Q 40: Poster: Quantum Optics and Photonics II

Time: Wednesday 17:00–19:00 Location: P OGs

Q 40.1 Wed 17:00 P OGs

Coupled Photon Condensates in Micropotentials — •Erik Busley, Christian Kurtscheid, Christian Schilz, David Dung, Tobias Damm, Frank Vewinger, Julian Schmitt, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

We present a recent experimental realization of coupled photon condensates in a microstructured optical microcavity. In earlier work we have realized Bose-Einstein condensation of photons in a dye-filled optical microcavity at room temperature. The dye solution acts both as a heat bath and a particle reservoir for the trapped photon gas. Thermal contact between the photons and the molecules is achieved by subsequent absorption and reemission processes in the high-finesse bispherical cavity. The microresonator introduces a low-frequency cutoff to the dispersion relation, resulting in a nontrivial ground state and the harmonically trapped photon gas becomes formally equivalent to a 2D gas of massive bosons.

In the here reported work, the cavity geometry is controlled by permanently deforming an initially plane mirror surface by thermo-optically induced delamination of the dielectric layers. Heat deposited by an absorbed green laser beam causes the mirror surface to bend up locally, and by transverse steering of the laser beam over the mirror surface one can create arbitrary trapping potentials for a photon gas within the microcavity. The deformation setup and measurements on photon tunneling between two lattice sites are presented.

Q 40.2 Wed 17:00 P OGs

Bose-Hubbard ladder in a cavity-induced artificial magnetic field — •Catalin-Mihai Halati, Ameneh Sheikhan, and Corinna Kollath — HISKP, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany

We consider ultra-cold interacting bosonic atoms confined to quasi-one-dimensional ladder structures formed by optical lattices and coupled to the field of an optical cavity. The atoms can tunnel along the leg direction and collect a spatial phase imprint during the tunneling along a rung. The phase imprint is realized via Raman transition employing a cavity mode and a transverse running wave pump beam. By adiabatic elimination of the cavity field we obtain an effective Hamiltonian for the bosonic atoms, which needs to be analyzed self-consistently. We characterize the system by performing a Bogoliubov theory for quasi-particles excitations on top of the bosonic condensate, whose spectrum has characteristic features of the superfluid phase. In this framework we solve the self-consistency condition and identify the steady states that can occur.

Q 40.3 Wed 17:00 P OGs

Non-equilibrium dynamics of interacting Bosons in an optical lattice — •René Hamburger[1], Christian Baals[1,2], Bodhaditya Santra[1,3], Jian Jiang[1], Ralf Labouvie[1,2], Andreas Müllers[1], and Herwig Ott[1] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Staudinger Weg 9, 55128 Mainz, Germany — [3]Zentrum für optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany

We study the non-equilibrium dynamics of ultracold Bose gases in optical lattices using a scanning electron microscope. In a first experiment we remove the atoms from a slice of a 3D optical lattice and study the subsequent refilling dynamics of different lattice configurations. We observe a transition from a superfluid refilling to the hopping dynamics of a Mott insulator. The latter strongly depends on the filling level of the lattice sites: a n=1 Mott insulator moves in a single-particle hopping process, whereas a n=2 shell can only tunnel via second-order processes. Furthermore, we investigate the dynamics of the center of mass in a three dimensional optical lattice. To this end we shift the position of the confining dipole trap after loading the atoms into the lattice. Finally the atomic cloud is imaged with high resolution using electron microscopy. Upon increasing the lattice depth we find a transition from an oscillating superfluid to a slow uniform movement in the Mott regime. Additionally we present our future project on dissipative generation and stabilization of a dark soliton in 3D.

Q 40.4 Wed 17:00 P OGs

Real-time observation of a quantum phase transition between two insulators — •Nishant Dogra, Lorenz Hruby, Katrin Kröger, Manuele Landini, Tobias Donner, and Tilman Esslinger — HPF D4, Quantum Optics Group, Institute for Quantum Electronics, ETH Zurich,Otto-Stern-Weg-1,Zurich-8093

The phase transition between two insulating phases with different density ordering is thermodynamically possible but can be blocked due to the existence of energy barriers between various stationary states. We explore such a phase transition in a lattice model with competing onsite and global-range interactions in a Bose-Einstein Condensate (BEC). The global-range interactions arise from the coupling of the BEC to a single mode of a high-finesse cavity and illuminating it with a transverse laser-field. In the limit of deep optical lattices, the system favors either a Mott insulator or a charge density wave insulator depending on the relative interaction strength which is tuned via the cavity resonance. The corresponding order parameter can be detected in real time via the cavity light field. We observe a hysteretic loop in the transition between two insulators which we attribute to the existence of metastable states in the system. Moreover, the temporal dynamics of the order parameter across the transition exhibits two different time scales due to the presence of compressible surface states in our system.

Q 40.5 Wed 17:00 P OGs

Nonthermal Fixed Points and Universal Scaling in Ultracold Bose Gases far from Equilibrium — •Markus Karl[1,2] and Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Universal spatio-temporal scaling behaviour is studied in the dynamics of isolated and driven-dissipative Bose gases by means of semi-classical stochastic simulations of the Gross-Pitaevskii model. The system is quenched far out of equilibrium by means of instabilities, by directly imprinting vortex defects, or by applying a stochastic driving force. We demonstrate that, under these non-equilibrium conditions, the long-time dynamics is mainly determined by nonthermal fixed points, close to which universal scaling laws are realised for time-dependent correlation functions. In particular, we find that the time evolution of single-particle occupation spectra is given by a scaling transformation of universal scaling functions. We determine the corresponding scaling exponents by means of numerical simulations and interpret them in the light of field-theoretic predictions. We analyse the relation of the identified temporal scaling laws to phase ordering kinetics and coarsening of vortex defect distributions, thereby relating phenomenological and analytical approaches to classifying far-from-equilibrium scaling dynamics with each other. Moreover, the relation to superfluid turbulence as well as to driven stationary systems is discussed.

Q 40.6 Wed 17:00 P OGs

Quantum Phases in an Extended Bose-Hubbard Model with Global-Range Interactions — •Katrin Kröger[1], Renate Landig[1,2], Lorenz Hruby[1], Nishant Dogra[1], Manuele Landini[1], Rafael Mottl[1], Tobias Donner[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Department of Chemistry and Chemical Biology, Harvard University, Cambridge, MA 02138, USA

Quantum simulations with ultracold atoms have for a long time been limited to short-range collisional interactions, as long-range interactions have proven to be difficult to implement. Here, we experimentally realize an extended Bose-Hubbard model with long-range interactions using an atomic quantum gas trapped in a three-dimensional optical lattice and coupled to a single mode of a high finesse optical cavity. The strength of the short-range on-site interactions is controlled through the optical lattice depth. The vacuum mode of the cavity mediates a global-range interaction in the presence of a transverse laser beam. The corresponding strength can be tuned by shifting the frequency of the cavity resonance with respect to the frequency of the transverse pump beam. The interplay of tunneling, short- and global-range interactions leads to a rich phase diagram. We observe the appearance of four distinct phases, namely a superfluid, a supersolid, a Mott insulator and a charge density wave.

Q 40.7 Wed 17:00 P OGs

Bottom-up approach to many-body physics with ultracold atoms in adjustable lattices — •Martin Sturm, Malte Schlosser, Gerhard Birkl, and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt

Ultracold atoms in optical lattices have proven to be a powerful toolbox for quantum simulation of many-body physics. With the demonstration of single-site resolved imaging, local properties have shifted into the focus of this field. This development is complemented by the construction of double-well systems from single atoms in optical tweezers.

We present an experimental avenue to scalable and adjustable arrays of optical dipole traps using microlens arrays and spatial light modulators. This setup closes the gap between the aforementioned approaches and allows for a bottom-up construction of many-body systems adding one atom at a time. In order to evaluate the experimental feasibility of this approach we compute the accessible parameter regime for ^{7}Li, ^{23}Na, ^{41}K, and ^{87}Rb from measurements and simulations of the light field. Further, we investigate the time scales and heating mechanisms for loading from a Bose-Einstein condensate as well as from a low entropy state in the deep Mott insulator regime. As a possible application we analyze the tunneling dynamics between two coupled ring lattices. This configuration exhibits additional many-body resonances as compared to bosonic Josephson junctions in double-well potentials.

Q 40.8 Wed 17:00 P OGs

Non-equilibrium dynamics of an interacting Fermi gas — •Johannes Kombe, Jean-Sébastien Bernier, and Corinna Kollath — HISKP, Universität Bonn

Thanks to recent experimental advances, investigating the non-equilibrium dynamics of interacting systems is now possible. Using time-dependent perturbations, one can probe from a different angle the mechanisms responsible for the collective phenomena present in correlated systems. Taking advantage of the recent progress, we investigate theoretically the evolution of a trapped three-dimensional Fermi gas during a slow interaction change. Our study, carried out on the BCS side, reveals various collective excitations.

Q 40.9 Wed 17:00 P OGs

Towards a lithium quantum gas microscope for small quantum systems — •Andreas Kerkmann, Michael Hagemann, Jan Mika Jacobsen, Justus Brüggenjürgen, Malte Hagemann, Benno Rem, Christof Weitenberg, and Klaus Sengstock — Institut für Laserphysik, Hamburg, Germany

We are setting up a new quantum gas microscope for the preparation and detection of degenerate samples of ^{6}Li/ ^{7}Li atoms to study strong correlations in small quantum systems. Our design is optimized for a short cycle time allowing good statistics even in the case of just a few atoms. It consists of a compact 2D-/ 3D-MOT chamber aiming for an all-optical preparation of degenerate samples. In our poster, we provide information about details of the design and the current status of the experiment.

Q 40.10 Wed 17:00 P OGs

Measuring transport properties of a quantum point contact for cold atoms — •Dominik Husmann[1], Martin Lebrat[1], Samuel Häusler[1], Sebastian Krinner[1], Laura Corman[1], Jean-Philippe Brantut[2], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, Switzerland — [2]Institute of Physics, EPFL Lausanne, Switzerland

Quantum point contacts (QPCs) featuring quantization of conductance are fundamental components for mesoscopic nanostructures. Here we study the evolution of quantized conductance with interaction strength across the BEC-BCS crossover in ultracold fermions. Our system is a two-terminal setup of lithium 6 atoms in two different hyperfine states, connected by an optically tailored QPC. We impose independently a spin or particle imbalance between the reservoirs, creating a restoring drive that allows to measure spin and particle conductance. With increasing attractive interactions we find a plateau in the particle conductance at values larger than the expected quantum of 1/h. Subsequently we observe an onset of superfluidity manifested in a abrupt increase of the conductance with density. The superfluid gap causes a suppression of spin excitations, which we see in a non-monotonous behavior in spin conductance as a function of density. Complementary to creating particle and spin bias, we can apply a temperature gradient between the reservoirs. The thermoelectric response of the system is an interplay between QPC and reservoir contributions. The high tunability of our system opens up a wide parameter range to study thermoelectricity through a QPC.

Q 40.11 Wed 17:00 P OGs

Spin- and density-resolved microscopy of antiferromagnetic correlations in Fermi-Hubbard chains — •Joannis Koepsell[1], Timon Hilker[1], Guillaume Salomon[1], Martin Boll[1], Ahmed Omran[1], Jayadev Vijayan[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institute für Quantenoptik — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, München

Important aspects of the puzzling physics of the doped Hubbard model are believed to be rooted in the complex interplay between magnetism in the spin sector and correlations in the density sector. A quantum simulator that at the same time resolves the spin and density degrees of freedom and thus allows to measure correlations between them would be a perfect tool to explore these systems. Here we report on details of the realization of such a quantum gas microscope for fermionic Lithium. Furthermore, we summarize recent measurements revealing antiferromagnetic correlations in 1d Hubbard chains. By a comparison to Quantum-Monte-Carlo simulations we infered an entropy below ln(2) at which longer ranged correlations emerge. Additionally, we report on ongoing measurements of spin-density correlations in doped systems and our progress with two dimensional systems.

Q 40.12 Wed 17:00 P OGs

Observing the hierarchy of energy scales in a periodically driven two-body system — •Kilian Sandholzer, Rémi Desbuquois, Michael Messer, Frederik Görg, Gregor Jotzu, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, Zürich, Switzerland

Applying time-periodic potentials is a very useful tool to experimentally realize exotic Hamiltonians. In the framework of Floquet theory the physics is described by slow dynamics of an effective Hamiltonian and the micromotion. By loading a two-component Fermi gas in an array of modulated double-wells we realize a driven building block of the Hubbard model. Measuring the number of doubly occupied sites and the spin-spin correlation the micromotion of the driven system is revealed and compared to theory. Tuning the interaction near to the driving frequency leads to an increased coupling to higher states. Here, we investigate whether the groundstates of the static and effective Hamiltonians are adiabatically connected. We show a regime where we are able to prepare and measure Floquet engineered Hamiltonians beyond the high-frequency expansion in an interacting two-particle system.

Q 40.13 Wed 17:00 P OGs

Controlling magnetic exchange couplings in periodically driven systems — •Michael Messer, Frederik Görg, Gregor Jotzu, Kilian Sandholzer, Rémi Desbuquois, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, Switzerland

Floquet engineering can be used to implement effective Hamiltonians that reach beyond the Hubbard model. By modulating the lattice position of an interacting system on an array of double wells we implement a Floquet Hamiltonian with controllable magnetic exchange energy. When shaking at a frequency slightly detuned to the interaction energy we can use the shaking amplitude to tune the strength of the magnetic exchange independently of the single particle tunneling. In addition Floquet engineering enables us to switch from static anti-ferromagnetic behavior to a ferromagnetic coupling within our fermionic system. We furthermore implement our scheme for interacting many-body systems and address the question whether experimental timescales are favorable to adiabatically connect states of the driven system to the initial states.

Q 40.14 Wed 17:00 P OGs

Exploring Quantum Antiferromagnets with single-site resolution — •Daniel Greif, Anton Mazurenko, Christie S. Chiu, Geoffrey Ji, Maxwell F. Parsons, and Markus Greiner — Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

Strongly correlated electron systems are at the center of many poorly understood phenomena in condensed matter systems, including high-temperature superconductivity, which is thought to be well described by the Hubbard model. Ultracold fermionic atoms trapped in a 2D layer of a square lattice provide a clean and tunable implementation of the Hubbard model. Optical microscopy on these systems permits an unprecedented degree of control and detection unavailable in traditional condensed matter systems. We report site-resolved measurements of strongly interacting many-body states, including 2D fermionic Mott insulators and band insulators. We further report site-resolved measurements of the spin correlation function in these samples, exhibiting antiferromagnetic correlations. High fidelity addressing with a digital micromirror device permits exploration of previously inaccessible regions of the Hubbard model at temperatures below the 3D Neel transition temperature. We detect the presence of antiferromagnetic long-range order at temperatures $T/t = 0.25$ directly from a peak in the spin structure factor, corresponding to a finite staggered magnetization, and a diverging correlation length of the spin correlation function. Our results open the path for a controlled study of the low-temperature phase diagram of the Hubbard model.

Q 40.15 Wed 17:00 P OGs

Gray molasses cooling of ^{6}Li towards a double-degenerate ^{133}Cs-^{6}Li Bose-Fermi mixture — •Manuel Gerken, Stephan Häfner, Binh Tran, Melina Filzinger, Bing Zhu, Juris Ulmanis, and Matthias Weidemüller — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

An ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li is an ideal system for the study of Efimov's scenario as well as polarons due to its large mass imbalance and the tunability of intra- and interspecies interactions via Feshbach resonances. Gray molasses on the D1 line of ^{6}Li is newly implemented in the experiment as a further cooling step after Doppler cooling in the MOT. We achieve Sub-Doppler temperatures of down to 42 μK with almost unit capture efficiency. This leads to a tenfold improvement in phase-space density and therefore better starting conditions for the generation of a double-degenerate Bose-Fermi mixture.

Q 40.16 Wed 17:00 P OGs

Laser Cooling in a Parabolic Mirror — •Thorsten Haase, Nils Trautmann, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt

The efficient coupling of light to single quantum receivers is of high interest in quantum optics and quantum communication. In current experiments coupling inside a parabolic mirror is investigated [1]. We propose a semiclassical theory for laser cooling inside the parabolic mirror which includes both standing waves and strongly focused waves. Our treatment predicts relevant deviations from the usual case of Doppler cooling which typically considers plane running waves only. These generalisations affect the motion of the particle and lead to different probability density functions inside the trap. Stochastic simulations are presented for the probability density function. First one-dimensional simulations show that the steady states inside the parabolic mirror deviate from Gaussian or thermal distributions, which are predicted by the theory of Doppler cooling with plane waves. This could explain recent experimental results. Also, we present three-dimensional simulations investigating these effects for more realistic setups.

[1] M. Fischer, M. Bader, R. Maiwald, A. Golla, M. Sondermann, and G. Leuchs, Applied Physics B 117 (2014)

Q 40.17 Wed 17:00 P OGs

New apparatus for laser cooling and trapping of Dy and K atoms — C. Ravensbergen[1,2], S. Tzanova[1,2], M. Kreyer[2], •E. Soave[2], A. Werlberger[2], V. Corre[1,2], E. Kirilov[2], and R. Grimm[1,2] — [1]IQOQI, Austrian Academy of Sciences, Innsbruck, Austria — [2]Insitute for Experimental Physics, University of Innsbruck, Innsbruck, Austria

We have developed a new apparatus for producing mixtures of dysprosium and potassium atoms. Atoms of K are first cooled with a 2D$^+$ MOT, which reduces the transverse velocities. A beam propagating along the longitudinal direction pushes atoms into the main chamber, where they are trapped in a 3D magneto-optical trap. We have achieved both a MOT of the bosonic ^{39}K and fermionic ^{40}K isotope. A Dy atomic beam is created in a high-temperature effusion oven, it is then slowed in a combination of transverse cooling and a Zeeman slower. In the main chamber atoms are trapped in a narrow-line 3D MOT. The beams with a 40 mm diameter are tuned to the 136 kHz linewidth transition at 626 nm. Because of the narrowness of the line, the laser is locked onto a high-finesse cavity. The lasers for the Dy MOT and for K are all fiber-laser systems. This brings the advantages of a linewidth of the order of 10 kHz, high beam quality, and both high mechanical and temperature stability.

Q 40.18 Wed 17:00 P OGs

Microtrap for hybrid Rb-Yb$^+$ systems — •Matthias Müller[1], Abasalt Bahrami[1], Jannis Joger[2], Rene Gerritsma[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Institute of Physics, Universiteit van Amsterdam

Mixtures of ultracold atoms and trapped ions [1] form interesting platforms for studying cold chemistry, cold collisions, polaron physics, but also quantum information and quantum simulation with strong links to condensed matter physics [2]. We have designed and fabricated a combined atom and ion trap based on modern chip trap technology that employs strong inhomogeneous magnetic fields generated by integrated electromagnets to trap the atoms. Such tight magnetic traps will allow wavepacket sizes of the atoms in the range of the atom-ion interaction range. Straight-forward magnetic field control should make it possible to resolve the atom-ion interaction with sub-μm precision [3].

[1] A. Härter, J. Hecker Denschlag, Cont. Phys., 55, 33 (2014).
[2] C. Zipkes, S. Paltzer, C. Sias and M. Kohl, Nature 464, 388 (2010).
[3] J. Joger, Master thesis, University of Mainz (2013).

Q 40.19 Wed 17:00 P OGs

Spin-dependent Transport of Neutral Atoms in a 2D Polarization-Synthesized Optical Lattice — •Max Werninghaus, Stefan Brakhane, Geol Moon, Gautam Ramola, Carsten Robens, Alexander Knieps, Richard Winkelmann, Wolfgang Alt, Dieter Meschede, and Andrea Alberti — Institut für angewandte Physik Bonn

Discrete time quantum walks can be realized by deterministically transporting atoms based on their internal state. We recently reported on a new scheme for the polarization synthesis of a spindependent optical lattice that overcomes limitations of previous EOM-based setups by enabling arbitrary transport distances in a single step [1]. Here, we present an implementation extending the concept of polarization-synthesized to two dimesions, allowing spin-dependent transport in x- and ydirection [2] . The polarization synthesis to create an arbitrary polarization relies on the phase - and intensity control of two independent overlapped beams of opposite circular polarization[1]. I present the experimental realization and characterization of the opto-electronic control loops relying on a digital controller which allows us to use feedforward procedures based on internal model control.

[1] C. Robens et al: Fast, high-precision optical polarization synthesizer for ultracold-atom experiments, arXiv:1608.02410 (2016)
[2] T. Groh et al: Robustness of topologically protected edge states in quantum walk experiments with neutral atoms Phys. Rev. A (editors suggestion) **94** (2016)

Q 40.20 Wed 17:00 P OGs

Van der Waals interactions of Rydberg excitons — •Johannes Block and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Strasse 23, D-18059 Rostock, Germany

Rydberg atoms experience strong van der Waals interactions due to their large dipole moments that result in a so-called Rydberg blockade [1,2]. Similarly, Rydberg excitons in semiconductors such as Cu_2O with wavefunctions in the μm-range [3] are likely subject to strong van der Waals interactions. We apply well-known atomic calculations [2,4] to the excitonic system to obtain the Rydberg blockade. Here we show that the small level spacing including quantum defects [5] as well as the confining symmetry of the semiconductor crystal [6] provide additional contributions to the interaction.

[1] E. Urban *et al.*, Nature Physics **5**, 110 - 114 (2009).
[2] T.G. Walker, M. Saffman, Phys. Rev. A **77**, 032723 (2008).
[3] T. Kazimierczuk *et al.*, Nature **514**, 343 (2014).
[4] J. Han, Phys. Rev. A **82**, 052501 (2010).
[5] F. Schöne *et al.*, J. Phys. B **49**, 134003 (2016).
[6] H. Safari, M.R. Karimpour, Phys. Rev. Lett. **114**, 013201 (2015).

Q 40.21 Wed 17:00 P OGs

Electric field controlled collisions between polar molecules

and Rydberg atoms — •Ferdinand Jarisch and Martin Zeppenfeld — Max Plank Institut für Quantenoptik, Garching

Controlling collisions and chemical reactions via external electric or magnetic fields provides unprecedented control over such processes, with applications including Feshbach association of ultracold molecules from ultracold atoms. We present electric field controlled collisions between polar molecules and Rydberg atoms. State changing collisions between polar molecules and Rydberg atoms are mediated by Förster resonant energy transfer. Changing the resonance condition via electric fields allows the collision cross section to be varied. Our work is a first step towards quantum control of hybrid molecule-Rydberg-atom systems, with possible applications including efficient nondestructive detection of polar molecules[1].

[1] M. Zeppenfeld, "Nondestructive Detection of Polar Molecules via Rydberg Atoms", Nov. 2016, arXiv:1611.08893 [physics.atom-ph]

Q 40.22 Wed 17:00 P OGs

Magnetic shielding of an atomic chip trap — •Florian Grewe and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

In context of the QUANTUS project, degenerated quantum gases are created in weightlessness for high precision measurements. In order to achieve degeneracy, atoms have to be trapped and cooled down over several steps. A combination of coils and a carefully designed atomic chip [1, 2, 3, 4] is used to generated magnetic fields to trap, cool and manipulate the cold atomic gas. In addition to the atomic chip, there is a cylindrical mu-metal shielding to cancel the earth's magnetic field and other residual perturbations. Clearly, this shield has also an effect on the field created by the chip trap.

Here we present our analysis of the magnetic field inside the shielding leading to corrections of the atomic magnetic potential.

[1] W. Herr, Eine kompakte Quelle quantenentarteter Gase hohen Flusses für die Atominterferometrie unter Schwerelosigkeit, PhD thesis, Gottfried Wilhelm Leibniz Universität Hannover, 2013.

[2] J. Fortágh, C. Zimmermann, Rev. Mod. Phys. 79, 235 (2007).

[3] J. Schmiedmayer, et al., Adv. At. Mol. Opt. Phy. 48, 263 (2002).

[4] T. W. Hänsch, J. Reichel, et al., Nature 413, 498 (2001).

Q 40.23 Wed 17:00 P OGs

Compact and stable potassium laser system for dual-species atom interferometry in microgravity — •Julia Pahl[1], Christoph Grzeschik[1], Aline Dinkelaker[1,2], Max Schiemangk[1,2], Markus Krutzik[1], Achim Peters[1], and The QUANTUS-Team[1,3,4,5] — [1]HU Berlin — [2]FBH Berlin — [3]U Bremen — [4]LU Hannover — [5]JGU Mainz

We present a laser system for laser cooling and atom interferometry with ^{41}K atoms for future dual-species experiments in microgravity testing the Einstein equivalence principle with ultracold quantum matter. This potassium laser system will be integrated into the QUANTUS-2 drop capsule already performing atom-chip based rubidium BEC experiments at the drop tower in Bremen. Demanding limitations on mass and size due to the capsule's technical restrictions as well as strong accelerations during the catapult launch require the laser system to be compact and robust. High-power, micro-integrated distributed-feedback diode laser modules in combination with novel compact electronics allow to meet these strict requirements while keeping the output power and spectral characteristics compliant with ^{41}K BEC generation. In this poster, we present the details of our laser system, focussing on overcoming technical demands and discuss the challenges of ^{41}K featuring a hyperfine splitting comparable to the natural linewidth.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1552-1557.

Q 40.24 Wed 17:00 P OGs

Influence of external forces in near-field matter-wave interferometry — •Filip Kiałka, Benjamin Stickler, and Klaus Hornberger — Faculty of Physics, University of Duisburg-Essen, Lotharstraße 1-21, 47048 Duisburg, Germany

Molecular matter-wave interferometry is an established experimental technique with applications in precision metrology and fundamental quantum science [1]. In this work, we analyze the interference pattern observed in a generic Talbot-Lau interferometer (TLI) subject to external forces. In particular, we study the influence of the Coriolis force, which will become significant for interferometers with long flight times. We quantify the loss of interference contrast and explore the strategies to correct for the Coriolis effect in a TLI setup. Finally, we examine how the external force exerted by an electric field with a constant gradient could be used for metrological purposes.

[1] Testing the limits of quantum mechanical superpositions, M. Arndt and K. Hornberger, Nature Physics 10 (2014) 271-277

Q 40.25 Wed 17:00 P OGs

Compact diode laser system for dual-species atom interferometry with Rb and K in space — •Oliver Anton[1], Klaus Döringshoff[1], Vladimir Schkolnik[1], Simon Kanthak[1], Markus Krutzik[1], Achim Peters[1], and The MAIUS Team[1,2,3,4,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand Braun Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]ZARM, Universität Bremen — [4]Institut für Physik, JGU Mainz — [5]IQO, Leibniz Universität Hannover

The MAIUS II/III missions will perform dual-species atom interferometry with BEC's onboard sounding rockets, enabling longer, uninterupted timescales of micrograviy than any other ground based facility. By therefore effectively increasing interferometer times beyond the typical limits imposed by, for example, the maximum height of terrestrial instruments, MAIUS II/III will allow for high-precision measurements of Einsteins's Equivalence principle.

This poster presents the design of our laser system for this mission in detail. All key components such as micro-integrated high power diode lasers, optical fiber splitter system and Zerodur bench technology will be highlighted. The laser sources are exetended cavity diode laser (ECDL) master oscillator power amplifier (MOPA) modules. They feature wavelengths of 780 nm and 767 nm for Rb and K as well as 1064 nm for a dipole trap.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WP1432.

Q 40.26 Wed 17:00 P OGs

MAIUS-B: Towards dual species atom interferometry with Bose-Einstein condensates in space — •Baptist Piest[1], Wolfgang Bartosch[1], Dennis Becker[1], Michael Elsen[2], Kai Frye[1], Maike D. Lachmann[1], Wolfgang Ertmer[1], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, LU Hannover, Hannover, Deutschland — [2]DLR Institut für Raumfahrtsysteme, Bremen

We explore the feasibility of a quantum test of the Einstein equivalence principle with a dual species atom interferometer in space. The precision of such an experiment can be enhanced by the extended free fall of the matter waves in the interferometer. Goals of the sounding rocket mission MAIUS-2 are the generation of K-41 and Rb-87 BECs and the first demonstration of Raman based matterwave interferometry in space. The design builds on the MAIUS-A experiment [1]. The new system has been commissioned and qualified on ground and first results on ground-based cooling of alkaline atoms are presented.

[1] J. Grosse et al., J. Vac. Sci. Technol. A 34, 031606 (2016).

Q 40.27 Wed 17:00 P OGs

Demonstration of an all digital optical phase-lock for precision measurements. — •Alexandros Papakonstantinou, Thijs Wendrich, Wolfgang Bartosch, Ernst Rasel, and Wolfgang Ertmer — Institut für Quantenoptik, Universität Hannover

For many applications in quantum optics involving for example an atom interferometer, one will need lasers with a precise phase relation. The residual phase noise transfers directly to the performance of an atom interferometer. In this poster we present an all-digital optical phase-lock implemented in an FPGA. The FPGA receives a pre-scaled beat signal between two lasers and outputs an analog signal that directly drives the laser. Its firmware includes the phase frequency detector as well as the loop filter and enables an easy, software based, optimization of loop parameters for best performance in different tasks. This new phase-lock technique can enable phase-locks for tasks in quantum optics that previously used less advanced techniques, and can be used to further improve experiments like the MAIUS missions.

This work is part of the Quantus/Maius project which is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under grant number 50WM1239.

Q 40.28 Wed 17:00 P OGs

Control electronics for precision measurements on a sounding rocket. — •Wolfgang Bartosch, Thijs Wendrich, Ernst Rasel, and Wolfgang Ertmer — Institut für Quantenoptik, Universität Hannover

Interferometry experiments with ultra-cold degenerate quantum gases under microgravity conditions offer possibilities to test fundamental laws of physics to unprecedented precision. The MAIUS-1 mission will explore BEC interferometry in space. Operation on sounding rockets poses stringent requirements on the mass, volume and especially features such as reliability robustness of the payload. In this poster we show the electronics we designed to control an atom interferometer experiment on a sounding rocket. We had to downsize lab filling electronics to match the requirements on a sounding rocket both in size and toughness while maintaining its accuracy.

The QUANTUS/MAIUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 604 107 22.

Q 40.29 Wed 17:00 P OGs

Progress report towards a portable ^{27}Al^{+} optical clock — •Stephan Hannig[1], Nils Scharnhorst[1], Johannes Kramer[1], Lennart Pelzer[1], Stepanova Mariia[1], Leroux Ian D.[3], Tanja E. Mehlstäubler[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany — [3]National Research Council Canada, 1200 Ottawa, Canada

We present the status of our aluminium ion optical clock using quantum logic techniques for cooling and reading out the clock ion. The design goals for the frequency standard are an inaccuracy below 10^{-17} and relative instability better than 10^{-15} in one second. ^{27}Al^{+} provides a narrow (8 mHz) clock transition at 267 nm which exhibits no electric quadrupole shift and a low sensitivity to black-body radiation. A single ^{27}Al^{+} ion will be confined in a linear Paul Trap together with a ^{40}Ca^{+} logic ion. The latter is used for sympathetic cooling and internal state detection of the clock ion via Coulomb interaction.

A second generation, new vacuum chamber and complete Ca^{+} laser system have been set up, partly using fiberized components to feature miniaturization and thereby portability. The chamber includes a segmented multi-layer linear Paul trap. This design enables the implementation of multi-ensemble, multi-ion clock protocols which can advance the stability of ion-based optical clocks.

We will use such a transportable optical clock for aplications such as relativistic geodesy.

Q 40.30 Wed 17:00 P OGs

Investigation of fast ground state cooling schemes for a trapped Ca ion — Nils Scharnhorst[1], •Johannes Kramer[1], Javier Cerrillo Moreno[2], Alex Retzker[3], Ian D. Leroux[4], and Piet O. Schmidt[1,5] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Technische Universität Berlin, 10623 Berlin — [3]The Hebrew University of Jerusalem, 91904 Jerusalem — [4]National Research Council Canada, 1200 Ottawa — [5]Leibniz Universität Hannover, 30167 Hannover

One of the major systematic uncertainties of frequency standards based on light atoms, such as the aluminium ion, is the time dilation shift from residual motion. This requires fast near-ground state cooling of all motional modes to reduce this shifts and minimise dead time between interrogations. Conventional Doppler cooling techniques typically do not achieve the required reduction in motional energy. Sideband cooling techniques achieve this goal, but typically only for a single motional mode at a time. In multi-level atoms, coherences between levels can be used to design non-Lorentzian scattering spectra that selectively suppress heating processes, promising cooling times comparable to Doppler cooling. We investigate double-EIT cooling [1], based on a tripod level scheme in a calcium ion, involving the two ground states $S_{1/2}$ and the metastable $D_{5/2}$ levels. We demonstrate simultaneous cooling of the radial and axial motional modes of a ^{40}Ca^{+} ion near to the ground state in a single, short laser pulse.

[1] Evers, J. and Keitel, C. H., *Europhys. Lett.*, **68** 370 (2004).

Q 40.31 Wed 17:00 P OGs

Precise optical bulk and surface absorption measurements in high purity silicon. — •Johannes Dickmann[1,2,3], Stefanie Kroker[1,2], Carol Bibiana Rojas Hurtado[1,2], René Glaser[3], and Ronny Nawrodt[3] — [1]Physikalisch-Technische Bundesanstalt — [2]Technische Universität Braunschweig — [3]Friedrich-Schiller-Universität Jena

Silicon is a promising material for high-precision metrological applications such as gravitational wave detectors and frequency stabilized laser systems for the realization of optical clocks. In order to maximize the performance of such experiments, the optical absorption of all involved elements should be as small as possible. This sets high demands to the purity of the utilized silicon material. For quantitative statements on the optical performance it is essential to measure the surface and bulk absorption separately. Photothermal deflection spectroscopy is a powerful tool for these measurements. In this contribution, theoretical and experimental aspects of such high resolution measurements are discussed. Numerical calculations are presented which help to estimate the influence of all parameters and thereby to optimize the experimental setup. We present results of the following measurements: Bulk absorption of silicon samples with variable doping gradients, room temperature surface absorption in dependence of surface roughness as well as temperature dependent surface and bulk absorption down to 4 K. The developed experimental setup is very sensitive to material disturbances. Therefore, an application in quality control of 2D (thin films) and 3D (bulk materials) is possible.

Q 40.32 Wed 17:00 P OGs

Asymmetry induced resonances for performance prediction of short wavelength periodic nanostructures — •Carol Bibiana Rojas Hurtado[1,2], Johannes Dickmann[1,2], Thomas Siefke[1,3], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt — [2]Technische Universität Braunschweig — [3]Friedrich-Schiller-Universität Jena

Nano-optical elements for applications at short wavelengths are subject to strict requirements with respect to structural accuracy. Even deviations in the range of a few nanometers can have a considerable impact on the optical performance of the related elements. In this contribution, we investigate asymmetry induced guided mode resonances (GMR) as a measure for structure deviations in nano-optical wire grid polarizers made of titania. Hereby, the structural asymmetry arises from the self-aligned double patterning process - a well-established technique for the realization of structures with small periods. The guided mode resonances yield information about the structure geometry and enable the prediction of the polarizer performance at short wavelengths < 200 nm. Thus, easily accessible reflectance and transmission spectral measurements at a wavelength around 370 nm can replace an elaborate optical characterization in the DUV region. An additional advantage of this method is that no calibration is necessary which promises high application potential as in-situ tool. Furthermore, the presented method can be extended to applications at even shorter wavelengths down the extreme ultraviolet spectral region as well as to 2D periodic structures of versatile shape.

Q 40.33 Wed 17:00 P OGs

Pulse shaping of single photons with pulsed cavity SPDC sources — •Simon Laibacher[1] and Vincenzo Tamma[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, D-89069 Ulm, Germany — [2]Faculty of Science, SEES, University of Portsmouth, Portsmouth PO1 3QL, UK

Cavity-enhanced spontaneous parametric down conversion (SPDC) is used extensively as a light source in quantum optics. Such sources are nowadays often integrated into waveguides where high finesses cannot easily be achieved and thus reservoir theory cannot be applied to describe the coupling of the cavity. Recently, a description of such sources for arbitrary sub-threshold gain has been published for continuous pumping [1].

Our work aims to extend this description by including a finite phase matching bandwidth and allowing for a pulsed operation of the source. We derive the general Bogolioubov transformation between the input and output fields of the cavity for Type-II SPDC under these conditions. Our approach allows us to easily calculate arbitrary correlation functions of the generated two-mode state. We then use our formalism to investigate how the shape of the pump pulse and post-selection in the heralding time of the idler photons can be employed to engineer the shape of the signal photons. Further, corrections to the signal-idler cross correlation function reported in [1] are found in the limit of near-threshold squeezing.

[1] Zielińska and Mitchell, Phys. Rev. A **90**, 063833 (2014).

Q 40.34 Wed 17:00 P OGs

Optimizing the correlation signals in Hanbury-Brown-Twiss-setups — •André Pscherer, Raimund Schneider, Thomas

Mehringer, Johannes Hölzl, and Joachim von Zanthier — FAU Erlangen-Nürnberg, Erlangen, Deutschland

When measuring the correlations between arrival times of photons at two detectors like in the original Hanbury-Brown and Twiss (HBT) experiment the key to satisfactory results is a good understanding of the various parameters affecting the second order photon correlation function $g^{(2)}(\vec{r}_1, \vec{r}_2, \tau)$. We discuss in particular effects like a finite detector size and limited temporal resolution and investigate how they influence the trade-off between count rates and the contrast of the $g^{(2)}(\vec{r}_1, \vec{r}_2, \tau)$-function.

Q 40.35 Wed 17:00 P OGs

Microwave quantum logic for high fidelity quantum simulation with $^9\mathrm{Be}^+$ ions — •Sebastian Grondkowski[1], Timko Dubielzig[1], Fabian Ude[1], Hening Hahn[2,1], Giorgio Zarantonello[2,1], Martina Wahnschaffe[2,1], Amado Bautista-Salvador[2,1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Physikalisch-Technische-Bundesanstalt Braunschweig, Bundesallee 100, 38116 Braunschweig

We describe the necessary experimental infrastructure to perform experiments with an integrated microwave near-field surface-electrode ion trap developed in our group [1] at cryogenic temperatures with applications in quantum simulation and quantum logic. We discuss our loading scheme using a pulsed laser for ablating and a subsequent cw-laser at 235 nm for photo-ionization [2]. An additional laser beam at 313 nm is used for cooling, repumping and detetion of $^9\mathrm{Be}^+$ hyperfine qubit ions, similar to [3]. We use a set of water cooled coils which produce a magnetic field of 22.3 mT. At this field the qubit transition becomes field-independent in first order, making the qubit robust against fluctuations. We discuss a sophisticated pulse-shaping scheme to implement quantum logic operations with high fidelity using short microwave pulses (cf. [4]).

[1] M. Carsjens et al., Appl. Phys. B 114, 243-250 (2014)
[2] H.-Y. Lo et al., Appl. Phys. B 114, 17-25 (2014)
[3] A.C. Wilson et al., Appl. Phys. B 105, 741-748 (2011)
[4] D. Hayes et al., PRL 109, 020503 (2012)

Q 40.36 Wed 17:00 P OGs

Simulating boson sampling in free space — •Marc-Oliver Pleinert[1,2] and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany

Boson sampling constitutes a promising model of quantum computation, which probably for the first time will show post-classical calculations, even though it is restricted and non-universal. Here, we investigate a particularly simple boson sampling device consisting of freely propagating photons of different statistics. We relate the boson sampling probabilities to correlation functions in free-space setups. We find that the structure of the multi-photon interferences and spatial correlation functions reflect exactly those occurring in boson sampling and thus are characterized by the permanent of a propagation matrix. As a result, we are able to simulate boson sampling-like computations in free space. We also investigate the computational complexity of such a setup.

Q 40.37 Wed 17:00 P OGs

2D arrays of ion traps in cryogenic environment for quantum information processing — •Philip Holz[1], Kirill Lakhmanskiy[1], Stefan Partel[2], Stephan Kasemann[2], Volha Matylitskaya[2], Johannes Edlinger[2], Muir Kumph[4], Mike Brownnutt[5], Yves Colombe[1], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Uni Innsbruck, Austria — [2]Fachhochschule Vorarlberg, Dornbirn, Austria — [3]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria — [4]IBM Thomas J. Watson Research Center, Yorktown Heights, USA — [5]The University of Hong Kong, Pokfulam, Hong Kong

Linear chains of trapped ions are used for quantum simulation of 1D spin systems [1]. 2D arrays of ion traps may allow to extend the range of accessible simulations to systems with more than one spatial dimension, because of the physical arrangement of the individual trapping sites. We have realized a microfabricated 2D array of individual RF point traps with a 100 micron pitch between trapping sites. The interion distance may be reduced while maintaining a stable trap by varying the RF amplitude on electrodes between two adjacent trapping sites [2]. In this way, coherent operations mediated by the Coulomb interaction should become possible. We report on our progress towards operating the system at cryogenic temperatures and present surface trap designs for a new generation of 2D arrays based on parallel linear traps.

[1] C. Monroe et al., Proceedings of the International School of Physics 'Enrico Fermi', Course 189, pp. 169-187 (2015)
[2] M. Kumph et al., New J. Phys. 18, 023047 (2016)

Q 40.38 Wed 17:00 P OGs

Controlled absorption of a single photon by a single atom via adiabatic transfer — Luigi Giannelli[1], •Tom Schmit[1], Susanne Blum[1,4], Daniel M. Reich[2,3], Christiane P. Koch[2], Tommaso Calarco[5], and Giovanna Morigi[1] — [1]Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Universität Kassel, 34132 Kassel, Germany — [3]Aarhus University, 8000 Aarhus C, Denmark — [4]Theodor-Heuss-Gymnasium, 73730 Esslingen am Neckar, Germany — [5]Universität Ulm, 89069 Ulm, Germany

We analyse the dynamics of a single photon propagating in free space and incident on the mirror of an optical cavity, in which an atom is localized and characterise both numerically as well as analytically the efficiency of protocols which achieve photon absorption by adiabatic transfer [1-3] as a function of dissipative processes and of fluctuations in the experimental parameters. We further characterize the efficiency of the protocols when the signal is an attenuated laser pulse.

[1] M. Fleischhauer, et al., Opt. Commun. 179, 395 (2000).
[2] A. V. Gorshkov, et al., Phys. Rev. A 76, 033804 (2007).
[3] J. Dilley, et al., Phys. Rev. A 85, 023834 (2012).

Q 40.39 Wed 17:00 P OGs

Characterizing Bell Polytopes for loophole free Bell tests in multipartite scenarios — •Alexander Sauer, Nils Trautmann, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt

Loophole free violations of Bell inequalities are crucial for fundamental tests of quantum nonlocality. They are also important for future applications, such as device-independent quantum cryptography. We estimate the minimal requirements on detectors for performing a loophole free Bell test with dichotomic observables in multipartite scenarios, based on a detector model which includes detector inefficiencies and dark counts. We investigate the structure of Bell polytopes via principal component analysis and take the possible quantum correlations and the no-signaling polytope into account to find suitable Bell inequalities for such tests.

Q 40.40 Wed 17:00 P OGs

Squeezing Distillation from Atmospheric Fluctuations — •Kevin Günthner[1,2], Ömer Bayraktar[1,2], Andreas Thurn[1,2], Christian Peuntinger[1,2], Dominique Elser[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany. — [2]Department of Physics, University of Erlangen-Nuremberg (FAU), Germany.

We show the distillation of squeezed states of light, that have been transmitted through a 1.6 km urban, atmospheric free-space channel [1]. Squeezed states of light are interesting and important non-classical states for quantum information processing [2]. The efficiency of possible applications, e.g., quantum key distribution [3], crucially relies on a state's nonclassicality, i.e., the degree of squeezing. The atmospheric channel introduces intensity fluctuations through beam wandering and scintillation considering the finite receiving aperture size. This real physical, non-gaussian noise will unavoidably lead to reduction of squeezing after transmission. We combat this degrading by employing various purification and distillation protocols, hence selecting states with high degree of squeezing [1,4].

[1] C. Peuntinger *et al.*, Phys. Rev. Lett. **113**, 060502 (2014).
[2] U. L. Andersen *et al.*, Physica Scripta **91**, 053001 (2016).
[3] L. S. Madsen *et al.*, Nature Comm. **3**, 1083 (2012).
[4] J. Heersink *et al.*, Phys. Rev. Lett. **96**, 25 (2006).

Q 40.41 Wed 17:00 P OGs

Construction of a single-NV setup for single-molecule NMR — •Till Lenz[1], Lykourgos Bougas[1], Arne Wickenbrock[1], Samer Afach[1], John W. Blanchard[1], Liam McGuinness[2], Fedor Jelezko[2], and Dmitry Budker[1,3] — [1]Helmholtz Institute, Johannes Gutenberg University, Mainz, Germany — [2]Institut für Quantenoptik, Ulm, Germany — [3]University of California Berkeley, Berke-

ley, USA

Nuclear magnetic resonance (NMR) spectroscopy plays a central role in modern science, with applications ranging from fundamental physics and chemistry to biomedical imaging. NMR spectroscopy can provide detailed information about the structure and dynamics of molecules, but the realization of measurements with sensitivities at the single-molecule level requires fundamentally new detection strategies. Nitrogen-Vacancy (NV) color centers in diamond have emerged as unique magnetic resonance sensors, marked by the recent remarkable demonstrations of nanoscale spectroscopy and imaging of single electron and nuclear spins. Our goal is to extend the magnetic resonance techniques using NV-centers to Zero- and Ultralow-Field NMR (ZULF-NMR), an alternative technique where measurements are performed in the absence of a strong external magnetic field, which is already used to investigate macroscopic NMR samples. ZULF-NMR allows us to perform single-molecule identification via analysis of J-coupling data.We report on our current efforts in designing, constructing and characterizing a single-NV-based ZULF-NMR spectrometer in Mainz.

Q 40.42 Wed 17:00 P OGs

Properties of the Quantum free-electron laser — •Peter Kling[1,2], Enno Giese[3,2], Roland Sauerbrey[1], and Wolfgang P. Schleich[2,4] — [1]Helmholtz-Zentrum Dresden-Rossendorf, D-01314 Dresden — [2]Universität Ulm, D-89069 Ulm — [3]University of Ottawa, Ottawa, Ontario K1N 6N5, Canada — [4]Texas A & M University, College Station, Texas 77843, USA

In contrast to all existing free-electron lasers (FELs), which purely rely on classical physics, quantum effects are crucial for the 'Quantum FEL' [1]. In this device the discrete recoil of the electron dominates the dynamics, which is characterized by two resonant momentum levels [2,3].

We present intuitive arguments for the transition to the quantum regime and discuss quantities such as gain and photon statistics in this limit. Moreover, we identify effects which distinguish the Quantum FEL from the classical FEL.

[1] R. Bonifacio , N. Piovella and G. R. M. Robb, Fortschr. Phys. **57**, 1041–1051 (2009).
[2] P. Kling *et al.*, New. J. Phys **17**, 123019 (2015).
[3] P. Kling *et al.*, Appl. Phys. B (accepted).

Q 40.43 Wed 17:00 P OGs

Birth, death and revival of spontaneous emission of a three-atom system — Simon Mährlein[1,2], Kevin Günthner[1,3], Jörg Evers[4], and •Joachim von Zanthier[1,2] — [1]Institute of Optics, Information and Photonics, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany — [3]Quantum Information Processing Group (QIV), Max-Planck-Institut für die Physik des Lichts, 91052 Erlangen, Germany — [4]Theoretical Quantum Dynamics and Quantum Electrodynamics, Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

Death and revival phenomena can be observed in many areas in quantum physics and can appear in different aspects and forms. We investigate the time behavior of spontaneous emission of a three-atom system which collectively shares a single excitation. Two atoms are assumed to be closer than a wavelength to each other, while the third atom is many wavelength away. In a detailed analysis we demonstrate that at certain detector positions the spontaneous emission of the photon can display a birth, i.e., the probability to detect the photon does not decay as a function of time but increases from zero, or a non-periodic death, i.e., the photon detection probability drops to zero, followed by a revival of the signal. We further show that the spontaneous emission process of the fully excited system can be monitored by higher order intensity correlation measurements.

Q 40.44 Wed 17:00 P OGs

Characterisation of open acess microcavities — •Olaf Zimmermann, Andrea Kurz, Felix Glöckler, and Alexander Kubanek — Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany

In order to increase the interaction strength between a single mode of light and the optical transition of an emitter, the emitter can be placed inside the mode of a cavity. To optimize coupling strength either the quality factor can be increased or the mode volume can be decreased. Many cavities that have ultra small mode volumes do not have open access and are not tunable. We present the current status in our development of designing an open accessable, tunable, Fabry-Perot resonator with femtolitre mode volume.

Q 40.45 Wed 17:00 P OGs

Collective sensing at x-ray energies — Paolo Longo, •Dominik Lentrodt, Christoph H. Keitel, and Jörg Evers — MPI für Kernphysik, Heidelberg

We theoretically demonstrate that the cooperative emission from a layer of ^{57}Fe nuclei embedded in an X-ray waveguide can be used as a tool for sensing the presence of external nuclei. The internal nuclei are necessary to counteract the low Q-factor of the cavity. Our approach is based on an evanescent side-coupling mechanism and collective effects from within the waveguide [1] that realise a sufficiently high response for nuclei attached to the waveguide cladding. The results show that a shift of the emission line is only observable if deliberately excited off-resonance. The predicted collective modification of the Lamb shift and linewidth are qualitatively verified using the software package CONUSS.

[1] P. Longo, C. H. Keitel and J. Evers, Sci. Rep. 6, 23628 (2016), arXiv:1503.04532

Q 40.46 Wed 17:00 P OGs

A Lorentz-covariant master equation for a scalar quantum field — •Marduk Bolaños and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

The interaction of quantum particles with their environment has been thoroughly studied in the non-relativistic regime. However, ongoing superposition experiments involving large numbers of photons [1] call for an extension of decoherence models to the electro-magnetic quantum field, which is inherently relativistic. Relativistic models of decoherence will also enable the extension of empirical measures of macroscopicity of the kind introduced in [2] to this regime. As a starting point we consider a relativistic quantum particle, described as an excitation of a scalar field, subject to random momentum kicks. This study will pave the way to a Lorentz-covariant master equation for the dynamics of quantum fields.

[1] E. Nagali et al, PRA 76, 042126 (2007).
[2] S. Nimmrichter and K. Hornberger, PRL 110, 160403 (2013).

Q 40.47 Wed 17:00 P OGs

Thermalization in an isolated quantum system - dynamics and time scales — •Govinda Clos[1], Diego Porras[2], Matthias Wittemer[1], Ulrich Warring[1], and Tobias Schaetz[1] — [1]Albert-Ludwigs-Universität Freiburg, Germany — [2]University of Sussex, Brighton, UK

For an isolated quantum system, the dynamics is governed by the Liouville-von Neumann equation and is, thus, unitary and reversible in time. Yet, few-body observables of (possibly highly-entangled) many-body states can yield expectation values that feature equilibration and thermalization [1]. We use a trapped-ion system to study a spin coupled to a phononic environment of engineerable complexity [2]. While the total system evolves unitarily, we record the dynamics of a subsystem observable, and find the emergence of thermalization. With this time-resolved measurement, we address associated time scales of equilibration, thermalization, and the information flow between the subsystem and its environment.

[1] Eisert *et al.*, Nat. Phys. **11**, 124 (2015).
[2] Clos *et al.*, Phys. Rev. Lett. **117**, 170401 (2016).

Q 40.48 Wed 17:00 P OGs

Asymmetric fiber cavities for quantum opto-mechanics with SiN-membranes — •Jan Petermann[1], Tobias Wagner[1], Philipp Christoph[1], Christoph Becker[1], Klaus Sengstock[1], Hai Zhong[2], Alexander Schwarz[2], and Roland Wiesendanger[2] — [1]Center for Optical Quantum Technologies, Hamburg, Germany — [2]Insitute for Applied Physics, Hamburg, Germany

We are currently setting up a quantum hybrid experiment, which aims at coupling a Bose-Einstein condensate to a cryogenically pre-cooled SiN membrane via long-range light interaction. A fiber cavity is used to enhance the coupling between light and membrane by a factor of the finesse. Asymmetric coating of the cavity mirrors enables finite on-resonance reflectivity required to establish a mutual resonant coupling between the atomic sample and the membrane motion. Our results reveal that the on-resonance reflectivity is extremely sensitive to the mode match between fiber- and cavity mode. Best mode match is achieved for plano-concave cavities. Using standard single mode fibers with mode a field diameter of $5.2\mu m$, we derive an optimal mode match for a radius of curvature close to $50\mu m$ and a cavity length of $L \approx 25\mu m$. We optimize depth and width of our laser machined gaussian mirror profiles by numerical simulations and achieve values for the on-resonance power reflectivity ideally suited for our envisaged quantum hybrid system.

Q 40.49 Wed 17:00 P OGs

A classical linear Boltzmann equation for rotational friction and diffusion — •Lukas Martinetz, Benjamin A. Stickler, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

Motivated by recent experiments [1,2,3], we derive the classical linear Boltzmann equation for the ro-translational dynamics of an arbitrarily shaped anisotropic nanoparticle interacting with a dilute gas. It accounts for specular as well as diffuse thermal reflection of the gas atoms at the particle surface. As a limiting case, the Boltzmann equation describes rotational friction and diffusion. By specifying the form of the nanoobject, we derive the friction and diffusion coefficients for spheres, cylinders and cuboids and discuss the equilibration of the orientation state.

[1] Kuhn et al., Cavity-Assisted Manipulation of Freely Rotating Silicon Nanorods in High Vacuum, Nano Lett. 15, 5604 (2015)

[2] Hoang et al., Torsional Optomechanics of a Levitated Nonspherical Nanoparticle, Phys. Rev. Lett. 117, 123604 (2016)

[3] Kuhn et al., Full Rotational Control of Levitated Silicon Nanorods, arXiv:1608.07315 (2016)

Q 40.50 Wed 17:00 P OGs

Coupling cold atoms to a cryogenically cooled optomechanical device — •Philipp Christoph[1], Jan Petermann[1], Tobias Wagner[1], Christina Staarmann[1], Klaus Sengstock[1,2], Christoph Becker[1,2], Hai Zhong[3], Alexander Schwarz[3], and Roland Wiesendanger[3] — [1]Center for Optical Quantum Technologies, Luruper Chaussee 149 , 22761, Hamburg, Germany — [2]Institute of Laser Physics, Luruper Chaussee 149 , 22761 Hamburg, Germany — [3]Institute for Applied Physics, Jungiusstrasse 11, 20355 Hamburg, Germany

We present work towards a new hybrid quantum system consisting of a sample of cold atoms coupled to a cryogenically precooled mechanical oscillator. Our ultimate goal is the investigation of two very different macroscopically large quantum systems coherently coupled to each other. For this purpose we have set up a Rubidium-BEC apparatus coupled to a SiN membrane placed inside a fiber Fabry Perot cavity via an optical lattice. This membrane in the middle system is cooled to below 500mK in a dilution refrigerator. We present details on the coupling lattice laser system and a highly sensitive homodyne setup for detecting and manipulating the membrane motion. The coupling lattice is operated very close to atomic resonance in order to allow for the required large lattice depth for resonant atom-membrane coupling at low coupling light powers. First results of loading ultracold atoms from a dipole trap into this near resonant lattice are presented.

This work is supported by the DFG grants no. BE 4793/2-1 and SE 717/9-1.

Q 40.51 Wed 17:00 P OGs

Single photon emission from point defects in hexagonal boron nitride flakes — •Bernd Sontheimer[1], Merle Braun[1], Nikola Sadzak[1], Igor Aharonovich[2], and Oliver Benson[1] — [1]Humboldt-Universität zu Belrin — [2]University of Technology Sydney

Single photon emitters play an important role in a variety of quantum technologies, including quantum communications and computing. Here, we introduce Hexagonal boron nitride (hBN), an emerging twodimensional wide-bandgap material, as a host for a multitude of point defects. We investigate those defects and find stable ones at room temperature that show extraordinary bright single photon emission at various wavelengths in the visible and near infrared. Furthermore, present our latest measurements on the temperature dependence of the spectral properties of those defects and show and analyze the apparent spectral diffusion at different time scales as well as optical coherence properties at cryogenic temperatures.

Q 40.52 Wed 17:00 P OGs

Widefield Microwave Imaging using NV Centres — •Andrew Horsley[1], Janik Wolters[1], Patrick Appel[1], James Wood[1], Jocelyn Achard[2], Alexandre Tallaire[2], Patrick Maletinsky[1], and Philipp Treutlein[1] — [1]University of Basel, Switzerland — [2]LSPM, Universite Paris 13, France

We present a microscope for widefield electromagnetic field imaging using NV centres in diamond. We expect to realise $> 1\,\mathrm{mm}^2$ field of view and sub-ms temporal resolution, exceeding the state-of-the-art for widefield NV imaging. The microscope provides $5\,\mu$m spatial resolution, given by the thickness of the near-uniaxial NV layer, and our current sensitivity is hundreds of $\mathrm{nT\,Hz}^{-1/2}$, which we expect to improve.

We use the microscope for microwave near-field imaging, which we are pursuing in the context of microwave device characterisation [2-4]. Such devices form the backbone of many scientific and technological applications, from quantum devices (atom chips, ion traps, atomic clocks, qubits...) to telecommunications (wifi, mobile phones...). Our technique promises to transform device development, characterisation, and debugging. Our high-resolution NV microscope may also be of interest for medical microwave sensing and imaging, particularly in skin-cancer screening.

[1] Steinert et al., Rev. Sci. Instr. 81, 043705 (2010)

[2] Horsley and Treutlein, APL 108, 211102 (2016)

[3] Horsley, Du, and Treutlein, NJP (FTC), 17(11), 112002, (2015)

[4] Appel et al., NJP (FTC), 17(11), 112001, (2015)

Q 40.53 Wed 17:00 P OGs

Low temperature spectroscopy of quantum emitters in 2D materials — •Korbinian Kottmann[1], Andreas Dietrich[1], Stefan Häussler[1], Kerem Bray[2], Igor Aharonovich[2], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Insitute for Quantum Optics, Ulm University, D-89081 Ulm — [2]School Mathematical and Physical Sciences, University of Technology Sydney, Ultimo, New South Wales 2007, Australia

In the previous decade, atomically thin materials have drawn much attention in science and technology because of their extraordinary physical properties due to spatial confinement in two dimensions [1]. We investigate optical properties of individual color centers at very low temperatures (4K). Quantum emission of single photons in the visible spectrum at very high rates make them a promising prospect for applications in quantum communications and photonics. Henceforth, single or few layers can easily be implemented in a micro resonator by virtue of their small size, heralding the possibility of a tunable cavity QED platform.

[1] A. Gupta, T. Sakthivel, S. Seal, Progress in Materials Science 73, 2015

Q 40.54 Wed 17:00 P OGs

Low Temperature spectroscopy of color center in thin diamond layer — •Andreas Dietrich[1], Stefan Häussler[1], Kobinian Kottmann[1], Lukas Antoniuk[1], Kerem Bray[2], Igor Aharonovich[2], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]School of Mathematical and Physical Sciences, University of Technology Sydney,Ultimo, New South Wales 2007, Australia

Color center in high band gab material, such as diamond, appeared as important and valuable quantum systems for emerging quantum technologies [1]. Engineered diamond materials are demanded for future quantum optics and quantum sensing applications. Preserving optical properties like narrow linewidth and spectral stability in thin membranes is a major task. We investigate in thin diamonds membranes the spectral properties of color centers at low temperature.

[1]F. Jelezko, J. Wrachtrup, Phys. Stat. Sol. 203, 13, 2006

Q 40.55 Wed 17:00 P OGs

Low Temperature spectroscopy of color center in thin diamond layer — •Andreas Dietrich[1], Stefan Häussler[1], Korbinian Kottmann[1], Lukas Antoniuk[1], Kerem Bray[2], Igor Aharonovich[2], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]School of Mathematical and Physical Sciences, University of Technology Sydney,Ultimo, New South Wales 2007, Australia

Color center in high band gab material, such as diamond, appeared as important and valuable quantum systems for emerging quantum technologies [1]. Engineered diamond materials are demanded for future quantum optics and quantum sensing applications. Preserving optical properties like narrow linewidth and spectral stability in thin membranes is a major task. We investigate in thin diamonds membranes the spectral properties of color centers at low temperature.

[1]F. Jelezko, J. Wrachtrup, Phys. Stat. Sol. 203, 13, 2006

Q 40.56 Wed 17:00 P OGs

Frequency Doubling of Fiber Amplified Picosecond Laser-pulses for Ion Beam Cooling — •Christian Kühnel, Daniel Kiefer, and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, Schlossgartenstr. 7, 64289 Darmstadt

White light cooling is an efficient way for reducing the phase space density of relativistic bunched ion beams [1]. For this purpose we present pulsed SHG in a noncritical phase-matched lithiumniobate crystal. The pulses are provided by a MOPA system with flexible pulse duration.

The MOPA system delivers pulses at 1030 nm and a repetition rate of up to 1.5 MHz. The pulse duration is variable between 70 and 740 ps and switchable to 50 ns. The setup for SHG is typically done for one specific set of laser parameters. However, here it needs to be variable, since the pulse length is tunable. Therefore, the peak power differs so that exceeding damage thresholds and varying SHG efficiencies have to be considered. The current status of the system is presented compared with theoretical and numerical predictions [2]. In addition the future development will be shown. [1] S. N. Atutov. Phys. Rev. Lett. 80 (1998), 2129-2132. [2] H. Wang and A. M. Weiner, IEEE Journal of Quantum Electronics, vol. 39, no. 12, 1600-1618.

Q 40.57 Wed 17:00 P OGs

Tabletop 20 kHz laser source for circularly polarized vacuum ultraviolet radiation — •Tobias Reiker, Daniel Nürenberg, and Helmut Zacharias — Westfälische Wilhelms-Universität, Münster, Deutschland

We present a high repetition rate table top laser source at a photon energy of 10.5 eV with full control over the polarization. The radiation is generated from a 20 kHz Nd:YVO4 laser with a wavelength of 355 nm by frequency tripling in Xenon to a wavelength of 118nm. In this regime, no suitable material for birefringent optics is available. Instead we use a reflection induced phase shift to control the polarization. The Stokes parameter of the radiation are measured by a reflective vacuum ultraviolet polarizer. Circularly polarized light from this source is proposed to be used in spin-resolved photoelectron spectroscopy on surfaces.

Q 40.58 Wed 17:00 P OGs

Stimulated Raman scattering microscopy by Nyquist modulation of a two-branch ultrafast fiber source — •Peter Fimpel, Claudius Riek, Peyman Zirak, Christoph Kölbl, Alfred Leitenstorfer, Daniele Brida, and Andreas Zumbusch — Universität Konstanz

A highly stable setup for stimulated Raman scattering (SRS) microscopy[1] is presented. It is based on a two-branch femtosecond Er:fiber laser operating at a 40 MHz repetition rate. One of the outputs is directly modulated at the Nyquist frequency with an integrated electro-optic modulator (EOM). This compact source combines a jitter-free pulse synchronization with a broad tunability and allows for shot-noise limited SRS detection. The performance of the SRS microscope is illustrated with measurements on samples from material science and cell biology. [1] C. Riek et al., Opt. Lett. 41, 3731 (2016)

Q 40.59 Wed 17:00 P OGs

Atom interferometry with ultracold thermal clouds and realistic laser pulses — •Jens Jenewein, Albert Roura, Wolfgang P. Schleich, and the QUANTUS Team — Universität Ulm, Ulm, Germany

We have developed a real-time simulation for a symmetric and an asymmetric Mach-Zehnder like light-pulse atom interferometer. Realistic laser pulses of arbitrary shape are employed based on single and double Bragg diffraction leading to velocity selectivity and excitation of off-resonant diffraction orders. This feature makes the simulation which also includes lensed thermal atoms more feasible for the description of experiments. We can also estimate the contrast C that contributes together with the atom number to the sensivity. Various effects such as delta-kick collimation and the amount of evaporative cooling affect C.

The QUANTUS 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 50WM1556.

Q 40.60 Wed 17:00 P OGs

Light propagation in a 1D medium of high optical density — •Roman Sulzbach and Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstr. 7, 64289, Darmstadt

Electromagnetically induced transparency (EIT) has found many applications in quantum optics, since its experimental demonstration in 1990 [1]. Recently, it was possible to demonstrate EIT and the related effects of slow and stationary light pulses in a hollow fiber containing a thin medium of cold Rubidium atoms [2]. These hollow fibers have a diameter of 7 μm and a length of 10 cm. Therefore, this system represents a one-dimensional medium of high optical density.

We use Maxwell-Bloch theory to simulate the pulse propagation of the probe-beam inside this fiber. This leads to a paraxial Schrödinger-equation as well as to corrections. We will present results of numerical simulations of this strongly interacting light-matter system.

[1] K. Boller, A. Imamoglu, and S. Harris, *Observation of electromagnetically induced transparency*, Phys. Rev. Lett. **66**, 2593 (1991)
[2] F. Blatt, L. Simeonov, T. Halfmann, and T. Peters, *Stationary light pulses and narrowband light storage in a laser-cooled ensemble loaded into a hollow-core fiber*, Phys. Rev. A. **94**, 043833 (2016)

Q 40.61 Wed 17:00 P OGs

From incoherent to coherent: modeling quantum-dot superluminescent diodes — •Franziska Friedrich and Reinhold Walser — Institut für Angewandte Physik

Commercial devices for optical coherence tomography greatly benefit from the appealing features of broadband light emitting quantum-dot superluminescent diodes (QDSLDs), where light is generated in the regime of amplified spontaneous emission (ASE). But also from the fundamental point of view, these devices exhibit uncommon properties considering field and intensity correlations, $g^{(1)}(\tau)$ and $g^{(2)}(\tau)$: a reduction of $g^{(2)}(0)$ from 2 to 1.33 at $T = 190$ K was observed in the lab in 2011 [1]. The understanding of these hybrid coherent light states, which are simultaneously incoherent in $g^{(1)}(\tau)$ and coherent in $g^{(2)}(\tau)$, represents an interesting and challenging topic of research.
In the present contribution, we will discuss a multimode quantized field theory of the QDSLD and study the generation of the amplified spontaneous emission on a microscopic level [2]. As a main result, we analyze the external power spectrum. Comparison with experimental measurements exhibits good agreement.

[1] M. Blazek, W. Elsäßer, Phys. Rev. A **84**, 063840 (2011)
[2] to be published

Q 40.62 Wed 17:00 P OGs

Direct probing of higher order Fock states — •Johannes Tiedau, Georg Harder, Vahid Ansari, Tim J. Bartley, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Optical quantum state characterisation is an important task for different scenarios. For many applications, particularly in protocols involving continuous variables, balanced homodyne detection is used to reconstruct a quasi-probability distribution in phase-space to describe the state. However, this method can only investigate the part of the signal field which is overlapping with a strong probe field. In contrast, using a weak local oscillator and photon counting overcomes this problem and enables us to investigate the full quantum state. Depending on the configuration, one can call this weak-field homodyne detection and or direct probing, in which the displaced parity operator of the state is measured. Since there is no intrinsic filtering during measurement, in order to see quantum effects an extremely pure quantum state is required. In our case this is achieved by precise Parametric-Down-Conversion source engineering. We report on our latest progress using this technique, namely direct probing of higher order (>=2) Fock states.

Q 40.63 Wed 17:00 P OGs

Qudi: a modular Python suite for experiment control including implemented modules for confocal microscopy, quantum optics and quantum information experiments — •Jan M. Binder[1], Alexander Stark[1,2], Nikolas Tomek[1], Jochen Scheuer[1], Florian Frank[1], Kay D. Jahnke[1], Christoph

Müller[1], Simon Schmitt[1], Mathias H. Metsch[1], Thomas Unden[1], Tobias Gehring[2], Ulrik L. Andersen[2], Lachlan J. Rogers[1], and Fedor Jelezko[1,3] — [1]Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, Ulm 89081, Germany — [2]Department of Physics, Technical University of Denmark, Fysikvej, Kongens Lyngby 2800, Denmark — [3]Center for Integrated Quantum Science and Technology (IQST), Ulm University, 89081 Germany

Qudi is a general, modular, multi-operating system suite written in Python 3 for controlling laboratory experiments.

It provides a structured environment by separating functionality into hardware abstraction, experiment logic and user interface layers.

The core feature set comprises a graphical user interface, live data visualization, distributed execution over networks, rapid prototyping via Jupyter notebooks, configuration management, and data recording.

Currently, the included modules are focused on confocal microscopy, quantum optics and quantum information experiments, but an expansion into other fields is possible and encouraged.

Qudi is available from https://github.com/Ulm-IQO/qudi and is freely useable under the GNU General Public Licence 3.

A preprint describing the design is avaliable at arXiv:1611.09146.

Q 40.64 Wed 17:00 P OGs

Limits on the time-multiplexed photon-counting method — •Regina Kruse, Johannes Tiedau, Tim Bartley, Sonja Barkhofen, and Christine Silberhorn — Applied Physics, Universität Paderborn, Warburger Str. 100, D-33098 Paderborn

Building large and reliable quantum networks requires sophisticated detection techniques to verify the correct operation of the network. To this aim, we investigate the limits of a cost and resource efficient time-multiplexed detection method [1]. We quantify the optimal number of time-bins for such a setup under the constraints of convolution effects and realistic setup losses by simulating the overlap of specified Fock states after passing the time-multiplexed detector.

[1] Kruse et al., arXiv:1611.04360

Q 40.65 Wed 17:00 P OGs

Laserinduzierte Hochspannungsentladung zur Erzeugung eines Plasmawellenleiters für die Elektronenbeschleunigung — •Carola Wirth[1], Alexander Sävert[1,2], Wolfgang Ziegler[1] und Malte C. Kaluza[1,2] — [1]Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena — [2]Helmholtz-Institut Jena

Die Erzeugung hochenergetischer Elektronen durch die Laser-Plasmabeschleunigung gewinnt in der Wissenschaft immer mehr an Bedeutung. Bei dieser Art der Beschleunigung werden Elektronen in eine von einem Laserpuls erzeugte Plasmawelle injiziert und können so innerhalb weniger Zentimeter auf Energien von bis zu einigen GeV beschleunigt werden. Um die hohen beschleunigenden Felder der Plasmawelle effektiv nutzen zu können, muss die Welle über eine möglichst lange Strecke bestehen bleiben. Erreicht werden kann dies beispielsweise durch die Führung des treibenden Laserpulses in einem Plasma-Wellenleiter. Ähnlich einer Glasfaser mit einem Gradientenbrechungsindexprofil, in dem Laserstrahlen mit konstantem Strahldurchmesser geführt werden können, kann ein hochintensiver Laserpuls in einem Plasma mit einem transversal parabolischen Brechzahlprofil geführt werden. Eine Technik zur Erzeugung dieses Profils ist die Hochspannungsentladung in einer gasgefüllten Kapillare.

Wir stellen eine Analyse des Stabilitätsverhaltens einer Hochspannungsentladung in einer Kapillare zur Erzeugung eines Plasmakanals vor. Dazu wurde der Einfluss der Vorionisation des Gases mit Hilfe eines intensiven fs-Laserpulses auf das Stabilitätsverhalten und das Führungsverhalten des Plasmakanals untersucht.

Q 40.66 Wed 17:00 P OGs

Three-dimensional Direct Laser Written Waveguides on a Chip — •Alexander Landowski[1,2], Dominik Zepp[1], Sebastian Wingerter[1], Michael Renner[1], Georg von Freymann[1,3], and Artur Widera[1,2] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern, Erwin-Schroedinger-Str. 56, 67663 Kaiserslautern — [2]Graduate School Materials Science in Mainz, Erwin-Schroedinger-Str. 56, 67663 Kaiserslautern — [3]Fraunhofer-Institute for Physical Measurement Techniques IPM, Fraunhofer-Platz 1, 67663 Kaiserslautern

We engineer three-dimensional waveguides from a low fluorescent photoresist on a chip using a commercial system for direct laser writing. Using a silica substrate and air cladding, we are able to fabricate waveguide bends with small radii down to 40 μm and three-dimensional coupling structures, that enable addressing all input and output ports of our waveguide network through the substrate via one microscope objective simultaneously. Due to the low fluorescence, our waveguides in principle allow integration of single quantum emitters for quantum optical experiments on a chip.

Here we present detailed characterization of stadium waveguides with three-dimensional coupling structures. We discuss the limits of the single mode operation of the waveguides and show first beamsplitting devices. We analyze coupling, propagation and bend losses of our waveguides. Further, we characterize the fluorescence of the photoresist used.