Symposium Quantum Optics on the Nanoscale: From Fundamental Physics to Quantum Technologies (SYQO)

jointly organized by
the Semiconductor Physics Division (HL),
the Thin Films Division (DS),
the Surface Science Division (O), and
the Low Temperature Physics Division (TT)

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Presently technologies that rely on quantum functionality are based on macroscopic elements such as optical fibers and bulk nonlinear optical materials. Thus the prospect of miniaturization is rather limited. However, the advancement and widespread use of quantum technologies will rely on the development of suitable nanoscale devices making quantum optics on the nanoscale an important field of research.

Quantum phenomena in nanoscale systems lead to new scales of quantum complexity. Topical key issues in this field and at least partially addressed in this symposium comprise among others i) manipulation, detection, and storage of quantum states of light at the nanoscale, ii) nonlinearities and ultrafast processes in nanostructured media, iii) nanoscale quantum coherences and coherent transport, as well as iv) quantum cooperative effects and correlations in nanoscale optical fields. The topics combine state-of-the-art research from rather diverse areas such as semiconductor physics, plasmonics, low temperatures, or surface physics.

Overview of Invited Talks and Sessions

(Lecture room HSZ 02)

Invited Talks

SYQO 1.1	Thu	9:30–10:00	HSZ 02	**Quantum dot based quantum technologies** — •Pascale Senellart
SYQO 1.2	Thu	10:00–10:30	HSZ 02	**Controlled strong coupling of a single quantum dot to a plasmonic nanoresonator at room temperature** — Heiko Gross, Joachim M. Hamm, Tommaso Tufarelli, Ortwin Hess, •Bert Hecht
SYQO 1.3	Thu	10:30–11:00	HSZ 02	**High efficiency and directional emission from a nanoscale light source in a planar optical antenna** — •Mario Agio
SYQO 1.4	Thu	11:30–12:00	HSZ 02	**Tailoring quantum states by measurement** — •Jörg Wrachtrup
SYQO 1.5	Thu	12:00–12:30	HSZ 02	**Quantum optics and quantum control at the nanoscale with surface plasmon polaritons** — •Stéphane Guérin

Sessions

SYQO 1.1–1.5	Thu	9:30–12:30	HSZ 02	**Quantum Optics on the Nanoscale: From Fundamental Physics to Quantum Technologies**

SYQO 1: Quantum Optics on the Nanoscale: From Fundamental Physics to Quantum Technologies

Time: Thursday 9:30–12:30 Location: HSZ 02

Invited Talk SYQO 1.1 Thu 9:30 HSZ 02

Quantum dot based quantum technologies — •Pascale Senellart — CNRS - Université Paris-Saclay, 91460 Marcoussis, France

Scaling optical quantum technologies requires efficient single photon sources and two-photon gates. Such devices can be obtained using artificial atoms like semiconductor quantum dots (QDs). Yet, an ideal atom-photon interface is required, where the QD interacts with only one mode of the optical field and is free from decoherence. We have developed a near-optimal QD-photon interface by deterministically coupling a QD to a microcavity [1]. With an electrical control, the QD transition is shown to be almost decoherence free. The QD-cavity devices present a cooperativity of 12 and the QD state can be coherently manipulated with a π-pulse obtained for only 4 incident photons [2]. The devices operate as bright solid-state single-photon sources with single photon purity and indistinguishability above 98% and a brightness exceeding 20 times that of parametric down-conversion sources [3]. We also report on a single-photon filter that converts a coherent pulse into a highly non-classical light wavepacket [4], a first step toward deterministic two photon gates.

[1] A. Dousse, et al., Phys. Rev. Lett. 101, 267404 (2008). [2] V. Giesz, et al., Nature Communications 7, 11986 (2016). [3] N. Somaschi, et al., Nature Photonics 10, 340 (2016). [4] L. De Santis, et al., arXiv:1607.05977.

Invited Talk SYQO 1.2 Thu 10:00 HSZ 02

Controlled strong coupling of a single quantum dot to a plasmonic nanoresonator at room temperature — Heiko Gross[1], Joachim M. Hamm[2], Tommaso Tufarelli[2], Ortwin Hess[2], and •Bert Hecht[1] — [1]Nano-Optics and Biophotonics Group, Universität Würzburg, 97074 Würzburg, Germany — [2]The Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom

We demonstrate controlled and tunable strong coupling of a mesoscopic plasmonic slit resonator and a single colloidal quantum dot at room temperature. Strong coupling is achieved (i) by placing the quantum dot within the mode field of the nanoresonator with nm precision using scanning probe technology and (ii) by exploiting the collective coupling of the band-edge multiplet of states to the broadband plasmonic resonance. Due to the resulting fast rate of energy exchange the strong coupling regime is reached and besides the exciton also the otherwise quenched trion state couples strongly with the slit resonator resulting in a four-peaked spectrum under strong-coupling conditions.

Invited Talk SYQO 1.3 Thu 10:30 HSZ 02

High efficiency and directional emission from a nanoscale light source in a planar optical antenna — •Mario Agio — Laboratory of Nano-Optics, University of Siegen, 57072 Siegen, Germany

Light emission and absorption are critical to applications such as lighting, sensing and information technology. Despite fundamental progress in the manipulation of light-matter interaction, coupling electromagnetic modes to nanoscale sources and detectors with a very high efficiency remains a challenge. Here, we introduce a simple planar antenna structure based on thin-film optics that attains more than 90% outcoupling efficiency and, at the same time, directional emission with a semiangle below 10 degrees [1,2]. Our findings are particularly relevant for materials with a high refractive index, like semiconductor-based nanophotonic devices, which typically exhibit a large mismatch to free-space and guided modes. Furthermore, our approach is general and thus applicable to any wavelength, provided that materials with the required optical properties are available. Finally, we discuss some results in the context of solid-state singlephoton sources.

[1] S. Checcucci et al., Light: Science & Applications 6, e16245 (2017). [2] H. Galal, M. Agio, to be submitted.

Coffee Break

Invited Talk SYQO 1.4 Thu 11:30 HSZ 02

Tailoring quantum states by measurement — •Jörg Wrachtrup — Institute for Quantum Science and Technology, IQST, University of Stuttgart, 70569 Stuttgart, Germany

Measurement induced back action is a unique property of quantum mechanics. It is a central challenge for a variety of applications, like error correction. However, it is also a unique tool in e.g. dissipative generation of entanglement or ground state cooling. In my talk, I will describe ways to control spin quantum states by tailored photonic measurements. I will describe of how to extend those measurement to a general scheme also, e.g. allowing to cool mesoscopic elements like mechanical oscillators.

Invited Talk SYQO 1.5 Thu 12:00 HSZ 02

Quantum optics and quantum control at the nanoscale with surface plasmon polaritons — •Stéphane Guérin — UMR 6303 CNRS-Université Bourgogne Franche-Comté, 21078 Dijon, France

The quantum control of emitters is a key issue for quantum information processing at the nanoscale. This generally necessitates the strong coupling of emitters to a high Q-cavity for efficient manipulation of the atoms and field dynamics (cavity quantum electrodynamics or cQED). Since almost a decade, strong efforts are put to transpose cQED concepts to plasmonics in order to profit of the strong mode confinement of surface plasmons polaritons [1]. Despite the intrinsic presence of lossy channels leading to strong decoherence in plasmonics systems, it has been experimentally proven that it is possible to reach the strong coupling regim [2]. In this work, we derive an effective Hamiltonian [3,4], which allows us to describe the metallic nanoparticle-emitter interaction in full analogy with cQED formalism using a multimodal lossy cavity. We discuss (i) the concept of dressed states of quantum emitter strongly coupled to a metal nanoparticle [5], leading for instance to efficient/blockade population transfers or superradiance/subradiance effects, and (ii) the multi-emitter adiabatic control via quantum plasmonics, for instance via stimulated Raman adiabatic processes [3].

[1] M.S. Tame, et al., Nature Physics 9, 329 (2013). [2] G. Zengin, et al., Phys. Rev. Lett. 114, 157401 (2015). [3] B. Rousseaux, et al., Phys. Rev. B 93, 045422 (2016). [4] D. Dzsotjan, et al., Phys. Rev. A 94, 023818 (2016). [5] H. Varguet, et al., Opt. Lett. 41, 4480 (2016).