Atypical thermally-induced carrier relaxation processes in self-assembled $In_{0.3}Ga_{0.7}As/GaAs$ quantum dots

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Due to their unusual optical and electronic properties $In_{0.3}Ga_{0.7}As/GaAs$ quantum dots (QDs) are excellent objects for the study of quantum optical effects at low temperatures. This particular QD system is an exemplary target system for optoelectronic devices utilizing cavity quantum electrodynamics effects. Its peculiar properties like low QD surface density and enhanced transition oscillator strength can lead to the development of dot-in-cavity structures characterized by a superior photon extraction efficiency, highly directed emission, tunable photon emission rate. Moreover, they facilitate the observation of strong coupling in micropillar cavities.[1] These are related to at least a few applications starting from single dot lasers and photon emitters, quantum information processing devices based on single QDs or QD molecules.[2]

Hereby, we focus on the carrier dynamics in such QDs pointing out at the important role of the wetting layer (WL) in the carrier relaxation scheme. Temperature dependent macro- and micro- photoluminescence experiments of the WL emission suggest the existence of a large density of zero-dimensional (0D) states, efficiently acquiring carriers at low temperatures. At elevated temperatures, the carriers are released from the 0D WL states and redistributed between QDs in the vicinity of the two-dimensional (2D) WL channel. This process is predominantly controlled by rising phonon bath and enhancement of carrier-phonon interaction.

Time-resolved photoluminescence reveals the complexity of the above-mentioned carrier relaxation scheme. Instead of a monotonic decrease of the ground state PL rise time with temperature typical for QDs, for these dots the PL rise time atypically increases from ~100 to ~200 ps in the temperature range of 10 - 45 K, and then decreases at higher temperatures.

To analyze the aforementioned effect qualitatively we propose a multi-level rate equation model in which we assume a thermal hoping transport between two types of energetically and spatially separated 0D density of states (namely 0D WL and QDs) in the vicinity of 2D mobility channel (2D WL). Results of simulations show that the observed increase in the carrier density population build-up time of the fundamental states in the ensemble of QDs can be achieved only when the density of 0D WL states exceeds significantly the density of QDs. Thus, the elongated QD PL rise time is related to time-consuming, acoustic phonon mediated carrier migration within the 0D WL density of states in the presence of 2D WL mobility edge.

[1] J.P. Reithmeier et al. Nature **432**, 197 (2004); **[2]** T. Heindel et al., Appl. Phys. Lett. **96**, 011107 (2010), S. Reitzenstein et al. Appl. Phys. Lett. **89**, 051107 (2006); D. Press et al. Phys. Rev. Lett. **98,** 117402 (2007), S. M. Ulrich et al. **98,** 043906 (2007).