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(S)TEM Analysis of the Strain and Morphology of InAs Quantum Dots using GaAs(Sb)(N) Capping Layers for Solar Cell Applications

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Stranski-Krastanov In(Ga)As/GaAs quantum dots (QDs) are the subject of great scientific and technological interest, primarily aimed to broaden the emission wavelength towards 1.3-1.55 μm, required for optical fiber telecommunications [1]. More recently, this QD system has drawn a lot of attention owing to their unique properties, which could be also used to boost the energy conversion efficiency of solar cells and exceed the Schockley-Queisser limit [2]. Additionally, the utilization of capping layers (CLs) with materials different than GaAs covering the InAs QDs may provide all these approaches with extra advantages. In this respect, strain-reducing layers (SRLs) such as GaAsSb extend the emission wavelength by reducing the valence band offset while strain compensated layers (SCLs) such as GaAsN CL improve the InAs QD luminescence extending the emission wavelength via conduction band offset reduction, together with a compensation of the compressive strain derived from the InAs QDs. As a consequence, the use of GaAsSbN quaternary alloys as a CL for InAs/GaAs QDs could open even more possibilities allowing independent tailoring of the electron and hole confinement potentials and the strain states of the QDs in a wide range, which could be useful for many applications [3]. However, the nature and the growth conditions of such CLs are critical parameters to determine the resulting properties of the QDs. Processes such as intermixing, segregation or strain-enhanced diffusion could occur during the capping process that modify the shape, composition and strain fields of the QDs [4]. The aim of this study is to compare in a statistical way the effect of several capping materials with different designs and growth conditions of the CL on the morphology of InAs/GaAs QDs.

The samples consist on 10-stacked InAs-QD layers embedded with different 5 nm-thick GaAs(Sb)(N) CLs grown by molecular beam epitaxy (Figure 1 (left)). They are studied by advanced transmission electron microscopy (TEM) and photoluminescence techniques. In particular, atomic-scale distribution and the strain-state of the nanostructures were obtained using high-resolution aberration-corrected scanning-TEM (HRSTEM) and conventional HRTEM.

Firstly, cross sectional g200DF images taken along both [110] directions of buried QDs have been used to characterize the QD morphology in order to obtain a statistical distribution of heights and base diameters (Figure 1 (right)). Comparing among buried QDs, the GaAsN CL gives a strong protection against the QD erosion in comparison to the GaAs CL, while the GaAsSbN exhibits the highest QD decomposition. Under these growth conditions (2 ML/s growth rate), the shield effect attributed to the presence of Sb in the CL is not only suppressed but the erosion is even intensified (Figure 2). Therefore, the growth rate strongly affects the shield effect of the Sb and it is evidenced as a key factor. The use of short-period superlattice CLs moderates this behavior achieving the best results for a low Sb content.

In order to understand the CL effect on the QD morphologies, the strain fields of the regions close and away from the InAs QDs are calculated by using Geometrical Phase Algorithm on HREM images, allowing the estimation of the compositional distribution of the SRL/SCL and nanostructures. Moreover, qualitative chemical information from atomic column-resolved high-resolution aberration-corrected Z-contrast images was extracted by calculation of integrated intensities. Our results indicate that the Sb distribution on top and around the QD is strongly affected by the growth rate. A mechanism to explain these outcomes is proposed [5].

References:

[1] Y. Qiu, P Gogna, S Forouhar, A Stintz, LF Lester, Appl Phys Lett **79** (2001), p. 3570.
[2] W. Shockley and H.J. Queisser, J. Appl. Phys. **32** (1961), p. 510.
[3] JM. Ulloa, DF. Reyes, M. Montes, K. Yamamoto, DL. Sales, D. Gonzalez, A. Guzman, Appl Phys Lett **100** (2012), p. 013107.
[4] G. Costantini, A Rastelli, C Manzano, P Acosta-Diaz, R Songmuang, G Katsaros, O Schmidt and K Kern, Phys. Rev. Lett. **96** (2006), p. 226106.
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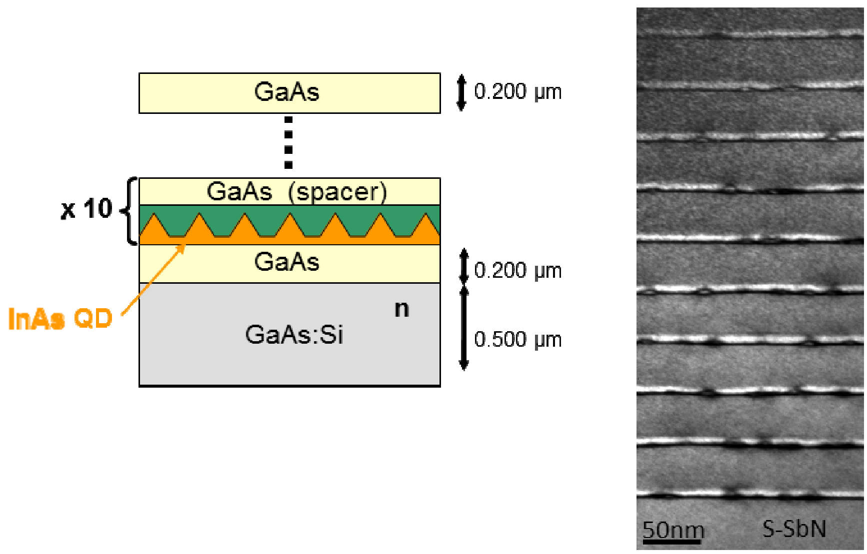

Figure 1. (Left) scheme of samples and (right) g002 dark field TEM image of one of the analyzed samples (5 nm thick $GaAs_{0.88}Sb_{0.1}N_{0.02}$ CL).

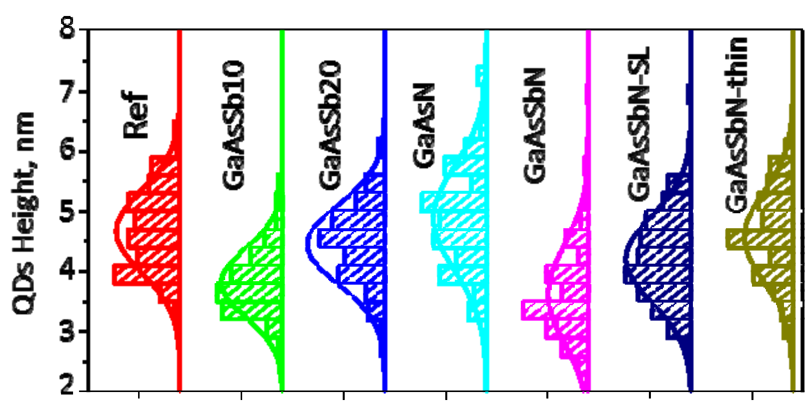

Figure 2. QD height distribution measured from g200 DFTEM images of all samples.

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