Coherent and Sequential Photonic Coupling of Semiconductor Quantum Dots in Micropillar Cavities

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The enormous progress in the fabrication of quantum dot - microcavities has paved the way for the observation of cavity quantum electrodynamics effects in the solid state. Recently, mutual coherent coupling of multiple quantum dots (QDs) mediated by a common cavity field has become an important area of interest [1-3]. This type of coherent coupling of multiple spatially separated QDs is considered a key element for the realization of long-range coherent interactions between cavities for quantum logic gates and networks.

In this report we focus on strong coupling (SC) between multiple QDs and the fundamental cavity mode (CM) of a micropillar cavity [4, 5]. For this purpose, self-assembled $In_{0.4}Ga_{0.6}As$ QDs with a high oscillator strength of approx. 20 and a surface density of $5x10^{10}$ cm^{-2} are embedded into high quality AlAs/GaAs micropillar cavities with a nominal diameter of 1.8 µm and Q-factors up to 20 000. Due to exceptional sample quality we were able to observe several tens of cases of SC between single and multiple QDs and the fundamental CM. It is noteworthy, that approx. 90% of the investigated micropillars exhibited SC and vacuum Rabi splittings up to 110 µeV at resonance.

The high yield of SC in this sample enabled us to study in detail the coherent coupling of multiple QDs with a CM and, moreover, to observe the transition between the fully coherent and sequential SC of a two QDs-cavity system. Within a detailed statistical analysis we describe spectral features characteristic for limiting cases as well as the intermediate regime. For coherent coupling of two degenerate QD transitions, the effective vacuum Rabi splitting is increased by a factor of $\sqrt{2}$ in comparison to the single QD as expected from theory. For finite energy difference between the QD transitions comparable to the single exciton-photon coupling energy one needs to consider also an incoherent contribution to the splitting on resonance [1]. As the spectral distance between the QDs is increased beyond the exciton-photon coupling energy, one enters the regime of sequential SC of individual QDs with the CM. The comprehensive experimental data and analysis of different cases of coherent and sequential coupling enabled us to identify characteristic features of both cases which will in future be very beneficial for the coherent manipulation of multiple coupled quantum objects.

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