Towards Optical Clocks based on Multi-Ion Systems

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In order to exploit their full potential and to resolve frequencies with a fractional frequency instability of 10^{-18}, optical ion clocks need to integrate over many days to weeks. For the characterisation of systematic shifts of the clock, as well as for applications, such as relativistic geodesy, these long times scales pose severe limits. Scaling up the number of ions for optical clock spectroscopy is a natural way to significantly reduce integration times, but is hindered so far by on-axis micromotion, poor control of the dynamics of coupled many body systems and systematic shifts due to interacting ions[1,2].

However, ion species, such as Yb^+, In^+ or Al^+, with low or zero quadrupole moments of the clock states are interesting candidates for frequency standards based on multiple ions. In our experiment we investigate linear chains of $^{172}Yb^+$ and $^{115}In^+$ ions for an optical clock based on the $^1S_0$-$^3P_0$ transition in $^{115}In^+$, for which we show that a fractional inaccuracy of 10^{-18} can be reached[2].

For optimum control of the ion motion and lowest frequency shifts due to micromotion and excess heating rates we have developed a new segmented ion trap with on trap filter boards and a protected spectroscopy segment[3]. The operating prototype trap with minimized axial micromotion allows us to trap and cool large ion Coulomb crystals, in which we observed the creation of topological defects during the transition from linear to zigzag phase. The good control of the trap parameters allowed us to perform a measurement of the rate of defect creation and to study the dynamics of the phase transition[4].

In order to reduce systematic shifts due to blackbody radiation, this trap design is transferred to an AlN based chip trap, which is laser machined at PTB. At CMI the temperature distribution of this trap is modeled with a finite element code and will be experimentally compared to infrared measurements on the trap. We report on the results and the expected improvement in temperature control.

Another advantage of multi-ion clocks is that the requirements on the stability of the clock laser are more relaxed compared to lasers for single-ion standards, due to the shorter locking times onto the atomic reference. We developed a 30 cm long ULE reference cavity with low vibration sensitivity and compare it to our ultra-stable laser. With its simple design, the cavity fulfills the requirements for an optical ion clock with short-term stability of $1x10^{-16}$ in 1 s [5].

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