Ultrastable Laser System Using Room-Temperature Optical Cavity with $4.8 \times 10^{-17}$ Thermal Noise Limit

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Abstract—A new clock laser system using an optical cavity with $4.8 \times 10^{-17}$ thermal noise limit has been developed for rapid evaluation of ytterbium lattice clocks. This was realized by using a 30-cm-long ULE cavity, fused-silica mirror substrates, and crystalline mirror coatings. The frequency stability of the beating signal between the new clock laser and the old clock laser was limited by the latter. The linewidth and the frequency stability of the new clock laser will be measured by comparing the frequency between two similar systems.

Keywords—optical lattice clock, ytterbium, clock laser, crystalline coating, frequency stability, linewidth, optical cavity

Yb optical lattice clocks have been developed at KRISS (Korea Research Institute of Standards and Science), and the total systematic uncertainty has reached $5 \times 10^{-17}$ in 2018 [1–4]. The interleaved measurement for the systematic shift evaluation of the Yb optical lattice clock shows the frequency stability of the current clock laser [3] to be about $5 \times 10^{-15}$ at 1 s. With this clock laser, the optical lattice clock evaluation at $10^{-18}$ level will require an excessive amount of time (more than $10^7$ s), thus, a new clock laser system with a frequency stability below $10^{-16}$ has been designed and is under development [5–7]. Here we show that one new clock laser setup has been completed, the comparison result with the old clock laser is described, and the future perspective will be given.

The new clock laser system is based on second harmonic generation [8, 9] for the 578 nm laser for the Yb clock transition. With a tapered amplifier laser system at 1156 nm (maximum fiber-coupled output of about 500 mW) and a ridge-type waveguide periodically-poled lithium niobate crystal, more than 20 mW power at 578 nm could be obtained. The optical cavity for the new clock laser is made of a 30-cm-long cuboid-shaped ULE spacer, fused silica mirror substrates, ULE compensation rings as in Fig.1 [6]. The ULE rings were used to compensate for the mirror deformation due to the difference of thermal expansion coefficients. Crystalline mirror coatings [10] at 1156 nm has been adopted to reduce the thermal noise. The transmission loss and the {scattering + absorption} loss were estimated to be 8 ppm and 2 ppm, respectively. The thermal noise limit of this cavity is estimated to be $4.8 \times 10^{-17}$ at room temperature ($3.5 \times 10^{-17}$ from the ULE spacer, $3.2 \times 10^{-17}$ from the mirror coatings, and $8.5 \times 10^{-18}$ from the fused-silica substrates). The loss angle of the crystalline coating is assumed to be $4.8 \times 10^{-5}$ in this estimation [11]. The cavity is mounted horizontally by Viton pads at the points with minimum vibration sensitivity, and the temperature of the cavity was stabilized using one aluminum layer for the active temperature control and two passive thermal shields (aluminum and gold-coated copper) (Fig. 1). The thermal lifetime of the vacuum chamber was measured to be 3.3 days by monitoring the

![Fig. 1. Optical cavity for the new clock laser (left) and the vacuum chamber (right).](image)

![Fig. 2. Thermal lifetime of the vacuum system for the cavity.](image)
The 1156 nm laser light was sent to the cavity using a phase-stabilized single-mode polarization maintaining fiber, and the frequency of this laser was stabilized to the resonance of the cavity, using the Pound-Drever-Hall method. In Fig. 3, the finesse of the cavity was measured to be 310,000 by the cavity ring-down technique. The cavity-stabilized 1156 nm laser was frequency-doubled and the beating signal was obtained with the old clock laser, which is currently used for the Yb lattice clock interrogation. This result is shown in Fig. 4. The Allan deviation of the beating signal between the old clock laser and the new clock laser is shown with a red solid line, and that of the linear-drift-removed beat signal is shown with a red dashed line. It can be seen that this is limited by the old clock laser, when we consider the stability of the interleaved measurement for the Yb lattice clock uncertainty evaluation using the old clock laser (green dashed line). This implies that the frequency stability of the new clock laser is much better than the old clock laser. The exact frequency stability and the linewidth of the new clock laser will be measured using an additional identical clock laser of the same design and the result will be presented at IFCS-EFTF 2019.

REFERENCES


