

Electrically Driven High Quality Factor Micropillar Cavities

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Abstract

Semiconductor quantum dots as artificial atoms in a solid-state platform provide a promising route for on demand single photon generation by electrical excitation. In order to benefit from semiconductor cavity quantum electrodynamics effects for more wide spread applications it is highly desirable to electrically contact these structures while maintaining high quality factors. In this contribution we report on such micropillar cavities with semiconductor quantum dots exhibiting both weak and the onset of strong coupling. The photon antibunching observed under cavity enhanced emission in the weak coupling regime shows the good prospects of these devices for future applications in quantum key distribution systems.

Introduction

Single semiconductor quantum dots (QDs) have attracted considerable attention in recent years for generating single photons on demand for quantum key-distribution (QKD) [1]. By utilizing cavity quantum electrodynamic (cQED) effects in micropillar cavities in both the weak [1-3] and the strong [4] coupling regime, the efficiency of single photon extraction can be significantly enhanced. From the application point of view, it is highly desirable to generate single photons by electrical excitation with high efficiency. This demands to realize electrical contacts to microcavities characterized by prominent cQED effects. Recently, electrical excitation of microcavities which show such cavity enhanced emission has been demonstrated [5, 6]. In this contribution we present photon autocorrelation measurements under direct current on devices fabricated as reported in Ref 5, which exhibit photon antibunching, thus clearly showing the potential of these devices for applications.

Device Fabrication and Results

The electrically pumped high-quality factor (high-Q) micropillar cavities containing a low density layer of GaInAs QDs were fabricated on planar microcavity structures grown by molecular beam epitaxy on n-doped GaAs substrate. The undoped GaAs cavity is embedded between doped highly reflective distributed Bragg reflectors, consisting of 23 (27) pairs of alternating quarter-wavelength thick layers of GaAs and AlAs in the upper (lower) DBR. The actual device fabrication involves several delicate nano-processing steps, including metallization of the n-contact, plasma etching of the pillar structures, planarization and patterning of a ring-shaped Au p-contact at the top of the structure..

Micro-electroluminescence (μ EL) measurements at low temperatures revealed high quality factors exceeding 16.000, which paves the way for a wide range of applications for these photonic devices including QKD.

In addition, as can be seen from Fig. 1a excellent single QD tuning behavior by temperature is observed yielding a strong enhancement of the excitonic emission intensity on resonance with the cavity mode. Direct current photon autocorrelation measurements showed clearly antibunching, demonstrating the promise of the structures as single photon sources.

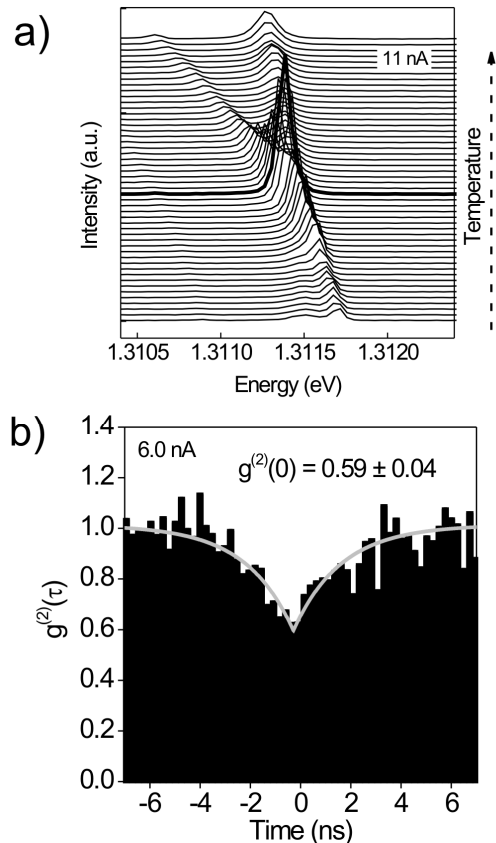


Figure 1: a) Temperature tuning characteristics of an electrically driven micropillar ($3 \mu\text{m}$ diameter, $Q = 13.000$) in the weak coupling regime. b) Photon correlation measurements under DC current injection reveal photon antibunching as a clear signature of non-classical light emission

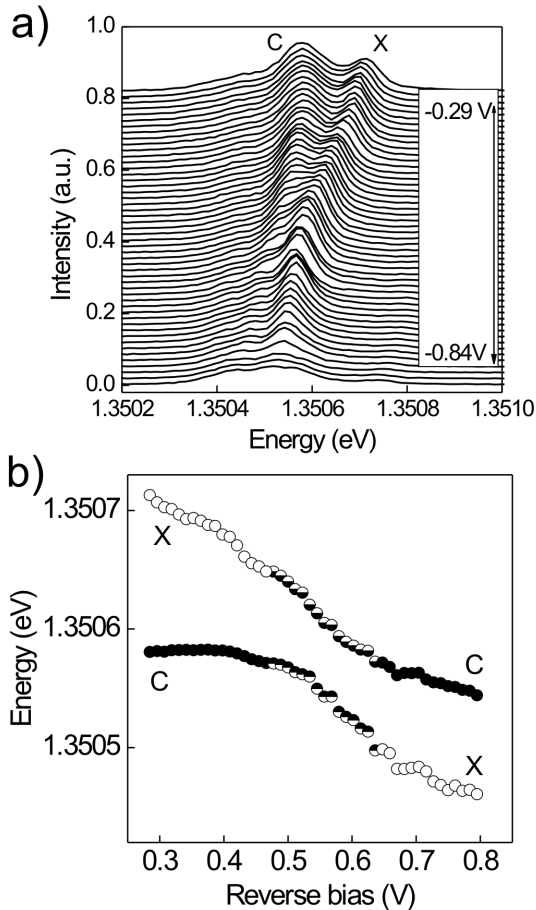


Figure 2: μ PL spectra showing electro-optic tuning of a single excitonic quantum dot line (X) into resonance with the cavity mode (C) in the strong coupling regime.

Autocorrelation correlation measurements on a $3\ \mu\text{m}$ structure showed antibunching with a minimal experimental $g^2(0)=0.59$ when a QD exciton was tuned on resonance with the pillar's fundamental mode. This non-ideal value can be explained by the collection of uncorrelated background emission from the cavity mode. Taking the uncorrelated background emission into account leads to $g^2(0)=0.06$ for the interacting QD [8].

Furthermore we performed electro-optic tuning experiments, whereby the micropillars were optically excited while an increasing reverse bias was applied to the p-i-n-diode like structures leading to a red shift of the QD emission lines due to the quantum confined Stark effect. When a QD was tuned through resonance of the fundamental mode of a pillar with

$1.9\ \mu\text{m}$ diameter and a Q-factor of 14.000, we observed the onset of strong coupling as can be seen in Fig. 2. The corresponding vacuum Rabi-splitting amounts to $63\ \mu\text{eV}$ and a coupling constant $g=40\ \mu\text{eV}$ are determined [7]. This could also be promising for realization of efficient single photon emission in the strong coupling regime [4].

Main achievements

Electrically contacted high-Q micropillar cavities, which show pronounced cavity quantum electrodynamics effects in both the weak and strong coupling regime, have been fabricated and characterized.

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