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Cavity-Quantum Electrodynamics with Single Diamond Tin-Vacancy Centers

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Abstract: We show diamond Tin-Vacancy centers, coherently-coupled to a tunable microcavity. The exceptional optical properties of this emitter in combination with a stable, high quality cavity enables a cavity transmission signal modulated by a single emitter.
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1. Introduction

Quantum networks can enable fundamentally new applications, both for applied sciences and pure research [1]. Individual nodes of the network need to be capable of storing and processing quantum information, in combination with a photonic interface to generate remote entanglement between nodes. Color centers in diamond, such as the Tin-Vacancy center, are promising candidates to realize these stationary nodes, but they lack efficient extraction of coherent photons, serving as flying qubits. An optical cavity can dramatically enhance this by improving on two major bottlenecks: the emission of coherent photons useful for quantum information and the collection efficiency [2,3]. Due to their large tunability and high flexibility of sample integration, open-access microcavities combined with direct fiber integration pose an excellent platform to realize such an optical interface.
Here, we demonstrate the coupling of individual Tin-Vacancy (SnV) centers to a microcavity. SnVs, created by ion-implantation, are incorporated into the cavity via a micrometer-thin diamond membrane, providing several tens of SnVs per cavity spot. The full tunability of the microcavity allows us to detect and selectively enhance single SnVs (see Fig. 1). The microcavity is cooled in a closed-cycle cryostat to about 8 K, and due to an optimized isolation system a passive stability of 27 pm in root mean square cavity length fluctuations is achieved. This vibration level is almost negligible on the performance of the system.

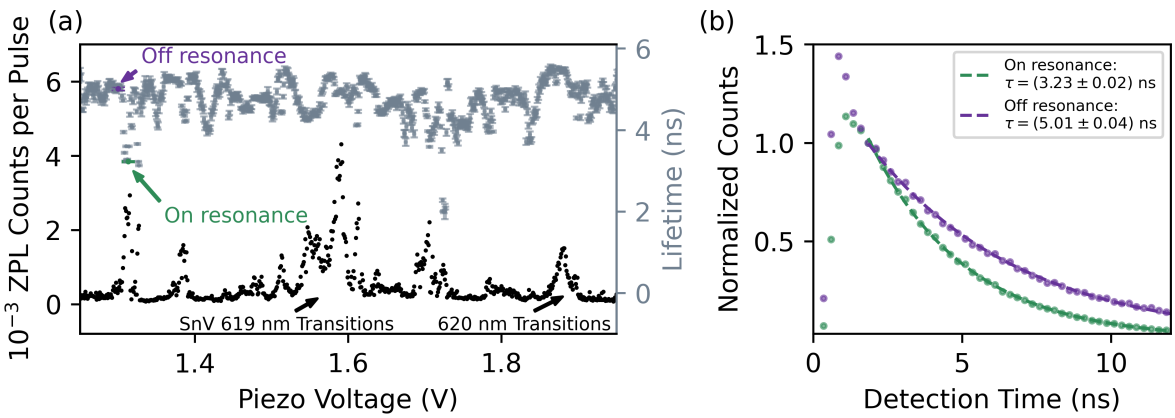

Fig. 1. SnV centers coupled to the microcavity. (a) Pulsed, off-resonant excitation and detection in the zero photon line is used. The cavity resonance frequency is scanned over several SnV centers and a lifetime measurement is recorded at every step. Two bunched areas indicate the 619 nm and 620 nm transitions of SnV center located inside the cavity. Well-coupled SnV centers can be identified by a high Purcell-reduced lifetime. (b) Individual lifetime measurements from (a) for the cavity fully on and off resonance with an single SnV.

2. Results

We find several positions on the diamond membrane with a finesse of up to 1000, which leads to a significant Purcell-enhancement. On such a spot, we select a well-coupled SnV center by measuring the excited state lifetime reduction and further quantify the coupling by the SnV linewidth with photoluminescence excitation. Comparing the linewidth for an on and off resonance cavity leads to a coherent cooperavity of $C_{\text{coh}} = 0.69 \pm 0.07$, entering the regime of coherent interaction between an individual SnV center and cavity. We further explore this effect, by resonantly probing the cavity in transmission, which reveals a signal modulated by the single SnV center (Fig. 2). Moreover, we study the saturation behaviour and the altered photon statistics. This work constitutes the first demonstration of nonlinear quantum effects with a hybrid diamond cavity [4].
Due to the outstanding versatility of the microcavity platform, the demonstrated methods can be applied to a large palette of color centers in solid states and two-dimensional materials. Improvements of the diamond membrane and cavity finesse would allow to reach a cooperatively exceeding 10. Furthermore, this system is directly compatible with recently shown SnV spin qubit control in strained diamond membranes [5].

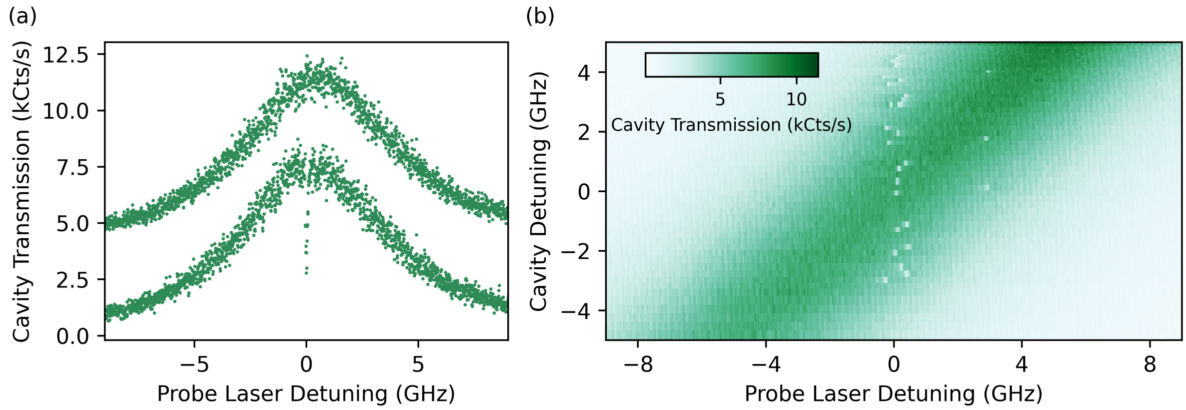

Fig. 2. Cavity transmission modulated by a single SnV center. The cavity is probed with a resonant laser. (a) Individual scans for for the cavity on resonance with the SnV center. In the upper trace (offset of 4 kCts/s), the interaction is switched-off by ionizing the SnV with an off-resonant laser. (b) The cavity resonance is tuned over the 619 nm transision of the SnV center. A significant modulation of the cavity transmission is observed. In each scan, an off-resonant laser pulse is applied in the beginning, which leads to spectral diffusion of the SnV center.

3. Acknowledgment

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