instrument diagnostic, and effects such as aperture charging, residual aberrations and the effect of chromatic aberrations can also be observed.

[1] P.D. Nellist and P. Wang, Annual Review of Materials Research 42 (2012) 125-143.
[2] J.M. Rodenburg, B.C. McCallum and P.D. Nellist, Ultramicroscopy, 48 (1993) 303-314.

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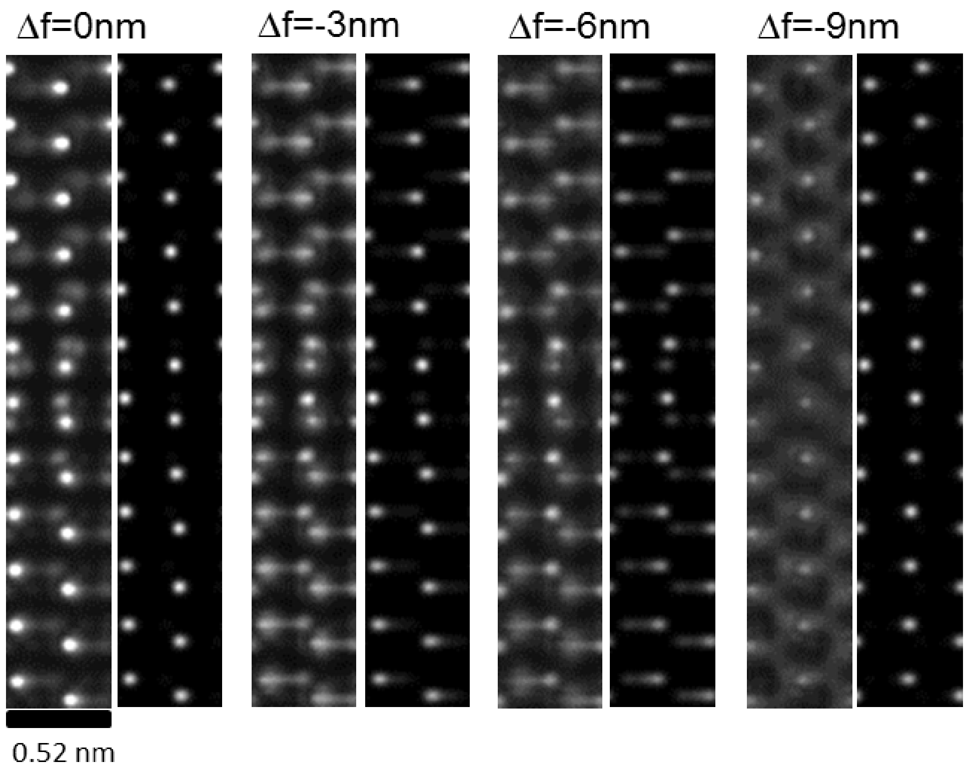

Fig. 1: Aberration-corrected ADF STEM simulated images along the a lattice direction for a 10 nm thick sample of GaN containing a screw dislocation lying parallel to [0001] in the mid-plane of the foil. For each defocus , the left panel shows a full frozen phonon calculation using the QSTEM code and the right panel a simple weighted potential approach.

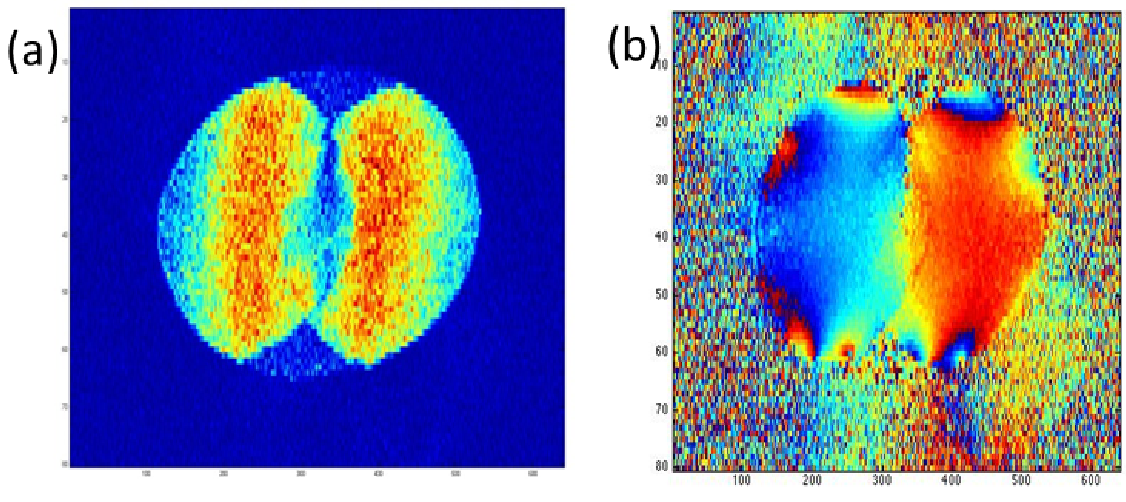

Fig. 2: The (a) amplitude and (b) phase of the interference observed in the BF disc for one particular spatial frequency with respect to probe position in the 4D data set. The data was recorded from bilayer graphene at 60 kV using a Nion UltraSTEM 200 with a convergence angle of 30 mrad.