Ramsey-CPT spectroscopy in buffer-gas filled Cs vapor micro-fabricated cells

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***Abstract*—We report the detection and spectroscopy of Ramsey-CPT fringes in Cs-Ne micro-fabricated cells. The push-pull optical pumping technique is used, allowing to detect high-contrast resonances. The central fringe is recorded versus several experimental parameters including the incident laser power or the Ramsey-CPT sequence parameters, such as the pumping time, the free-evolution time or the detection window. The CPT coherence lifetime T_2 in the cell is measured to be about 400 microseconds. Preliminary short-term fractional frequency stability results will be reported in CW and pulsed regimes at the conference for comparison.**

Keywords—miniature atomic clock, coherent population trapping, Ramsey-CPT spectroscopy, microfabricated cell.

I. INTRODUCTION

Over the last decade, significant efforts have been pursued in numerous laboratories and industries towards the development of miniature atomic clocks based on coherent population trapping (CPT) [1-3]. These sources are attractive candidates through their ability to combine a reduced volume, power consumption and fractional frequency stability at the level of 10^{-11} at 1 day integration time. These clocks are based on a micro-fabricated buffer gas-filled alkali vapor cell. Atoms in the cell interact with a bi-chromatic optical field generated by a vertical-cavity surface-emitting laser modulated at half the atom ground-state hyperfine splitting frequency. Using the CPT phenomenon, a narrow so-called dark resonance can be detected at the output of the cell using a photodiode and be exploited to stabilize the frequency of a local oscillator driving the VCSEL.

In miniature atomic clocks, continuous atom-light interaction is generally performed. In this regime, the clock short-term fractional frequency stability is optimized for low laser intensities, resulting from a trade-off between the CPT signal and linewidth and detection noise.

In this study, we investigate the use of a pulsed CPT interaction scheme [4,5] to detect narrow Ramsey-CPT fringes in Cs-Ne micro-fabricated vapor cells. We study the impact of different experimental parameters on the characteristics (linewidth, amplitude, contrast) of the central Ramsey-CPT fringe. At quite high laser intensity, narrow Ramsey-CPT fringes with a reasonable signal-to-noise ratio are detected.

II. EXPERIMENTAL SET-UP

Figure 1 shows the experimental setup used for the detection of Ramsey-CPT fringes in the microfabricated cell.

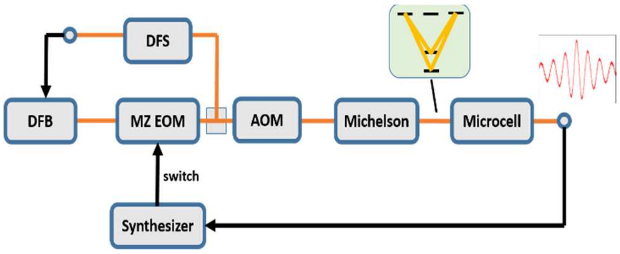

Fig. 1. Schematic of the Cs CPT clock. DFS: Dual-frequency Doppler-free spectroscopy.

The setup combines a distributed feedback diode laser tuned on the Cs D_1 line (894.6 nm), a Mach-Zehnder electro-optic modulator (MZ EOM) driven by a microwave frequency synthesizer at 4.596 GHz for optical sidebands generation, an acousto-optic modulator to compensate for the buffer-gas induced optical frequency shift in the CPT cell and to produce the pulsed interaction by switching on and off the microwave frequency, a Michelson-based polarization orthogonalizer and delay-line system to produce the PPOP scheme [6,7]. The laser is frequency-stabilized on an evacuated Cs cell using the technique described in [8]. The output laser beam is sent into a microfabricated Cs-Ne cell [9], shown in Fig. 2, with a diameter of 2 mm and an optical path length of 1.4 mm.

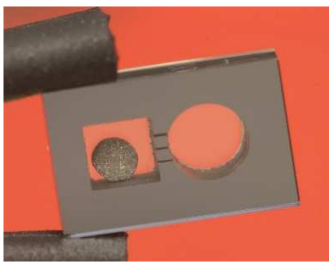

Fig. 2. Photograph of a Cs-Ne microfabricated cell.

The buffer gas pressure in the cell is about 70 Torr. The cell is temperature stabilized at 75°C where the CPT contrast is maximized. In the pulsed regime, atoms interact with a sequence of optical CPT pulses. The typical pumping time is

400 µs while the free-evolution time is in the 100-800 µs range. The transmitted light through the cell is detected 10 µs after the beginning of the pulse in a 10 µs-length detection window. A data acquisition card and personnal computer allows to pilot the whole experiment.

III. Results

Figure 3 shows Ramsey-CPT fringes detected in the Cs-Ne microcell. The free-evolution time is 300 µs and the laser power incident in the cell is 114 µW. The central fringe linewidth is 1358 Hz. Its contrast is about 3.8 %.

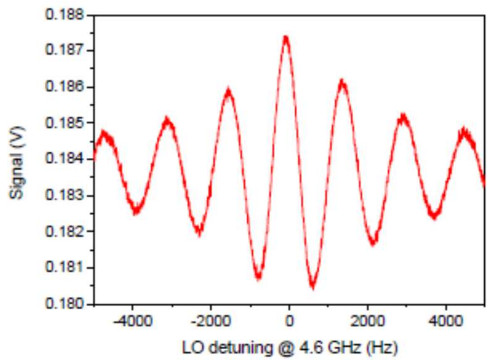

Fig. 3. Ramsey-CPT fringes detected in a Cs—Ne microfabricated cell.

Figure 4 reports the contrast of the central fringe versus the laser power. The latter is found ton increase for laser powers up to 130 µW.

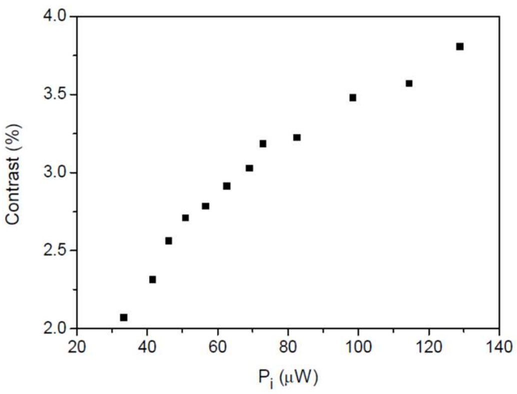

Fig. 4. Fringe contrast versus the incident laser power. Experimental parameters are TR = 300 µs, Tb = 400 µs.

Figure 5 reports the evolution of the central fringe amplitude versus the free-evolution time T_R. Experimental data are well-fitted by an exponential decay function with a time constant of about 396 µs. The latter can be considered as an estimation of the CPT microwave coherence relaxation time T_2 in the microfabricated cell.

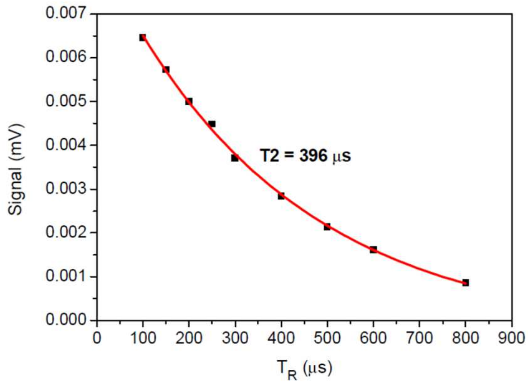

Fig. 5. Fringe amplitude versus the free-evolution time TR.

Further tests will be performed up to the conference time. We expect also to compare results obtained in the continuous and pulsed regimes. Preliminary frequency stability results will be performed in both regimes. Latest results will be shown at the conference.

Acknowledgment

The authors thank colleagues in FEMTO-ST (P. Abbé, C. Rocher), ANR-DGA ISIMAC project and LabeX FIRST-TF.

References

[1] S. Knappe, V. Shah, P. D. D. Schwindt, L. Hollberg, J. Kitching, L. A. Liew and J. Moreland, A microfabricated atomic clock, Aplpied Physics Letters 85, 9, 1460 (2004).

[2] https://www.microsemi.com/products/timing-synchronization-systems/embedded-timing-solutions/components/sa-45s-chip-scale-atomic-clock

[3] Y. Zhang, W. Yang, S. Zhang and J. Zhao, Rubidium chip-scale atomic clock with improved long-term stability through lihgt intensity optimization and compensation for laser frequency detuning, JOSAB 33, 8, 1756 (2016).

[4] T. Zanon, S. Guérandel, E. De Clercq, D. Holleville, N. Dimarcq and A. Clairon, High-contrast Ramsey fringes with coherent population trapping pulses in a double-lambda atomic system, Physical Review Letters, 94, 193002 (2013).

[5] X. Liu, J. M. Mérolla, S. Guérandel, E. De Clercq and R. Boudot, Ramsey spectroscopy of high-contrast CPT resonances with push-pull optical pumping in Cs vapor, Optics Express 21, 10, 12451 (2013).

[6] Y.Y. Jau, E. Miron, A. B. Post, N.N. Kuzma and W. Happer, Push-pull optical pumping of pure superposition states, Phys. Rev. Lett. 93, 160802 (2004).

[7] X. Liu, JM. Merolla, S. Guérandel, C. Gorecki, E. De Clercq and R. Boudot, Coherent population trapping resonances in buffer-gas filled Cs vapor cells with push-pull optical pumping Phys. Rev. A 87, 013416 (2013).

[8] M. Abdel Hafiz, G. Coget, E. De Clercq and R. Boudot, Doppler-free spectroscopy on Cs D1 line with a dual-frequency laser, Optics Letters, 41, 13, 2982 (2016).

[9] M. Hasegawa, R. K. Chutani, C. Gorecki, R. Boudot, P. Dziuban, V. Giordano, S. Clatot and L. Mauri, Microfabrication of Cs vapor cells with buffer gas for MEMS atomic clocks, Sensors Actuators A 167, 594 (2011).