Q 21: Quantum Technologies: Color Centers II (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: F442

Q 21.1 Tue 11:00 F442

Purcell-Enhanced Emission from Individual SiV$^-$ Center coupled to a Photonic Crystal Cavity — •Niklas Lettner[1,2], Lukas Antoniuk[1], Konstantin Fehler[1,2], Anna P. Ovvyan[3], Nico Gruhler[3], Viatcheslav N. Agafonov[4], Wolfram H.P. Pernice[3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [4]Universite F. Rabelais, 37200 Tours, France

The combination of classical integrated photonic structures with color centers in diamond, like the Silicon Vacancy (SiV$^-$) Center, offer a promising platform for on-chip quantum optics experiments. We functionalize classical silicon nitride photonic crystal cavities with SiV$^-$ color centers in nanodiamonds in a hybrid approach. We show the experimental results coupling SiV$^-$ centers efficiently to a photonic crystal cavity mode and the Purcell enhanced emission of individual SiV$^-$ transitions [1]. By utilizing two mode coupling we achieved lifetimes of 460 ps [2].

[1] Fehler, Konstantin G., et al. Nanophotonics 9.11 (2020): 3655-3662.

[2] Fehler, Konstantin G., et al. ACS Photonics 8.9 (2021): 2635-2641.

Q 21.2 Tue 11:15 F442

Fabrication and characterization of μm-thin color center enriched diamonds for an open microcavity quantum network node — •Colin Sauerzapf[1,2], Julia Brevoord[1], Julius Fischer[1], Yanik Herrmann[1], Leonardo Wienhoven[1], Matteo Pasini[1], Laurens Feije[1], Matthew Weaver[1], Maximilian Ruf[1], Jörg Wrachtrup[2], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628 CJ, Netherlands — [2]3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany

Quantum network nodes are an essential building block to realize a Quantum Internet [1]. Color centers in diamond, like the established Nitrogen-Vacancy (NV) with its long spin coherence and spin register capabilities or the emerging Tin-Vacancy (SnV) centers, are promising candidates to realize such quantum nodes [2]. Integrating the color center into an open microcavity and therefore boosting the emission of coherent photons via the Purcell effect can significantly improve the entanglement rate of the system [3, 4]. Here we present a fabrication method for the required μm-thin color center enriched diamond platelets bonded to a Bragg mirror as well as the characterization of those samples in terms of emitter properties and performance in an open microcavity [5].

[1] S. Wehner et al., Science 362, 6412 (2018) [2] M. Ruf et al., J. Appl. Phys. 130, 070901 (2021) [3] M. Ruf et al., Phys. Rev. Applied 15, 024049 (2021) [4] E. Janitz et al., Optica 7, 1232-1252 (2020) [5] M. Ruf et al., Nano Lett. 19, 6, 3987*3992 (2019)

Q 21.3 Tue 11:30 F442

Overcoming spectral diffusion of NV defect centers in diamond nanostructures for enhanced entanglement generation — •Laura Orphal-Kobin[1], Kilian Unterguggenberger[1], Tommaso Pregnolato[1,2], Natalia Kemf[2], Mathias Matalla[2], Ralph-Stephan Unger[2], Ina Ostermay[2], Gregor Pieplow[1], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

In large-distance quantum networks, quantum nodes are entangled by single photons. Using NV defect centers in diamond, network entanglement protocols were demonstrated in bulk-like microstructured samples. Performances could be significantly improved by coupling NVs to nanostructures, which increases the photon collection efficiency into a particular optical mode. However, ionization of surface defects leads to spectral diffusion of the NV zero-phonon-line resonance.

We demonstrate NVs in nanostructures that exhibit spectrally stable emission suited for entanglement generation [1]. Choosing a substrate with a high density of bulk nitrogen defects incorporates natural NVs and seems to screen fluctuating electric fields from the surface. Moreover, long ionization times allow for resonant control sequences in which high energy pulses can be circumvented for many entanglement attempt repetitions (optical π-pulses). By suppressing spectral diffusion, we propose spin-photon entanglement rates on the order of hundreds of kHz using NVs in nanostructures.

[1] L. Orphal-Kobin et al., arXiv:2203.05605 (2022).

Q 21.4 Tue 11:45 F442

High-precision localization of color centers in diamond for deterministic coupling to quantum photonic nanostructures — •Maarten H. van der Hoeven[1], Julian M. Bopp[1], Maximilian Kähler[1], Tommaso Pregnolato[1,2], Marco Stucki[1,2], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Department of Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Quantum photonic circuits are fundamental building blocks for quantum information applications, like secure communication or quantum computing. In the past decades, it has been demonstrated that color centers in diamond have excellent properties to serve as qubits in such systems [1]. To create an efficient spin-photon interface, the color centers have to be coupled to quantum photonic nanostructures. The scalable fabrication of such devices with high yield and optimal performance requires deterministic alignment techniques [2]. This is achieved with high-precision localization of color centers in bulk diamond with uncertainties of a few tens of nanometers. Our approach is to determine the color center positions relative to alignment markers etched into the diamond's surface and subsequently fabricate nanostructures around them [3]. This technique allows for a pre-selection of the emitters and only the ones with the most suitable properties are chosen and integrated into a photonic device.

[1] M. Ruf et al., *Journal of Applied Physics* 130, 070901 (2021)
[2] S. Rodt et al., *J. Phys.: Condens. Matter* 32, 153003 (2020)
[3] T. Pregnolato et al., *APL Photon.* 5, 086101 (2020)

Q 21.5 Tue 12:00 F442

A novel open microcavity setup for an efficient spin-photon interface with diamond color centers — •Julius Fischer[1], Yanik Herrmann[1], Julia Brevoord[1], Colin Sauerzapf[1,2], Leonardo Wienhoven[1], Matteo Pasini[1], Laurens Feije[1], Matthew Weaver[1], Maximilian Ruf[1], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628 CJ, Netherlands — [2]3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany

Open microcavities are capable of equipping color centers in diamond with an efficient spin-photon interface [1,2] enabling their use as quantum nodes for quantum internet applications [3]. The well-established Nitrogen-Vacancy (NV) center with its long spin coherence times and spin register capabilities as well as the emerging Tin-Vacancy (SnV) center are two promising candidates. We recently showed Purcell enhancement under resonant excitation of NV centers in open microcavities [4]. However, the performance was limited by cavity length variations due to vibrations [4]. Here we present a new cryogenic low-vibration open microcavity setup including first measurements on defect center enriched μm-thin diamond samples.

[1] M. Ruf et al., Journal of Applied Physics 130, 070901 (2021) [2] E. Janitz et al., Optica 7, 1232-1252 (2020) [3] S. Wehner et al., Science 362, 6412 (2018) [4] M. Ruf et al., Phys. Rev. Applied 15, 024049 (2021)

Q 21.6 Tue 12:15 F442

Advances in Nanoscale Nuclear Magnetic Resonance with NV centers in diamond — •Marcel Martin[1], Nicolas Palazzo[2,3], Erik Knall[2], Daniel Kim[2,3], Nadine Meister[2], Ryan Gelly[2,3], Ryan Cimmino[2], Bartholomeus Machielse[2], Elana Urbach[2], Mikhail Lukin[2], Hongkun Park[2,3], and Nabeel Aslam[1] — [1]Institute of Condensed Matter Physics, Technische Universität Braunschweig, Braunschweig, Germany — [2]Department of Physics, Harvard University, Cambridge, USA — [3]Department of Chemistry and Chemical Biology, Harvard University, Cambridge, USA

Limitations of traditional nuclear magnetic resonance (NMR) can be overcome by using Nitrogen vacancy (NV) centers in diamond as local NMR probes which rely on statistical rather than thermal polarisation.

Proof-of-concept NMR measurements with NV centers have success-

fully been demonstrated in the past but revealed new challenges. One of them being the fast diffusion of molecules in liquids out of the detection volume, prohibiting NMR sensing by the NV centers. This can be solved by confining liquids in close proximity to the NV sensor. We realized this by structuring the diamond surface with nanowells, which function as traps for zeptoliter scale samples. In addition we demonstrated the controlled creation of NV centers underneath these nanostructures. We present NMR data measured with NV centers in such devices.

The promising technique of nanoscale NMR using NV centers is not restricted to liquids though but can be applied to a wide variety of materials. We will discuss a selection of potential applications.

Q 21.7 Tue 12:30 F442

Highly-efficient extraction of single photons from silicon vacancy in diamond using plasmonic nanoantenna — Ilya Fradkin[1], Mario Agio[2], and •Dmitry Fedyanin[1] — [1]Dolgopudny, Moscow, Russia — [2]University of Siegen, Siegen, Germany

Color centers in diamond and related wide-bandgap semiconductors are considered as one of the most promising quantum optoelectronic systems for single-photon sources and spin qubits. However, one of the major obstacles towards their practical exploitation is the high refractive index of diamond, which limits the maximum photon extraction efficiency to only a few percent for a horizontally oriented dipolar emitter, while for a vertically oriented emitter, the collection efficiency is even lower. At the same time, for practical applications, the efficiency of photon extraction of higher than 70% is typically required even at 100% quantum efficiency of the emitter. In this work, we develop a plasmonic nanoantenna that not only dramatically enhances the quantum efficiency of the silicon-vacancy (SiV) center in diamond but also improves the collection efficiency of the vertically oriented emitter by more than two orders of magnitude. We numerically demonstrate that the proposed nanoantenna allows to achieve the collection efficiency of more than 85%. Even more remarkable result is that the collection efficiency almost does not depend on the distance from the SiV center to the nanoantenna at distances from 10 to 100 nm and exceeds 80%, which is particularly beneficial for practical applications.

Q 21.8 Tue 12:45 F442

Fabrication of suspended "Sawfish" photonic crystal cavities in diamond — •Tommaso Pregnolato[1,2], Marco Stucki[1,2], Julian Bopp[1,2], Maarten van der Hoeven[2], and Tim Schröder[1,2] — [1]Ferdinand-Braun-Institut gGmbH, Berlin, Germany — [2]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany

Color centers in diamond are a promising candidate for the development of quantum photonic applications: for example, their long spin-coherence times make them the optimal choice for building spin-based quantum networks [1]. Such networks will be formed by many nodes containing color centers that are all interconnected by photonic channels. An efficient interface between spin and photon is key for the success of such a system, as it enables the transfer of information from the stationary qubits (i.e. the spins) to the flying qubits (i.e. the propagating photons). Such interface can be achieved by coupling a defect center to a photonic crystal cavity [2]. Here, we report on our progress of fabricating such photonic crystal cavities, based on our recently proposed "sawfish" cavity design [3]. Our design is optimized for enhancing the interaction between tin-vacancy centers in diamonds and single-mode light fields. We present our fabrication procedure to obtain such suspended devices, our investigations on how different parameters affect the relevant etching rates and our first optical characterizations.

[1] M. Atatüre, et al., Nat. Rev. Mater. 3, 38-51 (2018) [2] T. Schröder, et al, J. Opt. Soc. Am. B 33, B65-B83 (2016) [3] J. Bopp, et al., arXiv:2210.04702 (2022)