32nd SFB FoQuS meeting: Lists of abstracts

Thursday, April 7th

Hugues de Riedmatten
ICFO, Barcelona

Solid-state spin-wave photonic quantum memories

Rare-earth (RE) doped crystals are promising candidates as quantum memories for light as they offer coherence properties comparable to those of atomic systems, but free of the drawbacks deriving from atomic motion. The research on RE based quantum memories has been so far mostly focused on the mapping of photonic quantum bits to optical collective excitations, but this leads to short lived and mostly pre-determined storage. However, some RE ions, as Praseodymium and Eu, exhibit the suitable energy level scheme, with three long-lived hyperfine ground states, to enable the spin-wave storage by transferring the collective optical excitations into collective spin excitations. In this talk, I will review our recent and current efforts towards the realization of a long-lived on-demand quantum memory for photonic qubits in a solid-state environment based on a Praseodymium doped crystal. This includes the first demonstration of a spin-wave quantum memory for time-bin qubits [1], the demonstration of a novel memory protocol based on stopped light in spectral holes [2] and a new approach for integrated optical memories based on laser written waveguides [3]. I will also describe the challenges and recent progress towards the storage and retrieval of quantum light states in solid-state spin-waves.

References

[1] M. Gündoğan, et al., Phys. Rev. Lett. **114**, 230501 (2015).
[2] K. Kutluer, et al, arXiv:1509.03145 (2015).
[3] G. Corrielli, et al, arXiv:1512.09288 (2015).

Daniel Hümmer
IQOQI, Innsbruck

Towards trapping of neutral atoms in dispersion-force potentials

Over the last decades, physicists have achieved fine experimental control over atom gases, single atoms, and even nanoscale bodies isolated in vacuum using electromagnetic fields, and gained detailed theoretical understanding of the interactions between photons and atoms that allow such manipulations. Today, there is a growing interest in taking the next step: to trap and study particles close to surfaces. There are, for example, ideas (1) to optimize the coupling to optical systems like waveguides, (2) to miniaturize setups down to a “lab on a chip”, or (3) to measure dispersion forces and gravity at very short distances. Canonical magneto-optical traps, however, quickly reach their limits since they are overcome by (usually attractive) surface-induced dispersion forces at small particle-surface separations, causing the loss of the trapped particles. This has given rise to the idea of exploiting dispersion forces themselves to localize particles close to surfaces. Stable, static dispersion-force levitation of dielectric bodies is not straightforward [1]. Current proposals and experiments rely on suitable media [2,3], or on external fields [4] to to attain repulsive dispersion forces and enable levitation or trapping.

We report on work in progress concerning the possibility of trapping neutral atoms in vacuum close to a surface, without applying external fields. As a first proof-of-principle, we consider a two-level atom in the vicinity of a perfectly reflecting wire or thin cylinder: The atom experiences an attractive dispersion force, countered only by the Pauli repulsion that prevents penetration of the wire. These forces give rise to radially bound states, trapping the atom in lateral direction through the presence of the wire alone. We will further discuss the possibility to load these states from an atom beam, and outline some important next steps.

References
[1] Rahi et al., Phys. Rev. Lett. **105**, 070404 (2010).
[2] Munday et al., Nature **457**, 170 (2009).
[3] Rahi, Zaheer, Phys. Rev. Lett. **104**, 070405 (2010).
[4] Chang et al., Nat. Commun. **5**, 4343 (2014).

Raisa Trubko
Atominstitut, TU Vienna

Tune-Out Wavelength Measurements with Atom Interferometry

A tune-out wavelength for Potassium atoms was measured with sub-picometer precision using a Mach-Zehnder atom beam interferometer built with nanogratings. A multi-pass optical cavity was used as an interaction region to increase the magnitude of atom interference fringe phase shifts induced by light near a tune out wavelength.

Tune-out wavelengths are associated with roots in the dynamic polarizability, and can be experimentally observed as zero-crossings in the light-induced phase shift spectra. Precision measurements of tune-out wavelengths serve as a benchmark test of atomic structure calculations and can be used to report ratios of atomic transition dipole matrix elements. Systematic errors can arise from broadband light and also from the Earth's rotation. We demonstrate ways to minimize such errors. We also demonstrated ways to use laboratory measurements of tune-out wavelengths as a novel read-out mechanism for an atom interferometer gyroscope.

Adèle Hilico
Atominstitut, TU Vienna

Nonreciprocal optical elements based on chiral light-matter interaction

Nanophotonic components confine light at the wavelength scale and enable the control of the flow of light in an integrated optical environment. The strong confinement leads to an inherent link between the local polarization of the light and its propagation direction - the light obtains a chiral character - and thereby fundamentally alters the physics of light-matter interaction [1]. We employ this effect in order to investigate the realization of novel nonreciprocal optical devices that operate at the single-photon level. For this purpose, we use a single spin-polarized ^{85}Rb atom that is strongly coupled to a novel type of whispering-gallery-mode microresonator - a so-called bottle microresonator [1] - which is interfaced by two optical nanofibers. These resonators offer the advantage of being fully tunable and provide very long photon lifetimes in conjunction with near lossless coupling to the nanofibers. This renders them ideal for the investigation of nonreciprocal light propagation based on chiral light-matter interaction.

Coupling one nanofiber to the bottle microresonator, we studied the on-resonance performance of the system and observed a strong imbalance between the transmissions in forward and reverse direction of 13 dB [2]. This realizes an optical diode whose directional behavior is controlled by the internal state of a single atom. By interfacing the bottle microresonator with two nanofibers we extended this system to a 4-port device, where photons are nonreciprocally directed from one fiber port to the next. In contrast to the diode such an optical circulator is based on a non-dissipative process and thus can be used in quantum information protocols. In my talk I will explain the underlying principles of such an optical circulator and present our latest experimental results.

References
[1] C. Junge et al., Phys. Rev. Lett. 110, 213604 (2013).
[2] C. Sayrin et al., Phys. Rev. X 5, 041036 (2015).

Ralf Riedinger
University of Vienna

Nonclassical Photon-Phonon Correlations in a Nanomechanical Resonator

In modern quantum science, it is a key capability to interface quantum devices with single photons, thereby permitting various techniques of manipulation and long-distance distribution of quantum information. Here, we report the observation of non-classical correlations between single photons and phonons from a nanomechanical resonator. A full quantum protocol involving initialization of the resonator in its quantum ground state of motion and subsequent generation and readout of correlated photon-phonon pairs is demonstrated. The observed violation of a Cauchy-Schwarz inequality is clear evidence for the nonclassical nature of the generated mechanical state. Our results show the availability of on-chip solid-state mechanical resonators as light-matter quantum interfaces.

Alexey A. Melnikov
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Coherent controlization using transmon qubits

Coherent controlization is a process by which an arbitrary (priori unspecified, or “unknown”) operation on subsystems is coherently conditioned on the state of a control qubit. This process is important for flexible implementation of many quantum subroutines and plays a pivotal role in the flexible construction of the quantum-enhanced deliberation of learning agents in the context of the projective simulation model for artificial intelligence [1,2]. The practical realization of coherent controlization requires an auxiliary system in addition to the control and target qubits. However, the details of the implementation depend on the nature of the ancilla system and the type of qubit used. Here, we propose a method that allows coherent controlization in a register of superconducting transmon qubits coupled to an auxiliary microwave resonator [3].

References

[1] H.J. Briegel and G. De las Cuevas, Sci. Rep. **2**, 400 (2012).
[2] A.A. Melnikov, et al., Artif. Intell. Res. **3**, 3 (2014).
[3] N. Friis, et al., Sci. Rep. **5**, 18036 (2015).

Friday, April 8th

Johannes Fink
IST Austria, Klosterneuburg

Quantum electro-opto-mechanics on dielectric nanomembranes

Superconducting circuits are at the focus of quantum engineering research because of their potential for scalable quantum information processing and simulation. One disadvantage of circuit QED systems is that they can only operate in ultra-cold environments where thermal noise and resistive losses are negligible. We are working towards an on-chip integrated microwave-photonic device, that has the potential to efficiently convert microwave to telecom wavelength photons using radiation pressure forces. Utilizing compact ultra-high impedance LC circuits suspended on dielectric nano-membranes enables efficient coupling to the mechanical modes of one dimensional acoustic bandgap nanobeam resonators compatible with nano-photonics. With this new platform we demonstrate motional ground state cooling of the dielectric beam's fundamental mode, as well as mechanically mediated efficient microwave frequency conversion over 2 GHz.

Our most recent generation of devices is based on commercial silicon on insulator substrate where we just started to integrate superconducting qubits. This system should allow to synthesize and manipulate acoustic quantum states without the need for active cooling. Coupling these excitations to mechanical wave guides, entanglement between itinerant multi-phonon states could be studied in analogy to quantum optical systems. Coupling to photonic crystals on the other hand would put within reach the realization of hybrid long distance quantum communication networks.

Mario Krenn
IQOQI, Vienna

Automated Search for new Quantum Experiments

Quantum mechanics predicts a number of, at first sight, counterintuitive phenomena. It therefore remains a question whether our intuition is the best way to find new experiments. Here, we show the development of the computer algorithm Melvin which is able to find new experimental implementations for the creation and manipulation of complex quantum states. Indeed, the discovered experiments extensively use unfamiliar and asymmetric techniques which are challenging to understand intuitively. The results range from the first implementation of a high-dimensional Greenberger-Horne-Zeilinger state, to a vast variety of experiments for asymmetrically entangled quantum states—a feature that can only exist when both the number of involved parties and dimensions is larger than 2. Additionally, new types of high-dimensional transformations are found that perform cyclic operations. Melvin autonomously learns from solutions for simpler systems, which significantly speeds up the discovery rate of more complex experiments. The ability to automate the design of a quantum experiment can be applied to many quantum systems and allows the physical realization of quantum states previously thought of only on paper.

References

[1] Mario Krenn et al., Phys. Rev. Lett. **116**, 090405 (2016).

Stephan Götzinger
MPI Erlangen, Germany

Efficient Generation and Manipulation of Photons with Single Molecules

Novel concepts aiming at an efficient processing of information require a strong and controlled coupling of single photons with single atomic quantum systems. In this talk I will first give an introduction into the efficient generation of single photons using planar dielectric antennas. These antennas serve to direct

the emission from an arbitrarily oriented single quantum emitter with >99% efficiency towards a collection optics.
In the second part of the talk I will discuss our efforts towards the realization of quantum networks and present experiments where photons and single solid state emitters strongly interact. A single molecule can amplify a weak laser beam and generate nonlinear effects like three-photon amplification and four-wave mixing. In order to achieve an even stronger interaction we have started to implement various approaches including waveguides and microcavities.

Andreas Schindewolf
University of Innsbruck

Creation of RbCs Feshbach molecules in an optical lattice with high filling fraction

Ultracold dipolar systems are of high interest for quantum chemistry, precision spectroscopy, quantum many-body physics, and quantum simulation. The goal of our project is to prepare an ultracold sample of dipolar RbCs ground-state molecules in an optical lattice with a high filling factor. To this end, atomic Rb and Cs samples are mixed in an optical lattice to efficiently form Rb-Cs atom pairs as precursors to ground-state molecules. The basic idea is to go through the superfluid-to-Mott-insulator phase transition twice, first for Cs to create a sample with single-site occupancy, then for Rb on top of Cs to create a homogenous distribution of atom pairs.
We investigate the transport properties of superfluid Rb samples while they are moved on top of a strongly interacting sample of Cs atoms. Overlapping is realized in the vicinity of a Feshbach-resonance zero crossing to tune the interspecies interactions. Our experiments show that atom-pair formation is optimized for nulled interactions. We estimate the filling fraction to be 30% in the center of our trap.