Q 41: Nano-Optics

Time: Wednesday 16:30–18:30 Location: P

Q 41.1 Wed 16:30 P

Nanoscale Cavity Antennae for Photoemission Enhancement of Color Centers in Silicon Carbide — •Jonah Heiler[1], Jonathan Körber[1], Philipp Fuchs[2], Erik Hesselmeier[1], Rainer Stöhr[1], Christoph Becher[2], Jörg Wrachtrup[1], and Florian Kaiser[1] — [1]3rd Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology IQST, 70569 Stuttgart, Germany — [2]Universität des Saarlandes, Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken, Germany

Color centers in solids form a promising quantum information processing platform. Their quantum state can be initialized with lasers and read out optically through emitted photons. The high refractive index of common host crystals like diamond or silicon carbide causes total internal reflection, thus limiting the photon emission rate into free space. An emission enhancement, together with a reduction of the saturation excitation laser power, was recently achieved by coating a diamond membrane with silver on both sides, acting as mirrors to form a planar Fabry-Pérot cavity [1]. Our goal is the fabrication of a similar cavity-based antenna for silicon vacancy color centers in silicon carbide. Optimization of the structure for the V2 center promises a theoretical photon collection enhancement of factor 70 compared to the bulk crystal. Here, we show the latest results of our work, including the fabrication of sub-micrometer membranes with chemical mechanical polishing and subsequent reactive ion etching and the spin-optical properties of silicon vacancy centers in thin silicon carbide membranes.

[1] Philipp Fuchs et al., APL Photonics 6, 086102 (2021)

Q 41.2 Wed 16:30 P

Fabrication of photonic crystal cavities towards a coherent spin-photon interface with color centers in SiC — •Jonathan Körber[1], Marcel Krumrein[1], Rainer Stöhr[1], Jonah Heiler[1], Vadim Vorobyov[1], Raphael Nold[1], Lukas Niechziol[1], Lin Jin[2], Patrick Berwian[3], Wolfram Pernice[2], Jörg Wrachtrup[1], and Florian Kaiser[1] — [1]3rd Institute of Physics, IQST and Research Centre SCoPE, University of Stuttgart, Germany — [2]Institute of Physics, AG Pernice, University of Münster, Germany — [3]Fraunhofer Institute for Integrated Systems and Device Technology IISB, Erlangen, Germany

Color centers in SiC promise applications in the fields of distributed quantum computing and quantum sensing. However, as a consequence of the high refractive index, SiC-based color centers in the bulk show small photon count rates due to total internal reflection. Moreover, Debye-Waller factors of 8 (9)% [1] for the V1 (V2) center in SiC further lower the rate of resonantly emitted photons. To overcome these limitations we fabricate photonic crystal cavities in SiC, based on the approach from [2] in diamond, aiming at a Purcell enhancement of 10-100 and near-deterministic fiber coupling. Here, we report on the most recent updates of our work based on rectangular cross-section photonic structures that are patterned by electron-beam lithography and transferred into the SiC by reactive-ion etching. Furthermore, we show perspectives for color center integration.

[1]: Udvarhelyi, P. et al., Phys. Rev. Applied 13:054017 (2020)
[2]: Quan, Q. et al., Appl. Phys. Lett. 96:203102 (2010)

Q 41.3 Wed 16:30 P

Fabrication of Photonic Crystal Cavities with Triangular Cross-Section in Silicon Carbide — •Marcel Krumrein[1], Rainer Stöhr[1], Jonathan Körber[1], Vadim Vorobyov[1], Raphael Nold[1], Lukas Niechziol[1], Lin Jin[2], Patrick Berwian[3], Wolfram Pernice[2], Florian Kaiser[1], and Jörg Wrachtrup[1] — [1]3rd Institute of Physics, IQST, and Research Centre SCoPE, University of Stuttgart, Germany — [2]Institute of Physics, AG Pernice, University of Münster, Germany — [3]Fraunhofer Institute for Integrated Systems and Device Technology IISB, Erlangen, Germany

Defect centers in Silicon Carbide (SiC) are promising candidates for quantum information applications as they possess very good optical and spin properties. As published recently, triangular-shaped waveguides can guide the defect centers' emission very efficiently and are quite resilient to fabrication imperfections [1]. The implantation of the V2 center into waveguides with triangular cross-section while preserving their spin-optical properties as nearly lifetime-limited emission was recently shown [2]. On this basis, the integration of these defect centers into cavities to enhance the photon emission is desirable. This is important for efficient single-shot read-out and other quantum information protocols. In this contribution, we present the necessary steps of fabricating photonic crystal cavities in 4H-SiC including e-beam lithography and reactive ion etching. Our focus lies on the simultaneous realization of an efficient interface for waveguide-fiber coupling.

[1] Sridhar Majety et al., J. Phys. Photonics 3 034008 (2021).
[2] Charles Babin et al., arXiv:2109.04737 [quant-ph] (2021).

Q 41.4 Wed 16:30 P

An organic molecule strongly coupled to a microcavity: Single-photon nonlinearity — •André Pscherer[1], Manuel Meierhofer[1], Daqing Wang[1], Hrishikesh Kelkar[1], Diego Martín-Cano[1], Tobias Utikal[1], Stephan Götzinger[2,1,3], and Vahid Sandghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander University Erlangen-Nürnberg (FAU), Erlangen, Germany — [3]Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany

The response of a single quantum emitter to a single photon is qualitatively different from its response to classical light. In a free-space scheme, optical nonlinearities are intrinsically weak. Here, we show that by reaching the strong coupling regime of cavity quantum electrodynamics, four-wave mixing and optical switching become possible at the level of single photons and single molecules. Furthermore, we demonstrate vacuum Rabi oscillations and super bunching [1].

[1] A. Pscherer, *et al.*, Phys. Rev. Lett. **127**, 133603 (2021)

Q 41.5 Wed 16:30 P

Influence of sample preparation on the optical properties of NV centers in nanodiamonds — •Jana Bauer[1,2], Justus Christinck[1,2], Franziska Hirt[1,2], Helmuth Hofer[1], and Stefan Kück[1,2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology (LENA), Braunschweig, Germany

Nitrogen vacancy (NV-) centers are promising candidates as single-photon emitters in quantum metrology, though a reproducible preparation of samples based on nanodiamonds containing NV centers is still a major challenge. Especially the single-photon purity is fundamentally influenced by the sample preparation. We present a preparation routine based on cover glasses cleaned in oxygen plasma and the ensuing application of the nanodiamond particles via spin coating. Atomic force microscope as well as confocal microscope measurements were performed to examine the samples. The correlation of data sets allowed the identification of clusters as well as the classification of the diamond particles regarding their position and their optical properties. A metrological characterization in terms of the single-photon purity, spectral distribution, and the recording of the count rate as a function of the excitation power was performed. A detailed evaluation will be shown at the conference.

Q 41.6 Wed 16:30 P

Preparation methods for growing a stabilizing organic matrix for molecule-based single-photon emitters — •Franziska Hirt[1,2], Justus Christinck[1,2], Mike Stummvoll[1,3], Andreas Reutter[1,3], Uta Schlickum[1,3], and Stefan Kück[1,2] — [1]Laboratory for Emerging Nanometrology, Braunschweig, Deutschland — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland — [3]Technische Universität Braunschweig, Braunschweig, Deutschland

Polycyclic aromatic hydrocarbons, such as dibenzoterrylene (DBT), offer promising properties as emitters in a single-photon source. One prerequisite is their embedding in a crystalline matrix and a cryogenic environment. When fulfilled, high photostability and quantum yield, as well as a short excited state lifetime with a lifetime-limited spectral emission mainly in the zero-phonon-line are observed.

We report on two strategies concerning the fabrication of a stable, crystalline matrix surrounding a single DBT molecule.

One approach is based on a reprecipitation method that ideally leads to the production of anthracene nanocrystals with a size of less than 450 nm, containing single DBT.

The second approach deals with the deposition of C60-fullerenes using organic molecular beam epitaxy, which can serve as a capsule for one dibenzoterrylene molecule and, on the other hand, act as a protective layer, when the molecules are placed between two C60 layers.

A detailed overview about the procedures will be given at the conference.

Q 41.7 Wed 16:30 P

Laser Annealing of Quantum Emitters in Hexagonal Boron Nitride — •Tjorben Matthes[1], Antonia Klein[2], Uwe Zeitner[1,2], Falk Eilenberger[1,2], and Tobias Vogl[1] — [1]Institute of Applied Physics, Friedrich-Schiller-University Jena, Albert-Einstein-Straße 15, 07745 Jena, Germany — [2]Fraunhofer-Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany

Quantum emitters based on fluorescent defects in wide-bandgap materials such as the 2D material hexagonal boron nitride (hBN) are promising candidates for usage in quantum information applications. There are several fabrication mechanisms of these emitters, however, in most of these methods the emitter formation is probabilistic at random locations. The crystals are typically irradiated extensively with defects forming over the entire area and subsequently annealed as a whole. The position and number of the thereby created emitters are not reliably controllable.

In this presentation we localize the emitter formation using a high power laser. With an ultrashort pulse it is possible to induce damage to the crystal lattice. Using slightly less intense recurring pulses we subsequently anneal the sample in a small area within the laser spot size. Simulations have shown that the typical annealing temperatures of 850°C are reached within 0.5 ms for our laser configuration. With confocal excitation through a second laser, we can monitor the fluorescence count-rate and get a feedback when an emitter has been formed and activated, thereby making this fabrication method deterministic.

Q 41.8 Wed 16:30 P

Towards a cryogenic quasi-deterministic single-photon source — •Siwei Luo[1], Luis Morales[1], Michael Becker[1], Jan Renger[1], Tobias Utikal[1], Vahid Sandoghdar[1,2], and Stephan Götzinger[2,1] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Friedrich-Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany

Highly efficient single-photon sources are key elements for many applications in emerging quantum technologies. Our strategy to realize a quasi-deterministic single-photon source relies on the combination of a metallo-dielectric antenna and single molecules at cryogenic temperature. Theoretical calculations predict a near-unity photon collection efficiency, larger than 99% for an arbitrarily oriented emitter. However, this concept so far has only been verified at room temperature [1]. Our new antenna design, compatible with a cryogenic environment, comprises molecules in a crystalline matrix which are sandwiched between a solid immersion lens and a reflective metal layer. We will showcase our latest results on single molecules embedded in these new antenna structures.

[1] X.-L. Chu et al., Nature Photonics 11, 58 (2017).

Q 41.9 Wed 16:30 P

Coupling of quantum emitters in 2D materials to laser-written waveguides — •Josefine Krause[1], Simone Piacentini[2], Roberto Osellame[2], Falk Eilenberger[1], Giacomo Corrielli[2], and Tobias Vogl[1] — [1]Institute of Applied Physics, Friedrich-Schiller-University Jena, Germany — [2]Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche (IFN-CNR) and Dipartimento di Fisica, Politecnico di Milano, Italy

Optical quantum technologies have the potential to revolutionize future information processing and sensing. For practical applications, it is essential to combine the required components to manipulate light as well as the photon source itself within compact optical chips. A possible route is combining room temperature solid-state emitters with ultrafast laser-written waveguides. Quantum emitters hosted by atomically thin 2D materials can be easily attached to the optical circuits. Moreover, the photon extraction is near-ideal, as the emitters are not surrounded by any high refractive index material.

In this work, we transfer 2D material-based emitters to the entry facet of a laser-written waveguide. We use the fluorescence of the free exciton in monolayer WS_2 as a benchmark to demonstrate the coupling between 2D emitters and the waveguide. The excellent optical properties of the free exciton are preseved after the transfer. The waveguide features an on-chip directional coupler that allows us to measure the photon statistics. We are currently extending our platform to single photon emitters in hexagonal boron nitride and actively-tunable Mach-Zehnder interferometers for quantum state manipulation.

Q 41.10 Wed 16:30 P

Improving the optical coherence of tin vacancy centres in diamond by long term low temperature and low pressure annealing — •Dennis Herrmann[1], Johannes Görlitz[1], Philipp Fuchs[1], Michael Kieschnik[2], Jan Meijer[2], and Christoph Becher[1] — [1]Fachrichtung 7.2, Universität des Saarlandes — [2]Applied Quantum Systems, Felix-Bloch Institute for Solid-State Physics, Universität Leipzig

The negatively charged tin-vacancy (SnV) centre is a promising candidate for applications in QIP combining single photon emission rates exceeding the well-known silicon-vacancy (SiV) centre by a factor of 10 while still offering large Debye-Waller factors, high single photon purity (g2(0)=0.05) and narrow Fourier limited linewidths down to 20 MHz. Furthermore the large ground state splitting of 850 GHz together with an optical stabilization of the defect charge state allows for spin dephasing times on the order of $T_2^* \sim 5\mu s$. Since strain being induced during implantation of heavy tin ions dramatically influences the SnV properties a consequent annealing step is crucial to heal the diamond lattice. Up to now a high temperature and high pressure (HPHT, 2100°C at 7.7 GPa) annealing has shown a strong reduction of implantation-induced strain. As HPHT annealing is an elaborate process we here present an alternative way of reducing strain by a long term annealing procedure at lower temperatures and low pressures (LPLT, 1200 °C and vacuum) leading to improved spectral properties such as a narrow inhomogeneous distribution of line positions and reduced linewidths/ground state splittings indicating low strain.

Q 41.11 Wed 16:30 P

Plasmon assisted ultrafast photodynamic of silicon-vacancy color centers in nanodiamond — •Tanya Agrawal[1], Assegid M. Flatae[1], Haritha Kambalathmana[1], and Mario Agio[1,2] — [1]Laboratory of Nano-Optics and Cμ, University of Siegen, Siegen, Germany — [2]National Institute of Optics (INO), National Research Council (CNR), 50019 Sesto Fiorentino, Italy

Nanoscale ultrafast single-photon sources based on color centers in diamond are desirable in quantum technologies and fundamental quantum optics. Particularly, silicon-vacancy (SiV) color centers in diamond have shown promising results as its emission is concentrated in a narrow zero-phonon line and has an excited state lifetime in the order of 1 ns. Currently, we are developing optical- and microscopy techniques for a controlled nearfield coupling of plasmonic nanostructures (gold nanorods/ nanocones) to SiV color centers in nanodiamond for ultrafast photon emission. [1] S. Lagomarsino, et al., Diam. Relat. Mater. 84, 196 (2018). [2] H. Kambalathmana, et al., Proc.SPIE 11091, 1109108 (2019). [3] A. M. Flatae, et al., J. Phys. Chem. Lett. 10, 2874 (2019).

Q 41.12 Wed 16:30 P

High-yield placement of colloidal quantum dot single-photon sources on nanophotonic chips — •Tobias Spiekermann, Alexander Eich, Helge Gehring, Lisa Sommer, Julian Bankwitz, Wolfram Pernice, and Carsten Schuck — Institute of Physics, University of Münster, Germany

Integrated photonics benefits many quantum technology applications because it allows for replicating crucial circuit components with high yield and high reproducibility. While the integration of single-photon sources with nanophotonic devices has recently been achieved [1], extending the approach to larger numbers of independently controllable emitters has remained challenging. Here we introduce an iterative procedure for site-selective placement of individual colloidal quantum dots (CQD) that provides means for embedding single-photon sources with high yield into photonic integrated circuits at wafer-scale. We lithographically pattern arrays of apertures in polymer thin films, apply CQDs in solution to the sample and remove excess emitters in a lift-off process. We assess emitter placement at aperture positions via confocal microscopy and repeat the process with a modified lithography mask that only contains aperture locations which had remained vacant. This iterative procedure quickly converges towards high-yield and we confirm single-photon emission from predefined sites by recording second-order autocorrelation functions. We further passivate CQD-sites employing atomic layer deposition of alumina (Al_2O_3), which benefits the emitters photostability.

[1] Alexander Eich et al., arXiv:2104.11830, (2021)

Q 41.13 Wed 16:30 P

Creation of luminescent defects in SiC by focused ion beam processing — •Osamah Sufyan[1], Neha Aggarwal[2], Kevin Thommes[1], Victor Deinhart[1], Sofia Pazzagli[3], Arno Rauschenbeutel[3], João Marcelo Lopez[2], and Katja Höflich[1] — [1]Ferdinand-Braun-Institut gGmbH, Berlin, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany — [3]Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany

Defects in silicon carbide (SiC) can serve as colour centers which enable single-photon emission and coherent spin state control. Given its large transparency window and technical maturity, SiC is thus a promising platform for photonic quantum technologies. Focused ion beam processing is a powerful direct writing tool that can be employed as scalable method to create defects in materials. It was recently shown that a He focused ion beam can be used to create defects in epitaxial graphene on SiC. These defects acted as nucleation sites in the epitaxial growth of hexagonal boron nitride (hBN).

Based on these encouraging results, we plan to investigate the defect formation in the underlying SiC substrate due to the focused ion beam processing by varying the beam parameters. We will characterize the defects in view of their use as quantum emitters in a custom-built confocal epifluorescence microscope. Samples consisting of epitaxial graphene on SiC are favourable in this context as the graphene quenches near-surface emitters in SiC that have broad a spectral distribution and may hide the colour centers in the bulk.

Q 41.14 Wed 16:30 P

High-Accuracy Localization of Defect Centers in Diamond for Deterministic Fabrication of Quantum Photonic Structures — Julian M. Bopp[1,2], Maarten van der Hoeven[1], •Maximilian Kähler[1], Tommaso Pregnolato[1,2], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

For the past decades, color centers in diamond have evolved into possible key ingredients for quantum photonic applications such as quantum light sources or quantum memories [1] because of their promising optical characteristics. Quantum light sources as a building-block for photonic integrated circuits can be realized by embedding a single diamond color center into a diamond cavity [2]. The reliable fabrication of such photonic stuctures requires the localization of single color centers in bulk diamond with an accuracy of down to tens of nanometers [3].

We present our progress in improving the localization accuracy towards the required level. This will enable the high-yield deterministic fabrication of diamond-based quantum emitters.

[1] S. Mouradian et al., Phys. Rev. X 5, 031009 (2015)
[2] S. Mouradian et al., Appl. Phys. Lett. 111, 021103 (2017)
[3] T. Pregnolato et al., APL Photon. 5, 086101 (2020)

Q 41.15 Wed 16:30 P

Direct writing of chiral and nonlinear plasmonic devices — •Aleksei Tsarapkin[1], Thorsten Feichtner[2], and Katja Hoeflich[1] — [1]Ferdinand-Braun-Institut gGmbH, 12489 Berlin, Germany — [2]Politecnico di Milano, 20133 Milano, Italy

The miniaturization of electrical and optical components allowed many technological and economic advancements over the last decades. Devices that permit control over the polarization of light are crucial in telecommunication and quantum optics but are usually realized as bulky optical systems and thus require further miniaturization. Here we aim at designing a uniquely compact converter and detector based on plasmonics. The structure consists of a vertically oriented gold double helix coupled to a planar two-wire transmission line. The helix acts as a sensitive antenna for circularly polarized light, while the plasmonic transmission line exhibits two different modes depending on the incident polarization state and guides them on-chip. FEM and FDTD analysis show that antisymmetric modes can be excited in both double helix and two-wire waveguide. Furthermore, one can adjust the geometry of these structures to optimize coupling strength and finely tune their optical response to the desired wavelength range. Finally, we developed fabrication protocols: while the helices can be directly written with an electron-induced deposition, the plasmonic waveguides can be cut from single-crystalline gold flakes utilizing focused gallium-ion beam milling. We achieved high structuring resolution with both methods, allowing for efficient coupling to transform linear to circular polarization while retaining a device size of just a few microns.

Q 41.16 Wed 16:30 P

Broadband home-built confocal microscope for the characterization of quantum emitters — •Kevin Thommes[1,2], Katja Höflich[1,2], Arno Rauschenbeutel[2], and Sofia Pazzagli[2] — [1]Ferdinand-Braun-Institut gGmbH - Leibniz-Institut für Höchstfrequenztechnik — [2]Humboldt-Universität zu Berlin - Institut für Physik

In the field of future quantum technologies, single-photon emitters are of fundamental importance. However, it is still unclear which of the many possible solid-state-based quantum emitters, such as molecules or defects in crystals, will be most suitable for specific future applications. Therefore, we have established a multi-color setup for confocal epi-fluorescence microscopy, which allows different wavelengths in excitation and detection and thus gives access to different solid-state systems. Combined with a configurable beam path in excitation, we can acquire white light and photoluminescence images as well as spectra with an electron multiplier CCD camera and spectrometer over a wide spectral range. Controlling the excitation polarization and the choice of detection polarization gives us additional information about the absorption and emission characteristics and, if necessary, the orientation of the dipolar emitter. To accurately determine the position of the emitters on the sample with respect to a current configuration, we can perform confocal scans. Finally, photon emission statistics can be measured determining the second-order autocorrelation function in a Hanbury-Brown-Twiss setup. We will show example measurements for defect centers in hexagonal boron nitride, which are characterized by high brightness and robustness of quantum emission.

Q 41.17 Wed 16:30 P

Flat-top beam shaping and it's use in modern microscopy — •Leona Licht[1], Philipp Kellner[1], Giovanni DeAngelis[1], Christian Eggeling[1,2], and Herbert Gross[3] — [1]Institut für angwandte Optik und Biophysik, Friedrich-Schiller-Universität, Philosophenweg 7, 07743 Jena — [2]Leibniz-Institut für photonische Technologien, Albert-Einstein-Straße 9, 07745 Jena — [3]Institut für angwandte Physik, Friedrich-Schiller-Universität, Albert-EInstein-Straße 15, 07745 Jena

Light microscopy, although known for more then 300 years by now, is still one of the most versatile tools for observation of living biological samples and their analysis. Nowadays illumination in most microscopes is done by laser-radiation and it's inherent gaussian profile. On this poster we present recent developments in microscope illumination using flat-top shaped laser-beams paving the way towards highly uniform illumination used in single-molecule tracking or as a prerequisite in advanced analysis methods. The beam shaping can be achieved by microstructured phaseplates or by special optical components. We will elaborate on the usability of these all-optics approaches to beam-shaping in widefield and confocal microscope configurations.