

Strong coupling between a single artificial atom and an integrated silicon carbide microresonator

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Abstract: The strong coupling regime between a photonic cavity and an artificial atom in 4H-Silicon Carbide-on-insulator photonics is demonstrated, using a high-finesse whispering gallery mode resonator and a single silicon vacancy center.

An optically-addressable solid-state spin strongly coupled to a photonic resonator enables deterministic gates between a flying qubit (a photon) and a quantum memory qubit (electron spin), a valuable resource for building scalable photon-mediated entanglement [1, 2]. Whereas emitter-cavity systems with large cooperativity but in the weak coupling regime enable the modification of cavity transmission spectrum [3] for efficient read-out of the spin state, in a strongly-coupled system, an entangled light-matter state can be directly produced. A large cooperativity requires that the atom-cavity coupling rate g^2 far exceeds the product of the cavity decay rate κ and the atom dephasing/decay rates (γ). Therefore, a system can still have a large cooperativity even when $g < \kappa$, *i.e.* when cavity loss rate dominates. In contrast, for the strong coupling metric, the rates κ and γ are treated on an equal footing. A system is considered strongly coupled if the condition $4g > \kappa, \gamma$ is met. The condition $4g > \kappa$ is challenging to satisfy in integrated photonics and is typically the limiting factor for achieving strong coupling. This is especially true for color centers, which have a relatively small dipole moment compared to, for instance, semiconductor quantum dots.

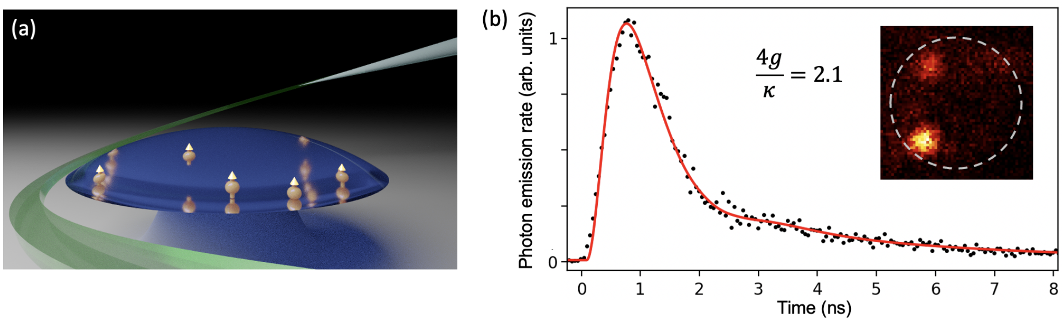

Fig. 1. (a) Illustration of photonic device. A low-roughness resonator is fabricated via photoresist reflow pattern transfer [4], and addressed via waveguide-fiber interface [5]. The resonator contains multiple randomly-placed emitters. (b) By spectrally tuning the resonator to the edge of the emitter inhomogeneous distribution, we isolate a detuning where only a single emitter is well-coupled to the cavity (spatial distribution scan shown in inset). By fitting the measured temporal dynamics of the emitter cavity system after excitation with a pulsed laser, we obtain $4g/\kappa = 2.1$.

Here, we integrate silicon vacancy color centers [6, 7] into high-finesse whispering gallery mode resonators in 4H-SiC on Insulator [8], and reach the strong coupling regime through a dramatic reduction of cavity loss rate κ. Following the technique described in Refs. [4, 5, 9], we fabricate whispering gallery mode resonators with finesse exceeding 10^3. An illustration of the device is shown in Fig. 1(a). To observe strong coupling between a single emitter and the resonator, we tune the optical mode via cryogenic gas condensation to the edge of the inhomogenous distribution of the emitters, such that color center emission into the cavity mode is dominated by a single emitter, as confirmed via second-order autocorrelation measurements as well as a photoluminescence map of the device. The optical mode loaded quality factor of $8.55 \cdot 10^5$ is measured via laser transmission, corresponding to $\kappa = 383$ MHz. By exciting the emitter via a pulsed above-resonant mode-locked laser, we observe fast temporal dynamics of photon emission from the cavity mode (Fig. 1(b)). Under above-resonant excitation, the emitter undergoes spectral diffusion, which is modeled by sampling dynamics for a distribution of emitter detunings. The result of the model captures the experimentally observed dynamics with the emitter-cavity coupling strength as a free parameter. The obtained coupling rate $g = 198$ MHz, higher compared to the previous demonstration [9], is consistent with the reduced mode volume of the device. Hence, $4g/\kappa = 2.1$, which exceeds the threshold for strong coupling by two times. We then characterize the single-photon purity and indistinguishably of the light emitted by the system, observing $g^{(2)}(0) = 0.02$ and interference visibility of 0.75, which confirms that the realized strongly coupled system is a source of pure and indistinguishable single photons.

This demonstration is a step toward deterministic gates between stationary and flying qubits mediated by the solid-state artificial atom spin-optical interface.

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