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A Fiber-based Microcavity for Color Centers in Diamond Membranes

Julius Fischer,[1*] Yanik Herrmann,[1] Julia M. Brevoord,[1] Colin Sauerzapf,[1] Leonardo G. C. Wienhoven,[1] Laurens J. Feije,[1] Matteo Pasini,[1] Martin Eschen,[1,2] Maximilian Ruf,[1] Matthew J. Weaver,[1] and Ronald Hanson[1]

[1] *QuTech and Kavli Institute of Nanoscience, Delft University of Technology, 2628 CJ Delft, The Netherlands*
[2] *Netherlands Organisation for Applied Scientific Research (TNO), P.O. Box 155, 2600 AD Delft, The Netherlands*
[*]*julius.fischer@tudelft.nl*

Abstract: We report on the realization of a fiber-based microcavity, exhibiting low cavity length fluctuations in combination with full spatial and spectral tunability. The microcavity is used to demonstrate Purcell-enhancement of diamond Tin-Vacancy centers. © 2024 The Author(s)

1. Introduction

Quantum networks based on remote entanglement generation can enable applications such as secure communication and distributed quantum computing [1]. Diamond color center qubits like the Nitrogen-Vacancy (NV) center and the group IV-Vacancy centers are excellent quantum node candidates, but the lack of efficient spin-photon interfaces is limiting the remote entanglement rates. The integration into fiber-based microcavities is a promising approach to establish an efficient interface via the Purcell effect [2, 3]. Recently, Purcell-enhancement of NV centers was demonstrated in a microcavity under resonant excitation [4]. However, cavity length fluctuations have been the main challenge to develop this system further into a quatnum network node. We tackle that challenge with a new cryogenic microcavity setup, which preserves a high cavity length stability in combination with full spatial and spectral tunability. Such systems are expected to speed up NV entanglement rates by at least a factor of 100, which is an important step towards large scale quantum networks.

Figure 1 (a) shows a schematic of the microcavity setup that is used in a closed-cycle optical cryostat. It is composed of a concave fiber input mirror and a flat output mirror [5], to which micrometer-thin diamond samples are bonded. These samples host optically coherent diamond color centers [6], that are coupled to the cavity mode by changing the lateral fiber mirror position and tuning the cavity air gap. Figure 1 (b) shows the air-diamond hybrid mode dispersion of such a system as a function of the air gap, demonstrating the full spectral tunability.

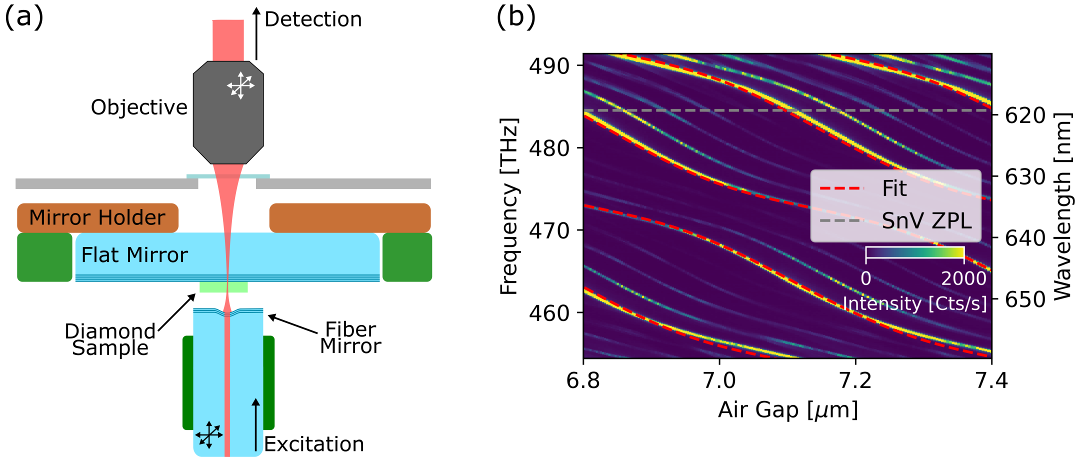

Fig. 1. (a) Schematic of the air-diamond hybrid cavity. (b) Hybrid cavity mode dispersion. The cavity transmission of a supercontinuum laser is monitored with a spectrometer as a function of the air gap. The dashed grey line shows the ZPL wavelength of the SnV center, indicating the cavity operation point at about 7.1 μm.

2. Results

Our microcavity is cooled in a closed-cycle optical cryostat, reaching sample temperatures of about 8 K. At cryogenic temperatures root mean square cavity length fluctuations of about 30 pm are measured, which is a five times improvement to our previous implementation [4]. With a diamond sample the system reaches cavity quality factors of up to 10^6 with cavity mode volumes of about $50\,\lambda^3$, resulting in achievable Purcell factors of above 10.
We use our system to demonstrate the first Purcell-enhancement of diamond Tin-Vacancy (SnV) centers in microcavities. Figure 2 (a) shows the Purcell-enhanced zero-phonon line (ZPL) SnV emission together with the measured excited state lifetime depending on emitter-cavity detuning. On cavity resonance a Purcell-reduced SnV lifetime of $\tau = (1.88 \pm 0.04)$ ns is measured (see Fig. 2 (b)). Accounting for the SnV Debye-Waller factor, quantum efficiency, branching ratio, dipole orientation and the residual cavity vibrations the expected Purcell-enhancement is almost reached for the presented data. Moreover, for a different SnV center we demonstrate coherent coupling and observe quantum non-linear effects in the cavity transmission signal [7].

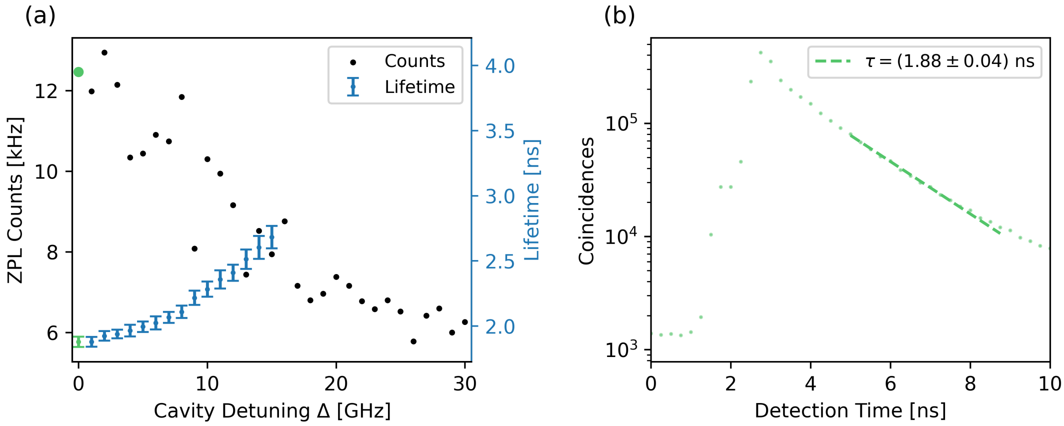

Fig. 2. (a) Purcell-enhanced ZPL SnV emission and measured excited state lifetime. The ZPL emission of a single SnV center is shown as a function of cavity detuning. For each cavity detuning the emitter lifetime is measured. (b) Lifetime measurement on cavity resonance ($\Delta = 0$), resulting in a maximally Purcell-reduced excited state lifetime of $\tau = (1.88 \pm 0.04)$ ns.

3. Acknowledgment

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