An ultra-low frequency noise laser based on a 48 cm long ULE cavity for a Sr lattice clock

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Ultra-stable lasers are essential instruments to interrogate narrow atomic transitions, e.g. in optical atomic clocks. The stability of ultra-stable lasers is obtained from the length stability of an external reference cavity, which is fundamentally limited through the thermal noise of the material, especially of the mirror coatings. It has been shown that low noise materials like silicon can reduce the frequency instability to 1×10^{-16}, unfortunately this approach requires cryogenic cooling and is limited to wavelengths not used for optical clocks[1]. For cavities using glass spacers, the Brownian motion of the coatings is typically dominating the fractional frequency instability. As this contribution scales inversely proportional to the cavity length, the stability can be improved by increasing the length of the cavity.

We have designed a 48 cm long cavity made of ultra low expansion glass. Avoiding deformation through acceleration of such a long cavity raises a technical challenge. For a typical 4-point support of a horizontal spacer a force symmetry of better than 1×10^{-6} is needed in order not to degrade the stability set by thermal noise. Manufacturing tolerances can easily cause much larger force asymmetries. Implementing a balance mounting to obtain a 3-point support, we achieve sensitivities to acceleration of 4×10^{-11}/g. Using three heat shields and low-gradient temperature controls we obtain a thermal time constant of about 10 days and a temperature stability close to the cavity of 2 μK in 1000 s.

From a comparison to three other ultra-stable lasers and to the Sr lattice clock we observed a laser instability of 7×10^{-17} at 300 s averaging time. With the laser the clock instability was reduced down to $4\times10^{-16}\,(\tau/\mathrm{s})^{-1/2}$.

This work was supported by QUEST, DFG (RTG 1729), and the European Metrology Research Programme (EMRP) in IND14, ITOC, and QESOCAS. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the EU.

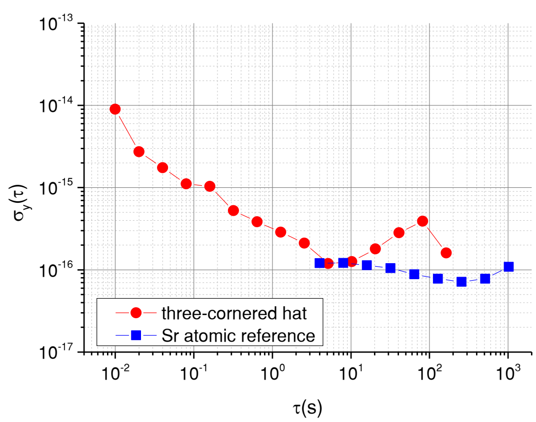

Fig. 1: Stability measured from a three-cornered-hat comparison (circles) and against Sr reference (squares).

[1]T. Kessler et al., "A sub-40-mHz-linewidth laser based on a silicon single-crystal optical cavity", Nature Photonics, vol. **6**, p. 687-692, 2012.