HL 19: Materials and Devices for Quantum Technology 1

Time: Wednesday 9:30–13:00 Location: H34

Invited Talk HL 19.1 Wed 9:30 H34

Quantum Interference of Identical Photons from Remote GaAs Quantum Dots — •Giang Nam Nguyen[1], Liang Zhai[1], Clemens Spinnler[1], Julian Ritzmann[2], Mattias 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 — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

Efficient generation and detection of coherent single photons are key to advances in photonic quantum technologies such as quantum computation, quantum simulation, and quantum communication. For applications, a significant roadblock is the poor quantum coherence upon interfering single photons created by independent emitters.

Here, we present near-unity two-photon interference visibilities from two separate GaAs quantum dots [1]. This high visibility (~93%) is achieved under rigorous conditions: there is no Purcell enhancement, no temporal post-selection, no narrow spectral-filtering, nor frequency stabilization. Using photons emitted from two remote quantum dots, we demonstrate a photonic CNOT gate. Interfering photons in this quantum logic gate, we generate an entangled two-photon state using photons from separate semiconductor chips. We obtain an entanglement fidelity of (85 +- 1)%, exceeding the CHSH threshold for violating Bell inequalities. This result highlights the importance of the high two-photon visibility for high fidelity entanglement operations.

[1] L. Zhai et al., Nature Nanotechnol. (2022)

HL 19.2 Wed 10:00 H34

Optimizing quantum teleportation with imperfect quantum dot sources — •Francesco Salusti[1], Francesco Basso Basset[2], Lucas Schweickert[3], Michele B Rota[2], Davide Tedeschi[2], Saimon Filipe Covre da Silva[4], Emanuele Roccia[2], Val Zwiller[3], Klaus D Jöns[1], Armando Rastelli[4], and Rinaldo Trotta[2] — [1]Department of Physics, Paderborn University, Paderborn, Germany — [2]Department of Physics, Sapienza University of Rome, Rome, Italy — [3]Department of Applied Physics, Royal Institute of Technology, Stockholm, Sweden — [4]Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Linz, Austria

All-optical quantum communication protocols such as teleportation and entanglement swapping require the generation of entangled photons. Quantum dots, with their on-demand generation and low unwanted multi-photon emission are excellent candidates to realize these protocols. However, finding quantum dots with near-perfect quantum optical properties remains challenging. Instead, in our work we demonstrate that it is possible to improve a quantum teleportation protocol by acting exclusively on the experimental setup. [1] Despite selecting a source with non-ideal figures of merit, we have been able to enhance the overall protocol fidelity. The obtained values agree with our developed model, taking the quantum dot properties into account. Our model provides predictive power for future source optimization. Reference: [1] F. Basso Basset, F. Salusti et al., npj Quantum Information 7, 7 (2021)

HL 19.3 Wed 10:15 H34

Time Dependent Redfield Dynamics of Semiconductor Quantum-Dot Molecules — •Steffen Wilksen, Isabell Hüllen, Frederik Lohof, and Christopher Gies — Institute for Theoretical Physics, University of Bremen, Bremen, Germany

Semiconductor quantum dots provide a promising platform for applications in quantum information technologies, like quantum repeaters, which enable secure quantum communication over long distances. Two quantum dots, seperated by a small tunneling layer, can be combined into so-called quantum dot molecules (QDMs) which exhibit properties similar to classical molecules. These properties can be tuned by applying an external electric field, which allows to perform switching operations on QDM-based qubits.

The QDM can not be treated in isolation, since the electron-phonon interaction plays a crucial role in the systems dynamics. We thus treat the QDM as an open quantum system coupled to the external phonon reservoir. The application of a time-dependent electric field not only changes the QDM's properties, but also the form of the electron-phonon interaction, which allows for a time dependent tuning of dissipative effects.

We investigate the behaviour of the system for different switching speeds of the electric field using a time-dependent Redfield master equation approach. Slow switching leads to predictable and controlled adiabatic behaviour but limits the clock rate of the quantum repeater, whereas fast switching allows for higher clock rates but leads to non-adiabatic behaviour.

HL 19.4 Wed 10:30 H34

Three-dimensional electrical control of the excitonic fine structure for a quantum dot in a cavity — •Martin Esmann[1,2], Hélène Ollivier[1], Priya Priya[1], Abdelmounaim Harouri[1], Isabelle Sagnes[1], Aristide Lemaître[1], Olivier Krebs[1], Loic Lanco[1], Daniel Lanzillotti-Kimura[1], and Pascale Senellart[1] — [1]Université Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies (C2N), Palaiseau, France — [2]Institut für Physik, Universität Oldenburg, Germany

The excitonic fine structure plays a key role for the quantum light generated by semiconductor quantum dots, both for entangled photon pairs and single photons [1]. Controlling the excitonic fine structure has been demonstrated using electric, magnetic, or strain fields, but not for quantum dots in optical cavities, a key requirement to obtain high source efficiency and near-unity photon indistinguishability [2]. Here, we demonstrate the control of the fine structure splitting for quantum dots embedded in micropillar cavities. We propose and implement a scheme based on remote electrical contacts connected to the pillar cavity through narrow ridges. Numerical simulations show that such a geometry allows for a three-dimensional control of the electrical field. We experimentally demonstrate tuning and reproducible canceling of the fine structure, a crucial step for the reproducibility of quantum light source technology.

[1] P. Senellart, G. Solomon, and A. White, Nature Nanotechnology 12, 1026 (2017). [2] R. Trotta et al. PRL 114, 150502 (2015). [3] H. Ollivier et al. arXiv:2112.00400.

HL 19.5 Wed 10:45 H34

Design study of electrically contacted quantum dot circular Bragg gratings — •Quirin Buchinger, Tobias Huber, and Sven Höfling — Technische Physik, Universität Würzburg, 97074 Würzburg, Germany

Recently, photonic quantum networks receive a lot research interest. Semiconductor quantum dots offer a local memory, utilizing single spins and are highly efficient single or entangled photon sources. Therefore, they are among suitable candidates for a scalable hardware platform for quantum networks. To enhance brightness and extraction efficiency the quantum dots are typically embedded into microcavities, here circular Bragg gratings. By incorporating the quantum dots into a diode structure they can be charged with a single electron or hole and thus generate a ground state spin qubit [1]. This provides opportunity for spin photon coupling [2]. To apply voltage to the quantum dot inside of a circular Bragg grating, bridges through the etched rings have to be leaved unetched as a path for the current to the central disc of the microcavity. We discuss different layouts of these bridges and their influence on cavity wavelength, quality factor and polarisation.

[1] Warburton, R., Nature Mater 12, 483-493 (2013)
[2] De Greve, K., et al. Nature 491, 421-425 (2012)

30 min. break

HL 19.6 Wed 11:30 H34

Influence of extended defects on the formation energy, hyperfine structure, and zero-field splitting of NV centers in diamond — Wolfgang Körner[1], •Daniel Urban[1], and Christian Elsässer[1,2] — [1]Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstr. 11, 79108 Freiburg, Germany — [2]University of Freiburg, Freiburg Materials Research Center (FMF), Stefan-Meier-Straße 21, 79104 Freiburg, Germany

We present a density-functional theory analysis of nitrogen-vacancy (NV) centers in diamond, which are located in the vicinity of extended defects, namely, intrinsic stacking faults, extrinsic stacking faults, and coherent twin boundaries on 111 planes in diamond crystals [1]. Several sites for NV centers close to the extended defects are energetically preferred with respect to the bulk crystal. This indicates that NV centers may be enriched at extended defects. We report the hyperfine structure and zero-field splitting parameters of the NV centers at the extended defects, which typically deviate by about 10% but in some cases up to 90% from their bulk values. Furthermore, we find that the influence of the extended defects on the NV centers is of short range: NV centers that are about three double layers (corresponding to ~ 6) away from defect planes already show bulklike behavior.

[1] W. Körner, D. F. Urban, and C. Elsässer, Phys. Rev. B 103, 085305 (2021).

HL 19.7 Wed 11:45 H34

Topological insulator based axial DC SQUID quantum interferometer structure — •Erik Zimmermann[1,2], Benedikt Frohn[1,2], Jan Karthein[1,2], Gerrit Behner[1,2], Abdur Rehman Jalil[1,2], Tobias Schmitt[2,3], Michael Schleenvoigt[1,2], Gregor Mussler[1,2], Peter Schüffelgen[1,2], Hans Lüth[1,2], Detlev Grützmacher[1,2,3], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany — [3]Peter Grünberg Institut (PGI-10), Forschungszentrum Jülich, 52425 Jülich, Germany

Three-dimensional topological insulators (TIs) form a new material class that may enable robust topological quantum computing when combining them with a superconductor by using so-called Majorana zero modes. Recently, Josephson junctions and SQUIDs using a TI as a weak link are investigated for interface characterization. We present the in-situ fabrication of an interferometer structure formed by an axial DC SQUID that is based on a ternary TI with a $Bi_{0.18}Sb_{1.82}Te_3$ composition. For the in-situ fabrication shadow mask techniques and selective area growth by molecular beam epitaxy are used. Furthermore, magnetotransport measurements are shown, revealing induced superconductivity in both Josephson junctions and an in-plane magnetic field dependent interference pattern corresponding to SQUID oscillations. Lastly, the Shapiro response of the device is investigated.

HL 19.8 Wed 12:00 H34

Top-down nanofabrication of silicon nanopillars hosting telecom photon emitters — •Nagesh S. Jagtap[1,2], Michael Hollenbach[1,2], Ciarán Fowley[1], Juan Baratech[1], Verónica Guardia-Arce[1], Ulrich Kentsch[1], Anna Eichler-Volf[1], Nikolay V. Abrosimov[3], Artur Erbe[1], ChaeHo Shin[4], Hakseong Kim[4], Manfred Helm[1,2], Woo Lee[4], Georgy V. Astakhov[1], and Yonder Berencén[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstrasse 400, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]Leibniz-Institut für Kristallzüchtung, 12489 Berlin, Germany — [4]Korea Research Institute of Standards and Science, 34113 Daejeon, Republic of Korea

Silicon, a ubiquitous material in modern computing, is an emerging platform for realizing a source of indistinguishable single-photons on demand. The integration of recently discovered single-photon emitters in silicon into photonic structures is advantageous to exploit their full potential for integrated photonic quantum technologies [1] [2]. Here, we show the integration of an ensemble of telecom photon emitters in a two-dimensional array of silicon nanopillars. We developed a top-down nanofabrication method, enabling the production of thousands of individual nanopillars per square millimeter with state-of-the-art photonic-circuit pitch, all the while being free of fabrication-related radiation damage defects. We found a waveguiding effect of the 1278 nm G-center emission along individual pillars accompanied by improved brightness, compared to that of bulk silicon.

HL 19.9 Wed 12:15 H34

Large hBN single-photon emitter arrays fabricated by capillary assembly — •Johann Adrian Preuss, Eduard Rudi, Johannes Kern, Robert Schmidt, Rudolf Bratschitsch, and Steffen Michaelis de Vasconcellos — University of Münster, Institute of Physics and Center for Nanotechnology, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Convenient and readily available quantum light sources are a crucial building block for quantum photonic technologies. Recently, single-photon emitters have been discovered in hexagonal boron nitride (hBN), which efficiently emit single photons even at room temperature. Controlling the positioning of nanocrystals hosting these light emitters is an important technique for the bottom-up fabrication of functional nanostructures. Here, we demonstrate the fabrication of mm^2-sized rectangular arrays formed by tens of thousands of hBN nanoplatelets [1]. Using capillary assembly, we arrange commercially available hBN nanopowder. Positioning yields of >95% are achieved on individual fields. We find stable and spectrally narrow quantum optical light emitters in 16% of the positions. Our preparation method opens the way for the combination of quantum light emitters in hBN with further fabrication steps for integrated photonic chips, which can provide thousands of single-photon sources at different emission energies.

[1] J. A. Preuß et al., 2D Materials 8, 035005 (2021)

HL 19.10 Wed 12:30 H34

Single-electron Shuttling by Si/SiGe Quantum Bus — •Ran Xue, Inga Seidler, Tom Struck, Simon Humphol, Tobias Hangleiter, Hendrik Bluhm, and Lars R. Schreiber — JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany

The electron-spin in gate-defined quantum dots in a Si/SiGe heterostructure is one of the most promising qubits for scalable quantum computing. Qubit gates beyond the error-correction threshold have been widely investigated, however, the long range coupling of qubits remains challenging. Here we study the feasibility of single electron shuttling by forming a propagating sinusoidal potential in a gate-defined 1-dimensional channel. A $99.42 \pm 0.02\%$ high single-electron shuttle fidelity over a distance of 420 nm has been demonstrated in our recent research. [1] It provides adiabatic movement of a quantum dot filled by a single electron representing the qubit. An extension to $10\,\mu m$ long devices is in progress. The number of control lines is intrinsically independent from the shuttle length, therefore, no additional scalability complexity regarding signal generation and wiring is expected. Our concept is compatible with industrial CMOS fabrication lines and ultimately might lead to transport spin qubit information without much loss of spin-coherence.

[1] Seidler, I. *et al.*, Conveyor-mode single-electron shuttling in Si/SiGe for a scalable quantum computing architecture. arXiv:2108.00879 (2021).

HL 19.11 Wed 12:45 H34

Device-Scale Modeling and Simulation of Solid State Spin-Qubit-Shuttles — •Lasse Ermoneit, Markus Kantner, and Thomas Koprucki — Weierstrass Institute for Applied Analysis and Stochastics (WIAS), 10117 Berlin, Germany

We develop a theoretical model and a numerical simulation framework for a spin-qubit shuttling device for coherent transfer of quantum information between remote arrays of gate-defined quantum dots. The goal is to provide a device-scale simulation environment that solves the Schrödinger wave packet propagation problem in the presence of specific disorder potentials inside the shuttling device. Time-dependent electrostatic potentials of the gate electrodes and perturbations are obtained as solutions of Poisson's equation. We present our modeling approach together with first simulations results and outline how methods of model order reduction and optimal control theory can be employed to find a solution that ensures a high transmission fidelity in the presence of dephasing.