Intersectional Symposium Hybrid Quantum Systems - Interfacing Atoms, Solids and Light (SYHQ)

lead by the Low Temperature Physics Division (TT)

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Hybrid quantum systems combine in a well-controlled fashion quantum states from the fields of optics (photons), atomic physics (e.g. Bose-Einstein condensates, single atoms or ions), and condensed matter physics (e.g. charge and spin excitations, mesoscopic electronic and mechanical devices). As a long-term perspective, hybrid quantum systems might combine the individual advantages of the different quantum systems (such as coherence, addressability, scalability) to improve the performance of future quantum devices. In this colloquium, recent fundamental approaches for hybrid quantum systems will be presented.

Overview of Invited Talks and Sessions

(lecture room HSZ 01)

Invited Talks

SYHQ 1.1	Thu	10:30–11:00	HSZ 01	**Circuit Quantum Electrodynamics with Electrons on Helium** — •David Schuster
SYHQ 1.2	Thu	11:00–11:30	HSZ 01	**Strong coupling of a spin ensemble to a superconducting resonator** — •Patrice Bertet, Yuimaru Kubo, Florian Ong, Denis Vion, Vincent Jacques, Dingwei Zheng, Anaïs Dréau, Jean-François Roch, Alexia Auffeves, Fedor Jelezko, Jörg Wrachtrup, Philippe Bergonzo, Daniel Esteve
SYHQ 1.3	Thu	11:30–12:00	HSZ 01	**Interfacing ultracold atoms and micromechanical oscillators** — •Philipp Treutlein, Maria Korppi, Andreas Jöckel, Stephan Camerer, David Hunger, Theodor W. Hänsch
SYHQ 1.4	Thu	12:00–12:30	HSZ 01	**Interfacing Optomechanics and Atoms** — •Klemens Hammerer, Markus Aspelmeyer, Jeff Kimble, Florian Marquardt, Eugene Polzik, Philipp Treutlein, Jun Ye, Peter Zoller
SYHQ 1.5	Thu	12:30–13:00	HSZ 01	**Ultracold Atoms near Carbon Nanotubes** — •Andreas Günther

Sessions

SYHQ 1.1–1.5	Thu	10:30–13:00	HSZ 01	**Hybrid Quantum Systems – Interfacing Atoms, Solids and Light**

SYHQ 1: Hybrid Quantum Systems – Interfacing Atoms, Solids and Light

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

Invited Talk SYHQ 1.1 Thu 10:30 HSZ 01

Circuit Quantum Electrodynamics with Electrons on Helium
— •David Schuster — University of Chicago, Chicago, USA

One of the first systems proposed as the basis of a quantum computer[1], electrons on helium has the highest known electron mobility[2] and extremely long predicted spin coherence[3]. Further it is already experimentally possible to manipulate thousands of floating electrons in parallel using CCD's much like those used in digital cameras[4], yet the coherence of individual electrons has thus far eluded measurement. I will present a new circuit quantum electrodynamics inspired technique for both detecting the quantum state of the electron's spin and motion as well performing gates between electrons[5]. This approach seeks to make an "end-run" around the scaling problem for quantum computing and as well as open a new window onto the spin physics of this unique two dimensional electron gas. [1] Platzman, et. al. Science 284, 1967 (1999) [2] Shirahama, K. JLTP 101, 439-444 (1995) [3] Lyon, S. PRA 74, (2006) [4] Sabouret, G. APL 88, 254105 (2006) [5] Schuster, D.I., et. al. PRL 105, 040503 (2010)

Invited Talk SYHQ 1.2 Thu 11:00 HSZ 01

Strong coupling of a spin ensemble to a superconducting resonator
— •Patrice Bertet[1], Yuimaru Kubo[1], Florian Ong[1], Denis Vion[1], Vincent Jacques[2], Dingwei Zheng[2], Anaïs Dréau[2], Jean-François Roch[2], Alexia Auffeves[3], Fedor Jelezko[4], Jörg Wrachtrup[4], Philippe Bergonzo[5], and Daniel Esteve[1] — [1]Quantronics group, SPEC/IRAMIS/DSM, CEA-Saclay, 91191 Gif-sur-Yvette, France — [2]LPQM, CNRS/ENS Cachan, 94235 Cachan, France — [3]Institut Néel - CNRS-UJF, 38042 Grenoble, France — [4]3. Physikalisches Institut, Universität Stuttgart, 70550 Stuttgart, Germany — [5]Diamond Sensors Laboratory,CEA, LIST, 91191 Gif-sur-Yvette, France

Bridging the gap between quantum-optical and solid-state implementations of quantum information is currently one of the major challenges in the field. Microscopic quantum systems have long coherence times, whereas artificial superconducting atoms can be manipulated and entangled very rapidly and with high fidelity; it is therefore appealing to combine them to form hybrid quantum circuits. Here we report a first important step towards this goal. We have realized a quantum circuit where an ensemble of electronic spins is coupled to a frequency tunable superconducting resonator. The spins are Nitrogen-Vacancy centers in a diamond crystal. The achievement of strong coupling is manifested by the appearance of a vacuum Rabi splitting in the transmission spectrum of the resonator when it is tuned through the NV center electron spin resonance frequency [1].

[1] Y. Kubo et al., Phys. Rev. Lett. 105, 140502 (2010)

Invited Talk SYHQ 1.3 Thu 11:30 HSZ 01

Interfacing ultracold atoms and micromechanical oscillators
— •Philipp Treutlein[1,2], Maria Korppi[1,2], Andreas Jöckel[1], Stephan Camerer[2], David Hunger[2], and Theodor W. Hänsch[2] — [1]Departement Physik, Universität Basel, Switzerland — [2]Max-Planck-Institut für Quantenoptik und LMU München, Germany

We report on an experiment in which we have realized an optomechanical interface between ultracold atoms and a micromechanical oscillator [1]. The oscillator is a low-stress SiN membrane with a mechanical quality factor exceeding one million. Ultracold atoms are trapped in an optical lattice that is created by retroreflecting a laser beam from the membrane. The lattice laser light thus mediates a coupling between the membrane vibrations and the motion of the atoms in the lattice [2]. We observe bi-directional coupling between the two systems and show that the dissipation of the membrane can be engineered by coupling it to laser-cooled atoms.

The optomechanical coupling between atoms and a membrane can be strongly enhanced by placing both systems in a laser-driven high-finesse optical cavity [3]. This may give access to the strong coupling regime, providing a quantum interface allowing the coherent transfer of quantum states between the two systems. This opens the door to coherent manipulation, preparation and measurement of micromechanical objects via the well-developed tools of atomic physics.

[1] S. Camerer et al., to be published. [2] K. Hammerer et al., PRA 82, 021803 (2010). [3] K. Hammerer et al., PRL 103, 063005 (2009).

Invited Talk SYHQ 1.4 Thu 12:00 HSZ 01

Interfacing Optomechanics and Atoms
— •Klemens Hammerer[1,2,3], Markus Aspelmeyer[4], Jeff Kimble[5], Florian Marquardt[6], Eugene Polzik[7], Philipp Treutlein[8], Jun Ye[9], and Peter Zoller[2,3] — [1]Leibniz Universität Hannover, Hannover, Deutschland — [2]Universität Innsbruck, Innsbruck, Österreich — [3]IQOQI, Innsbruck, Österreich — [4]Universität Wien, Wien, Österreich — [5]Caltech, Pasadena, USA — [6]Universität Erlangen, Erlangen, Deutschland — [7]NBI, Kopenhagen, Dänemark — [8]Universität Basel, Basel, Schweiz — [9]NIST, Boulder, USA

We propose and analyze setups interfacing opto-mechanical systems with single atoms or atomic ensembles. In particular we show that strong, coherent coupling between a single trapped atom and a mechanical oscillator can be mediated via a laser-driven high-finesse cavity. In free space it is still possible to achieve a coherent coupling between a micromirror and an ensemble of atoms trapped in a standing wave field reflected thereof. Finally, in a travelling wave, pulsed scheme allows for a quantum non-demolition measurement of hybrid atomic-micromechanical Einstein-Podolsky-Rosen variables. The wave function of the massive mechanical oscillator and the collective atomic spin is thereby collapsed into an entangled EPR state. These setups provide the basic toolbox for coherent manipulation, preparation and measurement of micro- and nanomechanical oscillators via the tools of atomic physics.

Invited Talk SYHQ 1.5 Thu 12:30 HSZ 01

Ultracold Atoms near Carbon Nanotubes
— •Andreas Günther — Center for Collective Quantum Phenomena, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

Hybrid quantum systems, which combine ultracold atoms with solid state devices, have attracted considerable attention in the last few years. I report on our experimental efforts towards the realization of such systems based on ultracold atoms near carbon nanotubes and superconductors.

I present recent experimental data taken on the contact interaction between ultracold atoms and carbon nanotubes. Free standing single nanotubes, periodic structures, and carpets of nanotubes are vertically grown on the surface of an atom chip. Using a novel, cold atom scanning probe microscope, we are able to measure the surface topography of these nano-structures and to laterally resolve a single carbon nanotube. Spatially overlapping ultracold thermal clouds or Bose-Einstein condensates with such a single nanotube, we record atom losses and measure the inelastic scattering cross section between ultracold rubidium atoms and the carbon nanotube. From the scattering data we derive the velocity dependent scattering radius of the nanotube and gain information about the fundamental Casimir-Polder interaction. In addition, we describe a novel atom detector based on field ionization of ground state atoms near carbon nanotubes and subsequent ion counting.