MON 5: Optical Quantum Devices

Time: Monday 14:15–16:00 Location: ZHG006

MON 5.1 Mon 14:15 ZHG006

Magneto-optical trap of aluminium monofluoride — •Jose Eduardo Padilla-Castillo[1], Jionghao Cai[1], Russell Thomas[1], Sebastian Kray[1], Boris Sartakov[1], Stefan Truppe[2], Gerard Meijer[1], and Sidney Wright[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]Centre for Cold Matter, Imperial College, SW7 2AZ London, UK

Despite impressive progress in direct laser cooling of molecules, magneto-optical trapping has thus far been restricted to species with spin-doublet electronic ground states. These molecules are chemically reactive and only support a simple laser cooling scheme when exciting from the first rotationally excited level of the ground state.

In this talk, we will present the first magneto-optical trap (MOT) of the diatomic molecule aluminium monofluoride (AlF). This $^1\Sigma^+$ ground state molecule is amongst the most deeply bound molecules known, and even survives collision with vacuum walls of our experiment. Despite the challenging laser wavelengths required for the MOT (λ = 227.5 - 232 nm), we take advantage of the intense $A^1\Pi \leftarrow X^1\Sigma^+$ transition in AlF, which allows trapping three different rotationally excited levels of the ground via their respective Q(J) lines.

Our results set a new record for the shortest wavelength MOT, narrowly surpassing the 18 year-old milestone set by atomic Cd ($\lambda = 228.9$ nm). Similar to Cd, AlF possesses a spin-forbidden transition between its two lowest spin-singlet and triplet states. Magneto-optical trapping is a key step towards precise spectroscopy and control of the molecule via this narrow, ultraviolet transition.

MON 5.2 Mon 14:30 ZHG006

Material aspects for high-precision optical metrology — •Nico Wagner[1,2], Liam Shelling Neto[1,2], and Stefanie Kroker[1,2,3] — [1]Institut für Halbleitertechnik, Technische Universität Braunschweig, Hans-Sommer-Str. 66, Braunschweig, 38106 Germany — [2]Laboratory for Emerging Nanometrology, Langer Kamp 6a-b, Braunschweig, 38106 Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

High-precision optical metrology relies on materials with outstanding thermal and mechanical stability to push the limits of frequency accuracy. We explore material solutions that enhance the performance of ultra-stable optical cavities and laser systems. NEXCERA, a ceramic with a ultra-low thermal expansion coefficient at room temperature, shows reduced thermal noise compared to commonly used materials, making it ideal for cavity spacers. In mirror development, crystalline AlGaAs/GaAs coatings demonstrate lower mechanical loss than traditional amorphous coatings, though light-induced effects can introduce additional noise. We present insights into how illumination affects the mechanical loss and elasticity of GaAs. Furthermore, metamirrors—structured single-layer reflectors—offer a route to high reflectivity with significantly reduced thermal noise. For spectral-hole burning applications, the rare-earth-doped crystal Eu^{3+}:Y_2SiO_5 exhibits low cryogenic mechanical losses, making it a promising candidate for alternative laser stabilization techniques. These material innovations contribute to the advancement of robust and compact systems for future applications in optical frequency standards and precision metrology.

MON 5.3 Mon 14:45 ZHG006

Shapiro steps in driven atomic Josephson junctions — •Vijay Singh[1], E. Bernhart[2], M. Röhrle[2], H. Ott[2], G. Del Pace[3], D. Hernandez-Rajkov[3], N. Grani[3], M. Frometa Fernandez[3], G. Nesti[3], J. A. Seman[4], M. Inguscio[3], G. Roati[3], L. Mathey[5], and L. Amico[1] — [1]QRC, TII, Abu Dhabi, UAE — [2]RPTU Kaiserslautern, Germany — [3]LENS, University of Florence, Italy — [4]UNAM Mexico — [5]ZOQ and IQP, Universität Hamburg, Germany

We report the observation of Shapiro steps in atomic Josephson junctions formed by coupling two ultracold atom clouds. As predicted in the theoretical proposal, periodic modulation of the position of the tunneling barrier induces Shapiro steps in the dc current-chemical potential characteristic. Experiments on a Josephson junction of ^{87}Rb atoms display Shapiro steps in the current-potential characteristic, exhibiting universal features and providing key insight into the microscopic dissipative dynamics associated with phonon emission and soliton nucleation. Experiments with strongly-interacting Fermi superfluids of ultracold atoms also show the creation of Shapiro steps in the current-potential characteristics, with their height and width reflecting the external drive frequency and the junction nonlinear response. Direct measurements of the current-phase relationship reveal the underlying dissipation mechanism via the emission of vortex-antivortex pairs. These results establish a significant connection between superconducting and atomic Josephson dynamics, with unprecedented control and flexibility over physical parameters. Finally, our results lay the foundation for the development of new atomtronic devices and sensors.

MON 5.4 Mon 15:00 ZHG006

A Free-Electron-Driven Quantum Light Source — •F. Jasmin Kappert[1,2], Armin Feist[1,2], Guanhao Huang[3], Germaine Arend[1,2], Yujia Yang[3], Jan-Wilke Henke[1,2], Arslan Sajid Raja[3], Rui Ning Wang[3], Hugo Lourenco-Martins[1,2], Rudolf Haindl[1,2], Zheru Qiu[3], Junqiu Liu[3], Ofer Kfir[1,2], Tobias J. Kippenberg[3], and Claus Ropers[1,2] — [1]MPI for Multidisciplinary Sciences, Göttingen, Germany — [2]4th Physical Institute, University of Göttingen, Germany — [3]Institute of Physics, Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland

Tailored nonclassical light is essential for photonic quantum technologies, yet generating complex optical states remains challenging. Inelastic free-electron scattering offers a promising new method for creating parametric and wavelength-tunable quantum light, particularly through coherent cathodoluminescence.

Here, we present a novel platform that efficiently couples free-electron beams to silicon nitride integrated photonics [1], enabling the generation of electron-photon pair states [2]. By post-selecting electrons with quantized energy loss, we can herald nonclassical single and multi-photon states [2,3]. This establishes a versatile source of tailored quantum light, potentially leading to a new class of hybrid quantum technology that combines electrons and photons.

[1] J.-W. Henke, FJK et al., Nature 600, 653 (2021)
[2] A. Feist, FJK et al., Science 377, 777 (2022)
[3] G. Arend et al., arXiv:2409.11300 (2024)

MON 5.5 Mon 15:15 ZHG006

Optimal quantum control and optical beam shaping for atomic gravi-gradiometer. — •Joel Gomes Baptista, Louis Pagot, Léo Rol, Niranjan Myneni, Leonid Sidorenkov, Sébastien Merlet, and Franck Pereira Dos Santos — LTE-Observatoire de Paris, Paris, France

Cold-atom interferometry-based inertial sensors represent a highly developed quantum technology, capable of achieving performances comparable to those of conventional sensors. Our sensor measures simultaneously the vertical component of the gravitational acceleration $\vec{g}$ and its gradient using a Mach-Zehnder-like interfermoter on two laser cooled ^{87}Rb atomic cloud separated by 1 m. Currently, the clouds temperature ($\approx 2\mu K$) limits the performance of the gradiometer. The Doppler detunings and the ballistic expansion at long interrogation times ($T \approx 200$ ms) reduce the efficiency of the atom-optics based on high-order Bragg transitions.

Here, we use an optimal control theory algorithm based on GRAPE method to generate dedicated evolution patterns of the coupling phase during the interrogation pulses and demonstrate the enhanced fidelity of Bragg atom-optics in our gravi-gradiometer.

In addition, we mitigate the coupling inhomogeneities originating from the usual Gaussian beam using a custom-built top-hat collimator, which generates a uniform intensity profile and maintains a stable wavefront over 3.5m propagation. We explore the integration of OCT methods with top-hat laser beam profiles to overcome key limitations of large momentum transfer atom optics for μK-range atom sources.

MON 5.6 Mon 15:30 ZHG006

Modeling and Characterization of Active Silicon Microring Resonators — •Kambiz Jamshidi, Abdou Shetewy, and Menglong He — Integrated Photonics Devices Group, Chair of RF and Photonics, Technische Universität Dresden, 01069, Dresden, Germany

Silicon ring resonators can be used for several applications in communication, signal processing, and computing. By embedding the silicon waveguide in a pn junction, it is possible to tune the free carrier lifetime of the waveguide, which provides an additional degree of freedom to tune the steady-state response of these resonators and therefore the regime in which they operate. A theoretical framework is required to model the dynamics of light evolution in these resonators, taking into account the number of free carriers in the resonator and its temperature. In this article, the nonlinear coupled equations required for this modeling will be reviewed. In addition, characterization results of the resonators, which are fabricated in a standard process using silicon-on-insulator technology, will be discussed. Finally, several applications of the resonators at different biases will also be presented.

MON 5.7 Mon 15:45 ZHG006

Leveraging Large Language Models as Qualitative Figures of Merit — •Liam Shelling Neto[1], Nico Wagner[1], and Stefanie Kroker[1,2] — [1]Technische Universität Braunschweig, Institute of Semiconductor Technology, Hans-Sommer-Str. 66, Braunschweig, 38106, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, Braunschweig, 38116, Germany

Inverse design of photonic components, particularly in quantum technology, typically relies on quantitative figures of merit (FoMs) such as efficiency, transmission, or beam waist, metrics derived from precisely defined simulation data. However, many design goals are inherently qualitative or difficult to express numerically. We propose using large language models (LLMs) as evaluators of qualitative figures of merit (qFoMs) to complement traditional FoMs. These qFoMs can assess visual or descriptive attributes of optical responses, such as field distributions, via natural language prompts and image inputs. For example, when optimizing a grating coupler to produce a Gaussian beam, early designs often yield patterns far from Gaussian, rendering quantitative fits ineffective. An LLM-based qFoM, similar to a human, can still assign a "Gaussianity" score to guide the optimizer in the right direction, even in these early, low-performance stages. By integrating qFoMs with traditional metrics, LLMs act as pseudo-intelligent agents that bridge the gap between human intuition and algorithmic evaluation, enabling more robust and flexible optimization, especially when the target functionality is poorly defined or initially unmet.