Q 51: Poster: Quantum Optics and Photonics IV

Time: Wednesday 16:15–18:15 Location: Redoutensaal

Q 51.1 Wed 16:15 Redoutensaal

Observation of parametric instabilities in 1D interacting shaken optical lattice systems — •Karen Wintersperger[1,2], Jakob Näger[1,2], Marin Bukov[3], Martin Reitter[1,2], Samuel Lellouch[4], Ulrich Schneider[5], Nathan Goldman[4], Immanuel Bloch[1,2], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität München, Schellingstr. 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching — [3]Boston University, 590 Commonwealth Ave., Boston, MA 02215 — [4]Université Libre de Bruxelles, CP 231, Campus Plaine, 1050 Brussels, Belgium — [5]University of Cambridge, Cambridge, UK

We study the dynamics of BECs in a driven optical 1D lattice using 39K atoms that have an accessible Feshbach resonance allowing for the control of interactions. The short-time dynamics is mostly dominated by parametric instabilities [1] and can be well described within Bogoliubov theory. At longer times this description seizes to be accurate and the dynamics can be captured by a Fermi*s golden rule approach [2]. We observe the transition between the two regimes for different shaking parameters and interactions. Also, we compare the quasimomentum of the most unstable modes to the values expected from Bogoliubov theory.

[1] S. Lellouch et al., PRX 7, 021015, 2017
[2] M. Reitter et al., PRL 119, 200402, 2017

Q 51.2 Wed 16:15 Redoutensaal

Nonlinear standing waves in an array of coherently coupled 1D Bose-Einstein condensates — •Christian Baals[1,2], Antonio Muñoz Mateo[3], Herwig Ott[1], and Joachim Brand[3] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Germany — [3]Dodd-Walls Centre for Photonics and Quantum Technologies, Centre for Theoretical Chemistry and Physics, New Zealand Institute for Advanced Study, Massey University, Auckland, New Zealand

We study the stability of dark soliton states in an array of linearly coupled 1D BECs within the Gross-Pitaevskii theory against linear excitations by solving the Bogoliubov equations. In this context we show that overlapped dark solitons can decay into patterns of Josephson vortices over the stack of Josephson junctions. By analytically solving the Bogoliubov equations for dark solitons, the Josephson vortices are demonstrated to bifurcate as nonlinear standing waves for decreasing values of the linear coupling. This result is very well confirmed by numerical studies. Furthermore, we discuss the connection with the stability of dark solitons in two dimensional systems and consider the feasibility for an experimental realisation.

Q 51.3 Wed 16:15 Redoutensaal

A quantum gas machine for local photoionization of ultracold ^{87}Rb on ultrafast time-scales — •Jakob Butlewski[1], Tobias Kroker[1,2], Bernhard Ruff[1,2], Juliette Simonet[1,2], Philipp Wessels[1,2], Markus Drescher[1,2], and Klaus Sengstock[1,2] — [1]Zentrum für Optische Quantentechnologien (ZOQ), Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg, Germany

Combining ultracold atoms with ultrashort laser pulses offers novel experimental possibilities such as the creation of hybrid quantum systems by local ionization of atoms in strong laser fields or the investigation of quantum Zeno physics with pulsed dissipation.

Here, we report on our progress in setting up an experiment for local photoionization in quantum gases and the detection of thereby created charged particles. The ultracold atomic sample is prepared in a combined magnetic quadrupole and optical dipole trap and is transported into the focal region of the ionizing femtosecond laser beam using optical tweezers. Subsequently, the emerging photoelectrons shall be detected with spatial resolution while counting the ions in coincidence. In order to obtain unperturbed trajectories of the charged particles electrical stray fields are shielded and an active magnetic field compensation has been set up.

Q 51.4 Wed 16:15 Redoutensaal

Non-equilibrium dynamics of interacting Bosons in an optical lattice — •Johannes Bauer[1], René Hamburger[1], Jens Benary[1], Christian Baals[1,2], Jian Jiang[1], Andreas Müllers[1], and Herwig Ott[1] — [1]Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, 55128 Mainz, Germany

We study the non-equilibrium dynamics of ultracold Bose gases in optical lattices using a scanning electron microscope. In a first experiment we characterize the emerging steady-states of a driven-dissipative Josephson junction array, realized with a BEC in a one-dimensional optical lattice. By locally applying dissipation using the electron beam at an initially full site, we can induce a superfluid response which keeps the respective site filled. This can be seen as an extension of the paradigm of Coherent Perfect Absorption (CPA). CPA refers to the complete extinction of incoming radiation by spatially localized absorber embedded in a wave-guiding medium. Furthermore, we make use of the Talbot effect to study phase coherence in an optical lattice at a finite range. The interferometer which relies on the fast blanking of the lattice potential is applied to study the spread of phase coherence after a quench of the lattice depth. Our current work is focused on the generation and stabilization of dark solitons in 3D. To imprint the phase step of π onto a BEC we use a Digital Micromirror Device to create a sharp edge in the beam profile of a 532nm laser. We will then make use of the electron beam as a source of local dissipation to stabilise the dark soliton.

Q 51.5 Wed 16:15 Redoutensaal

Bloch oscillations in the second band of an optical lattice — •Carl Hippler, José Vargas, Thorge Kock, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

The overall goal of our experiment is to explore ultracold bosonic quantum gases in excited bands of an optical lattice. We investigate Rb-87 atoms in a bipartite interferometric 2D lattice allowing us to change the lattice geometry dynamically. We observe the formation of a chiral superfluid order, arising from the interplay between the contact interaction of the atoms on each lattice site and the degeneracy of the p orbitals in the second Bloch band. A periodic pattern of locally alternating orbital currents and circular currents establishes in the lattice, time-reversal symmetry being spontaneously broken. We report on Bloch oscillations in the second band of the lattice, starting at the two inequivalent X points.

Q 51.6 Wed 16:15 Redoutensaal

Non-equilibrium dynamics in a quasi-1D spinor BEC: demonstration and new probing tools — •Stefan Lannig, Rodrigo Rosa-Medina Pimentel, Maximilian Prüfer, Philipp Kunkel, Christian-Marcel Schmied, Daniel Linnemann, Helmut Strobel, Thomas Gasenzer, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg

We employ a spinor Bose-Einstein condensate of ^{87}Rb confined in an elongated dipole trap to study far from equilibrium dynamics with spin exchange interactions. In order to investigate the underlying dynamics we prepare the system in the polar phase and quench into the easy-plane ferromagnetic phase. After an exponential build-up of excitations we identify the emergence of a universal scaling function for intermediate times. By rescaling the power spectra of the transversal spin auto-correlations we extract the corresponding scaling exponents, thereby observing self-similar evolution in time.

We further present an extension of our experimental toolbox for performing local spin rotations. Using acousto-optical deflectors the atomic cloud is addressed by a steerable laser beam. The resulting AC vector Stark shift influences the energies of the individual Zeeman spin components similar to an applied magnetic bias field. Modulating the light intensity at the Larmor frequency enables the implementation of spatially resolved spin rotations. This allows us to explore different initial configurations, and we envision schemes to probe time-time correlations.

Q 51.7 Wed 16:15 Redoutensaal

An experimental setup for the study of universality far from equilibrium with degenerate ^{39}K — •Maurus Hans, Celia Viermann, Alexander Impertro, Marius Sparn, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Deutschland

In thermal equilibrium different physical systems close to a phase transition are described by the same set of critical exponents given by the corresponding universality class. This concept can be extended to non-equilibrium dynamics where theoretical studies show that universal scaling in time and space appear also away from an equilibrium critical point [1]. In degenerate quantum gases, universality can be reached by a quench close to such a critical point [2], but also by just abruptly changing the scattering length such that the system is driven out of equilibrium [3,4]. For this purpose, a ^{39}K Bose-Einstein condensate is an especially promising experimental system since it exhibits a broad magnetic Feshbach resonance for interaction tuning. Here, we present the status of the current experimental setup and schemes for the detection of universal time dynamics.

[1] B. Nowak et al., in Strongly Interacting Quantum Systems out of Equilibrium, ed. T. Giamarchi et al., Lecture Notes of the Les Houches Summer School Vol. 99, 2016 [2] E. Nicklas et al., Phys. Rev. Lett. 115, 245301 (2015) [3] J. Berges et. al., Phys. Rev. Lett. 114, 061601 (2015) [4] B. Nowak et al., Phys. Rev. B 84, 020506(R) (2011)

Q 51.8 Wed 16:15 Redoutensaal

Creating a superfluid by kinetically driving a Mott insulator
— •Gregor Pieplow, Charles E. Creffield, and Fernando Sols — Departamento de Física de Materiales, Universidad Complutense de Madrid, E-28040 Madrid, Spain

We study the effect of time-periodically varying the hopping amplitude (which we term "kinetic driving") in a one-dimensional Bose-Hubbard model, such that the time-averaged hopping is zero. By using Floquet analysis we derive a static effective Hamiltonian in which nearest-neighbor single-particle hopping processes are suppressed, but all even higher-order processes are allowed. Unusual many-body features arise from the combined effect of nonlocal interactions and correlated tunneling. At a critical value of the driving, the system passes from a Mott insulator to a superfluid formed by two quasi-condensates with opposite nonzero momenta. A many-body cat state combining the two macroscopically-occupied momentum eigenstates emerges even with hard-wall boundary conditions. We also explore Bogoliubov-de Gennes theory, which allows to infer the nature of the excitations of the fragmented superfluid. This work shows how driving of the hopping energy provides a novel form of Floquet engineering, which enables atypical Hamiltonians and exotic states of matter to be produced and controlled.

Q 51.9 Wed 16:15 Redoutensaal

Dynamics of Vector Solitons in Spinor Bose-Einstein Condensates
— •Kevin Geier[1], Sebastian Erne[1,2,3], Christian-Marcel Schmied[1], Markus K. Oberthaler[1], and Thomas Gasenzer[1] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [3]VCQ, Atominstitut, TU Wien, Stadionallee 2, 1020 Wien, Austria

We study the role of topological excitations in the non-equilibrium dynamics of a spin-1 Bose-Einstein condensate in one spatial dimension. In absence of the Zeeman effect and spin-spin interactions, the equations of motion reduce to the completely integrable Manakov system, which supports exact vector soliton solutions of dark-bright type. Integrability imposes strong constraints on the system's dynamics, such that, in essence, solitons always scatter elastically. Tuning the couplings to different mean-field phases, we study the effects of integrability breaking on the solitons' dynamics by numerically solving the full spin-1 Gross-Pitaevskii equations. Our results reveal non-trivial interaction effects such as inelastic scattering and the decay of solitons into domain walls. We furthermore study the time evolution of correlation functions for a random distribution of solitons in the easy-plane phase in comparison to a system initially prepared in the polar ground state. We find that the system approaches power-law distributions in momentum space reflecting the self-similar coarsening dynamics induced by dynamical instabilities.

Q 51.10 Wed 16:15 Redoutensaal

Floquet engineering in periodically driven optical lattices —
•Alexander Ilin, Tobias Klafka, Julius Seeger, Mario Neundorf, Christoph Ölschläger, Juliette Simonet, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

Time-periodic forcing is a powerful technique to explore new exciting phenomena in quantum many-body systems, e.g. artificial magnetism or topological phases of matter. For atoms in optical lattices it allows engineering of exotic band structures where coupling to higher Bloch bands can have severe effects even at moderate shaking amplitudes and off-resonant driving.

Here, we focus on band structure engineering for a BEC in a 1D optical lattice subject to monochromatic shaking near band inversion by varying the shaking strength across the point where the effective nearest neighbour tunneling parameter t_{NN} has a zero-crossing. The point of band inversion, characterizing the transition in the occupation of states from zero quasi-momentum to the Brillouin zone edge, has been recorded systematically as a function of lattice depth and shaking frequency. Our measurements reveal a striking dependence upon these variables which can be explained by admixtures of higher Bloch bands.

Q 51.11 Wed 16:15 Redoutensaal

In situ observation of Bloch oscillations in an optical cavity
— •Christoph Georges[1], Jens Klinder[1], Hans Kessler[1,2], and Andreas Hemmerich[1,3] — [1]Institut für Laser-Physik, Universität Hamburg — [2]Instituto de Física de São Carlos, Universidade de São Paulo — [3]Wilczek Quantum Center, Zhejiang University of Technology

Observing the Bloch oscillations of an ultracold quantum gas in an optical lattice is a promising approach to measure weak forces with high precision. The creation time of these ultracold quantum gas in combination with the common detection via Time-of-Flight imaging inherit a bad data acquisition speed.

In our Recent work [1] we have shown experimentally, the direct observation of Bloch oscillation of a strong cooperative coupled BEC inside an optical cavity via the light leaking out of this cavity. And in this way, we accelerated the acquisition speed for the Bloch-frequency substantially.

Here we report on our newest results on open questions concerning this detection scheme. Among others, we investigated the question if our coupling scheme changes the Bloch-frequency.

[1] H Keßler et al 2016 New J. Phys. 18 102001

Q 51.12 Wed 16:15 Redoutensaal

Dissipation-induced steady states in Rydberg-dressed quantum gases in an optical lattice — •Mathieu Barbier, Andreas Geissler, and Walter Hofstetter — Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität Frankfurt am Main

In recent years, research on quantum gases trapped in optical lattices has flourished impressively and the addition of Rydberg excitations to such systems promises to lead to exotic phases. Alongside the insulating density waves with crystalline order and superfluids, intriguing quantum phases referred to as supersolids have been predicted. Those phases are characterized by a spatially modulated condensate, combining the long-range spatial order of solids and the superfluid flow of condensates.

We focus on the realization of various quantum phases of a bosonic Rydberg-dressed gas, trapped in an optical lattice. Using the master equation in Lindblad form within the Gutzwiller theory and its approximations, we enrich the system with realistic dissipative mechanisms in order to closely model the experiment. We let the non-dissipative ground states evolve and observe the influence of dissipation. Are stable supersolids attainable in experiments or do dissipative processes prevent their existence?

Q 51.13 Wed 16:15 Redoutensaal

Observation of a pure Goldstone mode in the quench dynamics of an ultracold BCS Fermi gas — •Peter Kettmann[1], Simon Hannibal[1], Mihail Croitoru[2], Vollrath Martin Axt[2], and Tilmann Kuhn[1] — [1]Institute of Solid State Theory, University of Münster — [2]Theoretical Physics III, University of Bayreuth

Ultracold Fermi gases are a convenient system to probe and study the properties of phases like the BEC and the BCS phase and the crossover in between those regimes. In particular, ultracold Fermi gases can be used as a test bed to study the two fundamental dynamical modes –the Higgs and the Goldstone mode– which result from spontaneous symmetry breaking in these phases.

We investigate the Goldstone mode in the dynamics of a cigar-shaped cloud of ultracold ^{6}Li after a moderate interaction quench on the BCS side of the BCS-BEC crossover. To this end, we numerically solve Heisenberg's equations of motion for the Bogoliubov single-particle excitations in the framework of the Bogoliubov-de Gennes formalism. We observe that the quench leads to the emergence of a homogeneous Goldstone mode which does not couple to the trap and which is –as a result– gapless. In contrast to previous studies, we therefore observe the emergence of a pure Goldstone mode, i.e., a Goldstone mode in the original sense of the Goldstone theorem.

Furthermore, we investigate several ways to experimentally access the pure Goldstone mode, i.e., via a collective motion of the condensate, via its single-particle excitations, and via an interference setup.

Q 51.14 Wed 16:15 Redoutensaal

Persistent oscillations in the Higgs mode in a cigar-shaped ultracold Fermi gas — •Simon Hannibal[1], Peter Kettmann[1], Mihail Croitoru[2], Vollrath Martin Axt[2], and Tilmann Kuhn[1] — [1]Institute of Solid State Theory, University of Münster — [2]Theoretical Physics III, University of Bayreuth

Ultracold Fermi gases in optical traps provide a unique system to study the many body physics of systems composed of fermionic constituents. Both, the BEC and the BCS superfluid state are observed. Furthermore, the transition between these states is well controllable by means of a Feshbach resonance, which allows to tune the scattering length over a wide range from negative to positive values.

We employ an inhomogeneous BCS mean field theory and calculate the dynamics of the BCS gap of a confined ultracold Fermi gas after an interaction quench. Due to the spontaneously broken U(1) symmetry in the superfluid phase two fundamental modes of the BCS gap evolve, i.e., the amplitude (Higgs) and phase (Goldstone) mode. Here, we focus on the Higgs mode on the BCS side of the BCS-BEC crossover.

We investigate the dynamics resulting from interaction quenches starting deep in the BCS regime and ending in the BCS-BEC crossover region. We find a nonlinear persistent dynamics with one dominant frequency. For all quenches, this frequency stays closely connected to the long time average of the modulus of the BCS gap. We show that both are determined by a breaking of Cooper pairs at the time of the quench. Furthermore, we find that our model exhibits a chaotic behavior for large quenches ending in the BCS-BEC crossover region.

Q 51.15 Wed 16:15 Redoutensaal

Local control of transport in an atomic quantum wire — •Philipp Fabritius[1], Samuel Häusler[1], Martin Lebrat[1], Dominik Husmann[1], Laura Corman[1], Jean-Philippe Brantut[2], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland — [2]Institute of Physics, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

We demonstrate the local control of fermionic lithium atoms flowing through a one-dimensional structure by imprinting holographically shaped optical potentials with a high-resolution microscope. Similar to the scanning gate technique applied to solid-state devices we image the transport through a quantum wire at the scale of the Fermi wavelength by scanning the position of a sharp, repulsive optical gate. Imprinting complex structures such as a lattice enables us to study the metal-insulator transition in an interacting one-dimensional Fermi gas. We find that the insulating state is robust even for strong attractive interactions, which supports the existence of a Luther-Emery liquid in the one-dimensional wire.

The flexibility of our setup makes it possible to project additional structures onto a wire or a quantum point contact. In particular close-to-resonance light can be used to implement dissipative lattices or a spin valve.

Q 51.16 Wed 16:15 Redoutensaal

Exploring the Single-Particle and Many-Body Mobility Edge in a 1D Quasiperiodic Optical Lattice — •Thomas Kohlert[1,2], Sebastian Scherg[1,2], Henrik Lüschen[1,2], Michael Schreiber[1,2], Pranjal Bordia[1,2], Monika Aidelsburger[1,2], Xiao Li[3], Sankar Das Sarma[3], and Immanuel Bloch[1,2] — [1]Ludwig-Maximilians-Universität, Schellingstr. 4, 80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [3]Condensed Matter Theory Center and Joint Quantum Institute, University of Maryland, College Park, Maryland 20742-4111, USA

A single-particle mobility edge (SPME) marks a critical energy separating extended from localized states in a quantum system. In this work, we find experimental evidence for the existence of such a SPME in a one-dimensional quasi-periodic optical lattice. Specifically, we find a regime where extended and localized single-particle states coexist, in good agreement with theoretical simulations, which predict a SPME in this regime. In the corresponding interacting system we find that the dynamics is continuously slowing down as we approach a critical disorder strength, indicating that the system shows many-body localization (MBL). We juxtapose two models with and without SPME and compare their dynamics on short and long timescales and find that the interacting system does not delocalize on short timescales despite the presence of single-particle extended states. Finally, we discuss whether a many-body mobility edge (MBME) might be present in our system.

Q 51.17 Wed 16:15 Redoutensaal

Many-body phases of fermions coupled to an optical waveguide — •Kieran Fraser and Francesco Piazza — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Ultracold atoms subject to a single cavity mode will, above a threshold pump strength, undergo a self-organisation transition, related to so-called superradiance. A similar effect is observed for atoms in the evanescent field of an optical fibre. We study the phase diagram and collective excitations of a degenerate Fermi gas coupled to the propagating modes of a multimode optical waveguide. The interplay between superradiant and Umklapp scattering gives rise to a rich phase diagram and to peculiar collective excitations.

Q 51.18 Wed 16:15 Redoutensaal

Experimental investigation of Floquet dynamics in the driven Fermi-Hubbard model — •Frederik Görg[1], Michael Messer[1], Kilian Sandholzer[1], Joaquín Minguzzi[1], Gregor Jotzu[1,2], Rémi Desbuquois[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Max Planck Institute for the Structure and Dynamics of Matter, 22761 Hamburg, Germany

Driving a many-body system allows to engineer new Hamiltonians and realize interesting phases which are beyond the reach of static platforms. One example is the near-resonantly driven Fermi-Hubbard model, where the modulation frequency is chosen to be close to the interaction energy. To lowest order, the system is described by an effective Hamiltonian in which the single particle tunnelling and the magnetic exchange energies can be controlled independently. When going beyond this approximation, the underlying many-body state shows interesting dynamics on different timescales: Starting from fast micromotion during a single modulation period, the system is entering a regime described by the effective Hamiltonian on intermediate timescales before eventually heating up due to energy exchange with the drive. The experimental implementation of this model allows us to investigate all these timescales and observe the built-up and destruction of double occupancies and spin-spin correlations. In addition, we investigate the adiabaticity of the preparation protocol starting from a thermal state in the static lattice. We compare our results to theoretical predictions for the driven Fermi-Hubbard model.

Q 51.19 Wed 16:15 Redoutensaal

Towards Quantum Simulation of the Kondo Lattice Model — •Benjamin Abeln[1], Marcel Diem[1], Koen Sponselee[1], Maximilian Hagenah[1], Bodhaditya Santra[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Over the last decade ultracold fermionic alkaline earth quantum gasses attracted a lot of attention due to their unique properties such as an ultra-narrow optical clock transition, a long-lived meta-stable state, SU($\mathcal{N}$) symmetric interactions, and the existence of an interorbital Feshbach resonance. In particular, fermionic ytterbium (Yb) quantum gases loaded into a state-dependent optical lattice allow for quantum simulation of lattice systems with orbital degrees of freedom, like the Kugel-Khomskii model or the Kondo lattice model (KLM). In the state-dependent lattice, the ground state atoms mimic the mobile spins in the KLM, whereas the excited state atoms represent the localized spin impurities.

We present progress towards the quantum simulation of the KLM with fermionic Yb atoms, including the loading of ground state atoms into a state-dependent lattice and the necessary refinements to the optical clock setup for flexible initial state preparation.

This work is supported by the DFG within the SFB 925.

Q 51.20 Wed 16:15 Redoutensaal

Manipulating spin correlations in a periodically driven many-body system — •Kilian Sandholzer[1], Frederik Görg[1], Michael Messer[1], Joaquìn Minguzzi[1], Gregor Jotzu[1,2], Rémi Desbuquois[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [2]Max Planck Institute for the Structure and Dynamics of Matter, 22761 Hamburg, Germany

Periodic driving can be used to coherently control the properties of a many-body state and to realize new phases which are not accessible in static systems. In this context, cold fermions in optical lattices provide a highly tunable platform to investigate driven many-body systems and additionally offer the prospect of quantitative comparisons to theoretical predictions. We implement a driven Fermi-Hubbard model by periodically modulating a 3D hexagonal lattice. In the regime where the drive frequency is much higher than all other relevant energy scales, we verify that the interacting system can be described by a renormalized tunneling. Furthermore, we achieve independent control over the single particle tunneling and the magnetic exchange energy by driving near-resonantly to the interaction. As a consequence, we are able to show that anti-ferromagnetic correlations in a fermionic many-body system can be enhanced or even switched to ferromagnetic correlations. The implementation of more complex modulation schemes opens the possibility to combine the physics of artificial gauge fields and strongly-correlated systems.

Q 51.21 Wed 16:15 Redoutensaal

High temperature pairing in a strongly interacting two-dimensional Fermi gas — •Marvin Holten, Puneet Murthy, Luca Bayha, Ralf Klemt, Gerhard Zürn, Philipp Preiss, and Selim Jochim — Physikalisches Institut, University of Heidelberg, Germany

On this poster we present our observation of many-body pairing in a two-dimensional gas of ultracold fermionic atoms at temperatures far above the critical temperature for superfluidity. We use spatially resolved radio-frequency spectroscopy to measure pairing energies spanning a wide range of temperatures and interaction strengths. In the strongly interacting regime, where the scattering length between fermions is on the same order as the inter-particle spacing, the pairing energy in the normal phase significantly exceeds the intrinsic two-body binding energy of the system and shows a clear dependence on local density. This implies, that pairing in this regime is driven by many-body correlations rather than two-body physics. We find this effect to persist at temperatures close to the Fermi temperature, which demonstrates that pairing correlations in strongly interacting two-dimensional fermionic systems are remarkably robust against thermal fluctuations. In addition, we present our study of collective excitation modes of our fermionic atom cloud in its two-dimensional harmonic confinement. Our current results support the observation of a quantum anomaly due to interactions breaking the scale invariance of the two-dimensional gas.

Q 51.22 Wed 16:15 Redoutensaal

Bridging the thermoelectric and superfluid fountain effects with ultracold fermions — •Martin Lebrat, Dominik Husmann, Samuel Häusler, Philipp Fabritius, Laura Corman, Jean-Philippe Brantut, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zürich, Switzerland

An out-of-equilibrium system with temperature and chemical potential gradients needs both heat and matter currents to relax to thermodynamical equilibrium. The relaxation dynamics illuminates the microscopic mechanisms responsible for transport and energy conversion between heat and work, which is of great technological importance for cooling (Peltier effect) or power generation (Seebeck effect).

Using two reservoirs of fermionic lithium-6 atoms connected by an optically-shaped constriction, we demonstrate such thermoelectric effects and investigate the influence of interactions and constriction properties. With weak interactions and a 2D constriction, thermoelectric coupling can be optimized by controlling the geometry or introducing disorder [1]. With strongly interacting fermions close to the superfluid transition and a quasi-1D constriction, the system evolves towards a non-equilibrium steady state, associated with a reduced heat diffusion and a strong violation of the Wiedemann-Franz law. Measuring thermoelectric transport coefficients as a function of constriction anisotropy and degeneracy, we underline the analogies and differences between our observations and the celebrated fountain effect shown with superfluid helium-4.

[1] J.-P. Brantut et al., Science **342**, 713 (2013)

Q 51.23 Wed 16:15 Redoutensaal

Fast, long-distance transport of single atoms using quantum optimal control — •Thorsten Groh[1], Manolo Rivera[1], Natalie Thau[1], Max Werninghaus[1], Carsten Robens[1], Wolfgang Alt[1], Dieter Meschede[1], Antonio Negretti[2], and Andrea Alberti[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany

We present a digital phase and amplitude control loop setup based on a field programmable gate array (FPGA) which enables fast transport of single cesium atoms in polarization-synthesized optical lattices over macroscopic distances. Using analog control techniques, we could demonstrate fast atom transport over single lattice sites with minimal motional excitations and transport times down to the quantum speed limit. This is achieved by modulating both position and depth of the optical lattice potential by means of quantum optimal control theory. The new FPGA-based control system allows us to implement internal model control schemes enabling feed-forward driving. This dramatically extends the bandwidth of the feedback from 1 MHz to about 10 MHz. This not only allows single-site transport of atoms in less than the oscillation period of the trapping potential, but also provides an ideal platform for long distance and multiple step transport sequences. Fast atom transport over macroscopic distances will enable high precision atom interferometry and quantum information applications.

Q 51.24 Wed 16:15 Redoutensaal

Designing two-dimensional dynamical potentials using fast controllable devices — •Mareike Hetzel, Andreas Hüper, Cebrail Pür, Jiao Geng, Ilka Kruse, Jan Peise, and Carsten Klempt — Institut für Quantenoptik, Leibniz Universität Hannover

Arrays of atoms trapped by optical tweezers enable the study of phenomena in the field of quantum computing and many-body physics. The individual control of each site allows the precise quantum engineering of freely adjustable Hamiltonians. Here, we present the generation of arbitrary two-dimensional light patterns with fast dynamic control. The patterns are created by an acousto-optic deflector together with a versatile software-based radio-frequency generator. Our solution offers higher dynamic modulation speeds compared to competing system with digital micromirror devices or spatial light modulators. We present a test setup that is used to characterize the key components and demonstrate its capabilities by generating a set of optical potentials including lattice patterns, defects and dynamically generated structures. We further show a possible implementation of the setup in our experimental apparatus.

Q 51.25 Wed 16:15 Redoutensaal

Optical trapping of ion Coulomb crystals — •Julian Schmidt, Yannick Minet, Pascal Weckesser, Fabian Thielemann, Markus Debatin, Leon Karpa, and Tobias Schaetz — Physikalisches Institut, Universität Freiburg, Deutschland

Ion Coulomb crystals are the key to many applications with trapped ions, as the crystal phonons mediate interaction between ions and allow coupling of electronic and motional states on the quantum level [1]. However, rf-micromotion in ion traps poses fundamental limits for applications with higher-dimensional Coulomb crystals [2] and in ultracold chemistry experiments. Optical dipole traps for trapped ions [3] do not exhibit this micromotion, but only trapping of single ions had been demonstrated thus far.

We now demonstrate trapping of ion crystals consisting of up to six Barium ions in an optical dipole trap aligned with the crystal axis without confinement by radio-frequency (RF) fields. The dependence on the trap parameters, in particular the interplay of beam waist, laser power and axial confinement by DC electric fields, is investigated. As a proof-of-principle experiment, we detect the center-of-mass and stretch modes for an optically trapped two-ion crystal. Finally, we present prospects for optical trapping of higher-dimensional Coulomb crystals.

[1] D.J. Wineland, Rev. Mod. Phys. 85, 1103 (2013)
[2] R. Thompson, Contemp. Phys. 1,56, 63-79 (2015)
[3] A. Lambrecht et al., Nat. Phot. 11, 704-707 (2017)

Q 51.26 Wed 16:15 Redoutensaal

Laser cooling of dysprosium — •Niels Petersen[1,2], Florian Mühlbauer[1], Lena Maske[1], Carina Baumgärtner[1], and Patrick Windpassinger[1,2] — [1]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany

Ultra-cold dipolar quantum gases enable the study of many-body physics with long-range, inhomogeneous interaction effects due to the anisotropic character of the dipole-dipole interaction. These systems are expected to show novel exotic quantum phases and phase transitions which can be studied with dysprosium atoms. Dysprosium is a rare-earth element with one of the largest ground-state magnetic moments (10 Bohr magnetons) in the periodic table. Therefore, the dipole-dipole interaction is not a small perturbation but becomes comparable in strength to the s-wave scattering. This influences significantly the physical properties of the trapped atomic sample, such as its shape and stability. This poster presents the current status of our experimental setup to generate dysprosium quantum gases. We present our results in laser cooling of dysprosium atoms and give an overview of our laser system and vacuum design.

Q 51.27 Wed 16:15 Redoutensaal

Setup of a new micro-structured linear Paul trap with integrated electro magnets and reduced axial micromotion — •Hendrik Siebeneich, Timm F. Gloger, Peter Kaufmann, Michael Johanning, and Christof Wunderlich — Department Physik, Universität Siegen, 57068 Siegen, Germany

We present the experimental status of a new 3d segmented ion trap setup with integrated electro magnets. Here, an improved design allows for a substantial reduction of axial micromotion and for an increased magnetic gradient necessary for radio frequency-driven conditional quantum dynamics. The trap consists of three layers of gold plated alumina, where the segmented outer layers provide the trapping potentials [1]. The newly designed middle layer contains microstructured electro magnets that create a spatially inhomogeneous magnetic field. This gradient field gives rise to coupling between internal and motional states of trapped ions. The trap is mounted on a ceramic chip carrier that, at the same time, acts as an ultra-high vacuum interface, featuring about 100 thick-film printed current and voltage feedthroughs. The RF- and DC-electrodes of the segmented trap as well as Ytterbium ovens and electro magnets are connected to the vacuum interface via printed circuit boards. The contact between the thick-film printed wires and the boards is made by a silk-screen printed solder that melts at a low temperature of 150°C.

[1] D. Kaufmann et al.: Thick-film technology for ultra high vacuum interfaces of micro-structured traps, Appl. Phys. B **107**, 935 (2012).

Q 51.28 Wed 16:15 Redoutensaal

Next generation atom chip development — •Alexandros Papakonstantinou[1], Hendrik Heine[1], Melanie Le Gonidec[1], Alexander Kassner[2], Mathias Rechel[2], Waldemar Herr[1], Marc C. Wurz[2], Wolfgang Ertmer[1], and Ernst M. Rasel[1] — [1]IQ, Leibniz Universität Hannover — [2]IMPT, Leibniz Universität Hannover

Despite the additional efforts imposed by their production, atom chips are an interesting source for Bose-Einstein condensates (BECs) since they are versatile, robust and also fast in the creation of a BEC. New applications in sensing and interferometry even live on further, expanding the functionalities on reduced outgassing and optical functionality.

On this poster we will present the recent developments of our atom chips featuring non-adhesive conjunction techniques, advanced materials and the combination of atom chips with optical gratings. This will lead to simplification and compactification of the overall setup enabling compact quantum sensors in the future. Furthermore we will show our new experiment, which is optimized for fast testing of atom chips.

This work is supported by the Deutsche Forschungsgemeinschaft (DFG) in the scope of the SFB 1128 geo-Q and by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under grant number DLR 50WM1650 (KACTUS).

Q 51.29 Wed 16:15 Redoutensaal

Characterization of a source of slow metastable Kr atoms — •Ergin Simsek, Markus Kohler, Carsten Sieveke, Pablo Woelk, Christoph Becker, and Klaus Sengstock — Universität Hamburg, Deutschland

Kr^{85} is produced only anthropogenically by nuclear fission. Therefore its concentration in the atmosphere has increased since the beginning of the nuclear age. With its half life of 10.76 years, Kr^{85} can be used as a tracer for measuring the regeneration cycles of young ground waters.

For this application we are developing a measurement chain including sampling, sample preparation and an isotope-selective concentration measurement. For the determination of Kr^{85} content our setup is based on the Atom Trap Trace Analysis (ATTA) method which is sensitive to the parts-per-trillion level.

The measurement device uses a 2D-3D magneto-optical trap (MOT), capable of capturing and counting specific isotopes down to the single atom regime. As it is not possible to cool and trap Kr from the ground state, we first prepare the atoms to a metastable state.

To avoid cross contamination we implement an all-optical excitation scheme which includes an in-house developed VUV lamp emitting 123 nm and a 819 nm diode laser system. Because of the complex relationship between excitation and capturing dynamics within the 2D MOT we evaluate spatial distribution of the excitation by measuring the loading rate of the 3D MOT.

Q 51.30 Wed 16:15 Redoutensaal

Gauge fields and topological states with ultracold erbium atoms — •Roberto Vittorio Röll, Daniel Babik, Carl Cheung, Jens Ulitzsch, and Martin Weitz — Institut für Angwandte Physik, Universität Bonn

We report on progress in an ongoing experiment directed at the observation of topological states of ultracold erbium atoms in a synthetic magnetic gauge field.

In alkali atoms with their S-ground state configuration in far detuned laser fields with detuning above the upper state fine structure splitting the trapping potential is determined by the scalar electronic polarizability. In contrast, for an atomic erbium quantum gas with its $L > 0$ electronic ground state, the trapping potential for inner-shell transitions also for far detuned dissipation-less trapping laser fields becomes dependent on the internal atomic state (i.e. spin). Therefore it is expected to reach much longer coherence times with atomic erbium in spin-dependent optical lattice experiments and for far detuned Raman manipulation in comparison with the usual alkali atoms.

In our Bonn experiment an atomic erbium Bose-Einstein condensate (BEC) is generated in a quasistatic optical dipole trap provided by a focused mid-infrared CO_2-laser beam. In the next experimental step, we plan to realize synthetic magnetic fields by phase imprinting with Raman manipulation beams. The goal is to observe fractional quantum Hall physics for atoms in a strong synthetic magnetic field.

Q 51.31 Wed 16:15 Redoutensaal

Satellite-based links for Quantum Key Distribution: a comprehensive model — •Carlo Liorni, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität, Institut für Theoretische Physik III, Düsseldorf, Germany

Quantum Key Distribution has the potential to become the first quantum technology to be applied in a real-world scenario. For intercontinental distances, the intrinsic losses introduced by silica fibres become too detrimental to establish any kind of useful communication. Satellite-based quantum links could, in principle, allow to cover such long distances. Uplinks and downlinks, comprising either a sending or a receiving ground station, are subjected to the deleterious effects of turbulent atmosphere and bad weather conditions.

We start from the model proposed in [1], in order to analyse the propagation of quantum light in a turbulent atmosphere with additional scatterers, like rain or fog. Many additional aspects must be considered: inhomogeneity of the atmosphere, pointing errors, variation of the link length along the orbit, presence of clouds, noise due to environmental light. The information-theoretic security criterion proposed in [2] will be adopted, allowing us to take into account finite-key effects, particularly important when considering links based on Low Earth Orbit satellites. Different implementations (continuous and discrete variables) and different protocols are differently affected by the noise. We use a comprehensive model that helps to find the most efficient choice in every scenario.

Q 51.32 Wed 16:15 Redoutensaal

Quantum interference with frequency-locked dissimilar light sources — •Chris Müller[1], Tim Kroh[1], Yanting Teng[2], Andreas Ahlrichs[1], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin — [2]University of Illinois at Urbana-Champaign

To realize a quantum network, it will be necessary to process, store and send photons over long distances. It is unlikely that a single physical system can perform all these operations, therefore, dissimilar quantum systems have to be utilized. The first step towards a quantum network is to show that quantum information can be exchanged between its dissimilar subunits, for instance, via Hong-Ou-Mandel(HOM)-type coincidence measurements [1] on photons emitted by the subunits.

We demonstrate HOM interference between photons from two dissimilar quantum light sources. One is a cavity enhanced spontaneous parametric down-conversion source [2] and the other is a semiconductor quantum dot [3]. In order to establish photon indistinguishability, we frequency-lock both sources to the cesium D1 line (894.3 nm). Active frequency-locking is mandatory to allow for data accumulation over a sufficiently long time and for expanding the quantum network by additional units. We discuss limits of indistinguishability and how it can be improved by additional filtering of the emitted photons in the time domain.

[1] Hong et al., Phys. Rev. Lett. 59, 2044 (1987)
[2] Ahlrichs and Benson, Appl. Phys. Lett. 108, 021111 (2008)
[3] Rastelli et al., Physica Status Solidi B, 249, 687 (2012)

Q 51.33 Wed 16:15 Redoutensaal

Single-photons versus weak-coherent pulses for quantum memories — •Tom Schmit[1], Luigi Giannelli[1], Stephan Ritter[2], Gerhard Rempe[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse , 85748 Garching, Germany

We theoretically analyse the absorption of light incident on a cavity by a single atom within the resonator. We model the atom with a three-level Λ-system and assume that one transition interacts with a single cavity mode while the other is driven by an external laser field. We further include the resonator's and the atom's losses. We then compare the fidelity of absorption when the incident light is a weak coherent pulse and when it is a single photon.

Q 51.34 Wed 16:15 Redoutensaal

A theoretical framework for QR-PUFs — •Giulio Gianfelici, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Physical Unclonable Functions (PUFs) are physical systems with a challenge-response behaviour intended to be hard to clone or simulate. This emerging technology has been proposed in several cryptographic protocols, with particular emphasis on authentication protocols. Recently, extensions of such systems to quantum protocols, the so called Quantum Readout of PUFS (QR-PUF), were suggested. However, a well-defined agreement about theoretical assumptions and definitions behind the intuitive ideas of QR-PUFs, and therefore our ability of characterising the security of cryptographic protocols, is limited. We aim to build a theoretical framework in which we define and quantify the security properties of QR-PUFs. Such a framework will allow us to develop new protocols to derive security thresholds for QR-PUF authentication.

Q 51.35 Wed 16:15 Redoutensaal

Carving of Two-Atom Entangled States using a Cavity — •Bastian Hacker, Stephan Welte, Severin Daiss, Lin Li, Stephan Ritter, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

In a quantum network, optical resonators provide an ideal platform to mediate interactions between matter qubits. This is achieved by the exchange of photons between the resonator-based network nodes, and in this way enables the distribution of quantum states and the generation of remote entanglement. Here we demonstrate how photons can also be used to generate local entanglement between matter qubits in the same network node. Such entangled states are a valuable resource in many quantum communication protocols. We employ neutral atoms, that are strongly coupled to a high-finesse optical cavity. Two protocols are implemented, which rely on the reflection of coherent light from the atom-cavity system. Detection of a polarisation flip heralds the entanglement and postselection allows us to remove parts of the combined two-atom wave function, a method called carving. We created all four Bell-states and achieve fidelities with the ideal Bell states of up to 90%. Our entangling mechanism does not depend on the interatomic distance and can be applied to any matter qubit with a closed optical transition. Furthermore, no individual addressing of the atoms is required. One of the potential applications of the presented entangling scheme is the entanglement swapping procedure in a quantum repeater based on neutral atoms in optical resonators.

Q 51.36 Wed 16:15 Redoutensaal

Sagnac-type setup for the generation of tunable polarization entangled photon pairs — •Golnoush Shafiee[1,2], Gerhard Schunk[1,2], Florian Sedlmeir[1,2], Alexander Otterpohl[1,2], Ulrich Vogl[1,2], Dmitry Strekalov[1,2], Harald G. L. Schwefel[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]MPL, Erlangen, Germany — [2]Institute of Optics, FAU, Erlangen, Germany — [3]University of Otago, Dunedin, New Zealand

Single photons and photon pairs are an important resource for quantum information processing. Our compact source of photon pairs [1] and squeezed light [2] is based on spontaneous parametric down conversion (SPDC) in a triply resonant whispering-gallery resonator (WGR) made of lithium niobate. Signal and idler radiation inside the resonator have each been demonstrated to be single mode. The central wavelength of the emitted light can be tuned over hundreds of nanometers [3]. Currently, we investigate PDC in counter-propagating modes of a single WGR. We want to show identicality between the counterpropagating signals (or idlers) by studying interference above and below the oscillation threshold.

In this compact and monolithic system, we want to generate identical single photons from two independent sources, which opens up novel possibilities for the creation of polarization-entangled photon pairs for proposed quantum repeater schemes.

[1] M. Förtsch et al., Nat. Commun. 4, 1818 (2013). [2] J. U. Fürst et al., Phys. Rev. Lett. 106, 113901(2011). [3] G. Schunk et al., Optica 2, 773-778 (2015).

Q 51.37 Wed 16:15 Redoutensaal

Two-Atom Quantum Gate employing an Optical Resonator — •Stephan Welte, Bastian Hacker, Severin Daiss, Lin Li, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Optical high-finesse resonators provide an interface between flying photonic qubits and stationary matter qubits [1], which is the foundation of an extended quantum network for quantum communication and distributed quantum computing. For the construction of a scalable network architecture, each node is required to hold several qubits that are connected through quantum gate operations. We present our experiment [2] where such a gate [3] is realized on two neutral Rubidium atoms trapped inside of a strongly coupled optical resonator. The gate itself is mediated by one optical photon, travelling in the network channel of our resonator. This creates an interaction that is independent of the distance between the atoms. We demonstrate the functionality of our gate as a CNOT as well as its ability to entangle the two atoms. The presented gate mechanism has the potential to serve as an entanglement swapping protocol in a future quantum repeater based on cavity QED systems.

[1] A. Reiserer, G. Rempe, *Rev. Mod. Phys.* **87**, 1379 (2015).
[2] S. Welte, B. Hacker, S. Daiss, S. Ritter, G. Rempe, *Phys. Rev. Lett.* **118**, 210503 (2017).
[3] L.-M. Duan, B. Wang, H. J. Kimble, *Phys. Rev. A* **72**, 032333 (2005).

Q 51.38 Wed 16:15 Redoutensaal

Increasing photon collection efficiency for faster remote entanglement of atoms — •Timon Hummel[1], Robert Garthoff[1], Kai Redeker[1], Tim van Leent[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Entanglement of atomic quantum memories separated by large distances will be a key resource for future applications in quantum communication including the quantum repeater and quantum networks. Currently, the efficiency of generation of remote entanglement in schemes based on entanglement swapping is limited by the efficiency of collecting photons from the quantum memory.

Here we present the experimental details on our route for improvement of the photon collection efficiency from a quantum memory based on single trapped atoms. Using a custom designed microscope objective with a high numerical aperture we estimate an improvement of the remote entanglement rate by one order of magnitude relative to that achieved in our previous measurements [1].

[1] Phys. Rev. Lett. 119, 010402 (2017).

Q 51.39 Wed 16:15 Redoutensaal

Heralded Entanglement of Single Atoms over Long Distances — •Tim van Leent[1], Robert Garthoff[1], Kai Redeker[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quan-

tenoptik, Garching

The concept of quantum repeaters paves the way towards a scalable quantum network, which is essential for large scale quantum communication and distributed quantum computing. The basis of a quantum network is entanglement between separated quantum memories. One of the current experimental challenges is to generate entanglement over long distances.

Here we present an experimental setup which entangles two Rb-87 atoms separated by a distance of 400 meters. Starting with atom-photon entanglement in both traps, the entanglement swapping protocol is employed to generate heralded entanglement between the atoms [1]. Together with a fast and efficient atomic state readout scheme a loophole-free violation of Bell's inequality was demonstrated [2], which is the key element in advanced protocols, such as certified generation of random numbers and device-independent quantum key distribution.

The next goal is to increase the distance between the entangled atoms. Milestones along this path are increasing the event rate, converting photons to telecom wavelengths, and improving the coherence time of the atomic state.

[1] J. Hofmann, Science 337, 72 (2012)

[2] W. Rosenfeld, Phys. Rev. Lett. 119, 010402 (2017)

Q 51.40 Wed 16:15 Redoutensaal

Entwicklung und Ergebnisse eines deterministischen Einzelionen-Mikroskops — •Felix Stopp, Georg Jacob, Karin Groot-Berning, Kai-Vincent Mettang und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Wir präsentieren die Ergebnisse eines Implantationsexperiments, für das wir eine deterministische Quelle verwenden [1]. Wir haben erfolgreich Stickstoff als NV-Zentren in Diamant implantiert und machen zur Zeit große Fortschritte mit der Implantation von auf 23(7) nm fokussierten $^{141}Pr^{+}$. Mit der Methode des sympathetischen Kühlens via $^{40}Ca^{+}$-Ionen in einer linearen Paulfalle werden uns neue Möglichkeiten eröffnet, z.B. die Implantation von $^{140}Ce^{+}$ oder P^{+} in Silizium (in Zusammenarbeit mit D. Jamieson, http://www.cqc2t.org/). Unsere Messgenauigkeit ist limitiert durch mechanische Vibrationen und thermischen Drifts. Deshalb wird weiterhin die Entwicklung eines hochstabilen Einzelionen-Mikroskops präsentiert. Zwei Ziele eröffnen uns hierbei eine weite Bandbreite an neuen Möglichkeiten: wir wollen Fokusgrößen unter 1 nm und eine Extraktionsrate in der Größenordnung von 1 kHz für schnellen Datenerwerb erreichen. Beide Ziele können durch unsere kompakten und austauschbar steckbaren Module realisiert werden. Hohe Extraktionsraten werden hierbei durch ein Ca^{+}-Reservoir in der Falle erreicht. Von hier aus werden sie zu dem Segment transportiert [2], wo sie zu einer Einzellinse extrahiert werden.

[1] Jacob et al., Phys. Rev. Lett. **117**, 043001 (2016)

[2] Ruster et al., Phys. Rev. A **90**, 033410 (2014)

Q 51.41 Wed 16:15 Redoutensaal

Spin-photon interface controlled switching in a nanobeam waveguide — •Tim Schröder[1], Alisa Javadi[1], Dapeng Ding[1], Martin Hayhurst Appel[1], Sahand Mahmoodian[1], Matthias C. Löbl[2], Immo Söllner[2], Rüdiger Schott[2], Camille Papon[1], Tommaso Pregnolato[1], Søren Stobbe[1], Leonardo Midolo[1], Andreas D. Wieck[3], Arne Ludwig[3], Richard J. Warburton[2], and Peter Lodahl[1] — [1]Niels Bohr Institute, University of Copenhagen, Denmark — [2]Department of Physics, University of Basel, Switzerland — [3]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Coherent control of two-level quantum systems, for example, the electron spin of a solid-state emitter, is an integral requirement for the implementation of quantum information processing. Towards building quantum gates and creating spin-photon entanglement via spin-photon interfaces in photonic integrated circuits (PIC), we demonstrate an efficient, and optically controllable interface between an electron spin in a InGaAs quantum dot and photons guided in a PIC. The spin-state preparation fidelity reaches 96% and allows for the realisation of a proof-of-concept single spin controlled photon switch with a 4-fold switching ratio between ON and OFF states. The spin state lifetime T_1 times reaches 5 μs.

[1] A. Javadi, D. Ding, M. H. Appel, S. Mahmoodian, M. C. Löbl, I. Söllner, R. Schott, C. Papon, T. Pregnolato, S. Stobbe, L. Midolo, T. Schröder, A. D. Wieck, A. Ludwig, R. J. Warburton, and P. Lodahl, arXiv:1709.06369 (2017).

Q 51.42 Wed 16:15 Redoutensaal

Estimating the min-entropy of quantum random processes by exploiting Wigner functions — •Johannes Seiler[1], Thomas Strohm[2], and Wolfgang P. Schleich[1,3] — [1]Institut für Quantenphysik & Center for Integrated Quantum Science and Technology IQ^{ST}, Universität Ulm, D-89069 Ulm — [2]Robert Bosch GmbH — [3]Hagler Institute for Advanced Study, Institute forQuantum Science and Engineering (IQSE), and Texas A&M AgriLifeResearch, Texas A&M University, College Station, TX 77843-4242, USA.

An important advantage of a quantum random number generator (QRNG), compared to its classical counterparts, is that quantum mechanics ensures that the generated random numbers are, even in principle, not predictable. However, since QRNG devices are never completely perfect, there is always a classical noise contribution, which in principle allows one to retrieve information about the generated numbers. Hence, a crucial problem is to quantify how much of the data really originates from the underlying quantum mechanical process. This quantity can be expressed in terms of the min-entropy $H_{\min}(B|E)$ of the outcome random variable B conditioned on the environment E. Knowing this quantity, it is possible to create true random numbers from the raw numbers. However, it can be difficult to obtain $H_{\min}(B|E)$, or a good lower bound on it, from measurable quantities. In this poster, we investigate this problem for a simple spin-1/2 system. By using the Wigner function of the system and the measurement operator, we provide new insight into obtaining the optimal lower bound of $H_{\min}(B|E)$.

Q 51.43 Wed 16:15 Redoutensaal

Non-classical correlations between ultra-bright broadband twin beams — •Fabian Gumpert[1,2] and Maria Chekhova[1,2] — [1]Friedrich Alexander Universität, Erlangen, Deutschland — [2]Max Planck Institut für die Physik des Lichts, Erlangen, Deutschland

We investigate non-classical correlations between ultra-bright broadband twin beams. These beams are generated via high-gain parametric down conversion (PDC) in an aperiodically poled lithium niobate crystal. The spectral bands of the idler and signal beams are many times broader than in the case of a uniform (periodically poled) crystal. These ultra-bright broadband twin beams are particularly interesting for quantum information applications. The process of non-phase matched sum frequency generation (SFG) is used to measure the time of photon-number correlations between the twin beams. Because of dispersion effects within the aperiodically poled crystal the photons generated through PDC get additional spectral-dependent delays, which increase the observed correlation time. To reduce the correlation times, additional dispersive elements are added to the setup. A correlation time of 90 fs was recorded until now [1] and by designing the dispersive elements we are going to achieve much shorter correlation times.

[1] M. V. Chekhova, S. Germanskiy, D. B. Horoshko, G. Kh. Kitaeva, M. I. Kolobov, G. Leuchs, C. R. Phillips and P. A. Prudkovskii, arXiv:1710.08330 (2017).

Q 51.44 Wed 16:15 Redoutensaal

Single photon source with rubidium vapor cells — •Arzu Yilmaz — Physikalisches Institut Universität Tübingen, Tübingen, Deutschland

We report on our work towards a single photon source with optical fibers in rubidium vapor cells. Using high laser intensities, we excite the atoms in front of the fiber. This causes a broadening of the atomic fluorescence spectrum beyond the thermal doppler width. As a result, correlations within the fluorescence signal should be observable, which might be used to realize a deterministic single photon source. Such sources are essential for quantum communication protocols and will open up new perspectives in future quantum technology.

Q 51.45 Wed 16:15 Redoutensaal

Ion Implantation and Annealing Parameters and their Effect on Spin Properties of Color Centers in Diamond — •Johannes Lang, Ragul Sivakumar, Christian Osterkamp, Boris Naydenov, and Fedor Jelezko — Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm, Germany

The color center in diamond formed by a substitutional nitrogen and an adjacent vacancy (NV center) is amongst the most studied defects in diamond. It is a promising candidate for different applications such as e.g. qubit spin registers in future quantum computation [1] or for different sensing applications [2] as well as quantum communication. Besides the on-demand creation of these color centers by shallow $^{15}N^{+}$

implantation [3], increasing their creation yield and coherence time T_2 are key factors for the applications mentioned above [4]. Here, we present optimizations on our home built, low energy, UHV ion implanter as well as the UHV annealing oven, in combination allowing the creation of single, shallow (< 10 nm) color centers with well controllable properties regarding their implantation depth, density and position. We also present recent investigations on the effect of varying the annealing process parameters and their influence on the created NV centers.

[1] M. W. Doherty et al., Physics Reports 528 1-45 (2013)
[2] C. Müller et al., Nat. Comm. 5 4703 (2014)
[3] S. Pezzagna et al., New J. Phys. 12 065017 (2010)
[4] FF de Oliveira et al., Nat. Comm. 8 15409 (2017)

Q 51.46 Wed 16:15 Redoutensaal

Using Optical Nanofibers for Quantum Optics — •Sarah M. Skoff, Hardy Schauffert, Johanna Hütner, and Arno Rauschenbeutel — Institute of Atomic and Subatomic Physics, Vienna University of Technology, Stadionallee 2, 1020 Vienna, Austria

Optical nanofibers are a versatile tool for interfacing different quantum emitters with a light field. They are the tapered part of a commercial optical fiber that has a subwavelength diameter waist and therefore allows a significant amount of light to be guided outside the fiber in the form of an evanescent wave. We use such optical nanofibers to optically address individual molecules in solids and we will present this fully fiber-integrated system in more detail.

Due to the transverse confinement of the light field provided by the optical nanofiber, the interaction with quantum emitters is already significant. However this nanofiber-based approach can be combined with a fiber-based cavity to enhance the light-matter interaction even further and we will show the implementation of such a resonator.

Q 51.47 Wed 16:15 Redoutensaal

Collective molecular emission into a nanofiber — •Masoud Mirzaei[1,2], Tobias Utikal[1,2], Stephan Götzinger[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University of Erlangen-Nürnberg, Erlangen, Germany

Tapered optical fibers with a subwavelength diameter exhibit a highly confined mode with a pronounced evanescent field. These properties result in efficient coupling between emitters along the fiber and the guided mode and make it highly desirable for sensitive absorption and fluorescence spectroscopy. In this work, we report mirror-less, low-threshold laser-like action from an organic gain medium surrounding the nanofiber. We discuss variations in temporal and spectral widths as a function of the excitation pulse energy as well as a threshold in the emission signal in the context of self-absorption and re-emission.

Q 51.48 Wed 16:15 Redoutensaal

SiO2 on Si photonic platform with ultra-low intrinsic fluorescence for integrated single photon emitters based on diamond defect centers — •Florian Böhm[1], Christoph Pyrlik[2], Niko Nikolay[1], Jan Schlegel[2], Andreas Thies[2], Andreas Wicht[2], and Oliver Benson[1] — [1]AG Nanooptik, Humbodt-Universität zu Berlin, Germany — [2]Ferdinand-Braun-Institut für Höchstfrequenztechnik, Berlin, Germany

On-chip photonic structures, for example integrated solid-state single photon sources, effectively coupled to a single guided optical mode are one important tool towards future applications in quantum information science [1]. Typically excitation and fluorescence collection from single emitters requires bulky confocal microscopes.

We report on our approach towards an integrated single photon source, consisting of nano-sized quantum emitters (NV centers in diamond), evanescently coupled to photonic structures in SiO2. This novel hybrid system, based on pure, undoped SiO2, exhibits exceptionally low intrinsic fluorescence and allows high reproducibility and diversity in the fabrication of photonic elements e.g. waveguides, mode-size converters, couplers and resonators.

Our results are promising steps towards realizing a fully integrated single photon source. Deterministic [2] coupling of a single quantum emitter to the system could enable simultaneous on-chip excitation and collection, rendering the microscope objective unnecessary.

[1] Aharonovich, I., et al., Nature Photonics, 10(10), 631-641, (2016)
[2] Schell A.W., et al. Rev. Sci. Instrum., 82(7), 073709, (2011)

Q 51.49 Wed 16:15 Redoutensaal

Nano-Quantum Optics — •Vahid Sandoghdar[1,2] and Stephan Götzinger[1,2] — [1]Max-Planck-Institut für die Physik des Lichts, Erlangen — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg

The interaction of light and matter at the nanometer scale lies at the heart of quantum optics because it concerns elementary processes such as absorption or emission of a photon by an atom. These phenomena were studied with ensembles of light and material particles in the 20th century. However, controlled and efficient experiments with single photons and single quantum emitters have only recently become accessible. This advance owes much to the progress in the field of nano-optics, where the interaction of individual quantum emitters such as molecules, quantum dots or color centers with their nanoscopic environment can be tailored. In this poster presentation, we provide an overview of the exciting field of nano-quantum optics and its promise for engineering new quantum states of light and matter.

Q 51.50 Wed 16:15 Redoutensaal

Strong enhancement of radiative decay and efficient biexciton emission from a single quantum dot coupled to a plasmonic nanocone antenna — •Hsuan-Wei Liu[1], Korenobu Matsuzaki[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nürnberg, Erlangen, Germany

Semiconductor quantum dots are capable of emitting one, two or more photons after each excitation because of the possibility of generating multiple excitons within the same quantum dot. In the case where two excitons are created, recombination leads to a cascaded emission process. However, the quantum efficiency of such a two-photon emission is usually very low. In this study, we demonstrate a significant enhancement of the biexciton emission efficiency by coupling a single quantum dot to a plasmonic nanocone antenna, which was fabricated by focused ion beam milling [1]. We show that the quantum efficiency of the biexciton emission is increased by more than one order of magnitude to 70% in the coupled system. Moreover, by performing many quantitative insitu measurements on the same quantum dot, we demonstrate more than 100-fold radiative enhancement by the gold nanocone antenna for both excitonic and biexcitonic emission channels [2].

[1] Hoffmann *et al.*, *Nanotechnology* **26**, 404001 (2015). [2] Matsuzaki *et al.*, *Sci. Rep.* **7**, 42307 (2017).

Q 51.51 Wed 16:15 Redoutensaal

Nanodiamonds manipulation with AFM at nanoscale — •Yan Liu, Alexander Kubanek, and Fedor Jelezko — Institut für Quantenoptik, Universität Ulm

Nanodiamonds (ND) embedded with optically active colour centres have important applications. They are now widely used as bio-imaging makers at different wavelengths. in addition, they are excellent platforms for quantum optics study. Here we show the technique of manipulating nanodiamonds at nanoscale. Our experimental setup is the combination of AFM and a confocal fluorescence microscope also incorporated with synchronized microwave source, and it allows us to study the sizes of NDs, fluorescence properties and spin properties of negatively charged nitrogen vacancy colour centres in the NDs. Besides that, we can do repositioning with accuracy of about 20 nm and orientation flipping of the NDs using contact mode of the AFM. The results promote further studies on dipolar coupling of single photon emitters and spin-spin coupling of quantum platforms in different NDs, engineering integrated quantum optical circuits, etc.

Q 51.52 Wed 16:15 Redoutensaal

^{13}C enriched nanodiamonds — •yuliya mindarava[1], yan liu[1], vyacheslav agafonov[2], valeriy davydov[3], liudmila kulikova[3], christian laube[4], christian jentgens[4], and fedor jelezko[1] — [1]Institute of Quantum Optics, Ulm University, Ulm, Germany — [2]François Rabelais University, Tours, France — [3]L.F. Vereshchagin Institute for High Pressure Physics of the RAS, Troitsk, Russia — [4]Leibniz Institute of Surface Engineering, Leipzig, Germany

Nuclear hyperpolarization can be realized with nitrogen-vacancy (NV) color center incorporated with ^{13}C in nanodiamonds, which can be used as labels for magnetic resonance imaging (MRI). In this work, we employed a combined setup consisting of an atomic force microscope (AFM), a confocal fluorescence microscope, a microwave source, and a spectrometer to study ^{13}C incorporated NV centers in nanodiamonds (ND). Enrichment of ^{13}C in ND was analysed with optically detected magnetic resonance (ODMR) of NV centers. Sizes, fluorescence spectra, and fluorescence intensities of NDs can all be acquired. Therefore, we are able to calculate the density of NV centers. With hyperpolarization of ^{13}C and surface functionalization in the future, our study would promote targeted MRI, which owes great significance in medical and biological applications.

Q 51.53 Wed 16:15 Redoutensaal

XUV Microscopy with a Schwarzschild-Objective driven by high-harmonic generation — •Felix Wiesner[1], Julius Reinhard[1], Martin Wünsche[1,2], Johann Jakob Abel[1], Silvio Fuchs[1,2], Jan Nathanael[1], Christian Rödel[2], and Gerhard Paulus[1,2] — [1]Institute of Optics and Quantum Electronics Jena, Germany — [2]Helmholtz Institute Jena, Germany

We report on the development of an extreme ultraviolet light (XUV) microscope with a Schwarzschild objective (SSO). XCT is a 3D imaging technique, which is based on Optical Coherence Tomography and was realized using Synchrotron radiation sources [1] as well as a lab-scale high-harmonic XUV source [2,3]. The axial resolution of XCT reaches a few nanometers, whereas the lateral resolution is limited by the size of the focal spot, 23μm at present. To overcome this significant gap a special high-NA SSO is used. The SSO consist of two spherical mirrors and offers almost aberration-free imaging with a NA of 0.2 supporting lateral resolutions down to 70nm. The two optics have a broadband multilayer coating, a prerequisite of XCT. To test the imaging properties of the SSO, a transmission light microscopy setup has been built. With this setup, a pinhole and diffractive gold gratings were investigated as well as gold nanoparticles, carbon nanotubes and cancer cells. In first experiments, resolutions below 1μm have been reached. A combination with XCT is possible for thin samples and allows non-destructive 3D imaging with nanometer resolution in all dimensions. [1] Fuchs et al., Scientific Reports 6, 20658 (2016) [2] Fuchs et al., Optica 4, 903 (2017) [3] Wünsche et al., Optics Express 25, 6936 (2017)

Q 51.54 Wed 16:15 Redoutensaal

Infrared streak cameras: Overcoming low SNR by upconversion — •Markus Allgaier[1], Vahid Ansari[1], Christof Eigner[1], Viktor Quiring[1], Raimund Ricken[1], John Matthew Donohue[1], Thomas Czerniuk[2], Marc Assmann[2], Manfred Bayer[2], Benjamin Brecht[3,1], and Christine Silberhorn[1] — [1]Integrated Quantum Optics, Applied Physics, University of Paderborn, 33098 Paderborn, Germany — [2]Experimentelle Physik II, Technische Universität Dortmund, 44221 Dortmund, Germany — [3]Clarendon Laboratory, Department of Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

Streak cameras are the standard tool for studying semiconductor emission in the time domain, especially for picosecond time scales. While high performance on the single-photon level has been shown for visible wavelengths, sensitivity and noise performance for the infrared range is limited. We study noise sources and quantum efficiency in commercially available streak cameras, and show that the limitations in the infrared and particularly the telecom range can be overcome using an upconversion scheme. We experimentally demonstrate single-photon sensitivity in the telecom band using an engineered sum-frequency generation process in periodically poled Titanium-indiffused waveguides in Lithium Niobate, achieving picosecond resolution. Single-photon sensitivity is verified using a parametric downconversion (PDC) source with a known average photon number of 0.2.

Q 51.55 Wed 16:15 Redoutensaal

Topological order in finite-temperature and driven dissipative systems — •Lukas Wawer[1], Michael Fleischhauer[1], Charles Bardyn[2], Sebastian Diehl[3], and Alexander Altland[3] — [1]University of Kaiserslautern, Kaiserslautern, Germany — [2]Department of Quantum Matter Physics, University of Geneva — [3]University of Cologne, Cologne, Germany

There are many exciting topological properties of topological systems in pure states. Although mixed quantum states can be understood as a generalization of pure states their topological properties are not investigated so far. For example, quantization of charge transport in a so-called Thouless adiabatic pump is lifted at any finite temperature in topological insulators. Here we show, that many body correlations preserve the integrity of topological invariants for mixed Gaussian states in one dimension. In our approach we show that the expectation value of the many body momentum-shift operator leads to a definition of a physical observable called the "ensemble geometric phase" (EGP). It turns out that in analogy to the Zak phase of pure states this phase is a general representation of a geometric phase for mixed Gaussian quantum states in the thermodynamic limit. Additionally the EGP provides a topologically quantized observable which detects encircled spectral singularities of density matrices. [1] Bardyn et. al., arXiv:1706.02741v2

Q 51.56 Wed 16:15 Redoutensaal

Seeded Photon Triplet Generation — •Cameron Okoth[1], Andrea Cavanna[1], Nicolas Y. Joly[1,2], and Maria V. Chekhova[1,2,3] — [1]Max-Planck- Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Faculty of Physics, M. V. Lomonosov Moscow State University, 119991 Moscow, Russia — [3]University of Erlangen-Nuremberg, Staudtstr. 7/B2, 91058 Erlangen, Germany

As quantum systems become more integrated in commercial and industrial technologies, it is only natural to find the limitations of what we can experimentally achieve with regards to these systems. One particular area of interest is the generation of high number Fock states beyond single and pair states. We intend to produce a three photon state via cubic non-linearity in which a pump photon decays into three daughter photons.

We make a theoretical comparison of the expected photon triplet rates, both when the generation of the photon triplet state is spontaneous, and when the process is stimulated by supplying photons in one of the modes of the photon triplet state. By introducing a parameter known as the effective vacuum field it is possible to set-up some general statements about the relative efficiency of each process. By maximising the variables that enter photon triplet rate equation, we suggest several promising materials that can be exploited to generate photon triplets with reasonable rates.

Q 51.57 Wed 16:15 Redoutensaal

Characterization of Optically Dense Atomic Ensembles confined in Nanofiber-based traps — •Samuel Rind, Adarsh Prasad, Jakob Hinney, Christoph Clausen, Jürgen Volz, Philipp Schneeweiss, and Arno Rauschenbeutel — srind@tuwien.ac.at

Nanofiber based traps have been used for the last decade as novel interface between light and matter. Here we realize an efficient optical interface between fiber-guided light and laser-cooled atoms, which are arranged in two linear arrays in a two-color evanescent-field dipole trap around an optical nanofiber. In this configuration, we achieve a strong light-matter interaction where the probability of a nanofiber-guided photon being absorbed by a trapped atom is as high as 10%. To see this, we measure the transmission through the fiber as we scan the frequency of our probe field. When large ensembles of atoms are trapped (several 1000) this gives rise to a high optical density (OD) around the fiber. As a consequence, even for large detuning (>100MHz) from the atomic resonance the atoms completely scatter light. This makes accurate and quick measurements of OD difficult with standard instruments, such as an acousto-optic modulator (AOM), which typically have frequency scan ranges below 200MHz. Here, we implement an electro-optic modulator (EOM) based frequency scanning scheme that allows us to scan a range that exceeds 1GHz in our experimental time frame of 5ms easily. This enables us to measure OD well over 1000, vastly improving previous incarnations we had of OD measurement schemes.

Q 51.58 Wed 16:15 Redoutensaal

Limits on generating higher-order Fock states with parametric down conversion — •Johannes Tiedau[1], Tim J. Bartley[1], Georg Harder[1], Thomas Gerrits[2], and Christine Silberhorn[1] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA

Photon number (Fock) states are of both fundamental and practical interest. They are used as resources in quantum metrology schemes, and can be used to probe the boundary between quantum and classical phenomena. In general, the metrological advantages and photonic state regimes of interest scale with the number of photons, therefore generating higher-order Fock states n, where n>2, is required. To date, nonlinear interactions such as heralded parametric down conversion are the standard method to generate such states. However, the probabilistic nature of the down-conversion process leads to a fundamental trade-off between generation probability and fidelity of the final states to the desired Fock states. For single photon Fock states, generated in this way, it is known that the maximal generation probability is 25%. Here, we generalise this result to cover higher order Fock states, taking into account the possible spectral multimode nature of the PDC state. The generalisation is non-trivial as all combinatorial possibilities to generate n photons from m possible modes need to be considered. This is supported by experimental data demonstrating the trade-off in the case where a spectrally optimised source is used.

Q 51.59 Wed 16:15 Redoutensaal

Observing $g^{(2)}(0)$ at the lasing threshold with samplerates up to 1 MHz — •Johannes Thewes, Carolin Lüders, and Marc Assmann — Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany

Monitoring fast changes in the photon statistics of a light source, such as a diode laser driven close to its lasing threshold, demands a high speed evaluation of the second order correlation function $g^{(2)}(0)$. By employing an optical homodyne detection scheme, we achieved samplerates of up to 1 MHz for $g^{(2)}(0)$. Thus, we could observe how and on what time scales the light emitted from a diode laser driven close to its lasing threshold switches back and forth between Poissonian and super-Poissonian photon statistics, which indicate coherent and thermal light respectively. In this way, we are able to perform a detailed analysis of the coherence dynamics at the lasing threshold. In sum, our work demonstrates the feasibility of sampling $g^{(2)}(0)$ with up to 1 MHz and enables future research and applications with other light sources such as polaritons in microcavities or optical quantum memories.

Q 51.60 Wed 16:15 Redoutensaal

Generation of squeezed vacuum states in a nonlinear crystalline whispering gallery mode resonator — •Alexander Otterpohl[1,2], Florian Sedlmeir[1,2], Thomas Dirmeier[1,2], Ulrich Vogl[1,2], Gerhard Schunk[1,2], Golnoush Shafiee[1,2], Dmitry Strekalov[1,2], Harald G. L. Schwefel[3], Tobias Gehring[4], Ulrik L. Andersen[4], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nürnberg, Staudtstr. 7 B2, 91058 Erlangen, Germany — [3]The Dodd-Walls Centre for Photonic and Quantum Technologies, Department of Physics, University of Otago, 730 Cumberland Street, 9016 Dunedin, New Zealand — [4]Department of Physics, Technical University of Denmark, Fysikvej, 2800 Kgs. Lyngby, Denmark

Macroscopic crystalline whispering gallery mode resonators (WGMR) made out of $LiNbO_3$ are a versatile source of non-classical light generated via optical parametric down-conversion [1]. Previously, we demonstrated squeezing of a bright single parametric beam as well as twin-beam squeezing above threshold. Now, we operate our source below the oscillation threshold at the degenerate point to generate squeezed vacuum states. We currently achieve up to 1 dB squeezing closely below threshold, which corresponds to only tens of microwatts of pump power. The low threshold allows us to investigate squeezing in a regime closely above and below the threshold.

[1] J. U. Fürst et al., Phys. Rev. Lett. **106**, 113901 (2011).

Q 51.61 Wed 16:15 Redoutensaal

Towards integrating superconducting detectors on lithium niobate waveguides — •Jan Philipp Höpker[1], Frederik Thiele[1], Moritz Bartnick[1], Stephan Krapick[1], Evan Meyer-Scott[1], Nicola Montaut[1], Harald Hermann[1], Raimund Ricken[1], Viktor Quiring[1], Torsten Meier[1], Adriana Lita[2], Varun Verma[2], Thomas Gerrits[2], Richard Mirin[2], Sae Woo Nam[2], Christine Silberhorn[1], and Tim Bartley[1] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]National Institute of Standards and Technology, 325 Broadway, Boulder, CO, 80305, USA

Superconducting photon detectors and integrated optics have enabled a variety of quantum optical experiments. Lithium niobate is a promising platform for quantum photonics thanks to its large second order nonlinear susceptibility, large electro-optic coefficient, and low guiding losses. Therefore, lithium niobate works very well for fast modulation and single photon sources. However, detecting single photons inside lithium niobate waveguides remains a challenge. Fiber-coupled superconducting nanowire single photon detectors (SNSPDs) and transition edge sensors (TESs) show outstanding quantum efficiency with low dark count rates. We have taken the initial steps in depositing these detectors on lithium niobate waveguides, including room temperature absorption measurements, cryogenic flood illumination tests, and the investigation of fiber-pigtailing for cryogenic environments.

Q 51.62 Wed 16:15 Redoutensaal

Entangled Photons Recombination from Broadband Parametric Down Conversion — •Hani Abou Hadba[1,2,3], Kirill Spasibko[2,3], and Maria chekhova[2,3] — [1]School of Advanced Optical Technologies SAOT, Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [3]Max-Planck-Institut für die Physik des Lichts, Erlangen Germany

Parametric down-conversion (PDC) is widely used as a source of entangled photon pairs, which have numerous applications in quantum optics and quantum information. The reverse process to PDC is the sum frequency generation (SFG): while in PDC a pump photon decays into a photon pair, in SFG two photons recombine into one. This process is referred to as the pump re-construction as it gives arise, apart from a broad spectral background, to a narrow peak at exactly the pump wavelength. The background originates from photons belonging to different pairs.

In this work we study how the height of the recombination peak with respect to the back-ground depends on the number of entangled frequency modes. We show that the ratio between the peak and the background could be used as a measure of the number of modes and therefore a measure of entanglement.

Q 51.63 Wed 16:15 Redoutensaal

Amplification of high orbital angular momentum modes in a nonlinear interferometer — •Johan Ospina[1,2], Roman Zakharov[3], Olga Tikhonova[3], and Maria Chekhova[1,2,3] — [1]Max Planck Institute for the Science of Light, Staudtstrasse 2, 91058 Erlangen, Germany — [2]University of Erlangen-Nürnberg, Staudtstrasse 7/B2, 91058 Erlangen, Germany — [3]Department of Physics, M. V. Lomonosov Moscow State University, Leninskie Gory, 119991 Moscow, Russia

We study the orbital angular momentum (OAM) modes of bright squeezed vacuum (BSV). BSV is produced via high-gain parametric down conversion and it manifests quantum features despite its high (macroscopic) numbers of photons. In particular, its modes with opposite OAM values have the same photon numbers and therefore it is possible to observe quantum correlations between them. However, the observation of such correlations requires the efficient lossless sorting of OAM modes. Because the sorting of higher-order modes with opposite OAM values is easier, we are going to shape the spectrum of BSV in such a way that low-order OAM modes are suppressed. For this we use a Michelson-type nonlinear interferometer where BSV is generated in a nonlinear crystal and then gets reflected back into the same crystal together with the pump, which takes a separate path. By using additional optical elements inside the interferometer we provide the selective amplification of specific OAM modes. The OAM spectrum is studied by analysing the photon-number correlations in the output angular spectrum.

Q 51.64 Wed 16:15 Redoutensaal

Precise frequency estimation using a quantum sensor — Simon Schmitt[1], •Daniel Louzon[1,2], Tuvia Gefen[2], Liam McGuinness[1], Alex Retzker[2], and Fedor Jelezko[1] — [1]Institute of Quantum Optics, University of Ulm, Ulm, Germany — [2]Racah institute of Physics, the Hebrew University of Jerusalem, Jerusalem , Israel

Precision measurements play an important part in many of today's aspects of research, and are becoming an especially important part of the emerging field of quantum sensing. Reaching higher precision is paramount to gain meaningful information from such measurements with the majority of quantum sensing focused on optimizing the amplitude sensitivity to external field.

In this work use nitrogen vacancy center in diamond, as a single atom quantum sensor, in concert with dynamical decoupling to optimize the frequency precision with which an oscillating field can be detected. We show that given an AC signal with some knowledge on its frequency we can maximize the information we can gather on that frequency given some interaction time with our quantum sensor.

We also show, that the scaling of the Fisher Information about this frequency in this case is T^4 (T being the interaction time), which is the best purposed by theory. We show that this method is the best available method in the case of decoherence free subspace, or the more realistic case of a signal with short time phase correlations.

Q 51.65 Wed 16:15 Redoutensaal

3D printing of complex submillimeter-sized wide angle objectives — •Zhen Wang[1], Simon Thiele[2], Ksenia Weber[1], Chenyang Zhang[1], Alois Herkommer[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Institute of Technical Optics and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 9, 70569 Stuttgart, Germany

Compact image sensors with a variety of focal lengths, fields of view, and other optical parameters, will be the enabling technology of integrated devices for industry 4.0. In order to miniaturize the imaging devices from currently several mm^3 to below 1 mm^3, and to achieve diameters of the optics below 1 mm, 3D printing with femtosecond laser pulses is the method of choice. Here, we present several multilens designs as well as printed objectives with fields of view that range from 80° to 120°, and focal lengths in the range of 200-300 μm, with diameters around 800 μm, which allow for wide-angle imaging. We characterize their performances and report how to overcome some issues when printing such challenging designs. In the future, those objective can be directly printed onto CMOS imaging chips which will enable very compact image sensors.

Q 51.66 Wed 16:15 Redoutensaal

How to superimpose six light waves without interference — •Koen van Kruining[1], Rob Cameron[2], and Jörg Götte[3] — [1]Max Planck Institut für Physik komplexer Systeme, Dresden — [2]University of Strathclyde, Glasgow, UK — [3]Nanjing university, Nanjing, China

We present a set of superpositions of up to six plane light waves which have a homogeneous electric field strength. For most physical processes, including human eyesight, these superpositions can be considered noninterfering. Because of the homogeneity of the electric field strength effects beyond the electric dipole interaction become noticeable and the lights inhomogeneous helicity can be probed. Among others, our superpositions allow for writing a variety of periodic patterns in liquid crystalline polymers and to make periodic traps for birefringent particles suspended in water.

Q 51.67 Wed 16:15 Redoutensaal

3D printed combinations of fibers with complex optics for virtual and augmented reality applications — •Philipp Geser[1], Simon Ristok[1], Simon Thiele[2], Alois Herkommer[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Stuttgart — [2]Institute for Applied Optics and Research Center SCoPE, University of Stuttgart, Stuttgart

Virtual and augmented reality systems should be compact and virtually invisible to the outside observer. Clumsy goggles which are the standard right now do not fulfill these requirements. We combine fiber optics with 3D printed complex microoptics in order to realize a highly compact VR/AR system and demonstrate its use.

Q 51.68 Wed 16:15 Redoutensaal

Towards a whispering gallery mode resonator based wavemeter — •Thomas Halbauer[1,2], Golnoush Shafiee[1,2], Gerhard Schunk[1,2], Alexander Otterpohl[1,2], Florian Sedlmeir[1,2], Dmitry Strekalov[1,2], Harald G. L. Schwefel[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nürnberg, Staudtstr. 7 B2, 91058 Erlangen, Germany — [3]The Dodd-Walls Centre for Photonic and Quantum Technologies, Department of Physics, University of Otago, 730 Cumberland Street, 9016 Dunedin, New Zealand

Macroscopic crystalline whispering gallery mode resonators (WGMR) can provide the possibility for a whispering gallery type wavemeter (WGTW) in just one monolithic device. The frequency spacings between different modes of the WGMR represent a unique fingerprint of the frequency of the exciting laser. We use an electro-optic frequency tuning mechanism to shift the fingerprint of an unknown source with fixed frequency. The accuracy is only limited by the linewidth of resonances. In combination with our experimental resonance frequency analysis [1], this unambiguously reveals the excitation wavelength. For achieving the required temperature stability, we implement a scheme based on the differential shift between TE and TM modes of an additional locking laser.

[1] G. Schunk *et al.*, Opt. Express **22**, 30795 (2014).

Q 51.69 Wed 16:15 Redoutensaal

Towards amorphous superconducting single-photon detectors integrated with nanophotonic waveguides — •Matthias Häussler[1,2], Martin A. Wolff[1,2], Wolfram H. P. Pernice[1,2], and Carsten Schuck[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany

Future applications in photonics and quantum communication strongly depend on the development of suitable single-photon detectors. Superconducting nanowire single-photon detectors (SNSPDs) are among the most promising candidates offering high efficiency and bandwith at low noise and jitter.

Superconducting nanowires made from nanocrystalline superconducting materials such as NbN feature excellent electrical performance when grown on suitable substrates. Recently similar performance in terms of single-photon detection has also been achieved with amorphous superconducting films, which adapt to a wider range of substrates.

Here we aim for realizing SNSPDs made from amorphous molybdenum silicide (MoSi) superconducting films on dielectric material systems that are well suited for the fabrication of photonic integrated circuits. We present a cryogenic measurement system for testing the single-photon detection capabilities of MoSi thin films. Waveguide integrated SNSPDs are prototyped using standard nano-fabrication routines and performance tests are presented.