The effect of encapsulation on the morphology and chemical composition of InAs/GaAs quantum dots grown by molecular beam epitaxy

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The optoelectronic properties of quantum dot (QD) devices are influenced by the size, shape, arrangement, crystal morphology, and chemical composition of the QDs [1]. During the capping process, differences in atomic size between QD and capping layer results in strain, which in turn affects the electronic properties of the device [2]. The capping process also affects the shape and composition of the QD [3, 4]. In the present study, InAs/GaAs (001) QD structures with different GaAs capping layer thicknesses were fabricated by molecular beam epitaxy. A range of transmission electron microscopy (TEM) techniques, including diffraction contrast, high-resolution lattice imaging, and analytical electron microscopy, were used to characterise both the microstructure and the chemistry of the QDs close to the atomic scale. High-resolution X-ray scattering was also applied to characterise the QD structures. Uncapped InAs/GaAs QDs were found to be multi-faceted. The formation of {113} facets and {111} growth steps, which are visible along the $[1\bar{1}0]$ zone axis in HRTEM images, results in curved boundaries on the QDs. Following the capping process, the QD density was observed to decrease, presumably due to lateral spreading and coalescence. The In content of the QDs was reduced following the GaAs encapsulation, with the final In content in a fully buried QD determined to be 65-67% [5]. Compositional changes of the QDs also occurred after a thickness of 2ML GaAs capping as a result of mass transport and interdiffusion during the growth of the first few monolayers of the capping layers. Coalescence of adjacent QDs was observed directly in high-resolution images, following the lateral spreading of the QDs during the initial stages of capping. Figs. 1a and 1b show TEM images of an isolated QD before and after capping with 5Å GaAs. Figs 1c and 1d show two adjacent QDs before and after capping with 5Å GaAs. Fig. 2 shows a cross-sectional scanning transmission electron microscopy image of two-stacked layers of InAs QDs buried in a GaAs matrix with a 20 nm spacer and an energy-dispersive X-ray spectroscopy map.

References

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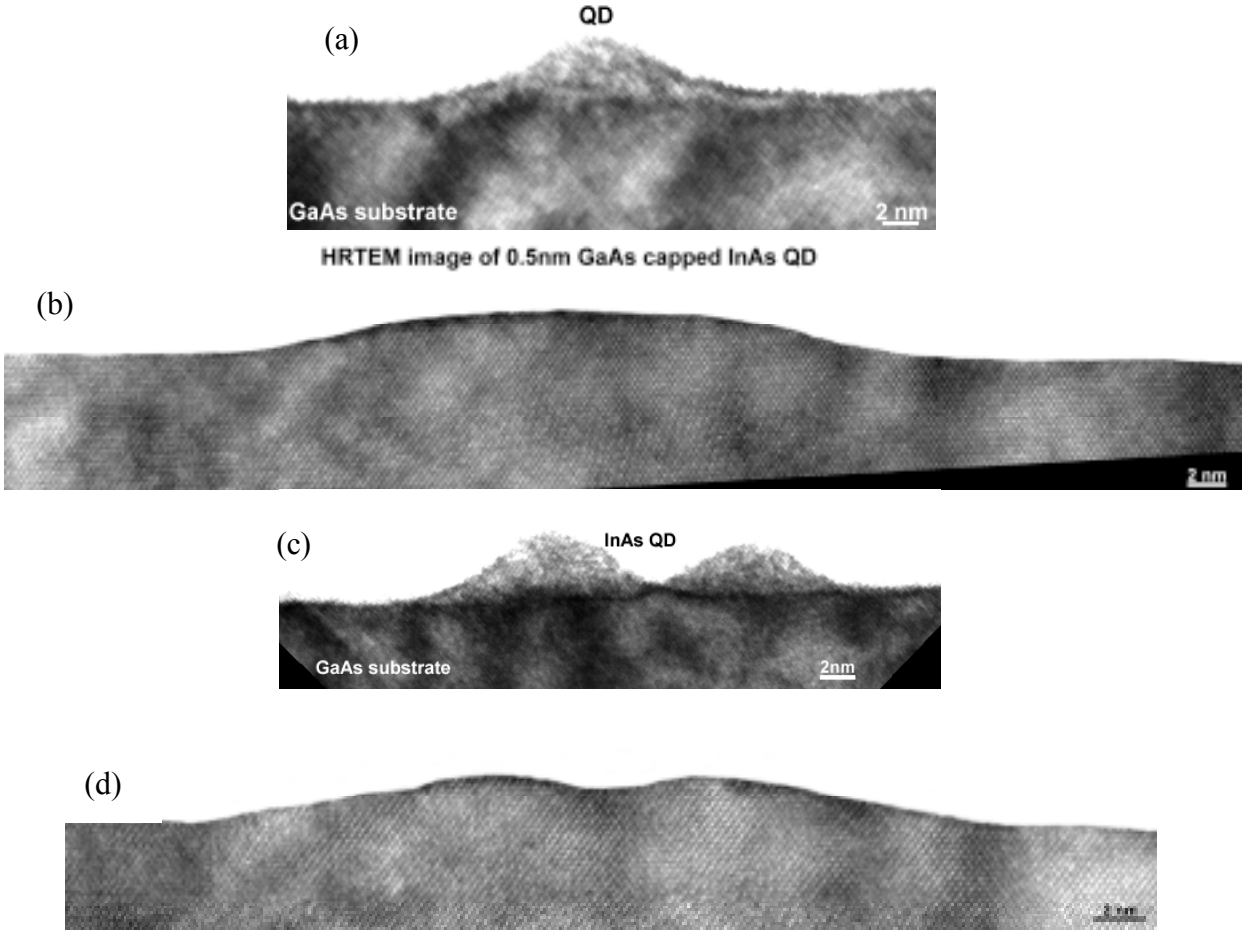

Fig. 1. TEM images of unburied QDs and 5Å GaAs capped QDs. (a) single uncapped QD, (b) 5Å GaAs capping on single QD, (c) two uncapped adjacent QDs, (d) 5Å GaAs capping on two adjacent QDs.

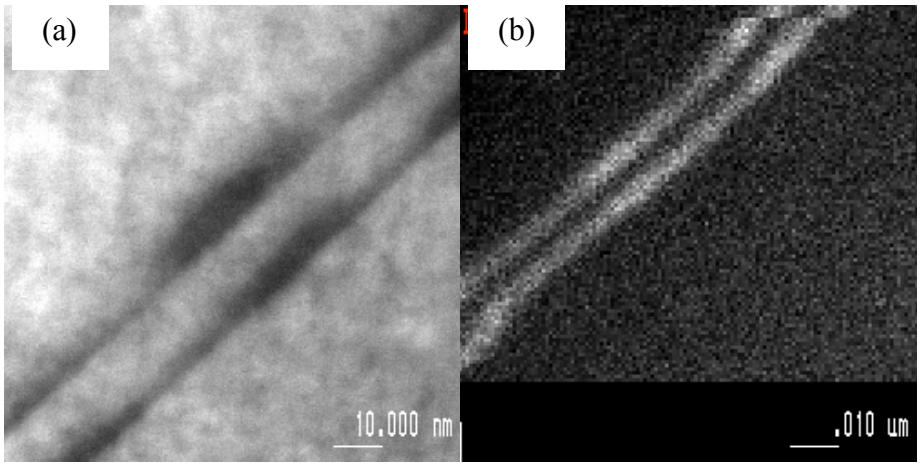

Fig. 2. (a) Cross-sectional STEM images of two stacked layers of InAs quantum dots buried in GaAs matrix with a 20nm- thick GaAs spacer between the InAs QD layer and (b) EDS In composition map.