Q 24: Quantum Information: Solid State Systems I

Time: Tuesday 14:30–16:15 Location: P 3

Group Report Q 24.1 Tue 14:30 P 3

Entanglement purification in an elementary quantum network — •Andreas Reiserer[1], Norbert Kalb[2], Peter C. Humphreys[2], Jacob J. W. Bakermans[2], Sten J. Kamerling[2], and Ronald Hanson[2] — [1]Quantum Networks Group, MPI für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]QuTech and Kavli Institute of Nanoscience Delft, Delft University of Technology, PO Box 5046, 2600 GA Delft, The Netherlands

Entanglement purification facilitates the generation of high-fidelity entangled states from an ensemble of resource states by eradicating a common statistical contamination. This will be essential for the realization of large quantum networks, in which stationary quantum nodes are connected via noisy photonic channels. Here, we show one round of entanglement purification in an elementary quantum network, consisting of two nodes that each contain two qubits. Using two-photon interference, we first generate entanglement between two of the qubits that are formed by the electronic spins of two nitrogen-vacancy centers in diamond at a separation of 2m. The electronic spin state is then transferred to two nuclear spins in close proximity to the NV centers. The resulting entangled nuclear spin state is kept while the electronic spins are entangled again. Then, the purification protocol is completed via local deterministic two-qubit quantum gates, followed by a fluorescence measurement of the electronic spins. Depending on the measurement result, the nuclear spins are projected to an entangled state of higher fidelity than the two raw states. Our results open the door towards the realization of larger quantum networks.

Q 24.2 Tue 15:00 P 3

Phase-controlled entanglement state generation between distant electron spins — •Lukas Huthmacher, Robert Stockill, Megan J. Stanley, Claire Le Gall, Clemens Matthiesen, and Mete Atatüre — Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge UK

Entanglement is one of the fundamental ingredients for the successful realisation of quantum networks and secure communication schemes. Here, we present the first experimental realisation of distant electron spin entanglement in semiconductor quantum dots. In our experiment, the two InGaAs quantum dots are incorporated in a Mach-Zehnder interferometer, allowing for phase-stable excitation and erasure of which path information. Upon detection of a single photon after the second beam-splitter the electron spins are projected into an entangled state [1]. We confirm the creation of entangled states with an average fidelity of 61.6 ± 2.3%, a violation of the classical limit by 5 standard deviations of the mean. We demonstrate active control over the phase of the entangled state through our choice of the interferometer phase. Combining the outstanding photonic properties of self-assembled quantum dots and the minimal heralding scheme we achieve an entanglement generation rate of 7.25 kHz, the highest reported to date.

[1] Cabrillo, C. et *al.*, PRA **59**, 1025-1033 (1999)

Q 24.3 Tue 15:15 P 3

Heralded control of quantum systems using single spins in diamond — •Durga Bhaktavatsala Rao Dasari, Johannes Greiner, S. Ali Momenzadeh, and Jörg Wrachtrup — 3. Physikalisches Institut, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany.

Steering the evolution of a complex many body system by a well controllable quantum system has applications in various quantum information protocols. Over the past decade a high degree control on the manipulation and measurement of electronic spins attached to single defect centers in diamond has been achieved. Additionally, a well-resolved optical spectrum at low temperatures allows these defect centers to act as good quantum optical systems. We show here how spin-selective optical excitation and readout of electron spins attached to the Nitrogen Vacancy center in diamond can be used to generate quantum correlations in an ensemble of spins, photons and also lead to near ground state cooling of a microcantilever.

Q 24.4 Tue 15:30 P 3

Sensing Weak Microwave Signals by Quantum Control — Timo Joas, •Andreas Waeber, Georg Braunbeck, and Friedemann Reinhard — Walter Schottky Institut and Physik-Department, Technische Universität München, Am Coulombwall 4, 85748 Garching

Solid state qubits, such as the nitrogen vacancy (NV) center in diamond, are attractive sensors for nanoscale magnetic and electric fields, owing to their atomically small size [1]. A major key to their success have been dynamical decoupling protocols (DD), which enhance sensitivity to weak AC signals such as the field of nuclear spins from a single protein [2]. However, those methods are currently limited to signal frequencies up to several MHz.

Here, we present a novel DD protocol specifically designed to detect weak fields close to the NV's transition frequency (≈ 2 GHz). Our scheme is a pulsed version of Autler-Townes spectroscopy [3] with improved spectral resolution. As a result, we demonstrate slow Rabi oscillations with a period up to $\Omega_{Rabi}^{-1} \sim T_2$ driven by a weak signal field. The corresponding sensitivity could enable various applications. Specifically, we consider detectors for radio-astronomy and ultrasound, as well as fundamental research on spin-phonon coupling.

[1] Taylor et al., Nature Physics 4 (2008) [2] Lovchinsky et al., Science 351 (2016) [3] Gordon et al., Appl. Phys. Lett. 105 (2015)

Q 24.5 Tue 15:45 P 3

Multi-qubit quantum memories for improved quantum sensing — •Nikolas Abt[1], Sebastian Zaiser[1], Philipp Neumann[1], Ville Bergholm[2], Thomas Schulte-Herbrüggen[2], and Jörg Wrachrup[1] — [1]3rd Institute of Physics, University of Stuttgart, Germany — [2]Department of Chemistry, Technical University Munich, Germany

Single nitrogen-vacancy (NV) centers in diamond are nanoscale quantum sensors for magnetic and electric fields and temperature, operating even under ambient conditions. Potential applications of such sensors are for example nuclear magnetic resonance (NMR) spectroscopy of nanoscopic samples [1] or steering and characterizing nuclear spin-based quantum simulators [2]. In a sense, NV centers are remote sensors, where the fluorescence response is the only channel to convey measurement results, which is classical information. Proximal ^{13}C nuclear spins couple strongly to the NV center's electron spin and constitute a quantum memory. Recently we have demonstrated the benefit of a single memory qubit for improving sensitivity of an NV center [3]. Here, we scale up the memory register and demonstrate the advantages of metrology information storage and processing for improved quantum sensing. For example, we apply the quantum Fourier transformation for high resolution NMR spectroscopy and obtain multi-bit measurement results.

[1] T. Staudacher, et al. Science 339, 561 (2013).
[2] J. Cai, et al. Nature Physics 9, 1683 (2013).
[3] S. Zaiser, et al. Nature Communications 7, 12279 (2016).

Q 24.6 Tue 16:00 P 3

Towards cavity-enhanced single rare earth ion detection — •B. Casabone[1,2], J. Benedikter[1], T. Hümmer[4], A. Ferrier[3], P. Goldner[3], T. Hänsch[1,4], H. de Riedmatten[2], and D. Hunger[5] — [1]Max Planck Institute of Quantum Optics, Garching — [2]ICFO, The Institute of Photonic Sciences, Castelldefels — [3]Chimie ParisTech, Paris — [4]Ludwig-Maximilians-Universität, München — [5]Karlsruhe Institute of Technology, Karlsruhe

Rare earth ions doped into solids provide outstanding optical and spin coherence properties, which renders them as promising candidates for quantum optical applications ranging from quantum memories to quantum-nonlinear optics. However, due to the dipole-forbidden nature of the coherent transitions, they couple only weakly to optical fields. This limits most experiments to macroscopic ensembles, where inhomogeneous broadening complicates and limits quantum control.

Here we present an approach to get efficient access to individual ions or small ensembles by coupling them to a high-Finesse optical microcavity. We employ fiber-based Fabry-Perot cavities[1] with high finesse and a free-space mode volume as small as a few λ^3 to achieve substantial Purcell enhancement. This offers the potential to boost the spontaneous emission rate by several orders of magnitude (up to 10^4), thereby making the weak transitions bright.

We report on the current status of our experiment, where we investigate $Eu3^+$:Y_2O_3 nanocrystals[2] coupled to a cavity in a cryogenic environment.

[1] Hunger, NJP 12, 065038 (2010) [2] Perrot, PRL 111, 203601 (2013)