TT 10: Materials and devices for quantum technology (joint session HL/TT)

Time: Wednesday 10:00–12:45 Location: H4

Invited Talk TT 10.1 Wed 10:00 H4

Quantum Interference of Identical Photons from Remote Quantum Dots — •Giang N. Nguyen[1], Liang Zhai[1], Clemens Spinnler[1], Julian Ritzmann[2], Matthias C. Löbl[1], Andreas D. Wieck[2], Arne Ludwig[2], Alisa Javadi[1], and Richard J. Warburton[1] — [1]Department of Physics, University of Basel, Switzerland — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr- Universität Bochum, Germany

Photonic quantum technology provides a viable route to quantum communication, quantum simulation, and quantum information processing. Scaling the complexity requires photonic architectures containing a large number of single photons, multiple photon-sources and photon-counters. Semiconductor quantum dots are bright and fast sources of coherent single-photons. For applications, a significant roadblock is the poor quantum coherence upon interfering single photons created by independent quantum dots.

Here, we present two-photon interference with near-unity visibility using photons from remote quantum dots. We show a Hong-Ou-Mandel visibility of 93% between photons from quantum dots separated in two cryostats. Exploiting the quantum interference, we demonstrate a photonic controlled-not circuit and a high-fidelity entanglement between photons of different origins. These results provide a long-awaited solution to the challenge of creating coherent single photons in a scalable way.

TT 10.2 Wed 10:30 H4

Natural heavy-hole flopping mode qubit in germanium — •Philipp M. Mutter and Guido Burkard — University of Konstanz, Konstanz, Germany

Flopping mode qubits in double quantum dots allow for coherent spin-photon hybridization and fast qubit gates when coupled to either an alternating external or a quantized cavity electric field. To achieve this, however, electronic systems rely on synthetic spin-orbit interaction by means of a magnetic field gradient as a coupling mechanism. Here we theoretically show that this challenging experimental setup can be avoided in heavy-hole systems in germanium by utilizing the sizable cubic Rashba spin-orbit interaction. We argue that the resulting natural flopping mode qubit possesses highly tunable spin coupling strengths that allow for qubit gate times in the nanosecond range when the system is designed to function in an optimal operation mode which we quantify.

TT 10.3 Wed 10:45 H4

On-chip Stark tuning of deterministically fabricated quantum dot waveguide systems — Peter Schnauber, Jan Grosse, Arsenty Kaganskiy, Maximilian Ott, Pavel Anikin, Ronny Schmidt, •Sven Rodt, and Stephan Reitzenstein — Institute of Solid State Physics, Technische Universit'at Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany

On-chip quantum photonic circuits based on monolithic waveguides structures provide a compact and robust solution for setting up quantum logics and processors. The required structuring has already reached a very high level in different material systems but the monolithic integration of a number of single-photon emitters with identical emission wavelength is still a crux of the matter. We tackle this issue by deterministically integrating single InGaAs/GaAs quantum dots (QDs) into pin-doped GaAs/AlGaAs waveguides by in-situ electron-beam lithography (iEBL) [1]. This approach promises the integration of QDs with quasi-identical emission wavelength in combination with a fine-tuning mechanism via the quantum confined Stark effect. The wavelength accuracy in the pre-selection step of iEBL was about 0.2 nm which is nicely covered by tuning-range of about 0.4 nm when applying a bias voltage of up to 1.2 V. This paves the way for the fabrication of scalable quantum photonic circuits that rely on photon interference from multi emitters.

[1] P. Schnauber et al., APL Photonics 6, 050801 (2021)

TT 10.4 Wed 11:00 H4

Integration of NV-centers in nanodiamond in 1D photonic crystal cavities — •Jan Olthaus[1], Philip P.J. Schrinner[2], Carsten Schuck[2], and Doris E. Reiter[1] — [1]Institute of Solid State Theory, University of Münster, Germany — [2]Institute of Physics, Center for NanoTechnology - CeNTech and Center for Soft Nanoscience - SoN, University of Münster, Germany

The scalable integration of single-photon emitters with photonic circuits remains a major hurdle for the realisation of quantum information technologies. Efficient integration requires an interface, combining low losses and high coupling strength between these components. Here, we show results for the coupling of nitrogen vacancy centers in nanodiamond to 1D on-substrate photonic crystal cavities. In the first step, we use 3D FDTD simulations to optimise the geometry of a on-substrate photonic crystal cavity based on tantalum pentoxide waveguides. Based on the optimised structures, we then analyse the coupling conditions, if a nanodiamond cluster of varying sizes is placed in different positions around the cavity center. We find that for a deterministic air-mode design, optimal coupling is achieved when placing the nanodiamond at the air-waveguide interface within the central air-hole. Then, we validate our results experimentally by placing nanodiamonds close to the determined optimal position. We measure antibunching of the integrated photoluminescence signal proving single-photon emission. The scalability of our approach is demonstrated by simultaneous readout of the electron-spin of two neighbouring devices in a optical detected magnetic resonance measurement.

TT 10.5 Wed 11:15 H4

Optoelectronic sampling of ultrafast electric transients with single quantum dots — •Sebastian Krehs[1], Alex Widhalm[1,2], Dustin Siebert[2], Nand Lal Sharma[1,3], Timo Langer[1], Björn Jonas[1], Dirk Reuter[1], Andreas Thiede[2], Jens Förstner[2], and Artur Zrenner[1] — [1]Paderborn University, Physics Department, Warburger Straße 100, 33098 Paderborn, Germany — [2]Paderborn University, Electrical Engineering Department, Warburger Straße 100, 33098 Paderborn, Germany — [3]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany

The use of quantum systems as sensors promises high sensitivity, high precision and access to nanoscale applications. In our work, we have pioneered optoelectronic sampling of ultrafast electric signals with low capacitance single quantum dots photodiodes as sensor devices [1]. Our concept exploits the Stark effect to convert a time-dependent electric signal into a time-dependent shift of the QD transition energy. Time resolved measurements of the shift can be measured by resonant ps laser spectroscopy with spectrally tunable photocurrent detection. With our method we are able to sample the laser synchronous output pulse of an ultrafast CMOS circuit at cryogenic temperatures. We demonstrate an impressive sub-20 ps time resolution and an amplitude resolution in the mV-range. Theoretical calculations show that the accuracy of our method is not affected or limited by a moderate timing jitter or the optical pulse width.

[1] http://arxiv.org/abs/2106.00994

15 min. break.

TT 10.6 Wed 11:45 H4

Bright Electrically Controllable Quantum-Dot-Molecule Devices Fabricated by In Situ Electron-Beam Lithography — •Johannes Schall[1], Marielle Deconinck[1], Nikolai Bart[2], Matthias Florian[3], Martin von Helversen[1], Christian Dangel[4], Ronny Schmidt[1], Lucas Bremer[1], Frederik Bopp[4], Isabell Hüllen[3], Christopher Gies[3], Dirk Reuter[5], Andreas D. Wieck[2], Sven Rodt[1], Jonathan J. Finley[4], Frank Jahnke[3], Arne Ludwig[2], and Stephan Reitzenstein[1] — [1]IFKP, TU Berlin, Germany — [2]LS AFP, Ruhr-Universität Bochum, Germany — [3]ITP, University of Bremen, Germany — [4]WSI, TU München, Germany — [5]Department Physik, Universität Paderborn, Germany

In quantum repeater networks it is of central importance to temporarily store and retrieve quantum information. Concepts based on quantum dot molecules (QDMs) promise storage times in excess of 1 ms. To make use of QDM based quantum memories, efficient coupling to flying qubits needs to be realized while maintaining precise electrical control. We report on the development of electrically tunable single-QDM devices with strongly enhanced broadband photon extraction efficiency. The quantum devices are based on stacked quantum dots in a pin-diode structure underneath a deterministically defined circular

Bragg grating using in situ electron beam lithography. We determine the photon extraction efficiency, demonstrate bias voltage dependent spectroscopy and measure excellent single-photon emission properties. The metrics make the developed QDM device an attractive building block for use in future photonic quantum networks.

TT 10.7 Wed 12:00 H4

Photon-number entanglement generated by sequential excitation of a two-level atom — Stephen C. Wein[1], Juan C. Loredo[2], Maria Maffei[3], Paul Hilaire[2], Abdou Harouri[2], Niccolo Somaschi[4], Aristide Lemaitre[2], Isabelle Sagnes[2], Loic Lanco[2,5], Olivier Krebs[2], Alexia Auffeves[3], Christoph Simon[1], Pascale Senellart[2], and •Carlos Anton-Solanas[2,6] — [1]Univ. of Calgary, Canada — [2]C2N-CNRS, France — [3]Inst. Neel-CNRS, France — [4]Quandela SAS, France — [5]Univ. Paris-Diderot, France — [6]Carl von Ossietzky Univ., Germany

During the spontaneous emission of light from an excited two-level atom, the atom briefly becomes entangled with the photonic field, producing the entangled state $\alpha|e, 0\rangle + \beta|g, 1\rangle$, where g and e are the ground and excited states of the atom, and 0 and 1 are the vacuum and single photon states [1].

We experimentally show that the spontaneous emission can be used to deliver on demand photon-number entanglement encoded in time [2]. By exciting a charged quantum dot (an artificial two-level atom) with two sequential π pulses, we generate a photon-number Bell state $\alpha|00\rangle + \beta|11\rangle$. We characterize the quantum properties of this state using time-resolved photon correlation measurements. We theoretically show that applying longer sequences of π pulses to a two-level atom can produce multipartite time-entangled states with properties linked to the Fibonacci sequence.

[1] V. Weisskopf, E. Wigner, Zeitschrift für Physik 63, 54 (1930). [2] S. C. Wein, et al., arXiv:2106.02049 (2021).

TT 10.8 Wed 12:15 H4

Evaluating Atomically Thin Quantum Emitters for Quantum Key Distribution — •Timm Gao[1], Martin v. Helversen[1], Carlos Anton-Solanas[2], Christian Schneider[2], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany

Single photon sources are considered key building blocks for future quantum communication networks. In recent years, atomic monolayers of transition metal dichalcogenides (TMDCs) emerged as a promising material platform for the development of compact quantum light sources. In this work, we evaluate for the first time the performance of a single photon source based on a strain-engineered WSe_2 monolayer [1] for quantum key distribution (QKD). Employed in a QKD-testbed emulating the BB84 protocol, we analyze the single-photon purity in terms of $g^{(2)}(0)$ and secret key rates as well as quantum bit error rates to be expected in full implementations of QKD. Furthermore, we exploit routines for the performance optimization previously applied to quantum dot based single-photon sources [2]. Our work represents a major step towards the application of TMDC-based devices in quantum technologies.

[1] L. Tripathi et al., ACS Photonics 5, 1919-1926 (2018)
[2] T. Kupko et al., npj Quantum Inform. 6, 29 (2020)

TT 10.9 Wed 12:30 H4

Single Photon Emission from a topological cavity — •Jonathan Jurkat[1], Sebastian Klembt[1], Tristan H. Harder[1], Johannes Beierlein[1], Monika Emmerling[1], Tobias Huber[1], Christian Schneider[2], and Sven Höfling[1] — [1]Technische Physik, Wilhelm-Conrad-Röntgen-Research Center for Complex Material Systems, and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Institute of Physics, University of Oldenburg, 26129 Oldenburg, Germany

We measured the emission enhancement as well as single photon emission of a In(Ga)As quantum in spectral resonance with a topological defect mode. The emission was measured in a microphotoluminescence setup under quasi resonant pumping with a pulsed laser. Spectral resonance was achieved by means of temperature tuning. The photonics lattice and topologically protected defect mode was implemented in an orbital Su-Schrieffer-Heeger chain. This zigzag chain of coupled micropillar devices was fabricated using molecular beam epitaxy in combination with an etch and overgrowth technique. These coupled resonators offer the exciting opportunity to combine a complex band structure formation with the emission of single localized quantum emitters.