A Ramsey-based microcell CPT clock with fractional frequency stability in the low 10^{-12} range at 10^5 s

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***Summary*— We demonstrate a microcell atomic clock based on coherent population trapping (CPT) using a Cs-Ne micro-fabricated cell built with low-permeation alumino-silicate glass (ASG) windows. The clock operates with the symmetric auto-balanced Ramsey (SABR) interrogation technique, coupled with servos of the setup box temperature, laser power and microwave power. The clock Allan deviation is measured to be 1.4×10^{-12} at 10^5 s.**

***Keywords*— miniature atomic clocks; microfabricated cell; auto-balanced Ramsey; alumino-silicate glass; frequency stability**

I. INTRODUCTION

Miniaturized atomic clocks based on coherent population trapping (CPT) combine excellent stability and low size-weight and power (SWaP) budget [1-3]. These clocks are deployed in navigation and positioning systems or underwater sensor networks.

Despite remarkable performances, their mid and long-term fractional frequency stability remains in general limited by light-shifts effects and variations of the cell inner atmosphere.

Techniques for mitigation of light-shifts in continuous wave-regime CPT clocks were proposed and demonstrated. One of them relies on the active stabilization of a specific microwave power value that cancels at the first-order the dependence of the clock frequency to laser power variations [4-6].

Alternative approaches to reduce light-shift effects consist in using a pulsed Ramsey-based sequence [7] of optical CPT pulses. The mitigation of light-shift sensitivity with Ramsey-CPT spectroscopy was already reported in micro-fabricated cells [8]. In [9], the use of the Symmetric Auto-Balanced Ramsey (SABR) technique in a micro-fabricated cell led to a further improvement. Indeed, in this case, a reduction of the dependence of the clock frequency to light-field parameters by a factor higher than 100 was shown so that the clock Allan deviation was reduced for integration times between 10^2 and 10^4 s.

Nevertheless, in [9], the clock stability remained limited for integration times higher than a few thousands of seconds by another contribution, that we attributed to Ne permeation of the glass windows of the micro-fabricated cell [10-12].

In the present study, we demonstrate frequency stability results of a microcell CPT clock that operates using the pulsed SABR interrogation method while using a micro-fabricated cell built with low-permeation alumino-silicate glass (ASG) windows [13]. In addition to these methods, active temperature stabilization of the setup, and microwave power and laser power servos are implemented.

II. METHODS/RESULTS

The CPT clock experimental setup is comparable to the one described in [9]. Cs atoms in a micro-fabricated vapor cell filled with Neon buffer gas are probed by an optically-carried 9.192 GHz signal, obtained by direct modulation of a vertical-cavity surface-emitting laser. An acousto-optic modulator is used to produce the SABR sequence.

We first recorded the frequency, using the SABR sequence, during 15 days, of the clock using a cell either with borosilicate glass (BSG) or ASG windows. For the cell with BSG windows, a negative clock frequency drift of about -0.3 Hz/day, attributed to a Ne gas leak, was obtained. With the cell using ASG windows, the fit of clock frequency data by a linear function yielded a slope of nearly 10^{-4} Hz/day [14]. Despite the improvement obtained with ASG, the clock Allan deviation at one day was still limited at a few 10^{-11}.

Observing a clear correlation between the clock frequency and the setup box temperature variations, we have then implemented a servo of the box temperature, improving the clock Allan deviation at 3.8 x 10^{-12} at 10^5 s.

The consecutive analysis of the mid-term stability budget indicated that light-shifts (effects of the microwave power and laser power) were again responsible for the clock stability at 1 day at the level of a few 10^{-12}. Therefore, two additional servos, one for the microwave power and one for the laser power, have been implemented.

Figure 1 shows the stability results obtained for the clock with the ASG cell, SABR interrogation technique and servos of the setup box temperature, the microwave power and the laser power. The clock frequency stability reaches 1.4 x 10^{-12} at 10^5 s [14]. This stability level at one day is competitive to best current microcell-based microwave atomic clocks [3,15].

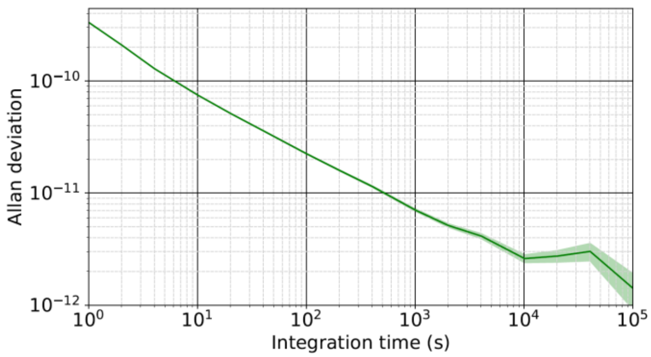

Fig. 1. Allan deviation of the clock frequency using SABR interrogation and stabilization of the box temperature, microwave power and laser power.

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