Efficient emission from InAlGaAs single quantum dots with low lattice misfit and AlGaAs indirect bandgap barrier

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We report on the MBE growth of single quantum dots (QD) of quaternary InAlGaAs with AlGaAs barrier and strong emission of red light from single QD. Such QDs might be used as single photon sources in the red range. Indirect bandgap AlGaAs barrier applied allowed to lower photon emission in the barrier and to enhance energy transfer to QDs. Low In content decreased a dot-barrier lattice misfit and, consequently, internal strain in QD, and resulted in an enhanced single QD emission, comparing to e.g. InAs/GaAs.

We discuss the influence of MBE-growth parameters on the intensity of "zero-phonon" emission and on low-temperature (T < 10K) broadening of single QD emission line. We have observed that stronger emission from a single QD is obtained for: (1) InAlGaAs alloys with smaller dot-barrier lattice mismatch and (2) higher MBE growth rate of QD layer, which yields smaller QD size. We have also noticed that lowered lattice misfit had resulted in a relatively wider range of epitaxial growth conditions of efficient emission from single QDs. We discuss those observations by the role of growth-influenced static inhomogeneous distortions of crystal lattice inside the QD on an increased probability of photon + phonon emission, using an analogy to the acoustic phonons effect at increased temperature. Within the picture discussed, a lower photon emission intensity and larger width of emission line from single QD is related to a degree of inhomogeneous strain inside the QD leading to higher Huang-Rhys factor.

MBE growth and properties of quaternary $In_{1-x}(Al_yGa_{1-y})_xAs$ self-assembled QDs in $Al_yGa_{1-y}As$ barrier with low In and high Al content ($1-x$ = 0.4, y = 0.75) grown on GaAs(001) substrates were studied. The In content was close to the low limit of self-assembled QD formation in Stranski-Krastanov (S-K) growth, usually reported as $1-x$ ~ 0.2-0.3. The average size of dots and dot surface density could be controlled by the deposition rate and total excess deposition over h_{crit} – a critical thickness deposited for 2d/3d QD transition. QDs size dependence on metals molecular beam flux intensity (deposition rate) is discussed within a kinetic nucleation and growth model including two competing processes: (1) new dots nucleation after locally overcoming of h_{crit} and (2) size increase of nucleated dots, involving surface diffusion of adatoms.

Efficient single quantum dot emission was observed by microphoto-luminescence (μ-PL) in the red range λ = 650-730 nm (Fig. 1). Low temperature μ-PL single dots emission linewidth ≥0.2 nm observed in InAlGaAs indicates a broadening of single dot emission line, as compared to natural linewidth estimated from time-resolved μ-PL, $\hbar/\tau \sim 1\,\mu eV$ (Fig.1). We relate this broadening to the presence of static lattice disorder inside InAlGaAs QD, considering Fourier components of static inhomogeneous lattice distortions and the matrix element of exciton-lattice coupling in deformation potential approximation. The phonon emission discussed contributes to the μ-PL linewidth and to QD emission intensity by higher Huang-Rhys factor.

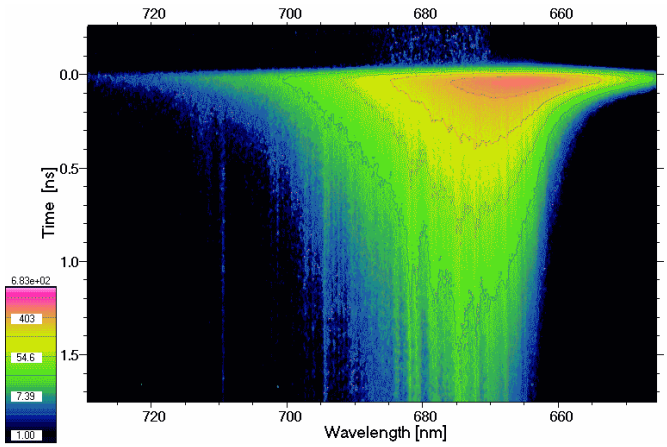

Fig.1. Time-resolved micro-photoluminescence of InAlGaAs/AlGaAs QDs at 4 K. Sharp single dot emission lines show relatively long lifetime τ ~ 1-1.5 ns, while shorter average lifetime is seen for broad unresolved ensemble emission band.

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