Preliminary studies of Rb microfabricated cells for a two-photon Rb optical frequency reference

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***Summary*— Doppler-free two-photon absorption spectroscopy is employed to characterize the purity of rubidium vapor micro-fabricated cells. The observed broadening suggests the presence of impurities and contaminants in the cell.**

Keywords—Rubidium Two Photon Absorption; Doppler Free Spectroscopy; Frequency Reference; Vapor Cell; Microfabricated cell;

I. Introduction

Recent years have seen the development of compact and miniaturized vapor cell optical clocks based on the use of the two-photon absorption transition (TPT) of Rb atom at 778 nm [1-4], or 780-776 nm [5], with remarkable stability results.

In such experiments, the purity of the cell inner atmosphere is crucial to access the full potential of the two-photon transition natural linewidth, of the order of 300 kHz [6]. Indeed, the presence of contaminants or impurities induce a collisional broadening of the transition of the order of a few tens of MHz/Torr [7].

We present here preliminary characterization studies towards the demonstration of microcells compatible with the development of an optical frequency reference using the Doppler-free TPT resonance of Rb at 778 nm. These microcells are fabricated similarly to Cs dispenser-based cells [8], but use Rb dispenser pills instead.

The reported tests aim to assess the cell purity through TPT resonance linewidth measurements. Results are compared with the ones obtained from an evacuated commercial glass-blown Rb cell.

II. Methods/Results

The experimental TPT setup involves a laser source composed of an extended cavity diode laser (ECDL), tuned at 778.1 nm, an optical isolation stage, and an acousto-optical modulator (AOM) employed to control the laser power. After the AOM, the light can be sent either in a glass-blown Thorlabs Rb vapor cell, or in a micro-fabricated Rb vapor cell. All tested cells contain a natural mixture of ^{85}Rb and ^{87}Rb. The glass-blown cell is hold by heating rings used to heat the cell, while the micro-fabricated Rb cell is mounted in a dedicated physics package. The laser power at the cell inputs is in the order of 16 mW. Once the two-photon transition is excited, the 420 nm fluorescence is measured using a photomultiplier (PMT).

Figure 1 shows a trace of the PMT signal as a function of the laser frequency, measured for the commercial glass blown cell. The hyperfine splitting of Rb is here easily identified.

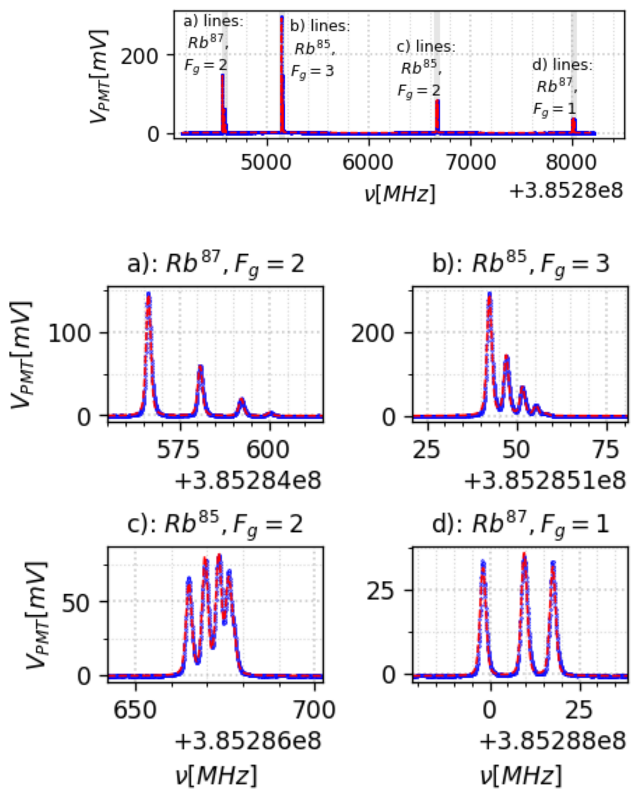

Figure 1: 778 nm Rubidium TPT spectrum in a high purity Thorlabs glass blown cell. The enlarged views in a,b,c,d) show the hyperfine line splitting

Fitting the peaks in Fig. 1 by a Voigt line profile leads to a linewidth for the observed resonances equal to (1040±70) kHz. The Voigt linewidth [9] can be further decomposed into two contributions: the Lorentzian linewidth due to the natural linewidth of the transition and collisional broadening, and the Gaussian linewidth due to the residual Doppler effect and instrumental broadening. A Lorentzian linewidth equal to (530±30) kHz and a Gaussian linewidth equal to (700±100) kHz were found from the fitting. The Lorentzian linewidth is about 200 kHz higher than the natural linewidth of 330 kHz.

This might come from helium from the atmospheric pressure that permeated and entered through the cell glass.

A similar test was performed for the micro-fabricated Rb cell. In this case, the peaks appear less-resolved, due to collisional broadening. Here, the measured Voigt profile is (3600±300) kHz, with a Lorentzian linewidth of (2350±70) kHz and a Gaussian linewidth of (2100±400) kHz. Compared to the results with the glass blown cell, the Lorentzian linewidth is much higher. This can be attributed to the presence of a larger amount of impurities in the microcell rubidium vapor. The increase in Gaussian linewidth might be due to the imperfect overlapping of the counter-propagating beams. Such investigations are currently pursued.

III. Conclusions

The preliminary results show that the measurement of the two-photon transition resonance is a useful non-destructive method to test the level of purity of vapor microcells. To date, significant line broadening is observed in Rb microfabricated cells, revealing the presence of impurities in the cell atmosphere. Cells with integrated non-evaporable getters [10] for the improvement of the cell inner atmosphere might be tested in the near future using the setup presented here. Latest results will be presented at the conference.

References

[1] K. W. Martin, G. Phelps, N. D. Lemke, M. S. Bigelow, B. Stuhl, M. Wojcik, M. Holt, I. Coddington, M. W. Bishop, and J. H. Burke, Compact Optical Atomic Clock Based on a Two-Photon Transition in Rubidium, Phys. Rev. Applied 9, 014019 (2018).

[2] Z. L. Newman, V. Maurice, T. Drake, J. R. Stone, T. C. Briles, D. T. Spencer, C. Fredrick, Q. Li, D. Westly, B. R. Ilic, B. Shen, M.-G. Suh, K. Y. Yang, C. Johnson, D. M. S. Johnson, L. Hollberg, K. J. Vahala, K. Srinivasan, S. A. Diddams, J. Kitching, S. B. Papp, and M. T. Hummon, Architecture for the photonic integration of an optical atomic clock, Optica **6**, 5, 680 (2019).

[3] V. Maurice, Z. L. Newman, S. Dickerson, M. Rivers, J. Hsiao, P. Greene, M. Mescher, J. Kitching, M. T. Hummon, and C. Johnson, Miniaturized optical frequency reference for next-generation portable optical clocks, Opt. Express 28, 24708-24720 (2020).

[4] Z. L. Newman, V. Maurice, C. Fredrick, T. Fortier, H. Leopardi, L. Hollberg, S. Diddams, J. Kitching and M. T. Hummon, High performance compact optical standard, Opt. Lett. 46, 18, 4702 (2021).

[5] C. Perrella, P.S. Light, J.D. Anstie, F.N. Baynes, R.T. White, and A.N. Luiten, Dichroic two-photon rubidium frequency standard, Phys. Rev. Appl. 12, 054063 (2019).

[6] F. Nez, F. Biraben, R. Felder and Y. Millerioux, Optical frequency determination of the hyperfine components of the $5S_{1/2}$ – 5D3/2 two-photon transitions in rubidium, Opt. Comm. 102, 432-438 (1993).

[7] N. D. Zameroski, G. D. Hager, C. J. Erickson and J. H. Burke, “Pressure broadening and frequency shift of the $5S_{1/2} \rightarrow 5D_{5/2}$ and $5S_{1/2} \rightarrow 7S_{1/2}$ two photon transitions in ^{85}Rb by the noble gases and N_2”, J. Phys. B: At. Mol. Opt. Phys. 47 (2014).

[8] R. Vicarini, V. Maurice, M. Abdel Hafiz, J. Rutkowski, C. Gorecki, N. Passilly, L. Ribetto, V. Gaff, V. Volant, S. Galliou and R. Boudot, Demonstration of the mass-producible feature of a Cs vapor microcell technology for miniature atomic clocks, Sens. Actuat.: Phys. A 280, 99-106 (2018).

[9] Y.C. Lee , H.C. Chui, Y.Y. Chen, Y.H. Chang, C.C. Tsai, Effects of light on cesium 6S–8S two-photon transition, Opt. Comm. 283 1788–1791 (2010).

[10] R. Boudot, J. P. McGilligan, K. R. Moore, V. Maurice, G. D. Martinez, A. Hansen, E. de Clercq and J. Kitching, Enhanced observation time of magneto-optical traps using micro-machined non-evaporable getter pumps, Sci. Rep. 10, 16590 (2020).