HL 51: Focus Session: Hybrid Quantum-Dot / Atom Systems

Time: Wednesday 9:30–13:00 Location: POT 112

Invited Talk HL 51.1 Wed 9:30 POT 112

Coupling atomic and solid state quantum systems — •Val Zwiller — KTH, Stockholm, Sweden — TU Delft, Netherlands

Devices based on single quantum dots enable us to efficiently generate non classical states of light at frequencies in resonance with atomic transitions. We will report on the development of devices based on GaAs/AlGaAs quantum dots tuned in resonance with Rb transitions with the aim of demonstrating a hybrid quantum memory where single photons generated in the solid state are stored in atomic memories.

HL 51.2 Wed 10:00 POT 112

An atomic memory suitable for semiconductor quantum dot single photons — •Janik Wolters, Lucas Beguin, Andrew Horsely, Jan-Philipp Jahn, Richard Warburton, and Philipp Treutlein — Universität Basel

Quantum networks will consist of many quantum memory nodes that are interconnected via photonic links, transporting single photons carrying quantum information. In the future, such quantum networks may enable: high-speed quantum cryptography for unconditionally secure communication; large scale quantum computers; and quantum simulators that will allow for exponential speed-up in solving specific complex problems. A promising route towards functional quantum networks is the heterogeneous approach, where different and separately optimized physical systems are used for single photon generation and storage. For example semiconductor quantum dots may be used as efficient, fast and deterministic single photon sources, while atomic ensembles allow for efficient storage of these photons.

We demonstrate a photonic memory in hot Rb vapor with on-demand storage and retrieval. In principle the memory is suitable for storing single photons emitted by an GaAs droplet quantum dot. Operation of the memory is demonstrated using attenuated laser pulses. For pulses with a bandwidth of ~ 100 MHz $\sim 0.5\mu$eV we achieve $\sim 25\%$ storage and retrieval efficiency, while the storage time approaches 1 μs. The developed quantum memory might become a cornerstone for future hybrid quantum dot-atom based quantum networks.

HL 51.3 Wed 10:15 POT 112

Generation of single photons with tailored waveforms using a quantum dot emitting at the Rb D2 line — •Jan-Philipp Jahn[1], Lucas Béguin[1], Janik Wolters[1], Mathieu Munsch[1], Yongheng Huo[2], Fei Ding[3], Rinaldo Trotta[2], Markus Reindl[2], Oliver G. Schmidt[3], Armando Rastelli[2], Philipp Treutlein[1], and Richard J. Warburton[1] — [1]University of Basel, CH-4056 Basel, Switzerland — [2]Johannes Kepler University Linz, A-4040 Linz, Austria — [3]IFW Dresden, D-01069 Dresden, Germany

Semiconductor quantum dots are excellent single photon sources, providing triggered single photon emission at a high rate and with high spectral purity. Independently, atomic ensembles have emerged as one of the best quantum memories for single photons, providing high efficiency storage and long memory lifetimes. We have recently demonstrated the emission of high quality photons from a single droplet quantum dot emitting at the Rb D2 transition [1]. However, there is a significant mismatch between the large bandwidth of the quantum dot photons and the relatively small bandwidth of a Rb ensemble. We present here a route to creating photons with a tailored waveform by exploiting a long-lived hole spin in a droplet quantum dot. The quantum dot spin is prepared in one of the spin states and is then driven into the other spin state by a control laser whose waveform determines the waveform of the photon. We demonstrate the creation of $10-100$ ns duration waveforms with single-photon character thereby overcoming the bandwidth mismatch.

[1] J.-P. Jahn *et al.*, Phys. Rev. B **92**, 245439 (2015)

HL 51.4 Wed 10:30 POT 112

Electrically-pumped wavelength-tunable GaAs quantum dots interfaced with rubidium atoms — •Huiying Huang[1], Rinaldo Trotta[1], Yongheng Huo[1], Thomas Lettner[1], Johannes Wildmann[1], Javier Martín-Sánchez[1], Daniel Huber[1], Marcus Reindl[1], Jiaxiang Zhang[2], Eugenio Zallo[3], Oliver Schmidt[2], and Armando Rastelli[1] — [1]Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Linz, Altenbergerstraße 69, 4040, Austria — [2]Altenbergerstr. 69 — [3]Paul-Drude-Institut für Festkörperelektronik Hausvogteiplatz 5-7, 10117 Berlin, Germany

The combination of semiconductor quantum-dots (QDs) and natural atoms may allow storing the state of single photons emitted from a QD in atomic vapors, which has the potential to become crucial ingredients for building up a quantum repeater. To achieve such interface, the QD emission has to be precisely tuned to atomic lines. In this talk, I will introduce the first light-emitting-diode based on single GaAs/AlGaAs QDs and demonstrate its operation as an energy-tunable source of photons with wavelength in resonance with the D2 transitions of 87Rb atoms. This device is a compact and completely electrically-driven source of non-classical light in which both the excitation and tunability are provided on-chip. By feeding the emitted photons into a 75-mm-long cell containing warm 87Rb atom vapor, we observe slow-light with a temporal delay of up to 3.4 ns. In view of the possibility of using 87Rb atomic vapors as quantum memories, this work makes an important step towards the realization of hybrid-quantum systems for future quantum networks.

Invited Talk HL 51.5 Wed 10:45 POT 112

Strain-tunable quantum dots interfaced with atomic vapors — •Rinaldo Trotta — Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Altenbergerstrasse 69, 4040, Austria

The development of quantum networks for the distribution of quantum information among distant parties will bring about a revolution in communication science and technology. Addressing this task successfully will most likely require merging different quantum systems, where the advantages of the different constituents are combined. Hybrid natural-atomic interfaces between semiconductor quantum dots (QDs) and atomic vapors are currently emerging as a promising route for quantum networking. However, coupling the two physical systems requires several outstanding challenges to be overcome. One challenge is to match the energy of the single and entangled photons emitted by QDs to absorption lines of the atomic vapors. In this talk, I will discuss how external strain fields provided by piezoelectric actuators can be used to address this task successfully [1,2,3]. In particular, I will show how full control over the QD in-plane strain tensor allows the energy of the entangled photons emitted by QDs to be precisely controlled in the spectral range in which a cloud of natural atoms behaves as a slow-light medium.

[1] J. S. Wildmann et al., Phys. Rev. B 92, 235306 (2015) [2] H. Huang et al., arXiv:1602.02122 [3] R. Trotta et al., Nature Comm. 7, 10375 (2016).

Coffee Break

Invited Talk HL 51.6 Wed 11:45 POT 112

Atomic-vapor-enabled variable optical delay for triggered single-photons from a semiconductor quantum dot — •Hüseyin Vural[1], Jonas Weber[1], Markus Müller[1], Simon Kern[1], Julian Maisch[1], Matthias Widmann[2], Robert Löw[3], Jörg Wrachtrup[2], Ilja Gerhardt[2], Simone Portalupi[1], Michael Jetter[1], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]3. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [3]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

Beside their enormous flux, quantum dots (QDs) allow for high photon indistinguishability and photonic entanglement generation, and their use as flying qubits for the quantum communication of the future. One limitation of QDs is the missing long lasting quantum memory. Here, we focus on the approach of storing light in an cesium (Cs)-vapor by slowing down single photons. High dispersion between ground-state hyperfine resonances of Cs-vapors enables lower group velocities, while maintaining transmission. Using a Cs-vapor as slow light-medium, we present a variable delay up to several ns for photons from resonantly excited QD's. Increasing the temperature in the vapor changes the dispersion, which allows us to control the amount of delay experienced by the photons. Eventually we investigate and compare the single-photon emission and two-photon interference of delayed and undelayed photons.

HL 51.7 Wed 12:15 POT 112

Relaxation of gate-controlled donor qubits in silicon — Peter Boross[1], Gabor Szechenyi[1], and •Andras Palyi[2] — [1]Eotvos University, Budapest, Hungary — [2]Budapest University of Technology and Economics, Hungary

Gate control of donor electrons near interfaces is a generic ingredient of donor-based quantum computing. Here, we address the question: how is the phonon-assisted qubit relaxation time T_1 affected as the electron is shuttled between the donor and the interface? We focus on the example of the 'flip-flop qubit' (Tosi et al arXiv:1509.08538v1), defined as a combination of the nuclear and electronic states of a phosphorus donor in silicon, promising fast electrical control and long dephasing times when the electron is halfway between the donor and the interface. We theoretically estimate that the flip-flop qubit relaxation time can be of the order of 100 μs, 8 orders of magnitude shorter than the value for an on-donor electron in bulk silicon, and a few orders of magnitude shorter (longer) than the predicted inhomogeneous dephasing time (gate times). This relaxation process is boosted by (i) the nontrivial valley structure of the electron-phonon interaction, and (ii) the different valley compositions of the involved electronic states. Reference: P. Boross et al., Nanotechnology 27, 314002 (2016)

Invited Talk HL 51.8 Wed 12:30 POT 112

Correlating independent spins via single-photon projections — •Mete Atature — Cavendish Laboratory, University of Cambridge, JJ Thomson Ave., Cambridge CB3 0HE UK

Optically active spins confined in solids provide interesting and rich physical systems. Their inherently mesoscopic nature leads to a multitude of dynamics within the solid state environment of spins, charges, vibrations and light. Implementing a high level of control on these constituents and their interactions with each other creates exciting opportunities for realizing stationary and flying qubits within the context of spin-based quantum information science. In particular, coherent single photon generation together with improving spin coherence allows for generating nonlocal correlations between distant spins at a very high rate. I will provide a snapshot of the progress and challenges for quantum optically interconnected solid-state spins.