PhD thesis open position

FEMTO-ST

Time-Frequency Department – OHMS Group

26 rue de l'épitaphe 25030 Besançon cedex, France

Titre: High-stability microcell-based optical frequency reference

Probing an atomic ensemble in mm-scale alkali vapor cells has allowed over the last decade the demonstration and development of a wide variety of high-precision and high-sensitivity chip-scale atomic devices [1], including in particular low-power consumption miniaturized atomic clocks [2]. Such microwave atomic clocks, now commercially-available [3,4], are attractive candidates for numerous industrial and strategic applications since they combine a total volume of about 15 cm^3, a power consumption of 150 mW and a fractional frequency instability in the range of 2 10^{-11} at 1 s and 1-2 10^{-11} à 1 day integration time.
At the same time, in the domain of time and frequency metrology, the performances of microwave Cs fountain clocks [5-6] have been significantly overcome by those of new-generation state-of-the-art optical atomic clocks. Optical clocks are now exceptional instruments that enable precision measurements with unrivaled stability and accuracy at to the 10^{-18} range [7-8]. These outstanding performances make such clocks attractive devices to be used in a wide variety of fundamental research activities including the measurement of possible variations of fundamental constants, the search for dark matter in the universe [9], the detection of gravitational waves [10] or relativistic and chronometric geodesy.

Inspired by significant progress demonstrated in these two domains, a stimulating and promising research path to explore concerns the development of new-generation miniaturized vapor cell optical frequency references. In this domain, different studies have already been reported in the literature. These studies describe the stabilization of VCSEL diode lasers onto Doppler-broadened optical resonances [11], the stabilization of a Brillouin scattering laser onto a Rb microcell [12], sub-Doppler spectroscopy technique using an integrated photonic waveguide [13] or the recent photonic integration of a miniaturized optical clock based on detection of the Rb 778-778 nm two-photon transition in a microfabricated cell [14]. The latter frequency reference exhibits a remarkable frequency instability level of 4 10^{-12} $\tau^{-1/2}$ until 1000 s whereas previous works [12-13] were often limited at the level of about 10^{-11} between 1 s and 10^4 s

In a recent study, the detection of high-contrast sign-reversed natural-linewidth sub-Doppler resonances in a Cs vapor cell has been reported using an original dual-frequency sub-Doppler spectroscopy (DFSDS) technique [15]. Important theoretical efforts [15,16], in close collaboration with Institute of Laser Physics (Novossibirsk, Russia) and SYRTE, Observatoire de Paris (France), have been performed in order to explain main physical processes involved into these high quality-factor resonances. Moreover, these studies have highlighted the advantage to apply such a technique in small-dimension cells. Recently, preliminary studies using DFSDS have demonstrated the stabilization of a diode laser to a Cs microcell with a fractional frequency instability level of 2 10^{-12} at 1 s and 3 10^{-12} at 1000 s [17]. These performances, that can certainly be improved and optimized, reveal to be encouraging since they are 50-100 times better on the short term than those of commercial microwave chip-scale atomic clocks based on coherent population trapping (CPT).

The PhD thesis work aims to pursue this research path at FEMTO-ST and to initiate in the laboratory the development of new generation miniaturized optical frequency references based on mm-scale alkali vapor cells (Cs or Rb). These references will ultimately target to exhibit frequency stability performances 100 times better than CPT-based microwave miniature atomic clocks, while keeping an extremely simple architecture, compatible with advanced miniaturization and reduced power consumption. In that sense, this PhD thesis work will constitute the starting point of a new research axe in our group and will aim to fix solid basis for the future development in our laboratory of extremely-high-performance miniaturized frequency references.

In a first part, the candidate will explore more in depth the potential of the dual-frequency sub-Doppler spectroscopy technique for the development of a high-stability microcell-based optical frequency reference. A dedicated experimental setup, combining an extended-cavity diode laser, a fibered electro-optic modulator, a vapor microcell and its physics package and electronics/instrumentation for the experiment control will be implemented. Relevant integration efforts will be led at an early stage. A rigorous metrological study will be led in order to explore the short-term stability potential of such a reference. The sensitivity of the laser frequency to several key-experimental parameters (laser power, microwave power and frequency, cell temperature, etc.) will be evaluated and solutions will be proposed to minimize these contributions and then improve the reference mid and long-term stability performances. Stability characterization will be possible by beating the output of the microcell-based optical frequency reference with an ultra-stable reference optical signal [18].

The optical frequency reference under study will be based on an alkali vapor microfabricated cell (Cs or Rb) technology developed at FEMTO-ST. This cell technology consists of a silicon-etched cavity with anodically-bonded glass wafers, for which filling with alkali vapor is performed using laser activation of a pill dispenser [19-20]. Tests will be performed to evaluate the impact of the cell inner atmosphere quality onto the performances of the frequency reference. Tests with cells using or not non-evaporable getters [21] could be performed in that sense. A contribution to in-progress developments of our microcell technology could then be envisioned during the PhD thesis.
Depending on the progress of the study using the dual-frequency Doppler-free spectroscopy technique, the candidate will contribute possibly in the second half of the phD thesis to start investigations and studies for the development of a new optical frequency reference based on the detection of a two-photon transition in an alkali atomic vapor microcell [22-25].

The candidate will integrate the OHMS group (http://teams.femto-st.fr/equipe-ohms/) in the Time-Frequency department of FEMTO-ST (www.femto-st.fr). The candidate should have a Master's degree (or equivalent, Ecole d'Ingénieurs). The candidate should have a significant interest for applied physics disciplines, high-precision and low-noise measurements and should have a good background in optics, electronics and instrumentation (coding and computing for piloting experiments). Basic knowledge in the fields of atomic physics and mechanical design are a real plus-value.
The candidate will integrate a research group composed of researchers, engineers and technicians. The candidate will be supported by electronics/mechanics/informatics services of FEMTO-ST institute and will evolve in an internationally-recognized laboratory with numerous infrastructure facilities for MEMS technologies or time and frequency metrology.
The candidate will aim to present his/her results in international conferences and will aim to submit his/her work for publication in scientific journals.

Application:

Required background : Master 2 or Diplôme d'Ingénieur (physics/engineering sciences)
Start date deadline: 01 December 2019.
Salary : about 1.5 k€/month.
Possibility to perform teaching courses/lab works during the PhD thesis in Université Bourgogne Franche-Comté or ENSMM.
Procedure: Send a CV, motivation letter and if available recommendation letters.

Contact:

Dr. Rodolphe Boudot
FEMTO-ST
Département Temps-Fréquence / Site ENSMM
26, rue de l'épitaphe 25030 Besançon, France.
Email: rodolphe.boudot@femto-st.fr
Tel : +33 (0)3 81 40 28 56

References

[1] J. Kitching, Appl. Phys. Rev. 5, 031302 (2018)
[2] S. Knappe, MEMS atomic clocks, Comprehensive microsystems, 3, 571-612 (2007).
[3] https://www.microsemi.com/product-directory/clocks-frequency-references/3824-chip-scale-atomic-clock-csac
[4] http://www.accubeat.com/product-item/nano-atomic-clock-nac1/
[5] G. Santarelli et al., Phys. Rev. Lett. 82, 4619 (1999).
[6] J. Guéna et al., IEEE Trans. Ultrason. Ferroelec. Freq. Contr. 59, 3, 391 (2012).
[7] M. Schioppo et al., Nature Photon. 11, 48 (2017).
[8] J. Grotti et al., Nat. Phys. 14, 437 (2018).
[9] S. Kolkowitz et al., Phys. Rev. D 94, 1519 (2016).
[10] A. Derevianko and M. Pospelov, Nat. Phys. 10, 933 (2014).
[11] F. Gruet et al., Opt. Lasers Eng. 51, 8, 1023-1027 (2013).
[12] W. Loh et al., Opt. Express 24, 13, 14516 (2016).
[13] M. T. Hummon et al., Optica 5, 4, 443449 (2018).
[14] Z. L. Newmann et al., ArXiV 1811.00616 (2018).
[15] M. Abdel Hafiz et al., Opt. Lett. 41, 2982 (2016).
[16] M. Abdel Hafiz et al., New Journ. Phys. 19, 073028 (2017).
[17] D. Brazhnikov et al., submitted to Phys. Rev. A (2018).
[18] A. Didier et al., Applied Optics 54, 12, 3682 (2015).
[19] M. Hasegawa et al., Sensors Actuators: Phys. A 167, 594-601 (2011).
[20] R. Vicarini et al., Sensors Actuators: Phys. A 167, 594-601 (2011).
[21] M. Hasegawa et al., J. Micromech. Microeng. 23, 055022 (2013).
[22] P. Fendel et al., Opt. Lett. 32, 6, 701 (2007).
[23] N. P. Georgiades et al., Opt. Lett. 19, 18, 1474 (1994).
[24] C. Y. Cheng et al., Opt. Lett. 32, 5, 563 (2007).
[25] F. Nez et al., Opt. Comm. 102, 432 (1993).
[25] V. Gerginov et al., Phys. Rev. Applied 10, 014031 (2018).