Scalable Quantum Nanophotonic Platforms in NOISE Lab

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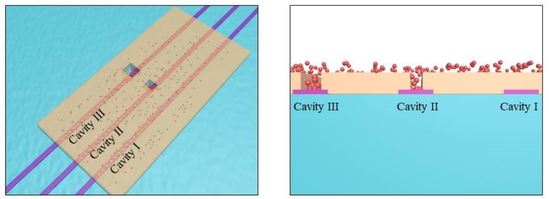
Deterministic positioning of colloidal quantum dots on silicon nitride nanobeam cavities[1]

Engineering an array of precisely located cavity-coupled active media poses a major experimental challenge in the field of hybrid integrated photonics. We deterministically positioned solution-processed colloidal quantum dots (QDs) on high quality (Q)-factor silicon nitride nanobeam cavities and demonstrate light-matter coupling. By lithographically defining a window on top of an encapsulated cavity that is cladded in a polymer resist, and spin coating the QD solution, we can precisely control the placement of the QDs, which subsequently couple to the cavity



Schematic of deterministically positioned solution-processed quantum dots on silicon nitride nanobeam cavities.

Highlights

We showed rudimentary control of the number of QDs coupled to the cavity by modifying the size of the window. Furthermore, we demonstratde Purcell enhancement and saturable photoluminescence in this QD-cavity platform. Our results pave the way for precisely controlling the number of QDs coupled to a cavity by engineering the window size, the QD dimension, and the solution chemistry and will allow advanced studies in cavity enhanced single photon emission, ultralow power nonlinear optics, and quantum many-body simulations with interacting photons

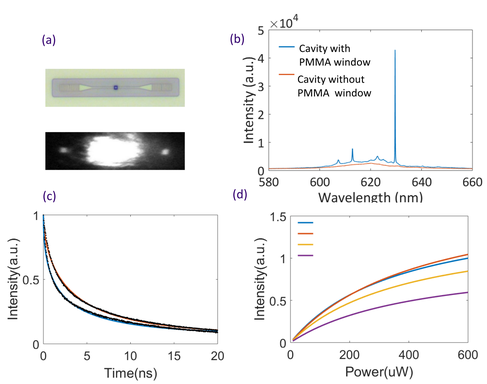
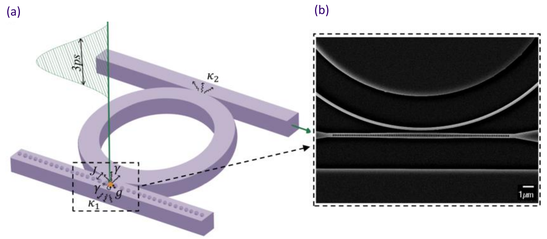


Figure (a) SEM and microscope image of deterministically positioned colloidal Cdse/CdS quantum dots on silicon nitride nanobeam cavity. (b) Spectrum of the cavity-coupled QD emission. (c) Purcell enhancement of QD's emission (d) Cavity-coupled PL emission intensity normalized by the cavity mode area in different window sizes.

Improving Indistinguishability of Single Photons from Colloidal Quantum Dots Using Nanocavities[2]

Obtaining indistinguishable photons from the colloidal quantum dots at room temperature is fundamentally challenging because they suffer from an extremely large dephasing rate. Here we proposed an experimentally feasible method of obtaining indistinguishable single photons from an incoherently pumped solution-processed colloidal quantum dot coupled to a system of nanocavities. We showed that by coupling a colloidal quantum dot to a pair of silicon nitride cavities, we can obtain comparable performance of a single photon source from colloidal quantum dots as other leading quantum emitters like defect centers and self-assembled quantum dots.



Experimental design. (a) Design schematic depicting colloidal QD with decay rate γ and dephasing rate γ* coupled to the nanobeam cavity with a coupling rate of g. The nanobeam cavity has a decay rate κ_2 and is coupled to a ring resonator with a coupling rate J. The ring resonator has a decay rate of κ_2. The QD is excited by 3ps wide pulse with an amplitude of $P_0 = 120\gamma$. The output is collected from the waveguide coupled to the ring resonator. (b) SEM image of a fabricated device structure inside the dotted black box shown in (a).

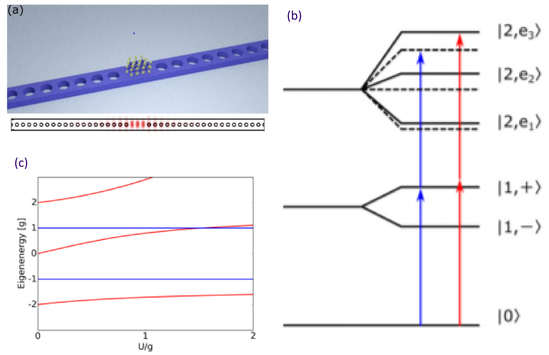
Table : Comparison between performance of broad quantum emitters: self-assembled QDs, SiV centers and colloidal QDs, as sources of indistinguishable single photons under incoherent pumping. $V_{effective}$ in the third row is the mode volume of the cavity to which the emitter is coupled

Category	Self-assembled QD in a single cavity	SiV center in coupled cavities	Colloidal QD in coupled cavities (optimal)	Colloidal QD in coupled cavities (experimental)
γ^*/γ	117	2500	83000	83000
Q_1 & Q_2	~5×10^4	7×10^3 & 5×10^5 / 3.6×10^3 & 5×10^4	6×10^4& 2×10^6	6×10^4& 2×10^6
$V_{effective}$	~$(\lambda/n)^3$	$0.007(\lambda/n)^3$	$0.1(\lambda/n)^3$	$1.2(\lambda/n)^3$
Indistinguishability	~0.6	0.94/0.78	0.9	0.63
Efficiency	12.1%	0.26%/0.99%	0.24%	0.15%

Our work lays a solid foundation for obtaining indistinguishable photons from colloidal QDs coupled to a nanophotonic platform and can potentially solve the long-standing challenge of the scalable quantum photonic technology.

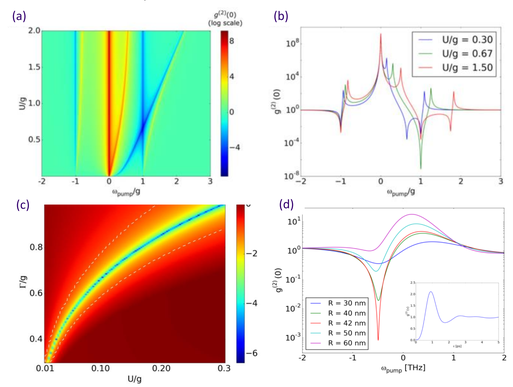
Strong photon antibunching in weakly nonlinear 2D exciton-polaritons[3]

A deterministic and scalable array of single photon nonlinearities in the solid state holds great potential for both fundamental physics and technological applications, but its realization has proved extremely challenging. Here we considered a hybrid light-matter platform, marrying an atomically thin two-dimensional material to a photonic crystal cavity, and analyze its second-order coherence function.



(a) Schematics of the patterned 2D TMDC monolayer on silicon nitride nanobeam cavity (b) Energy level diagram of the dressed states. (c) Eigenenergies as a function of the nonlinearity U, normalized by the exciton-photon coupling strength g

We analyzed the quantum optical nonlinearity of a 2D-material monolayer coupled to a low mode-volume photonic crystal defect cavity. We identified different mechanisms that give rise to nonclassical photon distributions and arrive at a robust regime, characterized by large dissipation and weak nonlinearity, whose second-order coherence function at zero time delay g2(0) is much less than unity.

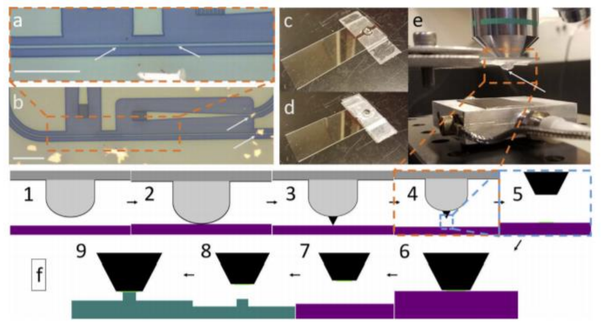


(a) g2(0) versus pump laser frequency relative to the exciton resonance for different values of U (b) Horizontal cross section of different U/g (c) Minimum g2(0) for different r and U. A 2D plot of the minimum value of the g2(0) that appears at negative pump frequency d) g2(0) vs pump laser frequency for different Radiuses of the patterned 2D material island

Finally, we considered the effect of the size of the monolayer on the system parameters. We numerically showed that by physically patterning the monolayer into different sizes, it is possible to drive its dynamics from a coherent state into a nonclassical regime with g2(0) ~ 1e-3. An observation of such strong photon antibunching in this hybrid platform would open the door to further experiments in coupled nonlinear cavities and scalable quantum simulators.

High-precision local transfer of van der Waals materials on nanophotonic structures[4]

Prototyping of van der Waals materials on dense nanophotonic devices requires high-precision monolayer discrimination to avoid bulk material contamination. We use the glass transition temperature of polycarbonate, used in the standard dry transfer process, to draw an in situ point for the precise pickup of two-dimensional materials. We transfer transition metal dichalcogenide monolayers onto a large-area silicon nitride spiral waveguide and silicon nitride ring resonators to demonstrate the high-precision contamination-free nature of the modified dry transfer method. Our improved local transfer technique is a necessary step for the deterministic integration of high-quality van der Waals materials onto nanocavities for the exploration of few-photon nonlinear optics on a high-throughput, nanofabrication-compatible platform.



a) 2D material transferred onto a nanobeam cavity indicated by the arrows. The monolayer material is not visible on the SiN subtrate. b) Bulk material on waveguides indicated by the arrows. Scale bars are 10 μm. c) Dome stamp on a glass slide. d) PC film secured to the dome stamp with Scotch tape. e) ≈ 1 mm drawn PC point indicated by the arrow. f) Visual schematic of the procedure described in the text. Steps numbered 1-9. Purple is the stage substrate (e.g. SU-8 or SiO2) and teal is the SiN waveguide. Dark gray is the glass slide, light gray is the PDMS dome, and black is the PC film. Green is the vdW material.

References:
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