Exciton emission dynamics of single-photon emitters based on InP/(Ga, In) P quantum dots

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The exciton recombination dynamics of individual InP/(Ga, In) P quantum dot (QD) single – photon emitters has been studied by time – resolved photoluminescence (TRPL) and photon correlation spectroscopy (PCS) as a function of temperature and dot size. An increase of temperature produces marked effects on the exciton photoluminescence (PL) decay time (τ_X) and on the anti-bunching time (τ_R). Both times are found to depend on the QD size. In small QDs both τ_X and τ_R increase with temperature, whereas in larger QDs τ_X remains constant and τ_R decreases for increasing temperature. A competition of the thermally activated Dark-to-Bright (DB) exciton transition and the thermal excitation of the carriers to - and from the QD give a good qualitative understanding of the observed results.

Self-assembled InP/(Ga,In) P QDs grown by molecular beam epitaxy are selected from the high energy tail of the ensemble PL emission in order to study single QDs with reduced influence of the neighboring ones. Both TRPL and PCS are performed under quasi-resonant excitation, either below the wetting layer absorption or in resonance with excited QD states. This minimizes the influence of carrier diffusion on the measured times. Temperature has been varied in the 10 – 40 K range. The TRPL is measured using a streak camera coupled to an imaging spectrometer (overall time resolution of 40 ps). For PCS we have used a Hanbury-Brown and Twiss interferometer coupled to one of the exits of a spectrometer. Three peaks are observed in the micro-PL spectra of each QD and are assigned to the exciton (X), bi-exciton (XX) and charged exciton (CX) recombination, respectively. The QD excited states have been identified by micro-PL excitation (PLE) measurements. We observe several peaks in the PLE spectra, which are indicative of QD excited states and of phonon-assisted absorption. QDs of different sizes have been selected considering their bi-exciton binding energy and their fine structure splitting.

For a given QD, the TRPL and PCS results indicate that in the X recombination both τ_X and τ_R are approximately twice as long as for XX, evidencing the XX decay into the X state. Upon increasing temperature, both τ_X and τ_R increase in small QDs (QD1, figure 1 (c) and (e)), as a result of the thermal excitation of holes out of the exciton, which reduces the emission probability of both X and XX. This occurs at low activation energies for small QDs (E_h = 7 meV), as measured from the $I_X/(I_X+I_{XX})$ intensity ratio (figure 1 (a)). In larger QDs (QD2 in figure 1) this activation energy is much higher (E_h = 30 meV, figure 1(b)) and therefore it is the DB exciton transition that dominates, leading to in a reduction of τ_R (figure 1 (f)). The τ_X value is found to be independent of temperature (figure 1 (d)) for QD2 as a result of the compensation between two competing effects: i) the DB transition, which reduces τ_X, and ii) the thermal scattering of carriers inside the QD, which delays their arrival to the ground state and therefore increases τ_X. Finally, preliminary experiments have revealed a marked reduction of τ_R upon resonant excitation at the QD p-states. Our results are relevant for the development of single photon emitters based on InP and working at high temperatures.

References

[1] A. K. Nowak, E. Gallardo, D. Sarkar, H. P. van der Meulen, J. M. Calleja, J. M. Ripalda, L. González, and Y. González, Physical Review B **80** (2009), 161305 (R).

Figures

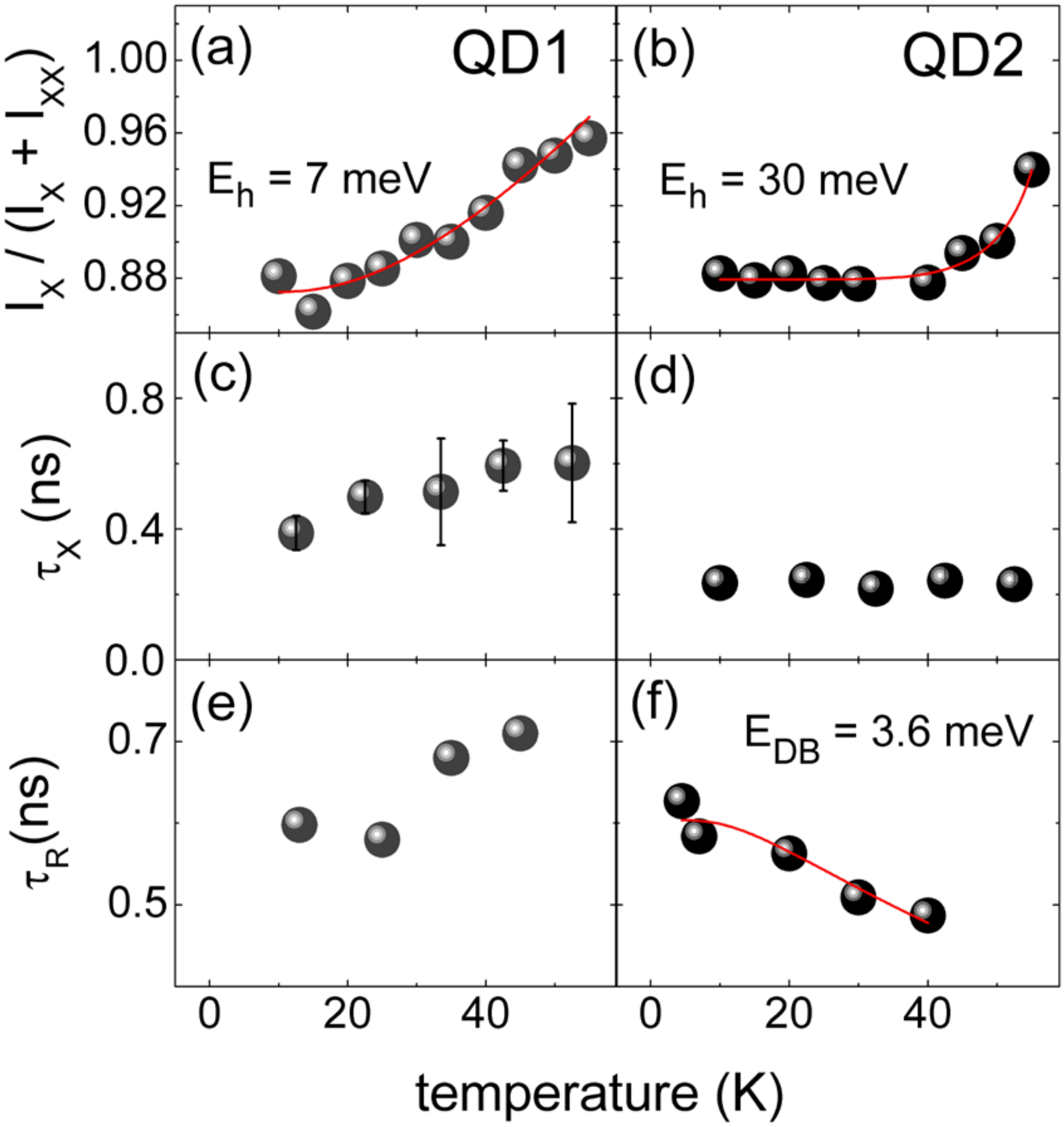

Figure 1. Temperature dependence of the QDs properties: (a), (b) PL intensity ratio of X and XX; (c), (d) X decay time τ_X; (e), (f) X-X auto-correlation anti-bunching time τ_R.