FM 73: Quantum Sensing: Applications & Spectroscopy

Time: Thursday 14:00–16:00 Location: Aula

FM 73.1 Thu 14:00 Aula

Resolving the positions of defects in superconducting quantum bits — •Alexander Bilmes[1], Anthony Megrant[2], Paul Klimov[2], Julian Kelly[2], Rami Barends[2], John M. Martinis[2], Gerog Weiss[1], Alexey V. Ustinov[1,3], and Juergen Lisenfeld[1] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Google Inc., Santa Barbara, USA — [3]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

We demonstrate a new technique to identify the spatial positions of decoherence-inducing material defects known as Two-Level-Tunneling systems (TLS) in superconducting qubits. For this, we operate a transmon qubit circuit in a DC-electric field that is generated by several electrodes surrounding the sample chip, and study the TLS response by monitoring their resonance frequencies using qubit swap spectroscopy. By comparing measured and simulated coupling strengths of TLS to each DC-electrode, we obtain information about the defect's location and the circuit interface at which it resides. This provides a viable tool applicable to various qubit types, which enables one to optimize qubit fabrication procedures by directly indicating which circuit interfaces must be improved in order to enhance qubit coherence.

FM 73.2 Thu 14:15 Aula

Probing Defects in Superconducting Qubits with Electric Fields — •Jürgen Lisenfeld[1], Alexander Bilmes[1], Anthony Megrant[2], Julian Kelly[2], Rami Barends[2], Paul Klimov[2], John M. Martinis[2], Georg Weiss[1], and Alexey V. Ustinov[1,3] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Google Inc., Santa Barbara, USA — [3]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

The coherence of superconducting quantum bits is severely reduced by atomic-scale material defects which provide a bath of parasitic two-state tunneling systems, so-called TLS. Here, we present a method to distinguish TLS contained in the tunnel barriers of the qubit's Josephson junctions from TLS residing on the surfaces of superconducting electrodes or the substrate. For this, we characterize the defect's responses to applied mechanical strain and electric DC-fields using the qubit as a sensor.

We find that 60% of the total dielectric loss in the investigated Xmon-qubit is due to defects on film interfaces and the substrate, while 40% comes from TLS in the tunnel barriers of Josephson junctions. Measurements of the TLS-qubit coupling strengths reveal that only about 3% of all defects are residing in the small qubit tunnel junctions, while most are contained in the large stray junctions that are used as wiring interconnects. The presented methods guide the way towards improved qubit coherence by indicating the critical circuit interfaces and fabrication steps that are promoting defect formation.

FM 73.3 Thu 14:30 Aula

Biomagnetic measurements with optically pumped magnetometers — •Thomas Middelmann, Stefan Hartwig, Victor Lebedev, Anna Jodko-Wladzinska, Rüdiger Brühl, Lutz Trahms, and Tilmann H. Sander — Physikalisch-Technische Bundesanstalt, Berlin, Germany

Optically pumped magnetometers (OPMs) pose an alternative method to measure tiny magnetic fields (fT-range) for applications that before could only be realized by superconducting quantum interference devices (SQUIDs) which essentially rely on cryogenic cooling. Biomagnetic methods such as Magnetoencephalography (MEG) or Magnetocardiography (MCG) can gain a lot from the flexibility of miniaturized OPMs. They enable to adapt the sensor arrangement to the individual shape of the body by mounting the sensors in a wearable 3D-printed structure. We present biomagnetic measurements with multichannel arrays of miniaturized OPMs, revealing the benefits and limits of today's best available OPMs. In particular we present stress-MCG, demonstrating the newly possible option to fix the sensors on the moving subject, and MEG of auditory evoked potentials, with an anatomy adapted sensor array, which enables a considerable reduction of the distance between field source and detector.

FM 73.4 Thu 14:45 Aula

Spectroscopy of nanoparticles without light — •Johannes Fiedler[1,2], Clas Persson[2], and Stefan Yoshi Buhmann[1,3] — [1]University of Freiburg, Freiburg, Germany — [2]Centre for Materials Science and Nanotechnology, Oslo, Norway — [3]Freiburg Institute for Advanced Studies, Freiburg, Germany

Spectroscopy is a tool for determining the electromagnetic response of particles, which is typically measured directly by exciting the investigated object with light. However, indirect measurements via interactions depending on this response provide an alternative methods. Dispersion forces are suitable candidates as they couple to the complete electromagnetic spectrum [1]. We propose a modification of well-studied Casimir experiments via atomic force microscopy [2] for determining the dielectric response of a test particle by adding a two-component liquid [3], leading to an enhancement of retardation and hence allowing for a reconstruction of spectral information based on spatial measurements.

[1] S.Y. Buhmann, Dispersion forces I, Springer (Heidelberg, 2012). [2] M. Sedighi et al., PRB **93**, 085434 (2016). [3] J. Fiedler et al. submitted to PRB (2019).

FM 73.5 Thu 15:00 Aula

Attosecond Time Delays in Photoionisation of Noble Gas Atoms — •Matteo Moioli[1], Hamed Ahmadi[1,2], Fabio Frassetto[3], Luca Poletto[3], Francesca Bragheri[4], Roberto Osellame[4], Cristian Manzoni[4], Giulio Cerullo[2], Claus Dieter Schröter[5], Robert Moshammer[5], Thomas Pfeifer[5], and Giuseppe Sansone[1] — [1]Physikalisches Institut, Universität Freiburg, Freiburg, Germany — [2]Dipartimento di Fisica, Politecnico, Milano, Italy — [3]Istituto di Fotonica e Nanotecnologie, CNR, Padova, Italy — [4]Istituto di Fotonica e Nanotecnologie, CNR, Milano, Italy — [5]Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Here, we present the preliminary results of the investigation of ultrafast dynamics in photoionisation in noble gas atoms. We also illustrate the scheme of an Optical Parametric Amplifier (OPA) setup for the generation of pulses with a stable Carrier-Envelope-Phase (CEP). In particular, using coincidence photoelectron-photoion spectroscopy, the correlated dynamics between photoelectron(s) and photoion(s) can be explored. In the experiment we investigated attosecond time delays in photoionisation using trains of attosecond pulses and a synchronized infrared (IR) pulse. The measured photoionisation time delays can be resolved in terms of emission angle and energy of the photoelectron. In order to maintain a reproducible electric field of the IR pulse, we generate passively CEP-stable pulses through Difference Frequency Generation (DFG) and then amplify them in an OPA setup. The broad amplification bandwidth of the OPA enables generating few-optical cycle pulses.

FM 73.6 Thu 15:15 Aula

Optomechanical stability of the superradiant laser — •Simon B. Jäger[1], John Cooper[2], Murray J. Holland[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]JILA, National Institute of Standards and Technology and Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA

Time and frequency standards require the realization of extremely stable high-Q oscillators. For lasers this oscillator is usually a small-linewidth resonator mode and the laser linewidth is bounded by fluctuations of the resonator length. Remarkably these limitations can be ovecome by coupling many atoms to a rather large-linewidth resonator mode and storing coherences in the atomic supperadiant collective dipole. In this superradiant laser the linewidth is bounded by the single-particle linewidth that can be of the order of mHz. This prediction has been obtained in studies discarding the effect of inhomogeneous broadening of the medium. In this work we theoretically study the optomechanical dynamics of an ensemble of atoms in the regime in which superradiant lasing is expected. We show that, in absence of an external confinement, self-stabilized lasing structures can form when the superradiant decay rate exceeds a threshold determined by the recoil frequency. The dynamics can become chaotic, leading to the emission of chaotic light, when the pump rate is below a certain threshold. These phases can be revealed in the coherence properties of the light at the cavity output and emerge from the interplay between quantum fluctuations, dissipation, and noise.

FM 73.7 Thu 15:30 Aula

State-to-state chemistry with resolution of magnetic spins —
•Markus Deiss, Joschka Wolf, Shinsuke Haze, and Johannes Hecker Denschlag — Institut für Quantenmaterie and Center for Integrated Quantum Science and Technology IQST, Universität Ulm, 89069 Ulm, Germany

State-to-state chemistry describes the determination of the quantum states of the final products given the quantum state of the reactants. We have developed and demonstrated a method to probe molecular product states of reactive processes both qualitatively and quantitatively [1]. Using the given method, we have investigated the recombination of three neutral rubidium atoms in an ultracold atomic gas. Now, we have extended the scheme of [1] to also resolve the magnetic quantum number of molecular product states. In this talk, measurements of product molecules as a function of the magnetic field strength and for different reactant states are presented. We can formulate a propensity rule with respect to the magnetic quantum number.

[1] J. Wolf *et al.*, Science 358, 921 (2017).

FM 73.8 Thu 15:45 Aula

Hyperpolarization and Bath Spectroscopy of Individual ^{13}C Nuclei in Diamond —
•K. Herb, K.S. Cujia, J. Zopes, and C.L. Degen — Department of Physics, ETH Zurich, Otto Stern Weg 1, 8093 Zurich, Switzerland

70 years ago, Erwin Hahn published the first experimental demonstration of a Free Induction Decay (FID) experiment. Advances in quantum optics and material science enable us today to record the free precession signal of single ^{13}C nuclear spins inside a diamond crystal. The experimental instrumentation to achieve this sensitivity is not of a classical and macroscopic scale as in Hahn's experiment, but rather of a microscopic scale. Indeed, the sensor is an electron spin: the electron spin of the Nitrogen-Vacancy (NV) center in diamond. In this talk, we focus on two key challenges towards single molecule NMR spectroscopy: the hyperpolarization of single nuclei in the vicinity of the NV center at room temperature and the detection scheme. We use the hyperfine coupling of the nuclei to the NV center to transfer electron spin polarization in a ramped-amplitude NOVEL-like scheme. By modulating the amplitude of the spin-lock pulse, we improved the robustness and the efficiency of the protocol for polarizing multiple nuclear spins with a priori unknown hyperfine couplings. To detect the nuclear spins, we propose the use of periodic weak measurements. This allows a continuous FID detection at the single spin level. By that, we demonstrate sensitive, high-resolution NMR spectroscopy of multiple individually resolvable nuclear spins in the vicinity of the NV center.