

Cavity-Quantum Electrodynamics with Single Diamond Tin-Vacancy Centers

Herrmann, Yanik; Fischer, Julius; Brevoord, Julia M.; Sauerzapf, Colin; Wienhoven, Leonardo G.C.; Feije, Laurens J.; Pasini, Matteo; Eschen, Martin; Ruf, Maximilian; Weaver, Matthew J.

DOI

[10.1364/QUANTUM.2024.QM2B.4](https://doi.org/10.1364/QUANTUM.2024.QM2B.4)

Publication date

2024

Document Version

Final published version

Published in

Proceedings Quantum 2.0 Conference and Exhibition

Citation (APA)

Herrmann, Y., Fischer, J., Brevoord, J. M., Sauerzapf, C., Wienhoven, L. G. C., Feije, L. J., Pasini, M., Eschen, M., Ruf, M., Weaver, M. J., & Hanson, R. (2024). Cavity-Quantum Electrodynamics with Single Diamond Tin-Vacancy Centers. In *Proceedings Quantum 2.0 Conference and Exhibition: QUANTUM 2024* Article QM2B.4 Optical Society of America (OSA). <https://doi.org/10.1364/QUANTUM.2024.QM2B.4>

Important note

To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy

Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

Green Open Access added to TU Delft Institutional Repository

'You share, we take care!' - Taverne project

<https://www.openaccess.nl/en/you-share-we-take-care>

Otherwise as indicated in the copyright section: the publisher is the copyright holder of this work and the author uses the Dutch legislation to make this work public.

Cavity-Quantum Electrodynamics with Single Diamond Tin-Vacancy Centers

Yanik Herrmann,^{1,*} Julius Fischer,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 Hanson¹

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

*y.s.herrmann@tudelft.nl

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.

© 2024 The Author(s)

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.

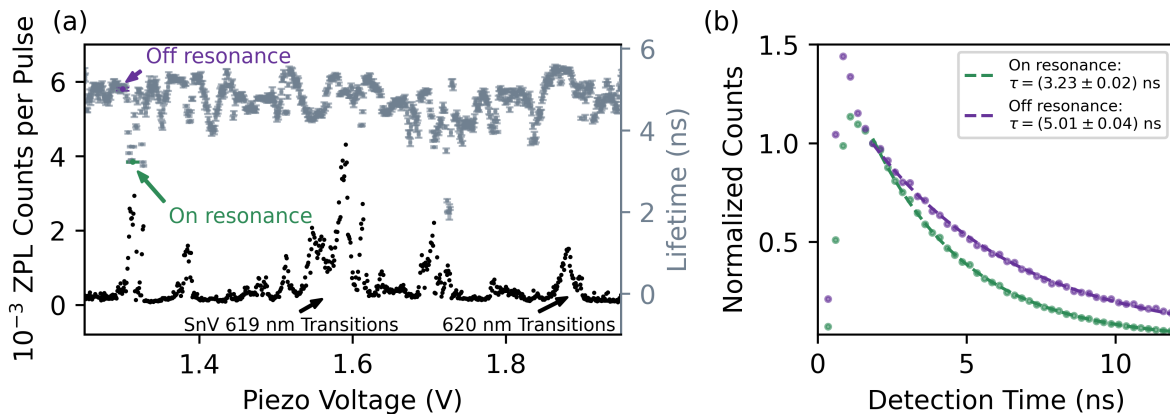


Fig. 1. SnV centers coupled to the microcavity. (a) Pulsed, off-resonant excitation and detection in the zero photon line is used. The cavity resonance frequency is scanned over several SnV centers and a lifetime measurement is recorded at every step. Two bunched areas indicate the 619 nm and 620 nm 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 a 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 cooperativity 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 cooperativity exceeding 10. Furthermore, this system is directly compatible with recently shown SnV spin qubit control in strained diamond membranes [5].

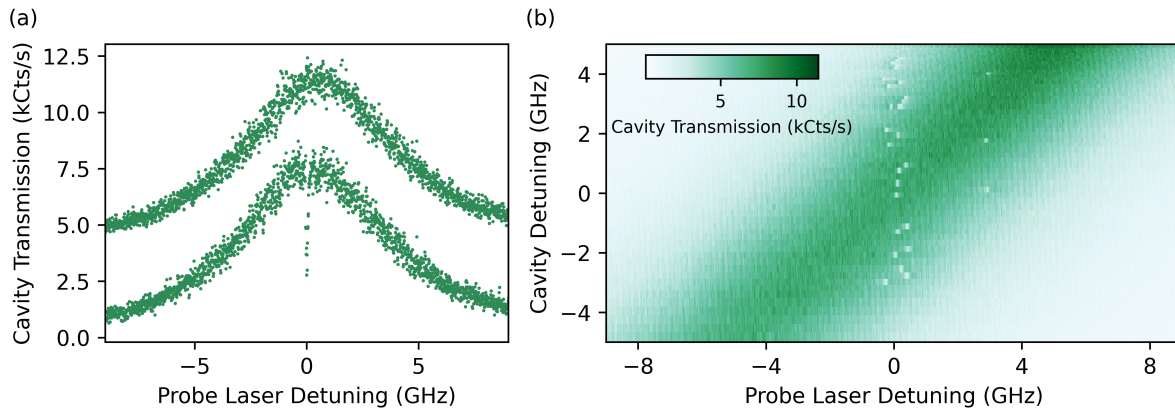


Fig. 2. Cavity transmission modulated by a single SnV center. The cavity is probed with a resonant laser. (a) Individual scans for the cavity on resonance with the SnV center. In the upper trace (offset of 4 kCts/s), the interaction is switched-off by ionizing the SnV with an off-resonant laser. (b) The cavity resonance is tuned over the 619 nm transition 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

We acknowledge financial support from the Dutch Research Council (NWO) through the Spinoza prize 2019 (project number SPI 63-264) and from the Dutch Ministry of Economic Affairs and Climate Policy (EZK), as part of the Quantum Delta NL programme. We gratefully acknowledge that this work was partially supported by the joint research program “Modular quantum computers” by Fujitsu Limited and Delft University of Technology, co-funded by the Netherlands Enterprise Agency under project number PPS2007.

References

1. S. Wehner, D. Elkouss, and R. Hanson, “Quantum internet: A vision for the road ahead,” *Science* **362**, eaam9288 (2018).
2. E. Janitz, M. K. Bhaskar, and L. Childress, “Cavity quantum electrodynamics with color centers in diamond,” *Optica* **7**, 1232 (2020).
3. M. Ruf, N. H. Wan, H. Choi, D. Englund, and R. Hanson, “Quantum networks based on color centers in diamond,” *J. Appl. Phys.* **130**, 070901 (2021).
4. Y. Herrmann, J. Fischer, J. M. Brevoord, C. Sauerzapf, L. G. C. Wienhoven, L. J. Feije, M. Pasini, M. Eschen, M. Ruf, M. J. Weaver, and R. Hanson, “Coherent coupling of a diamond tin-vacancy center to a tunable open microcavity,” *ArXiv:2311.08456* (2023).
5. X. Guo, A. M. Stramma, Z. Li, W. G. Roth, B. Huang, Y. Jin, R. A. Parker, J. Arjona Martínez, N. Shofer, C. P. Michaels, C. P. Purser, M. H. Appel, E. M. Alexeev, T. Liu, A. C. Ferrari, D. D. Awschalom, N. Deegan, B. Pingault, G. Galli, F. J. Heremans, M. Atatüre, and A. A. High, “Microwave-based quantum control and coherence protection of tin-vacancy spin qubits in a strain-tuned diamond-membrane heterostructure,” *Phys. Rev. X* **13**, 041037 (2023).