TUE 2: Quantum Networks: Technologies

Time: Tuesday 14:15–16:15 Location: ZHG002

TUE 2.1 Tue 14:15 ZHG002

Quantum Dots for Quantum Networks — •Klaus D. Jöns — PhoQS Institute, CeOPP, and Department of Physics, Paderborn University

Germany has started more than a decade ago to invest in a platform-agnostic approach to quantum repeaters, funding multiple technological pathways, including semiconductor-based quantum dots as one of the brightest quantum light sources. I will highlight some of the remarkable achievements based on quantum dots and discuss the feasibility of on-demand generation of entangled photon pairs for quantum repeaters architectures that integrate external quantum memories. I will critically discuss bottlenecks and challenges to deploy quantum dots and put our results in a broader perspective.

TUE 2.2 Tue 14:30 ZHG002

Development of Site-Controlled Quantum Dot Arrays for Multicore-Fiber-Coupled Quantum-Communication Source Modules — •Martin Podhorský[1], Maximilian Klonz[1], Lux Böhmer[1], Sebastian Kulig[1], Phillip Manley[2], Martin Hammerschmidt[2], Stefan Link[3], Gunnar Böttger[3], Henning Schröder[3], Nikolay Ledentsov[4], Vitaly Shchukin[4], Sven Rodt[1], and Stephan Reizenstein[1] — [1]Institut für Physik und Astronomie, Technische Universität Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany — [2]JCMwave GmbH, Bolivarallee 22, 14050 Berlin, Germany — [3]Fraunhofer IZM, G.-Meyer-Allee 25, 13355 Berlin, Germany — [4]VI Systems GmbH, Hardenbergstr. 7, 10623 Berlin, Germany

Fiber-based optical quantum communication is emerging as a robust alternative for traditional secure data transfer. We propose a monolithic device in which classical and quantum communication channels can be realised simultaneously using semiconductor quantum dots embedded in resonant cavities. We report on growth of positioned InGaAs quantum dots via the buried stressor method, achieving high precision, uniformity and reproducibility of the quantum dot placement. A detailed statistical analysis shows controlled quantum dot density variation and positioning accuracy. Furthermore, we present a micro-manufactured glass holder design for a passive multicore-fiber-coupling process, enabling scalable, efficient, and practical utilisation in quantum communication networks.

TUE 2.3 Tue 14:45 ZHG002

Building Blocks for Hybrid Quantum Repeaters — •Marlon Schäfer, Tobias Bauer, Pascal Baumgart, Max Bergerhoff, Christian Haen, Dennis Herrmann, David Lindler, Jonas Meiers, Robert Morsch, Jürgen Eschner, and Christoph Becher — Universität des Saarlandes, Fachrichtung Physik, Campus E2 6, 66123 Saarbrücken

Large-scale quantum networks require the development of quantum repeaters capable of high-fidelity entanglement distribution over long distances. We report progress toward heterogeneous quantum repeater nodes that integrate solid-state and atomic platforms. Specifically, tin-vacancy (SnV) centers in diamond and trapped calcium ions ($^{40}Ca^+$) are employed as quantum memories, with quantum frequency conversion bridging their respective emission to the low-loss telecom band. We demonstrate frequency conversion of indistinguishable photons from SnV centers and $^{40}Ca^+$ ions, and present results on quantum interference between photons emitted by these systems. To evaluate performance under realistic conditions, we operate a 14 km-long urban fiber testbed with a stable frequency reference frame distributed over the fiber link. These results represent critical steps toward scalable, hybrid quantum repeater architectures.

TUE 2.4 Tue 15:00 ZHG002

Automated Large-Scale Characterization of Solid-State Color Centers for Quantum Communication — •Julian M. Bopp[1,2], Maarten H. van der Hoeven[1], Marco E. Stucki[1,2], Tommaso Pregnolato[1,2], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Ferdinand-Braun-Institut (FBH), 12489 Berlin, Germany

Extending quantum networks toward a global quantum internet requires the serial-production of standardized building blocks, including highly efficient spin-photon interfaces. Due to variations in the local environment of optically active solid-state spin qubits, like diamond color centers, their quality differs spatially across sample substrates. Consequently, all spin qubits have to be characterized thoroughly before incorporating them into quantum network building blocks. However, characterization experiments are time-consuming since they regularly involve addressing qubits manually with a confocal microscope.

Paving the way toward the deterministic fabrication of quantum network building blocks on the wafer scale, we present the fully automated large-scale characterization of such solid-state qubits employing a combined widefield and confocal microscope. Moreover, we employ means of artificial intelligence to classify hundreds of acquired spectra and second-order correlation functions. Our approach enables the automated selection of qubits that are best suitable for quantum networking and the statistical investigation of sample treatment effects on the qubits [1].

[1] E. Corte et al., Adv. Photonics Res. 3, 2100148 (2021)

TUE 2.5 Tue 15:15 ZHG002

Quantum networking with microfabricated atomic vapor cells — •Roberto Mottola, Gianni Buser, Suyash Gaikwad, and Philipp Treutlein — Universität Basel, Basel, Schweiz

Quantum memories for photons are building blocks of quantum networks. Memories implemented in hot alkali vapor are attractive as they operate due to their technological simplicity and have been proven to perform well in a multitude of figures of merit [1]. In [2] we report on an elementary, hybrid network interconnect. We combine a low-noise quantum memory implemented in hot Rb vapor based on electromagnetically induced transparency with a tailored downconversion source. By spin polarizing the atomic ensemble and exploiting polarization selection rules we were able to significantly reduce the noise of the memory. This allowed us to observe for the first time a non-classical $g^{(2)}_{ret}$ for photons stored and retrieved in a broadband, ground-state alkali vapor quantum memory - yielding a measured $g^{(2)}_{ret} = 0.177(23)$ well below the classical limit of 1. Realistic visions of large-scale networks require a scalable and mass-producible platform. In this respect, microfabricated vapor cells are very promising. MEMS fabrication techniques have already been successfully used to miniaturize atomic quantum sensors, as atomic clocks, magnetometers, and gyroscopes. We report on the first implementation of an alkali vapor memory in microfabricated Rb cells compatible with wafer-scale mass production [3] - a crucial step towards scalability. [1] C. Simon et al., *Eur. Phys. J. D* **58**, 1–22 (2010). [2] G. Buser et al., *PRX Quantum* **3**, 020349 (2022). [3] R. Mottola et al., *Phys. Rev. Lett.* **131**, 260801 (2023).

TUE 2.6 Tue 15:30 ZHG002

Evaluating Cavity-enhanced Telecom-wavelength Quantum Dot Single-photon Sources for Quantum Cryptography — •Robert Behrends[1], Koray Kaymazlar[1], Mareike Lach[1], Martin v. Helversen[1], Pratim Saha[1], Daniel Vajner[1], Jochen Knaupp[2], Yorick Reum[2], Tobias Huber-Loyola[2], Sven Höfling[2], Andreas Pfenning[2], and Tobias Heindel[1] — [1]Institute of Physics and Astronomy, Technische Univeristät Berlin, 10623 Berlin, Germany — [2]Technische Physik, Physikalisches Institut and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Great advances are made in the fabrication of telecom-wavelength quantum light sources based on semiconductor quantum dots (QDs)[1]. Yet, further progress is needed towards practical applications. Here, we evaluate QD-based single-photon sources for applications in quantum cryptography in the telecom C-band. Exploiting cavity-enhanced devices with embedded InAs/InAlGaAs QDs, we achieve emitter lifetimes of 500 ps and g(2)(0)=0.044 under pulsed quasi-resonant excitation. Employed in a quantum cryptography testbed, we investigate dynamic polarization-state encoding using a customized fiber-coupled electro-optic modulator in single-pass configuration, which is controlled by an arbitrary waveform generator. The random preparation of four polarization states with low loss and low quantum bit error ratio thereby is crucial for applications in quantum key distribution and beyond[2].

[1] Holewa et al., Nanophotonics, 10.1515/nanoph-2024-0747 (2025)
[2] Vajner et al., arXiv:2412.14993 (2024)

TUE 2.7 Tue 15:45 ZHG002

Integrated quantum network nodes — •Jonas C. J. Zatsch[1,2], Tim Engling[1,2], Jeldrik Huster[1,2], Louis L. Hohmann[1,2], Shreya Kumar[1,2], and Stefanie Barz[1,2] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology (IQST)

Quantum networks require both local quantum information processing and the transmission of quantum information across the network. Integrated photonic circuits are promising candidates for quantum nodes, as they offer a compact footprint and scalability, while optical fibres allow for low-loss transmission between such nodes. A key challenge is the transfer of quantum states generated or manipulated on-chip to the network; and vice versa. Here, we present a silicon-on-insulator integrated photonic circuit capable of high-fidelity preparation of two-qubit states, which can be transferred to optical networks. In turn, quantum states sent over an optical network can be analysed using the same chip. We demonstrate its functionality by preparing different two-qubit states on-chip and transferring them to fibres. Additionally, we show its reverse operation by using the chip as a two-qubit quantum state tomography unit for an off-chip prepared state. This bidirectional operation makes our chip a versatile platform for the implementation of quantum networked protocols.

TUE 2.8 Tue 16:00 ZHG002

Synchronization of remote Time Taggers for quantum communication applications — •Mickey Martini, Edoardo Mornacchi, Timon Eichhorn, Jan Bruin, and Mirco Kolarczik — Swabian Instruments GmbH, Stuttgart, Germany

Synchronous detection of photon events at large distances is a key enabler for quantum communication. While local Time Taggers reach a timing resolution below 2 ps, synchronization of Time Taggers on the scale of kilometers at a comparable resolution level is a challenge. The precise correlation between photon streams and characterization of single events within the stream allows for advanced filtering mechanisms that can target for suppression of background noise as well as for recognition of attacks on the communication channel. The impact of these approaches depends strongly on the effective timing resolution of the synchronized time-tagging system.

In this presentation, we give an overview of software components that contribute to a flexible and easy-to-use synchronization solution. As a first level of synchronization, we demonstrate the use of commercially available White Rabbit (WR) technology for clock distribution. WR promises sub-nanosecond accuracy (clock offsets) at picosecond precision (clock stabilization). We demonstrate that the additional jitter of such a system is below 4 ps. To handle the data from remote sites, we present a merging solution based on standard network protocols. Finally, we provide insights into the development of a second synchronization layer that aligns the photon streams.