FM 41: Poster: Quantum Sensing

Time: Tuesday 16:30–18:30 Location: Tents

FM 41.1 Tue 16:30 Tents

Fast and high-fidelity motional state control of trapped ions — •Jan-Philipp Schröder, Matthias Wittemer, Frederick Hakelberg, Philip Kiefer, Daniel Rieländer, Ulrich Warring, and Tobias Schaetz — Department of Experimental Atomic, Molecular, and Optical Physics, University of Freiburg, Germany

Laser-cooled ions, trapped in radio-frequency potentials, are well established experimental systems for quantum simulations [1]. Here, we report on a hardware platform compound of Mg^+ ions in a linear rf Paul trap. We manipulate and couple the ions electronic (pseudo spin-$\frac{1}{2}$) and motional (bosonic) states. Via resolved sideband cooling they are initialized in their motional ground state. As recently demonstrated, we can real-time control the ion's storage potential and non-adiabatically evolve its ground state wavefunction into a squeezed motional state [2]. We make use of this quantum squeezed state by performing measurements of residual electric stray fields with enhanced sensitivity.

[1] H. Schmitz, et al., Appl. Phys. B (2009) 95: 195
[2] M. Wittemer, et al., arXiv:1903.05523 [quant-ph] (2019)

FM 41.2 Tue 16:30 Tents

Detecting the motion of mechanical oscillators with superconducting quantum interference devices — •K. Uhl[1], J. Hofer[2], J. Slater[2], C. Schneider[3], G. Kirchmair[3], O. F. Kieler[4], T. Weimann[4], M. Aspelmeyer[2], D. Koelle[1], and R. Kleiner[1] — [1]Physikalisches Institut and Center for QuantumScience (CQ) in Lisa+, Universität Tübingen, Germany — [2]Vienna Center for Quantum Science and Technology, University of Vienna, Austria — [3]Institute for Experimental Physics, University of Innsbruck, Austria — [4]Fachbereich Quantenelektronik, Physikalisch- Technische Bundesanstalt (PTB) Braunschweig, Germany

Levitating solid-state objects, like a superconducting particle in a magnetic trap or a cantilever with a superconducting strip, offer a unique approach to the realization of nano- or even micro-sized quantum systems with potentially minimal decoherence. In combination with cryogenic temperatures, the coherence times in the quantum mechanical ground state can be increased significantly. Our goal is to employ a superconducting quantum interferometer to gain information on position and oscillatory behavior of the levitated objects. To optimize magnetic coupling between oscillator and SQUID, we performed numerical simulations based on London equations and evaluated various SQUID designs. The results of the numerical simulations and experimentally determined SQUID performance will be presented.

FM 41.3 Tue 16:30 Tents

Chip-based magnetic traps for superconducting levitation of μm-sized particles — •Martí Gutierrez Latorre, David Niepce, Matthias Rudolph, and Witlef Wieczorek — Quantum Technology Laboratory, Chalmers University of Technology, Gothenburg, Sweden

Levitated mechanical resonators are a unique platform capable of reaching unrivaled performance in quantum-enhanced sensing and, potentially, in realizing macroscopic quantum superposition states. This is enabled by their expected ultra-low coupling to the environment, resulting in ultra-high mechanical quality factors. Furthermore, the trapping frequency of such a levitated resonator can be increased by exploiting high magnetic field gradients achievable via miniaturization. As a first step, we develop chip-based traps and particles for superconducting magnetic levitation. We present FEM simulations of integrated trap architectures for levitation of μm-sized particles. The force, potential energy and magnetic field on the levitated particles are calculated, showing that trapping frequencies of a few hundreds of kHz are readily achievable and that the corresponding mechanical motion can be detected via pick-up coils connected to high-sensitivity SQUIDs. We further demonstrate the fabrication of such integrated magnetic traps and superconducting particles made of Nb on Si substrates via conventional micro-fabrication techniques. Our results pave the way to observing and sensing superconducting levitated μm-sized particles at 4K.

FM 41.4 Tue 16:30 Tents

High-reflectivity AlGaAs-based on-chip optomechanical devices for quantum optics experiments — •Sushanth Kini M[1], Karim Elkhouly[1], Jamie Fitzgerald[2], Shu Min Wang[3], Phillippe Tassin[2], and Witlef Wieczorek[1] — [1]Quantum Technology Laboratory, Department of Microtechonolgy and Nanoscience, Chalmers University of Technology, Sweden — [2]Department of Physics, Chalmers University of Technology, Sweden — [3]Photonics Laboratory, Department of Microtechonolgy and Nanoscience, Chalmers University of Technology, Sweden

Cavity optomechanical devices exploit the interaction between light and mechanical motion for controlling mechanical resonators down to the quantum regime. A major challenge in the field remains accessing a strong interaction on the level of single quanta. The concept of multi-element optomechanics has been proposed to reach this regime. In the present work, we fabricate mechanical devices in an AlGaAs heterostructure with the goal to realise this concept. One of the requirements to achieve single photon strong coupling is to have highly reflective mechanical devices. Therefore, we pattern the mechanical devices with a photonic crystal that results in an out-of-plane reflectivity close to unity. We show results on simulation, fabrication and the optical and mechanical characterization of the optomechanical resonators. Our device concept should allow for a fully integrated realization of multi-element optomechanical system in the near future.

FM 41.5 Tue 16:30 Tents

Zerodur®-based optical setup for a transportable aluminium ion quantum logic optical clock — •Benjamin Kraus[1], Stephan Hannig[1], Ortwin Hellmig[2], Moritz Mihm[3], Patrick Windpassinger[3], and Piet O. Schmit[1,4] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Universität Hamburg, 20148 Hamburg, Germany — [3]Johannes Gutenberg-Universität Mainz, 55122 Mainz, Germany — [4]Leibniz Universität Hannover, 30167 Hannover, Germany

We present Zerodur®-based optical components for applications in a transportable aluminium ion quantum logic optical clock.

A transportable optical ion clock requires a compact and robust setup. These requirements are fulfilled by rigid Zerodur®-based breadboards[1] as shown for sounding rocket missions. We present a distribution board, where light with the wavelengths 375 nm, 397 nm, 422 nm 854 nm and 866 nm is coupled into an LMA fibre. The temperature and acceleration stability of the setup will be characterized and compared to a classical optical setup. As a second step, we show a design study of a Zerodur®-based double pass AOM setup for a wavelength of 397 nm. Both setups are developed for a transportable aluminium ion quantum logic optical clock. However, such Zerodur® breadboards could become part of robust laser systems for a broad range of quantum optics experiments in the future.

[1] Mihm, Moritz, et al, "ZERODUR® based optical systems for quantum gas experiments in space." Acta Astronautica 159, 166-169 (2019); https://doi.org/10.1016/j.actaastro.2019.03.060

FM 41.6 Tue 16:30 Tents

Zerodur based optical and vacuum systems for the field application of quantum technologies — •Moritz Mihm[1], Sören Boles[1], Jean Pierre Marburger[1], André Wenzlawski[1], Ortwin Hellmig[2], and Patrick Windpassinger[1] — [1]Institut für Physik, JGU Mainz — [2]ILP, UHH Hamburg

Numerous quantum technologies are used in extreme environments. The operation outside the laboratory makes high demands on the experiment and especially the laser system regarding miniaturization and power consumption as well as mechanical and thermal stability.

We have developed a technology for stable fiber-coupled optical modules, consisting of Zerodur based optical benches with free-space optics. Our toolkit allows the assembly of modules e.g. for laser frequency stabilization as well as distribution, overlap and switching of laser beams. Developed in the context of atom interferometry with ultracold atoms in space, suitability of the technology has been demonstrated in the successful sounding rocket missions FOKUS, KALEXUS and MAIUS.

I will present the fundamentals of our technology and discuss current efforts to build Zerodur based vacuum systems. The combination of miniaturized and stable vacuum chambers with our laser system technology allows the development of integrated quantum optical systems for applications outside laboratory environments.

Our work is supported by JGU Stufe 1 Funding and the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers 50 WP 1433 and 50 WP 1703.

FM 41.7 Tue 16:30 Tents

Design and optimization of a confocal microscopy setup for the investigation of nitrogen-vacancy centres in diamond — •Lukas Götz, Tingpeng Luo, Felix Hahl, and Jan Jeske — Fraunhofer IAF, Freiburg, Germany

Nitrogen vacancy centres in diamond are a promising and widely employed system in a variety of applications as a highly sensitive or nanoscale magnetic field sensor. Diamond as a carrier material as well as the NV centre have to be characterized with high precision. In our work, we focus on crucial points and improvements in the design of a custom-built confocal microscope for this purpose.

We present a combined confocal setup for fluorescence maps, identification of single NVs, optical spectra, optically detected magnetic resonance (ODMR), and pulsed coherence time measurements of the NV centre. Our setup aims to combine flexibility with rigorous stability and fast measurements (collection efficiency and control). The setup presented here relies largely on fibres. In particular, the coupling into a fibre substitutes the confocal pinhole, and a fibre beam splitter allows for the Hanbury-Brown-Twiss (HBT) experiment. The stability and advantages of the fibre solution will be discussed.

FM 41.8 Tue 16:30 Tents

NV-doped diamond for ultrasensitive laser threshold magnetometry — Felix Hahl, Tingpeng Luo, Lukas Götz, Julia Langer, Volker Cimalla, and •Jan Jeske — Fraunhofer-Institut für Angewandte Festkörperphysik (IAF), Tullastr. 72, 79108 Freiburg, Germany

The concept of laser threshold magnetometry (LTM) suggests using nitrogen-vacancy (NV) centres in diamond as a laser medium to realise a magnetic-field dependent laser output and laser threshold. This could improve the sensitivity significantly to a theoretical shot-noise limit with NV-doped bulk diamond rivalling the best current sensors. While the evidence of stimulated emission in NV doped diamond is further motivation, an NV laser poses strong material demands.

We performed theoretical calculations of the laser threshold, required pump power and loss rates and identified high NV density, combined with low absorption and birefringence the major challenges in the material properties of NV diamond for LTM. In order to tackle these we combine characterization methods of absorption, birefringence, nitrogen concentration and NV spin properties with chemical vapour deposition (CVD) growth of diamond and have preliminary results on highly nitrogen-doped CVD diamonds.

Based on our simulations we furthermore developed a cavity design with a geometry to minimize power requirements for lasing. The cavity is designed to characterize diamond samples through cavity loss rates, measure amplification and work towards lasing with NV centres.

FM 41.9 Tue 16:30 Tents

Sensitive DC magnetometry with nitrogen-vacancy center ensembles in diamond — •Chen Zhang[1], Vadim Vorobyov[1], Junichi Isoya[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Research center for knowledge communities, University of Tsukuba, Japan

Negatively charged nitrogen vacancy (NV-) center ensembles in diamond has demonstrated a great potential with achieving a subpicotesla magnetic field sensitivity (T. Wolf, 2015), which makes it a competitive candidate for various applications in bio-sensing and brain-science. In order to take full advantages of the diamond magnetometer, the DC field sensitivity need to be further improved to meet the requirements. In this work, 13C purified diamonds with an extraordinary T2* time of 10 μs and T2 time of 200 μs were used, demonstrating a ~80 kHz continuous wave optically detected magnetic resonance (CW-ODMR) linewidth and ensuring the high DC sensitivity limit. A BaLn2Ti4O12 wide band MW resonator is used to provide homogeneous MW field for multi-frequency MW driving of all the hyperfine lines as well as NV-ensembles of different orientations (P. Kapitanova, 2018; C. Zhang, 2018), in order to improve the fluorescence contrast which is linearly related to the sensitivity limit. Balanced detection and lock-in amplifier are used to suppress optical fluctuation and to figure out the noise floor of the setup. By all the techniques we present, we are reaching a DC magnetic field sensitivity of 15 pT/Hz^(1/2) and targeting to 10 pT/Hz^(1/2), which could meet the basic requirement for the MEG signal sensing with a distance of 1 cm from the brain surface.

FM 41.10 Tue 16:30 Tents

Cavity design and simulations for a NV centre laser and laser threshold magnetometry — •Felix Hahl, Lukas Götz, and Jan Jeske — Fraunhofer-Institut für Angewandte Festkörperphysik IAF, Freiburg, Germany

The concept of laser threshold magnetometry (LTM) suggests to use nitrogen-vacancy (NV) centre in diamond as a laser medium to realise a magnetic-field dependent laser output and laser threshold. This could improve the sensitivity significantly to a theoretical shot-noise limit with NV doped bulk diamond of fT/sqrt(Hz). The first step for realising a lasing system out of diamond was the evidence of stimulated emission of NV doped diamond. However, to achieve a lasing system the diamond needs to be highly NV doped and of a good optical quality, meaning minimizing the absorption caused by nitrogen defects and minimizing deviations from perfect single crystal structure, causing birefringence. Via simulations, we have estimated the cavity and pump power requirements to realise NV lasing based on measured material properties. We furthermore quantify how material improvements such as reduced absorption or increased NV density can significantly lower required pump powers. Based on the simulations we present a macroscopic cavity design for two purposes: precise characterisation of material through cavity-enhanced absorption spectroscopy measurements and our work towards lasing with NV centres. This is the major step towards LTM, which would strongly improve magnetic sensing for medical applications such as magnetoencephalography.

FM 41.11 Tue 16:30 Tents

VECSEL system for quantum manipulation of trapped magnesium ions — •Till Rehmert[1,2], Maximilian J. Zawierucha[2], Jan Christoph Heip[2], Fabian Wolf[2], and Piet O. Schmidt[1,2] — [1]Leibniz Universität Hannover, Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Optical pumped vertical-external-cavity surface-emitting lasers (VECSEL) have been demonstrated to be a promising technology for applications ranging from spectroscopy to quantum computing and quantum simulation [1]. VECSELs combine compact size and high optical power and the advantage of a wide wavelength coverage.

We employ a gain mirror from Vexlum Ltd consisting of GaInAs/GaAs quantum wells strained with GaAsP layers to achieve a centre wavelength of 1118 nm with a tuning range of 30 nm [2]. With an optical-to-optical efficiency of approximately 25% we achieve up to 5 watts of optical output power.

For quantum logic spectroscopy with trapped magnesium ions the 1118 nm light has to be frequency doubled twice to access our target wavelength of 280 nm. We expect an overall UV output power of 20 mW and a laser linewidth of tens of MHz which allows us to use it for Doppler cooling, repumping and Raman transition.

[1] Burd et al, Optica Vol.3, No. 12 (2016)
[2] Ranta et al, J. Cryst. Growth 355, 4-9 (2011)

FM 41.12 Tue 16:30 Tents

Optical dipole trapping in a drop tower experiment — •Marian Woltmann[1], Christian Vogt[1], Sven Herrmann[1], Claus Lämmerzahl[1], and the PRIMUS Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM) — [2]LU Hannover, Institute of Quantum Optics

The application of an atom interferometer in weightlessness offers the potential of largely increased interrogation times. As the interferometers sensitivity scales with the square of the free evolution time, the sensitivity is significantly increased. While most such microgravity based experiments use magnetics traps formed by an atom chip, we develop an optical dipole trap for use in weightlessness as an alternative source of cold atom ensembles. Optical dipole traps offer unique advantages like an improved symmetry of the trapping potential and the accessibility of Feshbach resonances. Using a 10W trapping laser at a wavelength of 1949nm, we implement a dual species (Rb and K) cold atom experiment for use in the drop tower in Bremen. With our poster, we will give an overview of the experiment and report on the latest results for the evaporation from an optical dipole trap in microgravity. The PRIMUS-project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 1642.

FM 41.13 Tue 16:30 Tents

Characterisation of wavelength-shifted Photon Pairs for Quantum Imaging Applications — •Florian Herbst[1], Florian Elsen[2], Bernd Jungbluth[2], Hans-Dieter Hoffmann[2], and Reinhart Poprawe[1,2] — [1]Chair for Laser Technology RWTH Aachen University, Aachen, Germany — [2]Fraunhofer Institute for Laser Technology, Aachen, Germany

The mid-infrared spectral range (MIR) is gaining more and more importance for analytics and research, e.g. via spectroscopy and imaging applications. Such techniques usually require both photon generation and photon detection. By utilising spontaneous parametric down-conversion (SPDC), G. B. Lemos et al. (Nature, 2014) have demonstrated the feasibility of imaging with undetected photons. This even allows for imaging in spectral ranges for which detectors are not available. While many previous works that employed this scheme relied on visible (VIS) and near-infrared (NIR) photons, we aim to expand this scheme by using MIR photons instead of NIR ones. For this, our investigations started by examining emission properties of wavelength-shifted photon pairs generated from SPDC in the experimentally easily accessible regime of VIS and NIR, focussing on time-wise correlations. This source was then used to build an NIR-imaging device. With investigations going on, these setups serve as benchmarks for the prospective SPDC-based MIR-imaging prototype.

FM 41.14 Tue 16:30 Tents

Modeling and simulation of SPDC sources for quantum imaging experiments — •Felix Riexinger[1,2], Patricia Bickert[1], Björn Haase[1,2], Mirco Kutas[1,2], Daniel Molter[1], Michael Bortz[1], and Georg von Freymann[1,2] — [1]Fraunhofer-Institute for Industrial Mathematics ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), 67663 Kaiserslautern, Germany

Quantum imaging is a promising method to improve imaging applications in many sectors. Most setups use nonlinear crystals pumped in the low-gain regime as a source for entangled photons. We developed and implemented a general model for these SPDC sources, taking into account the finite extent of the crystal. This model allows us to explore the source characteristics without relying on certain approximations.

To allow for a comparison with the experimental spectra we also modeled the optical system of the experiment. The model agrees well with experimental results for various lithium niobate crystals pumped at 660nm. We applied our model to predict relevant quantities for imaging experiments, e.g., visibility and field of view.

Understanding the influence of the source parameters on the emitted photons allows for the design of optimal sources leading to improved imaging setups. Our work is an important step towards an improved development cycle for quantum imaging experiments and applications.

FM 41.15 Tue 16:30 Tents

A quantum acousto-optical transducer based on induced coherence without induced emission — •Joel Schmidt, Raphael Nold, Tobias Linkewitz, Florian Kaiser, and Jörg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

Laser and fibre microphones are amongst the most sensitive sound recording devices. They enable applications such as interaction-free long-range sound recognition and espionage, intestinal medical exams and high-sensitivity hearing-aids. Quantum optical sensors can achieve performance beyond the classical shot noise limit, however, sampling rates are severely limited by the necessity of using photon number resolving detectors (PNRD). Here, we show how to perform quantum-enhanced optical phase sensing using entangled photon pairs that are created via induced coherence without induced emission. This removes the necessity for PNRDs and promises much higher sampling rates. Our goal is to make humans hear the quantum advantage by demonstrating a quantum optical microphone with sub-shot noise performance.

FM 41.16 Tue 16:30 Tents

Master equation for enseble of multilevel atoms — •Aleksei Konovalov, Andreas Buchheit, and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

The development of stable atomic clocks for quantum metrology requires an accurate knowledge of the spectroscopic properties of atomic ensembles. Line shifts due to quantum interference in the decay channels of single atoms are measurable [1] and shall be reliably described by a master equation formalism. In this work we present a master equation formalism which systematically includes the interference effects in the incoherent decay of an ensemble of multilevel atoms. This master equation has the Lindblad form. In the single-atom limit it can be reduced to the master equation for a single atom including the cross damping terms, which lead to quantum interference in dissipative process [2], while for two-level atoms it reproduces the well-known master equation for superradiance [3]. We determine the spectroscopic signals for an ensemble of Hydrogen atoms and show that the interplay between crossdamping terms and superradiant decay can lead to significant modifications of the line shapes.

References

[1] N. Kolachevsky, A. Beyer, L. Maisenbacher et al, AIP Conference Proceedings 1936, 020015 (2018) [2] Andreas Alexander Buchheit and Giovanna Morigi, PHYSICAL REVIEW A 94, 042111 (2016) [3] M. Gross, S. Haroche, Superradiance: an essay on the theory of collective spontaneous emission, PHYSICS REPORTS 93, No 5 (1982) 301-396

FM 41.17 Tue 16:30 Tents

Progress Towards an Al^+ Quantum Logic Optical Clock — Johannes Kramer[1], Fabian Dawel[1], •Nicolas Spethmann[1], Sara Panahandeh[1], and Piet Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

We present the status of our aluminum ion optical clock, based on a single $^{27}Al^+$ clock ion trapped together with a $^{40}Ca^+$ logic ion used for sympathetic cooling and quantum logic state readout. $^{27}Al^+$ provides a narrow clock transition and low sensitivity to external field shifts. A measurement of the trap temperature combined with numerical simulations allows us to bound the black-body radiation shift to smaller than 10^{-19}. Micromotion has been compensated to a level well below a fractional frequency uncertainty of 10^{-17}. We developed double-bright electromagnetically induced transparency (D-EIT) cooling as a novel, fast multi-mode ground state cooling technique. Using D-EIT we demonstrated for the first time ground-state cooling of all three motional degrees of freedom of a trapped $^{40}Ca^+$ ion within a single, short cooling pulse. Extrapolating from these results, we expect a fractional second order Doppler shift from residual motion of an Al^+/Ca^+ crystal of well below 10^{-18}. We will present results of reading out the state of $^{27}Al^+$ using quantum logic and progress towards quantum logic spectroscopy of the clock transition.

FM 41.18 Tue 16:30 Tents

Control of the spin relaxation in hot atomic ensembles for spatially resolved magnetometry — •Victor Lebedev, Stefan Hartwig, and Thomas Middelmann — PTB 8.21, Abbestr. 2-12, D-10587 Berlin, Germany

Spin relaxation, both longitudinal and transverse, plays an essential role in quantum sensors based on thermal spin-polarized vapor. In case of magnetic field sensor, balance between pumping on one side, and collisional and inhomogeneous broadening, on the other side, defines the sensitivity and spatial resolution of the sensing atomic subensemble. Recent developments in optical pumping techniques open new ways in such ensemble preparation, using diode lasers with high spatial and temporal coherence, spatially resolved and high-bandwidth light-polarization instrumentation and fast intelligent control electronics. We investigate various approaches for the local spin preparation, ranging from conventional pump-probe techniques to structured light pumping and spin polarization imaging. We discuss fundamental and technical limitations of such systems and their possible applications. Our pilot results on inhomogeneous broadening suppression in alkali vapor magnetometer will be presented at the meeting.

FM 41.19 Tue 16:30 Tents

Microwave Raman Transitions in the Multilevel Electronic Ground State of the NV Center — •Sascha Neinert[1,2], Florian Böhm[1,2], Niko Nikolay[1,2], Nikola Sadzak[1,2], Bernd Sontheimer[1,2], and Oliver Benson[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Germany — [2]IRIS Adlershof, Humboldt-Universität zu Berlin, Germany

The nitrogen-vacancy (NV) center in diamond is the most prominent defect in diamond due to its outstanding properties as a quantum light source and its manipulable electron spin. NV applications range from quantum information processing to high sensitivity nanomagnetometry.

We discuss our recent progress of the population swapping via microwave Raman transitions in the multilevel electronic ground state of a single NV center. The here presented scheme relies on the polarization of the nuclear spin of the NV center at low magnetic fields. This hyperpolarization of the NV center's intrinsic nitrogen-15 can be achieved by recursive polarization via the NV center's electron spin [1,2].

[1] Pagliero, D. et al., Appl. Phys. Lett. 105.24 (2014): 242402.
[2] Chakraborty, T. et al., NJP 19.7 (2017): 073030.

FM 41.20 Tue 16:30 Tents

100 kHz Attosecond Pulse Source for Coincidence Spectroscopy — •Dominik Ertel[1], Anna-Lena Jäger[1], Samuel Kellerer[1], Matteo Moioli[1], Hamed Ahmadi[1], Fabio Frassetto[2], Luca Poletto[2], and Giuseppe Sansone[1] — [1]Institute of Physics, University of Freiburg, Stefan-Meier-Str. 19, 79104 Freiburg, Germany — [2]CNR-Institute of Photonics and Nanotechnologies (CNR-IFN), via Trasea 7, 35131 Padova, Italy

Attosecond coincidence spectroscopy builds a powerful tool to study ultrafast phenomena in atoms and molecules. Here, we present an attosecond XUV pulse source with high repetition rates up to 100 kHz, developed for photoelectron/-ion coincidence spectroscopy. Near infrared (NIR) laser pulses with up to 400 μJ pulse energy and a pulse duration of around 300 fs are temporally compressed using a gas-filled hollow-core fiber. Afterwards we use these pulses to generate trains of attosecond pulses via high-order harmonic generation in noble gases. RABITT (Reconstruction of Attosecond Beating by Interference of Two-photon Transitions) based coincidence pump-probe spectroscopy is performed using a reaction microscope. The long acquisitions measurements require an ultrastable control of the delay between pump (XUV) and probe (NIR). A novel non-interferometric delay line enables intrinsic delay synchronisation within a few attoseconds over several hours. Our unique coincidence spectroscopy setup will enable the investigation of electronic and coupled electronic-nuclear dynamics. Thus, shedding new light on the first instants of photoionization and subsequent nuclear dynamics in small size molecules.

FM 41.21 Tue 16:30 Tents

State-resolved photoionization time delays in CF_4 using two-color coincidence laser spectroscopy — •s. h. Ahmadi[1,2], m. moioli[1], e. plesiat[3], a. palaciosp[3], m. reduzzi[2], a. Stenftlebens[4], f. frassetto[5], l. poletto[5], f. bragheri[6], r. osellame[6], p. decleva[7], c. d. schröter[8], r. moshammer[8], t. pfeifer[8], f. martin[3], and g. sansone[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany — [2]Dipartimento di Fisica, Politecnico, Milano, Italy — [3]Departamento de Qumica, Universidad Autónoma de Madrid, Madrid, Spain — [4]Institute of Physics and CINSaT, University of Kassel, Kassel, Germany — [5]Istituto di Fotonica e Nanotecnologie, CNR, Padova, Italy — [6]Istituto di Fotonica e Nanotecnologie, CNR, Milano, Italy — [7]Dipartimento di Scienze Chimiche e Farmaceutiche, Universitá di Trieste, Trieste, Italy — [8]Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Photoionization time delays between photoelectrons leaving CF_4^+ in its X $^2T_1$ and C $^2T_2$ states are experimentally measured and simulated using pump(XUV)-probe(IR) coincidence laser spectroscopy in the photon-energy range of 20-46 eV. We acquired the photoelectron spectra as a function of the relative delay between the XUV and IR pulse. Simulations are performed by numerically solving TDSE using density functional theory. The results suggest complex photoionization dynamics on an attosecond time scale between photoelectrons leaving these two electronic states. The molecular-frame angular dependence of the photoelectrons can also be accessed and will be discussed.

FM 41.22 Tue 16:30 Tents

Attosecond pulse generation at FERMI FEL — •Praveen Kumar Maroju — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg Hermann-Herder-Straße 3, 79104 Freiburg, Germany

Extreme ultraviolet table-top sources based on high-order harmonic generation (HHG) in gases deliver attosecond pulses (trains and isolated), but at rather low photon flux, due to the intrinsic low-conversion efficiency of the HHG-process. On the other hand, Free Electron Lasers (FELs) deliver femtosecond pulses with energies up to the mJ-level. However, the majority of FELs operating in the XUV and X-ray spectral range are based on the self-amplified spontaneous emission (SASE) mechanism, resulting in a poor longitudinal coherence. Recently the temporal coherence between two harmonics of the same seed wavelength, was demonstrated at the seeded-FEL FERMI[1]. This experiment suggested the possibility to synthetize a comb of phase-locked frequencies, which should correspond in the time domain to a train of attosecond pulses. In this work we demonstrate for the first time the attosecond pulse train generation and characterisation at the FERMI FEL along with independent amplitude and phase control.

References:
1. K. C. Prince et al., Nat. Photonics 10, 176, (2016)

FM 41.23 Tue 16:30 Tents

Quantum Sensing of Microwave Magnetic Fields with Sensor Unlimited Resolution — •Jonas Meinel, Vadim Vorobyov, Boris Yavkin, Durga Dasari, and Jörg Wrachtrup — Universität Stuttgart, 3. Physikalisches Institut, Stuttgart, Germany

Diamond quantum sensors are sensitive to weak microwave magnetic fields resonant to the transitions in the quantum system [1]. The state of the art sensing protocols improved the sensors spectral resolution beyond T2* and are ultimately limited by T1. Here we demonstrate that heterodyne detection methods, widely applied for quantum sensing of radio frequency fields [2], could be extended to the microwave regime. We use phase control of the initial pulses of the sequences, which allows to create correlations between consecutive measurements. We show experimentally a Fourier limited linewidth for a single frequency source. Additional we resolve two 500 Hz separated frequencies demonstrating a corresponding spectral resolution beyond coherence time of the sensor. This work allows to sense ultra long coherent microwave fields, e.g. maser radiation, using a quantum sensor with a wide tuning range covering the full microwave spectrum (1 - 100 GHz).

[1] Joas, Timo, et al. "Quantum sensing of weak radio-frequency signals by pulsed Mollow absorption spectroscopy." Nature communications 8.1 (2017): 964. [2] Schmitt, Simon, et al. "Submillihertz magnetic spectroscopy performed with a nanoscale quantum sensor." Science 356.6340 (2017): 832-837.

FM 41.24 Tue 16:30 Tents

Nanodiamonds in three-dimensional direct-laser-written Waveguides for On-Tip-Sensing — •Jonas Gutsche[1,2], Stefan Dix[1], Alexander Landowski[1], and Artur Widera[1,2] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Kaiserslautern, Germany

Waveguide-coupled sensors have several applications such as magnetometry, electrometry or thermometry, harnessing the resolution of nano-sized probes as well as tight light control in macroscopic waveguide networks.

We present the incorporation of nanodiamonds into direct-laser-written (DLW) three-dimensional photonic structures. The nanodiamonds house ensembles of 10^3 nitrogen vacancy (NV) centers, acting as probes that can be read-out optically. Guided by on-chip waveguide structures and three-dimensional out of plane couplers integrated nanodiamonds are addressed and read out using a single microscope objective from below the substrate. We show optically detected magnetic resonance spectra together with Rabi oscillations on an effective two-level system in waveguide-embedded nanodiamonds. We compare their performance with free-space emission and numerical simulations.

Based on these structures, we show our approach to utilize DLW for further miniaturization of components needed for NV-magnetometry to a fiber tip. This approach paves the way for on-tip three-dimensional structures leading to a single-device endoscope for optically integrated spin-based sensing.

FM 41.25 Tue 16:30 Tents

Quantum sensing with superconducting microwave circuits — •Matti Partanen[1], Kirill G. Fedorov[1,2], Stefan Pogorzalek[1,2], Michael Renger[1,2], Qi-Ming Chen[1,2], Achim Marx[1], Frank Deppe[1,2,3], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

Quantum mechanics offers intriguing opportunities for sensing applications with accuracies beyond the classically obtainable limits. An especially interesting approach is based on using entangled microwave photons for radar applications. Here, we discuss a novel frequency-degenerate scheme for quantum sensing with superconducting microwave circuits. The same microwave regime is utilized in conventional radars owing to the transparency window of the atmosphere. Hence, our scheme suffers no conversion losses and, therefore, is promising for future real-world applications.

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FM 41.26 Tue 16:30 Tents

Optimal sensing with NV Centers in Diamond. — •Nimba Oshnik Pandey and Elke Neu — Universität des Saarlandes, Saarbrücken, Germany

Quantum optimal control theory has been extensively utilized in fields like NMR, atomic/molecular physics, Quantum computation to overcome various limitations posed by the experimental conditions and setup [1]. In this work we aim to develop and test nano-photonic diamond scanning probe structures containing Nitrogen Vacancy centers and implement optimal control fields to improve the sensitivity and robustness of the quantum sensing protocols.

NV centers in diamond have been well studied and utilized as quantum sensors owing to their long spin coherence times, and also the spin-dependent fluorescence. Using such atomic scale single-spin sensors in a scanning probe geometry enables sensing and imaging with maximum spatial resolution; in principle down to order of few nm [2]. We aim to develop control techniques using quantum optimal control algorithms for enhancing the full imaging capability, and to achieve desired robustness against control field amplitude variations and experimental limitations, further test optimization approaches for spin manipulation followed by first proof of principle experiments on optimized sensing.

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[2] Fuchs et. al. New J. Phys. 20 125001. 2018.

FM 41.27 Tue 16:30 Tents

Some practical considerations of quantum inertial sensors in navigation — •Benjamin Tennstedt and Steffen Schön — Institut für Erdmessung, Leibniz Universität Hannover, 30167 Hannover

In this contribution we will present some application cases for atom interferometry as an inertial sensor for navigation purposes. While there are more complex attempts for a six-degrees of freedom setup [2], which have not yet been realized and tested in a navigation filter framework, a simple setup of two counterpropagating interferometers, eg. [3], is already sufficient for specific navigation purposes like estimating the 2D-position and orientation of a non-holonomic vehicle on a plane, like it is the case with driverless transportation vehicles.

For 3D-navigation, additional supporting sensors are needed. By using error models based on real data [4] and our navigation simulation framework, we will point out some concrete examples and use-cases of the proposed setup in navigation, while also giving a hint on the specifications like sensitivity and stability the new sensors need to provide.

[1] M. Kasevich and S. Chu (1991), Atomic interferometry using stimulated Raman transitions, Phys. Rev. Lett. 67, pp. 181-184.

[2] B. Canuel et al. (2006), Six-axis inertial sensor using cold-atom interferometry, Phys. Rev. Lett. 97, 010402:1-010402:4.

[3] A. Gauguet et al. (2009), Characterization and limits of a cold atom Sagnac interferometer, <hal-00403630v3>.

[4] P. Berg et al. (2015), Composite-Light-Pulse Technique for High-Precision Atom Interferometry, Phys. Rev. Lett. 114, 063002.

FM 41.28 Tue 16:30 Tents

T^3-interferometry — •Matthias Zimmermann[1], Maxim A. Efremov[1], Omer Amit[2], Yair Margalit[3], Frank A. Narducci[4], Wolfgang P. Schleich[1], and Ron Folman[2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, Ulm, Germany — [2]Department of Physics, Ben-Gurion University of the Negev, Be'er Sheva, Israel — [3]Research Laboratory of Electronics, MIT-Harvard Center for Ultracold Atoms, Department of Physics, MIT, Cambridge, USA — [4]Department of Physics, Naval Postgraduate School, Monterey, USA

By exploiting the Kennard phase [1], we have proposed an atom interferometer [2] probing a linear potential and having a phase shift that scales as T^3, in contrast to conventional atom interferometers with a phase scaling as T^2, where T denotes the total interferometer time.

In this scheme we make use of two magnetic sensitive atomic states $|1\rangle$ and $|2\rangle$ leading to the respective state-dependent accelerations a_1 and a_2. Based on this work [2] a Stern-Gerlach interferometer [3] has been constructed which reveals the pure cubic phase scaling and represents the first atom optics observation of the Kennard phase. As this device does not require light pulses and its accumulated phase is very sensitive to magnetic fields, it may serve as a unique probe for magnetic surface properties.

[1] G. Rozenman et al., *Phys. Rev. Lett.* **122**, 124302 (2019)
[2] M. Zimmermann et al., *Appl. Phys. B* **123**, 102 (2017)
[3] O. Amit et al., submitted to *Phys. Rev. Lett.* (2019)