Ramsey–CPT Resonance Observation Using Different Laser Sideband Combinations for the Two Interrogation Pulses

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***Summary*—We investigated the Ramsey–coherent population trapping (CPT) characteristics of a new observation method that employs different laser sideband combinations as the two interrogation pulses during Ramsey–CPT resonance observation. In an experimental setup using a gas cell containing Cs atoms, Ramsey–CPT resonance was observed using the 1st-1st sideband combination for the common preparation pulse and the 1st-1st and C-2nd sideband combinations for the detection pulse. The Ramsey–CPT spectral shapes were inverted to each other. The light shift characteristic was 2.7 times different to its light sensitivity. This difference in the light shift characteristics is expected to allow the estimation of the light frequency shift in the Ramsey–CPT atomic clock during operation.**

Keywords—CPT; Ramsey–CPT; modulated laser; VCSEL; miniature atomic clock

I. Introduction

Coherent population trapping (CPT)-based atomic clocks have attracted attention as the next generation of highly accurate and stable oscillators [1]. These small atomic clocks improve performance over a wide variety of applications, including telecommunications, global navigation, and network synchronization. The dominant factor determining the mid- and long-term frequency stability of a CPT clock is the light intensity dependence of the clock frequency. Various methods have been proposed and demonstrated to reduce light shift [2, 3].

The authors have studied the Ramsey–CPT scheme without an external optical modulator, which is applicable to miniature atomic clocks, to enhance the frequency stability [4]. In our technique, a di-chromatic laser light is generated by a modulated semiconductor laser; the combination of sidebands for two interrogation pulses to observe the Ramsey–CPT can then be arbitrarily selected based on their interval to match the clock frequency.

In this study, we observed the Ramsey–CPT spectra by changing the combination of the laser sidebands of the preparation and detection pulses in the Ramsey–CPT scheme, and measured the light shift in order to verify whether light shift correction is viable utilizing a change in resonance characteristics resulting from the selection of the laser sidebands.

II. Concept

Fig. 1 shows a schematic diagram of the Ramsey–CPT scheme. In our method, a di-chromatic laser field is generated by modulating a semiconductor laser at half the clock transition frequency of the alkaline atom to observe CPT resonance. Fig. 1(a) shows the laser sideband combination used for the conventional observation of Ramsey–CPT resonance; the observation was performed with a first-order sideband pair. In this scheme, the same laser sideband combination is used in both pulses (preparation and detection) for observing the Ramsey–CPT resonance. Fig. 1(b) shows the proposed Ramsey–CPT scheme used in this study. This method uses different laser sideband combinations for the two pulses. Because the laser sideband combinations of the two pulses are different, the resultant light shift after the two pulses is expected to be different from that observed using two identical sideband pulses. In this experiment, the 1st-1st sideband combination was used for the preparation pulse, and the 1st-1st and Carrier-2nd sideband combination was used for the detection pulse.

III. Result

For the experimental setup, an 894 nm VCSEL modulated at 4.6 GHz was used as the laser light source. The vapor cell of length 20 mm and diameter 20 mm contained Cs and Ne at 4.2 kPa. The free evolution time was set at 400 µs.

Fig. 2 shows the Ramsey–CPT spectra obtained using the new method. The most significant difference between experiments was that the two spectral shapes were inverted. This difference in spectral shape is due to the different phase conditions in each laser sideband. Because the absorbed light intensity of the C-2nd sideband combination is smaller than the 1st-1st sideband combination, the ratio of background light intensity that does not contribute to absorption is larger, and as a result, the resonance contrast is small. The contrast of the resonance spectra detected by the 1st-1st sideband combination and the C-2nd sidebands combination were 5.3 % and 1.13 %, respectively. The full width at half maximum (FWHM) of the resonance spectrum was 900 Hz for the 1st-1st sideband combination and 860 Hz for the C-2nd sidebands combination.

Fig. 3 shows the light-shift performance. Markers are the experimental results, and solid lines are linear curves fit to the data in the range 2.0–6.0 mW/cm^2. The light shift sensitivity for the C-2nd sideband combination was 2.71 times higher than that for the 1st-1st sideband combination.

IV. Conclusions

Using two different combinations of laser sideband interrogation pulses, we measured the Ramsey–CPT spectrum, the contrast, the FWHM of the resonance spectra, and the light shift performance. When different combinations of laser sidebands were used for the preparation and the detection pulse of the Ramsey–CPT scheme, the results showed that the shape of the resonance spectrum was inverted owing to the difference in phase conditions between the laser sidebands used for the two pulses. The light shift characteristics showed that the frequency sensitivity differs by 2.7 times under two detection conditions: the 1st-1st sideband combination and the C-2nd sideband combination. This method enables the estimation of the variation of the light intensity from the frequency variation by measuring the resonance frequency observed by the C-2nd sideband combination with reference to the resonance frequency observed by the 1st-1st sideband combination. The resonance frequency observed by the 1st-1st sideband combination can be light-shift corrected from the estimated intensity variation, and is expected to enhance the mid- and long-term frequency stability.

References

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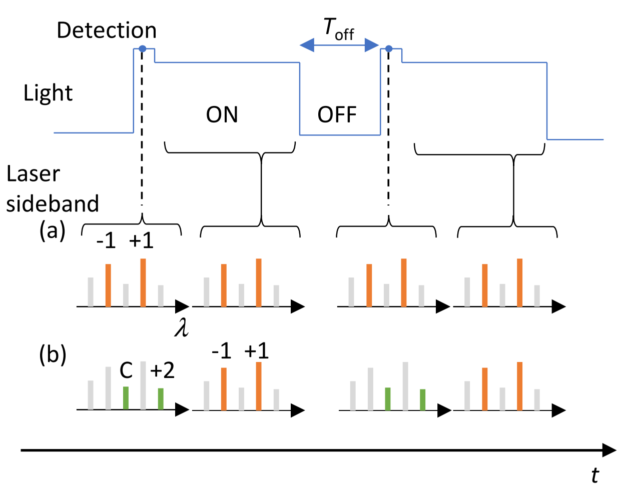

Fig. 1 Ramsey-CPT spectroscopy sequence. (a) Same laser sideband combination. (b) Differential laser sideband combination.

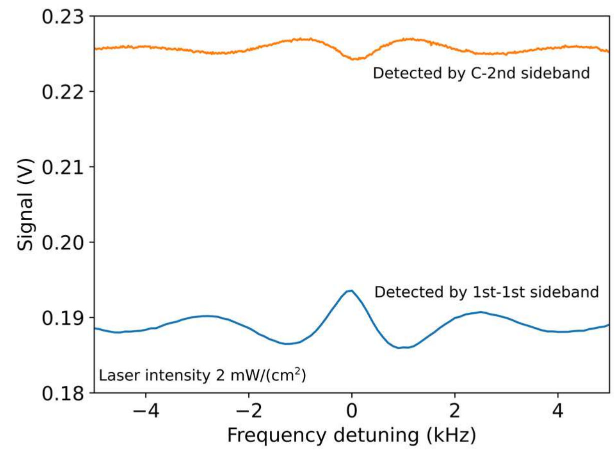

Fig. 2 Ramsey–CPT spectra with the 1st-1st sideband combination used as the preparation pulse and the 1st-1st and C-2nd sideband combinations used for the detection pulse.

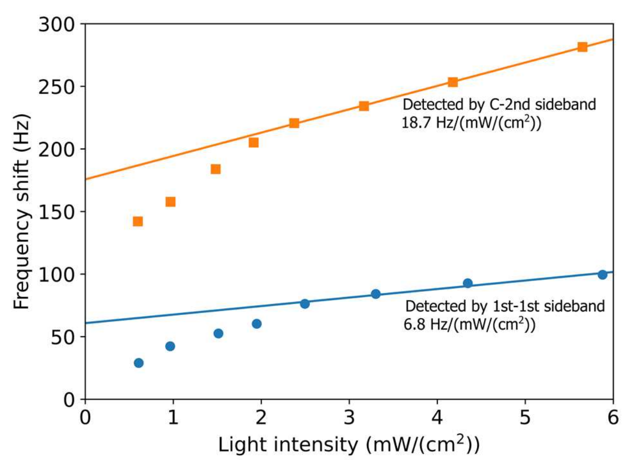

Fig. 3 Light shift characteristics when the 1st-1st sideband combination is used for the preparation pulse and the 1st-1st and C-2nd sideband combinations are used for the detection pulse.