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Optical Study of Strain-driven Tuning of the Emission Energy in InAs/InGaAs Quantum-dot Nanostructures

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We report on photoreflectance (PR) measurements, in the 0.8-1.5 eV photon energy range and at temperatures from 80 to 300 K, of InAs self-assembled quantum dots (QDs) grown by Atomic-Layer Molecular Beam Epitaxy (ALMBE) in In(0.15)Ga(0.85)As matrices. The sample structure was designed highlighting the possibility to control the characteristic red-shift of the QD emission energy by varying the thickness of the lower confining layer (LCL) [1] (that modifies the QD strain). We observed clear and well-resolved spectral features due to the optical response of both QD ensemble and InGaAs confining layers (CLs).
The samples consist of: 1) a 100 nm thick GaAs buffer layer grown by MBE on (100) GaAs substrates, 2) a In(x)Ga(1-x)As lower confining layer (LCL) with x = 0.15 and thickness t (opportunely selected in the 10-360 nm range) grown by MBE at 490 °C, 3) a plane of InAs QDs with a 3 ML InAs coverage deposited by ALMBE at 460 °C, and 4) a 20 nm thick In(x)Ga(1-x)As upper confining layer (UCL) grown by ALMBE at low temperature (360 °C), in order to reduce the interaction among confining layers and QDs. The samples have been previously characterized by spectroscopic ellipsometry, micro-Raman and photoluminescence. The mean sizes of QDs were determined by Atomic Force Microscopy of structures without UCL, grown under similar conditions. [1]
Taking advantage of the derivative-like nature and high room temperature performance of PR spectroscopy, signals coming from different region of the samples were detected (see Figs. 1-2) allowing unambiguous assignment of the spectral features to bulk- and/or QD-related transitions. The effect of thickness and composition of the confining layers on the emission energy of the InAs QDs was investigated by analyzing the experimental structure according to lineshape models characteristic of modulation spectroscopy in bulk and confined semiconductor systems. [2]
The simultaneous determination of the QD ground-state critical point energy Egs, of the fundamental band gap Eg(HH) of InGaAs confining layers and of their valence band splitting ΔE, self-consistently leads to a valuable correlation of the barrier height and strain status [3] of the embedding matrix (see the inset of Fig. 1) with the QDs emission energy. The barrier lowering and the QD strain reduction contributions to the tuning mechanism in InAs/InGaAs nanostructures are separated and it is proved that QDs emission energy can be accurately tuned to 1.3 micron by controlling the mismatch to the confining layers on the basis of the predictions of the Marée *et al.* theory on strain relaxation [4] (see the inset of Fig. 2).

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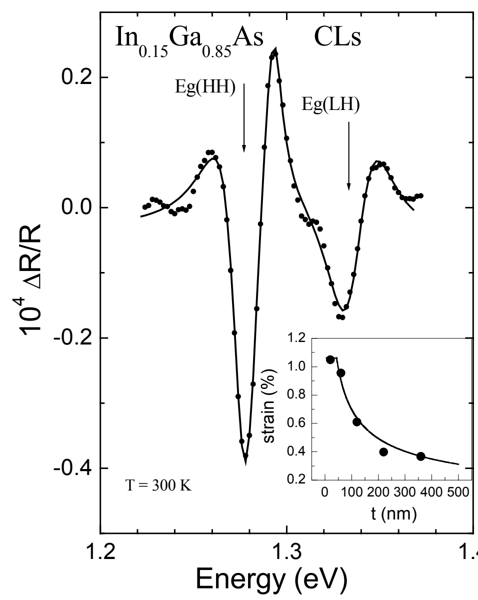

Figure 1. Typical 300 K PR spectrum of a sample with a partially-relaxed LCL (d = 60 nm) displaying the splitting ΔE of the HH and LH valence bands of the InGaAs LCL. Arrows mark the transition energies as derived from the best fit (solid line) of the experimental structure (dots). In the inset, it is shown the residual strain (dots) for LCLs of different thickness t, as determined from ΔE on the basis of the deformation potentials theory. The predicted behavior for strain relaxation proposed in Ref. 4 (solid line) is also reported.

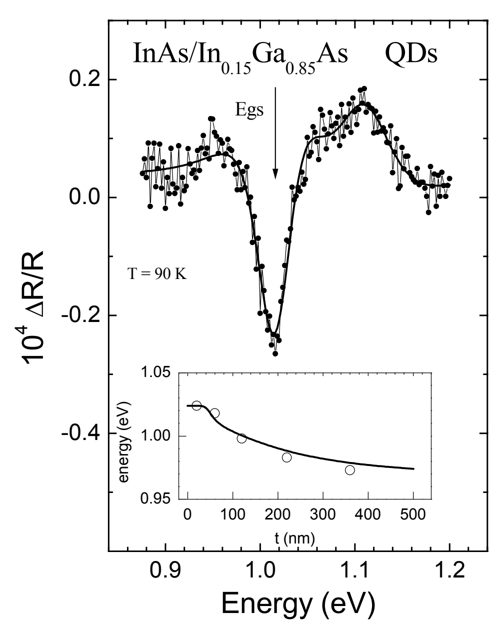

Figure 2. 90 K PR spectrum for the same sample of Fig. 1 displaying the optical response due to the ground-state transition Egs of the InAs/InGaAs QDs ensemble. In the inset, the experimentally derived Egs (circles) of samples with LCL of different thickness are compared with calculations (solid line) performed according to the strain relaxation model developed in Ref. 4.