Q 5: Precision Measurements and Metrology I

Time: Monday 10:30–12:45 Location: S SR 111 Maschb.

Q 5.1 Mon 10:30 S SR 111 Maschb.

Development of miniaturized optical dipole trap setups for integrated atomic quantum sensors — •Marc Christ[1,2], Anne Stiekel[1,2], Andreas Wicht[2], and Markus Krutzik[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

Operation of compact quantum sensors in field and space implicates challenging requirements on components, subsystems and integration technologies. In our work, we want to realize miniaturized, ultra-stable and ultra-high vacuum (UHV) compatible optical setups, which are integrated inside the vacuum chamber of cold atom sensors and thus lead to a significant reduction of system size and complexity. Besides challenging demands on alignment precision and thermo-mechanical durability, we specifically address UHV-compatibility of our integration technologies and optical components. A versatile UHV qualification system is currently being commissioned, enabling residual gas analysis and measurements of total gas rates down to $5 \cdot 10^{-10}$ mbar l/s.
Furthermore, a prototype design of an UHV-compatible, crossed beam optical dipole trap setup and its application within a cold atomic quantum sensor is described.
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 5.2 Mon 10:45 S SR 111 Maschb.

$\mathcal{T}^3$-interferometry — •Matthias Zimmermann[1], Maxim A. Efremov[1], Wolfgang Zeller[1], Wolfgang P. Schleich[1], Jon P. Davis[2], and Frank A. Narducci[3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, Germany — [2]AMPAC, North Wales, USA — [3]Department of Physics, Naval Postgraduate School, Monterey, USA

In recent years, several atom interferometers have been suggested [1] and realized [2,3], where the phase shift contains a contribution that scales as $\mathcal{T}^3$ in contrast to conventional atom interferometers with a scaling of $\mathcal{T}^2$. Here $\mathcal{T}$ denotes the total interferometer time. We review and compare these interferometers by applying a representation-free formalism [4] and obtain the cubic phase shift as a result of a piecewise constant, but branch-dependent acceleration of the atoms. Moreover, we relate this phase to the area in space-time enclosed by the two branches of the interferometer.

[1] M. Zimmermann et al., *Appl. Phys. B* **123**:102 (2017)
[2] G.D. McDonald et al., *EPL*, **105**(6):63001 (2014)
[3] private communication with O. Amit, Y. Margalit, and R. Folman
[4] M. Zimmermann et al., to be submitted

Q 5.3 Mon 11:00 S SR 111 Maschb.

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 5.4 Mon 11:15 S SR 111 Maschb.

Twin-lattice interferometry — •Martina Gebbe[1], Matthias Gersemann[2], Sven Abend[2], Jan-Niclas Siemss[2,3], Naceur Gaaloul[2], Sven Herrmann[1], Klemens Hammerer[3], Claus Lämmerzahl[1], Ernst M. Rasel[2], and The Quantus Team[1,2,4,5,6,7] — [1]ZARM, Uni Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]ITP, LU Hannover — [4]Institut für Physik, HU Berlin — [5]Institut für Quantenphysik, Uni Ulm — [6]Institut für Angewandte Physik, TU Darmstadt — [7]Institut für Physik, JGU Mainz

Large momentum transfer in combination with Bose-Einstein condensates (BECs) is a key technique for future atomic gravitational wave detectors as well as for miniaturized inertial quantum sensors. Our twin lattice allows us to efficiently manipulate our delta-kick collimated BECs to form symmetric scalable beam splitters consisting of a combination of Double Bragg diffraction and Bloch oscillations. We succeed to interfere BECs moving at a differential velocity of up to 2.2 m/s in an interferometer involving a total of 1632 transferred photon momenta. We investigate the scalability of the momentum transfer both theoretically and experimentally. Studying the spatial interference reveals that our method is limited technically rather than fundamentally.

This work is supported by the CRC 1128 geo-Q and by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. DLR 50WM1552-1557 (QUANTUS-IV-Fallturm).

Q 5.5 Mon 11:30 S SR 111 Maschb.

Perturbation theory for atom light-pulse interferometers — •Christian Ufrecht, Fabio Di Pumpo, Alexander Friedrich, Stephan Kleinert, Albert Roura, Enno Giese, Wolfgang P. Schleich, and the Quantus team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm

In recent years a number of methods to calculate phase and contrast of atom light-pulse interferometers have been proposed, see for instance [1], [2]. Even though they are well suited within their range of validity, the application to anharmonic potentials often requires numerical simulations.
In this talk we will introduce a formalism to analytically calculate the effect of arbitrary - however small - anharmonic potentials, and show how to obtain a straightforward perturbative expansion of phase and contrast in powers of these contributions. As an example we will analytically calculate the influence of the gravitational potential beyond the quadratic approximation.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1556 (QUANTUS IV).

[1] Dimopoulos et. al., Phys. Rev. D 78, 042003, 2008
[2] Kleinert et. al., Phys. Rep. 605,1, 2015

Q 5.6 Mon 11:45 S SR 111 Maschb.

Quantum Geometric Phase in Light-Pulse Atom Interferometry — •Stephan Kleinert, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm

In the presence of a time-dependent Hamiltonian, a quantum state accumulates, apart from a dynamical phase, a geometric phase which solely depends on the topology of the projective Hilbert space.

Our talk focuses on geometric phases acquired by motional states in light-pulse atom interferometers. To address this problem, we use an operator approach [1] which fully describes the external motion by means of displacement operators. Due to the induced kinematic boosts on the external Hilbert space, the generators of the associated Weyl-Heisenberg group give rise to the definition of a quantum geometric phase in external phase space.

As an example, we consider a Mach-Zehnder pulse sequence and can identify global as well as relative quantum geometric phases.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1556 (QUANTUS IV).

[1] S. Kleinert, et al., *Representation-free description of light-pulse atom interferometry including non-inertial effects*, Physics Reports **605**, 1 (2015).

Q 5.7 Mon 12:00 S SR 111 Maschb.

Symmetric atom interferometers based on double Bragg diffraction for large momentum transfer — •Jens Jenewein, Albert Roura, Wolfgang P. Schleich, and the QUANTUS team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm

Combined with Bloch oscillations in accelerated optical lattices, double Bragg diffraction constitutes a central element of symmetric atom interferometers reaching a large relative momentum between the two arms. Unfortunately, the diffraction inefficiencies of the double Bragg pulses are an important source of contrast loss in current experiments with this kind of interferometers. We investigate these effects in detail by numerical simulations that take into account velocity selectivity effects, off-resonant transitions and imperfect laser-beam polarisations. Both partial pulse sequences and full interferometers are analysed in order to identify the main causes of diffraction inefficiencies and optimise the interferometer contrast.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1556 (QUANTUS IV).

Q 5.8 Mon 12:15 S SR 111 Maschb.

Bragg beam splitters with misaligned Gaussian laser beams — •Antje Neumann and Reinhold Walser — Institut Angewandte Physik, Technische Universität Darmstadt, Darmstadt, Deutschland

Atomic beam splitters are a central component of matter wave interferometers, which provide the opportunity of high-precision rotation and acceleration sensing. Potential applications range from fundamental physics to inertial navigation. In the QUANTUS free-fall experiments atom interferometry is the central method as well [1].

Beam splitters are used to prepare coherent superpositions of atomic wave packets in momentum space by transferring photon momentum from a laser field. Like optical systems matter wave devices require exact specifications and ubiquitous imperfections need to be quantified.

We analyse the aberrations of quasi Bragg beam splitters in 3D. In particular, we characterise the non-ideal behaviour due to spatial variations of the laser beam profiles and wave front curvatures, regarding realistic Gaussian laser beams instead of ideal plane waves. Especially, we study the effect of slightly decentered and tilted lasers. In addition, different temporal pulse shapes will be considered.

We present results of numerical and analytical studies of the velocity dependence of the complex reflectivity of the beam splitter and finally, we match our theory with experimental data [2].

This work is supported by the German Aeronautics ans Space Administration through grant 50 WM 1557.

[1] D. Becker et al., Nature 562, 391-395 (2018).
[2] M. Gebbe, Universität Bremen, Zarm, private communication.

Q 5.9 Mon 12:30 S SR 111 Maschb.

A highly homogeneous magnetic environment for Very Long Baseline Atom Interferometry — •Etienne Wodey[1], Michael Müller[2], Mischa Widmer[2], Urs Schläpfer[2], Stefan Stuiber[3], Dorothee Tell[1], Wolfgang Ertmer[1], Christian Schubert[1], Dennis Schlippert[1], Peter Fierlinger[3], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover — [2]IMEDCO AG — [3]Technische Universität München

Atom-interferometric measurement instruments of e.g. inertial forces owe their remarkable stability and well-known bias to the fine understanding of interactions between the atoms and external fields. Controlling spurious fields coupling to the atomic test masses is therefore of utmost importance. Here, magnetic field gradients play a dominant role through the quadratic Zeeman effect which is not canceled for states with vanishing magnetic quantum number.

In this contribution, we present the baseline section of the Hannover Very Long Baseline Atom Interferometry facility (VLBAI). In a fully passive and scalable design, we realized a ten-meter long magnetic shield that provides high magnetic field homogeneity over more than eight meters length. This allows constraining the corresponding error for acceleration measurements to a few parts in 10^{13}. A paramagnetic ultra-high vacuum vessel equipped with temperature sensors distributed along the whole length completes the part to make it suitable for high-performance atom interferometry.

The VLBAI facility is a major research instrument funded by the DFG with support from the CRCs 1128 “geo-Q” and 1227 “DQ-mat”.