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Exciton – Photon Interactions in a Quatum Dot Mircocavity

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In contrast to the common feeling, spontaneous emission is not an intrinsic property of a material. This is due to the fact that spontaneous emission processes require the coupling of an emitter in an excited state to modes of the vacuum field. As was shown already more than fifty years ago by E. Purcell for microwaves, the spontaneous emission rate can be modified by orders of magnitude, if an emitter is embedded in a cavity with a matching resonance frequency. This so called "weak coupling effect" is due the enhancement of the photon density of states at the cavity resonance and is exploited e.g. in vertical surface emitting lasers and single photon sources based on cavities. A qualitatively different effect called "strong emitter – photon coupling" is expected when a two level emitter is brought into efficient interaction with a fully discretized optical mode. If the corresponding rate describing the coupling of the emitter and the light is faster than the rates of dissipative processes in the system, the emitter and the photon mode ideally just exchange a single excitation periodically. In this situation the spontaneous emission becomes a reversible process. In a real system, however, dissipative processes like the photon escape from the cavity will result in a limited number of exchange processes.

We have investigated strong coupling effects in semiconductor microcavities with InGaAs quantum dots. The cavities are based on undoped GaAs/AlAs VCSEL structures. Micropillar cavities with diameters between 1.0 µm and 4 µm are realized by reactive etching using an inductively coupled plasma or an electron cyclotron resonance enhanced plasma process based on Ar/Cl_2. The etching results in an in plane confinement by total internal reflection at the pillar surface. The process has been optimized to realize very smooth and vertical sidewalls in order to minimize sidewall losses from the cavities. In combination with the vertical optical confinement the etching of pillars allows to obtain discrete photon modes. We obtain microcavities with quality factors Q of about 5.000 to 35.000, which correspond to photon lifetimes in the cavities between 2 and 18 ps. The quantum dot density and emission energy range has been optimized in order to locate only single quantum dot excitons close to the cavity resonance. At low excitation powers these structures can therefore be used to investigate the interaction of a single quantum dot exciton and the vacuum field. By using dots with large dipole moments we observe clear anticrossing effects due to strong interaction between the exciton QD and the vacuum field characterized by a vacuum Rabi splitting of up to 140µeV.

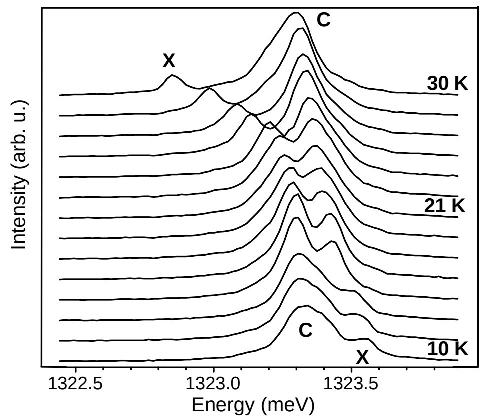

Fig. 1 Temperature series of emission spectra of a single quantum dot exciton and a cavity mode in the strong coupling regime which is characterized by a non zero vacuum Rabi splitting between the two lines (here about 140 µeV)

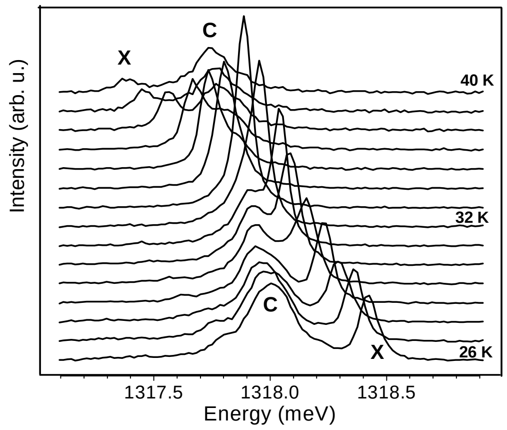

Fig. 2 Temperature series of emission spectra of a single quantum dot exciton and a cavity mode in the weak coupling regime. The weak coupling regime is characterized by a strong intensity enhancement of the QD exciton on resonance and the absence of a line splitting.