Q 66: Quantum Effects: QED III

Time: Friday 11:00–12:45 Location: f442

Group Report Q 66.1 Fri 11:00 f442

High finesse Fabry-Perot fiber resonators for efficient photonic interfacing: optimal mode-matching and stabilization

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In recent years optical Fabry-Perot fiber resonators have been used in an increasing number of scientific applications. Due to their small resonator mode volume and their intrinsic fiber coupling these resonators, for example, are employed as efficient interfaces between single optical photons and a wide range of quantum systems, including cold atoms, ions and solid state emitters, as well as in quantum opto-mechanical experiments. Here we address some important practical questions that arise during the experimental implementation of high finesse fiber cavities: How can optimal fiber cavity alignment be achieved and how can the individual mode matching efficiencies be characterized? How should optical fiber cavities be constructed and to fulfill their potential for miniaturization and integration into robust devices? To answer the first question, we present an analytic mode matching calculation that relates the alignment dependent fiber-to-cavity mode-matching efficiency to the dip in the reflected light power at the cavity resonance. The latter question we explore by investigating a novel, intrinsically rigid fiber cavity design that makes use of the high passive stability of a monolithic cavity spacer and employs thermal self-locking and external temperature tuning. Finally, we also discuss the issue of fiber-generated background photons in fiber Fabry-Perot cavities.

Q 66.2 Fri 11:30 f442

Nonreciprocal light propagation based on chiral interaction of light and matter

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Nanophotonic components confine light at the wavelength scale and enable the control of the flow of light in an integrated optical environment. Such strong confinement leads to an inherent link between the local polarization of the light and its propagation direction and fundamentally alters the physics of light-matter interaction [1]. We employ this effect to demonstrate low-loss nonreciprocal transmission of light at the single-photon level through a silica nanofiber. For this purpose, we use a single spin-polarized atom that is strongly coupled to the nanofiber via a whispering-gallery-mode resonator [1]. These resonators provide very long photon lifetimes and near lossless in- and out-coupling of light via tapered fiber couplers. This renders them ideal for the investigation of nonreciprocal light propagation based on chiral light-matter interaction. In a first experiment, we study the on-resonance performance of the system and observe a strong imbalance between the transmissions in forward and reverse direction of 13 dB while the forward transmission still exceeds 70% [2]. The resulting optical isolator exemplifies a new class of nanophotonic devices based on chiral interaction of light and matter, where the state of single quantum emitters defines the directional behavior.

[1] C. Junge et al., Phys. Rev. Lett. 110, 213604 (2013).
[2] C. Sayrin et al., arXiv 1502.01549 (2015).

Q 66.3 Fri 11:45 f442

Towards strong ion-photon coupling in an ion-trap fiber-cavity apparatus

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Quantum networks offer a compelling solution to the challenge of scalability in quantum computing. With atoms coupled to optical cavities it is possible to build up quantum interfaces between stationary and flying qubits in a quantum network. By using fiber-based optical cavities, we expect to reach the strong coupling regime of cavity quantum electrodynamics with single trapped ions. This regime allows higher fidelity and efficiency in protocols for quantum interfaces.

The challenge in integrating fiber cavities with ion traps is that the dielectric fibers should be far enough from the ions so that they do not significantly alter the trap potential. However, with our previous fiber-mirror machining process, cavity lengths were limited to about 250 μm due to deviations from the mirrors' ideal spherical shape. Therefore, we have developed new CO_2-laser ablation techniques for the fiber facets. With the resulting fibers, we have constructed fiber cavities with finesses up to 70,000 at a length of 550 μm. To integrate these fiber cavities with ions, we have built a new miniaturized calcium ion trap in the "Innsbruck" linear design.

Q 66.4 Fri 12:00 f442

Collective behaviour of spins in waveguide networks

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We investigate a strongly correlated system of light and matter inside a two dimensional array of optical waveguides. We formulate an effective Hamiltonian for two-level atoms coupled to cavity modes and sourced by an external laser field. We perform large scale quantum Monte Carlo simulations and analytical calculations of the ground state properties of the system. We show the phase diagram for interacting atomic spins and cavity modes together with results obtained in a dispersive regime where the cavity field has been eliminated, leading to an effective spin-spin Hamiltonian. We also discuss the properties of the system in geometries with frustrated interactions.

Q 66.5 Fri 12:15 f442

Localization transition in presence of cavity backaction

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We study the localization transition of an atom in a bichromatic lattice, when the depth of the second, incommensurate lattice depends on the spatial wave function of the atoms. This situation can be realised when the second potential is the standing wave of a high-finesse cavity, which strongly couples with the atom in the dispersive regime and whose wavelength is incommensurate with the wavelength of the confining optical lattice. By means of a mapping to a Hubbard type Hamiltonian, we identify the extended and the localised phases of the atom as a function of the strength of the cavity nonlinearity and of the depth of the second lattice, and show that the cavity nonlinearity preserves the main properties of the localization transition. We discuss possible experimental realizations in recent cavity electrodynamics experiments.

Q 66.6 Fri 12:30 f442

Nanofriction and cooling in cavity QED

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I will describe the process of self-organisation of ions in an optical cavity due to the interplay between the Coulomb forces of the ions and the optical forces from the cavity. This can be described in the language of the well known Frenkel-Kontorova model whereby tuning the depth of the cavity lattice one can realise structural transitions. As the depth of this lattice is increased the ions undergo a transition, from a sliding frictionless phase to a pinned phase with increasing static friction, once the strength of the lattice exceeds a critical point. As a consequence of the ion-cavity coupling there is an associated back-action of the ions on the cavity field which establishes a long range interaction between the ions changing the nature of the transition. The cavity field can also act as a tunable reservoir which may cool the ion chain through the coupling of the cavity and ion fluctuations. We show how this can be tuned by changing the cavity detuning and the structural phase of the crystal to achieve sub-Doppler cooling of the chain. Observation of these effects is proposed by utilising the spectrum of the cavity output field.