Coherence properties of resonantly driven semiconductor quantum dots

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Solid-state systems like semiconductor quantum dots (QDs) are very attractive as building blocks for quantum information processes. QDs show an atom-like spectrum which makes them attractive in this regard. However, a single QD constitutes an open quantum system coupled to its surrounding solid-state environment, like the phonon bath and the fluctuating electrostatic environment. This has important consequences on the coherence properties of the electronic system and the QD is a probe to study these fundamental interactions. Using an original geometry, we have demonstrated the possibility to address and coherently control a single exciton state in InAs/GaAs self-assembled QDs embedded in a one-dimensional waveguide with a strictly resonant pulsed laser excitation [1].

Recently, we addressed the issue of dephasing experienced by the dot due to two main decoherence processes: the spectral diffusion which is a consequence of the charge (or spin) noise and the interaction with the phonon bath [2]. Using Fourier spectroscopy and temperature-dependent resonant HOM experiments, we showed that these two mechanisms occur on very different time scales: spectral diffusion is a slow dephasing process acting on microseconds, while phonon interaction takes place in less than one ns. Then, the loss of indistinguishability in HOM measurements is only related to dephasing induced by the coupling to the phonon bath as explained very well by a full microscopic theoretical model that we developped. The TPI visibility is preserved around 85 % at low temperature, followed by a rapid loss of coherence at a critical temperature of about 13 K. Then, virtual phonon transitions to higher lying excited states become the dominant dephasing mechanism, leading to broadening of the zero phonon line and a corresponding rapid decay in the visibility. This process places limitations in the operating regimes of QDs.

Moreover, charge noise can be detrimental as it strongly limits or even suppresses the QD resonance fluorescence (RF). The RF quench has been attributed to the structure residual doping and defects which create a fluctuating electrostatic environment. This can lead to a Coulomb blockade effect preventing the photocreation of an electron-hole pair in the QD. We have demonstrated [3] how a revival of the RF can be achieved by using a suitably designed voltage-controlled device that stabilizes the resonantly photocreated electron-hole pair in the dot. By controlling the QD electric field environment by the gate voltage, the charging/discharging mechanisms from the nearby trap states to the QD are disabled. The resonantly photocreated electron-hole pairs give rise to a very intense RF line and an increase in the coherence time. However, the radiative limit is not reached, suggesting that charge and/or spin noise are still present, leading to residual inhomogeneous broadening. Still, the gate control allows the conversion of one laser pulse into one emitted photon and optimization of the collection efficiency remains the last step to achieve for using such a device in quantum technology applications.

References

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