Intersectional Symposium Cavity meets Circuit Quantum Electrodynamics (SYQE)

lead by the Low Temperature Physics (TT)

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In Cavity and Circuit Quantum Electrodynamics (QED) experiments, the interaction of natural and artificial solid state atoms with quantized electromagnetic fields is studied on the most fundamental level. Recently, tremendous progress has been made in these fields, allowing for experiments which can be considered modern realizations of the thought experiments imagined by Bohr and Einstein to test the fundamental concepts of quantum theory. The symposium aims to highlight the recent breakthroughs in both cavity and circuit QED, resulting from joint efforts in the quantum optics and solid state community.

Overview of Invited Talks and Sessions

(lecture room HSZ 01)

Invited Talks

SYQE 1.1	Fri	10:30–11:00	HSZ 01	**The driven Jaynes-Cummings system: from atoms and cavities to circuits** — •Howard Carmichael
SYQE 1.2	Fri	11:00–11:30	HSZ 01	**Light shifts of ground-state quantum beats in Cavity QED, a consequence of quantum jumps.** — •Luis Orozco
SYQE 1.3	Fri	11:30–12:00	HSZ 01	**Tomography and Correlation Function Measurements of Propagating Microwave Photons** — •Andreas Wallraff
SYQE 1.4	Fri	12:00–12:30	HSZ 01	**Artificial atom in 1D open space** — •Yasunobu Nakamura
SYQE 1.5	Fri	12:30–13:00	HSZ 01	**Quantum dot based bright sources of quantum light.** — •Pascale Senellart, Adrien Dousse, Jan Suffczynski, Vivien Loo, Steffen Michaelis de Vasconcellos, Olivier Gazzano, Loic Lanco, Aristide Lemaitre, Isabelle Sagnes, Alexios Beveratos, Olivier Krebs, Jacqueline Bloch, Paul Voisin

Sessions

SYQE 1.1–1.5	Fri	10:30–13:00	HSZ 01	**Cavity meets Circuit Quantum Electrodynamics**

SYQE 1: Cavity meets Circuit Quantum Electrodynamics

Time: Friday 10:30–13:00 Location: HSZ 01

Invited Talk SYQE 1.1 Fri 10:30 HSZ 01

The driven Jaynes-Cummings system: from atoms and cavities to circuits — •Howard Carmichael — University of Auckland, Private Bag 92019, Auckland, new Zealand

The Jaynes-Cummings Hamiltonian models the interaction of a qubit and a single mode of the electromagnetic field. Adding an external field and dissipation defines the driven Jaynes-Cummings system. Through two decades of exciting development this elementary model has come to form a bridge between a wide array of experiments, all focused on the quantum mechanics of photons, their manipulation and control: qubits are realized with Rydberg atoms, optical transitions in atoms and quantum dots, and Josephson junction devices; electromagnetic fields in microwave cavities or striplines, optical cavities, and photonic crystals are considered. I review highlights from this history, following the trajectory from experiments with thermal atomic beams and optical cavities to those with superconducting circuits. The driven Jaynes-Cummings system is presented as an example of an open quantum system that carries the physics of photon interactions from microwave to optical frequencies, from two-state atoms to the Cooper-pair box, while accounting for the central importance of interactions between these elements and their environment.

Invited Talk SYQE 1.2 Fri 11:00 HSZ 01

Light shifts of ground-state quantum beats in Cavity QED, a consequence of quantum jumps. — •Luis Orozco — Joint Quantum Institute, Department of Physics and National Institute of Standards and Technology, University of Maryland, College Park, MD 20742

We present a study of ground-state light shifts with weak coherent excitation when the light is quasi-resonant with an electronic excited state of Rb (within a linewidth). This mechanism is only discernible through the polarization mode selection (drive V, measure H) available in cavity QED and the ground-state quantum beats, seen through correlation measurements on the H mode. The shift requires the presence of spontaneous emission, which generally preserves the ground-state coherence but induces a significant frequency shift with the presence of even a single photon.

Quantum trajectories show that quantum jumps on the driven V mode that happen in-between H detections cause phase shifts on the Larmor precesion. Quantum jumps interrupt the atomic dipole and transfer the differential phase accumulated by the excited state to the ground state. The stochastic process of the quantum jumps produces both a frequency shift, if the phase jumps are frequent but small compared to π, and a broadening from the phase diffusion process.

Work performed with Adres D. Cimmarusti, David G. Morris, Pablo Barberis-Blostein and H. J Carmichael with support from NSF, USA; CONACYT, Mexico; and The Marsden Fund of the Royal Society of New Zealand.

Invited Talk SYQE 1.3 Fri 11:30 HSZ 01

Tomography and Correlation Function Measurements of Propagating Microwave Photons — •Andreas Wallraff — ETH Zurich, Zurich, Switzerland

At optical frequencies the radiation produced by a source, such as a laser, a black body or a single-photon emitter, is frequently characterized by analyzing the temporal correlations of emitted photons using single-photon counters. At microwave frequencies, however, there are no efficient single-photon counters yet. Instead, well-developed linear amplifiers allow for efficient measurement of the amplitude of an electromagnetic field. Here, we demonstrate first- and second-order correlation function measurements of a pulsed microwave-frequency single-photon source integrated on the same chip with a 50/50 beam splitter followed by linear amplifiers and quadrature amplitude detectors [1]. We clearly observe single-photon coherence in first-order and photon antibunching in second-order correlation function measurements of the propagating fields [2]. We also present first measurements in which we reconstruct the Wigner function of itinerant single photon Fock states and their superposition with the vacuum. For these measurements we have developed efficient methods to separate the detected single photon signal from the noise added by the amplifier by analyzing the moments of the measured amplitude distribution up to 4th order. The methods demonstrated here may find application in quantum optics and quantum information processing experiments at microwave frequencies.

[1] M. P. da Silva et al., Phys. Rev. A 82, 043804 (2010)

[2] D. Bozyigit et al., Nat. Phys. in print (2010), also arXiv:1002.3738

Invited Talk SYQE 1.4 Fri 12:00 HSZ 01

Artificial atom in 1D open space — •Yasunobu Nakamura — NEC Green Innovation Research Laboratories, Tsukuba, Japan — RIKEN, Wako, Japan

Circuit QED has been beautifully demonstrated in an on-chip coplanar wave guide resonator: The large dipole moment of a superconducting qubit as an artificial atom interacts strongly with the discrete modes of the microwave resonator. An even simpler, but less commonly studied setup in quantum optics may be an atom strongly coupled with a continuum of 1D electromagnetic modes. Again, the large dipole moment and the tightly confined field in a microwave transmission line enable us to realize such a case with a dominant spontaneous emission rate of the artifical atom to the 1D mode. Thanks to the one-dimensionality, the spatial mode matching for the interference between the incident microwave and the absorbed and re-emitted microwave can be perfect, resulting in extinction of the transmission at the resonant frequency of the atom. Additionally, by using the higher exciation level of the atom, we can implement further functions such as switching and amplification of the transmitted microwave by the single atom in the transmission line. This can be a basic tool for microwave quantum optics applications.

Invited Talk SYQE 1.5 Fri 12:30 HSZ 01

Quantum dot based bright sources of quantum light. — •Pascale Senellart[1], Adrien Dousse[1], Jan Suffczynski[1,2], Vivien Loo[1], Steffen Michaelis de Vasconcellos[1], Olivier Gazzano[1], Loic Lanco[1], Aristide Lemaitre[1], Isabelle Sagnes[1], Alexios Beveratos[1], Olivier Krebs[1], Jacqueline Bloch[1], and Paul Voisin[1] — [1]Laboratoire de Photonique et de Nanostructures, CNRS, Route de Nozay, 91460 Marcoussis, FRANCE — [2]Present address: Institute of Experimental Physics, University of Warsaw, 69 Hoz.a Street, 00-681 Warsaw, Poland.

A single semiconductor quantum dot (QD) is a promising system to achieve a solid-state source of single photons or entangled photon pairs. Controlling the radiative lifetime of a QD in the weak coupling regime (Purcell effect) is a way to make sure that the photons emitted by the QD are funnelled into a cavity mode and efficiently collected. For the last few years, the main challenge has been to control both the spectral and spatial matching between a single QD and a cavity mode. We have developed an in-situ lithography technique that allows deterministically coupling a single QD to a cavity mode [1]. Using this technique, we demonstrate the scalable fabrication of ultrabright sources of single photons or of entangled photon pairs [2]. The same technique is also used to demonstrate on- demand strong coupling regime between a QD and a cavity mode. In this regime, we evidence optical non-linearities on a few photon scales.

[1] A. Dousse et al., Phys. Rev. Lett. 101, 267404 (2008) [2] A. Dousse et al, Nature 466, 217 (2010).