Compact and miniature atomic clocks using hot and cold rubidium atomic vapors

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ABSTRACT

This talk concerns our research in the field of compact and miniature vapor-cell frequency standards, using hot and cold alkali atoms.

We will first give an overview of our initial developments in the field of “traditional” vapor cell atomic clocks. This research has led to the realization of industrial and space-qualified Rubidium frequency standards that have been commercialized and are currently employed in applications such as telecommunication and satellite navigation [1]. It has also allowed us to demonstrate the potential improvements and main limitations associated with the use of a laser instead of a discharge lamp to optically-pump the atoms and detect the resonance signal [2, 3].

In the second part of the talk, we will describe some of our contributions to the progress in the two following sub-topics of our domain: (1) compact high-performance vapor-cell frequency standards and (2) chip-scale atomic clocks (CSACs).

Concerning the first sub-topic, we have investigated and improved the short and medium to long term frequency stability, using laboratory setups [4]. In collaboration with the Italian colleagues from INRIM [5], we have also employed the pulsed double-resonance Ramsey scheme [6] with a compact magnetron-type microwave cavity developed with the group of Prof. A. Skrivervik, from Ecole Polytechnique Fédérale de Lausanne (EPFL) [7]. After having sufficiently controlled and reduced all the main sources of instability (at the 10^{-14} level), we evidenced some previously overlooked and/or not fully understood environmental sensitivities such as the so-called “barometric effect” [8, 9].

Concerning the second sub-topic (chip-scale atomic clocks), our research has included the realization and evaluation of microfabricated discharge lamps [10] as well as the development of micro-fabricated wall-coated cells [11], that required a novel type of low temperature bonding of microfabricated vapor cells. The new physics and the potential advantages of using glass-blown anti-relaxation wall-coated cells (instead of buffer-gas cells) has also been a topic that we have investigated in depth [12, 13]. Another particularly original aspect of our approach to CSACs has been to employ microwave-optical double-resonance instead of coherent population trapping. Thanks to this method, that provides a resonance signal with a much better contrast, state-of-the-art short-term frequency stabilities could be achieved (below 10^{-11} at one second averaging time) [14].

In the last part of the talk, we will describe our more recent investigations in both of these sub-topics (high performance and CSACs)

Concerning the first one (high performance standards), we are currently developing a compact laser-cooled double-resonance atomic clock in collaboration with the group of Prof. E. Riis, from the University of Strathclyde [15]. After a first optimization of the interrogation cycle, very promising Ramsey fringes have been observed and preliminary clock frequency stability measurements, in various configurations, could be realized. Our latest results will be presented at the conference.

We could also pursue our studies on chip-scale atomic clocks and apply, for the first time, the Ramsey double-resonance scheme on a microfabricated vapor-cell. This work paves the way towards CSACs that achieve not only superior short-term frequency stabilities, but also medium to long term performances at the10^{-12} level, thanks in particular to the strong suppression of the light-shift effect [16].

Note that for all these types of double-resonance atomic clocks, we have successfully implemented microwave cavities that were realized by additive manufacturing (3D-printing), which has several advantages and a great potential, in comparison to more traditional machining techniques [17, 18]. We have also performed technological and application-oriented studies on another critical component of vapor-cell standards, the laser diode source, such as the “spectral” aging [19] and the possibility to employ 1,5 μm telecom sources [20].

We will conclude our presentation with some considerations concerning the future perspectives in our field, in relation to specific applications such as the Global Navigation Satellite Systems (GNSS) [21].

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REFERENCES


