TT 39: Focus Session: Quantum Nanophotonics in Solid State Systems I (joint session HL/TT)

Photonic quantum technologies provide revolutionary concepts and innovative solutions in the fields of sensing, communication and computing in the so called "second quantum revolution". Activities in this area involve light-matter interaction, light propagation, light manipulation and light detection, mainly at the single photon level. The Focus Session aims at presenting and discussing the current status of quantum nanophotonics, open challenges as well as future directions and perspectives in this very active field of solid state research.

Organizers: Alexander Szameit(U Rostock), Ruth Oulton (U Bristol), and Stephan Reitzenstein (TU Berlin)

Time: Tuesday 9:30–15:45 Location: EW 201

Invited Talk TT 39.1 Tue 9:30 EW 201

Exploring the limits of position measurement with optomechanics — Sergey A. Fedorov, Vivishek Sudhir, Nils J. Engelsen, Ryan Schilling, Hendrik Schütz, Amir H. Ghadimi, Mohammad J. Bereyhi, Dalziel J. Wilson, and •Tobias J. Kippenberg — Institute of Physics (IPHYS), École polytechnique fédérale de Lausanne, 1015 Lausanne, Switzerland

Optomechanics provides a platform to investigate the quantum limits on position measurements and extend quantum control to macroscopic objects. We utilized a microdisk optical cavity with a nanobeam mechanical oscillator in the near-field to perform sensitive measurements of the oscillator position. At cryogenic temperatures, we attained a measurement rate approaching the thermal decoherence rate. Using the measurement record as an error signal, we feedback-cooled the oscillator to a mean phonon number of 5.3 (16% ground state probability). In the same system, we observed ponderomotive squeezing of light and distilled quantum sideband asymmetry from the thermal noise using measurement-based feedback. At room temperature, we demonstrated quantum correlations of light and used these quantum correlations to enhance force sensitivity. However, thermal decoherence remains a major obstacle in our experiments—any potential quantum state preparation must be performed within the decoherence time. Therefore, we have developed ultra-high quality factor mechanical resonators, capable of hundreds of coherent oscillations at room temperature. We are now working to integrate these oscillators with an optical cavity to enable operation in the measurement-backaction dominated regime.

Invited Talk TT 39.2 Tue 10:00 EW 201

On-chip integration of superconducting single photon detectors — •Wolfram Pernice — Universität Münster, Physikalisches Institut, Heisenbergstr. 11, 48149 Münster

Nanophotonic circuits employ waveguiding devices to route light across quasi-planar integrated optical chips in analogy to electrical wires in integrated electrical circuits. Using materials with high refractive index allows for confining light into sub-wavelength dimensions as efficient optical wires. Interaction with the environment is possible through near-field coupling to the evanescent tail of propagating optical modes, given that the measurable system is close to the waveguide surface. The interaction length can then be conveniently tailored by simply choosing a sufficiently long waveguide. This approach is particularly interesting for designing highly sensitive detectors which are able to register individual photons. Because nanophotonic circuits are well-suited for the study of single photon effects on chip, such detectors constitute a fundamental building block for emerging quantum photonic technologies. I will present recent progress on waveguide integrated single photon detectors, with a focus on superconducting nanowire single photon counters. Besides covering the basics of single photon threshold detection, advanced designs for multi-photon and coherent detection will be discussed. In combination with waveguide coupled single photon sources, such detectors are promising ingredients for fully integrated quantum circuits. The heterogeneous integration with nanophotonic circuits allows for implementing compact hybrid systems for non-classical optics in a chipscale framework.

TT 39.3 Tue 10:30 EW 201

Indistinguishable single photons from a quantum dot coupled to a ridge waveguide — •Lukasz Dusanowski[1], Soon-Hong Kwon[1,2], Christian Schneider[1], and Sven Höfling[1] — [1]Technische Physik, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Department of Physics, Korea University, Seoul 136-701, Korea

Here we report on resonance fluorescence of an InAs/GaAs quantum dot coupled to a distributed Bragg-reflection ridge waveguide. The pulsed, resonant excitation was carried out from the top of the waveguide and emitted photons collected from the side facet of the ridge after 2 mm travel distance. Based on the calculations and time-resolved-measurements coupling efficiency into waveguide was estimated to be around 20%. In this case highly linearly polarized photons have been observed with a single-photon purity of >99% and indistinguishability >95% demonstrating a realistic pathway for on-chip quantum photonics.

TT 39.4 Tue 10:45 EW 201

Deterministic integration of QDs into on-chip multimode interference couplers via in-situ electron beam lithography — •Peter Schnauber[1], Johannes Schall[1], Samir Bounouar[1], Jin-Dong Song[2], Theresa Hoehne[3], Sven Burger[3], Tobias Heindel[1], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut fuer Festkoerperphysik, Technische Universitaet Berlin, Berlin, Germany — [2]Korea Institute of Science and Technology, Seoul, Korea — [3]Zuse Institut Berlin, Freie Universitaet Berlin, Berlin, Germany

The deterministic integration of quantum emitters into on-chip photonic elements is crucial for the implementation of scalable on-chip quantum circuits. Recent activities include multistep-lithography[1] as well as AFM tip transfer[2]. Here we report on the deterministic integration of single QDs into on-chip beam splitters using single step in-situ electron beam lithography[3]. In order to realize 50/50 coupling elements acting as central building blocks of on-chip quantum circuits we chose tapered multimode interference (MMI) splitters which feature relaxed fabrication tolerances and robust 50/50 splitting ratio. We demonstrate the functionality of the deterministic QD-waveguide structures by μPL spectroscopy and photon cross-correlation between the two MMI output ports. The latter confirms single-photon emission and on-chip splitting associated with $g^{(2)}(0) < 0.5$.

[1] Coles et al., Nature Communications 7, 11183 (2016)
[2] Zadeh et al., Nano Letters 16, 2289 (2016)
[3] Gschrey et al., Nature Communications 6, 7662 (2015)

15 min. break.

Invited Talk TT 39.5 Tue 11:15 EW 201

Integrated III-V nonlinear quantum optical devices — •Gregor Weihs — Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

For fundamental tests of quantum physics as well as for quantum communications, non-classical states of light are an important tool. In this talk, we will present our work on nonlinear AlGaAs waveguides. Most III-V semiconductors exhibit a large second-order optical nonlinearity, but phase-matching the nonlinear interaction is notoriously difficult. As a solution Bragg-reflection waveguides (BRW) allow efficient creation of photon pairs through spontaneous parametric down-conversion. They have the potential to be integrated with a pump laser on the chip for a miniaturized room-temperature entangled photon pair source.

In our BRWs we can create high-fidelity polarization and time-bin entangled photon pairs, which cover a large frequency band in the low-loss telecommunication window, suitable for serving multiple users through wavelength division multiplexing. For all our applications it is important that we can design the desired linear and nonlinear properties, which in turn makes precise characterization necessary. For this purpose we have developed a Fourier-transform Fabry-Perot spectroscopy technique, which yields the relevant device parameters with superior accuracy. Finally, we will present our latest results on devices that integrate electrically injected lasers and the nonlinear conversion and give an outlook on the possible integration of other optical elements on-chip.

TT 39.6 Tue 11:45 EW 201

Temporally adjustable photon pairs from semiconductor waveguides — •K. Laiho[1,2], B. Pressl[2], A. Schlager[2], S. Auchter[2], H. Chen[2], T. Günthner[2], H. Suchomel[3], J. Gessler[3], M. Kamp[3], S. Höfling[3,4], C. Schneider[3], and G. Weihs[2] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [3]Technische Physik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [4]School of Physics & Astronomy, University of St Andrews, St Andrews KY16 9SS, UK

Semiconductor Bragg-reflection waveguides (BRWs) are efficient photon-pair sources and well suited for integrated optics. These monolithic structures are made of AlGaAs and profit from its strong second order optical non-linearity. Our BRWs rely on type-II parametric down-conversion (PDC) achieved via spatial mode matching.

In order to become truly practical, BRWs need to be reliably fabricated and applicable in various quantum optics tasks. Our simulations show that too coarse tolerances in fabrication easily distort the design properties. Further, we experimentally investigate the characteristics of PDC emission, verify the indistinguishability of photon pairs and prepare polarization entangled states with a temporally adjustable degree of entanglement [1]. To conclude, a careful study of the PDC process parameters is necessary for controlling and manipulating the BRW's performance in the investigated tasks.

[1] A. Schlager et al., Opt Lett. 42, 2102 (2017) and references therein.

TT 39.7 Tue 12:00 EW 201

On-chip hybrid quantum photonic circuits — Ali W. Elshaari[1], Iman Esmaeil Zadeh[2], Andreas Fognini[2], Dan Dalacu[3], Philip J. Poole[3], Michael E. Reimer[4], Val Zwiller[1,2], and •Klaus D. Jöns[1] — [1]Applied Physics Department, KTH Stockholm, Sweden — [2]Kavli Institute of Nanoscience, TU Delft, The Netherlands — [3]National Research Council of Canada, Ottawa, Canada — [4]Institute for Quantum Computing, University of Waterloo, Canada

Quantum communication applications require a scalable approach to integrate bright on-demand sources of entangled photon-pairs in complex on-chip quantum circuits. Currently, the most promising sources are based on III/V semiconductor quantum dots. However, complex photonic circuitry is mainly achieved in silicon photonics due to the tremendous technological challenges in circuit fabrication. We take the best of both worlds by developing a new hybrid on-chip nanofabrication approach [1], allowing to integrate III/V semiconductor nanowire quantum emitters into silicon-based photonics. We demonstrate for the first time on-chip generation, spectral filtering, and routing of single-photons from selected single and multiple nanowire quantum emitters all deterministically integrated in a CMOS compatible silicon nitride photonic circuit [2]. Our new approach eliminates the need for off-chip components, opening up new possibilities for large-scale quantum photonic systems with on-chip single- and entangled-photon sources.

[1] I. Esmaeil Zadeh et al., Nano Lett. 16(4), 2289-2294 (2016).
[2] A. W. Elshaari et al., Nat. Commun. 8, 379 (2017).

TT 39.8 Tue 12:15 EW 201

Reconfigurable integrated optical circuits on an stretchy polymer chip — •James A. Grieve[1], Kian Fong Ng[1], Filip Auksztol[1], Manuel J.L.F. Rodrigues[2], Neo Ho[2], José Viana-Gomes[2,3], and Alexander Ling[1,3] — [1]Centre for Quantum Technologies, National University of Singapore, Singapore — [2]Centre for Advanced 2D Materials and Graphene Research Centre, National University of Singapore, Singapore — [3]Department of Physics, National University of Singapore, Singapore

We describe the development of a waveguide platform in the flexible, stretchy polymer polydimethylsiloxane (PDMS). The pliable substrate enables tuning of integrated optical components by mechanical deformation of the host chip, overcoming a key limitation in many bespoke waveguide platforms. We illustrate this capability via the continuous on-chip tuning of a beamsplitter. We also apply these techniques to continuously coupled photonic random walks. Here, appropriate deformation of the chip allows reconstruction the spatial evolution of light in a coupled 1D array by observation of the end face alone. The PDMS platform is compatible with visible wavelengths and is insensitive to polarization, making it a compelling candidate for the integration of quantum optics experiments.

TT 39.9 Tue 12:30 EW 201

Confined microcavity polaritons: effect of trap geometry on potential shape — •Alexander Kuznetsov, Paul Helgers, Klaus Biermann, and Paulo Santos — Hausvogteiplatz 5-7, 10117 Berlin, Germany

Micorcavity (MC) exciton-polaritons (MPs) result from the strong light-matter coupling. MPs may be quantum-confined using micrometer-sized static potentials (traps). Arrays of such traps have been suggested for quantum-simulators. The latter require energy- and spatial overlap of wave functions of trapped single polaritons and thus precise control of the trap shape and size. In this work, we investigate the two-dimensional and three-dimensional confinement of MPs in traps produced by shallow etching and overgrowth of (Al,Ga)As MC. Using low-temperature photoluminescence, atomic-force microscopy and numerical modeling we correlate trap shape and size with the energy spectrum and spatial profile of MPs wave functions. We find that the um-sized potential is of neither purely square nor parabolic type. We show that the trap potential is anisotropic due to the different overgrowth kinetics along [-110] and [-1-10] directions. We present a model to explain non-degenerate energy levels in the emission spectra of confined MPs, which also predicts the minimum size and confinement strength of MPs traps.

TT 39.10 Tue 12:45 EW 201

Photo-luminescence of defects in GaAs double quantum wells in the trion blockade regime — •Mingyun Yuan, Alberto Hernández-Mínguez, Colin Hubert, Klaus Biermann, and Paulo Santos — Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany

Electrostatic traps are commonly used to control excitons in double quantum well (DQW) structures, in our case a GaAs/AlGaAs DQW. When the traps are biased to the flat-band regime, only direct (i.e. in the same QW) excitons and trions can be formed. Away from the flat-band, indirect (in different QWs) excitons appear due to their favorable binding energies. At the edge of the flat-band, we observe a narrow regime in which the photo-luminescence (PL) of direct excitons, trions and indirect excitons is supressed, while unexpected narrow spectral lines from individual emission centers become visible.

We conclude that such PL spectra arise from trion blockade. The excess charge of a trion cannot break away and tunnel to the second QW, since the resulted direct exciton would have a higher energy. However, if defect states with sufficiently lower energies exist in the second QW, the excess charge can tunnel and recombine with such a defect, emitting photons during the process. By moving the sub-micron excitation spot we can map out the precise location and the density of these emission centers. Their intensity saturates with increasing excitation power, indicating their single-photon nature. This phenomenon in the trion blockade regime can assist engineering of defects in a DQW. The potential of using them as single photon sources can also be explored.

TT 39.11 Tue 13:00 EW 201

Enhanced single-photon emission from a CdSe quantum dot in a ZnSe nanowire featuring a bottom-up photonic shell — Mathieu Jeannin[1], Thibault Cremel[2], Teppo Häyrynen[3], •Niels Gregersen[3], Edith Bellet-Amalric[2], Gilles Nogues[1], and Kuntheak Kheng[2] — [1]Université Grenoble Alpes, CNRS, Institut Néel, Grenoble, France — [2]Université Grenoble Alpes, CEA, Grenoble, France — [3]DTU Fotonik, Technical University of Denmark, Kongens Lyngby, Denmark

A quantum dot in a semiconductor nanowire represents an attractive platform for an efficient single-photon source. While demonstrations so far have mainly been for III-V materials, the II-VI platform offers the possibility of room-temperature operation, where CdSe quantum dots inserted in ZnSe nanowires have demonstrated the ability to emit single photons at 300 K.

In this work, we present a bottom-up approach to fabricate a photonic nanowire-like structure around such CdSe quantum dots by depositing an oxide shell using atomic-layer deposition. Simulations suggest that the intensity collected in a 0.6 NA microscope objective can be increased by a factor 7 with respect to the bare nanowire case. Combining micro-photoluminescence, decay time measurements, and numerical simulations, we obtain a fourfold increase in the collected photoluminescence from the quantum dot. We show that this improvement is due to an increase of the quantum-dot emission rate and a redirection of the emitted light.

45 min. break.

Invited Talk TT 39.12 Tue 14:00 EW 201

Hybrid waveguide platforms for quantum optics — •Michal Bajcsy — IQC, University of Waterloo, Waterloo, ON, Canada

While often challenging to implement, combining systems and building blocks from different areas of quantum optics and nanophotonics can open avenues for realizing novel devices and for studies of previously unexplored phenomena. I will describe three hybrid nanophotonic platforms my group has been exploring in the past few years.

In the first platform, we attempt to integrate superconducting-nanowire single-photon detectors with waveguide arrays laser-written in glass. In the second platform, we propose to couple individual quantum emitters, such as trapped atoms, colour centres, or quantum dots, with dispersion engineered chiral waveguides to implement deterministic single-photon subtraction. Our third platform combines hollow-core waveguides with dielectric metasurfaces acting as mirrors to realize integrated Fabry-Perot cavities that can be designed to be polarization selective.

TT 39.13 Tue 14:30 EW 201

Heterogeneous quantum networks: Combine QDs with long lived atomic quantum memories — •Janik Wolters[1], Lucas Béguin[1], Roberto Mottola[1], Jan-Philipp Jahn[1], Andrew Horsley[1], Fei Ding[2], Armando Rastelli[3], Oliver G. Schmidt[2], Richard J. Warburton[1], and Philipp Treutlein[1] — [1]Universität Basel, Department Physik, Switzerland — [2]IFW Dresden, Germany — [3]Johannes-Kepler Universität Linz, Austria

Semiconductor quantum dots (QDs) are excellent single-photon sources, providing triggered single-photon emission at a high rate and with high spectral purity. Independently, atomic ensembles have emerged as one of the best quantum memories for single photons, providing high efficiency storage and long memory lifetimes. We aim at combining these two disparate physical systems to exploit the best of both worlds. For this, the bandwidth mismatch between QDs typically emitting GHz-broad photons and atomic lines of 10 MHz width must be solved. We demonstrate a scheme to generate temporally shaped narrow-bandwidth single photons with QDs [1], and we push forward an EIT-based quantum memory to store broadband photons in a dense ensemble of 87Rb atoms [2].

[1] L. Béguin et al., On-demand semiconductor source of 780 nm single photons with controlled temporal wave packets, arXiv:1710.02490 (2017).

[2] J. Wolters et al., Simple atomic quantum memory suitable for semiconductor quantum dot single photons, Phys. Rev. Lett. 119 060502 (2017).

TT 39.14 Tue 14:45 EW 201

Rare-earth doped nanoparticles with millisecond-long spin coherence lifetime — •Diana Serrano[1], Jenny Karlsson[1], Alexandre Fossati[1], Alban Ferrier[1,2], Alexandre Tallaire[1], and Philippe Goldner[1] — [1]Institut de Recherche de Chimie Paris (IRCP), UMR 8247 CNRS Chimie-Paristech, 11 rue Pierre et Marie Curie, 75005 Paris — [2]Sorbonne Universités, UPMC Université Paris 06, 75005, Paris, France

Nanoscale systems possessing long-lived spins and the ability to coherently couple to light are highly demanded for quantum devices implementations. Several approaches, like NV centers in diamond, semiconductor quantum dots are intensively investigated in the field, where an outstanding challenge is to preserve properties, and especially optical and spin coherence lifetimes, at the nanoscale. Here, we investigate for the first time the spin coherence properties of rare-earth doped nanoparticles. Using all-optical techniques, we observed spins echoes and measured spin coherence lifetimes up to T2=2.9 ms at 5 K. Moreover, we achieve spin T2 extension using all-optical spin dynamical decoupling and observe high fidelity between excitation and echo phases. Rare-earth doped nanoparticles are thus the only reported nano-material in which optically controlled spins with millisecond coherence lifetimes have been observed.

Acknowledgement:

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TT 39.15 Tue 15:00 EW 201

Cavity Optomagnonics — •Silvia Viola Kusminskiy[1], Florian Marquardt[1,2], Hong Tang[3], and Jasmin Graf[1,2] — [1]Max Planck for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [3]Yale University, New Haven, USA

In optomagnonics, light couples coherently to collective magnetic excitations in solid state systems. This topic is of high interest for quantum information processing platforms at the nanoscale, and recent experiments have demonstrated the optomagnonic coupling for the first time. In this talk, I show how to obtain the microscopic optomagnonic Hamiltonian starting from the Faraday effect and discuss the optically-induced classical nonlinear dynamics for a homogeneous magnetic mode. A unique feature of optomagnonic systems is moreover the possibility of coupling light to spin excitations on top of magnetic textures. For the case of a microdisk geometry, I discuss the coupling between magnon modes in the presence of a magnetic vortex, and light confined to whispering gallery modes.

TT 39.16 Tue 15:15 EW 201

Quantization of three-dimensional leaky and lossy cavities using quasinormal modes — •Sebastian Franke[1], Stephen Hughes[2], Andreas Knorr[1], and Marten Richter[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, EW 7-1, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany — [2]Department of Physics,Engineering Physics and Astronomy,Queen's University, Kingston, Ontario, Canada K7L 3N6

Open cavity systems, e.g. plasmonic metal nanoparticles or micropillar cavities, are of high interest in modern research on quantum optics and quantum plasmonics. However, the dissipative character of these systems prevents the use of a canonical quantization scheme with the open cavity photon modes.

We develop a rigorous quantization scheme using a Green's function approach[1] of an inhomogeneous and dispersive medium, and quasinormal modes[2] (QNMs) with complex eigenfrequencies $\tilde{\omega}_\mu$ and complex eigenfunctions $\tilde{\mathbf{f}}_\mu$ as a basis for the mode expansion of the quantization. In this way we obtain suitable annihilation and creation operators for modified QNMs to create QNM multi-photon Fock states. Applications to density matrix equations and comparison to the Jaynes-Cummings model will be shown, including extensions to the multi-mode case.

[1]T. Gruner, and D.-G. Welsch, *Phys. Rev. A* **53**, 1818, 1996

[2]P. T. Leung, S. Y. Liu, and K. Young, *Phys. Rev. A* **49**, 3057, 1994

TT 39.17 Tue 15:30 EW 201

Quantum correlations of strongly-coupled emitters inside a nanoantenna-enhanced plasmonic cavity — •Matthias Hensen[1], Tristan Kenneweg[2], Tal Heilpern[3], Stephen K. Gray[3], and Walter Pfeiffer[2] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Center for Nanoscale Materials, Argonne National Laboratory, 9700 Cass Avenue, Lemont, Illinois 60439, USA — [3]Fakultät für Physik, Universität Bielefeld, Universitätsstraße 25, 33615 Bielefeld, Germany

Plasmon-mediated strong coupling between spatially separated and thus selectively addressable quantum emitters is a worthwhile goal for conveying quantum optical many-body interactions to ultrafast timescales. For this purpose we employ a recently demonstrated hybridization scheme [1] that combines the longevity and waveguide character of an elliptical plasmon cavity with the strong field enhancement of nanoantennas positioned in the associated focal spots. Quantum dynamical simulations reveal an oscillatory exchange of excited state population and a notable degree of entanglement between the attached quantum emitters over a distance of 1.8 μm [2].

Presently, we study coherent control and time-resolved spectroscopy of quantum emitter-related nonclassical photon correlations in this device and show first results.

[1] Aeschlimann et al., *Light: Science & Applications* 6, e17111 (2017)

[2] Hensen et al., *ACS Photonics*, doi:10.1021/acsphotonics.7b00717