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Removing Light Shift in Ramsey-Coherent Population Trapping Resonance with Different Free Evolution Time

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A light shift is a significant factor in degrading the long-term stability of vapor cell-based atomic clocks, such as miniature atomic clocks and chip-scale atomic clocks [1]. A Ramsey-coherent population trapping (CPT) resonance based on pulsed excitation significantly reduces the light shift. The light shift of the Ramsey-CPT is inversely proportional to the free evolution time, T_{off} [2]. Therefore, the resonance frequency, which is removed the light shift, can be estimated from the infinity of T_{off}. We developed a method for removing the light shift from frequency measurements at multiple difference, T_{off}.

The proposed light shift removal method is based on equation (1), which expresses the behavior of the light shift [2]:

$$S_m(T_{off}) = \frac{\tau_{\text{eff}}}{\tau_{\text{eff}} + T_{\text{off}} e^{-\tau_m/\tau_p}} S_{21} \tag{1}$$

where τ_m is the observation time, τ_p is the pumping rate, S_{21} is the light shift of the continuous excitation, and τ_{eff} is expressed as follows.

$$\tau_{\text{eff}} = \tau_p\left(1 - e^{-\frac{\tau}{\tau_p}}\right). \tag{2}$$

The resonance frequency, f, at $T_{off} \to \infty$ is considered the frequency, which was excluded from the light shift because $S_m(\infty) = 0$. In practice, f cannot be measured; hence, f is calculated from measurements at different T_{off}.

In this study, we used the drive current modulation [3] as the pulsed excitation scheme. The drive current modulation is suitable for satisfying the low size, weight, and power (SWaP) performance requirements because an external acousto-optic modulator can be eliminated from the optical setup. To calculate f, we measured frequencies at five T_{off} points (200, 500, 1000, 1500, and 2000 μs). Based on the proposed method, the residual frequency shift $f_r = f - f_0$, where f_0 is the ground-state transition frequency of Cs, was 18074±2 Hz. This result indicates that it is possible to remove and evaluate the light shift on the operating atomic clock because f_r is calculated via several frequency measurements at different T_{off} values.

In this study, we developed a light shift removal method based on the Ramsey-CPT scheme. This method can estimate the light shift on running atomic clocks. The long-term frequency stability of atomic clocks can be improved using the estimated light shift.

References

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