A Cold Atomic Beam Ramsey CPT Clock

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***Abstract*— We have developed a cold atomic beam coherent population trapping clock with the goal of creating a compact, low power device. The clock employs traditional two-zone Ramsey interrogation performed on the D2 line of an atomic beam of ^{87}Rb generated from a 2D$^+$-MOT. The current fractional frequency instability is 2.5 × $10^{-11}\tau^{-1/2}$. A preliminary evaluation of systematics and noise limiting the current performance is presented.**

Keywords—Atomic Clock; Coherent Population Trapping; Cold Atoms;

I. INTRODUCTION AND MOTIVATION

An atomic beam combined with the method of separated oscillating fields is a classic architecture for an atomic clock [1]. Commercial clocks based on thermal atomic beams and Ramsey spectroscopy have been exclusively based on direct microwave interrogation [2], however examples of Ramsey spectroscopy performed with thermal beams also include interrogation with coherent population trapping (CPT) [3].

The Ramsey fringe width for beam clocks scales as the atom velocity divided by the length of the drift region, which is unfavorable for the development of high-performance portable instruments based on thermal atoms. The use of laser-cooled atoms in place of thermal beams reduces the length of the drift region needed to achieve a narrow fringe width.

To reduce the complexity of the laser system over previous clocks based on cold-atom CPT [4], the atoms can be probed on the D2 transition at 780 nm, which is also needed for laser cooling. Since the atoms are cold, the excited-state hyperfine levels can be clearly resolved and high contrast can be observed. This is in contrast to CPT interrogation of thermal atoms in vapor cells, which demonstrate much better CPT contrast when probed on the D1 transition than on the D2 transition [5]. However, because of the closeness of nearby non-resonant hyperfine levels in the excited state, the light shifts are worse for D2 excitation than for D1 excitation.

II. EXPERIMENT

The clock is based on a laser cooled 2D$^+$-MOT [6]. Such systems reliably generate atomic beams with a low peak velocity (~10 m/s) and a narrow velocity distribution (FWHM ~3 m/s) [6]. With a 2D$^+$-MOT source, a 100 Hz fringe width is expected for a drift zone of 5 cm. The flux is typically 10^9 atoms/s for 30 mW of cooling light, with a mean velocity and velocity spread that agree well with beam parameters reported in reference [6]. An electro-optic modulator is used to apply the sideband for repumping to the cooling light.

A portion of the same laser source used for laser cooling probes the atoms with CPT. An acousto-optic modulator shifts the carrier frequency to be resonant with the F=2 to F'=2 transition and serves as an optical switch. The light passes through a second EOM driven at 6.835 GHz to produce the spectrum for CPT interrogation. The atoms are probed with the $\sigma_+ - \sigma_-$ interrogation scheme [7, 8].

The clock is operated in pulsed mode with a typical cycle period of 33 ms. An 11 ms cooling period generates a pulse of atoms that propagates through two spatially separated CPT beams. The CPT beams are elliptical with a width of 2 mm and a height of 8 mm (1/e^2), limited by an aperture in the single-layer magnetic shield surrounding the vacuum cell. The first zone is 13 cm downstream from the exit aperture of the 2D$^+$-MOT, and the second CPT zone is 5 cm further downstream. Fluorescence is collected from the second zone on a photomultiplier tube and integrated over the duration of the atom pulse to construct the signals that lock the clock.

III. RESULTS

A Ramsey fringe spectrum is shown in Fig. 1. The SNR is 140 and the fringe width is 214 Hz. This width is about twice as broad as expected for a beam velocity of 10 m/s, but gives the best short-term stability that has been observed so far. This may relate to the relatively broad cold-atom beam divergence expected from the 2D$^+$-MOT of 43 mrad [6], which would predict a beam diameter of 1.5 cm 18 cm downstream from the aperture for an average velocity of 10 m/s.

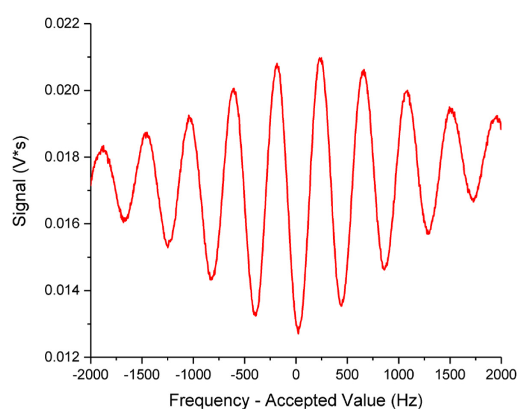

Fig. 1. Ramsey fringes measured with a cycle period of 33 ms per shot and no averaging.

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The measured fractional frequency stability is currently $2.5\times10^{-11}\tau^{-1/2}$, and it averages down to 2×10^{-12} at 1000 seconds. The dominant noise sources are laser intensity and frequency noise. Temperature instability, causing changes in an end-to-end phase shift, is currently the main source of the long-term instability. This is due to differences in the zone 1 and 2 optical path length.

Efforts continue to evaluate performance limits, optimize the clock performance, simplify and miniaturize the physics package, and reduce the power requirements.

ACKNOWLEDGMENTS

This research was developed with funding from the Defense Advanced Research Projects Agency (DARPA). The views, opinions and/or findings expressed are those of the authors and should not be interpreted as representing the official views or policies of the Department of Defense or the U.S. Government. This work is a contribution of the U.S. government and is not subject to U.S. copyright. Distribution Statement "A": Approved for Public Release, Distribution Unlimited.

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