Multiemitter cavity quantum electrodynamics in 4H-silicon carbide-on-insulator photonics

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Abstract: We demonstrate small-ensemble ($N \sim 10$ emitters) cavity quantum electrodynamics with silicon vacancy color centers in microresonators using the 4H-Silicon Carbide on Insulator photonics platform.

Solid-state cavity quantum electrodynamics (CQED) systems, such as cavity-coupled quantum dots [1,2], color centers in diamond [3–5] and silicon carbide [6], and rare-earth ions [7], have enabled the studies of cavity-coupled emitters in both microscopic and macroscopic regimes. Experimentally-realized microscopic systems such as single- and two-emitter CQED devices [1–4,6,7], owing to their low dimensionality, can be solved exactly. Macroscopic systems, where large ensembles ($\sim 10^6$ emitters) are coupled to a cavity [8], can via analyzed with semiclassical approximations. The intermediate — mesoscopic — regime has not yet been experimentally realized in the solid-state.

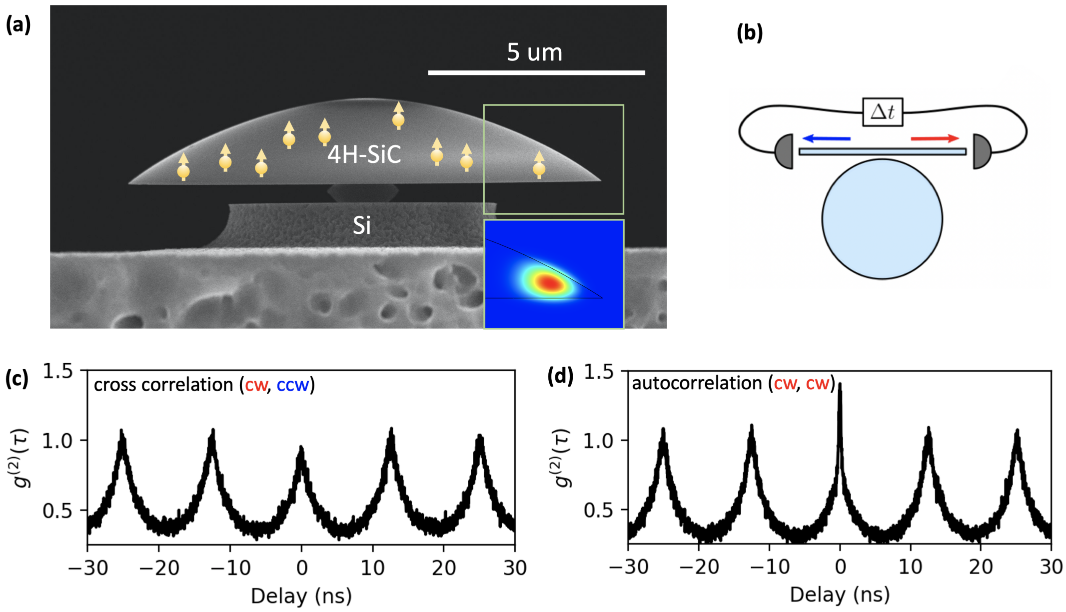

Fig. 1. (a) Scanning electron micrograph (SEM) of the SiC-on-insulator resonator. Inset shows the field profile of the transverse-magnetic (TM) whispering gallery mode. The TM mode couples optically to the V_{Si} emitter ensemble. (b) Clockwise and counterclockwise emission from the resonator can be independently analyzed via single photon detectors. (c) Second-order photon cross-correlation measurement of the ensemble emission. Correlating clockwise and counterclockwise photon statistics results in a quasi-distinguishable statistics, with $g^{(2)}(0) = 0.9$. (d) autocorrelation on the clockwise emission reveals superradiant emission, evidenced by $g^{(2)}(0)$ exceeding unity.

Here, using silicon vacancy (V_{Si}) color centers in silicon carbide coupled to a photonic resonator, we demonstrate the superradiant emission of a small ($N \sim 10$) ensemble of emitters in a cavity. The device fabrication is performed as follows: a 20 μm n-doped (nitrogen concentration $2 \cdot 10^{13}\text{cm}^{-3}$) SiC epilayer is grown via chemical vapor deposition on an n-type (0001) 4H-SiC substrate. The sample is irradiated with 2 MeV electrons with a fluence of $3.5 \cdot 10^{14}$ cm^{-2} to generate V_{Si} defects. The 4H-SiC-on-insulator material stack is produced via grinding and polishing [9, 10]. A photoresist reflow process [11] is used to fabricate the photonic resonators with low surface roughness as follows: Photoresist (S1822, Shipley) is patterned using direct write lithography, followed by post-development bake (30 seconds at 135° C) to induce photoresist reflow. Then, the pattern is transferred into SiC via a reactive ion etch (SF_6 gas, Oxford Plasmalab 100). The resonators are undercut via a wet hydroflouric acid etch and a gas XeF_2 etch. A side-view of a completed device is shown in Fig. 1(a).

Experiments are performed in a 4 K closed-cycle cryostat (Montana Instruments). Coupling to the resonator is achieved via a tapered fiber. Cryogenic argon gas condensation is used to tune the microdisk on-resonance with the emitter ensemble. The above-resonant excitation of the emitter ensemble is performed using a 80 MHz repetition rate femtosecond pulsed laser (wavelength 740 nm). The emission is filtered with a home-built monochromator with a 20 GHz bandwidth. By correlating photon emission into opposite directions inside the resonator (correlating clockwise emission and counterlockwise emission), we can observe quasi-distinguishable emission behavior for randomly-placed emitters [6] (Fig. 1(c)), allowing us to estimate the effective number of emitters from the $g^{(2)}(0)$ value to be $N_{\text{eff}} = 10$. In contrast, performing the photon autocorrelation on a single emission direction reveals superradiant bunching (Fig. 1(d)), indicating indistinguishable emission of the ensemble of emitters.

This demonstration is a step towards investigating mesoscopic disordered multi-emitter systems. Furthermore, combined with integrated spectral control of individual emitters via dc Stark shift [12], the demonstrated device architecture may enable the engineering of controllable multi-emitter interactions.

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