

Recent progress towards the quantum limit of optical lattice clocks

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Abstract

Optical lattice clocks have already proven to be good candidates for next generation atomic clocks. Due to the atomic confinement, their ultimate accuracy should be comparable to the one of trapped ion clocks. In terms of stability, however, they can potentially outperform their ion counterparts by using a large number of atoms. The main limitation of the clock stability remains the clock laser frequency noise associated with the Dick effect. This limit can be pushed by improving both the laser frequency noise and the duty cycle of the clock.

Regarding the laser noise, we present a new laser locked to an ultra-stable ULE cavity with silica mirrors. This cavity has a low thermal noise thanks to the use of a fused-silica mirror substrate. We show that the relatively high thermal expansion coefficient of silica can be accommodated for with a high performance temperature stabilization of the cavity vacuum chamber down to a few 100 K, and massive passive thermal shielding of the cavity inside vacuum. We demonstrate a laser stability better than 10^{-15} for averaging times up to several tens of seconds.

As for the duty cycle, we have developed a non-destructive detection scheme of the clock transition probability based on a phase measurement of a weak laser beam propagating the atomic cloud. The detection scheme allows us to keep more than 95% of the atoms in the dipole trap from cycle to cycle, opening up the possibility for vastly reduced loading time and increased duty cycle. We have performed a numerical optimization of the clock cycle that takes into account our experimental pa-

rameters, as well as the ultra-stable laser residual noise. A clock stability as low as $2 \times 10^{-16} \tau^{-1/2}$ is expected.

To demonstrate this stability one would have to compare the clock with an equally stable second clock. We have constructed a second Sr lattice clock. Several comparison techniques exist between two identical clocks sharing the same clock laser, as is the case for our experiment. We show that the stability when comparing two clocks using the same clock laser, where the interrogation windows are triggered randomly, is at the same level as when comparing two completely independent clocks. Furthermore, it would be possible to interleave the interrogation periods of the two clocks, such that one would simulate a completely dead-time free clock, which would be independent of the clock laser frequency noise, thus reaching the heralded quantum projection noise limit of optical lattice clocks.

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