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Many-body effects in hybrid In(Ga)As dot-well nanostructures

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Many-body interactions result in many remarkable effects like Fermi-edge singularity, fractional quantum Hall effect, etc in physics of semiconductor heterostructures. Here we report the observation of many-body effects in the optical spectra of hybrid semiconductor In(Ga)As nanostructures where the InGaAs quantum well (QW), acting as the carrier injector, is coupled with InAs quantum dot (QD) layer, acting as the emitter, through the separating barrier. In such structures, the localized, quasi-zero-dimensional (0D), QD states are tunnel-coupled with the two-dimensional (2D) QW states, creating 0D-2D hybrid structures used for high-performance tunnel injection lasers.

We investigate both the regime of weak coupling (thick GaAs barrier) and strong coupling (thin GaAs spacer), which markedly modifies the optical spectra. Using time-resolved spectroscopy and the state filling effects in the continuous-wave excitation regime the basic characteristics of inter-level, inter-sublevel and dot-well relaxation are determined for the InAs QD/ $In_{0.15}Ga_{0.85}As$ QW heterostructures. The mechanisms of the dot-well coupling are discussed. Opposite renormalization of the ground- and excited-state transition energies is observed with increasing exciton occupation of the QDs. The ground-state transition energy decreases by ~9 meV whereas the excited-state transition energies increase up to ~8 meV. The shrinkage of the ground-state transition energy normalized to the exciton binding energy is significantly smaller than band-gap renormalization in higher dimensional systems. The shift of the photoluminescence bands with increasing excitation intensity depends on the GaAs barrier thickness. Our experimental results demonstrate significant many-body effect on the excited states of semiconductor QDs and are of importance for the technological implementation of quantum dots in devices for quantum information processing.