

STEM Electron Tomography for Nanoscale Materials Science

P.A. Midgley^{*}, M. Weyland^{*}, T. Yates^{*}, J. Tong^{*}, R. Dunin-Borkowski^{*} and J.M. Thomas^{*,**}

^{*} Department of Materials Science and Metallurgy, University of Cambridge, Pembroke Street, Cambridge, CB2 3QZ, UK.

^{**} Davy-Faraday Laboratories, Royal Institution of Great Britain, 21 Albermarle Street, London, W1X 4BS UK.

Over the last 3-4 years, electron tomography has grown in popularity within the materials science community and is now seen as a critical tool for the characterisation of nanoscale materials and device structures grown within the nanotechnology field [1]. In particular, it is being suggested as a versatile technique to be used for 3D nano-metrology, i.e. the measurement of structure and composition (and indeed other physico-chemical properties) at the nanoscale and in three dimensions. Commercial nanoscale structures will need to be grown in an accurate and reliable fashion, and will require verification by nano-metrological techniques. Many of the tomographic techniques developed for the life sciences have been adapted for materials science. However, the tomographic ‘projection requirement’ necessitates the use of incoherent imaging modes for crystalline and strongly scattering objects, prevalent in materials science. This has led to the development of STEM-based tomography using a HAADF detector [2] and EFTEM tomography [3, 4] to yield 3D structural and compositional information.

The acquisition of a tilt series required for subsequent reconstruction is now a semi-automated process with software written in-house and by commercial manufacturers allowing complete control of the goniometer, scan coils (for STEM) and focus control. It is common to acquire a series every 1 or 2 degrees from +70 to -70 degrees, or even over a larger tilt range where possible to minimise the influence of the missing wedge of information present in any single-tilt series. High fidelity 3D reconstructions are achieved using either conventional weighted back-projection or iterative techniques incorporating constraints at each iteration.

The inherently high spatial resolution of STEM tomography lends itself to the imaging of nanoscale 3D objects. Here we show three examples of this. Firstly we show, in Figure 1(a), two perspective views of a gold-alumina sample grown to investigate novel dielectric properties. The gold particles range from 2nm to 20 nm in diameter and their elongated shape has been reconstructed faithfully. In Figure 1(b) we show another surface render of a nanocrystal, this time a magnetite crystal of prismatic habit originating from the ‘backbone’ of a magneto-tactic bacterium.

Figure 2(a) shows a slice through a reconstruction of a Si-Ge quantum dot grown on the surface of a Si substrate. Although the characteristic pyramidal QD shape is revealed in this figure, it is the intensity distribution within the dot that is most striking. It is surmised that the mismatch strain present in the Si-Ge alloy leads to the Ge preferentially accommodated near the surface of the dot well away from the substrate interface. It is tempting to use the atomic number contrast of such an image to attempt to quantify the asymmetric intensity distribution, as seen in Figure 2(b), but this requires significant calibration before the Ge composition can be determined in a reliable fashion [5].

References

- [1] P.A. Midgley and M. Weyland, *Ultramicroscopy* 96 (2003) 413.
- [2] P.A. Midgley, M. Weyland, J.M. Thomas and B.F.G. Johnson, *Chem. Comm.* 18 (2001) 907.

- [3] G. Mobus and B.J. Inkson, *Applied Physics Letters* 79 (9) (2001) 1369.
 [4] M. Weyland and P.A. Midgley, *Microsc. Microanal.*, 9 (2003) 542.
 [5] We acknowledge A. Petford-Long, P. Buseck and B. Joyce for the provision of the gold-alumina, magnetite and quantum dot samples respectively. We thank the EPSRC, the Royal Society, the Isaac Newton Trust and FEI for financial support.

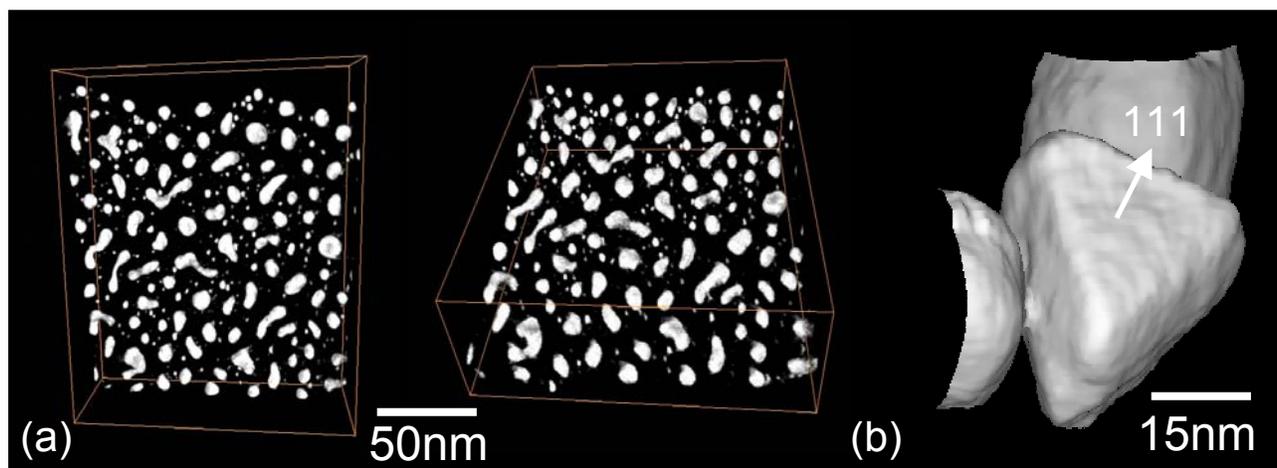


FIG. 1. (a) Two perspective views of a reconstruction of Au particles embedded within an alumina matrix. There is a bimodal size distribution with the larger particles between 10-20 nm in diameter, the smaller about 1-2nm. (b) The prismatic habit of a magnetite nano-crystal is well revealed in this surface render.

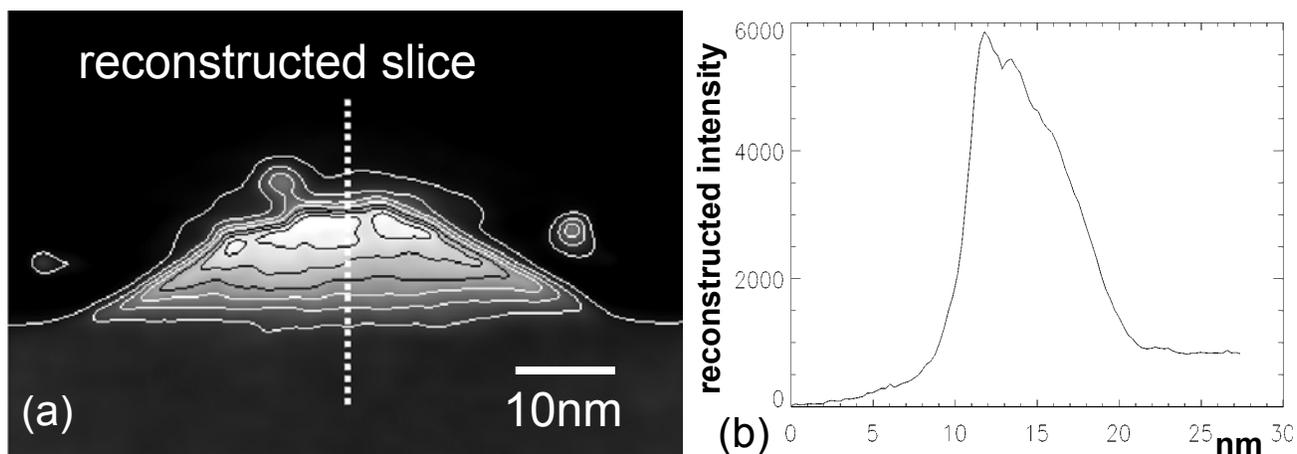


FIG. 2. (a) Slice through a reconstruction of a Si-Ge quantum dot (QD) showing the internal STEM HAADF intensity changes, related to the changes in the Ge composition in the QD. (b) Line trace along the dotted line in (a) indicating the asymmetry in the intensity distribution indicating perhaps a significant increase in Ge content at the QD surface.