Mitigation of He permeation in microfabricated vapor cells with alumino-silicate glass and Al_2O_3 coatings

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***Summary*— We study helium permeation in micro-fabricated Cs vapor cells built with alumino-silicate glass (ASG) or borosilicate (BSG) windows, coated or not with Al_2O_3 layers. Gas permeation rate is derived from long-term measurements of the pressure-shifted clock hyperfine transition frequency in a coherent population trapping (CPT) clock setup. We find that the use of ASG windows reduces, in comparison with BSG, He permeation by more than two orders of magnitude whereas cells with Al_2O_3 coated BSG exhibit permeation rates up to 100 times smaller than those measured with bare BSG.**

Keywords*— Microfabricated cells; alumino-silicate glass; Al_2O_3 coatings; permeation rate; buffer gas; frequency stability;

I. INTRODUCTION

Vapor cell atomic clocks, magnetometers or gyroscopes permit the measurement of physical quantities with extreme precision [1-2]. With the progress of microfabrication technologies and integrated photonics, small-size, low-power atomic devices have become real and are now deployed in a large spectrum of applications [3].

Such chip-scale atomic devices relies on an alkali vapor micro-fabricated cell usually made of a silicon-etched cavity sandwiched between two anodically-bonded glass wafers.

In atomic clocks, variations of the cell inner atmosphere can be responsible for variations of the clock transition frequency through the pressure shift [4], leading to clock frequency instabilities. It is then of crucial importance to maintain alkali atoms in a well-controlled and stable cell inner atmosphere for stability performances.

Gas permeation through the cell glass windows was identified among the possible causes of the cell inner atmosphere evolution, especially when light buffer gases, such as helium or neon, are used [5-6]. In [7], the leak of Ne through the BSG windows of a micro-fabricated cell was estimated to limit the clock fractional frequency stability at a level of about 5×10^{-11} at 1 day, at a cell temperature of 80°C. In [8], the use of alumino-silicate glass (ASG) for micro-fabricated cells was demonstrated to reduce He permeation by more than two orders of magnitude, in comparison with borosilicate glass (BSG). In [8], helium permeation rate was extracted by measuring the positive drift of the frequency of a CPT clock due to the progressive entrance of helium into the cell (placed inside a chamber filled with He). In [9], the mid-long-term fractional frequency stability of a pulsed Cs-Ne microcell atomic clock was improved by the use of a MEMS cell featuring ASG windows.

In this study, we report on measurements of helium permeation rate of glass windows of more than 25 micro-fabricated alkali vapor cells filled with He, and built with ASG or BSG windows, combined or not with Al_2O_3 layers. The permeation rate is extracted from routine measurements of the pressure-shifted clock frequency over weeks to months.

II. METHODS AND RESULTS

Helium permeation through the glass windows of micro-fabricated cells is measured with a CPT clock setup. The typical fractional frequency stability at one day of the clock is about 10^{-10}, leading to a resolution on the gas pressure variation of about 1 mtorr of helium per day [10]. In order to extend the number of tested cells, we have developed an experimental setup that embeds six cells packages on an motorized rotation platform so that each cell can be interrogated sequentially in clock configuration. The setup uses a unique and fixed optical path provided by a vertical-cavity surface-emitting laser (VCSEL) directly modulated at 4.596 GHz. The MEMS cell technology is comparable to the one described in [11]. Various cell wafers were developed with different glass substrate configurations.

Helium permeation rate is extracted from the fit with an exponential decay function of the clock frequency experimental data, using the gas permeation law [7-8]. Figure 1 shows an example of a clock frequency measurement of a Cs-He cell using BSG, at a cell temperature of 70°C, over about 40 days. In this example, the extracted permeation rate K is about 5.8×10^{-19} $m^2.s^{-1}.Pa^{-1}$.

Our measurements show that the deposition of Al_2O_3 coatings onto BSG reduces He permeation rate by a factor up to 100 in comparison with bare BSG. Despite some dispersion in the measured performances for BSG cells coated with Al_2O_3 layers, attributed to the different atomic layer deposition (ALD) processes used, our results tend to demonstrate that Al_2O_3 coatings, known to slow down alkali consumption and then its disappearance in MEMS cells [12-13], are also able to mitigate He permeation in MEMS cells.

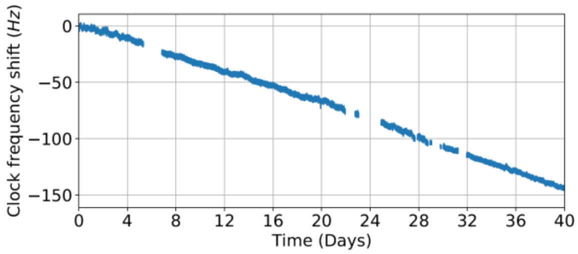

Figure 1: Temporal trace of the clock frequency for a Cs-He cell with BSG windows.

ASG is found to reduce He permeation with a permeation rate lower than $2x10^{-21}$ $m^2.s^{-1}.Pa^{-1}$ at 70°C. In comparison with BSG, the He permeation is reduced by more than two orders of magnitude, in correct agreement with results reported in [8]. Our studies also allow the extraction of the energy of activation of ASG, not reported in the literature to our knowledge.

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