Efficient Source of Single Photons from Charge-Tunable Quantum Dots in a Micropillar Cavity

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Abstract: A single photon source is demonstrated using a novel oxide-apertured micropillar cavity embedded with InGaAs quantum dots. A bright 80 MHz count rate is enabled by the Purcell effect and charge-tuning of the quantum dots.

OCIS codes: (300.6470) Spectroscopy, Semiconductors; (230.6080) Sources

Introduction

Single photon sources (SPS) are a vital component in many quantum cryptography and computation schemes [1]. To date, most SPS are limited due to small emission rates and rapid saturation. Up to date the highest single photon rates of 0.2 MHz have been observed from self-assembled quantum dots (QDs) embedded in etched micropillar structures [2,3], which largely outperform approaches based on photonic crystal cavities [4]. However, submicrosecond memory effects due to trapping of individual charges and dark excitons inside the QDs strongly limits the efficiency of those SPS devices [3]. Here, we overcome these difficulties by coupling a charged QD to a high quality cavity mode, enabling a single photon source with a count rate of 80 MHz.

Methods

The quantum dots are grown by molecular beam epitaxy in the Stranski-Krastanow growth mode using the partially covered island technique to shift the emission to around 930nm. AlGaAs/GaAs micropillar structures are fabricated using a low density of QDs embedded between two DBR stacks. The fifth DBR layer from the QDs is n-doped and acts as a top contact. Electrons can tunnel into the QDs from a Si delta doped layer 25 nm below the QDs. Each of these doped layers is contacted by etching down from the top of the sample. Then, trenches are etched away as shown in Fig. 1, leaving a roughly 20 um diameter pillar which is still connected via bridges to the surrounding material. Finally, an oxide aperture is introduced to decrease the mode volume while keeping the cavity mode away from the rough sidewalls, thereby increasing the quality factor (Q) [5].

We study these systems by performing timing-resolved micro-photoluminescence spectroscopy. The sample rests in vacuum at 4.2 K in a variable temperature He-flow cryostat and is connected to a voltage sourcemeter. The photoluminescence is directed into one of two measurement apparatuses; a 1.25 m spectrometer with a nitrogen-cooled CCD camera or a Hanbury-Brown and Twiss (H-B&T) setup. The combination of these instruments allows the determination of the electrical, spectral, and temporal properties as well as the photon statistics of the emitted light field.

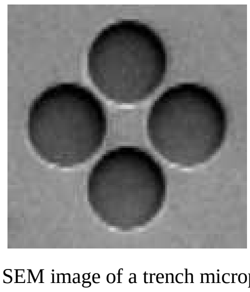

Figure 1. A SEM image of a trench micropillar cavity.

Results

We tune the QD into resonance with a cavity mode (Q ~ 40,000) and perform a time-correlated photon counting measurement to determine the excitonic lifetime. We obtain a value of 400 ps from a fit to a single exponential, thus demonstrating a Purcell effect of 2 to 3. In addition, the single exponential behavior of the decay signifies a reduction in the population of excitonic dark states, meaning the quantum dot is likely charged. Also, we measure the second-order intensity correlation function using the H-B&T setup and extract $g^{(2)}(0)$ to obtain information about the photon statistics. This is done as a function of the input pump power and is show in Fig. 2. Up to a collected count rate of 12 MHz (see Fig. 2 inset for a spectra), $g^{(2)}(0)$ remains less than 0.5, proving the single photon nature of the emitted light field. Once experimental losses are accounted for, 12 MHz of collected photons corresponds to an actual single photon rate of 80 MHz, which is a 400 times improvement over the best prior report [3].

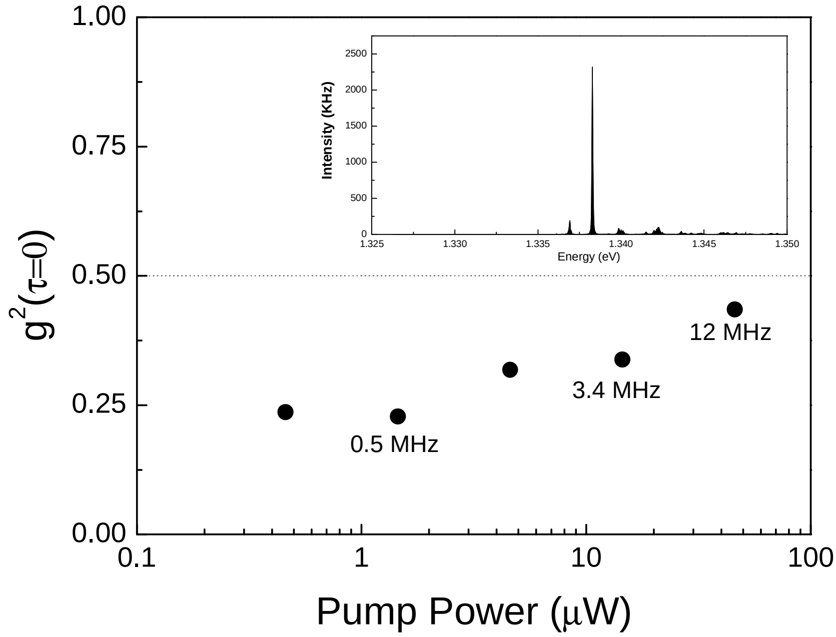

Figure 2. A plot of $g^{(2)}(0)$ for a quantum dot on resonance with a cavity mode as a function of pump power. Note that $g^{(2)}(0) < 0.5$, proving the emitted field is comprised of single photons. Inset: The spectra of the dot on resonance with a cavity mode.

Conclusions

We have demonstrated the highest count rate for a single photon source and have proven it is indeed comprised of single photons by measuring the second order intensity correlation function. The combination of the enhanced spontaneous emission rate due to the Purcell factor as well as removal of dark states by charge tuning enabled this drastic increase over prior reports. This combination of factors can only be realized in a novel device structure such as our trench design where a high quality, small volume cavity mode and electrical-gating are integrated in one device.

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