Q 57: Poster: Quantum Optics and Photonics III

Time: Thursday 16:15–18:15 Location: S Fobau Physik

Q 57.1 Thu 16:15 S Fobau Physik

BECCAL: A atom optics experiment for the International Space Station — •Kai Frye[1], Dennis Becker[1], Christian Schubert[1], Sven Abend[1], Thijs Wendrich[1], Christian Schubert[1], Ernst Rasel[1], and Team BECCAL[1,2,3,4,5,6] — [1]Leibniz University Hannover — [2]University Ulm — [3]FBH Berlin — [4]Humboldt University Berlin — [5]Johannes Gutenberg-University Mainz — [6]ZARM, University Bremen

The multi-user and -purpose facility Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) will be important for advancing atom optics for space. Operated at the International Space Station it will open up a large variety of experiments with ultracold Rb and K atoms, therefore providing an extraordinary platform in a permanent microgravity environment.

German and US scientists jointly proposed research topics including atom interferometry, atom optics, physics of quantum degenerate gases and their mixtures. These will greatly benefit from extended free evolution times and the microgravity conditions.

Here, the scientific capabilities and the design of the device is presented. Our solutions to the constraints set by an accommodation aboard the International Space Station and our approach to cover a broad range of possible experiments will be shown.

The BECCAL project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under the grant numbers 50 WP 1431 and 1700.

Q 57.2 Thu 16:15 S Fobau Physik

Fiber based Raman laser system for atom interferometry — •Matthias Gersemann[1], Sven Abend[1], Christian Schubert[1], Martina Gebbe[2], Sven Herrmann[2], Claus Lämmerzahl[2], Ernst M. Rasel[1], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]Institut für Physik, HU zu Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Raman atom interferometry is a well proven tool for precise measurements of gravity, rotation, and fundamental constants. Nowadays field applications targeting improved accuracy, reduced complexity and lower instability have shown the necessity to transfer laboratory setups into small and robust devices. We report on the realization of novel a Raman laser system based on established telecom fiber technology allowing for the manipulation of ^{87}Rb atoms to split, redirect and recombine the quantum mechanical wave function. The fiber based setup utilizes electro-optic modulation and frequency doubling. Key techniques of the system are the succesful suppression of undesired electronical (-24 dB) and optical sidebands (-20 dB) which would otherwise induce systematic errors and impair intrinsic signal-to-noise ratio.

This work is supported by the DLR with funds provided by the BMWi under grant no. DLR 50WM1552-1557, the VDI with funds provided by the BMBF under grant no. VDI 13N14838, the DFG in the scope of the SFB 1128 geo-Q and "Niedersächsisches Vorab" through QUANOMET.

Q 57.3 Thu 16:15 S Fobau Physik

Gravity gradient cancellation in satellite quantum tests of the Equivalence Principle — •Sina Loriani[1], Wolfgang Ertmer[1], Franck Pereira Dos Santos[2], Dennis Schlippert[1], Christian Schubert[1], Peter Wolf[2], Ernst Maria Rasel[1], and Naceur Gaaloul[1] — [1]Leibniz Universität Hannover, Institute of Quantum Optics, Germany — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, France

Recent tests of the Einstein Equivalence Principle based on the simultaneous operation of two atomic gravimeters have become a promising tool to compare the differential free fall acceleration of a large variety of test masses for diverse violation scenarios. However, the uncertainty in the initial co-location of the two atomic sources couples into the measurement in the presence of gravity gradients and rotations, displaying one major systematic uncertainty.

In this work, we present a combined strategy of gravity gradient compensation and signal demodulation, which allows to reduce the systematic contributions due to the initial co-location below the 10^{-18} level. Operating on a satellite in inertial configuration leads to temporally modulated gravity gradients in the local frame of the satellite, which requires an extension of the technique presented in [*Roura, Phys. Rev. Lett* ***118**, 160401 (2017)*] . We analyse the feasibility of this scheme and find that for moderate requirements, the mission duration dominated by verification measurements of the initial co-location can be reduced drastically. Moreover, it allows to integrate the induced differential acceleration uncertainty below 10^{-18} faster than shot-noise.

Q 57.4 Thu 16:15 S Fobau Physik

Perspectives for atom interferometry in space-borne geodesy — •Sven Abend, Christian Schubert, Dennis Schlippert, Waldermar Herr, Naceur Gaaloul, and Ernst M. Rasel — Institut für Quantenoptik, LU Hannover

Light-pulse atom interferometry is employed for the measurement of rotations, accelerations and for tests of fundamental physics. Current, atom gravimeters demonstrated an uncertainty of few 10^8 m/s^2 and atom gradiometers showed a noise floor of 1.4×10^9 s^{-2}Hz$^{1/2}$. Further improvements are anticipated by the integration of novel source concepts providing delta-kick collimated Bose-Einstein condensates and enhanced methods to coherently manipulate the matter waves. The QUANTUS collaboration pioneered these methods and exploited the unique features of microgravity in drop tower experiments and in a sounding rocket mission. All these activities serve as pathfinders for applications of atom interferometry in space. This contribution will outline capabilities of atom interferometers and the perspective for future space missions as gradiometry for earth observation based on atom interferometery.

This work is supported by the DLR with funds provided by the BMWi under grant no. DLR 50WM1552-1557, the VDI with funds provided by the BMBF under grant no. VDI 13N14838, the DFG in the scope of the SFB 1128 geo-Q and "Niedersächsisches Vorab" through QUANOMET.

Q 57.5 Thu 16:15 S Fobau Physik

A High-Performance Upgrade for Very Long Baseline Atom Interferometry — •Dorothee Tell, Christian Meiners, Etienne Wodey, Robert J. Rengelink, Dennis Schlippert, Christian Schubert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Scaling up atom interferometry to a vertical baseline of 10 m enables higher precision in absolute measurements of gravity and its gradients as well as in tests of fundamental physics, such as quantum macroscopicity limits or Einstein's equivalence principle.

In the Hannover Very Long Baseline Atom Interferometry facility (VLBAI) we aim for an increased control of systematic errors which affect devices of this scale factor by especially tackling the reduction and monitoring of environmental perturbations in the measurement sequence. This particularly constrains the choice of materials and design concepts, but also calls for the development of new techniques in atom optics.

In this contribution we present the performance of a dual layer octagonal magnetic shield, reducing the gradients along the baseline. Additionally, we provide details on the seismic attenuation system which uses a unique combination of passive and active isolation as well as monitoring of residual motion for post-correction. Finally, we show progress on the high-flux source of ultra-cold rubidium.

The VLBAI facility is a major research equipment funded by the DFG. We acknowledge support from the CRCs 1128 "geo-Q" (project A02) and 1227 "DQ-mat" (project B07).

Q 57.6 Thu 16:15 S Fobau Physik

Delta-Kick Collimation of BECs in an Optical Waveguide - A Source for Guided Atom Interferometry — •Knut Stolzenberg, Sebastian Bode, and Dennis Schlippert — Institut für Quantenoptik, Hannover, Germany

Guided atom-interferometers promise to be a candidate for compact inertial sensors with long pulse separation times, leading to a higher sensitivity of the atom interferometer [1]. After condensation in a crossed optical dipole trap the ^{87}Rb BEC is loaded into a one dimensional optical waveguide. This diabatic transfer drives collective excitations in the ensemble. Via an orthogonally applied optical delta-kick collimation pulse the oscillation amplitude and expansion rate can be dramatically reduced. The narrowed velocity distribution paves the way for a stable diffraction in the interferometry sequence [2]. The ensemble's time evolution is modelled by the scaling approach to simulate and optimise the collimation pulse [3]. Coherent manipulation of the collimated BEC during interferometry will be done via Double-Bragg-diffraction suppressing the impact of the Bragg-pulse phase noise [2].

[1] G. D. McDonald et al., PRA **87**, 013632 (2013)
[2] H. Ahlers et al., PRL **116**, 173601 (2016)
[3] R Corgier et al 2018 New J. Phys. **20** 055002 **116**, 173601 (2016)

Q 57.7 Thu 16:15 S Fobau Physik

Compact diode laser system for dual-species atom interferometry with Rb and K on an sounding rocket — •Oliver Anton[1], Klaus Döringshoff[1], Simon Kanthak[1], Benjamin Wiegand[1], Moritz Mihm[3], Ortwin Hellmig[4], André Wenzlawski[3], Patrick Windpassinger[3], Markus Krutzik[1,2], Achim Peters[1,2], and The MAIUS Team[1,2,3,4,5,6] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]Institut für Physik, JGU Mainz — [4]ILP, Universität Hamburg — [5]ZARM, Universität Bremen — [6]IQO, Leibniz Universität Hannover

The MAIUS 2/3 missions will perform dual-species atom interferometry with BEC's onboard sounding rockets, enabling longer, uninterupted timescales of microgravity than any ground based facility. As a result of increasing microgravity times, future missions with dual-species atom interferometry will allow for high-precision tests of Einsteins's Equivalence principle.
This poster presents the design of our laser system for this mission in detail, shows first results of frequency stability measurements and introduces the ground testbed activities in setting up a Rb/K dual-species quantum gas experiment. Key components such as micro-integrated high power diode lasers (767, 780, 1064 nm), optical fiber splitter system and Zerodur benches will be presented.
This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WP1432.

Q 57.8 Thu 16:15 S Fobau Physik

Optimized preparation for a superposition of opposite circular states in a Rydberg atom — •Fernando Gago Encinas[1], Sabrina Patsch[1], Michel Brune[2], Jean-Michel Raimond[2], Sébastien Gleyzes[2], and Christiane Koch[1] — [1]Theoretical Physics, University of Kassel, Kassel, Germany. — [2]Collège de France, Paris, France.

Circular states of Rydberg atoms, those with maximum projection of the electron angular momentum, have proven extremely useful in quantum sensing and quantum computation. The aim of this work is to achieve a superposition of the two opposite circular states in the same atom, with $+m_l^{max}$ and $-m_l^{max}$. The corresponding non-classical state would serve as a great starting point for quantum-enhanced measurement of magnetic fields. While elusive at first glance due to the need for a double circularization process, this objective presents an interesting and challenging control problem. To tackle this goal, we use optimal control theory in order to obtain shaped radio-frequency pulses that minimize both the time needed and the error made during the process.

Q 57.9 Thu 16:15 S Fobau Physik

High-precision quantum gravimeter GAIN — •Bastian Leykauf[1], Anne Stiekel[1], Sascha Vowe[1], Benjamin Wiegand[1], Hartmut Wziontek[2], Axel Rülke[2], Markus Krutzik[1], and Achim Peters[1] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Bundesamt für Kathographie und Geodäsie (BKG)

GAIN employs atom interferometry based on stimulated Raman transitions to precisely and accurately measure local gravity [1]. The performance of the device was assessed during a measurement campaign conducted at the geodetic observatory Wettzell in 2017 in cooperation with the German Federal Agency for Cartography and Geodesy (Bundesamt für Karthographie und Geodäsie, BKG).

We will report on recent improvements implemented into the apparatus, focusing on the status of a new modularized laser system. Furthermore, we discuss the study of systematic effects [2,3] and efforts towards simplified techniques for laser-cooling of ^{85}Rb and ^{87}Rb with a single diode laser.

[1] Freier et al. *Mobile quantum gravity sensor with unprecedented stability*, Journal of Physics: Conference Series **723** (2016)
[2] Hu et al. *Mapping the absolute magnetic field and evaluating the quadratic Zeeman-effect-induced systematic error in an atom interferometer gravimeter*, Physical Review A **96**, 033414 (2017)
[3] Hu et al. *Observation of vector and tensor light shifts in ^{87}Rb using near-resonant, stimulated Raman spectroscopy*, Physical Review A **97**, 013424 (2018)

Q 57.10 Thu 16:15 S Fobau Physik

Optimal control technique for fast excitation-less transport of BECs on an atom chip — •Sirine Amri[1,2], R. Corgier[2,1], D. Sugny[3], E.M Rasel[2], E. Charron[1], and N. Gaaloul[2] — [1]ISMO, Université Paris-Saclay, Bât.520, 91400 Orsay France — [2]Institute of Quantum Optics, LUH, Welfengarten 1 30167, Germany — [3]ICB, Université de Bourgogne, 20178 Dijon Cedex, France

Recent proposals for testing foundations of physics assume Bose-Einstein condensates (BECs)as sources of atom interferometry sensors. In this context, atom chip devices allow to build transportable BEC machines with high flux and high repetition rates, as demonstrated within the QUANTUS (drop tower) and MAIUS (sounding rocket) [D. Becker et al, Nature, 562, 391 (2018).] micro-gravity experiments. According to the specific atom interferometric sequence considered, the external degrees of freedom of the BEC need to be manipulated after its creation. We present optimal control theory protocols for the fast, excitation-less transport of BECs with atom chips, i.e. engineering transport ramps with durations not exceeding 200 ms with realistic 3D anharmonic traps. This controlled transport is implemented over large distances, typically of the order of 1-2 mm, i.e. of about 1,000 times the size of the atomic cloud. The advantages over shortcut-to-adiabaticity schemes reported by our team [R. Corgier et al. NJP 20, 055002 (2018)] will be discussed.

Q 57.11 Thu 16:15 S Fobau Physik

Universal atom interferometry simulator for precision sensing — •Florian Fitzek[1,2], Ernt M. Rasel[1], Klemens Hammerer[2], and Naceur Gaaloul[1] — [1]Institute for Quantum Optics, Hanover — [2]Institute for Theoretical Physics, Hanover

Quantum sensors based on light-pulse atom interferometers allow for high-precision measurements of inertial and electromagnetic forces, accurate determination of fundamental constants as the fine structure constant α or to test foundational laws of modern physics as the equivalence principle. The full potential, i.e. sensitivity of these schemes unfolds when large interrogation times or macroscopic arm separation could be implemented. Both directions, however, imply a substantial deviation from an ideal interaction of light with atomic systems. Indeed, real-life complications as finite pulse areas and fidelities, momentum width broadening of the cold clouds, atomic interactions or light fields distortions limit the measurements but more dramatically hinder a reasonable systematics study. This is mainly due to the limited number of analytical cases and to the realistic numerical calculations being intractable.

In this study, we present an efficient numerical solver of the timedependent dynamics of atom-light interactions in position space. It is designed to allow for a flexible simulation of a wide range of nonideal effects. This approach is also aimed to be cross-regime, valid for different types of beam splitters (Bragg, Raman and Bloch) and free from approximations incompatible with a metrological use.

Q 57.12 Thu 16:15 S Fobau Physik

Folded multi-loop atom interferometer for gravitational wave detection — •Christian Schubert, Dennis Schlippert, Sven Abend, Wolfgang Ertmer, and Ernst M. Rasel — Gottfried Wilhelm Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover

We will present the concept of a terrestrial detector for gravitational waves based on atom interferometry. It utilizes symmetric beam splitters and relaunches of the atoms to generate folded multi-loop geometries for a broadband detection mode and a resonant detection mode for increased sensitivity. The folded multi-loop geometries enable a setup with a single axis laser link in each of the two horizontal arms of the detector, resembling the setup for laser interferometers for gravitational wave detection. In broadband mode, the detector covers frequencies between 0.1 Hz and 5 Hz with a peak strain sensitivity of $10^{-21}/\sqrt{\mathrm{Hz}}$. The concept also eliminates stringend requirements onto the atomic source common to other proposals based on atom interferometry.
The presented work is supported by the CRC 1227 DQmat within the project B07, the CRC 1128 geo-Q within the projects A02, the QUEST-LFS, the German Space Agency (DLR) with funds provided

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Q 57.13 Thu 16:15 S Fobau Physik

Designing a dual species atom interferometer for the ISS

— •Alexandros Papakonstantinou[1], Thijs Wendrich[1], Wolfgang Bartosch[1], Manuel Popp[1], Christian Schubert[1], Christian Spindeldreier[2], Ernst M. Rasel[1], Wolfgang Ertmer[1], and BECCAL Team[1,2,3,4,5,6,7] — [1]Institut für Quantenoptik, Universität Hannover — [2]Institut für Mikroelektrische Systeme, Universität Hannover — [3]Universität Ulm — [4]Ferdinand Braun Institut — [5]Humboldt Universität Berlin — [6]Johannes Gutenberg Universität Mainz — [7]Zarm Universität Bremen

Atom interferometers with two species have been used to test the Einstein equivalence principle (EEP). To improve their precision, long evolution times in the interferometer are required. This can be accomplished with degenerate quantum gases and extended free fall in space. In order to increase the free evolution time the apparatus is moved into a microgravity environment. The BECCAL experiment will, for the first time, enable a multitude of experiments with a dual species atom interferometer in space where BEC's freely float for seconds. Operation on the ISS poses strict requirements on mass, size and operation safety of such an apparatus. To comply with these specific restrictions and the requested scientific capabilities, several payload elements will be new developments based on our experience from other space missions like the MAIUS 2/3 Sounding rocked missions. In this poster we show the overall design of the electronic components and the progress in our work.

Q 57.14 Thu 16:15 S Fobau Physik

Opto-mechanical resonator-enhanced atom interferometry

— •A. Rajagopalan[1], L. L. Richardson[1], H. Albers[1], L. Kumanchik[2], C. Braxmaier[2], F. Guzman[2], C. Schubert[1], W. Ertmer[1], D. Schlippert[1], and E. M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany — [2]DLR, Institute of Space Systems, 28359 Bremen, Germany

We combine an optical-mechanical resonator with an atom interferometer. A classical cantilever and matter waves sense their acceleration with respect to a joint reference. Apart from research on macroscopic quantum objects, applications are in the realm of quantum sensing. We demonstrate its robustness by operating an atom-interferometric gravimeter beyond its reciprocal response in a highly dynamic environment, exploiting the common mode signal. As a proof of concept, we have demonstrated post correction using the OMIS by instigating single frequency strong motion for a T=10 ms interferometer. An improvement factor of 16 was achieved yielding $5 \times 10^{-4} \mathrm{ms}^{-2}/\sqrt{\mathrm{Hz}}$ in the short term stability of gravitational acceleration measurements with our atom interferometer. We discuss the potential of an advanced OMIS set-up for field gravimeters.

Q 57.15 Thu 16:15 S Fobau Physik

Prospects of large momentum transfer with twin lattices for phase sensitive atom interferometry

— •Jan-Niclas Siemss[1,2], Sven Abend[2], Ernst M. Rasel[2], Klemens Hammerer[1], and Naceur Gaaloul[2] — [1]Institut für Theoretische Physik, LU Hannover — [2]Institut für Quantenoptik, LU Hannover

Large momentum transfer (LMT) schemes for atom interferometry with Bose-Einstein condensates combining Bragg pulses and Bloch oscillations allow for state-of-the-art momentum separation in an atom interferometer with up to 408 photon recoils ($\hbar k$). As their sensitivity is increasing with the spatial separation of the two interferometer arms, LMT techniques are likely to become integral parts in new-generation, high-performance sensors.

In our work, we investigate the fundamental limits of momentum separation in a phase sensitive atom interferometer using twin Bloch lattices. We evaluate the sensor's scalability up to thousand $\hbar k$ separation with respect to systematic effects as well as effects reducing the interferometric contrast considering noise sources such as laser intensity and phase noise or non-adiabatic losses during the lattice acceleration.

To analyze interferometric sequences involving symmetric optical lattices, we perform semi-analytical studies when possible and developed an efficient numerical time-dependent solver capable of dealing with a wide variety of realistic atom interferometry beam splitting processes.

The presented work is supported by the CRC 1227 DQmat within the project A05.

Q 57.16 Thu 16:15 S Fobau Physik

A three-mode inertial sensor for the measurement of the gravitational acceleration

— •Alexander Idel[1], Fabian Anders[1], Polina Feldmann[2], Jan Peise[1], Luis Santos[2], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für theoretische Physik, Leibniz Universität Hannover

Atom interferometers can measure the gravitational acceleration by sensing gravitational phase shifts on spatially displaced superposition states. Future large-scale atomic gravimeters will employ Bose-Einstein condensed samples due to their well-controlled spatial mode and the low expansion rates. These gravimeters are fundamentally limited by the Standard Quantum Limit (SQL). The SQL can be overcome by engineering entangled input states for the interferometer. Such entangled states are routinely produced in the spin degree of freedom and concepts for their transfer to the spatial degree of freedom are outstanding. Here, I present an atomic gravimeter that creates superpositions in three spin states and transfers these superpositions to momentum states. The concepts can be employed in the future to demonstrate an atomioc gravimeter beyond the SQL.

Q 57.17 Thu 16:15 S Fobau Physik

Signal contributions in photothermal deflection spectroscopy for optical absorption measurements

— •Walter Dickmann[1,2], Johannes Dickmann[2], Florian Bruns[1], and Stefanie Kroker[1,2] — [1]LENA Laboratory for Emerging Nanometrologie, TU Braunschweig, Langer Kamp 6a/b, 38106 Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt Braunschweig, Bundesallee 100, 38116 Braunschweig, Germany

Since its development in 1980, collinear photothermal deflection spectroscopy (PDS) has been used for the spatial resolved determination of optical attenuation coefficients. We investigate the influence of several previously unconsidered contributions (e.g. thermal surface deformation) on the measurement signal in crystalline silicon and gallium arsenide by comparing numerical results with experimental data. The results show that angular effects can increase the surface absorption signal by more than two orders of magnitude, depending on the detector distance and probe beam collimation. That is an important result concerning recently discussed dominating surface absorption in highly pure silicon [1].

[1] Khalaidovski, A., Steinlechner, J., & Schnabel, R. (2013). Indication for dominating surface absorption in crystalline silicon test masses at 1550 nm. Classical and Quantum Gravity, 30(16), 165001.

This research is supported by the DFG within research training group Metrology for Complex Nanosystems (GrK 1952/1).

Q 57.18 Thu 16:15 S Fobau Physik

Modeling of thermal noise in multiscale systems for high-precision metrology

— •Johannes Dickmann[1], Florian Bruns[2], Tim Käseberg[1], Jan Meyer[2], Carol Bibiana Rojas Hurtado[1], Walter Dickmann[2], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt Braunschweig, Germany — [2]Technische Universität Braunschweig, Germany

Thermal noise is a critical limitation in many optical high-precision metrological measurement devices like Michelson- or Fabry-Pérot interferometers. The modeling of thermal noise of the multiscale optical components like mirrors and beam splitters requires semi-analytical approaches. We present the holistic approach of computing thermal noise of optical components in interferometers. We present the results for Brownian, thermo-elastic and thermo-refractive noise. Furthermore, we briefly present the computation of carrier density induced noise of transmissive semiconductor optics.

Q 57.19 Thu 16:15 S Fobau Physik

Set-up for the precise determination of the photoelastic constants of dielectric materials

— •Jan Meyer[2], Johannes Dickmann[1], Walter Dickmann[1,2], Tim Käseberg[1], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt Braunschweig, Bundesallee 100, 38116 Braunschweig, Germany — [2]Technische Universität Braunschweig, LENA Laboratory for Emerging Nanometrology, Pockelsstraße 14, Braunschweig, Germany

Stress-induced birefringence due to the photo-elastic effect signficantly influences the functionality of optical and optomechanical devices, e.g. optical fibers or optical ring resonators. We present a set-up for the precise determination of the photoelastic constant. The sample is exposed to a well-defined stress applying a linear load. The birefringence is read out differentially using a polarimeter in transmission. In order to test the setup, the stress-induced birefringences of crystalline silicon and fused silica were characterized. The results are in good agreement with literature data. Since many high-precision optomechanical experiments operate at low-temperatures, corresponding measurements are in preparation.

Q 57.20 Thu 16:15 S Fobau Physik

Towards high precision quantum logic spectroscopy of single molecular ions — •Maximilian J. Zawierucha[1], Jan C. Heip[1], Fabian Wolf[1], and Piet O. Schmidt[1,2] — [1]Physikalisch- Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität, Hannover, Germany

High precision spectroscopy of trapped molecular ions constitutes a promising tool for the study of fundamental physics. Possible applications include the search for a variation of fundamental constants and measurement of the electric dipole moment of the electron. Compared to atoms, molecules offer a rich level structure, permanent dipole moment and large internal electric fields, which make them exceptionally well suited for those applications. However, the additional rotational and vibrational degrees of freedom result in a dense level structure and absence of closed cycling transitions. Therefore, standard techniques for cooling, optical pumping and state detection cannot be applied. This challenge can be overcome by quantum logic spectroscopy. In addition to the molecular ion, a well-controllable atomic ion is co-trapped, coupling strongly to the molecule via the Coulomb interaction. The shared motional state can be used as a bus to transfer information about the internal state of the molecular ion to the atomic ion, where it can be read out using fluorescence detection.

We will present steps towards the implementation of efficient molecular state preparation schemes, based on quantum logic. Achieving this goal will provide a complete and versatile toolbox for high precision spectroscopy of molecular ions.

Q 57.21 Thu 16:15 S Fobau Physik

Squeezed-Shot-Noise Prototype of the Einstein-Telescope — •Justin Nico Hohmann, Sebastian Steinlechner, and Roman Schnabel — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

The design study for the next generation gravitational-wave detector, the Einstein Telescope, suggests using light powers of several megawatts and 10dB-squeezed vacuum states of light. So far, no experimental demonstration exists, that combines high light powers and high squeeze factors. At Hamburg University, we set up a squeezed-shot-noise prototype of the Einstein-Telescope at a scale of 1:10,000. The arm cavity length is about one meter with final optical power of 1 MW, in combination with 10 dB shot-noise squeezing. Our prototype is a table-top device, with planned high measurement sensitivity for arm length changes at ultra-sonic and radio frequencies.

Q 57.22 Thu 16:15 S Fobau Physik

Progress Towards an Al^+ Quantum Logic Optical Clock — •Johannes Kramer[1,2], Nils Scharnhorst[1,2], Nicolas Spethmann[1], Ludwig Krinner[1], Javier Cerrillo[3], Ian D. Leroux[1], Alex Retzker[4], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, D — [2]Leibniz Universität Hannover, 30167 Hannover, D — [3]Technische Universität Berlin, 10623 Berlin, D — [4]The Hebrew University of Jerusalem, 91904 Jerusalem, IL

We present the status of our aluminum ion optical clock, based on a single $^{27}Al^+$ clock ion confined in a linear Paul trap together with a $^{40}Ca^+$ logic ion. The latter is used for sympathetic cooling and quantum logic schemes for state readout. $^{27}Al^+$ provides a suitable clock transition and favorably low sensitivity to external field shifts. A measurement of the trap temperature combined with numerical simulations allows us to bound the black-body radiation shift to $< 10^{-19}$. Micromotion has been compensated to a level well below a fractional frequency uncertainty of 10^{-17}. We developed double-bright electromagnetically induced transparency (D-EIT) cooling as a novel scalable approach to standard EIT cooling. Using the D-EIT scheme we demonstrated for the first time ground-state cooling of all three motional degrees of freedom of a trapped $^{40}Ca^+$ ion within a single, short cooling pulse [1]. Extrapolating from these results, we expect a fractional second order Doppler shift from residual motion of an Al^+/Ca^+ crystal of well below 10^{-18}. Progress towards quantum logic spectroscopy of Al^+ will be presented. [1] Scharnhorst et al., Phys. Rev. A **98**, 023424 (2018)

Q 57.23 Thu 16:15 S Fobau Physik

Dynamical response of Bose-Einstein condensates to oscillating gravitational fields — •Dennis Rätzel[1], Richard Howl[2], Joel Lindkvist[3], and Ivette Fuentes[2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom — [3]Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria

Bose-Einstein condensates (BECs) are very small and extremely cold systems of a large number of atoms. These properties are famously exploited for high precision measurements of forces using atom interferometry. A further way of utilizing BECs as sensors for forces is to measure the forces' effect on the collective oscillations of atoms in BECs. In this presentation, it is explained how BECs can be used to measure oscillating gravitational fields. Accelerations due to gravitational fields and their gradients give rise to effective external potentials, oscillations on resonance with elastic modes of BECs lead to the creation of phonons. For strong enough gravitational fields this effect can, in principle, be detected. For weaker gravitational fields, a squeezed probe state can be prepared and its change due to the interaction with the oscillating gravitational field may be measured. We illustrate our experimental proposal with the easily accessible example of the gravitational field of a small oscillating gold sphere.

Q 57.24 Thu 16:15 S Fobau Physik

A robust clock transition on $^{40}Ca^+$ with a continuous dynamical decoupling scheme — •Kai Dietze[1], Lennart Pelzer[1], Nati Aharon[2], Nicolas Spethmann[1], Alex Retzker[2], and Piet O. Schmidt[1,3] — [1]Physikalisch Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904 — [3]Leibniz Universität Hannover, 30167 Hannover, Germany

Dynamical decoupling is a promising approach for protecting an optical clock transitions against dominant environmental shifts. By applying continuous radio frequency (rf) fields, we generate a decoherence-free subspace with largely suppressed field shifts. In particular, it is possible to remove inhomogeneous line shifts in large crystals of ions, enabling the operation of an optical frequency reference with many ions and correspondingly reduced statistical uncertainty. We present predictions and limitations for the achievable linewidths and residual shifts, using this scheme [1]. In first experiments spectroscopic measurements for a trapped $^{40}Ca^+$ ion were performed for which the $4S_{1/2}$ and the $5D_{5/2}$ Zeeman states were dressed, resulting in a reduction of linewidth broadening of the 729 nm clock transition by one order of magnitude. Additionally we evaluate the suppression of magnetic field shifts for this single stage dressing approach. The final scheme will involve four rf fields to realize doubly-dressed states, protecting the system against power fluctuations of the first driving fields, Zeeman-, quadrupole-, and tensor ac-Stark shifts from the rf driving field of the Paul trap.

[1] Aharon *et al.*, arXiv:1811.06732v1

Q 57.25 Thu 16:15 S Fobau Physik

Gas-mediated mirror cooling for cryogenic gravitational-wave detectors — •Mikhail Korobko and Roman Schnabel — Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 146, 22761 Hamburg

Thermal fluctuations in mirrors and suspensions limit the sensitivity of gravitational-wave observatories (Advanced LIGO, Advanced Virgo and KAGRA). The most direct way to reduce these fluctuations is to cryogenically cool the mirrors. Cryogenic technology is currently used in KAGRA, and is planned for future detectors, such as the Einstein Telesope. One of the main challenges of a cryogenic detector is extracting the heat out the mirrors without introducing additional noises. It can be done though the mirror's suspensions, which need to be thick enough to ensure good thermal conductivity, but that reduces their mechanical quality and leads to additional thermal noises. The other approach of attaching soft links from the cold plate directly to the mirror substrate, lowers the mechanical quality of the substrate itself.

We propose an alternative: cooling the suspended mirrors by local buffer gas (*e.g.* helium). By design this gas is trapped between the side cylindrical surface of the mirror and the cold shield, transferring the heat from the mirror to the cold shield. The advantage of such approach is that the mirror suspensions are not used for heat extraction and can be optimized for best mechanical properties. The mirror in this approach is cooled uniformly, preventing the heat-induced deformations. We study the approach theoretically, analyse the optimal operational regime and the noise performance.

Q 57.26 Thu 16:15 S Fobau Physik

A trajectory in phase-space surpassing the Heisenberg- uncertainty limit — •Jascha Zander and Roman Schnabel — Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

The quantum uncertainty in a physical system is limited by the well-known Heisenberg-Uncertainty-Relation (HUR), which contains the amount of information that can be extracted from two non-commuting observables. Representatives are the position and momentum of a particle ($\Delta\hat{p}\Delta\hat{x} \leq \hbar/2$) or the electric field strengths in the extrema and the zero crossings of a monochromatic light wave, which is normalized to zero-point fluctuations ($\Delta\hat{X}\Delta\hat{Y} \leq 1$).

Although mathematical precise formulated, the physical interpretation is not obvious. On the basis of the HUR, in 1935 Einstein, Podolsky and Rosen (EPR) wrongly conjectured that quantum theory does not provide a complete description of the actual reality. In this Experiment we demonstrate the EPR-Gedankenexperiment by simultaneous measurement on a single gaussian wave packet, in principle to arbitrarily small precision. Consequently, there should be a simultaneous measurement protocol for a very weak and time varying signal in the phase-space. Furthermore we show a trajectory within vacuum noise, with a resolution of $\Delta\hat{X}(t)\Delta\hat{Y}(t) \approx 0.3$ over an extended period of time. Based on this approach, the aim is to develop a clearer physical picture of the Heisenberg-Uncertainty-Relation.

Q 57.27 Thu 16:15 S Fobau Physik

Rubidium vapor-cell references based on the 5S to 6P transitions — •Julien Kluge, Aline N. Dinkelaker, and Markus Krutzik — Humboldt-Universität zu Berlin

Optical frequency standards based on spectroscopy of Rubidium vapor benefit from high component technology readiness level, allow for vapor-cell micro-integration and physics package miniaturization. In conjunction with an optical frequency comb, these standards could be advanced to compact and simple vapor-cell based clocks which have the potential to achieve fractional instabilities comparable to state-of-the-art commercial systems [1,2].

In this poster, we discuss the optical properties of Rubidium beyond the D1/D2 line and highlight two concepts we currently study for future compact references onboard small satellites. One is based on direct modulation transfer spectroscopy of the 5S → 6P transition using GaN based diode laser operating at 420 nm, the other on spectroscopy of the two-photon transition from 5S → 5D at 778 nm. We give an overview on system design, compare the expected performance and discuss the prospects of integrating a payload which meets the stringent size, weight and power (SWaP) requirements of a small satellite.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1857

[1] Martin, Kyle W., et al. Phys. Rev. A 9.1 (2018): 014019.

[2] Zhang, Shengnan, et al. Review of Scientific Instruments 88.10 (2017): 103106.

Q 57.28 Thu 16:15 S Fobau Physik

Qualification of integration technologies for miniaturized optical setups in UHV — •Anne Stiekel[1,2], Marc Christ[1,2], and Markus Krutzik[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

Development of compact atomic quantum sensors based on cold atoms enable novel applications (e.g. timekeeping, sensing and communications) in mobile devices and in space. Besides physics package and electronics, this also requires miniaturization of the optical distribution and beam manipulation systems. Precise alignment and micro-integration of the optical components is necessary for miniaturized and rugged optical setups, eventually being used within ultra-high vacuum (UHV) assemblies. Hence the used materials, components and integration technologies have to meet challenging demands regarding thermal and mechanical durability, as well as ultra-low out-gassing.

To qualify the UHV-compatibility, an adaptable system is being set up for residual gas analysis and measurement of total gas rates down to $5 \cdot 10^{-10}$ mbar l s^{-1}. This poster gives an overview on the UHV-system architecture and first results towards its commissioning.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1648.

Q 57.29 Thu 16:15 S Fobau Physik

Optimization of the cooling process in a mixed species ion Coulomb crystal — •Leon Schomburg, Dimitri Kalincev, André P. Kulosa, and Tanja E. Mehlstäubler — PTB, Braunschweig, Germany

We report on laser cooling of multiple ions forming a so-called Coulomb crystal, which is confined in a linear rf Paul trap. In particular, we investigate the use of a mixed In^+ - Yb^+ crystal, where indium is used as a clock ion and is sympathetically cooled with ytterbium [1].

Increasing the number N of ions benefits clock spectroscopy as the averaging time decreases with 1/N, but it raises the challenge to maintain the control over systematic shifts of a single particle in ion chains. Our system supports excellent control over a crystal with tens of ions, reaching systematic clock uncertainties of 10^{-19} [1].

The efficiency of the cooling dynamics strongly depends on trap parameters and the crystal configuration. Similar results have been reported in [2]. Experimentally determined heating rates allow for the calculation of equilibrium temperatures, effective cooling rates and shifts for different configurations. We combine experimental data and theoretical simulation in order to find optimal configurations regarding cooling times and clock shifts. Interesting extensions of the theory include micromotion, as discussed in [3].

[1] J. Keller, arXiv:1803.08248v2 (2018), accepted for publication in Phys. Rev. A

[2] Tomasz P. Sakrejda and Boris B. Blinov, arXiv:1809.00240 (2018)

[3] H. Landa, arXiv:1809.10519 (2018)

Q 57.30 Thu 16:15 S Fobau Physik

High-precision linear ion trap for the demonstrator of a commercial multi-ion optical clock — •Malte Brinkmann[1], Alexandre Didier[1], Hendrik Siebeneich[2], Michael Johanning[2], Christof Wunderlich[2], Stefan Brakhane[3], Dieter Meschede[3], and Tanja E. Mehlstäubler[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Universität Siegen, Germany — [3]Universität Bonn, Germany

Today's best ion optical clocks have demonstrated fractional systematic uncertainties of a few parts in 10^{18} and are based on single ions. This outstanding performance is nevertheless limited by the low fluorescence given by a single ion. Performing spectroscopy on multiple chains of ions in a scalable linear ion trap is a way to push down these uncertainties even further.

Optical clock experiments are complex, bulky and can be operated by trained scientists only. The opticlock consortium develops a robust and easy-to-use demonstrator of a commercial optical clock. In the frame of the project we develop a multi-ion trap which will be integrated in a compact system.

The trap is composed of a stack of four laser-cut and gold coated AlN wafers comprising electrodes used for applying the rf and dc fields required for the trapping and control of multiple Coulomb crystals. The electrodes' geometry is optimized via FEM simulations for small micromotion suitable for clock operation. We present the fabrication of the high-precision trap, which is assembled with tolerances below 10 μm, and a first produced test version.

Q 57.31 Thu 16:15 S Fobau Physik

QUEEN: Design Study and Ground Testbed for Two-Photon Optical Frequency References on Small Satellites — •Sven-E. Reher[1], Akash Kaparthy[1,3], Aline N. Dinkelaker[1], Merlin Barschke[3], Markus Krutzik[1,2], and The QUEEN Team[1,2,3,4] — [1]Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik — [3]Technische Universität Berlin — [4]QUARTIQ GmbH

As part of the design study QUEEN, we explore frequency references based on a 778 nm two-photon transition of ^{85}Rb as payload on small satellites. Space-based frequency references have application in current and planned earth-observation and fundamental science missions, where inter-spacecraft ranging relies on stabilized lasers. In this context, the system has to be compact, robust, and energy efficient. To study payload architectures and systematic effects, a ground testbed is set up. Currently, cell heating, isolation, and thermal management options are investigated alongside ongoing radiation tests of optical components. As satellite platform, the modular, flightproven TUBiX20 platform will be adapted to match the payload's requirements. In this poster we will report on the status of the QUEEN mission, discuss our payload design and show recent results on our qualification and test activities.

The QUEEN project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers 50 WM 1753-1755 and 50 WM 1857-1859.

Q 57.32 Thu 16:15 S Fobau Physik

Quantum parameter-estimation of a damped harmonic oscillator — •Patrick Binder — Institute of Theoretical Physics, University Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We determine the quantum Cramér-Rao bound for the precision with which the oscillator frequency and damping constant of a damped quantum harmonic oscillator can be estimated. This goes beyond standard quantum parameter estimation of a single mode Gaussian state, as for the latter a mode of fixed frequency is assumed. We present a scheme through which the frequency estimation can nevertheless be based on the known results for single-mode quantum parameter estimation with Gaussian states. Based on these results, we investigate an optimal measurement scheme. For measuring the oscillator frequency, our results unify previously known partial results and constitute an explicit solution for a general single-mode Gaussian state.

Q 57.33 Thu 16:15 S Fobau Physik

Ultra-stable UV laser system for an Indium multi-ion clock — •Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Alexandre Didier[1], Stepan Ignatovich[2], and Tanja E. Mehlstäubler[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institute of Laser Physics, Novosibirsk, Russia

Multi-ion clocks at optical wavelengths are very promising candidates for atomic clocks with fractional uncertainties below 10^{-18}. Our approach is to perform spectroscopy on Coulomb crystals of ^{115}In$^+$ sympathetically cooled by ^{172}Yb$^+$. ^{115}In$^+$ is directly detectable via the narrow intercombination line ^{1}S$_0$ to ^{3}P$_1$ at 230.6 nm. Spectroscopy can be performed on the electronic ^{1}S$_0$ to ^{3}P$_0$ transition at 236.5 nm.

To address both narrow transitions, we developed two ultra-stable lasers at 922 nm and 946 nm. We achieve a short-term stability of 1.1×10^{-16} at 1 s with the clock laser at 946 nm. To reach an even better stability, the laser is stabilized to another laser frequency locked to a cryogenic Silicon cavity, exhibiting a fractional frequency instability of 4×10^{-17} at 1 s. The lasers are frequency quadrupled to reach the transitions at 230 nm and 236 nm.

To prevent stray light at these deep-UV wavelengths we mode-clean the light with hydrogen loaded and UV-cured large mode-area fibers. We present the assembly process of these fibers and their characterization.

Q 57.34 Thu 16:15 S Fobau Physik

Towards Testing Lorentz Violation with ^{172}Yb$^+$ Ions — •Chih-Han Yeh, André P. Kulosa, Dimitri Kalincev, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38166 Braunschweig, Germany

We report on an experiment that will test the Lorentz violation (LV) in the electron-photon sector [1] with ^{172}Yb$^+$ ions. Similar tests have been carried out with optical entanglement of two Ca$^+$ ions [2] and by comparing two independent ^{171}Yb$^+$ clocks [3]. The maximum LV signal for Yb$^+$ ions is a factor of 14 stronger compared to Ca$^+$. We interrogate the $4f^{13}6s^2\ ^2F_{7/2}$ state which has a life time of about six years. Together with AN ion trap heating rate of 1ph/s our experiment will allow for extended Ramsey times of several seconds. Coherent excitation of such a long-lived state for the preparation of entangled states as in [2] requires tens of ms pulse durations, possibly being limited by magnetic field noise in our current experimental setup. Therefore, we investigate the use of dynamical decoupling [4] which allows the ions to be first-order insensitive to magnetic field noise during the interrogation by mixing the Zeeman states. Theoretically, operating dynamical decoupling with 10 ions and a Ramsey time of 10s with 48h of total measurement time would allow us to gain a factor of 10 in sensitivity compared to the current limit [3]. [1] D. Colladay and V. Alan Kostelecký, *Phys. Rev. Lett.* **58**, 116002 (1998). [2] C. Sanner et al., arXiv:1809.10742 (2018). [3] E. Megidish et al., arXiv:1809.09807 (2018). [4] R. Shaniv et al., *Phys. Rev. Lett.* **120**, 103202 (2018).

Q 57.35 Thu 16:15 S Fobau Physik

iqClock - the European integrated quantum clock — •Markus Gellesch[1], Jonathan Jones[1], Yeshpal Singh[1], Kai Bongs[1], and the iqClock Consortium[2] — [1]University of Birmingham, School of Physics and Astronomy, B15 2TT, Birmingham, UK — [2]University of Amsterdam, Institute of Physics, Science Park 904, 1090 GL Amsterdam, The Netherlands

Optical clocks are frequency standards with unmatched stability. Bringing those clocks from the laboratory into a robust and compact form will have a large impact on telecommunication, geology, astronomy, and other fields. Likewise, techniques developed for robust clocks will improve laboratory clocks, potentially leading to physics beyond the standard model. To make this transition a reality, we have brought together the iqClock consortium (https://www.iqclock.eu), assembling leading experts from academia, strong industry partners, and relevant end users. We will seize on recent developments in clock concepts and technology to start-up a clock development pipeline along the TRL scale. Our first product prototype will be a field-ready strontium optical clock, which we will benchmark in real use cases. This clock will be based on a modular concept, already with the next-generation clocks in mind, which our academic partners will realize.

Q 57.36 Thu 16:15 S Fobau Physik

Towards a steady-state superradiant optical clock — •Shayne Bennetts, Rodrigo Gonzalez Escudero, Chun-Chia Chen, Benjamin Pasquiou, and Florian Schreck — Institute of Physics, University of Amsterdam

Superradiant lasers have been proposed as a next generation optical atomic clock [1]. Recently, a pulsed superradiant laser was demonstrated using the ^{87}Sr clock transition [2] but a clock with millihertz stability requires steady-state operation.

Building on our earlier work [3] we have demonstrated sources ideal for pumping a steady-state superradiant laser. Firstly, our steady state beam guided horizontally by a dipole laser has a radial temperature of 1μK and a flux $> 6 \times 10^6$ ^{88}Sr/s. Additionally, by using a new deceleration and cooling technique [4] we show we are able to cool and trap this beam in a dipole trap forming a continuously loaded reservoir of atoms. These show great potential for pumping a continuous superradiant laser and making a steady-state BEC or atom laser. We also demonstrate operation of this architecture on the ^{87}Sr isotope which is of particular interest for clocks. Finally, we will describe a next generation machine we are constructing based on these techniques which aims to produce a steady state superradiant laser.

[1] Meiser *et al.*, PRL 102, 163601 (2009).
[2] Norcia *et al.*, Sci Adv **2**, 10, e1601231 (2016).
[3] Bennetts *et al.*, PRL 119, 223202 (2017).
[4] Chen *et al.*, arXiv:1810.07157 [physics.atom-ph] (2018).

Q 57.37 Thu 16:15 S Fobau Physik

Quantitative measurement of CO with non-dispersive infrared absorption spectroscopy — •Christian Niklas, Fabian Müller, Hainer Wackerbarth, and Georgios Ctistis — Laser-Laboratorium Göttingen e.V., Hans-Adolf-Krebs-Weg 1 , 37075 Göttingen, Deutschland

Global climate change calls for efficient handling of energy and, consequently, has led to stricter regulations of gas emissions, resulting in a higher demand for gas sensors. To satisfy the demand of these sensors, alternatives to the market dominating chemical sensors have to be developed. Optical detection techniques provide a non-invasive, stable and durable solution, which also work under harsh environments.

In this work, we use non-dispersive infrared spectroscopy (NDIR) for a sensor, capable to detect carbon monoxide (CO), an odourless and toxic gas. Furthermore, this sensor is targeted to be competitive on the market. The basic setup for the detection of CO consists of a light source, a filter and a detector. The nonlinear relation between measured transmittance and the gas density given by Beer-Lambert's law is calculated based on absorption cross sections from the HITRAN database under consideration of the spectral influences of the materials. This is used as a look-up table for the measurement process of the sensor.

Q 57.38 Thu 16:15 S Fobau Physik

Towards an integrated PDC source at cryogenic temperatures — •Moritz Bartnick, Frederik Thiele, Jan Philipp Höpker, Raimund Ricken, Viktor Quiring, Harald Herrmann, Christine Silberhorn, and Tim J. Bartley — Universität Paderborn, Warburger Str. 100, 33098 Paderborn, Germany

For applications in quantum communication, integrated photonics provide a powerful technology which is robust, scalable and not sensitive to ambient conditions. Exhibiting a wealth of physical properties, lithium niobate represents a versatile platform in which many highly efficient integrated optical devices could have been realised.

Recently, a fibre-coupled plug-and-play integrated PDC single photon source with a heralding efficiency $\eta > 50\%$ has been demonstrated in lithium niobate [1]. The most promising integrated single photon detectors that have been realised in lithium niobate are superconducting detectors, requiring cryogenic temperatures. Thus, it is now interesting to unify all integrated photonic components at very low temperatures.

The goal of the presented work is to implement a periodically-poled PDC source integrated in lithium niobate at cryogenic temperatures. To adapt the poling period, the refractive index of lithium niobate needs to be characterised at cold temperatures. Since lithium niobate is pyroelectric, it should not be exposed to a fast change in temperature. Further, it is challenging to construct stable fibre-to-waveguide links being efficient both at 775nm and 1550nm wavelength.

[1] Montaut et al. "High-efficiency plug-and-play source of heralded single photons." Physical Review Applied 8.2 (2017): 024021.

Q 57.39 Thu 16:15 S Fobau Physik

Towards Cryogenic Polarisation Modulation in Lithium Niobate Waveguides — •Frederik Thiele, Jan Philipp Höpker, Patrick Bartowiak, Felix vom Bruch, Harald Herrmann, Raimund Ricken, Viktor Quiring, Christine Silberhorn, and Tim J. Bartley — Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Lithium niobate is an important platform for integrated optics given its high second-order nonlinearity and electro-optic properties. In this material are high-speed electro-optic modulation and polarization conversion can be realised. Superconducting detectors and other quantum optic devices are operated at cryogenic temperatures. The aim of this work is to implement modulators at cryogenic temperatures in order to achieve high system efficiencies from the source through the modulators to the detectors. We report on the progress towards this goal. High coupling efficiency from single mode fibres from room temperature to cryogenic temperatures have been realised. Periodically poled polarization modulators in titanium in-diffused lithium niobate waveguides are dependent on quasi-phase matching and need to be adapted for cryogenic temperatures. The expected change in the poling period can be extrapolated from previously determined refractive indices of lithium niobate.

Q 57.40 Thu 16:15 S Fobau Physik

Development of Ta2O5 based photonic circuitry as new platform for integrated optics — •Lukas J. Splitthoff[1,2], Martin A. Wolff[1,2], and Carsten Schuck[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm Str. 10, 48149 Münster, Germany — [2]CeNTech, Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany

Integrated optical quantum information systems that work in the single-photon regime rely on low-loss and CMOS-compatible nanophotonic platforms, which enable the on-chip integration of quantum emitters and single-photon detectors. The high refractive index contrast between Ta2O5 and SiO2 as well as the low self-fluorescence of Ta2O5 enable on-chip quantum experiments in the visible wavelength range [1] as well as the telecommunications C-band [2] with high-quality devices and small footprint. Therefore, Ta2O5 serves as a promising candidate for outperforming existing photonic platforms such as Si3N4.

Here we report on the development of nano-photonic components on the Ta2O5 on insulator platform. We fabricate single-mode waveguides, grating couplers, resonators, and power splitters and characterize their performance for applications in integrated quantum photonics. We further assess the implementation of superconducting nanowire single-photon detectors (SNSPDs) and single-photon sources like nitrogen-vacancy (NV) centers.

[1]Liebermeister et al., arXiv:1710.03095 [quant-ph] (2017) [2]Belt et al., Optica 4, 10.1364/OPTICA.4.000532 (2017)

Q 57.41 Thu 16:15 S Fobau Physik

Comparison of different silicon nitride materials for technological fabrication of photonic components — •Oliver Kurzel[1,2], Harald Richter[1], Mirko Fraschke[1], Marco Lisker[1], Thomas Grabolla[1], Lars Zimmermann[1,3], and Andreas Mai[1,2] — [1]IHP - Leibniz-Institut für innovative Mikroelektronik, Frankfurt (Oder) — [2]Technische Hochschule Wildau — [3]Technische Universität Berlin

In the recent years silicon nitride (SiN) was demonstrated as a high performance alternative solution for photonic integrated circuits in silicon photonics platform with additional features and strength. This work is focused on the development of a manufacturing process for SiN waveguides and grating couplers. SiN is deposited by either Low Pressure Chemical Vapor Deposition at high temperature or by Plasma Enhanced CVD at low temperature, to enhance material properties for photonic device applications. Different technological steps were identified with a significant influence to the performance of high-quality SiN waveguides: Surface roughness on top and on the sidewalls of the waveguide was decreased by additional polish steps as well as by optimization of the SiN plasma etch process, respectively. The plasma etch process using a CF chemistry results in waveguides characterized by rectangular profiles. The hydrogen concentration in SiN is reduced by a final annealing step. Propagation loss values less than 0.5 dB/cm verify the manufacturing process quality. Finally, influence of high temperature annealing was investigated which currently restricts applications of such photonic components for integration in CMOS technologies.

Q 57.42 Thu 16:15 S Fobau Physik

Domain structure sensitive phonon modes in PPKTP waveguides — •Julian Brockmeier, Christof Eigner, Laura Padberg, Peter Mackwitz, Christine Silberhorn, Gerhard Berth, and Artur Zrenner — Department Physik, Universität Paderborn, 33098 Paderborn, Germany

Periodically poled Potassium Titanyl Phosphate (KTP) is highly interesting for quantum optical applications. However, there are many challenges regarding the fabrication of periodically poled waveguide structures for domain periods in the submicron regime. Therefore a fundamental understanding of the underlying physics of the domain inversion process in such materials is necessary. Here, Raman spectroscopy presents a powerful method to uncover various material properties like stoichiometry, strain or ferroelectricity.

In this work the phonon modes for different scattering geometries are fully characterized by confocal Raman spectroscopy. Here the sensitivity of the vibrations linked to the ferroelectric domain structure in bulk and the rubidium indiffused KTP are studied. In this context the local material properties are expressed by variations of mode intensity, FWHM and center frequency. In our study we found specific modes with different vibrational signatures in the vicinity of domain boundaries and within the rubidium exchanged area. Further we perform Raman imaging on different structures in KTP based on our sensitivity analysis resulting in images with different content of characteristic material features.

Q 57.43 Thu 16:15 S Fobau Physik

Waveguide-integrated superconducting nanowire single-photon detectors made from amorphous molybdenum silicide — •Matthias Häussler[1,2], Martin A. Wolff[1,2], Wolfram Pernice[1,2], and Carsten Schuck[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany

The growing interest in quantum optics experiments on silicon chips has created a need for efficient, low-noise yet scalable single photon detectors. Superconducting nanowire single-photon detectors (SNSPDs) fabricated directly on top of nanophotonic waveguides integrate seamlessly with established nanophotonic platforms and combine attractive performance with a small footprint in a scalable fashion.

Integrated SNSPDs from crystalline superconducting thin-films have been realized on a variety of waveguide materials, however the integration into large-scale circuits is limited by poor detector yield. Integrated SNSPDs from amorphous superconductors are believed to show similar performance and can be fabricated with high yield on a wider range of material platforms as lattice matching becomes irrelevant.

In this work we take advantage of the high substrate compatibility of amorphous superconducting molybdenum silicide thin films and realized waveguide-integrated SNSPDs in high-quality silicon nitride-on-insulator nanophotonic circuits. We present measurements on the performance of the devices that reveal intrinsic differences between SNSPDs made from amorphous and crystalline materials.

Q 57.44 Thu 16:15 S Fobau Physik

Stimulated Raman scattering of fused silica within the discontinuous Galerkin time-domain framework — •Dan-Nha

Huynh[1] and Kurt Busch[1,2] — [1]Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany — [2]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

A common nonlinear phenomenon in dielectrics is Raman-scattering. It is an indirect resonant, dissipative process, which is best described in terms of a third-order nonlinear polarization. In the following, we show how to integrate a material model for Raman-active dielectrics into a numerical discontinuous Galerkin time-domain scheme for two and three-dimensional systems. To this end, we present a scheme of auxliliary differential equations by which we describe the process of stimulated Raman-scattering.