LEMAC: LTF-EPFL Miniature Atomic Clock

current status

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***Summary*—We present the latest development of our in-house miniature atomic clock (LEMAC). The clock scheme is based on the continuous wave (CW) optical-microwave double resonance (DR) interrogation. Significant efforts have been put in a newly designed miniature microwave loop-gap resonator (LGR), laser locking scheme, and integrated Physics Package design. In its final state, our clock is expected to show a short-term stability performance of $\sigma_y(\tau)<1 \times 10^{-11}\ \tau^{-1/2}$ in terms of Allan deviation, for an insulated (magnetic and thermal) resonator volume <20 cm^3.**

Keywords*—*miniature atomic clock, double-resonance, rubidium, microfabricated cell, micro loop gap resonator.

I. Introduction

Miniaturization of atomic clock has been for a long time the subject of intense investigations. After the success encountered by the first commercial chip-scale atomic clock SA.45s from Microsemi [1], most of the efforts have been oriented towards coherent population trapping (CPT) interrogation scheme for apparent obvious miniaturization potential. Though miniaturization is impressive, miniaturized CPT clock struggle to show short-term stabilities significantly below $1 \times 10^{-10}\ \tau^{-1/2}$. We decided to pursue the classical optical-microwave continuous wave double resonance approach to miniaturized clocks. Although some commercial clocks, like mRO-50, exploit as well the DR scheme with glass blown cells and off resonance resonator, we are convinced that an optimized microwave resonator design and microfabrication techniques (for the cell and the resonator) can drastically improve the performances of the clock, especially in terms of stability. Therefore, the effort of our development focused on a newly designed miniature loop-gap resonator, the μ−LGR, smaller and presenting a better field orientation factor than the previous version [2].

Here we will present our latest results and status of this newly designed continuous DR clock. We will discuss the originality of the designs and present preliminary results in terms of spectroscopy and stability performances.

This activity was conducted and was funded under the Navigation Innovation and Support Program (NAVISP) of the European Space Agency (ESA), to support innovation and competitiveness in the field of Position, Navigation and Time (ESTEC contract nr 4000129974). The views expressed in this document are those of the authors and cannot be taken to reflect the official opinion of the European Space Agency.

II. LEMAC Design

The present miniature atomic clock demonstrator exhibits several significant modifications with respect to the first resonator demonstrated in [3].

a) *A Newly designed μ-LGR:* The core of our clock consists of a 4 mm-size microfabricated cell [4] filled with a natural isotopic ratio of Rb. An additional buffer gas mixture of N_2 and Ar allows for temperature compensation [5]. The cell is placed within an upgraded version of the μ-LGR presented in [2]. For the present version, we focused on size reduction and Field orientation factor (FOF) improvement. The volume of this new μ-LGR is now 0.6 cm^3 (Figure 1 right), 30% smaller than the previous version, while maintaining an excellent FOF > 0.9.

b) *An innovative LGR cavity with asymmetrical C-field coil*: The LGR cavity integrates now a first heating stage and asymmetric magnetic field coils for enhanced C-field homogeneity within the cell and tighter thermal control.

c) VCSEL for optical pumping: The optical pumping is provided by a low-power VCSEL laser emitting at 795 nm. Almost exclusively employed in CPT clock [6], we demonstrate its potential in miniature DR clock.

d) Optical reference scheme: The VCSEL emission frequency is now referenced directly on the optical absorption spectrum of the clock cell; therefore, no external stabilization scheme is required.

e) *An all-integrated physics package:* including light module, resonator module, detection module, we achieved a lab demonstrator with a total volume of V_{tot} < 132 cm^3, see Figure 1 left (mass<500 gr).

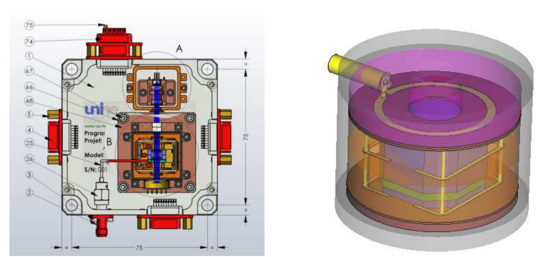

Fig. 1 Preliminary design of the LEMAC Physics Package (left) and of the μ-LGR (right).

III. DISCUSSION/CONCLUSION

We are currently in the development stage, the clock realization and assembly is ongoing. At the conference, we will present the detailed clock design and discuss the fully integrated clock physics package, along with first spectroscopic and clock operation results. With the integrated LEMAC clock, the preliminary short-term stability of $<3 \times 10^{-11}\,\tau^{-1/2}$ is expected to be improved, as well as its mid-to-long-term stability to below 10^{-11} up to 10^4s.

ACKNOWLEDGMENTS

We thank P. Waller (ESA-ESTEC) for following the project and for fruitful technical exchanges. We also thank our colleagues P. Scherler and F. Gruet of LTF-Unine for valuable technical assistance, and M. Veljovic (formerly EPFL-MAG) for contributions to the early phase of the project.

REFERENCES

[1] R. Lutwak *et al.*, “The SA.45s Chip-Scale Atomic Clock – Early Production Statistics,” in *Proceedings of the 43rd Annual Precise Time and Time Interval Systems and Applications Meeting*, Nov. 2011, pp. 207–220, Accessed: Dec. 10, 2021. [Online]. Available: http://www.ion.org/publications/abstract.cfm?jp=p&articleID=10786.

[2] M. Violetti *et al.*, “The micro loop-gap resonator: A novel miniaturized microwave cavity for double-resonance rubidium atomic clocks,” *IEEE Sens. J.*, vol. 14, no. 9, pp. 3193–3200, 2014, doi: 10.1109/JSEN.2014.2326337.

[3] M. Pellaton, “High-resolution spectroscopic studies in glass-blown and micro-fabricated cells for miniature rubidium atomic clocks,” University of Neuchâtel, 2014.

[4] Y. Pétremand *et al.*, “Microfabricated rubidium vapour cell with a thick glass core for small-scale atomic clock applications,” *J. Micromechanics Microengineering*, vol. 22, no. 2, p. 25013, 2012, doi: 10.1088/0960-1317/22/2/025013.

[5] J. Vanier, R. Kunski, N. Cyr, J. Y. Savard, and M. Têtu, “On hyperfine frequency shifts caused by buffer gases: Application to the optically pumped passive rubidium frequency standard,” *J. Appl. Phys.*, vol. 53, no. 8, pp. 5387–5391, Aug. 1982, doi: 10.1063/1.331467.

[6] D. K. Serkland *et al.*, “VCSELs for atomic clocks,” in *Vertical-Cavity Surface-Emitting Lasers X, Proc. SPIE 6132*, 2006, doi: https://doi.org/10.1117/12.647095.