Pushing down the mid-long term stability of CPT-based microcell atomic clocks

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CPT-based miniature atomic clocks are attractive ultra-compact, low-power and high-stability frequency references. However, their mid-long-term frequency stability suffers from several limitations including mainly light shifts and the possible evolution of the cell inner atmosphere or optical absorption.

In this study, we explore several approaches to mitigate these contributions. Our CPT clocks experiments are based on a pill-dispenser-based buffer-gas filled Cs vapor MEMS cell [1] and a VCSEL laser tuned on the Cs D1 line (894nm) and directly modulated at 4.596 GHz by a microwave frequency synthesizer.

The first axis of the study concerns the mitigation of light-shift effects. In this domain, several approaches have been investigated. In a VCSEL-chip based fully-miniaturized HTCC physics package [2], we have studied the individual and combined benefits of additional stabilization loops on the clock mid-long term frequency stability. The first added stabilization loop stabilizes the actual VCSEL chip temperature instead of the VCSEL temperature sensor while the second servo loop corrects the microwave power. The VCSEL temperature stabilization improves the clock Allan deviation by a factor 4 at 10^4 s while the simultaneous operation of both loops improves the stability by a factor 7 at 10^4 s. More recently, Auto-Balanced Ramsey (ABR) protocols [3-5]-inspired sequences adapted to continuous-regime (CW) clocks were proposed [6-7]. Analog studies are in progress in our laboratory.

The second axis concerns the cell technology. In this domain, inspired by [8], a reduction of gas permeation issues in several Cs-He microcells has been observed in our cells thanks to the use of low-He permeation alumino-silicate glass (ASG) wafers. More recently, it was observed on several cells that a cell baking procedure after dispenser activation helped to reduce significantly a significant "early-aging" [9] clock frequency drift of "freshly-activated" cells. At the same time, activation parameters have to be properly controlled to avoid the progressive condensation of alkali droplets on the cell windows [10] during clock operation. In a second packaged-VCSEL lab-scale clock system, with optimized thermal control and placed in an actively-pumped chamber, fractional frequency stability at the level of 5-6 10^{-12} at 10^5 s are now routinely measured, still clearly limited to date by laser power variations. Latest progress will be reported at the conference.

[1] M. Hasegawa et al., Sensors Actuators 167, 594-601 (2011) ; R. Vicarini et al., Sensors Actuators 280, 99-106 (2018).
[2] R. Vicarini et al., IEEE Trans. Ultrason. Ferroelec. Freq. Contr. (2019).
[3] C. Sanner et al., Phys. Rev. Lett. 120, 053602 (2018)
[4] M. Abdel Hafiz et al., Appl. Phys. Lett. 112, 244102 (2018).
[5] M. Shuker et al., Appl. Phys. Lett. 114, 141106 (2019).
[6] C. Calosso et al., Proceedings EFTF-IFCS Orlando (2019).
[7] V. I. Yudin et al., ArXiv :1911.02935 (2019).
[8] A. Dellis et al., Opt. Lett. 41, 12, 2775 (2016).
[9] R. Lutwak et al., Proceedings of 39th PTTI, pp 269—290 (2007).
[10] S. Karlen et al., Opt. Express 25, 3, 2187 (2017).