Q 7: Precision Measurements

Time: Tuesday 16:30–18:30 Location: P

Q 7.1 Tue 16:30 P

Prototype of a compact rubidium-based optical frequency reference for operation on nanosatellites — •Aaron Strangfeld[1,2], Simon Kanthak[1,2], Max Schiemangk[2], Benjamin Wiegand[1], Andreas Wicht[2], Alexander Ling[3], and Markus Krutzik[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Deutschland — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Deutschland — [3]Centre for Quantum Technologies, National University of Singapore, Block S15, 3 Science Drive 2, Singapore 117543, Singapur

A compact laser system with integrated spectroscopy unit was developed as a prototype for optical frequency references on nanosatellites. Light from a distributed feedback laser diode is used for spectroscopy of rubidium in a vapor cell. The microintegration of optics with a size of a few millimeters allowed a significant size reduction ($70 \times 26 \times 19$ mm^3) while maintaining the performance of larger realizations: $\sigma_y(\tau = 1\mathrm{s}) = 1.7 \times 10^{-12}$.

This work has been done in a joint collaboration between Humboldt-Universität zu Berlin and National University of Singapore, supported by the Berlin University Alliance and by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50RK1971. The microintegration was realized at Ferdinand-Braun-Institut gGmbh, Leibniz-Institut für Höchstfrequenztechnik.

Q 7.2 Tue 16:30 P

Towards a strontium based Ramsey-Bordé optical frequency reference — •Oliver Fartmann[1], Conrad L. Zimmermann[1], Martin Jutisz[1], Vladimir Schkolnik[1,2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We report on the status of our optical frequency reference based on Ramsey-Bordé interferometry. We utilize the $^1\mathrm{S}_0 \rightarrow {}^3\mathrm{P}_1$ intercombination line at 689 nm in a thermal atomic strontium beam.

We will give an overview on the system architecture and present first results of the compact high flux atomic oven, the cavity stabilized laser system as well as the atom interferometer package.

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 DLR50WM1852 and by the German Federal Ministry of Education and Research (BMBF) within the program quantum technologies - from basic research to market under grant number 13N15725.

Q 7.3 Tue 16:30 P

Tandem Neural Network for Design of High-Reflectivity Metamirrors — •Liam Shelling Neto[1,3], Anastasiia Sorokina[1,3], Johannes Dickmann[1,3], Jan Meyer[1,3], Tim Käseberg[2], and Stefanie Kroker[2,3] — [1]Laboratory for Emerging Nanometrology (LENA), Technical University of Braunschweig, Langer Kamp 6a/b, 38106 Braunschweig — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [3]Cluster of Excellence QuantumFrontiers

In recent years, sub-wavelength structures that interact with light gained increasing attention thanks their ability to manipulate different aspects of the impinging electromagnetic wave, e.g. phase, amplitude or even polarization. The composition of such artificial structures pave the way for a multitude of applications such as ultrathin metalenses or hologram generation. In order to control the vast design space that unfolds with the desired flexibility of those nanostructures, many approaches have been reported in the past. Deep Learning efficiently tackles the problem of large parameter spaces since that is part of its intrinsic nature. In this Poster, we utilize a Tandem Neural Network to design focusing metamirrors with excellent phase agreement while maximizing reflectivity within a given design space.

Q 7.4 Tue 16:30 P

Test setup for cryogenic sensors and actuators working towards the Einstein Telescope — •Robert Joppe, Matthias Bovelett, Tim Kuhlbusch, Thomas Hebbeker, Vivek Pimpalshende, Oliver Pooth, Achim Stahl, Jan Wirtz, Franz-Peter Zantis, and Markus Bachlechner — RWTH Aachen, Aachen, Deutschland

The Einstein Telescope will be the first gravitational wave detector of the third generation. The sensitivity goal, especially in the low frequency region, will be achieved among other improvements by cooling the main parts of the interferometer. The required electronic components, sensors and actuators needed for mirror alignment and active dampening of suspension resonances have to perform at cryogenic temperatures.

In this poster we will present our work on electronics and mechanics within the E-TEST project. Furthermore the performance of our cryogenic UHV test setup will be explicated.

Q 7.5 Tue 16:30 P

Matter-Wave sensing for inertial navigation — •Mouine Abidi[1], Philipp Barbey[1], Vera Vollenkemper[1], Ashwin Rajagopalan[1], Yueyang Zou[1], Christian Schubert[1,2], Dennis Schlippert[1], Sven Abend[1], and Ernst.M Rasel[1] — [1]Institut für Quantenoptik - Leibniz Universität, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Germany

Precise inertial navigation and positioning play a determining role in our daily life. Actual navigation systems cannot be used for certain fields since they suffer from device-dependent drifts, requiring GNSS correction that is not possible for example in buildings or space. Therefore, solutions based on a new technology had become a huge demand.

Quantum hybrid navigation combines conventional Inertial Measurement Units with quantum sensors based on atom interferometry. Atom interferometers have proven to measure drift-free at very high sensitivities. They can be used regardless of their small bandwidth and dynamic range to subtract the drifts of the classical devices.

This combination proposes a better performance and security for traditional navigation domains and an efficient tool to explore inertial measurement in new areas. We present the current status of our test stand for a quantum navigation system employed on a gyro-stabilized platform.

This work is supported by the Ministry for Economic Affairs and Energy (BMWi) due to the enactment of the German Bundestag under Grand No. DLR 50RK1957 (QGyro).

Q 7.6 Tue 16:30 P

A Quantum Optical Microphone in the Audio Band — •Raphael Nold[1], Charles Babin[1], Joel Schmidt[1], Tobias Linkewitz[1], Mária Pérez Zaballos[2], Rainer Stöhr[1], Roman Kolesov[1], Vadim Vorobev[1], Daniil Lukin[3], Rüdiger Boppert[4], Stefanie Barz[1], Jelena Vuckovic[3], Christof Gebhardt[5], Florian Kaiser[1], and Jörg Wrachtrup[1] — [1]University of Stuttgart, Germany — [2]Cambridge University, UK — [3]Stanford University, USA — [4]Olgahospital Stuttgart, Germany — [5]Ulm University, Germany

The ability to perform high-precision optical measurements is paramount to science and engineering. Especially laser interferometry enables interaction-free sensing in which precision is ultimately limited by shot noise. Quantum optical enhanced sensors can surpass this limit. We introduce a novel cavity-free nonlinear interferometer that achieves sub-shot noise performance in continuous operation. We combine the advantages of low parametric gain operation and post selection free difference intensity detection with common mode noise cancellation. This allows us to measure phase-shifts more than four orders of magnitude faster compared to previous experiments based on photon number states. Further we present the implementation of a complex application as a quantum microphone in the audio band (frequency range $200 - 20{,}000$ Hz). Recordings of both, the quantum sensor and an equivalent classical counterpart are benchmarked with a medically-approved speech recognition test, which shows that the quantum sensor leads to a by 0.29 dB reduced speech recognition threshold. We thus make the quantum advantage audible to humans.

Q 7.7 Tue 16:30 P

Highly stable UV laser system for a transportable Al$^+$ quantum logic optical clock — •Benjamin Kraus[1,2], Stephan Hannig[1,2], Sofia Herbers[1,2], Dewni Pathegama[1], Fabian

Dawel[1], Johannes Kramer[1], Constantin Nauk[1,2], Christian Lisdat[1], and Piet O. Schmidt[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, 30167 Hannover, Germany — [3]Leibniz Universität Hannover, 30167 Hannover, Germany

Optical atomic clocks provide the most precise frequency standards. They enable high accuracy tests of fundamental physics, relativistic geodesy, and a possible future redefinition of the SI second. For side-by-side clock comparisons, highly accurate transportable optical clocks are necessary. We report on our newly built clock laser system for a transportable Al$^+$ clock with its clock transition at 267.4 nm. The system consists of the laser source at 1069.6 nm, a highly stable optical reference cavity, a frequency quadrupling system, and the electronic control system all built in one rack. In particular we highlight the frequency quadrupling system consisting of two cascaded single-pass second harmonic generation(SHG) stages. The set-up is interferometrically phase-stabilized and built inside a hermetically sealed aluminium box to form a robust, compact, and stable fibre-coupled module. Additionally, a robust fibre-coupled single-pass acousto-optical modulator module at 267.4 nm for frequency shifting or switching the laser light is presented.

Q 7.8 Tue 16:30 P

Hybridizing an atom interferometer with an opto-mechanical resonator — •Ashwin Rajagopalan[1], Lee Kumanchik[2,3], Claus Braxmaier[2,3], Felipe Guzmán[4], Ernst M. Rasel[1], Sven Abend[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover — [2]DLR - Institute of Space Systems, Bremen — [3]University of Bremen - Center of Applied Space Technology and Microgravity (ZARM),Bremen — [4]Department of Aerospace Engineering & Physics, Texas A&M University, College Station, TX 77843, USA

With hybridization we have a quantum and classical sensor measuring acceleration with respect to a joint inertial reference therefore enabling common mode noise rejection. We have used a novel opto-mechanical resonator in order to suppress the effects of inertial noise coupling in our atom interferometer. The OMR possesses a very small form factor, therefore apart from eradicating the need to use a vibration isolation system it also allows for compact dimensions of the sensor head. Therefore, considering the complimentary benefits of the quantum sensor and OMR we foresee the potential for a highly sensitive, portable, compact and robust hybrid quantum inertial navigation sensor.

Reference: Richardson, L.L., Rajagopalan, A., Albers, H. et al. Optomechanical resonator-enhanced atom interferometry. Commun Phys 3, 208 (2020). https://doi.org/10.1038/s42005-020-00473-4

Q 7.9 Tue 16:30 P

An ultra-stable clock laser system for an Al$^+$ ion clock — •Dewni Pathegama[1], Sofia Herbers[1,2], Eileen Annika klocke[1,3], Stephan Hannig[1,2], Benjamin Kraus[1,2], Piet O. Schmidt[1,2,4], Uwe Sterr[1], and Christian Lisdat[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany — [3]currently with Askion GmbH, Gera, Germany — [4]Leibniz University of Hannover, Hannover, Germany

Transportable optical clocks are increasingly used in applications like relativistic geodesy. One of the key components of an optical clock is an ultra-stable interrogation laser, whose instability affects the clock performance via the Dick effect.

Here we present a clock laser system designed for a transportable Al$^+$ clock [Hannig et al., Rev. Sci. Instrum. **90**, 053204 (2019)]. The system consists of a DFB fiber laser locked to a cavity with crystalline mirror coatings [Cole et al., Nat. Phot. **7**, 644 (2013)] to reduce the thermal noise contribution of the cavity below 10^{-16} fractional frequency instability. Additionally, suppression of residual amplitude modulation (RAM), power stabilization of the light oscillating in the cavity, and temperature stabilization of the cavity will be employed to reach an instability as low as 10^{-16}. The laser is operated at 1069.6 nm, and fourth harmonic generation is implemented to reach the 267.4 nm interrogation wavelength of Al$^+$. All the components including the cavity and electronics are designed to be installed inside a single rack.

Q 7.10 Tue 16:30 P

Characterizing the sensitivity levels of a shadow sensor - working towards a cryo-compatible sensor — •Vivek Pimpalshende, Markus Bachlechner, Matthias Bovelett, Thomas Hebbeker, Robert Joppe, Tim Kuhlbusch, Oliver Pooth, Achim Stahl, Jan Wirtz, and Franz-Peter Zantis — RWTH Aachen University, Aachen, Germany

The Einstein Telescope will be the first gravitational wave detector of the third generation. The sensitivity goal, especially in the low-frequency region, will be achieved among other improvements by cooling the main parts of the interferometer. Thus, the required electronic components, sensors, and actuators needed for mirror alignment and active damping of suspension resonances have to perform at cryogenic temperatures. In a shadow sensor, the displacement of a flag is measured from its shadow cast onto a photodiode. In this poster, we will present our work on the characterization of the noise level of a shadow sensor. Understanding the noise sources is crucial to improve the sensitivity, which is essential to design an efficient cryo-compatible sensor.

Q 7.11 Tue 16:30 P

Frequency stability of a cryogenic silicon resonator with crystalline mirror coatings — •Jialiang Yu[1], Thomas Legero[1], Fritz Riehle[1], Daniele Nicolodi[1], Dhruv Kedar[2], John Robinson[2], Eric Oelker[3], Jun Ye[2], and Uwe Sterr[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado, USA — [3]University of Glasgow, UK

The performance of ultra-stable lasers is ultimately limited by various types of thermal noise, with Brownian thermal noise of the optical coatings as the largest contribution.

We have set up a 21 cm long optical resonator made from single-crystal silicon with $\mathrm{Al_{0.92}Ga_{0.08}As/GaAs}$ crystalline mirror coatings, which is operated at a cryogenic temperature of 124 K. Compared to usual dielectric coatings, the crystalline coatings are expected to have a lower mechanical loss, thus improving the frequency stability to 1×10^{-17}. The most important technical noise sources affecting the frequency stability are suppressed to a level below this predicted thermal noise floor for averaging times between 5 s and 1000 s. However, the lowest measured frequency instability of 4.5×10^{-17} is significantly higher than predicted. Compared to dielectric coatings we observe a much more complex behavior of the crystalline semiconductor coatings on e.g. fluctuations of the intracavity power. The influence on cavity frequency stability is investigated by locking simultaneously two lasers to different cavity modes.

Q 7.12 Tue 16:30 P

A laser system for combining Bragg and Raman processes — •Ekim T. Hanimeli[1], Martina Gebbe[1], Matthias Gersemann[2], Simon Kanthak[3,4], Sven Abend[2], Sven Herrmann[1], Claus Lämmerzahl[1], and QUANTUS team[1,2,3,4] — [1]ZARM, Universität Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, HU Berlin — [4]Ferdinand-Braun-Institut, Berlin

Bragg and Raman diffractions are commonly used in atom interferometry to form beam splitters and mirrors. The two processes differ in their internal state transitions, so their combination enables the creation of novel interferometry topologies through the inclusion of both internal and external states. Here, we present the new fibre-optical laser system capable of implementing both Bragg and Raman processes as well as double diffractions, allowing a wide variety of possibilities to be achieved. Especially for Raman diffraction a low-phase noise implementation for the hyperfine splitting is mandatory. In our system this is realized with a combination of an electro-optical modulator and a fibre Bragg grating, which suppresses the unwanted optical sidebands in the modulation.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under Grant No. 50WM1952 (QUANTUS-V-Fallturm).

Q 7.13 Tue 16:30 P

Analytic Theory for Diffraction Phases in Bragg Interferometry — •Jan-Niclas Siemss[1,2], Florian Fitzek[1,2], Ernst M. Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

High-fidelity Bragg pulses operate in the quasi-Bragg regime. While such pulses enable an efficient population transfer essential for state-of-the-art atom interferometers, the diffraction phase and its dependence on the pulse parameters are currently not well characterized despite playing a key role in the systematics of these interferometers. We demonstrate that the diffraction phase when measuring relative atom numbers originates from the fact that quasi-Bragg beam splitters and mirrors are fundamentally multi-port operations governed by Landau-Zener physics (Siemß et al., Phys. Rev. A 102, 033709).

We develop a multi-port scattering matrix representation of the popular Mach-Zehnder atom interferometer and discuss the connection between its phase estimation properties and the parameters of the Bragg pulses. Furthermore, our model includes the effects of linear Doppler shifts applicable to narrow atomic velocity distributions on the scale of the photon recoil of the optical lattice.

This work is supported through the Deutsche Forschungsgemeinschaft (DFG) under EXC 2123 QuantumFrontiers, Project-ID 390837967 and under the CRC1227 within Project No. A05 as well as by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

Q 7.14 Tue 16:30 P

Measuring Gravity with Very Long Baseline Atom Interferometry — •Ali Lezeik, Klaus Zipfel, Dorothee Tell, Christian Meiner, Chrisitan Schubert, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover- Insititute für Quantenoptik, Germany

Matter-wave interferometers with ultracold atoms are highly sensitive to inertial quantities. The Very Long Baseline Atom Interferometry (VLBAI) facility at the Hannover Institute of Technology (HiTech) aims to exploit the linear scaling of this sensitivity with the free fall time of the atoms in a 10 m baseline [1]. This will enable precision measurements of gravitational acceleration, as well as tests of the weak equivalence principle and gravitational redshift [2,3].

We present the current status of the VLBAI, the 20cm diameter vacuum chamber with the high performance magnetic shield that achieved residual fields below 4 nT and longitudinal inhomogeneities below 2.5 nT/m over 8 m along the longitudinal direction. We additionally report on the source of laser-cooled ytterbium atoms delivering 1 × 10^9 atoms/s in a 3D magneto-optical trap. With such upgrades, tests of the universality of free fall with atomic test masses beyond the 10^{-13} level can be achieved.

[1] J. Hartwig et al., New J. Phys. 17 (2015)
[2] D. Schlippert et al., arXiv:1909.08524 (2019)
[3] S. Loriani et al., Sci. Adv. 5 (2019)