Coupling a charge-tunable quantum dot to a cavity mode with cooperativity above one hundred

Daniel Najer[1], Immo Söllner[1], Matthias C. Loebl[1], Daniel Riedel[1], Benjamin Petrak[1], Sebastian Starosielec[1], Vincent Dolique[2], Sascha R. Valentin[3], Ruediger Schott[3], Andreas D. Wieck[3], Arne Ludwig[3], and Richard J. Warburton[1]

[1]Department of Physics, University of Basel, Klingelbergstrasse 82, Basel 4056, Switzerland
[2]Laboratoire des matériaux avancés, CNRS (USR 3264), Univ Lyon, Univ Claude Bernard 69622 Villeurbanne, France
[3]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

Achieving a coherent exchange between an atomic excitation and a single photon – the so-called strong coupling regime of cavity quantum electrodynamics (cavity QED) – is key to creating coherent atom-atom couplings and single-photon transistors. Three parameters are crucial: the atom-photon coupling rate g, the atom decay rate γ, and photon loss rate κ. True strong coupling is achieved only when $g >> \gamma$ and $g >> \kappa$. A quantum dot (QD) is an ideal "atom" on account of its large optical dipole moment. The conundrum is that a large coupling g is achieved only by nanofabrication of the cavity, a process which usually leads to a large κ via scattering-induced losses and also increased quantum dot dephasing. The condition $g >> \kappa$ is particularly hard to achieve [1–2].

We report here an experiment in which we achieve both $g >> \gamma$ and $g >> \kappa$. We use a quantum dot embedded in a highly miniaturized, fully tunable Fabry-Pérot microcavity [3–4]. This gives reasonably large values of g, and, crucially, a way to miniaturize without increasing κ or γ. The quantum dot is embedded in a charge-tunable heterostructure which gives close-to-transform limited optical linewidths, *in situ* tuning via the Stark effect, and control of the quantum dot charge via Coulomb blockade. We achieve $g/2\pi$ up to 4.4 GHz with $\gamma/2\pi = 0.3$ GHz and $\kappa/2\pi$ typically 0.7 GHz corresponding to a Q-factor of $Q = 500{,}000$. The cooperativity, defined as $C = 2g^2/\kappa\gamma$, is typically 100; 150 in the best case.

We present this geometry as an ideal platform to explore and exploit both the strong and weak coupling regimes of cavity QED in the optical domain.

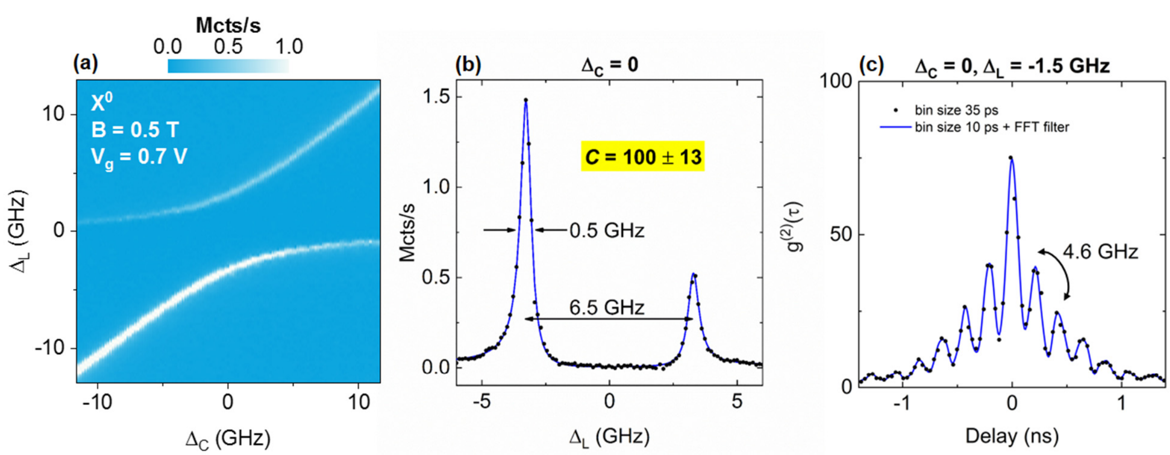

Figure 1: (a) Resonance fluorescence counts for laser–emitter detuning Δ_L vs. cavity–emitter detuning Δ_C (via cavity length tuning). (b) At resonance: vacuum Rabi splitting of 6.5 GHz and polariton linewidth of 0.5 GHz; yielding a cooperativity of 100. (c) Pronounced vacuum Rabi oscillations at 4.6 GHz in the intensity correlation function $g^{(2)}(\tau)$. Data from another QD than shown in (a) and (b).

References

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