Symposium Strong Coupling in Solid State Quantum Systems (SYSC)

jointly organized by the divisions
the Low Temperature Physics (TT),
the Dynamics and Statistical Physics (DY),
the Semiconductor Physics (HL), and
the Magnetism (MA)

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Like two atoms coupling to a molecule, solid state-based quantum systems can be designed to couple, forming artificial, hybrid superposition states. If the coupling rate exceeds the loss rates of the two (originally isolated) quantum systems, the so-called strong coupling limit is reached. In this regime, a coherent exchange of excitations between the two quantum systems becomes possible, which in particular enables quantum information conversion.

The symposium shall give an overview over the current state of the art in solid-state based strong coupling approaches, aiming to unravel the advantages and the challenges of the different experimental realization schemes, and to highlight future developments.

Overview of Invited Talks and Sessions

(Lecture Room H1)

Invited Talks

SYSC 1.1	Tue	9:30–10:00	H1	**Exploring the Physics of Superconducting Qubits Strongly Coupled to Microwave Frequency Photons** — •Andreas Wallraff
SYSC 1.2	Tue	10:00–10:30	H1	**Hybrid Quantum Circuit with a Superconducting Qubit Coupled to an Electron Spin Ensemble** — •Yuimaru Kubo, Cecile Grezes, Igor Diniz, Jun-ichi Isoya, Vincent Jacques, Anais Dreau, Jean-François Roch, Alexia Auffeves, Denis Vion, Daniel Esteve, Patrice Bertet
SYSC 1.3	Tue	10:30–11:00	H1	**Hybrid Quantum Systems with Rare-Earth Ion Spin Ensemble** — •Pavel Bushev
SYSC 1.4	Tue	11:00–11:30	H1	**Quantum Coherent Coupling between a Mechanical Oscillator and an Optical Mode** — Ewold Verhagen, Dalziel Wilson, Vivishek Sudhir, Nicolas Piro, Albert Schliesser, •Tobias Kippenberg
SYSC 1.5	Tue	11:30–12:00	H1	**Exploring Quantum Light-Matter Interactions of Quantum Dots in Photonic Crystal Nanostructures** — •Jonathan Finley, Arne Laucht, Michael Kaniber, Stefan Lichtmannecker, Thorsten Reichert, Guenther Reithmaier, Fabrice Laussy, Ulrich Hoheneester

Sessions

SYSC 1.1–1.5	Tue	9:30–12:00	H1	**Strong Coupling in Solid State Quantum Systems (SYSC)**

SYSC 1: Strong Coupling in Solid State Quantum Systems (SYSC)

Time: Tuesday 9:30–12:00 Location: H1

Invited Talk SYSC 1.1 Tue 9:30 H1

Exploring the Physics of Superconducting Qubits Strongly Coupled to Microwave Frequency Photons — •Andreas Wallraff — ETH Zurich, Switzerland

Using modern micro and nano-fabrication techniques combined with superconducting materials we realize electronic circuits the properties of which are governed by the laws of quantum mechanics. In such circuits the strong interaction of photons with superconducting quantum two-level systems allows us to probe fundamental quantum properties of light and to develop components for applications in quantum information technology. Here, I will present experiments in which we have created and probed entanglement between stationary qubits and microwave photons freely propagating down a transmission line [1,2]. In these experiments we use superconducting parametric amplifiers realized in our lab [3] to detect both qubit and photon states efficiently. Using similar techniques we aim at demonstrating a deterministic scheme for teleportation of quantum states in a macroscopic system based on superconducting circuits.

[1] C. Eichler et al., Phys. Rev. A **86**, 032106 (2012)
[2] C. Eichler et al., Phys. Rev. Lett., in print (2012) [arXiv:1209.0441]
[3] C. Eichler et al., Phys. Rev. Lett. **107**, 113601 (2011)

Invited Talk SYSC 1.2 Tue 10:00 H1

Hybrid Quantum Circuit with a Superconducting Qubit Coupled to an Electron Spin Ensemble — •Yuimaru Kubo[1], Cecile Grezes[1], Igor Diniz[2], Jun-ichi Isoya[3], Vincent Jacques[4], Anais Dreau[4], Jean-François Roch[4], Alexia Auffeves[2], Denis Vion[1], Daniel Esteve[1], and Patrice Bertet[1] — [1]Quantronics Group, SPEC (CNRS URA 2464), CEA-Saclay, 91191 Gif-sur-Yvette, France — [2]Institut Néel, CNRS, BP 166, 38042 Grenoble, France — [3]Research Center for Knowledge Communities, University of Tsukuba, 305-8550 Tsukuba, Japan — [4]LPQM (CNRS, UMR 8537), Ecole Normale Supérieure de Cachan, 94235 Cachan, France

We report the experimental realization of a hybrid quantum circuit combining a superconducting qubit and an ensemble of electronic spins. The qubit, of the transmon type, is coherently coupled to the spin ensemble consisting of nitrogen-vacancy (NV) centers in a diamond crystal via a frequency-tunable superconducting resonator acting as a quantum bus [1,2]. Using this circuit, we prepare arbitrary superpositions of the qubit states that we store into collective excitations of the spin ensemble and retrieve back into the qubit[3]. We also report a new method for detecting the magnetic resonance of electronic spins at low temperature with a qubit using the hybrid quantum circuit [4], as well as our recent progress on spin echo experiments.

[1] Y. Kubo et al., Phys. Rev. Lett. **105**, 140502 (2010)
[2] Y. Kubo et al., Phys. Rev. A **85**, 012333 (2012)
[3] Y. Kubo et al., Phys. Rev. Lett. **107**, 220501 (2011)
[4] Y. Kubo et al., Phys. Rev. B **86**, 064514 (2012)

Invited Talk SYSC 1.3 Tue 10:30 H1

Hybrid Quantum Systems with Rare-Earth Ion Spin Ensemble — •Pavel Bushev — Physikalisches Institut, Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany

Interfacing photonic and solid-state qubits within a hybrid quantum architecture offers a promising route towards large scale distributed quantum computing. Ideal candidates for such coherent interface are optically active spin ensembles coupled to a superconducting resonators. Laser crystals doped with rare-earth ions present an excellent material with active spins, transitions in optical frequency range and hyperfine structure. The magnetic anisotropy of these materials makes their application in hybrid quantum systems quite challenging.

I will present our study of Er:YSO crystal coupled to superconducting resonator. The comparions of erbium to other rare-earth ions will also be given.

Invited Talk SYSC 1.4 Tue 11:00 H1

Quantum Coherent Coupling between a Mechanical Oscillator and an Optical Mode — Ewold Verhagen, Dalziel Wilson, Vivishek Sudhir, Nicolas Piro, Albert Schliesser, and •Tobias Kippenberg — EPFL, Institute for Condensed Matter Physics, CH-1015, Switzerland

Cavity quantum optomechanics is a rapidly developing field which concerns the radiation pressure coupling of optical and mechanical degrees of freedom [1]. Using on-chip micro-cavities that combine both optical and mechanical degrees of freedom in one and the same device [2], radiation pressure back-action of photons is shown to lead to effective cooling [3] of the mechanical oscillator mode predicted by Braginsky [4]. In our research this is reached using cryogenic He-3 buffer gas precooling to ca. 700 mK in conjunction with laser cooling, allowing cooling of micro-mechanical oscillator to only 1.7 quanta, implying the oscillator resides more than 1/3 of its time in ground state. Moreover it is possible in this regime to observe quantum coherent coupling in which the mechanical and optical mode hybridize and the coupling rate exceeds the mechanical and optical decoherence rate [5]. This accomplishment enables a range of quantum optical experiments, including state transfer from light to mechanics using the phenomenon of optomechanically induced transparency [6].

[1] T. J. Kippenberg and K. J. Vahala, Science (2008)
[2] T. J. Kippenberg et al., Phys. Rev. Lett. (2005)
[3] V. B. Braginsky et al., Phys. Lett. A (2002)
[4] A. Schliesser et al., Nat. Phys. (2008)
[5] E. Verhagen et al., Nature (2012)
[6] S. Weis et al., Science (2010)

Invited Talk SYSC 1.5 Tue 11:30 H1

Exploring Quantum Light-Matter Interactions of Quantum Dots in Photonic Crystal Nanostructures — •Jonathan Finley[1], Arne Laucht[1,2], Michael Kaniber[1], Stefan Lichtmannecker[1], Thorsten Reichert[1], Guenther Reithmaier[1], Fabrice Laussy[1,3], and Ulrich Hoheneester[4] — [1]Walter Schottky Institut, Am Coulombwall 4a, 85748 Garching, Germany — [2]University of New South Wales, Sydney, Australia — [3]Facultad de Ciencias, C-V 509, Universidad Autónoma de Madrid C, Fco. Tomás y Valiente 7, 28049 Madrid, Spain — [4]Universität Graz, Austria

This talk will provide an overview of recent experimental and theoretical studies of electrically tunable few quantum dot (QD) photonic crystal nanostructures. Cavity-QED experiments performed in the strong coupling regime provide new information the temperature and excitation induced dephasing, allowing us to probe its influence on the emission spectrum [1-3]. Furthermore, we observe cavity mediated coherent coupling of two different quantum dots via a common optical mode [4], efficient guiding of single photons into the slow light modes of a linear waveguide [5] and demonstrate on-chip single photo detection using integrated superconducting single photon detectors [6].

[1] A. Laucht et al., New J. Phys. **11**, 023034 (2009)
[2] A. Laucht et al., Phys. Rev. Lett. **103**, 087405 (2009)
[3] A. Laucht et al. Phys. Rev. B **81**, 241302 (2010)
[4] A. Laucht et al., Phys. Rev. B **82**, 075305 (2010)
[5] A. Laucht et al., Phys. Rev. X **2**, 011014 (2012)
[6] G. Reithmaier et al., preprint (2012)