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Photoluminescence of 1.8 ML InAs quantum dots grown by SMEE on GaAs(100) misoriented surface

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Abstract. Photoluminescence (PL) study results of InAs/GaAs quantum dot (QD) arrays obtained by submonolayer migration enhanced epitaxy on GaAs(100) substrates misoriented towards [001] direction at InAs thickness fixed to 1.8 monolayers are reported. It is shown that PL peaks from QDs are shifted towards shorter wavelengths and their full width at half maxima decreases from 95 meV to 33 meV as misorientation angle raises from 0 to 7 degrees, corresponding to the decrease of mean lateral size of QDs and of the dispersion of their size distribution. The temperature dependence of PL spectra at 4.2–300 K may indicate to two maxima in the QDs size distribution.

Introduction

One of the most promising ways to fabricate nanostructures is the direct quantum dots (QDs) formation due to self-organization effects during molecular beam epitaxial (MBE) growth in mismatched heteroepitaxial systems. Spontaneous formation of the arrays of three dimensional (3D) islands was observed in various semiconductor systems, in particular InAs/GaAs [1]. The properties of InAs/GaAs QDs was studied by various methods. However, the main attention was paid to the study of nanoobjects obtained by conventional MBE on singular GaAs(100) surfaces. Recent scanning tunneling microscopy (STM) study shows that the use of submonolayer migration enhanced epitaxy (SMEE) technique for QDs fabrication and/or the growth on vicinal substrates lead to the formation of QDs with lower deviation from mean size [2]. The aim of this work is the study of the photoluminescence and its temperature dependence of InAs/GaAs QD arrays obtained by SMEE on the GaAs(100) misoriented substrates.

1 Experiment

The structures consist of the InAs layer containing QDs confined from both sides with wide-gap GaAs and $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}/\text{GaAs}$ superlattices (5 pairs, 2nm/2nm each) [3]. Singular and misoriented towards [001] and [010] direction by 3° – 7° GaAs(100) semi-insulating substrates are used. For better homogeneity of temperature distribution of substrate heater and molecular fluxes on the surface, the samples are indium mounted side-by-side on the same substrate holder. For SMEE growth [2], the shutters of In and As are switched on alternatively. In our experiments, 0.5 ML portion of In deposited during each pulse is followed by exposing the surface under As_4 flux. The growth

conditions are maintained the same for all samples: In flux intensity is $6 \times 10^{13} \text{ cm}^{-2} \text{ s}^{-1}$, As_4/In fluxes ratio is about 10, substrate temperature for InAs deposition is 470°C . The surface morphology is controlled in situ by reflection high energy electron diffraction (RHEED). Samples are grown with mean InAs thickness of 1.8 ML (just after the decomposition of pseudomorphic layer into the array of QDs) and of 3 ML, when a well-resolved spotty RHEED pattern is clearly observed.

2 Results and discussion

The band with the intensity maximum near 1.3 eV is observed in typical PL spectra of examined samples excited by Ar^+ laser at 4.2 K. This band corresponds to the exciton emission from QDs which is in agreement with the results obtained in [4]. In addition to this broad band emission peak, the lines with maxima at 1.514, 1.507 and 1.491 eV are observed near GaAs absorption band-edge. We assume these lines to be associated with the emission of GaAs free and bound excitons and acceptor state of carbon [5] from the residual atmosphere in the growth chamber, respectively. These results are confirmed by our study of PL excitation spectra and PL intensity maximum dependence on InAs layer thickness [6] and are in agreement with the results of STM study of similar structures [7] and also of the structures grown by MBE mode [4].

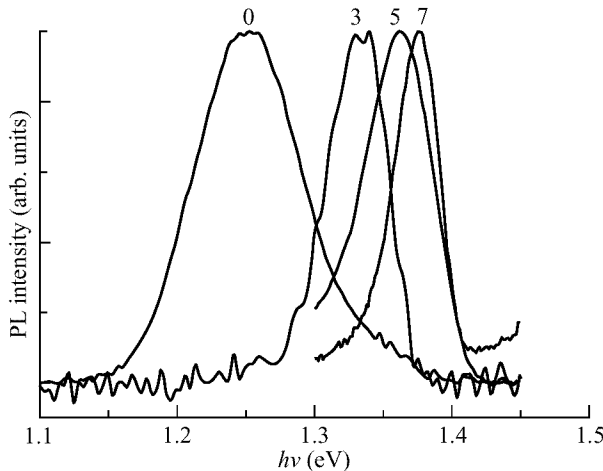


Fig 1. The dependence of QDs emission spectra at $T = 4.2 \text{ K}$ on the substrate misorientation angle towards $[001]$ direction. The mean thickness of InAs is fixed to 1.8 ML.

Monotonous shift of intensity maximum from 1.25 eV to 1.37 eV is observed as misorientation angle towards $[001]$ direction increases from 0° (singular substrate) to 7° . The emission band full width at half maxima (FWHM) decreases from 95 meV to 33 meV. To the best of our knowledge, the latter value is close to the record results reported on InAs/GaAs QD arrays. Strong decrease of FWHM with the rise of the misorientation angle could be attributed to the size distribution narrowing at increasing vicinity angle, while the mean lateral size of QDs decreases. Similar behavior was observed in STM studies of InAs/GaAs QDs grown by SMEE [7] methods on vicinal surfaces.

The dependence of QDs emission spectra on the substrate misorientation angle

towards [010] direction is qualitatively same but with the greater width of QD emission band. The exciton emission band of QDs is observed near 1.35 eV in PL spectrum of the sample with the surface misoriented to 5° towards [010] direction obtained at 4.2 K. This band (QD₁) have the weak longwave “tail”. PL spectrum doesn’t almost depend on the temperature up to 80 K except the moderate broadening of QD₁ band. At this temperature the raise of cw Ar⁺ excitation intensity from 10 to 200 mW leads to superlinear dependence of QD₁ band intensity, to narrowing of the band from 80 to 65 meV and shortwave shift of its maximum 10 meV. We assume this effect to filling of QD levels and to the superluminescence.

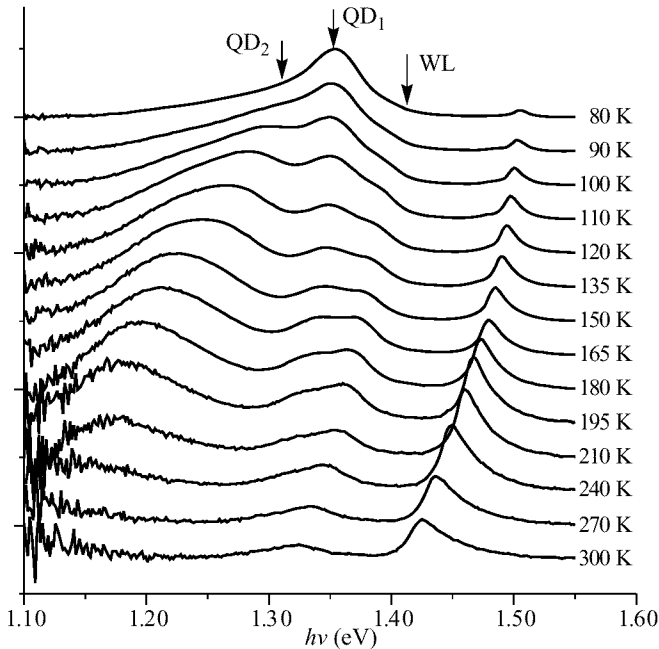


Fig 2. Temperature dependence of PL spectra at $T = 80\text{--}300$ K.

The relative intensity of QD₁ band longwave “tail” is increased at $T > 100$ K and then the latter transforms to the maximum (QD₂) in the PL spectrum. Besides that the once more band (WL) appears at the wavelengths shorter than the QD₁ one. The WL band was assumed to the emission of InAs wetting layer.

The PL complex curve has been decomposed to three gaussian contours in the whole temperature range 80–300 K. The QD₂ band is much more broader than QD₁ one and the temperature shift of QD₂ maximum is nearly by five times higher (1×10^{-3} eV/K) than temperature shifts of QD₁ and WL maxima. The latter shifts are near 2×10^{-4} eV/K and are close to temperature shift of GaAs bandgap.

STM study shows that the main part of QDs (QD₁) has the much more narrow size distribution than the small fraction of QDs with larger size and of QD complexes (QD₂) [8]. We assume both QD emission band to exciton recombination in corresponding fractions of QDs with different mean size so. In result the distribution of confinement energy and its mean value is lower for QD₁ than for QD₂ and QD₂ energy levels form the longwave “tail” of states.

The temperature increase leads to the delocalization of carriers from QD₁ during their lifetime and their diffusion through wetting layer to deeper energy levels of QD₂. Then the temperature shift of QD₂ emission maximum may be also explained by carrier delocalization from shallow levels of QD₂ “tail” of states.

3 Conclusions and acknowledgments

To conclude, we have studied PL spectra of InAs QDs grown by SMEE method on the GaAs(100) substrates misoriented towards [001] direction by inclination angles up to 7°. It is shown that PL peaks become narrower and are shifted towards shorter wavelengths with the rise of misorientation angle at fixed amount of InAs deposited. This corresponds to the decrease of mean lateral size of QDs and of the dispersion of their size distribution. The existence of two maxima in the QDs size distribution obtained from temperature dependence of PL spectra is confirmed by results of STM study.

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