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Highly indistinguishable photons from a QD-microcavity with a large Purcell-factor

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Abstract: We demonstrate the emission of highly indistinguishable photons from a quasi-resonantly pumped coupled quantum dot–microcavity system operating in the weak coupling regime. Furthermore we model the degree of indistinguishability with our novel microscopic theory.

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1. Introduction

Single indistinguishable photons are key to applications in the field of quantum communication [1], quantum networks [2], linear optical quantum computing [3] and quantum teleportation [4]. One of the most promising platforms for single photon sources are solid-state quantum dots (QDs) [5]. When embedded in a bulk semiconductor, however, QDs suffer from poor photon extraction efficiencies since only a minor fraction of the photons can leave the high refractive index material. This problem can be mitigated by integrating QDs into optical microcavities [8] , which can enhance extraction efficiencies to values beyond 50%.

2. Experiment

In this work, we exploit a microcavity with a high Purcell factor and weak non-resonant contributions of spectator QDs to probe the interference properties of photons emitted from a single QD as a function of the QD-cavity detuning. The QD is placed in an adiabatic micropillar [9] with a diameter of $d = 1050$ nm and a quality factor of $Q = 3200$. Via temperature tuning, we can sweep the QD-emission through the fundamental optical mode of the pillar. For spectral resonance between QD and cavity, we observe a pronounced enhancement of the emission. Via time-resolved measurements, we are able to measure the lifetime of the QD-excition for different detunings which yields a Purcell enhancement of $F_P = (7.8 \pm 2.3)$.
The QD was excited quasi-resonantly with a pulsed Ti:Sapphire Laser (repetition rate 82 MHz) assisted by a longitudinal optical phonon transition. Due to this excitation scheme, we were able to measure pure single photon emission with $g^{(2)}(0)$-values as low as $g^{(2)}(0) = (0.036 \pm 0.005)$.
Via a fiber-coupled unbalanced Mach-Zehnder-interferometer (MZI) we carried out two-photon-interference (TPI) measurements. Fig 1(a) shows the measured two-photon probability versus the time delay between both arms of the MZI resulting in the Hong-Ou-Mandel-dip with a maximal TPI-visibility of $\nu = (83 \pm 5)\%$.

Furthermore we studied the influence of the QD-cavity detuning on the degree of indistinguishability of the emitted photons (see Fig 1 (b)). In contrast to previous studies, where non-resonant coupling to spectator QDs [10] or strong temperature induced dephasing [11] dominated the experiments, we observe a strong improvement of the TPI-visibility on resonance, which exceeds a factor of 3 compared to the off-resonant case. We extend the theoretical model of Ref. [12] to derive an expression for the Hong–Ou–Mandel dip including the effects of both time-jitter and pure-dephasing on- and off-resonance. This allows us to reject timing-jitter, and attribute sources of pure-dephasing as the dominant factor limiting the indistinguishability of our photons. Furthermore, we show that the degree of symmetry

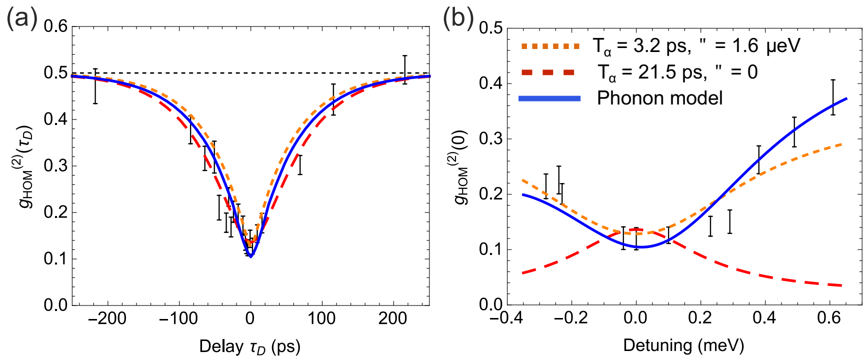

Fig. 1. (a) Two-photon-interference versus the time delay between both arms of the Mach-Zehnder-interferometer. (b) TPI-minimum versus the QD-cavity-detuning. Both curves are fitted by a microscopic model.

we observe for positive and negative detuning suggests pure-dephasing caused by both phonon coupling and spectral diffusion.

References

1. P. Gold, A. Thoma, S. Maier, S. Reitzenstein, C. Schneider, S. Hfling, and M. Kamp, *Two-photon interference from remote quantum dots with inhomogeneously broadened linewidths*, Phys. Rev. B **89**, 035313 (2014).
2. J.-W. Pan, Z.-B. Chen, C.-Y. Lu, H. Weinfurter, A. Zeilinger and M. Żukowski, *Multiphoton entanglement and interferometry*, Rev. Mod. Phys. **84**, 777–838 (2012).
3. P. Kok, W. J. Munro, K. Nemoto, T.C. Ralph, J. P. Dowling and G.J. Milburn, *Linear optical quantum computing with photonic qubits*, Rev. Mod. Phys. **79**, 135–174 (2007).
4. J. Nilsson, R. M. Stevenson, K. H. A. Chan, J. Skiba-Szymanska, M. Lucamarini, M. B. Ward, A. J. Bennett, C. L. Salter, I. Farrer, D. A. Ritchie and A. J. Shields, *Quantum teleportation using a light-emitting diode*, Nature Photon. **7**, 311–315 (2013).
5. C. Santori, D. Fattal, J. Vuckovic, G. S. Solomon and Y. Yamamoto, *Indistinguishable photons from a single-photon device*, Nature **419**, 594 (2002).
6. T. Heindel, C. Schneider, M. Lermer, S. H. Kwon, T. Braun, S. Reitzenstein, S. Hfling, M. Kamp, and A. Forchel, *Electically driven quantum dot-micropillar single photon source with 34% overall efficiency*, Appl. Phys. Lett. **96**, 011107 (2010).
7. P. Yao and V. S. C. Manga Rao and S. Hughes, *On-chip single photon sources using planar photonic crystals and single quantum dots*, Laser Photonics Rev. **4**, 499 (2010).
8. S. Reitzenstein and A. Forchel, *Quantum dot micropillars*, J. Phys. D: Appl. Phys. **43**, 033001 (2010).
9. M. Lermer et al., *Bloch-Wave Engineering of Quantum Dot Micropillars for Cavity Quantum Electrodynamics Experiments*, Phys. Rev. Lett. **108**, 057402 (2012).
10. S. Weiler, A. Ulhaq, S. M. Ulrich, S. Reitzenstein, A. Lffler, A. Forchel, P. Michler, *Highly indistinguishable photons from a quantum dot in a microcavity*, physica status solidi (b), **248**, (2011).
11. S. Varoutsis, S. Laurent, P. Kramper, A. Lematre, I. Sagnes, I. Robert-Philip, and I. Abram, *Restoration of photon indistinguishability in the emission of a semiconductor quantum dot*, Phys. Rev. B **72**, 041303 (2005).
12. P. Kaer, N. Gregersen and J. Mørk, *The role of phonon scattering in the indistinguishability of photons emitted from semiconductor cavity QED systems*, New Journal of Physics, **15**, (2013).