Dual-Wavelength Ultra-Stable Optical Cavity

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We present the development of a dual-wavelength ultra-stable optical cavity operating at 1064 nm and 908 nm – the wavelengths that, after frequency quadrupling, correspond to Hg clock transitions at 266 nm ($^1S_0$-$^3P_0$) and 227 nm ($^1S_0$-$^3P_2$). The cavity will be applied for precise spectroscopic measurements of clock lines of Hg atoms.

Keywords— Hg, mercury, isotope shift, King plot, fundamental physics, cavity, ULE

I. Introduction

An ultra-stable optical cavity is an integral part of a typical atomic clock [1]. A clock laser's frequency is tightly stabilized to the optical resonance of the cavity, yielding the stability transfer between the cavity length and the frequency of the laser [2]. Apart from the atomic clocks, the spectral narrowing of the laser line provided by the ultra-stable cavity can also be used for other studies, like accurate atomic spectroscopy and precise isotope shift measurement. The latter is of particular importance when combined with rich isotopic diversity. It can then become a basis for precise measurements of the King plot linearity – a promising experimental tool for probing new fundamental interactions. We already used this method for isotope shift spectroscopy and the determination of nuclear parameters of Hg [3,4].

A significant improvement is to take advantage of the extremely narrow transitions, $^1S_0$-$^3P_0$ and $^1S_0$-$^3P_2$, with natural line widths much below 1 Hz [5]. We present the development of the dual-wavelength ultra-stable optical cavity that makes this improvement possible. The cavity operates simultaneously at 1064 nm and 908 nm. These fundamental wavelengths correspond to Hg clock transitions at 266 nm ($^1S_0$-$^3P_0$) and 227 nm ($^1S_0$-$^3P_2$) before the frequency quadrupling of the clock lasers' outputs. The cavity enables precise King-plot-based fundamental research with isotopically-rich cold Hg atoms [6], which may pave the way for experimental verification of the Standard Model [7,8].

II. Methods/Results

The cavity consists of two fused-silica mirrors with finesse above 100000 at both wavelengths. To maintain the mirror spacing exceptionally stable, the mirrors are optically contacted to a mechanically rigid 100 mm long axially-notched cylindrical spacer made of ultra-low-expansion (ULE) glass. Additionally, one compensating ULE ring is optically contacted to each of the mirrors.

The ULE spacer is supported by 1.5 mm diameter Viton balls placed on the supporting Zerodur element. The optimal supporting points' positions were calculated with the FEM method. The ULE spacer is held in a temperature-stabilized three-layer aluminum (AW-6082-T6) vacuum system to isolate the cavity from the environment thermally and to reduce fluctuations of the index of refraction. Fig. 1 shows the cross-section of the vacuum system containing the ULE spacer with attached cavity mirrors and ULE compensating rings (grey), Zerodur support (violet), and three thermal isolation aluminum layers (red, yellow, and turquoise). The second aluminum layer is supported by three Peltier elements that provide thermal stabilization of the ULE spacer at the zero-crossing temperature, which was measured to be 34.3(1.0) °C.

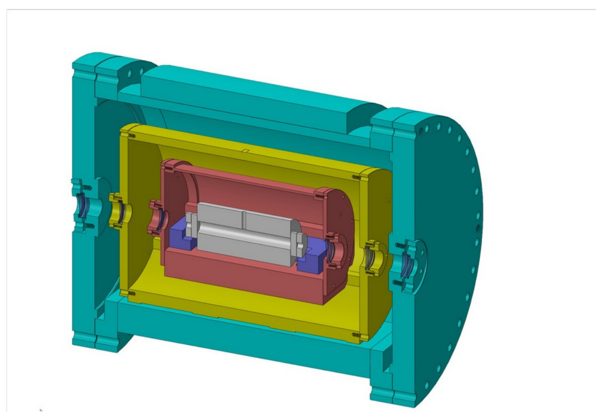

Fig. 1 Cross-section view of the vacuum chamber for the ULE cavity.

To reduce external vibration noise, the cavity vacuum housing is situated on the anti-vibration platform and closed inside an acoustic chamber. To ensure an ultra-high vacuum regime, the external aluminum layer is sealed with indium wire, and constant pumping is provided by a 20 l/s ion pump.

Fig. 2 shows the scheme of the laser system for the frequency narrowing of both laser beams (1064 nm and 908 nm). Before the frequency quadrupling, a small part of each of the beams is uncoupled and send to the ultra-stable cavity. A Pound-Drever-Hall technique is used for the lasers' frequency stabilization. Where needed, the cancellation of the fibre-noise and the amplitude residual modulation are implemented. Both fundamental laser beams are frequency referenced to the optical frequency comb.

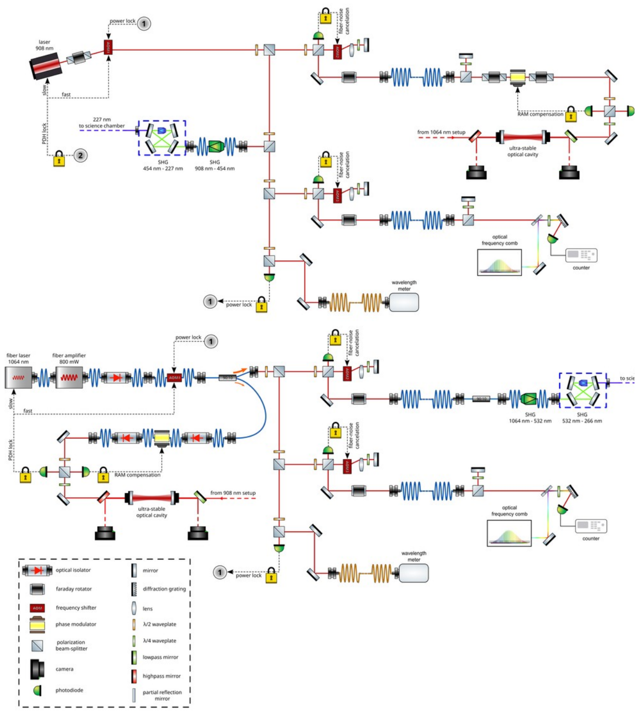

Fig. 2 Scheme of the laser setup for narrowing the laser linewidth of 908 nm (up) and 1064 nm (down) and referencing to the optical frequency comb.

III. Conclusions

We present the development of the ultrastable dual-wavelength cavity operating at two wavelengths corresponding to Hg clock transitions. In addition, we show the laser scheme for frequency narrowing and referencing both laser beams. The cavity enables precise King-plot-based fundamental research with isotopically-rich Hg atoms, which may pave the way for experimental verification of the Standard Model.

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