Frequency Biases in a Cold-Atom Coherent Population Trapping Clock

E. A. Donley, E. Blanshan, F.-X. Esnault, and J. Kitching
NIST, Boulder, CO, USA
E-mail: elizabeth.donley@nist.gov

A compact cold-atom clock based on coherent population trapping (CPT) has been developed. The clock typically demonstrates a short-term fractional frequency stability of $4\times10^{-11}/\sqrt{\tau}$, limited by frequency noise on the interrogation lasers. The clock interrogates a sample of 2×10^5 atoms under free-fall with typical cycle and Ramsey periods of 50 ms and 16 ms, respectively. The largest two systematic frequency shifts that can limit the clock's long-term stability are the light shift and the Doppler shift.

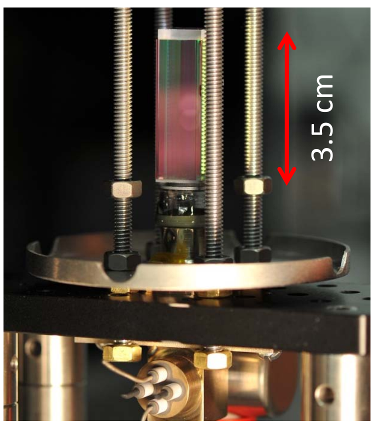

Fig. 1: Vacuum chamber shown with the bottom end cap for the magnetic shields. The system is based on a 9 cm^3 antireflection-coated vacuum cell. The vacuum-chamber volume, including the ion pump, is < 80 cm^3. The cell is surrounded by a single-layer magnetic shield that has a shielding factor of 100 perpendicular to the shield axis. Drift from magnetic field variations is not observed.

The atoms are interrogated with lin || lin CPT [1] by use of Ramsey spectroscopy [2] with phase-locked DFB/DBR lasers. Unlike conventional Ramsey spectroscopy with microwave pulses or coherent stimulated Raman transitions, $\pi/2$ pulses are not employed. Rather, the 1st pulse is long enough to put the atoms into the dark quantum superposition state, and the much shorter 2nd pulse probes the phase of that dark state [3].

The clock stability integrates down as $\tau^{-1/2}$ out to τ = 5000 s. So far, light shifts and Doppler shifts affect the stability at longer integration periods. Light-shift measurements are qualitatively explained by adding contributions from resonant CPT generating couplings [2], resonant non-CPT generating couplings, and far detuned couplings. Light shifts may be reduced by using optimized intensities and intensity ratios for the two CPT frequency components and optimized initial state populations, which is an area of continued study. Under conditions that minimize the light shift, the clock sensitivity to laser frequency drift is 0.45 Hz/MHz. The laser frequencies are stable at the few-kHz level (measured for 5 h), thus clock drift arising from laser frequency instability is estimated at < 3×10^{-13} out to 5 h. Improving the fraction of beat-note power in the coherent carrier from its current value of 75 % would also reduce the light shift.

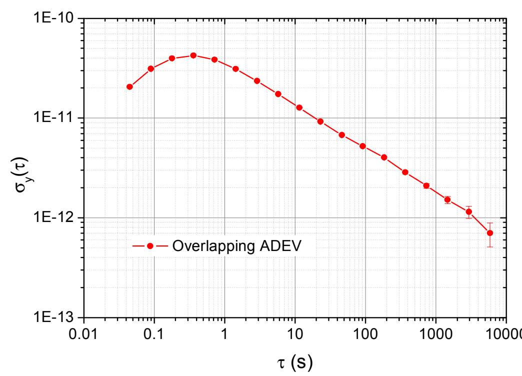

Fig. 2: Fractional frequency stability versus integration period.

The Doppler shift can be as large as 1×10^{-10} when the atoms are interrogated with travelling waves along the direction of gravity, but the shift can be made much smaller by probing the atoms with balanced, counter-propagating CPT beams [4]. Doppler shifts are also possible when the atoms are probed horizontally if the phases and/or intensities of the counter-propagating CPT beams are not uniform and well overlapped. At present, the drift from residual Doppler effects limits the long-term fractional frequency stability to the high 10^{-13} range. Improvements are planned that should reduce the clock's sensitivity to Doppler shifts.

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References

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