Microfabricated vapor cells for miniature atomic clocks based on post-sealing activated cesium dispensers

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Abstract—**We report techniques based on cesium dispensers to fill microfabricated vapor cells for miniature atomic clocks applications. Two main types of dispensers are considered, which take the form of pills or paste. Whereas the pill contains a large quantity of Cs, the paste is more compatible with wafer-level fabrication. In both cases, the main advantage is the release of the cesium vapor only once the cell has been sealed, ensuring an optimal cell fabrication. Activation is thus performed through local heating of the dispenser with a laser. Cells using both dispenser types are shown to be compatible with atomic clocks requirements, namely a clock frequency instability below 1 x 10^{-11} at one day integration time.**

Keywords—alkali vapor cells; alkali vapor dispensing; miniature atomic clocks

I. Introduction

Microfabricated alkali vapor cells are one of the main components of miniature atomic clocks. The advent of such miniaturized clocks has been partly allowed by microelectromechanical systems fabrications means, providing small and low-cost cells [1]. The latter are often based on silicon, in which cavities are etched, and glass, used to sandwich and thereby seal the cavities. Although this architecture is now being used by several actors, main differences still lie in the cell filling of alkali metals and buffer gas, for which various solutions have been proposed.

In early attempts, barium azide and cesium chloride were introduced in the cells before sealing, but it led to atmosphere instability because of recombination of nitrogen with barium [2]. Then, another solution consisted in pipetting elemental cesium in the cells, in order to avoid trapping any precursor after sealing. This approach yielded a much more stable atmosphere [3]. Nevertheless, the cells were filled one by one, and it was consequently later proposed to employ an array of micromachined nozzles aligned with the cell one [4].

A technique, more compatible with wafer-level fabrication, is based on cesium azide (CsN_3) [5]. In this case, the compound, is deposited by evaporation through a shadow mask, over the entire cell wafer. After anodic bonding, UV radiation is used to decompose the compound into elemental alkali metal and nitrogen. An alternative to deposit Cs azide is to dilute it in deionized water and pipetted it into the cells [6, 7]. Yet, the quantities of Cs and N_2 being linked, the consumption of Cs during cell passivation might not be compensated for the nominal N_2 pressures.

Our approach was thus to insert a Cs dispenser in the cells. Such dispenser has the main advantage to remain inert at the temperature of anodic bonding (typically 350°C) ensuring an optimal and hermetic sealing. Hence, once the cells are closed, a high power laser diode is used to locally heat the dispenser above 600°C, temperature at which the reduction reaction of the precursors starts and releases pure Cs vapor [8, 9]. Another advantage is that Cs quantity is not linked with buffer gas pressure as, e.g., in the cesium azide based solution.

In this framework, two different types of dispensers have been tested. On the one hand, we used a solid cesium dispenser (trade name Cs/AMAX/Pill/1-0.6 from SAES Getters) taking the form of a pill. It is composed of a zirconium-aluminum alloy powder mixed to chromium-free cesium precursor. This type of dispenser provides robustness and cell batches filled by this manner have already shown reliability over several years. Nevertheless, pills dispensers still presents several drawbacks. First of all, their insertion in the cell preform is a slow process and can be impeded by the tendency of pills to pick up ambient humidity and to disaggregate after a while. Secondly, pills are relatively cumbersome and the cavity hosting them is quite large. It typically occupies half the cell volume [10] and prevents decreasing the cell size.

On the second hand, we employed more recently a cesium dispensable paste [11]. This paste can more conveniently be deposited using conventional liquid dispensing techniques such

as screen or stencil printing, spray coating, micro-drop dispensing, stamping or inkjet printing. Such deposition techniques are more suitable for wafer-level production than pick and place solutions. Unlike dispenser pills, the paste can be patterned at the desired size so that the cell volume can be reduced. The paste was specifically developed and provided by SAES Getters. It is a proprietary chromate-free formulation composed of an organic-inorganic mixture of cesium molybdate (Cs_2MoO_4, Zr-Al alloy powder, a stabilizer and a binder). Once deposited and dried at room temperature, the paste can be consolidated through a heat treatment (typically at 200°C for 1 hour). Like for dispenser pills, a high-power laser can be used to decompose cesium molybdate and produce elemental cesium.
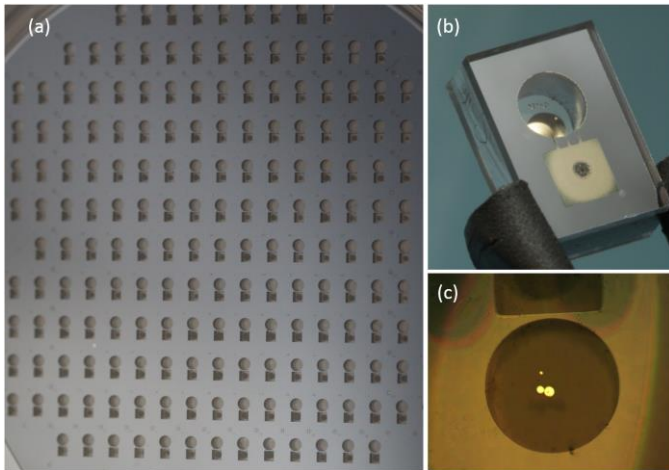

Fig. 1. Examples of (a) a 4" wafer including about 200 cells before dicing, (b) a cell with a high quantity of condensed Cs resulting from laser activation of a dispenser pill and (c) a reasonable quantity of condensed Cs.

II. CHARACTERIZATION & RESULTS

The fabricated cells have been characterized with a linear absorption spectroscopy setup where several cells can be measured in parallel over long period of time as well as with a bench-top clock prototype based on coherent population trapping (CPT).

Absorption spectroscopy shows that a cesium saturated vapor can be maintained within the cells for more than a year at 85°C. When using dispensers made of paste, a limited amount should be deposited within the cell. It is interesting to notice that cells containing a larger quantity of paste (which was then in contact with the Si sidewalls) did not show cesium absorption after a few weeks.

The cells were later on placed on a CPT based clock prototype, which includes a vertical-cavity surface-emitting laser (VCSEL) resonant with the Cs D_1 line and frequency-modulated at 4.596 GHz. In this case, the tested cells are filled with a neon buffer gas, in order to get a narrower resonance signal and a better frequency measurement resolution.

For the measurement of one cell filled with paste, the contribution of the AC Stark shift to the clock frequency has been discarded by measuring the clock frequency as a function of the optical power in order to extrapolate it at null laser power. Variations of such frequency over time are expected to partly correspond to the inner atmosphere variations of the cell. The fractional frequency drift rate recorded during nearly 2 weeks is estimated at around $-4.4 \cdot 10^{-12}$ per day, and thus makes the cell compliant with a clock fractional frequency stability objective at the level of $1 \cdot 10^{-11}$ at one day integration time.

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