Q 14: Precision Measurements and Metrology (Optical Clocks)

Time: Monday 14:00–16:15 Location: S SR 111 Maschb.

Group Report Q 14.1 Mon 14:00 S SR 111 Maschb.
Opticlock: Towards a transportable and user-friendly optical single-ion clock — •Ronald Holzwarth[1], Moustafa Abdel Hafiz[2], Bassem Arar[3], Maximilian Biethahn[4], Stefan Brakhane[5], Malte Brinkmann[2], Alexandre Didier[2], Peter Federsel[6], József Fortágh[6], Matthäus Halder[1], Nils Huntemann[2], Michael Johanning[7], Robert Jördens[8], Wilhelm Kaenders[5], Florian Karlewski[6], Florian Kienle[5], Maurice Lessing[1], Tanja Mehlstäubler[2], Dieter Meschede[9], Ekkehard Peik[2], Piet Schmidt[2], Hendrik Siebeneich[7], Jürgen Stuhler[5], Christian Tamm[2], Enrico Vogt[10], Andreas Wicht[3], and Christof Wunderlich[7] — [1]Menlo Systems GmbH — [2]PTB — [3]FBI, Berlin — [4]VACOM GmbH — [5]TOPTICA AG — [6]HighFinesse GmbH — [7]Uni Siegen, Department Physik, — [8]QUARTIQ GmbH — [9]Uni Bonn, Angewandte Physik — [10]Qubig GmbH

Today's most accurate and stable clocks are based on optical reference transitions of single ions or neutral atoms. Prototypes reach accuracies of a few parts in 10^{-18} which corresponds to a deviation of about one second over the age of the universe. Their unprecedented precision opens up numerous commercial applications, e.g. synchronization of large data networks, telecommunication systems and radio telescopes, as well as geodetic height measurements and global satellite navigation systems. Up to now, however, such optical clocks have to be operated by scientists in highly specialized laboratories under well-defined conditions.

The opticlock consortium (www.opticlock.de) is developing a robust and easy-to-use optical clock integrated into two mobile 19" rack assemblies, reliably operational in a standard industrial environment. For this purpose, industrial partners with engineering expertise and academic partners develop in close collaboration central components of the clock such as the cooling and clock lasers, the ion trap, the vacuum apparatus and the control of the clock. The clock will be based on the $^2S_{1/2} \rightarrow {}^2D_{3/2}$ transition of a single $^{171}Yb^+$ ion at 436 nm wavelength, as $^{171}Yb^+$ can be trapped for weeks and laser diodes for cooling and interrogation are commercially available.

We will give an overview of the opticlock system design and present the current development status of its subsystems and components.

Q 14.2 Mon 14:30 S SR 111 Maschb.
Characterization of a transportable aluminum ion quantum logic optical clock setup — •Stephan Hannig[1], Lennart Pelzer[1], Johannes Kramer[1], Mariia Stepanova[2], Nicolas Spethmann[1], Tanja E. Mehlstäubler[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

We present the status of a setup for an aluminum ion optical clock in which a co-trapped calcium ion is used for sympathetic cooling and readout.

A transportable hardware package including a segmented multi-layer trap, a compact titanium vacuum chamber, a near-diffraction-limited imaging system with high numerical aperture based on a single biaspheric lens, and an all-in-fiber $^{40}Ca^+$ repump laser system is presented. The trap-induced frequency shifts on $^{27}Al^+$ have been derived from measurements with a single $^{40}Ca^+$ ion. We determined the micromotion-induced second-order Doppler shift and the black-body radiation shift for $^{27}Al^+$ with uncertainties below 10^{-18}. Currently, the largest contribution is estimated to arise from background gas collisions to 1.5×10^{-18}. Moreover, heating rates of less than 10 quanta per second have been measured for all three motional modes at trap frequencies of $\omega_{\mathrm{rad,Ca+}} \approx 2\pi \times 2.5\,\mathrm{MHz}$ ($\omega_{\mathrm{ax,Ca+}} \approx 2\pi \times 1.5\,\mathrm{MHz}$). Furthermore, we show first results on ablation loading of $^{27}Al^+$ using photo-ionization.

Q 14.3 Mon 14:45 S SR 111 Maschb.
A Magnesium based optical lattice clock with Hz linewidth — •Waldemar Friesen-Piepenbrink, Dominika Fim, Klaus Zipfel, Nandan Jha, Steffen Sauer, Steffen Rühmann, Wolfgang Ertmer, and Ernst Maria Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

We report on an optical lattice clock utilizing the strongly forbidden $^1S_0 \rightarrow {}^3P_0$ transition where we perform spectroscopy of 10^3 precooled ^{24}Mg atoms in an optical lattice at the magic wavelength λ_m. Concerning its low sensitivity to black body radiation, Magnesium is a favorable species for an optical frequency standard.
Due to the low mass and the low λ_m of Magnesium a high trap depth is necessary to substantially suppress tunneling between adjacent lattice sites and therefore reduce the tunneling induced broadening of the clock transition. Recent improvements in our lattice setup enabled us to go to trap depths up to 60 E_{recoil} which resulted in a resolvable linewidth below 10 Hz. Therefore a characterization of the narrow clock transition with a reduced uncertainty was performed to improve stability as well as accuracy of the Magnesium lattice clock.

Q 14.4 Mon 15:00 S SR 111 Maschb.
Design of a compact optical frequency standard at 689 nm for space applications based on a cooled strontium beam — •Franz Balthasar Gutsch[1], Oliver Fartmann[1], Conrad Zimmermann[1], Frederik Böhle[2], Matthias Lezius[2], Ronald Holzwarth[2], Ahmad Bawamia[3], Christoph Pyrlik[3], Andreas Wicht[3], and Markus Krutzik[1,3] — [1]Humboldt-Universität zu Berlin — [2]MenloSystems GmbH — [3]Ferdinand-Braun-Institut, Berlin

Apart from field- and lab-based applications in metrology and sensing, compact and rugged optical frequency references receive increased attention with respect to spaceborne operation. Optical clocks built around those references using frequency combs could address a variety of precision timing applications. For example, such a device and the underlying key technologies are candidates for next-generation GNSS core equipment. Build upon our heritage of several sounding rocket missions [1, 2, 3], we are currently setting up a system for investigating the 7.6 kHz-broad $^1S_0 \rightarrow {}^3P_1$ intercombination line in ^{88}Sr. Using an optical Ramsey technique, we intend to perform high-resolution spectroscopy on 2D-laser-cooled Sr atomic beams probed by a pre-stabilized 689 nm diode laser. In this talk, we will give an overview on the system architecture and discuss first results from our ground testbed using thermal Sr gases. 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 DLR50WM1851-53. [1] Lezius et al., Optica Vol. 3 (2016); [2] Dinkelaker et al., Appl. Opt. 56 (2017); [3] Schkolnik et al., EPJQT 4 (2017)

Q 14.5 Mon 15:15 S SR 111 Maschb.
An extended-cavity diode laser at 497 nm for laser cooling and trapping of neutral strontium — Vladimir Schkolnik, •Oliver Fartmann, and Markus Krutzik — Humboldt-Universität zu Berlin

Among the best performing clocks are optical lattice clocks based on neutral strontium, which reach fractional uncertainties at the $2 \cdot 10^{-18}$ level. To trap atoms efficiently in the optical lattice, temperatures of the order of μK are neccessary. During the first laser cooling stage utilizing the broad $^1S_0 \rightarrow {}^1P_1$ transition at 461 nm, atoms can decay towards the meta-stable $^3P_2$ state with a branching of roughly 1 in 50,000. Several repump schemes have been employed. One possibility is the operation of only a single repump laser addressing the $^3P_2 \rightarrow {}^3D_2$ transition at 497 nm.

Until now the generation of light at this wavelength relied on second harmonic generation (SHG) from an infrared laser due to the lack of GaN laser diodes directly operating in this range. This talk presents the first extended-cavity diode laser in Littrow configuration operating in the cyan wavelength range around 497 nm. We discuss our compact, simple and low cost laser source, which has the potential to simplify laser systems for efficient cooling of strontium.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers DLR50WM1852 and 50WM1857.

Q 14.6 Mon 15:30 S SR 111 Maschb.
Setup for a long-term stable optical cavity — •Timm Wegehaupt[1,2], Josep Sanjuan[1], Martin Gohlke[1], Klaus Abich[1], Thilo Schuldt[1], and Claus Braxmaier[1,2] — [1]DLR Institute of Space Systems, Bremen, Germany — [2]University of Bremen, Center of Applied Space Technology and Microgravity, Bremen, Germany

Optical frequency references based on optical cavities have multiple applications in modern physics, including actual and future satellite missions. While they are usually used in order to reach high frequency stabilities on short integration times about 1 s up to 100 s, space-based tests of Special Relativity such as e.g. proposed within the BOOST mission, which has the goal to realize a Kennedy-Thorndike experiment in a low-Earth orbit, require a long-term stable optical frequency reference based on an optical cavity. We developed a compact and mechanical stable setup using an NPRO-type Nd:YAG laser at a wavelength of 1064 nm which is stabilized to an 8.7 cm long cubic ULE cavity (NPL design) with a Finesse of 400 000. The cavity has a calculated thermal noise limit caused by Brownian motion at the 4×10^{-16} level. For improved long-term stability, the cavity is mounted within a five-fold thermal shielding. We will present first results.

Q 14.7 Mon 15:45 S SR 111 Maschb.

Compact optical frequency references: Spaceborne vapour-cells and a Strontium beam standard. — •Franz Gutsch[1], Oliver Fartmann[1], Conrad Zimmermann[1], Vladimir Schkolnik[1], Ahmad Bawamia[2], Frederik Böhle[3], Ronald Holzwarth[3], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut Berlin — [3]MenloSystems GmbH, Martinsried

Apart from field-and lab-based applications in metrology and sensing, compact and rugged optical frequency references receive increased attention with respect to spaceborne operation. In many current (GRACE-FO) and planned (LISA) earth-observation and fundamental science missions, inter-spacecraft ranging relies on stabilized lasers. Furthermore, optical clocks built around those references are candidates for improving the accuracy of next-generation global navigation sattelite systems.

I will present our group's line-up in compact optical frequency references, that have been proven on sounding rockets of the TEXUS program multiple times. These flights include the recently launched first iodine-based frequency refence in space, JOKARUS, on which flight data will be presented.

To explore possibilities of compact frequency references beyond the 10^{-15} level, which is the current limit in vapour-cell setups, we are working on a Strontium beam clock. It is based on the $^1S_0 \rightarrow {}^3P_1$ transition in ^{88}Sr at 689 nm and will be presented as well.

Q 14.8 Mon 16:00 S SR 111 Maschb.

Towards a Transportable Optical Multi-Ion Frequency Standard — Hendrik Siebeneich[1], Alexandre Didier[2], Malte Brinkmann[2], Tanja Mehlstäubler[2], Maximilian Biethahn[3], Michael Flämich[3], Klaus Bergner[3], Stefan Brakhane[4], Dieter Meschede[3], •Michael Johanning[1], and Christof Wunderlich[1] — [1]Faculty of Science and Technology, Department of Physics, University of Siegen, 57068 Siegen, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [3]Vacom, In den Brückenäckern 3, 07751 Großlöbichau, Germany — [4]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany

The opticlock consortium [1] will provide a demonstrator for a transportable optical frequency standard using laser cooled trapped ions. Clocks based on single trapped ions already provide excellent accuracy as optical frequency standards, which can be further improved by using multiple ions. Within opticlock, we already work on the next generation of the soon to be expected single-ion demonstrator by combining transportability with the low frequency uncertainties of a multi-ion frequency standard. A novel segmented four layer ion trap featuring low micromotion is combined with a dedicated compact vacuum interface, excellent optical access and customized vacuum setup. We will report on the overall design concept, the vacuum and optical layout, and the status of the setup.

[1] opticlock is supported by the bmbf under grant no. 13N14385.