Q 41: Quanteninformation: Atome und Ionen 1

Time: Thursday 10:30–12:30 Location: V7.02

Group Report Q 41.1 Thu 10:30 V7.02

An Elementary Quantum Network of Single Atoms in Optical Cavities — •Stephan Ritter, Christian Nölleke, Carolin Hahn, Andreas Reiserer, Andreas Neuzner, Manuel Uphoff, Martin Mücke, Eden Figueroa, Jörg Bochmann, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Quantum networks form the basis of distributed quantum computing architectures and quantum communication. Single atoms in optical cavities are ideally suited as universal quantum network nodes capable of sending, storing and retrieving quantum information. We demonstrate this by presenting an elementary version of a quantum network based on two identical nodes in remote, independent laboratories. The reversible exchange of quantum information and the creation of remote entanglement are achieved by exchange of a single photon. The dynamic control of coherent dark states allows for the generation of a single photon in one system, which we subsequently store at the other node. This process is used to coherently transfer arbitrary quantum states. We show how to create maximally entangled Bell states of the two atoms at distant nodes and characterize their fidelity and lifetime. The resulting nonlocal state is manipulated via unitary operations applied locally at one of the nodes. This cavity-based approach to quantum networking allows for the reversible exchange of quantum information and offers a clear perspective for scalability.

Q 41.2 Thu 11:00 V7.02

Scalable architecture for quantum information processing with atoms in optical micro-structures — •Malte Schlosser, Sascha Tichelmann, Moritz Hambach, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

The ability to synchronously investigate multi-component quantum systems in multi-site architectures is fostering some of the most active research in the investigation of ultra-cold atomic quantum gases and quantum information processing (QIP). For this purpose, we have introduced the application of micro-fabricated optical elements for atom optics and QIP with atoms.

We present recent progress towards the realization of a scalable architecture for QIP using neutral atoms in two-dimensional (2D) arrays of optical microtraps as qubit registers. This approach is simultaneously targeting the important issues of single-site addressability and scalability, and provides versatile configurations for quantum state storage, manipulation, and retrieval. We present the initialization and coherent one-qubit rotation of 2D registers of individually addressable qubits, the coherent transport of atomic quantum states in a scalable quantum shift register, the sub-Poissonian loading of 2D qubit registers with 0 or 1 atom, and discuss the feasibility of two-qubit gates in 2D architectures.

Q 41.3 Thu 11:15 V7.02

Towards the detection of single rare-earth ions in a solid state crystal — •Tobias Utikal[1], Lutz Petersen[2], Stephan Götzinger[2], and Vahid Sandoghdar[1] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Laboratory of Physical Chemistry, ETH Zurich, 8093 Zurich, Switzerland

Single rare-earth ions embedded in a solid-state matrix are promising building blocks in future quantum information processing schemes. Importantly, they provide long coherence times in the microsecond to millisecond regime and different optically addressable energy levels. In this work we investigate the optical properties of single trivalent praseodymium ions doped in an yttrium orthosilicate crystal which are excited by a frequency doubled Ti:Sapphire laser. The experiments are carried out at cryogenic temperatures (T = 4K) in order to eliminate phononic interactions with the host. Since the optical transitions take place within the 4f shell, which is shielded from the surrounding by the 5s and 5p orbitals, linewidths as narrow as a few kilohertz can be achieved. This, however, necessitates frequency stabilization of the excitation laser source to the kilohertz regime and appropriate detectors for low photon numbers. From optical ensemble measurements we derive important quantities such as the absorption cross-section and the saturation intensity. We present our progress towards the detection and spectroscopy of single ions.

Q 41.4 Thu 11:30 V7.02

An ion-photon quantum interface — •Andreas Stute[1], Bernardo Casabone[1], Piet O. Schmidt[2], Tracy E. Northup[1], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, A-6020 Innsbruck — [2]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [3]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Otto-Hittmair-Platz 1, A-6020 Innsbruck

In a quantum network, information has to be transferred between spatially separated sites via flying qubits in a coherent fashion. As stationary qubits, ions have proved to be ideal for state initialization, coherent manipulation and state readout. A promising candidate for a flying qubit is the polarization state of a single photon. In order to realize a coherent interface between a single ion and a single photon, we couple a single calcium ion to two orthogonal polarization modes of a high-finesse optical resonator. Applying bichromatic Raman transitions between the $S_{1/2}$ and $D_{5/2}$ manifolds of $^{40}Ca^+$, we are able both to address the qubit states of the ion and to generate single photons with a polarization that depends on the ion's final state. In this way, we generate entanglement between ion and photon with a fidelity suitable for implementation of a quantum repeater. Furthermore, both amplitudes and phase of the entangled state are completely controlled.

Q 41.5 Thu 11:45 V7.02

Single-Photon Absorption in a Single Ion Signaled by a Raman-Scattered Photon — •Christoph Kurz[1], Jan Huwer[1,2], Michael Schug[1], Philipp Müller[1], José Brito[1], Joyee Ghosh[1,2], and Jürgen Eschner[1,2] — [1]Experimentalphysik, Universität des Saarlandes, Saarbrücken, Germany — [2]Institut de Ciencies Fotoniques, Castelldefels (Barcelona), Spain

In the context of quantum networking with single atoms and single photons, we pursue the photon-to-atom quantum state transfer by controlled absorption of single photons in a single ion. In the present work we explore heralding the absorption by detecting a single Raman-scattered photon. We prepare a single cooled and trapped $^{40}Ca^+$ ion in the long-lived $D_{5/2}$ state. Illuminating it with light at 854 nm wavelength excites it to the short-lived $P_{3/2}$ level from where it decays (with 94% probability) to the $S_{1/2}$ ground state, releasing a single photon at 393 nm which we detect with sub-ns time resolution. Exploiting the quantum correlation between the initial state, the polarizations of the absorbed and emitted photons, and the final state, this method may serve as a single-photon memory. We will discuss the prospects of this application, when our resonant single-photon source at 854 nm is used [1].

[1] N. Piro et al., Nature Physics **7**, 17 (2011)

Q 41.6 Thu 12:00 V7.02

Observation of strong coupling of single atoms to a whispering-gallery-mode bottle microresonator — •Danny O'Shea[1], Christian Junge[1], Konstantin Friebe[1,2], Jürgen Volz[1], and Arno Rauschenbeutel[1] — [1]Vienna Center for Quantum Science and Technology, TU Wien – Atominstitut, Austria — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany

We describe our recent results demonstrating strong coupling between single rubidium atoms and a high-Q whispering-gallery-mode bottle microresonator. We observe clear signals of individual atoms passing through the resonator mode with interaction times on the order of several microseconds. Given this brief interaction time, we have implemented a real-time atom detection/probing scheme to enable experiments on this timescale. In particular, we investigate the light transmission and reflection characteristics of the strongly-coupled atom-resonator system. As an application of this system, we describe our progress towards the realization of a four-port device capable of routing photons between two optical nanofibers coupled to the resonator mode.

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Q 41.7 Thu 12:15 V7.02

Probing Quantum Superpositions of Ion Coulomb Crystals by

Ramsey Interferometry — •Jens Domagoj Baltrusch[1,2], Cecilia Cormick[1], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, Germany — [2]Grup d'Optica, Universitat Autònoma de Barcelona, Spain

Recent progress in the creation and manipulation of many-body states of ion Coulomb crystals demands for detection techniques not only of the electronic but also the motional quantum states. Such states are used as a resource for quantum information processing, and were proposed for simulating quantum many-body Hamiltonians [1] as well as for the creation of crystalline cat-states [2,3]. We examine Ramsey interferometry to probe ion Coulomb crystals in state-dependent potentials, and develop a quantum theory for evaluating the overlap of the quantum states of the crystal, which determines the contrast of the Ramsey fringes. We show that Ramsey interferometry can allow one to infer the details of the crystal dynamics at the linear-zigzag structural transition [4].

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[2] T. Pruttivarasin, M. Ramm, I. Talukdar, A. Kreuter, and H. Häffner, New J. Phys. **13**, 075012 (2011).
[3] J. D. Baltrusch, C. Cormick, G. De Chiara, T. Calarco, and G. Morigi, Phys. Rev. A **84**, 063821 (2011).
[4] G. Morigi and S. Fishman, Phys. Rev. E **70**, 066141 (2004).