Redistribution of excitons localized in InGaN quantum dot structures

M. Dworzak, T. Bartel, M. Strassburg*, A. Hoffmann, A. Strittmatter, D. Bimberg

Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Abstract. Population processes and recombination mechanisms of excitons localized in InGaN/GaN quantum dot (QD) structures were investigated by time-resolved and spatially resolved photoluminescence (PL) measurements. Sharp lines originating from single QD's could be observed. Carrier transfer processes at low temperatures and thermally induced redistribution at elevated temperatures dominate the recombination dynamics.

InGaN/GaN heterostructures form the active layer in blue-green LED's and laser diodes commercially available today. Quantum dot (QD) structures are predicted to improve their performance enormously [1, 2]. Indium-rich fluctuations in ultra-thin InGaN layers act at low temperatures as a dense ensemble of QDs [3]. This leads to a complex potential landscape with localization sites of widely varying depth for excitons.

The investigated structures were grown by metal-organic chemical vapor-phase deposition on Si (111) substrate. The growth process and structural investigations are described elsewhere [4]. The sample was masked with a 70 nm thick metal cap leaving apertures of about 200 nm diameter for spatially resolved investigations. Previous cathodoluminescence investigations demonstrated sharp emission lines originating from single QD states. [4]

The InGaN QD structures were investigated by photoluminescence (PL) spectroscopy at temperatures between 5 K and 220 K. The QD PL was excited at 353 nm by the second-harmonic wave of a mode-locked Ti:Sa laser (pulse width: 2 ps) and collected through a microscope objective. While the luminescence of the entire QD ensemble was detected from unmasked areas single QD luminescence was detected through the 200 nm apertures of the metal mask. The detection system consisted of a double-grating 0.35 monochromators and an ultra-fast photo-detector (micro-channel plate, time resolution < 30 ps).

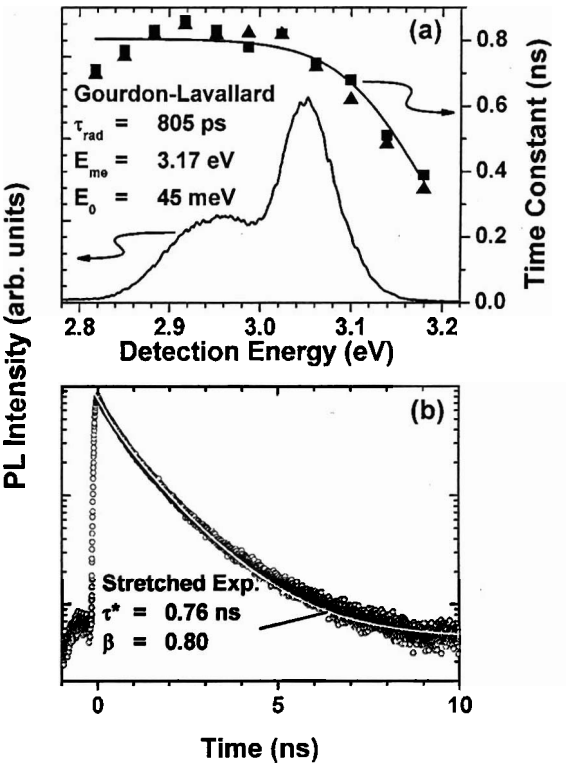

FIGURE 1. (a) Time-integrated ensemble PL, time constant τ_e of the 1/e-decay (squares) and the fitting parameter τ^* (triangles), fit with Eq. (2) (solid line). (b) Time resolved ensemble PL, fit with Eq. (1) (solid line).

* present address: Department of Physics and Astronomy, Georgia State University, 29 Peachtree Center Ave, Atlanta, Georgia GA-30303, USA.

CP772, *Physics of Semiconductors: 27th International Conference on the Physics of Semiconductors*, edited by José Menéndez and Chris G. Van de Walle

The QD ensemble PL shows a nonexponential decay (Fig. 1.b), fitted with the stretched exponential model

$$I(t) = I_0 \exp[-(t/\tau^*)^{\beta}] \qquad (1)$$

developed for heavily disordered materials [5] (solid line in Fig. 1.b). Here, τ^* is the time constant and β is the stretching parameter. The variation of β from unity is a measure for the degree of disorder in the material. In contrast, a monoexponential PL decay for sharp spectral lines of single QD states was observed. For similar transition energies different time constants were obtained. Therefore the nonexponential decay observed for the whole ensemble is attributed to the coexistence of QD's having similar ground-state transition energies, but significantly different exciton life-times.

The decrease of the time constants with increasing energies (Fig. 1.a) is generated by the rise of transfer processes from QD's providing smaller localization energy. Hence, the decrease of the decay time with increasing energies indicates the rising contribution of nonradiative recombination of localized excitons. To determine the radiative lifetime of the localized excitons as well as their average binding energy and mobility properties, we evaluated the results with a model introduced by Gourdon and Lavallard [6]:

$$\tau(E) = \frac{\tau_{rad}}{1+\exp[(E-E_{me})/E_0]} \qquad (2)$$

where τ_{rad} is the radiative lifetime, E_{me} the energy for which the radiative lifetime equals the lateral transfer time and E_0 is a characteristic energy for the density of states. The latter parameter is a measure for the average localization energy of the QD's. E_{me} denotes the change from 3D-localized QD states to QW states with higher exciton mobility. Above this energy the transfer of excitons is more probable than their radiative decay.

At elevated temperatures (above 100 K) the radiative recombination is suppressed indicating the enhancement of nonradiative processes. This effect is monitored by a s-shape behavior of the PL maximum (Fig. 2) and by decreasing decay times.

This work was supported by the Deutsche Forschungsgemeinschaft in the framework of SFB296. M.S. gratefully acknowledges the support by the Alexander von Humboldt-foundation.

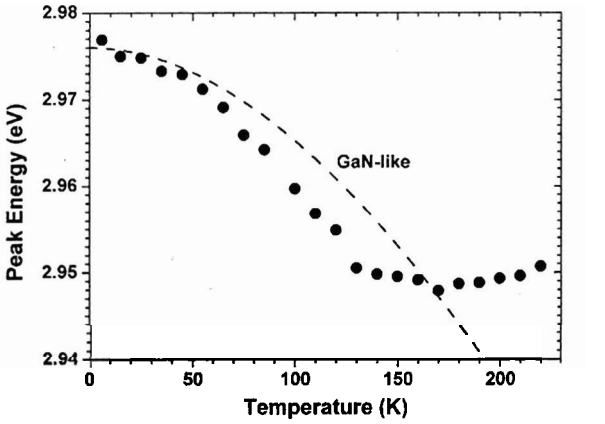

FIGURE 2. Peak energy of the PL maximum as a function of temperature.

REFERENCES

1. e.g., D. Bimberg, M. Grundmann, and N. N. Ledentsov, *Quantum Dot Heterostructures* (Wiley, New York, 1999).
2. Y. Arakawa, IEEE J. Sel. Top. Quantum Electron. **8**, 823 (2002).
3. I. L. Krestnikov, N. N. Ledentsov, A. Hoffmann, D. Bimberg, A. V. Sakharov, W. V. Lundin, A. F. Tsatsul'nikov, A. S. Usikov, Z. I. Alferov, Y.G. Musikhin, D. Gerthsen, Phys. Rev. B **66**, 155310 (2002).
4. R. Seguin, S. Rodt, A. Strittmatter, T. Bartel, A. Hoffmann, D. Bimberg, E. Hahn, D. Gerthsen, Appl. Phys. Lett. 84, 4023 (2004).
5. H. Scher, M. F. Shlesinger, J. T. Bender, Phys. Today **26**, 24 (1991).
6. C. Gourdon and P. Lavallard, phys. stat. sol. (b) **153**, 641 (1989).