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Control and manipulation of spontaneous emission in photonic crystal nanostructures down to the single photon level

Photonic crystal nanostructures offer an efficient and practical opportunity to manipulate and control the spontaneous emission from self-assembled quantum dots down to the single photon level. Realizing optical defect microcavities in such patterned photonic environments leads to an enhancement of the quantum efficiency of the emission, a modification of the spontaneous emission dynamics and can even enable to reach the strong coupling regime of light-matter-interaction. Furthermore, the planar geometry of two-dimensional photonic crystals allows the straight forward realization of waveguides that could channel light between different locations on the same semiconductor chip and, thus, pave the way for future on-chip (quantum) information processing applications.
I will begin by presenting detailed investigations on electrically tunable single quantum dot - photonic crystal microcavity systems operating in both the weak and strong coupling regime of the light matter interaction. These studies enable us for the first time to systematically investigate excitation or temperature induced dephasing and the coherent interaction of two individual quantum dots via a common cavity mode. Unlike previous studies that exploit for example temperature tuning of the quantum dot emission, our electro-optical approach employs the quantum confined Stark-effect to control the exciton-cavity detuning. This enables us to study the system as a function of external control parameters, such as excitation power density or temperature. In a second experiment, the different size and strain profiles of different individual self-assembled quantum dots enable us to tune two spatially separated quantum dots in resonance with each other and a common cavity mode simultaneously. Comparison of experimental and theoretical data reveals a triple peak at resonance, a clear signature of a coherently coupled system consisting of three quantum states.
In the second part of the talk I will discuss investigations of the emission properties of self-assembled InGaAs quantum dots embedded in GaAs photonic crystal waveguides. For an ensemble of quantum dots, we conduct spatially, spectrally and time-resolved measurements and find a ~21 x enhancement of the photoluminescence emission detecting normal to the plane of the photonic crystal. This enhancement is shown to be due to a combination of Purcell effect and angular redistribution of emission. Moreover, single quantum dots are investigated as a potential candidate for on-chip generation of single photons. Low temperature confocal microscopy performed with detection either perpendicular to the plane of the photonic crystal or at the cleaved edge of the waveguide facet allows us to compare the emission properties of the same quantum dot for the different emission geometries. We extract spontaneous emission coupling factors up to $\beta \approx 75\%$, power-dependent and time-resolved measurements show similar characteristics in both detection geometries and, most importantly, the corresponding autocorrelation spectroscopy measurements prove the single photon nature of the quantum dot emission.

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