Structural characterisation of Ge/Si quantum dots: a study using different electron microscopy techniques

D. Zhi, J.S. Barnard, M. Weyland, R.E. Dunin-Borkowski and P.A. Midgley

Department of Materials Science and Metallurgy, University of Cambridge,
Pembroke Street, Cambridge CB2 3QZ, UK

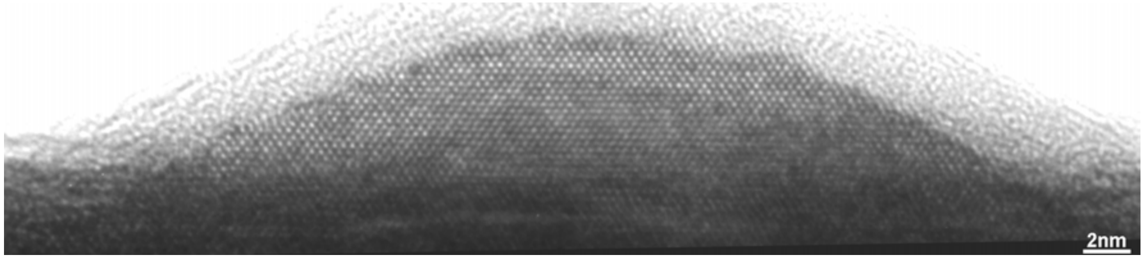
dz215@cam.ac.uk
Keywords: quantum dots, morphology, composition

The optoelectronic properties of quantum dot (QD) devices are influenced by the size, shape, arrangement, morphology and chemical composition of the QDs. During the growth process the differences in the atomic size between the QD and the matrix layer produces, by necessity, strain, and possibly defects. The electronic structures of QD devices are sensitive to these parameters, which depend in turn on processes such as 3D island formation, encapsulation overgrowth and post-growth annealing [1,2,3]. As a result of the small size and complicated growth processes of QDs, advanced electron microscopy techniques are required to analyse their structural and compositional evolution [4,5].

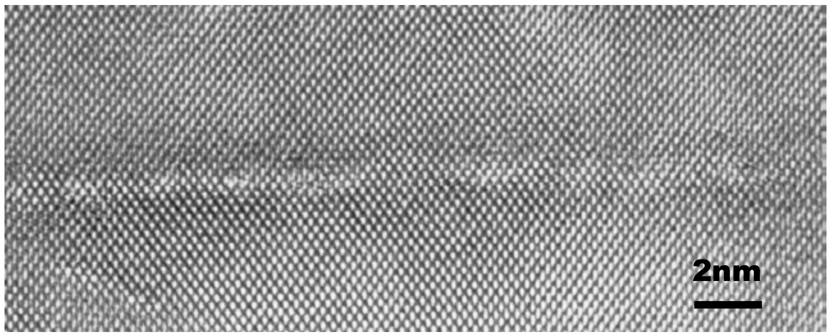
In the present study, several uncapped, capped and multiple stacked Ge/Si (001) QD structures, were fabricated by molecular beam epitaxy (MBE). Transmission electron microscopy (TEM) techniques, including diffraction-contrast imaging, high-resolution lattice imaging, scanning transmission electron microscopy (STEM), electron holography and electron tomography were applied to characterise the morphology, structure and chemistry of both the uncapped and the capped QDs in plan-view and cross-sectional geometries.

Figure 1(a) shows a cross-sectional high-resolution transmission electron microscopy (HRTEM) image of an uncapped Ge/Si QD, from which the multifacet nature of uncapped QDs can be directly revealed. Figure 1(b) is a HRTEM image of the wetting layer, which clearly shows the pseudomorphic growth. Defect formation within partially or fully relaxed QDs was observed using HRTEM, and can be related to the strain relaxation mechanism of the Ge/Si QDs. Figure 2 (a) shows plan-view [001] on-zone axis bright field (BF) image of an uncapped coherent GeSi QD. Figure 2 (b) and (c) show the STEM high-angle annular dark field (HAADF) images of multi-stacked Ge/Si QDs. The atomic scale details obtained by HRTEM can be combined with the results from field-emission gun scanning transmission electron microscopy (FEG-STEM), electron holography and tomography to provide information on the structure and composition of the QDs obtained at different growth conditions. The structural information about QDs will be discussed in relation to the QD growth phenomena and their formation mechanism. The QD morphology, chemistry, and growth will be discussed based on direct and indirect advanced microscopy analysis. [6]

1. Y. W. Mo, D. E. Savage, B. S. Schwartzentruber and M. G. Lagally, Phys. Rev. Lett. **65** (1990), p. 1020.
2. G. Medeiros-Ribeiro, A. M. Bratkovsky, T. I. Kamins, D. A. A. Ohlberg and R. S. Williams, Science **279**(1998), p. 353.
3. C. Lang, D. Nguyen-Manh and D. J. H. Cockayne, J. Appl. Phys. **94** (2003), p. 7067.
4. X. Z. Liao, J.Zou, D. J. H. Cockayne, J. Wan, Z. M. Jiang, G. Jin and K. L. Wang, Phys. Rev. B **65** (2002), p. 153306.
5. A. G. Cullis, D. J. Norris, T. Walther, M. A. Migliorato and M. Hopkinson, Phys. Rev. B **66** (2002), p. 81305.
6. We kindly acknowledge Professor Bruce Joyce in Imperial College for providing the QD samples and thank the EPSRC, the Isaac Newton Trust, the Royal Society and FEI compony for financial support.

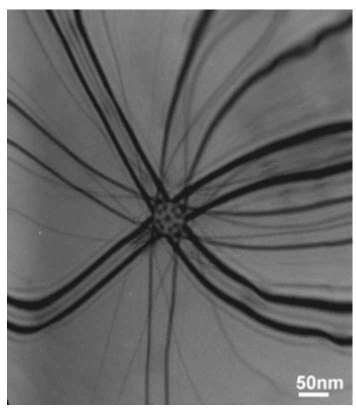


(a)

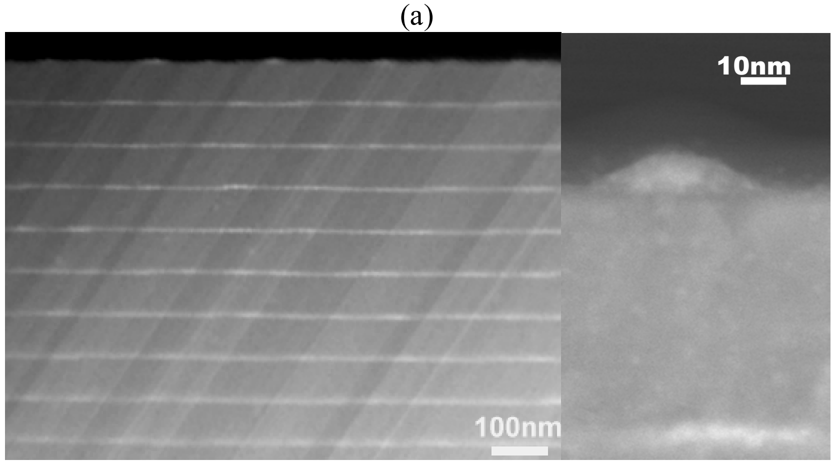


(b)

Figure 1. Cross-sectional HRTEM images of (a) a Ge/Si QD and (b) a wetting layer along [011].



(a)



(b) (c)

Figure 2. (a) Plan view [001] on-zone bright field TEM image of top layer QD. (b) and (c) show cross-sectional HAADF STEM images of 10 fold and double layer of Ge/Si QDs respectively.