Investigations for a Miniature Optical Frequency Reference Based on High-Contrast Sub-Doppler Resonance in a MEMS Cesium Vapor Cell

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Many of modern quantum technologies require the development of high-performance and low-power consumption miniaturized devices such as laser systems, atomic clocks, magnetometers and other quantum sensors. These instruments are to date often based on the use of chip-size diode lasers and microfabricated (MEMS) cells filled with alkali atoms [1]. An interesting challenge concerns the development of miniaturized optical frequency references (OFR). Different approaches have been engaged in this direction. One of the most successful example is a rubidium microcell-based OFR, involving the two-photon spectroscopy technique. This approach has recently demonstrated a remarkable frequency stability level of 4.4×10^{-12} at 1 s [2].

The present study is focused on a simple alternative approach based on sub-Doppler spectroscopy (SDS) with counter-propagating light beams. We propose to use dual-frequency light beams with orthogonal linear polarizations and frequency difference $\omega_1-\omega_2 = \Delta_{hfs}$, with Δ_{hfs} the frequency of the atom ground-state hyper-fine splitting. First dual-frequency sub-Doppler spectroscopy (DF SDS) experiments have been performed with cm-scale cells [3,4]. In the present study, we present preliminary spectroscopy and frequency stability results of a laser stabilized using DF SDS with a Cs vapor microfabricated cell [5] (Fig.1a). An extended-cavity diode laser (ECDL) source and a Mach-Zehnder intensity EOM are used to obtain the dual-frequency light field. A forward beam goes through the cell and is then reflected by a mirror to create the backward beam.

(a) (b)

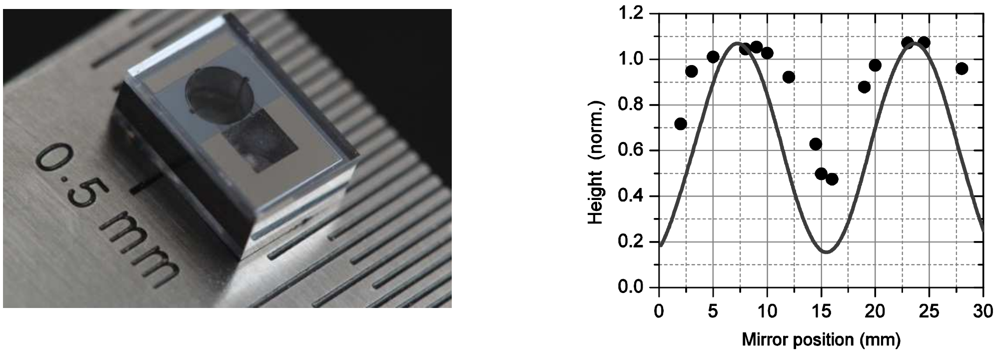

Fig. 1 (a) Photograph of a Cs microcell. The spectroscopy cavity has dimensions 2×1.4 mm. Photograph extracted from [7]. Courtesy of V. Maurice. (b) The effect of spatial oscillations of the sub-Doppler resonance height normalized to wide Doppler background.

An extended theoretical model taking into account the real structure of atomic energy levels and various nonlinear optical effects, such as optical pumping, light-induced coherences between magnetic sub-levels and multiple spatial harmonics of the atom's polarization has been developed [6]. Theory and experiments demonstrate spatial oscillations of the nonlinear resonance height (Fig.1b) with the mirror position change. This effect provides a bright advantage for short-length cells against standard cm-scale cells. Preliminary stability measurements of a laser beat-note between two lasers (one ECDL and one DFB laser) demonstrate an Allan deviation lower than $2\ 10^{-12}$ at 1 s and $3\ 10^{-12}$ at $4\ 10^{4}$ s. Latest results will be presented at the conference. The work was supported by Région Bourgogne Franche-Comté and Labex FIRST-TF. D. Brazhnikov thanks Russian Science Foundation (grant no. 17-72-20089).

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