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On-Chip Quantum Optics using Electrically Driven Quantum Dot - Micropillar Cavities

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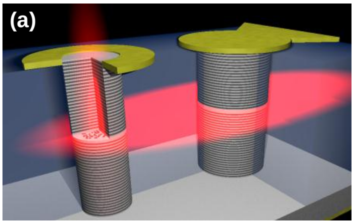
The prospect of studying quantum optics in the solid state and the quest for quantum light sources in the field of quantum communication has triggered enormous efforts in the development of micro- and nanocavity systems with embedded quantum dots (QDs). These structures exploit cavity quantum electrodynamics (cQED) effects and can act as efficient non-classical light sources and as high-β microlasers. Initially, QD-microcavities were exclusively excited optically by external lasers, while significant technological progress has enabled electrical pumping in advanced structures.
Here we report for the first time on an on-chip quantum optics experiment where an integrated microlaser excites a QD-micropillar cavity operating in the weak coupling regime of cQED. Our approach combines two very active but so far independent routes of cQED, namely high-β lasing and light-matter interaction at the quantum in a novel, integrated device concept. This concept is illustrated in Fig. 1(a) and relies on the fact that micropillar cavities allow for the localization of vertically emitting modes and laterally emitting whispering gallery modes (WGMs). We take advantage of these unique opportunity provided by the micropillar geometry to utilize an electrically pumped WGM micropillar as in-plane laser source. The integrated WGM microlaser resonantly excites radially displaced QD-micropillars. This specific configuration allows us to perform for the first time on-chip quantum optics in the cQED regime using an integrated coherent light source.



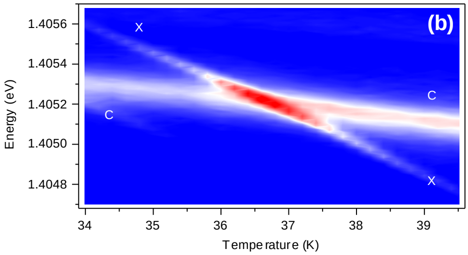


Figure 1. (a) Schematic view of device design for on-chip quantum optics (left panel). (b) Demonstration of Purcell enhancement of a QD–micropillar under resonant pumping via an electrically driven internal WGM microlaser.

The high quality electrically pumped WGM lasers were studied by means of micro-electroluminescence spectroscopy and show single mode emission, threshold currents below 10 µA and β-factors of about 0.1 at low temperature. Emission from such a WGM laser was used to resonantly excite a target quantum dot in an adjacent micropillar with a diameter of 2.5 µm via p-shell excitation. It is interesting to note, that resonant excitation schemes are crucial for generation of indistinguishable photons and are not feasible in conventional approaches for electrically driven quantum light sources based on simple pin-diodes.
Resonant p-shell pumping was then applied to excite a QD-micropillar system where a single QD exciton (X) was shifted through resonance with the fundamental cavity mode (C) by means temperature tuning (cf. Fig. 1 (b)). In this experiment, weak coupling associated with a Purcell factor of 4.1 was observed for the first time in a quantum device with an integrated coherent light source [1].

[1] E. Stock et al., Adv. Mat. 2012, DOI: 10.1002/adma.201202778.