Self-assembled quantum dots as non-classical light sources and optically active spin qubits

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Semiconductor quantum dots are promising for applications in photonic quantum technologies. This can be traced to their excellent optical properties such as fast emission rates, nearly transform-limited linewidth, ease of integration into nanophotonic resonators to enhance the light-matter interaction and ability to host single electron or hole spins as optically active qubits.

For the generation of non-classical light resonant excitation is essential since it avoids the creation of free carriers which cause fluctuations in the environment. For on demand single-photon generation, a two-level system given by an excitonic transition in a quantum dot is typically excited with a resonant laser pulse of area π. This prepares the two-level system in its excited state from where it spontaneously emits a single photon. However, emission that occurs already during the presence of the laser pulse allows for re-excitation and, thus, multi-photon emission which limits the single-photon purity [1]. In contrast, when exciting the system with a pulse of area 2π, the system is expected to be returned to the ground state. However, in this case emission during the presence of the pulse is most likely to occur when the system is in its excited state – exactly after an area of π has been absorbed. This restarts the Rabi oscillation with a pulse area of π remaining in the pulse which leads to re-excitation with near-unity probability and the emission of a second photon within the excited state lifetime [2,3]. In addition to the dynamics of this process I will discuss the potential of multi-level systems for single-photon generation with ultra-low multi-photon probability [4].

For single spins confined to quantum dots, decoherence occurs due to interactions with the nuclear spin bath. For electron spins, we observe fast ensemble dephasing (~2ns), slow spin relaxation due to nuclear spin co-flips with the central spin (>1µs) and at intermediate timescales (~750ns) an additional stage of incomplete non-monotonic dephasing which results from quadrupolar coupling of the nuclear spins to strain induced electric field [5]. In contrast, for hole spins we observe a more than two-orders of magnitude slower ensemble dephasing due to reduced hyperfine interaction [6].

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