Q 43: Poster II

Time: Wednesday 16:00–18:30 Location: Empore Lichthof

Q 43.1 Wed 16:00 Empore Lichthof

Ho:YLF Laser mit direkter Anregung durch einen GaSb-Laserdiodenstack bei 1940 nm — Karsten Scholle, •Felix Gatzemeier, Samir Lamrini, Peter Fuhrberg und Philipp Koopmann — LISA laser products OHG, Max-Planck-Str. 1, 37191 Katlenburg

Lasersysteme im Wellenlängenbereich um 2100 nm sind aufgrund ihrer Eigenschaften vielfältig einsetzbar, z. B. in der Medizin, der Kunststoffbearbeitung oder der Messtechnik. Außerdem können sie zur Anregung von optisch parametrischen Oszillatoren für die nichtlineare Frequenzkonversion in den mittelinfraroten Wellenlängenbereich genutzt werden. Ho:YLF Laser mit ihrer hohen Strahlqualität und polarisierten Emission eignen sich besonders gut für diese Anwendungen. Die richtungsabhängige Absorption des Kristalls kann bei der Anregung durch Laserdioden optimal ausgenutzt werden.

Bisher wurden Ho:YLF Laser immer mit Tm-Festkörper- oder Faserlasern angeregt, was zu komplexen Gesamtsystemen mit geringer Effizienz führt. Wir präsentieren einen Ho:YLF Hochleistungslaser, der erstmals mithilfe eines GaSb-basierten Laserdiodenstacks resonant angeregt wurde. Dabei wurden eine maximale Ausgangsleistung von 11,6 W und ein differentieller Wirkungsgrad von 25 % erzielt (0 °C Kristalltemperatur). Bei Raumtemperatur betrug die Ausgangsleistung bis zu 8,7 W. Die Emissionswellenlänge des Lasers war abhängig vom Auskoppelgrad und lag zwischen 2100 nm und 2060 nm.

Q 43.2 Wed 16:00 Empore Lichthof

Ein regenerativer Zweifarben-Ti:Sa Verstärker für ein Triplett-Solvatationsdynamik Experiment — •Carl Böhmer[1], Vincenzo Talluto[1], Thomas Walther[1] und Thomas Blochowicz[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt — [2]Institut für Festkörperphysik, Technische Universität Darmstadt, Hochschulstraße 8, 64289 Darmstadt

Die Triplett-Solvatationsdynamik ist eine Methode, mit der Relaxation in unterkühlten Flüssigkeiten nahe des Glasübergangs untersucht werden kann. Hierzu wird der Flüssigkeit ein Farbstoff beigemischt, welcher mittels eines UV-Laserpulses in einen langlebigen Triplettzustand angeregt wird. Über den zeitlichen Verlauf der Emissionswellenlänge des Farbstoffes kann die Relaxation der Solvatationshülle in einem Zeitbereich von 0.1 ms bis 1 s verfolgt werden. Je nach Farbstoff kann dabei eine dielektrische oder mechanische Response auf die Anregung des Farbstoffmoleküls beobachtet werden.

Um den nutzbaren Zeitbereich zu vergrößern, wird ein regenerativer Zweifarben-Ti:Sa Verstärker aufgebaut. Hiermit werden synchrone Pulse bei 320 nm und 940 nm erzeugt, mit denen eine stimulierte Besetzung des Triplettzustands möglich werden soll. Diese Methode verspricht hohe Transfereffizienzen in den Triplettzustand, wodurch der nutzbare Zeitbereich besonders zu kurzen Zeiten hin erweitert wird. Wir präsentieren erste Spezifikationen des Lasersystems sowie aktuelle Messungen.

Q 43.3 Wed 16:00 Empore Lichthof

Spectroscopy and self-pulsed red and orange laser operation of Sm^{3+} doped $LiLuF_4$ crystals — •Philip Werner Metz[1], Francesca Moglia[1], Sebastian Müller[1], Fabian Reichert[1], Daniel-Timo Marzahl[1], Nils-Owe Hansen[1], Matthias Fechner[1], Christian Kränkel[1,2], and Günter Huber[1,2] — [1]Universität Hamburg, Institut für Laser-Physik — [2]The Hamburg Center for Ultrafast Imaging

Most solid state lasers with emission wavelengths in the visible spectral region were so far based on nonlinear processes. In the recent years the development of new excitation sources emitting in the blue spectral region, e.g. InGaN-laser diodes and frequency doubled optically pumped semiconductor lasers (2ω-OPSL), have opened access to solid state lasers emitting directly in the visible spectral region. The most common ion for visible laser radiation within the rare earths is the praseodymium ion. However there are a couple of other rare earth ions with absorption lines in the blue spectral region which might support short wavelength laser operation. In this contribution we present spectroscopic investigations and our first results of laser experiments with Sm^{3+}:$LiLuF_4$ crystals. The lasers were continuously pumped by a 2ω-OPSL at a wavelength of 479 nm and emitted irregular pulses in the kHz range at wavelengths of 605 nm, and 640 nm with average output powers up to 30 mW and puls durations of several μs. The repetition rates of the lasers grow almost linear with the absorbed pump power while the pulse shapes remain almost constant, indicating a pulse mechanism comparable to a passive Q-switch.

Q 43.4 Wed 16:00 Empore Lichthof

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen im Ozean: Fortschritte am gepulsten Faserverstärker — •David Rupp, Andreas Rudolf und Thomas Walther — Institut für Angewandte Physik, AG Laser und Quantenoptik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Als Alternative zu kontaktbasierten Messverfahren entwickelt unsere Arbeitsgruppe ein flugtaugliches LIDAR-System zur Messung von Wassertemperaturprofilen im Ozean. Das Messprinzip basiert auf der Detektion von spontaner Brillouin-Streuung, welche eine temperaturabghängige Spektralverschiebung gegenüber dem eingestrahlten Licht aufweist.

Die verwendete Laserquelle muss schmalbandige ns-Laserpulse im grünen Spektralbereich bereitstellen. Hierfür entwickeln wir einen Ytterbium-dotieren Faserverstärker mit anschließender Frequenzverdopplung. Die Wellenlänge ist durch unseren atomaren Detektor auf Basis von Rubidium auf 543 nm vorgegeben.

Aus der kontinuierlichen, vorverstärkten Seed-Strahlung eines ECDLs werden mittels elektro-optischer Modulatoren fourier-limierte 10 ns-Pulse mit einer maximalen Wiederholrate von 5 kHz ausgeschnitten. Anschließend werden die Pulse in drei Yb-dotieren Fasern mit jeweils steigendem Kerndurchmesser verstärkt. Die beiden letzten Stufen besitzen photonische Kristallstruktur und zeigen keinerlei Limitierung durch nichtlineare Effekte. Abschließend erfolgt effiziente Frequenzverdopplung in einem KTP-Kristall. Die derzeit maximal erreichbare Pulsenergie liegt im dreistelligen μJ-Bereich.

Q 43.5 Wed 16:00 Empore Lichthof

Vollständig festkörperbasierter Ar^+-Laserersatz — •Tobias Beck, Benjamin Rein und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Vorgestellt wird eine Laserquelle, die bereits erfolgreich zur Kühlung relativistischer Ionen am Experimentierspeicherring der GSI eingesetzt wurde. Die Ausgangsleistung des Faserverstärkers beträgt bis zu 12 W bei 1029 nm. Die so erzeugte Strahlung kann spektral bis zu 26 GHz in 5 ms modensprungfrei abgestimmt werden. Bei einer Scanrate von 1 kHz kann stabil bis zu 4 GHz weit gescannt werden. Die Zentralwellenlänge lässt sich außerdem leicht um mehrere nm verschieben. Die Linienbreite beträgt unter 1 MHz. Anschließend wird durch Frequenzverdopplung in einem Überhöhungsresonator mit einem LBO-Kristall die Zielwellenlänge von 514 nm erreicht. Die Konversionseffizienz beträgt bereits bei einer IR-Leistung von 3, 5 W über 50 %. Das System wird mit Hilfe eines Offset-Locks auf eine externe Referenz absolut in seiner Frequenz stabilisiert. Zusätzlich ist es möglich mittels eines weiteren Überhöhungsresonators und einem BBO-Kristall die Frequenz auf 257 nm zu verdoppeln. Dabei wurden bisher Leistungen von bis zu 200 mW im UV-Bereich erzielt. Die so erzeugte UV-Strahlung lässt sich um 12 GHz in 25 ms abstimmen.

Q 43.6 Wed 16:00 Empore Lichthof

Universeller, VCSEL-geseedeter Ti:Sa Laser mit großer spektraler Abdeckung — •Tobias Krebs, Thorsten Führer und Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Schlossgartenstr. 7, 64289 Darmstadt

Eine VSCEL-Diode (Vertical Cavity Surface Emitting Laser) bei 850 nm wird als Injection-Seeder für einen Titan:Saphir-Laser verwendet. Pumpquelle ist ein kommerzieller, gepulster Nd:YAG-Laser. Der Resonator, bestehend aus zwei Spiegeln, dem Ti:Sa-Kristall und einem Prisma, wird mittels Polarisations-Spektroskopie nach Hänsch-Couillaud automatisch auf die Seedwellenlänge resonant gehalten. Durch den Einsatz der MEMS-Technologie (Micro-Electro-Mechanical System) bei VCSELn lässt sich prinzipiell ein modenspruchfreier Durchstimmbereich von 50 nm erreichen. Ziel des Projekts ist es, diesen weiten Durchstimmbereich auf den Ti:Sa-Laser zu übertragen, wodurch eine Verstärkung der schwachen Ausgangsleistung des VCSELs erreicht

wird. In Verbindung mit nichtlinearen Konversionsschritten ist es dann möglich, den gesamten Spektralbereich von 190 nm bis 6000 nm abzudecken. Es soll der aktuelle Stand des Projekts vorgestellt werden.

Q 43.7 Wed 16:00 Empore Lichthof

Detailed investigations on novel TBR-diode-lasers in external resonators — •Mario Niebuhr, Christof Zink, Danilo Skoczowsky, Axel Heuer, and Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Straße 24-25, Haus 28, 14476 Potsdam

Laser diodes are cheap and effective light sources. They generally lack high output powers due to the small active volume and the corresponding low damage threshold. Within a reasonable scope one can therefore extend the active region. Such broad area laser diodes exhibit higher optical output powers up to tens of watts, but suffer from poor beam quality because of diminished mode selection.

Introducing a Transversal-Bragg-Resonance-(TBR-)grating alongside the core region results in a variable propagation loss depending on the transversal mode structure itself. One can thereby stimulate specific low loss resonance modes by using an external resonator assembly.

We were able to achieve transversal single mode operation with a quasi diffraction limited beam using TBR-diodes with various core geometries. The corresponding experimental results and the influence of the external resonator will be discussed. Furthermore computer simulations will be presented to understand the emission characteristics and obtain suggestions for improvements.

Q 43.8 Wed 16:00 Empore Lichthof

Development of a narrowband laser system for spectroscopy of ultra cold mercury — •Anika Trautmann[1], Holger John[1], Sascha Tichelmann[2], and Thomas Walther[1] — [1]Technische Universität Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt — [2]Technische Universität Darmstadt, Institut für Angewandte Physik, Atome - Photonen - Quanten, Schlossgartenstraße 7, 64289 Darmstadt

Ultra cold neutral mercury trapped in an optical lattice lock has potential for a new time standard. A narrowband laser system with high stability on the $^1S_0$ - $^3P_0$ clock transition is required. We are working towards the realization of such a system. It is based on an external-cavity diode laser at 1062.4 nm which employs a low budget 4 nm broad interference-filter with a max. transition of 40%. Its output power is increased by amplification in an fiber amplifier. Subsequently, the wavelength of the clock transition at 265.6 nm will be reached by non-linear frequency conversion. The current state of the project will be presented.

Q 43.9 Wed 16:00 Empore Lichthof

Collective Spontaneous Emission from a System of Quantum Dots — •Wildan Abdussalam[1] and Paweł Machnikowski[2] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer strasse 38, d-01187 Dresden, Germany — [2]Institute of Physics, Wrocław University of Technology, 50-370 Wrocław, Poland

We study the spontaneous emission from a regular lateral array or a randomly distributed ensemble of quantum dots under strong excitation (full inversion) conditions. We focus on the similarities and differences between the cases of random and regular arrangement of the dots and show that there is very little difference between the evolution of luminescence in these two cases, both for identical dots and for a realistically inhomogeneously broadened ensemble. This means that the enhanced emission or superradiance effect is not due to accidental clustering of pairs of dots. Moreover, we point out that observation of an enhanced emission under weak excitation does not prove that true superradiance will develop in a fully inverted system.

Q 43.10 Wed 16:00 Empore Lichthof

VUV generation in a hollow core fiber — •Andreas Koglbauer[1], Thomas Diehl[1,2], Daniel Kolbe[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2], and Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität Mainz, 55099 Mainz — [2]Helmholtz-Institut Mainz, J.J.-Becher-Weg 36, 55128 Mainz

For future laser cooling of anti-hydrogen as well as quantum information processing with Rydberg ions, there is a need for a strong continuous vacuum ultraviolet (VUV) laser source in the region of 121-123 nm. Non-degenerate four-wave mixing (FWM) in metal vapors is a well-established method for VUV generation. Utilizing multi-photon resonances of the nonlinear medium, we recently demonstrated an important improvement in the mixing efficiency in mercury [1,2]. Further power enhancement can be achieved with an elongated interaction region of the fundamental beams, by confining the light in a vapor filled hollow core fiber.

We present a study of possible phase-matching scenarios and their associated VUV efficiencies, considering dispersion and losses due to the medium as well as the fiber. A gain of more than three orders of magnitude in the output power should be feasible. A sufficient mercury vapor within the fiber is demonstrated via absorption spectroscopy on the $6^1S - 6^3P$ transition in mercury transverse through the fiber, as well as the observation of two-photon resonance with longitudinally coupled beams.

[1] arXiv:1209.1519 (2012)
[2] Phys. Rev. Lett. 109, 063901 (2012)

Q 43.11 Wed 16:00 Empore Lichthof

Vierwellenmischen in einer mit Hg-Dampf gefüllten Hohlfaser zur Erzeugung von VUV-Strahlung — •Thomas Diehl[1,2], Andreas Koglbauer[1], Daniel Kolbe[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2] und Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität Mainz, D-55099 Mainz — [2]Helmholtz-Institut Mainz, J.J.-Becher-Weg 36, 55128 Mainz

Eine leistungsstarke und kontinuierliche Laserquelle im vakuumultravioletten (VUV) Bereich wird u.a. für zukünftige Präzisionsexperimente an gefangenem Anti-Wasserstoff benötigt. Die Erzeugung dieser Strahlung erreichen wir über einen Vierwellenmischprozess in Quecksilberdampf. Durch dreifach resonantes Vierwellenmischen mit fokussierten Gaußstrahlen ist es uns gelungen, eine leistungsstarke und effiziente kontinuierliche Laserquelle im Bereich um 121 nm zu verwirklichen [1].

Eine Hohlfaser bietet die Möglichkeit, den Wechselwirkungsbereich der Laserlichtfelder mit dem nichtlinearen Medium von ca. 1 mm, beim Vierwellenmischen mit fokussierten Gaußstrahlen, auf einige cm zu verlängern. Aus theoretischen Rechnungen geht hervor, dass dabei eine Effizienzsteigerung um drei Größenordnungen möglich ist.

Wir präsentieren den aktuellen Stand des Experiments sowie die jüngsten Ergebnisse beim Vierwellenmischen in einer dampfgefüllten Hohlfaser.

[1] Phys. Rev. Lett. 109, 063901 (2012)

Q 43.12 Wed 16:00 Empore Lichthof

High repetition rate continuously tunable near-IR and mid-IR nanosecond optical parametric oscillator — •Jens Bethge[1], Mateusz Ibek[1], Sophie Kröger[2], Hartmut Zimmermann[3], and Edlef Büttner[1] — [1]Angewandte Physik & Elektronik GmbH, Berlin, Germany — [2]Hochschule für Technik und Wirtschaft, Berlin, Germany — [3]Crystal Laser Systems GmbH, Berlin, Germany

Optical Parametric Oscillators (OPOs) with nanosecond pulse duration are of vital interest for applications in, e.g., chemistry, biology, and life-science. Most common systems provide a few 10 ns pulse duration and only some 10 Hz repetition rate, limiting the photon throughput in most experiments. We demonstrate a system with less than 2 ns pulse duration and up to 15 kHz repetition rate providing access to a new measurement regime. Using a passively Q-switched diode pumped pump laser at a wavelength of 1064 nm results in a cost effective system with an integrated pump laser and a small footprint. Further, the repetition rate can be freely tuned down to a few Hz or single shot operation. The presented cavity features a periodically poled magnesium oxide doped lithiumniobate crystal with a FAN-out design allowing for fast continuous tuning. Tuning in the near-IR spectral region from 1400-1970 nm (Signal wave) and in the mid-IR region from 2200-4200 nm (Idler wave) is demonstrated by tuning the crystal position only. Pulse energies of up to 4 uJ are measured, i.e., peak powers of more than 2 kW for the Signal.

Q 43.13 Wed 16:00 Empore Lichthof

Femtosecond-laser written waveguides in KTP for type II second harmonic generation — •Sebastian Müller[1], Thomas Calmano[1], Manuel Kirchen[1], Christian Kränkel[1,2], Carlota Canalias[3], Fredrik Laurell[3], and Günter Huber[1,2] — [1]Universität Hamburg, Institut für Laser-Physik, Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, Hamburg, Germany — [3]Department of Applied Physics, KTH, Albanova, Stockholm, Sweden

$KTiOPO_4$ (KTP) is a very suitable material for nonlinear optics due to a number of favorable properties like high nonlinear optical coeffi-

cients, wide transparency, good mechanical properties and strong resistance to visible light. It exhibits an extraordinary wide phasematching bandwidth for noncritical Type II frequency doubling of fundamental wavelengths around 1 μm. The technique of fs-laser writing gives the possibility to produce waveguiding structures in various active and passive dielectric media with the advantage of light confinement over long distances. In this contribution we present our results of efficient second harmonic generation in KTP waveguides. The waveguides were produced by writing double track structures in a 9.5 mm long z-cut KTP sample. Structures written with a track spacing of 22 μm enabled waveguiding of low loss (< 0.8 dB/cm) circular single modes. 1.3 mW of light at a wavelength of 540.4 nm were achieved by frequency doubling the output of an Yb-fiber laser. This led, compared to the launched power of 126 mW to a normalized conversion efficiency of 9.1%/(Wcm^2).

Q 43.14 Wed 16:00 Empore Lichthof

Four-wave mixing in a three-color cavity — •Peter Micke[1,2], Thomas Diehl[1,2], Andreas Koglbauer[1,2], Daniel Kolbe[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2], and Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität Mainz, 55099 Mainz — [2]Helmholtz-Institut Mainz, 55099 Mainz

Continuous coherent vacuum ultraviolet (VUV) radiation has fascinating applications. Radiation at Lyman-α (121, 6 nm) is needed for future laser cooling of antihydrogen in experiments to test the fundamental symmetry between matter and antimatter. Radiation at slightly longer wavelengths can be used for Rydberg excitation of trapped ions in quantum information processing.

We use solid-state laser systems to produce continuous coherent VUV radiation by four-wave sum-frequency mixing (FWM) in Hg vapor. We plan to boost the VUV yield by enhancing the power of the fundamental beams at 254 nm, 408 nm, and 545 nm in a three-color cavity. A small Hg vapor cell is placed in the common focus of the cavity. Brewster prisms are used to split the three beams into separate collimated cavity return paths for coupling and stabilization. Previous experiments have been limited by a residual deposition on the vacuum side of the Hg cell windows, induced by the fundamental beam at 254 nm. This ruins the enhancement of the cavity. We are presently constructing a miniature cryogenic trap to avoid this problem in the future.

Q 43.15 Wed 16:00 Empore Lichthof

Whispering gallery mode resonators made from BBO — Guoping Lin[1], •Josef Urban Fürst[1,2], Dmitry Strekalov[1], Ivan Grudinin[1], and Nan Yu[1] — [1]Jet Propulsion Laboratory, California Institute of Technology. Pasadena, California, USA — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg. Erlangen, Germany

We demonstrate the first whispering gallery resonators made from the nonlinear crystal beta barium borate. Quality factors were measured at various optical wavelengths and they exceeded 10^8 in the ultraviolet wavelength regime. From these measurements we inferred new upper bounds for the absorption coefficients of beta barium borate at 1560 nm, 980 nm and 370 nm. Additionally, the polarization properties of the resonances in this angle-cut birefringent resonator were characterized. With these measurements, we laid the basis to combine the outstanding properties of whispering gallery resonators with the nonlinear optical properties of beta barium borate. This offers novel applications for whispering gallery resonators in nonlinear optics in the ultraviolet wavelength regime.

Q 43.16 Wed 16:00 Empore Lichthof

Sensitive measurements of atmospheric absorption spectra in the cavity of a broadband Cr:forsterite laser — •Svetlana Kuznetsova, Peter Fjodorow, Klaus Sengstock, and Valeri Baev — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Chromium doped forsterite lasers are of high interest for molecular spectroscopy due to their broad emission, ranging from 1.1 to 1.4 μm [1]. We demonstrate a broadband Cr:forsterite laser around 1.26 μm, pumped by an Yb-doped fiber laser with variable pulse duration. We performed intracavity absorption measurements with this laser and achieved an effective absorption path length of about 1000 km. The laser system can be applied for simultaneous sensitive measurements of various atmospheric molecules, e.g., O_2, H_2O, CO_2, CH_4, N_2O and HO_2. Some pollutants, such as HF and HCl can be measured with a sub ppb sensitivity as well.

This project is supported by DFG within GRK1355.

[1]. I. McKinnie et al, Appl Opt. 36, 4985 (1997)

Q 43.17 Wed 16:00 Empore Lichthof

A sample-free calibration method for quantitative Raman spectroscopy of hydrogen isotopologues — Magnus Schlösser[1], •Simone Rupp[1], Hendrik Seitz[1], Sebastian Fischer[1], Beate Bornschein[1], Timothy M. James[2], and Helmut H. Telle[2] — [1]Institute for Technical Physics, Tritium Laboratory Karlsruhe, Karlsruhe Institute of Technology, Germany — [2]Department of Physics, Swansea University, United Kingdom

Accurate composition measurements of gaseous samples of hydrogen isotopologues (H_2, D_2, T_2, HD, HT, DT) are of high importance in various fields of research. One example is the KArlsruhe TRItium Neutrino Experiment (KATRIN), which uses a gaseous tritium source as β-emitter for a high-sensitivity measurement of the neutrino mass. Impurities of all other hydrogen isotopologues are present in the T_2-source; their concentrations have to be measured accurately in order to minimize systematic uncertainties in the neutrino mass measurement.

Raman spectroscopy is a favorable technique for composition measurements, allowing for non-contact, in-line and multispecies gas analysis with high sensitivity. The quantitative analysis of Raman spectra requires a calibration of the Raman system employed. This poster presents a sample-free calibration method which allows to determine the calibration factors for all six hydrogen isotopologues. The approach makes use of theoretical Raman signal amplitudes, i.e. it combines theoretical Raman intensities with a measurement of the spectral sensitivity of the Raman system. The obtained results were successfully verified by an independent calibration method using gas samples.

Q 43.18 Wed 16:00 Empore Lichthof

Photoluminescence excitation and spectral hole burning spectroscopy of silicon-vacancy centers in diamond — •Carsten Arend[1], Hadwig Sternschulte[2], Doris Steinmüller-Nethl[2], and Christoph Becher[1] — [1]Universität des Saarlandes, Experimentalphysik, D-66123 Saarbrücken — [2]rho-BeSt Coating Hartstoffbeschichtungs GmbH, 6020 Innsbruck

Silicon-vacancy (SiV) centers in diamond are promising sources for single photons because they provide narrow zero-phonon-lines (ZPLs) in the near infrared (738 nm), high photostability, weak phonon coupling and high brightness [1]. At cryogenic temperatures, the ZPL shows a four line fine structure due to the doubly split ground and excited states. We here report on the results of photoluminescence excitation (PLE) spectroscopy where we scan a narrow-band laser across the fine structure lines and detect fluorescence on the phonon sidebands. We measure linewidths and splittings of an ensemble of SiV centers in a high quality, homoepitaxial CVD film and obtain linewidths of about 10 GHz as compared to a lifetime limited width in the order of 0.1 GHz. This difference arises from the inhomogeneous broadening of the transitions caused by spectral diffusion. We report on spectral hole burning spectroscopy which enables measurement of the homogeneous linewidth.

[1] E. Neu et al., New. J. Phys. 13, 025012 (2011)

Q 43.19 Wed 16:00 Empore Lichthof

Stimulierte Raman-Streuung mit einem schnell durchstimmbaren nicht-kollinearen optisch-parametrischen Oszillator — •Claudia Hoffmann[1], Tino Lang[1,2] und Uwe Morgner[1,2,3] — [1]Institut für Quanten Optik, Leibniz Universität Hannover — [2]Quest, Hannover — [3]Laserzentrum Hannover e.V.

Wir präsentieren die schnelle und empfindliche Erfassung breitbandiger Raman-Spektren mit Hilfe der Stimulierten Raman-Streuung (SRS). Nichtlineare Raman-Spektroskopie weist eine sehr viel höhere Empfindlichkeit auf als klassische Raman-Spektroskopie und erlaubt somit prinzipiell eine schnellere Erfassung solcher Spektren. Eine maßgebliche Einflussgröße für die erreichbare Aufnahmegeschwindigkeit ist die Durchstimmgeschwindigkeit der Lichtquelle. In unserem Experiment wird ein ultra-breitbandig phasenangepasster nicht-kollinearer optisch-parametrischer Oszillator eingesetzt, der durch Änderung der Resonatorlänge durchgestimmt wird. Gepumpt wird der Oszillator von einem frequenzverdoppelten Yb:$KLu(WO_4)_2$-Scheibenoszillator bei einer Repetitionsrate von 34 MHz. Mit einer durchschnittlich erhältlichen Ausgangsleistung von über 2W sind die Ausgangspulse über einen weiten spektralen Bereich von 650 nm bis 1200 nm durchstimmbar. Wird dieser Puls als Pump-Puls zusammen mit einem direkt vom Laser gelieferten Stokes-Puls bei 1030 nm räumlich und zeitlich überlagert, so lassen sich damit SRS-Spektren mit Videoraten über den Bereich von

3600 cm^{-1} bis 700 cm^{-1} erzeugen. So können transiente chemische Prozesse verfolgt werden.

Q 43.20 Wed 16:00 Empore Lichthof

Robust, frequency-stable and accurate mid-IR laser spectrometer in the $5-12$ μm spectral range based on combining QCLs and optical frequency metrology using upconversion in orientation-patterned GaAs — •Michael Hansen[1], Ingo Ernsting[1], Stephan Schiller[1], Sergey Vasilyev[1], and Arnaud Grisard[2] — [1]Heinrich-Heine-Universität Düsseldorf, Institut für Experimentalphysik, Universitätsstr. 1, 40225 Düsseldorf — [2]Thales Research and Technology, France

We demonstrate a robust and simple method for measurement, stabilization and tuning of the frequency of cw mid-infrared (MIR) lasers, in particular of quantum cascade lasers, allowing implementation of flexible and "turn-key" spectrometers for a range of high-resolution spectroscopic tasks. The MIR laser wave is upconverted by sum-frequency generation in an orientation-patterned GaAs crystal with the output of a standard high-power cw 1.5 μm fiber laser, subsequent amplification of the sum-frequency wave, Continuous measurements of this wave's and the fiber laser's frequency by a standard Er:fiber frequency comb provide signals allowing frequency control of the MIR laser. The proof of principle is performed with a quantum cascade laser at 5.4 μm, which is upconverted to 1.2 μm. The absolute QCL frequency is determined with 100 kHz-level inaccuracy relative to an atomic frequency reference. Frequency stabilization to sub-10 kHz level, controlled frequency tuning and long-term stability are demonstrated.

Q 43.21 Wed 16:00 Empore Lichthof

Tm/Ho codoped fiber laser for sensitive intracavity absorption spectroscopy — •Peter Fjodorow, Ortwin Hellmig, Svetlana Kuznetsova, Klaus Sengstock, and Valeri Baev — Institut für Laserphysik, Universität Hamburg, Germany

The simultaneous incorporation of Thulium and Holmium ions into laser materials, not only gives the possibility to build up a laser source emitting in the spectral range of 1.8 - 2.2 μm [1], where many molecules show strong absorption, but it also enables the use of easily available diode lasers at 800 nm as pump sources.

We demonstrate a broadband Tm/Ho silica fiber laser, tunable by an intracavity lens and emitting in the above mentioned spectral region. By performing intracavity absorption measurements with this laser system, various gases, such as H_2O, CO_2, N_2O, CH_4, NO, NH_3, HCl, HBr and C_2H_2, can be simultaneously detected with a ppb sensitivity and without the need for clean samples. The recording time for the emission spectrum of an individual laser pulse can be set to 50 μs, allowing to perform very sensitive *in situ* measurements of nonstationary processes. This laser system can be applied, e.g. for environmental and medical purposes, as well as for the study of combustion processes.

This project is supported by DFG within GRK 1355.

Q 43.22 Wed 16:00 Empore Lichthof

Cancer cell therapy by upcoversion UV emission from Pr:YAG nanoparticles — Kangwei Xia[1], •Gengxu Chen[1,2], Andrea Zappe[1], Rolf Reuter[1], Rainer Stöhr[1], Tugrul Inal[1], Jan Meijer[3], Roman Kolesov[1], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, D-70569, Germany — [2]State Key Laboratory of Precision Spectroscopy, East China Normal University, Shanghai, 200062, China — [3]RUBION, Ruhr-Universität Bochum, Bochum, D-44780, Germany

Recently, rare-earth ions doped inorganic crystals have been introduced into cellular microscopic studies as new types of biomarkers due to optical upconversion process [1]. Furthermore, optical upconversion process in rare-earth doped materials can produce ultraviolet (UV) emission with visible or even infrared excitation. If such nanoparticles are located inside living cells, the cells will be killed by the UV emission with an appropriate excitation on the nanoparticles [2]. Here, we demonstrated the apoptosis of the HeLa cells incubated in a buffer containing Pr:YAG nanoparticles, which is on account of the photochemical effect caused by upconversion UV emission of Pr:YAG nanoparticles [2,3]. Our study might pave a way to novel methods of laser-assisted cancer treatment.

Reference [1] F. Wang and X. Liu, Chem. Soc. Rev. 38, 976-989 (2009) [2] R. Kolesov, K. Xia, R. Reuter, R. Stöhr, A. Zappe, J.Meijer, P.R. Hemmer, and J.Wrachtrup, Nat. Commun. 3:1029 doi: 10.1038/ncomms2034 (2012). [3] R. Kolesov, R. Reuter, K. Xia, R. Stöhr, A. Zappe, and J. Wrachtrup, Phys. Rev. B 84, 153413 (2011)

Q 43.23 Wed 16:00 Empore Lichthof

Design of ultrafast fluorescence spectroscopy for axial resolution of fluorophore distribution with low numerical apertures for ophthalmologic application — •Maximilian Gräfe[1], Andreas Hoffmann[1], and Christian Spielmann[1,2] — [1]Institut für Optik und Quantenelektronik, Abbe Zentrum für Photonik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena — [2]Helmholzinstitut Jena, Fröbelstieg 3, 07743 Jena

A new method for resolving the fluorophore distribution along the propagation direction of a laserbeam is presented. For reaching spatial resolution of several tens of micrometers the time dependent fluorescence signal is sampled in the femtosecond-regime by using a technique similar to fluorescence upconversion applying optical parametric amplification. Thus this approach is applicable to fluorescence spectroscopy in the human eye.

The overall aim is to develope a method, which does not need high numerical apertures as it is necessary in confocal scanning systems.

Q 43.24 Wed 16:00 Empore Lichthof

Sample environments to image single molecules at the European XFEL Facility — Charlotte Uetrecht[1,2], •Sadia Bari[1], and Joachim Schulz[1] — [1]Sample Environment, European XFEL GmbH, Hamburg, Germany — [2]Molecular Biophysics, Uppsala University, Uppsala, Sweden

Recent success in femtosecond X-ray protein nano-crystallography and imaging of single mimivirus particles demonstrate the prospects of free-electron lasers (FEL) for biophysics. X-ray FELs provide much higher peak powers than any synchrotron source. Due to the short fs pulses, diffraction patterns of a sample can be recorded before damaging occurs. Thereby, the major bottleneck in structural biology to obtain large high quality crystals may be overcome. Since the sample is destroyed by the X-ray pulse, a full dataset is recorded from constantly replenished sample. The technique can also be used to study structural changes in bioparticles in a time-resolved manner. We develop methodology for efficient delivery and X-ray interaction of bio-samples at European XFEL. The two methods currently available for this purpose, a liquid jet and an aerodynamic lens, both suffer from high sample consumption. Native mass spectrometry (MS) has a high potential to overcome this problem. Furthermore, it allows online separation of species from a mixture. Therefore, it is especially suited to selectively investigate the structures of reaction intermediates. We show an introduction to established sample delivery techniques, native MS in general and first considerations how such a spectrometer can be integrated at the SPB-instrument.

Q 43.25 Wed 16:00 Empore Lichthof

3D super resolution upconversion microscopy of praseodymium-doped yttrium aluminum garnet — •Tugrul Inal, Rainer Stöhr, Roman Kolesov, Rolf Reuter, and Jörg Wrachtrup — 3. Physikalisches Institut and Stuttgart Research Center of Photonic Engineering (SCoPE), Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Super resolution fluorescence microscopy has caught great attention due to providing an optical resolution beyond the Abbe diffraction limit. Several diffraction unlimited techniques such as stimulated emission depletion (STED) and ground state depletion (GSD) microscopy have been developed for that purpose [1].

In previous work, we have demonstrated super-resolution upconversion microscopy of praseodymium-doped yttrium aluminum garnet (Pr:YAG) nanoparticles.This technique provides background-free imaging due to ultraviolet upconverted fluorescence of Pr:YAG nanoparticles [2].Combining the upconversion properties with a super-resolution optical microscopy technique similar to STED, yields to a lateral resolution of approximately 40 nm which is of the order of the size of the particles under study.

In this contribution, we discuss an additional improvement to the technique by increasing also the axial resolution far beyond the diffraction limit. Using the appropriate phase retardation plates, a resolution of approximately 40 nm in all three dimensions is achieved.

[1] Hell, S. W. et.al. Science 316, 1153-1158(2007) [2] Kolesov, R. et al. Phys. Rev. B 84, 153413 (2011)

Q 43.26 Wed 16:00 Empore Lichthof

Spectroscopic in-situ traceability for absolute distance interferometry — Günther Prellinger, Karl Meiners-Hagen, and •Florian Pollinger — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

A popular approach to absolute distance measurements with interferometric accuracy is the so-called variable synthetic wavelength interferometry. The absolute length is deduced by the analysis of the phase shift of an interferometer signal observed during a defined frequency variation of the laser source. The accuracy of this method depends, inter alia, on the knowledge of the frequency change. Usually, technical references like Fabry-Perot interferometers or calibrated reference interferometers are used. Their stability and accuracy limits the uncertainty of the method today, in particular for the application in non-cooperative environments. In the presented study, Doppler-free iodine absorption spectroscopy is applied to determine the frequency change. A high-speed spectroscopic detection system has been realised capable of measurement times below 10 μs per absorption line. Thus, in-situ spectroscopic monitoring of the spectroscopic frequency markers can be performed in parallel to the interferometric phase measurement. First experiments indicate an achievable relative uncertainty better than 5×10^{-9} for the position of the frequency markers.

The project is funded by the DFG under grant PO1560/1-1.

Q 43.27 Wed 16:00 Empore Lichthof

An x-ray split and delay-unit for the European XFEL — •Sebastian Roling[1], Stefan Braun[2], Peter Gawlitza[2], Liubov Samoylova[3], Björn Siemer[1], Harald Sinn[3], Frank Siewert[4], Frank Wahlert[1], Michael Wöstmann[1], and Helmut Zacharias[1] — [1]Physikalisches Institut WWU Münster, Wilhelm-Klemm Straße 10, 48149 Münster — [2]Fraunhofer Institut IWS, Winterbergstraße 28, 01277 Dresden — [3]European XFEL GmbH, Alber-Einstein-Ring 19, 22761 — [4]HZB, Albert-Einstein-Straße 15, 12489 Berlin

For the European XFEL an x-ray split- and delay-unit (SDU) is built covering photon energies from 5 keV up to 20 keV. This SDU will enable time-resolved x-ray pump / x-ray probe experiments as well as sequential diffractive imaging on a femtosecond to picosecond time scale. The set-up is based on geometric wavefront beam splitting. The x-ray FEL pulses will be split by a sharp edge of a silicon mirror coated with Mo/B_4C multilayers for photon energies above 10 keV and W/B_4C below 10 keV. Both partial beams will then pass variable delay lines. For different wavelengths the angle of incidence onto the multilayer mirrors will be adjusted in order to match the Bragg condition. At a photon energy of 20 keV the reflectance of a Mo/B_4C multilayer coating with a multilayer period of 3.2 nm and $N = 200$ layers under a Bragg-angle of 0.57° amounts to $R = 0.92$. For a photon energy of 5 keV the reflectance of a W/B_4C coating with a multilayer period of 4 nm is $R = 0.73$. Because of the different incidence angles, the path lengths of the beams will vary as a function of wavelength between ± 3.7 ps at 20 keV and up to ± 40 ps at 5 keV.

Q 43.28 Wed 16:00 Empore Lichthof

Pulse compression and characterization of spectra supporting nearly single cycle pulses in the visible — •José Andrade[1,2], Anne Harth[1,3], Marcel Schultze[1], Claudia Hoffmann[1], Stefan Rausch[1,3], Thomas Binhammer[4], and Uwe Morgner[1,3,5] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]Grupo de Lasers e Plasmas, Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Lisboa, Portugal — [3]Quest: Center for Quantum Engineering and Space-Time Research, Hannover, Germany — [4]VENTEON Laser Technologies GmbH, Garbsen, Germany — [5]Lazer Zentrum Hannover, Hannover, Germany

We present a pulse compression scheme for the characterization and shaping of a two-colour pumped optical parametric chirped pulse amplified (OPCPA) laser system with spectra comprising of 1.5 octaves (from 430nm-1300nm; Fourier limit: sub-3 fs). A prism and an LCD spatial light modulator in a 4-f scheme is the base of our setup. Multiphoton intrapulse interference phase scan (MIIPS) is based on such an apparatus and is the most promising method to control the spectral phase. The study of the range of the needed specifications is being conducted, where theoretical simulations have been performed. This method has the advantage of both characterizing and compressing a pulse simultaneously through the use of a relatively simple setup.

Q 43.29 Wed 16:00 Empore Lichthof

Ultrakurzpulsoszillatoren der nächsten Generation — •Bernhard Kreipe[1], Jana Kampmann[1], Luise Beichert[1], Moritz Emons[1], Marcel Schultze[1] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Centre for Quantum Engineering and Space-Time Research (QUEST), Welfengarten 1, 30167 Hannover

Wir präsentieren Arbeiten zur Leistungs- und Energieskalierung gepulster Hochleistungsoszillatoren mit Pulsdauern im Bereich einiger 100 fs über Multikristall-Konzepte.

Durch das Hintereinanderschalten mehrerer Basismodule, bestehend aus je einem Yb:CALGO-Laserkristall mit Pumpelement in einer „zero-q"-Konfiguration, ist eine einfache Skalierung im Bereich der modengekoppelten Laseroszillatoren möglich. Neben der Reduzierung der thermischen Effekte durch die Aufteilung der Pumpleistung wird bei diesem Konzept insbesondere auch der Umlaufkleinsignalgewinn erhöht. In Kombination mit einer Auskopplung über Cavity-Dumping sollten damit bei 1 MHz Repetitionsrate hohe Pulsenergien im Bereich von 20 μJ direkt aus einem Oszillator möglich sein.

Q 43.30 Wed 16:00 Empore Lichthof

Hollow fiber pulse compressor for multi-mJ laser pulses — •Timo Rohrlapper[1], Martin Kretschmar[1,2], Peter Simon[3], Uwe Morgner[1,2,4], Milutin Kovacev[1,2], and Tamas Nagy[1,3] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, Hannover — [2]QUEST, Centre for Quantum Engineering and Space-Time Research, Welfengarten 1, Hannover — [3]Laser-Laboratorium Göttingen e.V., Hans-Adolf-Krebs-Weg 1, 37077 Göttingen — [4]Laser Zentrum Hannover e.V., Hollerithallee 8, Hannover

Lasers delivering few-cycle pulses (< 5 fs) play a prominent role in contemporary ultrafast science. Such lasers usually incorporate a spectral broadening stage, most frequently a hollow fiber compressor. Although this is an established technique which works well to sub-mJ pulses, it is still a great challenge to extend it to multi-mJ pulse energies. Such an energy scaling requires long hollow fibers. With our novel stretched flexible hollow fiber concept we can freely scale the length of the waveguide. Here we present the first experimental results of spectral broadening of ~2 mJ pulses with such fibers. By using a 3-m long fiber of 450 micron inner diameter filled with helium we could generate an octave-spanning spectrum with 1.5 mJ pulse energy giving a very high energy transmission of ~70%. The achieved spectral width supports 3.4 fs pulse duration.

Q 43.31 Wed 16:00 Empore Lichthof

Oberflächen-Plasmon-Polaritonen auf eindimensionalen Metallgittern nach Einstrahlung eines optischen Femtosekunden-Impulses — •Jens Bethge[1] und Roland Müller[2] — [1]Angewandte Physik & Elektronik GmbH, Berlin — [2]Max-Born-Institut, Berlin

Die Wechselwirkung zwischen Licht und strukturierten Metallfilmen ist in den letzten Jahren Gegenstand zahlreicher experimenteller und theoretischer Untersuchungen. Der Schwerpunkt dieser Arbeiten liegt auf dem Studium von Plasmon-Polaritonen auf Metalloberflächen. Wir stellen Ergebnisse theoretischer Untersuchungen vor, die den zeitlichen und räumlichen Verlauf des Lichtfeldes in optischen Transmissionsgittern nach Anregung mit einem 10fs Impuls beschreiben, vorausgesetzt, die Schlitzbreite der Gitter sei klein gegen die Lichtwellenlänge. Es werden zwei Modelle diskutiert: 1) Ein freistehendes Gitter und 2) ein Gitter auf einem dielektrischen Substrat. Im ersten Fall stimmen die Resonanzen der Plasmon-Polaritonen auf der Ober- und Unterseite des Metallgitters überein, während im letzteren die entsprechenden Resonanzstellen mit zunehmendem Brechungsindex im Substrat weiter auseinanderrücken. Dies führt zu unterschiedlich starker Kopplung zwischen den Feldern auf der Ober - und Unterseite in beiden Gittermodellen. Die Rechnungen zeigen deutliche Unterschiede in den Abklingkonstanten der Feldamplituden sowie stark differierende Transmissions-Spektren für die beiden Gittertypen. Ferner enthält die Arbeit Aussagen zur spektralen Dynamik im Nah- und Fernfeldbereich der Gitter.

Q 43.32 Wed 16:00 Empore Lichthof

Gepulste-Laser-Deposition von nichtlinearen Schichten und Charakterisierung mittels Erzeugung der dritten Harmonischen — •Mathias Hoffmann[1] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Laser Zentrum Hannover, Hollerithallee 8, 30419 Hannover

Mit Hilfe der gepulsten Laserdeposition (engl.: Pulsed Laser Deposition - PLD) können eine Vielzahl von Materialien als Schichten bzw. Schichtstrukturen deponiert werden. Bei der Schichtherstellung wird der Materialabtrag mit einem ns-Laser (1064 nm, 25 ns, 40kHz) durchgeführt. Deponiert werden Kupferoxid (CuO), Germanium (Ge), Silizium (Si) und Zinksulfid (ZnS) auf amorphe Substrate. Die entstandenen Schichten werden hinsichtlich ihrer Tauglichkeit als nichtlineares Medium als Frequenzverdreifacher untersucht. Hierzu wird mit Hilfe eines

fs-Lasers die Frequenzverdreifachte erzeugt und mit der dritten Harmonischen erzeugt am Quarzglas verglichen. Mögliche Anwendung dieser Schichten besteht in der Frequenzverdreifachung spektral breitbandiger Pulse zur Pulscharakterisierung. In diesem Beitrag werden aktuelle Ergebnisse hinsichtlich der Schichtparameter (Material, Schichtdicke) für die Frequenzverdreifachung präsentiert.

Q 43.33 Wed 16:00 Empore Lichthof

Generation of Functional Structures in Dielectrics on Nanometer Scale via Shaped Femtosecond Laser Pulses — •Nadine Götte[1], Cristian Sarpe[1], Jens Köhler[1], Dirk Otto[1], Lars Englert[1], Thomas Kusserow[2], Tamara Meinl[2], Yousuf Khan[2], Hartmut Hillmer[2], Matthias Wollenhaupt[1], and Thomas Baumert[1] — [1]University of Kassel, Institute of Physics and CINSaT, D–34132 Kassel, Germany — [2]University of Kassel, Institute of Nanostructure Technologies and Analytics and CINSaT, D–34132 Kassel, Germany

In our experimental setup temporal shaped infrared femtosecond laser pulses are used for high precision laser processing of wide band gap dielectrics. By applying double pulses with certain interpulse delay or temporal asymmetric pulse trains ablation structures can be generated well below the diffraction limit [1–3].

Here we investigate functional structures on 100 nm scale by direct laser writing to demonstrate the potential for applications in nanophotonics. This includes the fabrication of spectral filters based on Fano resonances.

[1] L. Englert *et al.* Opt. Express **15**, 17855–17862, (2007)
[2] M. Wollenhaupt *et al.*, JLMN, **4**, 144–151 (2009)
[3] L. Englert *et al.*, J. Laser Appl., **24**, 042002 (2012)

Q 43.34 Wed 16:00 Empore Lichthof

Real time observation of transient electron density in water irradiated with tailored femtosecond laser pulses — Cristian Sarpe, Jens Köhler, Thomas Winkler, •Bastian Zielinski, Nadine Götte, Jutta Mildner, Matthias Wollenhaupt, and Thomas Baumert — University of Kassel, Institute of Physics and CINSaT, D–34132 Kassel, Germany

Ionization mechanisms in water irradiated with bandwidth-limited and temporally asymmetric femtosecond laser pulses are investigated via ultrafast spectral interferometry [1]. By using a novel common-path interferometer with an enlarged temporal measurement window we observe directly the dynamics of a free electron plasma generated by shaped pulses. We proved that a temporally asymmetric pulse and its time reversed counterpart address multiphoton and avalanche ionization mechanisms in a different fashion as suggested for solid dielectrics [2,3]. Positive third-order dispersion shaped pulses produce a much higher free electron density than negative ones at the same fluence, instantaneous frequency and focusing conditions. From the experimental data obtained after irradiation with bandwidth-limited and shaped pulses the multiphoton and avalanche coefficients were determined using a generic rate equation [4].

[1] C. Sarpe *et al.* New. J. Phys. **14**, 075021, (2012)
[2] L. Englert *et al.* Opt. Express **15**, 17855, (2007)
[3] L. Englert *et al.*, Appl. Phys. A **92**, 749, (2009)
[4] J. Noack and A. Vogel *et al.*, IEEE J. of Quantum Electron. **35**, 1156, (1999)

Q 43.35 Wed 16:00 Empore Lichthof

Laserinduced heating of thin graphite and SAM-graphene monitored by Ultrafst Electron Diffration — •Silvio Morgenstern, Christian Gerbig, Cristian Sarpe, Matthias Wollenhaupt, and Thomas Baumert — Universität Kassel, Institut für Physik und Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany

Ultrafast Electron Diffraction (UED) has lately become one of the most promising techniques to directly provide insights into fundamental dynamics in solids at the microscopic level on the pico- to subpicosecond timescale [1,2].

In this contribution we present our UED-setup to reach a high spatial and temporal resolution. Additionally we present first results in time-resolved diffraction experiments on thin graphite and SAM-graphene [3] and compare these with results from CVD-graphene [4].

[1] M. Chergui & A. H. Zewail, Chem. Phys. Chem. 10, 28 (2009)
[2] C.T. Hebeisen et.al., Optic Letters Vol. 31, No. 23, 3517 (2006)
[3] A. Turchanin et.al.,ACS Nano Vol.5, No.5, 3896 (2011)
[4] M. Schäfer et.al., New J. Phys. 13, 063030 (2011)

Q 43.36 Wed 16:00 Empore Lichthof

Erzeugung Harmonischer Strahlung mit Goldnanoantennen — •Monika Noack[1,2], Nils Pfullmann[1,2], Christian Waltermann[1,2], Milutin Kovacev[1,2], Vanessa Knittel[3], Alfred Leitenstorfer[3], Dieter Akemeier[4], Andreas Hütten[4] und Uwe Morgner[1,2] — [1]QUEST Centre for Quantum Engineering and Space-Time Research — [2]Institut für Quantenoptik, Leibniz Universität Hannover — [3]Department of Physics and Center for Applied Photonics, University of Konstanz — [4]Thin Films & Physics of Nanostructures, Department of Physics, Bielefeld University

Nanoantennen aus Metall zeigen im optischen Bereich ähnliche Eigenschaften wie Antennen im Radiofrequenz-Bereich. Durch eine passend gewählte Geometrie kann eine Überhöhung des elektrischen Feldes um mehrere Größenordnungen in einem kleinen Volumen erreicht werden. Die Feldstärken können dabei so hoch werden, dass die Erzeugung Hoher Harmonischer Strahlung (HHG) durch Spülung der Strukturen mit Gas demonstriert wurde. Wir zeigen unsere Experimente zur Wechselwirkung ultrakurzer Laserpulse mit unterschiedlichen Geometrien von Nanoantennen sowie deren Simulation mittels der FDTD-Methode einschließlich des Temperaturverhaltens der verwendeten Antennen. Durch die Charakterisierung der verwendeten Gasdüse ist die Gasdichte sehr genau bekannt. Für die Erzeugung von HHG ist im Wechselwirkungsbereich der Antennen eine hohe Gasdichte notwendig. In einem Xenon- Gasstrahl wurden vergleichbare Photonenzahlen sowohl für die Wellenlänge der siebten Harmonischen des eingestrahlten Lasers als auch der Plasmalinien von Xenon gemessen.

Q 43.37 Wed 16:00 Empore Lichthof

Two-photon absorption and nonlinear refractive index in nominally undoped, thermally reduced $LiNbO_3$ — Holger Badorreck, •Stefan Nolte, Pia Baeune, and Mirco Imlau — School of Physics, Osnabrueck University, Germany

The two photon absorption coefficient β and the nonlinear index of refraction n_2 are determined in nominally undoped, thermally reduced $LiNbO_3$ single crystals by means of the z-scan technique. The crystals under investigation have become attractive for ultrafast photonics due to their unique photosensitive features over a huge timescale ranging from 100 fs to a few ms. It is well established that small bound Nb_{Li}^{4+} and Nb_{Li}^{4+}:Nb_{Nb}^{4+} polarons are at the origin of the photosensitivity and allow for visionary applications such as ultrafast holography (cf. e.g. M. Imlau et al. Opt. Express 19, 15322 (2011)). However, a non-neglectable impact of the small polaron density on the nonlinear electric susceptibility of third order can be expected, as well, that has not been studied, so far. We present our results on nominally undoped $LiNbO_3$ with thermal pre-treatment and compare our findings with untreated samples. An increase of the nonlinear electric susceptibility is distinguishable and is discussed in the frame of band-edge shifts due to alterations in the crystals' stoichiometry. We further discuss the impact of beam profile applied for the z-scan technique. Here, a spatial filtering with focusing mirrors has been realized to obtain a spatially trimmed Airy profile.

Financial support by the DFG (IM 37/5, INST 190/137-1) is gratefully acknowledged.

Q 43.38 Wed 16:00 Empore Lichthof

Stereo-Graphic Above-Threshold Ionization with 1.8 μm Few-Cycle Laser Pulses — •M. Möller[1], B. E. Schmidt[2], A. M. Sayler[1], G. Vampa[3], F. Legare[2], D. M. Villeneuve[3], G. G. Paulus[1], and P. B. Corkum[3] — [1]Helmholtz Institut Jena, Institut für Optik und Quantenelektronik, Max-Wien-Platz 1, 07743 Jena — [2]INRS,-EMT, 1650 Boulevard Lionel-Boulet, Varennes, Qc, J3X1S2, Canada — [3]JASLab, University of Ottawa/NRC, 100 Sussex Drive, Ottawa, Ontario K1A 0R6, Canada

Stereo-graphic above-threshold ionization (SATI) hase been the first phenomenon to show carrier-envelope phase (CEP) effects. It is now frequently used to characterize the CEP in strong-field light-matter interaction. So far, the concepts of the SATI-based CEP measurement have been established for pulses with a center wavelength around 800 nm. Here we present preliminary results from SATI measurements with passively CEP stable few-cycle pulses in the infrared spectral region around 1.8 μm. The CEP was continously ramped over more than 8 hours while the energy-dependent SATI spectra were recorded. The results show stronger CEP effects than reported previously particularly for the so-called direct electrons with energies around $2\,U_P$. In addition, large CEP-induced asymmetries for the left-right electron yield are found.

Q 43.39 Wed 16:00 Empore Lichthof

Ion Momentum Distributions from Strong-field Ionization of Atomic Ions using Linear and Elliptical Polarized Laser Light — •P. Wustelt[1], M. Möller[1,2], T. Rathje[1,2], D. Hoff[1,2], S. Trotsenko[2,3], Th. Stöhlker[1,2,3], A.M Sayler[1,2], and G.G. Paulus[1,2] — [1]Institute of Optics and Quantum Electronics Friedrich Schiller University Jena Germany — [2]Helmholtz Institute Jena, Germany — [3]GSI, Darmstadt, Germany

We investigate the multi-electron dynamics in strong field ionization with linear and elliptical polarized laser light. In contrast to linear polarization, for elliptically polarized many-cycle pulses, the final ion momentum distribution provides complete information on the ionization field strength as well as the ionization time. Elliptical polarization also allows one to suppress non-sequential ionization and determine the release times for subsequent ionizations, thereby probing electron correlation mechanisms not predicted by semi-classical tunneling models of sequential ionization. Moreover, starting from different initial charge states of the same atom allows us to isolate the effects of each ionization step. Here we present measurements of strong-field ionization of atomic ion beam targets (He^+, Ne^{n+}, Ar^{n+}, Xe^{n+}). The photoionized nuclei from the fast, transversally cold ion beam are detected using a position- and time-sensitive detector, which measures the momentum distribution and separates the initial and final charge states in space and time. In order to gain theoretical insight into the ionization dynamics, classical trajectory Monte-Carlo simulations are performed.

Q 43.40 Wed 16:00 Empore Lichthof

Characterization of supersonic gas jets as targets for laser-plasma interaction experiments — •Thomas Gangolf[1], Michael Schnell[1], Björn Landgraf[1,2], and Christian Spielmann[1,2] — [1]Institut für Optik und Quantenelektronik, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany

For studies of high power laser matter interaction, jets of neutral gases are widely used as targets for ultrashort pulses[1]. For the needs of a given experiment, a specifically tailored neutral gas density can be obtained from a particularly designed nozzle. In this contribution, we present a setup for the characterization of non-axisymmetric gas jet targets. We use a tomographic approach to measure the full 3D density profile and its temporal evolution by performing phase shift measurements with a Mach-Zehnder interferometer [2]. Additionally, we have carried out numerical simulations by solving the Navier-Stokes equations with a commercial computational fluid dynamics code. We have characterized divergent nozzles with different cross-sections. The realized supersonic gas jets have the expected plateau-like density profile. In this contribution we also report on successful laser wakefield acceleration experiments with rectangular shaped nozzles as well as about recent experiments studying the plasma dynamics with non-collinear laser beams in gas jets with elliptic cross-section.

[1] M. Schnell et al., Phys. Rev. Lett. **108**, 075001 (2012)
[2] B. Landgraf et al., Rev. Sci. Instrum. **82**, 083106 (2011)

Q 43.41 Wed 16:00 Empore Lichthof

Recombination effects in dielectrics irradiated with ultrashort intense laser pulses — •Nils Brouwer and Bärbel Rethfeld — TU Kaiserslautern, Erwin-Schrödinger-Straße 46, 67663 Kaiserslautern, Deutschland

Ultrashort laser pulses of high intensity are of increasing importance in material processing and fundamental research. In order to control or avoid laser damage to transparent dielectrics, a proper understanding of the involved microscopic processes is necessary. When modeling laser-excited dielectrics to trace dielectric breakdown, the valence band is often assumed to be fully occupied during the laser excitation. While this assumption certainly holds if the free electron density is several orders of magnitude below the valence band electron density, at high laser intensities its validity has to be examined, since recombination effects as Auger recombination can have a significant influence on the energy and particle density even on the subpicosecond timescale, if a considerable fraction of valence band states is unoccupied.

We extended our previous Boltzmann approach [1, 2] with an equation to model valence band dynamics and included collision integrals for Auger recombination. We present results for the free electron density, the free electron energy density and the phonon energy density with and without valence band dynamics.

[1] A. Kaiser, B. Rethfeld, M. Vicanek, G. Simon, *Phys. Rev. B* **61**, 11437 (2000)
[2] B. Rethfeld, H. Krutsch , D.H.H. Hoffmann, *Contrib. Plasma Phys.* **50**, 16 (2010)

Q 43.42 Wed 16:00 Empore Lichthof

Correlation measurements on single ultrashort light pulses — •Alexander Jänicke[1,2], Michael Förtsch[1,2], Jan Korger[1,2], Christoffer Wittmann[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max-Planck Institute for the Science of Light, Erlangen — [2]Institute for Optics, Information and Photonics, University Erlangen-Nuremberg

The generation of non-classical states of light in higher order spatial modes can potentially increase the information capacity in quantum communication. Therefore we study the quantum properties of single ultrashort pulses using a highly efficient CCD camera.

We demonstrate that the repetition rate of a Ti:Sapphire laser can artificially be reduced to 1 Hz by a two-stage pulse picker design. This allows sampling of individual pulses on the CCD camera. We have realized a balanced detection scheme and studied intensity variances. Early experimental results indicate a shot noise limited measurement system.

This provides the basis for further studies of the spectral and spatial quantum properties of single ultrashort pulses. In particular, we want to measure non-classical correlations induced by the Kerr nonlinearity of a photonic crystal fiber. We will report on the latest results.

Q 43.43 Wed 16:00 Empore Lichthof

Controlling the dynamics of a single atom interacting with a high-finesse cavity — •Katharina Rojan[1], Daniel Reich[2], Christiane Koch[2], and Giovanna Morigi[1] — [1]Universität des Saarlandes, 66123 Saarbrücken — [2]Universität Kassel, 34132 Kassel

Quantum state preparation of the electromagnetic field is a prerequisite for quantum networks. In microwave cavity quantum electrodynamics the field can be manipulated by atomic beams which cross the resonator. We consider the question, how to prepare an arbitrary target state of the cavity by means of the interaction with a single atom, assuming that both cavity and atom can be driven by external fields. The problem draws on the proposal of [1], who showed that in principle this can be realized with a suitably tailored time-dependent Hamiltonian. We identify the time-dependent dynamics which is required in order to achieve a set of target states in the fastest time using Optimal Control Theory, in particular Krotov's method [2].

[1] C.K. Law and J.H. Eberly, Phys. Rev. Lett. **76**, 1055 (1996)
[2] D.M. Reich, M. Ndong, and C.P. Koch, J. Chem. Phys. **136**, 104103 (2012)

Q 43.44 Wed 16:00 Empore Lichthof

Cavity Quantum Electrodynamics in an Ellipsoidal Cavity — •Nils Griebe, József Z. Bernád, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt, Germany

We discuss the dynamics of two two-level systems located in the foci of an ellipsoidal cavity which are coupled resonantly to a single photon of the radiation field inside this cavity. With the help of semiclassical methods a photonic path representation of the time evolution operator is developed. It is particulary well suited for describing the resonant photon exchange and modifications of the spontaneous decay process between both atoms inside the ellipsoidal cavity. In the limit of infinite separation of both foci our results reduce to the ones of a parabolic cavity.

Q 43.45 Wed 16:00 Empore Lichthof

Photon wave packet dynamics and resonant atom-photon interaction inside a parabolic cavity — •Johan David Eggers, József Zsolt Bernád, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt

The evolution of a single-photon electromagnetic wave packet is investigated, which is generated by a spontaneously decaying two-level system located at the focus of a parabolic half-open cavity with ideally conducting walls. In the rotating wave and dipole approximation a multiple scattering formalism is developed which represents relevant quantum mechanical probability amplitudes as sums of contributions of photonic paths in the cavity which have been scattered by the two-level system repeatedly. This photon-path representation is particularly well suited for describing the photonic wave packet dynamics in

the semiclassical limit of small photonic wave lengths. Furthermore, it gives physical insight into the nature of the quantum electrodynamical light-matter interaction and its modification by boundary conditions.

This work is supported by the BMBF-project QuORep.

Q 43.46 Wed 16:00 Empore Lichthof

all-optical light beam steering beyond the paraxial approximation — •Lida Zhang[1], Tarak N. Dey[2], and Joerg Evers[1] — [1]Max-Planck-Institut f\"{u}r Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg — [2]Department of Physics, Indian Institute of Technology Guwahati, Guwahati 781 039, Assam, India

We discuss all-optical steering of an optical beam. For this, we study light propagation in a suitable atomic medium driven beyond the paraxial approximation. Control fields are chosen such that they in essence optically create waveguide-like structures in the medium which allow to propagate the probe beam in a controlled way. We show that a branched waveguide can be implemented by employing control fields consisting of two parallel and one tilted Gaussian beams. This way, an input probe beam can be distributed between two output ports in an optically controlled way. The switching between the output ports can be controlled via the properties of the tilted coupling field. Interestingly, we find significant deviations from calculations in paraxial approximation already for light propagating in a single optically generated waveguide.

Q 43.47 Wed 16:00 Empore Lichthof

Coherent pulse propagation in nuclear media — •Xiangjin Kong and Adriana Pálffy — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

Moving towards quantum interactions in the x-ray regime, new physical systems come into play, e.g., nuclei with low-lying collective states naturally arise as candidates for x-ray quantum optics studies. The coupling of nuclei with the radiation field is however significantly weaker than for atoms. For low x-ray intensities, this can lead to the delocalized excitation of a single nucleus. However, as long as elastic, recoil-free scattering of the incident light occurs, the contributions of all potential scatterers (nuclei) are spatially in phase in the forward direction and interfere coherently [1]. Thus the time evolution of the forward scattering response does not follow a natural exponential decay as expected for fluorescence involving a single-scattering event, but exhibits pronounced intensity modulations characteristic for the coherent resonant pulse propagation [1].

Here we investigate the situation of two counterpropagating resonant x-ray fields incident on a nuclear sample and the spatial distribution of the nuclear excitation probability. The coherent propagation in one direction can be under certain conditions controlled by the second counterpropagating pulse. This is a first step towards the study of coherent nuclear excitation in an x-ray cavity using x-ray mirrors at normal incidence [2].

[1] U. van Bürck, Hyperfine Interact. 123/124, 483 (1999).
[2] Y. Shvyd'ko *et al.*, Nature Photon. 5, 539 (2011).

Q 43.48 Wed 16:00 Empore Lichthof

Absorption and emission of a NV center coupled to an optical cavity — •Ralf Betzholz, Marc Bienert, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123, Germany

We study a nitrogen vacancy center in a diamond crystal coupled to a single mode optical cavity. In particular the interaction of the electronic degree of freedom to bulk acoustic phonons is investigated. Starting from a Hamiltonian that includes the Jaynes-Cummings interaction and the Spin-Boson model a Master equation is derived that treats the spin-phonon interaction in a non-Markovian way. In order to model the absorption and emission spectra the population of the ground state and the excited state are calculated. In the calculations different forms of the spectral function, which represents the coupling of the excited state to the phonon modes, are taken into account. Furthermore, the influence of the cavity is investigated and the dependence of the absorption and emission behaviour on the temperature is studied.

Q 43.49 Wed 16:00 Empore Lichthof

Numerical treatment of non-linear effects on light propagation arising from vacuum polarisation — •Patrick Böhl, Ben King, and Hartmut Ruhl — Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 München

The upcoming availability of high-intensity laser facilities such as ELI [1] and XCELS [2], offer the possibility to test the predictions of QED in the non-linear regime. One such prominent prediction is the interaction of light with the polarised vacuum, which can be described by the so-called "Euler-Heisenberg" effective field theory. The resulting corrections to the classical Maxwell theory can be expanded in E/E_{cr} where $E_{cr} \approx 10^{16}\,V/cm$ is the critical field strength. We solve numerically, for the first time, the resulting implicit, non-linear equations of motion to lowest order in E/E_{cr}. The results describe light propagation at very high intensities and potentially hint at an ultimate limit of laser beam focussing due to the refractive interaction with the quantum vacuum.

[1] http://www.extreme-light-infrastructure.eu, Extreme Light Infrastructure (2012)
[2] http://www.xcels.iapras.ru, eXawatt Center for Extreme Light Studies (2012)

Q 43.50 Wed 16:00 Empore Lichthof

Speckle instabilities in non-linear disordered media — •Felix Eckert, Andreas Buchleitner, and Thomas Wellens — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3a, 79104 Freiburg

We study the emergence of instable, i.e. non stationary, behavior in disordered samples of non-linear point scatterers illuminated by a stationary monochromatic wave [1]. We perform a stability analysis of the system to determine the threshold-non-linearity where instable behavior sets in. We find that the position of the threshold depends crucially on the non-linear model we impose. This varying behavior of the different models can be qualitatively explained by a system composed of only two non-linear scatterers. We also examine coherent back scattering from non-linear scatterers and analyze to what extent this interference effect occurring in linear as well as in non-linear random media persists in the instable regime.

[1] B. Grémaud, T. Wellens, Phys.Rev.Lett. **104**, 133901 (2010)

Q 43.51 Wed 16:00 Empore Lichthof

Energy and phase dependence of the stability of three pulse soliton molecules in dispersion managed optical fibers — •Philipp Rohrmann, Alexander Hause, and Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

It has been shown that solitons in dispersion managed optical fiber can form bound states, the so called soliton molecules. Such bound states may be used as additional symbols for nonbinary coding. In addition to the known case of the two-soliton molecule, an experimental verification of a three-soliton molecule was reported recently [1].

Here we present an experimental investigation of the stability of such three-soliton molecules for different pulse energies and relative phases. The pulse parameters of triple pulses were adjusted with a pulse shaping setup. These triple pulses were launched into a dispersion managed fiber; the output shape was measured with a cross correlation setup.

The energy range in which the formation of the molecule happens could be shown. We could also demonstrate that the stability of the molecule directly depends on the relative phase of the pulses; a stable propagation of the three-pulse molecules can be seen only for antiphase pulses. The experimental data confirm the previous numerical work by our group.

[1] P. Rohrmann et al., Scientific Reports **2**, 866 (2012)

Q 43.52 Wed 16:00 Empore Lichthof

Comparison of Nelder-Mead Simplex and Genetic Algorithm Methods for Optimization of Soliton Molecules — •Sonia Gholami, Philipp Rohrmann, Alexander Hause, and Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

There are several suggestions to further increase the data rate in optical data transmission. The use of solitons, particularly robust short pulses, is generally considered to be restricted to binary coding. Recently soliton molecules, i.e. bound pairs and triplets of solitons have been observed in experiments [1]. Together with ordinary solitons they allow quaternary coding.

In order to find the best shape of these compounds we evaluate their changes of shape during propagation, in other words compare shapes at input and output of a dispersion-managed fiber, with the goal of minimizing the difference. Information about this difference is

then fed back to the initial pulse compound shape, in order to obtain an automatic optimization. This involves an algorithm for which we compare a Nelder-Mead simplex method and a genetic algorithm. We numerically test the optimization on known cases and proceed to more complex ones. We present a comparison of the algorithms in terms of speed and quality of convergence to the best shape.
[1] P. Rohrmann et al., Scientific Reports **2**, 866 (2012)

Q 43.53 Wed 16:00 Empore Lichthof

Optomechanical Crystals in Diamond — •Felix Guldner, Laura Kipfstuhl, and Christoph Becher — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

The realization of photonic crystal microcavities in diamond has successfully been demonstrated, both in simulation and fabrication. Generally, photonic crystals confining light can at the same time be designed as phononic crystals confining mechanical vibrations. The simultaneous localization of optical and acoustical modes in a single structure allows for optomechanical coupling due to the photoelastic effect and shifting material boundaries.

Its extraordinary mechanical properties, in particular its high Young's modulus, make diamond a very promising candidate for the realization of an optomechanical system with acoustical resonances in the range of few 10 GHz. Possible applications for these optomechanical crystals are manifold and reach from the area of quantum information science to high-precision measurements in sensing.

In a first step, we perform FDTD and FEM simulations to develop a design for optomechanical crystals capable of localizing both optical and acoustical modes. We outline methods for calculating and improving the coupling between these modes.

Q 43.54 Wed 16:00 Empore Lichthof

Preparation and spectral characterization of emitter-doped crystals on nanofibers — •David Papencordt, Ariane Stiebeiner, Moritz Numrich, and Arno Rauschenbeutel — VCQ, TU Wien – Atominstitut, Stadionallee 2, 1020 Wien, Austria

Tapered optical fibers with a nanofiber waist have proven to be a highly sensitive tool for surface spectroscopy which exhibits numerous advantages [1,2]. A possible route towards extending the range of applications to the single-molecule level is to deposit dye-doped organic crystals of sub-micron size onto the nanofiber section in order to interface them with the fiber-guided light via the evanescent field surrounding the nanofiber. We present and compare different ways of growing and depositing such crystals. In order to study crystal growth and guest-host interactions in the crystal, we carry out fluorescence and fluorescence excitation spectroscopy. This is achieved by exciting the crystals via the nanofiber while recording the fluorescence light which is coupled back into the fiber-guided mode. Measurements under cryogenic conditions allow us to reduce the homogeneous spectral broadening, a necessary prerequisite for spectrally addressing molecules out of the inhomogeneously broadened ensemble. As a first important step towards single molecule spectroscopy, we observed the statistical fine structure arising from the Poissonian fluctuations of the number of addressed molecules per spectral interval.
[1] F. Warken et al., Opt. Express, **15**, 11952 (2007)
[2] A. Stiebeiner et al., Opt. Express, **17**, 21704 (2009)

Q 43.55 Wed 16:00 Empore Lichthof

Fiber Fabry-Perot Cavities for CQED using Rb atoms — •Jose C. Gallego, Sutapa Ghosh, Miguel Martinez-Dorantes, Natalie Thau, Wolfgang Alt, Marcel Spurny, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn

CQED experiments rely on the coherent coupling of single or multiple atoms with an optical field inside a resonator. Recently a novel type of fiber-based cavities was presented, where the facet of optical fibers is machined with a CO_2-laser and coated with a dielectric to act as concave mirrors [1]. This kind of cavity provides much smaller mode waists (in the order of $5\mu m$) and thus stronger atomic coupling ($\frac{g}{\kappa} = 20$) as compared to conventional Fabry-Perot cavities. Here we present our first results on the fabrication and characterization of these cavities using our CO_2-laser setup.
[1] D Hunger *et al* 2010 *New J. Phys* **12** 065038.

Q 43.56 Wed 16:00 Empore Lichthof

Dual-polarity metalens based on plasmonic nanoantennas — Xianzhong Chen[1], Lingling Huang[1,2], •Holger Mühlenbernd[3], Guixin Li[4], Benfeng Bai[2], Qiaofeng Tan[2], Guofan Jin[2], Cheng-Wei Qiu[5], Shuang Zhang[1], and Thomas Zentgraf[3] — [1]School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, UK — [2]State Key Laboratory of Precision Measurement Technology and Instruments, Tsinghua University, Beijing 100084, China — [3]Department of Physics, University of Paderborn, Warburger Straße 100, D-33098 Paderborn, Germany — [4]Department of Physics, Hong Kong Baptist University, Hong Kong — [5]Department of Electrical and Computer Engineering, National University of Singapore, 4 Engineering Drive 3, Singapore 117576, Singapore

The refractive index profile and surface topography dictate the functionality of a lens. Therefore the properties of the lenses are fixed during the fabrication process and cannot be altered. Here, ultrathin metalenses based on plasmonic nanoantennas can provide a solution. For such metalenses it is necessary to use a more generalized form of Snell's law, which contains an additional phase-change due to the plasmonic resonators. By controlling the position of the plasmonic resonators, it is possible to control the spatial phase-change of the incident beam. With this we are able to design ultrathin lenses with dispersionless behavior and specific focal length. Furthermore, we will show that the phase change depends on the polarization state of the incoming light. This opens the possibility to design lenses which can be switched from convex to concave.

Q 43.57 Wed 16:00 Empore Lichthof

A Cavity Nanoscope — •Matthias Mader[1,2], Hanno Kaupp[1,2], Thomas Hümmer[1,2], Jakob Reichel[3], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [3]Laboratoire Kastler-Brossel, ENS, CNRS, UPMC, 24 rue Lhomond, 75005 Paris

We present a novel tool for extremely sensitive and spatially resolved absorption spectroscopy on nanoscale objects. To boost sensitivity, multiple interactions of probe light with an object are realized by placing the sample inside an high finesse scanning optical microcavity. It is based on a laser machined and mirror-coated end facet of a single mode fiber and a macroscopic plane mirror forming a fully tunable open access Fabry-Perot cavity [1]. Scanning the sample placed on the plane mirror through the microscopic cavity mode yields a spatially resolved map of absorptivity of the sample.

We show first proof-of-principle experiments with single gold nanospheres. We demonstrate polarization sensitive absorption measurements as well as measurements on dispersive and birefringent effects of the samples.
[1] D. Hunger, T. Steinmetz, Y. Colombe, C.Deutsch, T. W. Hänsch and J. Reichel *A fiber Fabry-Perot Cavity with high finesse*, New J. Phys. **12**, pp. 065038(2010)

Q 43.58 Wed 16:00 Empore Lichthof

Photonic time-stretch system for high-frequency nonrepetitive electrical signals — •Christoph Reinheimer[1,2], Stefan Weber[1,2], and Georg von Freymann[1,2] — [1]Fraunhofer Institute for Physical Measurement Techniques, Department Terahertz Measurement and Systems, 79110 Freiburg, Germany — [2]University of Kaiserslautern, Physics Department and Research Center OPTIMAS, 67663 Kaiserslautern, Germany

We present a time-stretch system for the measurement of high-frequency electrical signals. The time information of these signals is mapped to the frequency spectrum of a pre-chirped laser pulse using an electro-optical modulator. [Chou, J.; Boyraz, O.; Solli, D.; Jalali, B.: Appl.Phys.Lett. 91, 161105 (2007)] A dispersive fiber element is used to stretch the optical signal to allow for measurement with standard fast photo-diodes and oscilloscopes. A variable temporal magnification up to a factor of 100 and a variable time-aperture up to 880 ps can be achieved by using a resonator geometry for the second dispersive fiber. Signal reconstruction is done by means of an optical back-propagation algorithm. [Stigwall, J.; Galt, S.: J. Lightwave Technol. 25, 3017 (2007)]

Q 43.59 Wed 16:00 Empore Lichthof

High-resolution microscopy and spectroscopy of rare-earth doped crystals for single ion detection — Tobias Utikal, •Emanuel Eichhammer, Stephan Götzinger, and Vahid Sandoghdar — Max-Planck-Institute for the Science of Light and Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), D-91058 Erlangen, Germany

Rare-earth ion doped crystals have been considered for quantum mem-

ory applications due to their narrow spectral features and long spin coherence lifetimes on the order of seconds. While previous studies have worked with large ensembles of ions, many quantum information processing algorithms would benefit from control at the level of single material qubits. In our laboratory, we aim to spectrally isolate single praseodymium ions doped in an yttrium orthosilicate crystal. To address homogeneous linewidths below 100 kHz within an inhomogeneous band of 1 GHz, we have built a frequency-stabilized tunable laser system operating at 488 nm. In addition, we exploit various techniques of high-resolution microscopy to record the faint signal associated with transition lifetimes in the 100 μs. We present spectroscopic data and microscopic images of the system at hand and our progress towards the detection and spectroscopy of single ions.

Q 43.60 Wed 16:00 Empore Lichthof

Buried Rb-exchanged waveguides in KTP — •Christof Eigner, Helge Rütz, Olga Driesner, Raimund Ricken, Hubertus Suche, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Waveguides fabricated by Rb-ion-exchange in Potassiumtytanylphosphate (KTP) allow for highly efficient $\chi^{(2)}$- processes like parametric down-conversion (PDC) within the whole transparency range of KTP. Guiding in both, TM- and TE-polarization, together with a periodic poling, allows for a variety of quasi-phase matching.

We have expanded the usual waveguide fabrication process by a subsequent surface-near reversed exchange of Rb against K to achieve a buried index profile. To our knowledge, this is the first report on fabrication and characterization of such buried Rb-exchanged waveguides in KTP.

The buried index profile results in symmetrized mode-field distributions which offer several advantages: improved overlap of the mode-fields for $\chi^{(2)}$-processes, reduced influence of surface imperfections on the scattering losses, enhanced fiber-coupling efficiencies and an improved control over single-mode guiding. We characterize the waveguides in terms of propagation losses and non-critically phasematched type-II second harmonic generation. In addition, first results of electric field induced periodic poling of buried Rb-exchanged waveguides are presented.

Q 43.61 Wed 16:00 Empore Lichthof

Regeneration of QPSK signals using phase-sensitive amplification by dual-pump four-wave-mixing process — •Birgit Stiller[1,2], Georgy Onishchukov[1], Bernhard Schmauss[3], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen — [2]Institute of Optics, Information and Photonics, University Erlangen — [3]Chair for Microwave Engineering, University Erlangen

For the growing demand on higher capacity in fiber-optic communication systems, advanced modulation formats provide a promising solution for significant capacity gains. One of these is multi-level phase-shift keying. Since phase-encoded signals are sensitive also to phase noise, induced by i.e. amplified spontaneous emission or nonlinear phase noise, the regeneration of phase (and amplitude) of the signal is crucial for long-haul transmission systems. In this work, we investigate numerically phase-sensitive amplification of the quadrature phase-shift keyed (QPSK) signal. A four-wave mixing (FWM) scheme with two phase-conjugated pumps, which are equally spaced around the QPSK signal, is used. The pumps are produced by an additional FWM process in another highly nonlinear fiber (HNLF). Dependence of regenerator performance on HNLF parameters has been investigated for 40 Gbaud transmission.

Q 43.62 Wed 16:00 Empore Lichthof

Optical modulator based on electro-optically induced waveguides — •Martin Blasl, Haldor Hartwig, Kirstin Bornhorst, and Florenta Costache — Fraunhofer Institute for Photonic Microsystems, Maria-Reiche-Str. 2, 01109 Dresden, Germany

Optical modulators are used to dynamically control the power of signals transmitted in optical fibre networks.

We report on a new design of an optical modulator based on electro-optically induced waveguides (EOIW) in isotropic phase nematic liquid crystals. These materials exhibit, just above their clearing temperature, unusually high electro-optical Kerr coefficients and therefore they are particularly suitable for this EOIW concept.

We fabricated an EOIW based optical modulator-chip by means of silicon technology. The chip assembly includes structured wafers bonded together and enclosing in between a liquid crystal layer. The bottom wafer comprises stripe aluminium electrodes, which define the induced waveguide region, as well as V-grooves for precise fibre to EOIW coupling.

For the modulator chip, we demonstrate a modulation bandwidth (-3 dB) of 5 MHz and an extinction ratio of 12 dB. The insertion loss is 3 dB, which is in agreement with FEM-simulations. Additionally, we analysed the influence of voltage induced phase transition on the performance of the chip.

Q 43.63 Wed 16:00 Empore Lichthof

Optimising single-photon collection efficiency using three-dimensional laser-written structures — •Tanja Neumer[1], Andreas W. Schell[1], Oliver Benson[1], Johannes Kaschke[2], Joachim Fischer[2], and Martin Wegener[2] — [1]Nano-Optics, Institute of Physics, Humboldt-Universität zu Berlin, Newtonstraße 15, D-12489 Berlin, Germany — [2]Wegener Group, Institue for Applied Physics, Karlsruher Institut für Technologie, Wolfgang-Gaede-Straße 1, D-76131 Karlsruhe

Efficient extraction of single photons from solid-state emitters in high-index materials is a major challenge for integrated quantum technologies. We introduce a novel approach to enhance collection efficiencies of single-photons emitted from nanodiamonds using tailored solid immersion lenses (SILs). First, we describe farfield intensity distributions calculated by finite-difference time domain (FDTD) simulations targeting high collection efficiencies for microscope objectives with low numerical aperture. Then we introduce the fabrication technique of the structures which is based on the method of direct laser lithography in a photoresist. This resist can be mixed with nanodiamonds containing single nitrogen-vacancy centres as single-photon emitters. We present experimental results demonstrating the feasibility of our approach [1].

[1] Andreas W. Schell, Johannes Kaschke, Joachim Fischer, Rico Henze, Janik Wolters, Martin Wegener, Oliver Benson, arXiv:1209.2036 (2012)

Q 43.64 Wed 16:00 Empore Lichthof

Carbon Nanotube spectroscopy in optical microcavities — •Thomas Hümmer[1,2], Hanno Kaupp[1,2], Matthias S. Hofmann[1], Jonathan Noe[1], Alexander Högele[1], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Deutschland — [2]Max-Planck Institut für Quantenoptik, Garching, Deutschland

We use fiber-based Fabry-Perot optical microcavities[1] with mode volumes down to a few tens of wavelengths cubed and high quality factors up to 10^7 to study single-walled carbon nanotubes (SWCNTs). Very recent progress in the growth of freestanding narrow-diameter SWCNTs has demonstrated that this system can show exceptional fluorescence properties, including a strong optical dipole transition, single photon emission characteristics, and close to Fourier limited linewidth[2]. Placing nanotubes inside an optical microcavity promises ultimative sensitivity for absorption spectroscopy and strong Purcell enhancement of fluorescence emission. Harnessing the full tunability and open access of fiber-based microcavities allows us to address a variety of CNTs at different locations and wavelengths with a single cavity. We show first experimental results on cavity enhanced spectroscopy of individual SWCNTs and discuss the potential for cavity QED with this system.

[1] Hunger, Reichel et al., NJP 12, 065038 (2010)
[2] Hofmann, Högele et al., arXiv: 1209.3429 (2012)

Q 43.65 Wed 16:00 Empore Lichthof

Realization of a fiber based microcavity for coupling a single N-V center in diamond — •Alexander Bommer[1], Roland Albrecht[1], Christian Deutsch[2], Jakob Reichel[2], and Christoph Becher[1] — [1]Fachrichtung 7.2, (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken — [2]Laboratoire Kastler Brossel, ENS/UPMC-Paris 6/CNRS, 24 rue Lhomond, 75005 Paris, France

The coupling of color centers in diamonds to optical cavities is an important technology for realizing light-matter interfaces in many quantum information protocols. We here investigate coupling of single N-V-centers in nanodiamonds to fiber based micro-cavities. The cavity consists of a fiber mirror and a plane mirror with a length of $<5\mu m$. The fiber mirror is produced by laser machining a fiber facet to yield a spherical imprint with radii of curvature of about $80\mu m$ and depths of $1\mu m$ with a sub-nm surface roughness, followed by deposition of a dielectric mirror stack [1]. Nanodiamonds containing single N-V-centers have been spin coated onto the plane mirror which is mounted in ther-

mal contact with the cold finger of a liquid helium flow cryostat. At room temperature we observe phonon assisted emission of photons into the cavity mode and realize a single photon source tunable over the entire NV-emission spectrum. Theoretical simulations of the coupled emitter-cavity system predict that cooling of the nanodiamonds will allow to observe Purcell enhanced emission of the Zero-Phonon Line into the cavity mode.

[1] D. Hunger et al.,New J. Phys. 12, 065038 (2010)

Q 43.66 Wed 16:00 Empore Lichthof

Light propagation in an atomic ensemble — •Susanne Blum and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

A theoretical description of the dynamics of propagation of single photons in a EIT medium is developed. The model includes quantum noise within a Heisenberg-Langevin formalism. Applications for single-photon frequency conversion are discussed.

Q 43.67 Wed 16:00 Empore Lichthof

Stationary non-classical states of a two mode cavity — •Christian Arenz[1,2], Melanie Rolles[1,3], and Giovanna Morigi[1] — [1]Saarland University — [2]Aberystwyth University — [3]University of Luxembourg

The dynamics of the electromagnetic field of a high-finesse resonator is studied, when it interacts with individual atoms of a beam [1]. These dynamics are well modeled by a Jaynes-Cummings type of Hamiltonian. In the strong coupling regime it was shown that trapping states of one field mode can be observed for well defined interaction times [2,3]. Depending on the initial state of the atoms this leads to asymptotic states of the cavity field dynamics that have non-classical features [4].
In this work we consider the energy levels of the atoms in a V-type configuration, where the dipoles are resonantly coupled to two field modes. We show that for well defined interaction times a trapping condition similar to the one mode case can be defined. We determine the asymptotic state of the field dynamics if the atoms that are injected into the cavity are prepared in a coherent superposition of their excited levels. We show that the asymptotic state is a pure entangled state and characterize its properties.

[1] S. Haroche et. al., Nature 455, 510 (2008)
[2] H. Walther et. al., Phys.Rev. Lett. 82, 3795 (1999).
[3] P. Meystre et. al., J. Opt. Soc, 3, 906 (1986).
[4] John J. Slosser et. al., Phys. Rev. Lett. 63, 934 (1989).

Q 43.68 Wed 16:00 Empore Lichthof

Approximate quantum error correction for generalized amplitude damping errors with graph-theoretic considerations — •carlo cafaro[1,2,3] and peter van loock[1,2,3] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7/B2, D- 91058 Erlangen, Germany — [3]Institute of Physics, University of Mainz, Staudingerweg 7, 55128 Mainz, Germany

We extend the analysis of approximate quantum error correction schemes to generalized amplitude damping errors. We present an analytical investigation of the performance of the five and seven-qubit CSS quantum stabilizer codes and compare it to that of a quantum code obtained via concatenation of the quantum dual rail code with the perfect four-qubit quantum erasure code. The performance of these schemes is quantified by means of the entanglement fidelity as function of the photon loss probability and the nonvanishing environmental temperature. In addition, knowing that every stabilizer code is locally equivalent to a graph code and that every codeword stabilized code can be described by a graph and a classical code, we construct novel mathematical graphs that realize both the standard Leung's et al. four-qubit code and its extension, the proposed eight-qubit quantum concatenated code. Finally, the role that these channel-adapted mathematical graphs may play in approximate quantum error correction is discussed.

Q 43.69 Wed 16:00 Empore Lichthof

Photon triplet generation in a photonic crystal fibre — •Andrea Cavanna, Felix Just, Bhaskar Kanseri, John Travers, Xin Jiang, Nicolas Joly, Maria V. Chekhova, Gerd Leuchs, and Philip Russell — Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1, 91058 Erlangen

One of the challenging tasks in quantum optics is the creation of entangled photon triplets in Greenberger-Horne-Zeilinger (GHZ) states. Although several schemes for the production of three photon entangled states have been implemented, the photons lack the unique correlations that GHZ states offer and that make them essential in many quantum information and quantum computation protocols. We are working on the implementation of a source for GHZ states utilising the third-order nonlinearity in a microstructured photonic crystal fibre. Direct down-conversion from visible light at 532nm to triplets at 1596nm will be achieved by means of intermodal phasematching. This approach allows the efficiency to be increased by many orders of magnitude due to the much smaller confinement of the fields and the increased interaction length compared to a bulk crystal source. In order to verify the optimum fibre parameters for this specific phasematching, we are observing the inverse process, namely third harmonic generation. Guided by these results, a fibre specifically custom-designed for this purpose will be fabricated.

Q 43.70 Wed 16:00 Empore Lichthof

Single Photon Source with a Diamond Nanocrystal and an Optical Nanofiber — •Lars Liebermeister[1], Fabian Petersen[1], Daniel Burchardt[1], Juliane Hermelbracht[1], Toshiyuki Tashima[1,2], Markus Weber[1], Ariane Stiebeiner[3], Arno Rauschenbeutel[3], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Technische Universität Wien - Atominstitut, Wien, Austria

The development of high yield single photon sources is crucial for applications in quantum information as well as for experiments on the foundations of quantum physics. The NV-center in diamond is a promising solid state candidate. By using nanodiamonds this emitter can easily be coupled to integrated nano-optical and plasmonic [1] structures. Our approach is to utilize efficient coupling of fluorescence of a single NV-center to the evanescent field of an optical nanofiber [2].

Using a dip-pen technique we deposited few diamond nanorystals in the evanescent field of a nanofiber. When optically excited we observe fluorescence of few NV-centers (hosted in a single crystal) into the guided mode of the fiber. The measured antibunching of the photon statistics indicates its non-classical character. As no clean single photon emission into the fiber has been observed so far, we have set-up a new hybrid microscope (confocal microscope combined with an AFM) which allows us to optically preselect and position single nano-crystals onto the nanofiber. We report on the current experimental progress.

[1] PRL 106, 096801 (2011) [2] PRA 72(3), 032509 (2005)

Q 43.71 Wed 16:00 Empore Lichthof

Extractable squeezing from a degenerate waveguide PDC source — •Thomas Dirmeier[1,2], Nitin Jain[1,2], Georg Harder[3], Gerd Leuchs[1,2], Christoph Marquardt[1,2], and Christine Silberhorn[1,3] — [1]Max-Planck-Institut für die Physik des Lichts, Günther-Scharowsky-Str.1 Bau 24, 91058 Erlangen — [2]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen — [3]Integrierte Quantenoptik, Universität Paderborn, Warburgerstraße 100, 33098 Paderborn

A Parametric down-conversion (PDC) source is known to be a robust and versatile tool for the generation of states of photon pairs. It has recently been demonstrated that waveguide-embedded PDC sources are able to produce highly indistinguishable and pure photon pairs. In a continuous-variable picture, this corresponds to a single two-mode squeezed state. As a benchmark for future experiments, we record the attainable single-mode squeezing and analyze the remaining state impurities to characterize the extractable squeezing.

Q 43.72 Wed 16:00 Empore Lichthof

Multi-photon interference with pseudo-thermal light — •Florian Nägele, Simeon Müller, and Vincenzo Tamma — Institut für Quantenphysik, Universität Ulm

Multi-photon interference [1] with pseudo-thermal light is a promising new field of research that received increasing attention in recent years. Chen et al. have simulated Bell correlations and Franson-type correlations with a pseudo-thermal source [2,3]. We give a detailed theoretical description of such experiments, in order to describe the main physical aspects behind two-photon interference. Moreover, we generalize such a description to different experimental situations. Our analysis will lead us to the study of multi-photon interferometers of higher orders and the possibilities to exploit such schemes for quantum information

processing.

[1] Yanhua Shih, An Introduction to Quantum Optics: Photon and Biphoton Physics, Taylor and Francis (2011), Boca Raton, FL
[2] H. Chen, et al., New J. Phys. 13, 083018 (2011)
[3] H. Chen, et al., private communication

Q 43.73 Wed 16:00 Empore Lichthof

Continuous-variable entanglement between different degrees of freedom in cylindrically polarized modes of light — •Stefan Berg-Johansen[1,2], Christian Gabriel[1,2], Ioannes Rigas[1,2], Andrea Aiello[1,2], Peter van Loock[1,2,3], Ulrik Andersen[1,2,4], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7/B2, D-91058 Erlangen, Germany — [3]Institute of Physics, University of Mainz, Staudingerweg 7, 55128 Mainz, Germany — [4]Department of Physics, Technical University of Denmark, 2800 Kongens Lyngby, Denmark

Lately it has been shown that cylindrically polarized modes of light exhibit entanglement between the spatial and polarization degrees of freedom when undergoing quadrature squeezing [1]. This arises from a classical inseparability of the associated fields. Apart from being of fundamental interest, this hybrid entanglement can be used to generate multipartite entangled states for one-way quantum computing which are addressable via the spatial degree of freedom in addition to polarization [2]. We show how hybrid entanglement can be accessed experimentally [3] and give an account of progress towards its verification.

[1] C. Gabriel et al., Phys. Rev. Lett. **106**, 060502 (2011)
[2] I. Rigas, C. Gabriel et al., arXiv:1210.5188 (2012)
[3] C. Gabriel et al., Eur. Phys. J. D **66**, 172 (2012)

Q 43.74 Wed 16:00 Empore Lichthof

Experimental generation of photon-number squeezing in complex spatio-polarization modes with a spatial light modulator — •Marion Semmler[1,2], Stefan Berg-Johansen[1,2], Christian Gabriel[1,2], Peter Banzer[1,2], Andrea Aiello[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, Staudtstr. 7/B2, D-91058 Erlangen, Germany

We report on the generation of photon-number squeezing in higher-order spatio-polarization modes of light. Using a phase-only spatial light modulator, we transform squeezed Gaussian modes into higher-order Laguerre-Gaussian, Hermite-Gaussian and Bessel beams. By appropriate superposition of orthogonal polarizations, beams with a complex spatio-polarization pattern can be achieved. The implementation is straightforward and in particular does not rely on interferometry. The mode conversion is shown to preserve any non-classicality present in the initial Gaussian mode up to linear losses. We thus demonstrate photon number squeezing of more than -1.0 dB in a wide range of higher-order modes.

Q 43.75 Wed 16:00 Empore Lichthof

Ultra-low Noise Quantum Interconnect at Room Temperature — •Josef Schupp[1], Eden Figueroa[1,2], Tobias Latka[1], Andreas Neuzner[1], Christian Nölleke[1], Andreas Reiserer[1], Stephan Ritter[1], and Gerhard Rempe[1] — [1]Max-Planck-Institut fuer Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany — [2]Department of Physics and Astronomy, Stony Brook University, Stony Brook, New York 11794-3800, USA

The development of a simple and inexpensive platform for interconnecting light and matter at the quantum level has recently emerged as one of the key challenges of quantum engineering. Although elementary quantum memory capabilities have already been shown using ensembles of cold atoms [1] or single atoms in optical cavities [2], a scalable-friendly architecture might still require room temperature operation [3]. Here we use an ensemble of Rb atoms in the gaseous state and store light pulses at the single-photon level using EIT to demonstrate that even in a common vapor cell it is possible to achieve quantum-level operation with ultra-low background noise. We have obtained a measured signal-to-background noise ratio of 3.5, which is the first time this figure of merit has been lifted beyond unity for experiments with room temperature operation. In addition, we also show the capabilities of the system to arbitrarily tailor the temporal properties of the retrieved single-photon-level pulses.

[1] A. I. Lvovsky *et al.*, Nature Photonics 3, 706 (2009).
[2] H. Specht *et al.*, Nature 473, 190 (2011).
[3] I. Novikova *et al.*, Laser and Photonics Reviews 6, 333 (2012).

Q 43.76 Wed 16:00 Empore Lichthof

Bestimmung der Detektionseffizienz von Silizium Single-Photon Avalanche Diode — •Helmuth Hofer, Silke Peters, Waldemar Schmunk und Stefan Kück — Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig

Silizium Single-Photon Avalanche Dioden (Si-SPAD) werden zur Detektion einzelner Photonen heutzutage in vielen Bereichen, wie z.B. in der Quanteninformationstechnologie, eingesetzt. Die rückgeführte Bestimmung der Detektionseffizienz, eines der wichtigsten Parameter, auf das Normal für die optische Strahlungsleistung (das Kryoradiometer) fehlte aber bisher. In diesem Beitrag stellen wir ein an der Physikalisch-Technischen Bundesanstalt (PTB) entwickeltes Messverfahren zu ihrer Bestimmung vor, das eine lückenlose Kalibrierkette sicherstellt. Dabei wird die Strahlung eines definiert abgeschwächten Diodenlasers bei einer Wellenlänge von 770 nm verwendet. Die Detektionseffizienz ergibt sich aus der mit einem Si-SPAD gemessenen Photonenzählrate. Letztere wird mit der einfallenden Strahlungsleistung verglichen, die mittels einer zuvor gegen das Kryoradiaometer kalibrierten Silizium-Photodiode und kalibrierten Abschwächern bestimmt wurde. Insbesondere wird dabei die Photonenstatistik der einfallenden Laserstrahlung berücksichtigt, welche einen Einfluss auf die gemessene Photonenzählrate hat. Neben dem Kalibrierverfahren wird eine detaillierte Analyse der Messunsicherheit vorgestellt; diese liegt derzeit im Bereich von ca.1%.

Q 43.77 Wed 16:00 Empore Lichthof

Free Space Quantum Communication using Continuous Polarization Variables — •Bettina Heim[1,2], Christian Peuntinger[1,2], Christoffer Wittmann[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]MPI for the Science of Light, Günther-Scharowsky-Str. 1 / bldg. 24, Erlangen — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstraße 7 / B2, Erlangen

We present our experimental work on quantum communication using an atmospheric channel of 1.6 km in an urban environment. In a prepare-and-measure setup, we encode information into continuous polarization states. The signal states are measured using homodyne detection with the help of a local oscillator. Both, signal and local oscillator, are sent through the free-space quantum channel, polarization multiplexed and occupying the same spatial mode. This leads to an excellent interference at the detection and an auto-compensation of the phase fluctuations introduced by the channel. In addition, the local oscillator acts as a spatial and spectral filter which easily enables daylight operation. Currently, we are testing a protocol for continuous variable quantum key distribution (CVQKD) with discrete modulation of four signal states in terms of the channel's key properties, attenuation and excess noise. Those turned out to be low enough to pave the way towards free space CVQKD.

Q 43.78 Wed 16:00 Empore Lichthof

Key rates for practical quantum key distribution protocols — •Florian Köppen[1], Tobias Moroder[1], Norbert Lütkenhaus[2], and Otfried Gühne[1] — [1]Theoretische Quantenoptik, Department Physik, Universität Siegen — [2]Institute for Quantum Computing, Waterloo

Quantum key distribution, the method to provide secure communication, represents one of the cornerstone applications of quantum information and it has already evolved into its own research field. While the possible key rates of a generic quantum key distribution protocol are already fairly well known, its exact evaluation can often be quite tricky and cumbersome, in particular for practical implementations where one often needs to consider additional deviations between the ideal protocol and its realization. Moreover since these rates are often bounded analytically it is not clear whether one really evaluates the maximal possible rate or just a, possibly bad, lower bound of it.

In this work we develop a general method to overcome this drawback by using numerical techniques in the form of non-linear convex optimization. Via this powerful tool one can then start analysing the exact predicted rates of various different protocols. As a primary application we investigate the behaviour of implementations of the Bennett-Brassard protocol, where the weak coherent laser pulses still possess a global phase. This is in contrast to standard considerations of this

protocol where the phase is assumed to be randomized and thus inaccessible to the eavesdropper; an effect which can drastically change the key rate behaviour.

Q 43.79 Wed 16:00 Empore Lichthof

Distribution of squeezed states over an atmospheric channel — •Christian Peuntinger[1,2], Bettina Heim[1,2], Christian Gabriel[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max-Planck-Institut für die Physik des Lichts, Günther-Scharowsky-Str. 1 / Bau 24, 91058 Erlangen, Deutschland — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7 / B2, 91058 Erlangen, Deutschland

We experimentally investigate the transmission of squeezing through an atmospheric channel of 1.6 km length in an urban environment. At the sender we prepare bright polarization squeezed states of light with a noise reduction of almost 3 dB relative to shot noise. We use polarization encoding as it is well suited for atmospheric transmission. We also apply a purification protocol taking into account the channel transmission to counteract the channel fluctuations. Thus we observe 1 dB of squeezing at the receiver, which is in good agreement with the attenuation of the channel.

Q 43.80 Wed 16:00 Empore Lichthof

Dynamical quantum repeater using cavity-QED evolution and coherent light — •Denis Gonta[1] and Peter van Loock[2] — [1]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstrasse 7, 91058 Erlangen — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz

In the framework of cavity QED, we propose an efficient quantum repeater that uses coherent light and chains of atoms coupled to optical cavities. In contrast to conventional schemes, we completely avoid quantum gates and exploit solely the cavity-QED evolution for entanglement purification and swapping protocols. The entanglement distribution between the repeater nodes is realized with the help of pulses of coherent light. In our previous paper [1], we already proposed a high-fidelity protocol to purify a bipartite entangled state using the evolution of atomic chains coupled to optical cavities. Here, we incorporate this purification protocol into our extended scheme that, together with the entanglement distribution and swapping protocols, yields an efficient and experimentally feasible quantum repeater for long-distance quantum communication.

[1] D. Gonta and P. van Loock, Phys. Rev. A 86, 052312 (2012).

Q 43.81 Wed 16:00 Empore Lichthof

Wave form and spectral properties of single photons emitted by a single atom — •Tristan Tentrup, Jürgen Eschner, and Giovanna Morigi — Saarland University, Saarbrücken, Germany

Quantum networks require the controlled interaction of stationary and flying qubits, implemented for example by single ions that emit [1] and absorb [2] single photons. This requires the characterization and the possibility to tailor the wave form and spectrum of the photons emitted by single emitters. The wave packet and Fourier spectrum of a photon emitted by a single atom is theoretically characterized under several conditions. We consider in particular the situation when the atom is driven by a laser pulse of different spectral forms, or when it is excited by a single photon generated by a second emitter.

[1] M. Almendros *et al.*, Phys. Rev. Lett **103**, 213601 (2009); C. Kurz *et al.*, arXiv:1211.5922.
[2] N. Piro *et al.*, Nature Physics **7**, 17 (2011).

Q 43.82 Wed 16:00 Empore Lichthof

Error correction for CV-QKD with entangled squeezed states — •Jörg Duhme[1], Reinhard Werner[1], and Fabian Furrer[2] — [1]Institut für theoretische Physik, Leibniz Universität Hannover — [2]Department of Physics, University of Tokio

Common error corretion schemes like for example cascade and LDPC codes have been investigated and optimized for years. Since the alphabet on which these schemes operate has dimension two (that is the classical bit) they are not suited for the post processing required by the protocol proposed by Furrer et al. This protocol being secure against coherent attacks is designed for entanglement based QKD using squeezed gaussian states. But the error correction schemes mentioned above additionally do not exploit the gaussian characteristics of this protocol. We present first ideas for an error correction operating on an alphabet of almost arbitrary dimension explicitely designed for gaussian protocols.

Q 43.83 Wed 16:00 Empore Lichthof

SPDC-basierte Einzelphotonenquellen für Anwendungen in der Quanteninformation — •Sabine Euler[1,2], Pascal Notz[1] und Thomas Walther[1,2] — [1]Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, D-64289 Darmstadt — [2]CASED, Mornewegstraße 32, D-64293 Darmstadt

In periodisch gepoltem KTP werden durch einen temperaturstabilisierten cw-gepumpten Typ-II-PDC-Prozess degenerierte Photonenpaare um 808 nm erzeugt. Der Verlauf der Hong-Ou-Mandel-Interferenzen für verschiedene Kristalltemperaturen lässt auf eine Verschränkung der Photonen im entarteten Fall schließen.

Die Photonenquelle bildet die Grundlage für zwei verschiedene Anwendungen: In einem ersten Experiment wird ein QKD-Setup entsprechend dem BB84-Protokoll implementiert, die Einzelphotonenquelle wird für das Sender-Modul verwendet. Die Photonenpräparation erfolgt dabei durch die Verwendung von Strahlteilerwürfeln rein passiv. Ziel des zweiten Experimentes ist es, durch Rückkopplung eines der SPDC-Photonen in den Kristall in einem stimulierten Prozess zwei identische Photonen zu erzeugen, die anschließend an einem polarisierenden Strahlteiler ausgekoppelt und nachgewiesen werden können. Der aktuelle Stand beider Experimente wird präsentiert.

Q 43.84 Wed 16:00 Empore Lichthof

Four-wave mixing's effect on EIT propagation: spontaneous emission and vacuum noise — •Christopher O'Brien, Nikolai Lauk, and Michael Fleischhauer — Fachbereich Physik, Technische Universität Kaiserslautern

In electromagnetically induced transparency (EIT), a propagating signal field resonant with an optical transition is coupled in a Λ scheme by a strong resonant laser driving an adjacent transition, quantum interference then makes the medium transparent to the signal. In many EIT experiments, the driving laser also acts as a far-detuned field on the signal transition, which for high optical depth causes a four-wave mixing (FWM) process. The far-detuned field generates a new co-propagating idler field which along with the driving field moves population into the excited state, giving gain for the signal field. The presence of gain introduces noise on the signal field, due to both spontaneous emission as well as a vacuum contribution of the idler. To find analytic expressions for the noise, we solve the Maxwell-Bloch equations for the propagating field operator in a EIT FWM medium. We can then discuss the effect of FWM on EIT experiments, such as those done for EIT based quantum memories.

Q 43.85 Wed 16:00 Empore Lichthof

A High-Speed Quantum Random Number Generator Based on the Vacuum State — Bastian Hacker[1,2], Christian Gabriel[1,2], Christoffer Wittmann[1,2], Wolfgang Maurer[3], Metin Sabuncu[5,1], •Imran Khan[1,2], Elanor Huntington[4], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, 91058 Erlangen, Germany — [3]Siemens AG, Corporate Technology, 81739 Munich, Germany — [4]School of Engineering and Information Technology, University College, The University of New South Wales, Canberra ACT 2600, Australia — [5]Department of Electrical and Electronics Engineering, Dokuz Eylül University, Tinaztepe, Buca, 35160 Izmir, Turkey

Quantum random number generators are based on the inherent statistical nature of the quantum mechanical measurement process. In principle this allows for the extraction of unique random numbers from, in our case, a measurement of the quantum optical vacuum state. However, in practice, the detection process introduces electronic noise which modifies the measured signal. We apply spectral filtering to get rid of parasitic frequencies and apply a special binning technique to convert the measured signal to a string of random bits. We then evaluate the entropy of each frequency bin. Later, a one-way hashing function may be applied to limit the information content to quantum effects. A high-speed detector and the new bit extraction method allow for a random bit extraction speed in the GBit/s range.

Q 43.86 Wed 16:00 Empore Lichthof

Femtosecond laser written waveguides for integrated quantum optics modules — •Gwenaelle Vest[1,2], Stefan Frick[1], Markus Rau[1], Henning Weier[2], Harald Weinfurter[1,3], and Roberto Osellame[4] — [1]Fakultät für Physik, Ludwig-Maximilians-

Universität, 80799 München, Germany — [2]qutools GmbH, 80539 München, Germany — [3]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [4]Dipartimento di Fisica, Politecnico di Milano, 20133 Milano, Italy

Integrated optics has enabled small, fast and low power consuming communication devices. Further developments could lead to compact and stable platforms for manipulating quantum states, thereby boosting daily life implementation of quantum information processing. In this context femtosecond laser writing has emerged as a powerful fabrication tool, allowing cost-effective, single-step, rapid prototyping of two- and three-dimensional photonic microstructures [1].

Here we consider single-mode waveguide arrays and directional couplers written in borosilicate glass. We study the evolution of polarization encoded qubits in such structures, through birefringence and splitting ratio measurements at 850 nm. We characterize the mode size and investigate packaging solutions to ensure optimal in- coupling and light collection. The total system has a footprint of only a few cubic centimeters.

[1] Della Valle, G. et al. , J. Opt. A, Pure Appl. Opt. 11(1), 013001 (2009)

Q 43.87 Wed 16:00 Empore Lichthof

Metrologische Charakterisierung von Einzelphotonendetektoren — •Silke Peters, Helmuth Hofer, Waldemar Schmunk und Stefan Kück — Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig

Mit der kommerziellen Verfügbarkeit von Quantenkommunikationssystemen (QKD-Systeme) könnte der Einsatz von quantenkryptographischen Schlüsseln zukünftig die sichere Übertragung von Daten gewährleisten. Eine wesentliche Voraussetzung für die Nutzung von QKD-Systemen im Alltag ist unter anderem eine umfassende metrologische Charakterisierung ihrer optischen Komponenten: Einzelphotonenquelle, Übertragungskanal und Einzelphotonendetektor. In diesem Beitrag stellen wir erste Messergebnisse zu einer rückgeführten Bestimmung zweier solcher Parameter, der Totzeit und des Jitters von InGaAs Single-Photon Avalanche Dioden (SPAD) vor. Zur Messung ersterer erzeugen zwei auf Einzelphotonenlevel abgeschwächte Laser eine Abfolge von zeitlich zueinander verzögerten Lichtpulsen. Die Totzeit ergibt sich aus der Wahrscheinlichkeit beide Pulse abhängig von der variablen Zeitverzögerung gleichzeitige zu detektieren. Der Jitter des Detektors wird entsprechend der Standardmethode aus der vollen Halbwertsbreite der Instrumente-Antwortfunktion der SPAD bestimmt, die durch die zeitliche Korrelation von vielen Detektionsereignissen mit dem Triggersignal des Lasers gemessen wird. Bei beiden Messverfahren wird die Genauigkeit des Taktsignals, des Triggers sowie die Unsicherheit des elektronischen Zählers mittels eines Frequenznormals rückgeführt. Ebenso wird eine detaillierte Messunsicherheitsanalyse vorgestellt.

Q 43.88 Wed 16:00 Empore Lichthof

Towards a down-conversion source of positively spectrally correlated and decorrelated photon pairs at telecom wavelength — •Thomas Lutz[1,2], Piotr Kolenderski[1,3], and Thomas Jennewein[1] — [1]University of Waterloo, Institute for Quantum Computing, Waterloo, Canada — [2]Universitaet Ulm — [3]Nicolaus Copernicus University, Torun, Poland

The frequency correlation (or decorrelation) of photon pairs is of great importance in long-range quantum communications and photonic quantum computing. We experimentally characterize a spontaneous parametric down conversion (SPDC) source, based on Beta*-Barium Borate (BBO) crystal cut for type-II phase matching at 1550 nm which has the capability to emit photons with positive or no spectral correlations. Our system employs a carefully designed detection method exploiting two InGaAs detectors.