High-purity microwave signal from a dual-frequency semiconductor laser for CPT atomic clocks

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Coherent population trapping (CPT) is an interesting technique for the development of compact atomic frequency references[1]; it relies on the excitation of alkali atoms by two phase-coherent laser fields. We describe the design and operation of an innovating dual-frequency laser source dedicated to Cs CPT atomic clocks, based on the direct dual-frequency and dual-polarization operation of an optically-pumped semiconductor laser (OPSL) at $\lambda = 852.14$ nm.

An OPSL consists in a semiconductor chip, including both high-reflection Bragg mirror and active material, placed in an external cavity and directly pumped by a high-power laser diode. The dual-frequency operation of the laser is generated by intracavity birefringent components. They induce a controllable phase anisotropy within the laser cavity and force the emission on two cross-polarized longitudinal modes[2]. The laser emission is tuned at the Cs D_2 line and the frequency difference between the two modes is tunable in the microwave range.

The stabilization of the dual-frequency laser operation is achieved through two servo-loops. The optical frequency of one laser line is locked onto a Cs transition through correction of cavity length with a piezo-transducer. The frequency difference between the two laser lines is locked onto a stable RF synthesizer through feedback to an intracavity electro-optic modulator. The additive contribution of the laser and the phase-lock loop (PLL) to the beatnoise phase noise is 10^{-10} rad^2/Hz for frequencies below 3 kHz, which assesses the high purity of the microwave beatnote signal. The relative intensity noise (RIN) at each laser line is flat up to 1 MHz thanks to the lack of relaxation oscillations in OPSL. It is limited by pump intensity noise, at a level of 10^{-11} Hz^{-1}.

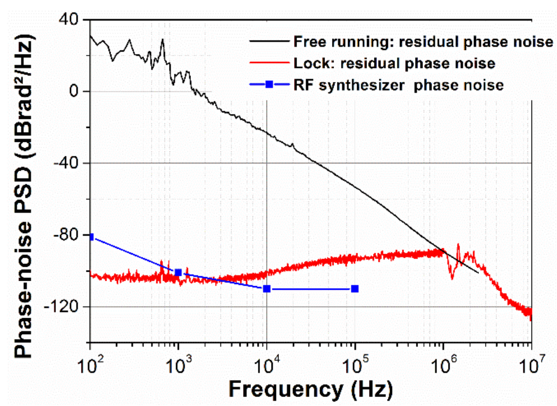

Fig. 1: Power spectrum density of the beatnote phase noise for the residual contribution (Laser + PLL) and the RF synthesizer contribution.

Finally, we have estimated the short-term clock stability that would be achieved with our laser source on a CPT Ramsey-like atomic clock[3]; a relative stability in the range of 3.10^{-13} over 1 s seems a realistic target with a reduction of the RIN contribution.

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[1] J. Vanier, "Atomic clocks based on coherent population trapping: a review," *Appl. Phys. B*, vol. 81, no. 4, pp. 421–442, Jul. 2005.
[2] F. A. Camargo et al, "Coherent Dual-Frequency Emission of a Vertical External-Cavity Semiconductor Laser at the Cesium D_2 Line," *IEEE Photonics Technol. Lett.*, vol. 24, no. 14, pp. 1218–1220, 2012.
[3] J.-M. Danet et al, "Dick effect in a pulsed atomic clock using coherent population trapping" , to be published in *IEEE Ultrason. Ferroelectr. Freq. Control*, 2014.