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High frequency single photon sources

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Recent years have shown tremendous progress in the fabrication of single photon sources (SPS) based on quantum dots (QDs) embedded in semiconductor micro and nanocavities which are of interest for applications in quantum information science [1].

Here we will review our recent work on high-frequency single photon sources operating at single photon emission rates above 100MHz. To effectively harvest the radiative recombination of QD excitons and to overcome the total internal reflection losses of high index semiconductor materials the emission can be coupled into a cavity mode. We have characterized the single photon emission of individual QDs from two types of cavities: Photonic crystal nanocavities with quality factors up to 18000 [2] and oxide apertured microcavities with quality factors up to 50000 [3,4]. Comparing the emission of QDs inside the cavity region with those in the unprocessed areas we find typical geometrical enhancement factors of 12-fold for photonic crystals and 45-fold for apertured microcavities. Measured values of the zero delay time peak are of the second-order correlation function are typically 3-7% at low pump powers. The comparison has been made for QDs with measured radiative lifetimes of about 1 ns, i.e. for those QDs which do not show a Purcell effect due to spatial and/or spectral mismatch between emitter and mode. Characterizing hundreds of devices and tuning mode and emitter into spectral resonance we typically do not find a Purcell enhancement for the photonic crystals due to the extremely small spatial mode extend and low areal density of QDs leading to a radiative lifetimes which is often inhibited up to an order of magnitude [2,5]. In contrast, about half of the fabricated oxide apertured microcavites devices display a 3-fold spontaneous emission enhancement [4-6] with best values up to a Purcell-factor of six [5]. From a technological point of view the oxide-tapered microcavities are preferred since they display larger geometrical enhancement factors, are mechanically rugged, can be easily coupled to an optical fiber, and provide an additional Purcell enhancement without the need for a sophisticated nanofabrication technique to actively match the mode and emitter spatial resonance condition.

In general, random carrier capture can lead to the occupation of bright and dark neutral exciton states within the QD. Formation of a dark state limits the ability of a SPS to emit single photons at higher repetition rates. In fact, while QD lifetimes down to about 50 ps have been measured and SPS have been triggered with GHz repetition rates, measured single photon count rates are typically limited to the kHz regime. We have recently demonstrated that utilization of negatively charged excitons can further improve the performance of SPS since formation of dark states will be suppressed to some degree. To this end we have developed a novel trench design allowing to introduce oxide tapered apertures as well as an electrical gate in close proximity to the active QD layer within a microcavity structure [6]. Applying a bias voltage to the back gate increases the QD emission by a factor of five. Utilizing negatively instead of neutral

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excitons improved the single photon count rate by another factor of three. In culmination, these effects contribute to a measured record high rate of single photons on demand up to 31 MHz, and promise rates above 116 MHz as probed by cw experiments [6]. We have furthermore achieved an on-chip voltage-control of the spectral resonance condition between mode and emitter as well as an on-chip control of the emitted linear polarization state of the single photons.

References:

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