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Photoluminescence kinetics in InAs quantum dots in an indirect bandgap AlGaAs matrix

T. S. Shamirzaev[1], A. M. Gilinsky[1], A. I. Toropov[1], A. K. Bakarov[1], D. A. Tenne[1], K. S. Zhuravlev[1], S. Schulze[2], C. von Borczyskowski[2] and D. R. T. Zahn[2]

[1] Institute of Semiconductor Physics, 630090 Novosibirsk, Russia
[2] Institut für Physik, TU Chemnitz, D-09107 Chemnitz, Germany

Abstract. Photoluminescence kinetics in InAs quantum dots embedded in indirect-gap AlGaAs matrices have been studied. It has been found that the low temperature photoluminescence decay duration strongly decreased from milliseconds to nanoseconds with decreasing the AlAs fraction in the AlGaAs matrix. The experimental results are interpreted in the framework of a model that takes into account the exchange splitting of excitonic levels in quantum dots.

Introduction

It is well known that nonequilibrium carriers recombine radiatively in self- assembled InAs quantum dots (QD's) embedded in a GaAs matrix with a lifetime of few nanoseconds [1]. The system of InAs QD's embedded in an AlAs matrix is very close to the system of InAs/ GaAs QD's from the point of view of the Stranski-Krastanov growth mode, since AlAs has practically the same lattice constant as GaAs. However the InAs/AlAs QD's system demonstrates the recombination dynamics quite different from that of the InAs/GaAs QD's system. Recently we have demonstrated that photoluminescence of InAs QD's embedded in an AlAs matrix displays unusually long nonexponential millisecond duration at low temperatures [2]. This puts a question on the mechanism of recombination which could result in such very long radiative recombination times in direct-gap QD's.

The principal differences InAs/AlAs QD's from that of InAs/GaAs are the high density of the QD's and the smaller dot size. In order to explain the recombination dynamics in InAs/AlAs QD's AlGaAs we have proposed a model which takes into account the exchange splitting of excitonic levels in the QD's, which are formed as a dense system with local carrier transfer between QD's. The exchange interaction splits the exciton levels in a spherical QD to the lower optically inactive (dark) states with a total angular momentum of 2 and a long lifetime (τ_t), and the upper optically active state having a total angular momentum of 1 and a short lifetime (τ_s) [3]. The value of the exchange splitting for an exciton strongly localized in a small QD embedded in a wide band gap matrix, as is the case for InAs QD's in AlAs, at low temperatures strongly exceeds the thermal energy kT, and therefore the excitonic lifetime is determined by (τ_t). The nonexponential decay kinetics is then explained by the redistribution of the electrons and holes between spatially separated QD's [2].

In this work in order to further attest the model we have grown and investigated a series of samples of self-assembled InAs QD's embedded in indirect band gap AlGaAs matrices with different QD sizes and densities.

1. Experimental

The samples were grown by molecular beam epitaxy on semi-insulating (100)-oriented GaAs substrates using a Riber 32P system and consisted of five layers of InAs QD's separated by 8 nm thick AlGaAs spacer layers. The AlGaAs matrix layers of the structures had the AlAs fraction of 50%, 75%, and 100%. The nominal amount of deposited InAs was 2.2 monolayers per QD layer. The QD layers were grown at substrate temperatures in the range 480-510 ^{o}C. The QD density was estimated to be 3×10^{11} cm^{-2} and 5×10^{10} cm^{-2} in the samples with the AlAs fraction in the matrix of 100% and 50%, respectively. The QD sizes, which decreased with increasing the AlAs fracture, were determined from high-resolution TEM cross- section images. The excitation of nonstationary PL was accomplished by 200-fs long pulses of a frequency-doubled mode-locked Ti:Sapphire laser pumped by a frequency-doubled cw Nd:YAG laser ($\hbar\omega = 3.10$ eV). Detection of PL was done by a Hamamatsu C4334 Streakscope streak camera (time resolution 15 ps) coupled to a CROMEX 250IS spectrometer.

2. Results and Discussions

The photoluminescence kinetics of the QD's in AlGaAs matrices with different AlAs fractions at a temperature of 15 K is shown in the figure 1. One can see that for the QD's embedded in an AlAs matrix (curve 1) the PL intensity

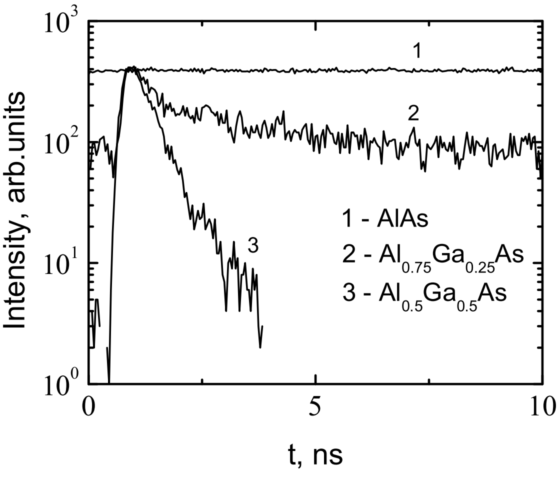

Fig. 1. Photoluminescence kinetics of the QD's in Al$_x$Ga$_{1-x}$As matrices with different AlAs fractions

does not change within the laser pulse repetition period, which was equal to 12,5 ns. The increase in the QD size for dots embedded in $\mathrm{Al}_{0.75}\mathrm{Ga}_{0.25}\mathrm{As}$ results in a decrease in the duration of the PL decay (curve 2), however, the decay kinetics is nonexponential due to the redistribution of carriers between neighboring QD's. Finally, the largest size and smaller dot density QD's embedded in the $\mathrm{Al}_{0.5}\mathrm{Ga}_{0.5}\mathrm{As}$ matrix demonstrated an exponential nanosecond-time decay kinetics (curve 3), as it was expected for a system of non-interacting QD's. Thus, the kinetics of the photoluminescence in a system of QD's with different dot sizes and densities confirm our model, which explains the long nonexponential PL kinetics in the InAs/AlAs QD's by the effect of the exchange splitting of excitonic levels in QD's, which are formed in a dense system with local carrier transfer between QD's.

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References

[1] D. Bimberg, M. Grundmann, and N. N. Ledentsov, *Quantum Dot Heterostructures* Wiley, New York, 1999.

[2] T. S. Shamirzaev, A. M. Gilinsky, A. I. Toropov, A. K. Bakarov, D. A. Tenne, K. S. Zhuravlev, C. von Borczyskowski, and D. R. T. Zahn, *JETP Lett.* **77**, 389 (2003).