CPT miniature atomic clock prototype preliminary performances

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Background

Atomic clocks provide time keeping with exquisite precision and stability which can be used as frequency standard for high demanding applications. Miniaturization of these devices will pave the way to their exploitation in many on field applications, from communication to navigation, requiring accurate synchronization and long integration times, together with reduced volume, mass, and power consumption.

Optical interrogation of atomic transitions provides a viable way for miniaturizing atomic clocks. Alkali vapor cells can be fabricated with MEMS technology and can be integrated with commercial narrow-line laser sources and photodetectors, to provide a Miniature Atomic Clock (MAC). Such devices can outperform temperature-compensated quartz crystal oscillators (TCXOs) over long times scales [1][2].

Although probed at optical frequencies, the alkali atoms provide a clock signal which is given by their hyperfine frequency splitting (HFS) in the microwave or radiofrequency domain. Among the different interrogation strategies, Coherent Population Trapping (CPT) has been widely investigated [3] as it provides an all-optical interrogation scheme without the need of additional radiofrequency components on the Physical Package (PP) of the clock.

When considering ^{87}Rb as alkali atoms, like in this work, the CPT consists in applying two coherent laser fields to the transition between the HFS of the $S_{1/2}$ ground state and the one of the exited $P_{1/2}$ states as schematically shown in Figure 1a. When the frequency difference between the two laser fields equals the HFS and the two fields are in-phase, quantum interference between the processes 1->3 and 2->3 arises, and excitation to the state 3 is quenched. This creates a transparency peak in the spectrum of absorption which inherits the stability properties of the alkali atoms ground states and can be used as signal for the clock.

Here we show characterization and preliminary performances of a CPT MAC prototype based on a PP developed within the Quantum Flagship project macQsimal (www.macQsimal.eu).

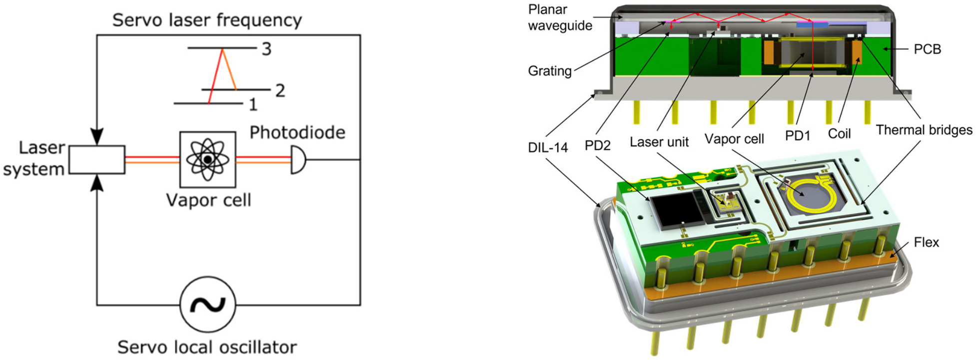

Figure 1 a) Scheme of an atomic clock set-up based on CPT. B) Overview of the PP developed in macQsimal.

Presentation

The PP is shown in Figure 1b. It is based on a patented [4] flat-form factor design using a planar optical waveguide detailed in [5]. It consists in an evacuated DIL-14 metallic package cavity that hosts a laser unit, two photodiodes and a MEMS atomic vapour cell. Laser light is sent to photodiodes and cell by the planar optical waveguide with grating couplers. The laser, MEMS cell and photodiode are mounted on an isostatic holder that ensures thermal insulation of the laser and the cell, which are thermally stabilized by NTCs and two separated closed loops at roughly 80°C and 95°C respectively. The C-field is provided by a solenoid coil.

The transmission spectrum of the ^{87}Rb cell is reported in Figure 2a, it shows the HFS of the ground state. When an RF modulation equal to half of the HFS is added to the laser, the two sidebands can be used as the two coherent fields needed for CPT. The spectrum changes as in Figure 2b, where the central dip is due to simultaneous absorption from the sidebands. The laser frequency is then locked to such spectral features.

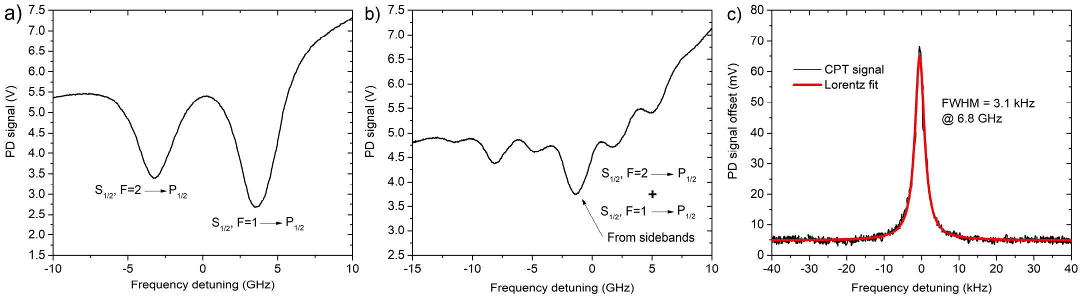

Figure 2 a) Absorption of the MEMS cell filled with ^{87}Rb. b) Absorption of the same cell probed with an RF modulated laser. c) CPT resonance

By scanning the RF modulation around the HFS, a narrow CPT signal of 3.1 kHz is recorded as a drop in the absorption (Figure 2c). The contrast of the CPT with respect to the absorption of Figure 2b is >1.5% when applying a C-field of 125 mG to resolve the Zeeman sub-levels.

The measured preliminary Allan deviation shows an excellent short-term frequency stability lower than 2E-11@1s and a fairly flat mid-term frequency stability. We attribute this behavior to instabilities of the optical and RF powers of the lab setup . At longer times, the system drifts mainly because of cell aging.

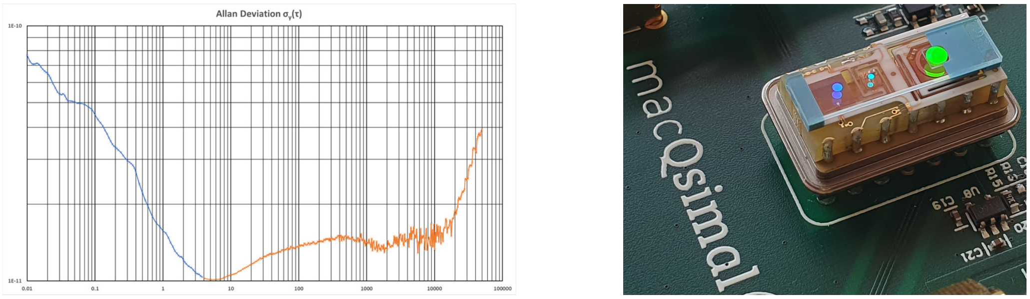

Figure 3 Allan Deviation (left) of the mid-term measurement on the DIL-14 based CPT MAC prototype (right).

In conclusion, we have shown preliminary measurements on a novel CPT MAC prototype targeting commercial deployment. The CPT signal shows 3.1 kHz linewidth and >1.5% contrast, which indicates that the clock provides good short-term stability [6]. We will report on optimized mid- and long-term frequency stabilities and comparison with a similar double resonance prototype developed in a parallel project funded by the European Space Agency.

References

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