Frequency of the unmodulated 778-nm rubidium clock measured in high vacuum

[1]Chi-Hsiang [1]Chu, Yu-Jhe Shih, [2]Po-Cheng Chang, [1]Dah-An Luh, [3]Ming-Shen Chang, [3]Tz-Wei Liu, [1]Yi-Ting Lin and [1]Wang-Yau Cheng

[1]Department of Physics, National Central University, Taoyuan 320317, Taiwan
[2]Telecommunication Laboratories, Chunghwa Telecom Co., Ltd, Taoyuan 32601,Taiwan.
[3]Institute of Atomic and Molecular Science (IAMS), Taipei 106319, Taiwan
Author e-mail address: wycheng@phy.ncu.edu.tw

Abstract: We update the frequency of a 778-nm two-photon-transition-based rubidium clock by a novel approach, where the frequency measurement is performed in high vacuum and with fitting the unperturbed spectral lineshape.

1. Motivation

Rubidium clock at 788-nm optical wavelength of which the frequency reproducibility was often examined [1] and was recently demonstrated as a highly reliable clock [2], is one of the popular optical clocks recommended by BIPM [3]. One reason is that the clock frequency could be generated from the second harmonic of the 1556- nm radiation where the comb laser size in this wavelength regime is reducible, hence a good candidate for the space-borne metrology [4]. Yet, two concerns are not clarified in the past. One is that the frequency shift caused by the cell outgassing as well as by the helium diffusion from atmosphere [5] is actually not ruled out; the other is that the laser frequency was always modulated for laser stabilization and hence the unmodulated clock frequency was not measured without additional offset locking to the other standards. In this report, we update the frequency of an unmodulated 778-nm rubidium clock that is measured in high vacuum to avoid alien gas collision, so that the aforementioned two concerns are solved.

2. method

Fig. 1 illustrates the concept of our experimental setup. A 200-mW, 778-nm coherent light source was presented from the second harmonic generation of one commercial fiber laser whose unmodulated frequency were employed to measure the frequency of ^{85}Rb $5S_{1/2} \rightarrow 5D_{5/2}$, F=3→F'=5 two-photon transition (clock transition) via one self-reference Ti:sapphire (Ti:S) comb laser. Unfortunately, the laser has ~ 2 MHz optical jitter width due to a fan-vibration installed for dissipating the heat of the pumping diodes of fiber laser. Therefore, one cold cavity having linewidth of ~800 kHz was used for reducing the laser jitter to smaller than 100-kHz optical jitter width via the double-pass AOM. Meanwhile, the other portion of light was phase modulated by a fiber EOM to artificially create

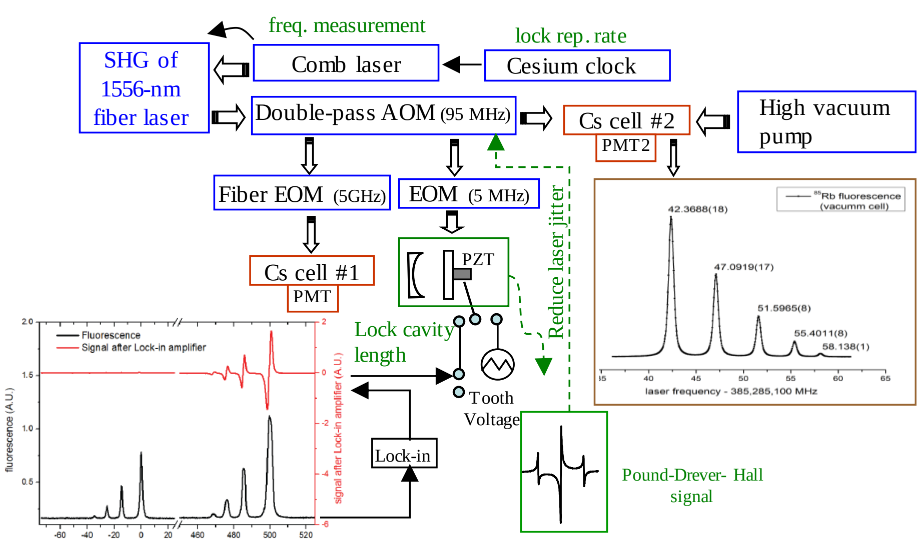

Fig. 1 Schematic diagram of our experimental setup.

a carrier-sideband "crossover" signal as shown by the black unmodulated spectra, namely, ^{87}Rb $5S_{1/2} \rightarrow 5D_{5/2}$, F=2→F'=1~4 transitions on the left-bottom of Fig. 1 where the left spectra was resolved by carrier photon pair and the right spectra was resolved by carrier-sideband "crossover", principle see reference [3]. When we modulated the sideband, only crossover spectra could be retrieved by lock-in amplifier as illustrated by the red spectra of Fig. 1, which was used for locking the length of the cold cavity. As we change the driving frequency of the fiber EOM, the length of cavity PZT will be changed and the unmodulated carrier frequency will then be tuned simultaneously to follow the cavity resonant condition, by which we can step-by-step resolve an unperturbed spectrum of the hyperfine transition from Cs cell #2. The brown inset of Fig. 1 displays the hyperfine structure with the scan rate 70 kHz/second in optical frequency, where the transverse axis was constantly calibrated by a Ti:S comb laser. The surrounding magnetic field was compensated by three-dimension Helmholtz coils. Since our scheme could precisely determine the spectral linewidth, we found that the spectral linewidth of clock transition was very sensitive to magnetic field and by monitoring the linewidth we were able to remove the cell magnetic field to be smaller than 1 mini-Gauss without need of a Gauss-meter. Moreover, this approach eliminates exactly the magnetic field of the place where the atom-photon interaction occurs. The vacuum of Cs cell #2 was constantly kept at the vacuum level around 10^{-5} torr which was limited by the Rb vapor pressure. The detail arrangement of vacuum system and rubidium source will be presented in conference.

3. results

Table 1 lists the main error sources in this measurement. The statistic error was obtained from repeated experiments and other error source could refer to reference [4]. We note that this experiment excludes the unclear collision shifts as people usually heated the glass cells up to 90 ^{0}C in previous experiments to obtain higher vapor pressure. Table 1 does not list the error source of "modulation shift" as well. Table 2 exhibits our new update frequencies of the hyperfine transitions of ^{85}Rb $5S_{1/2} \rightarrow 5D_{5/2}$, F=3→F'=5, where light shift, pressure shift and residual magnetic field and the inaccuracy of our cesium atomic beam clock multiplied by the mode number of comb laser were all considered into our error budget. Fig. 2 shows the comparisons with the results from some other laboratories.

Table 1. The error budget for the clock frequency measurement, ^{85}Rb $5S_{1/2} \rightarrow 5D_{5/2}$, F=3→F'=5

Statistic error	Light shift correction	Residual magnetic field	Self-collision	Cs clock inaccuracy
1.8 kHz	1.4 kHz	0.7 kHz	0.6 kHz	0.2 kHz

Table 2. The update absolute frequencies of ^{85}Rb $5S_{1/2} \rightarrow 5D_{5/2}$ by our scheme and the difference between our results and BIPM recommendation values

Hyperfine component	Absolute frequency (kHz), this work	Absolute frequency (kHz), BIPM recommends	Discrepancy (kHz)
F ' = 5 (clock)	385,285,142,372 (3)	385,285,142,375(5)	-3
F ' = 4	385,285,147,096(3)	385,285,147,093(9)	3
F ' = 3	385,285,151,601(3)	385,285,151,603(9)	-2
F ' = 2	385,285,155,404(2)	385,285,155,406(9)	-2
F ' = 1	385,285,158,139(86)	385,285,158,146(14)	-7

4. References

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