Versatile microfabricated alkali vapor cells using local sealing

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***Summary*—We report on a new technique to form and seal microfabricated cells that alleviates some of the limitations imposed by current solutions. The technique consists in integrating single-use sealing structures that can be actuated through laser irradiation, either to isolate cavities from each other or to connect them. Inspired by the well-established glass-blowing techniques, it reproduces on a wafer the "make-seal" and "break-seal" features found in conventional cell filling setups. By allowing cells to be evacuated, filled and sealed after having been fully-formed, this technique opens new venues for atomic devices. Here, we demonstrate both features and present one use case where alkali dispensers are used in association with non-noble gasses despite their gettering ability.**

Keywords— alkali vapor cells; microfabrication; atomic devices;

I. INTRODUCTION

Atomic sensors or clocks are nowadays among the best devices to probe physical quantities or deliver stable frequency signals. The interrogation of hot alkali vapors contained in microfabricated cells, in particular, has provided a path toward miniature devices that can be deployed in a variety of systems and environments [1]. Microfabricated cells are key in making such devices small and accessible as they allow replacing traditional glass-blown cells by cheap chip-size components. To structure them, the use of silicon and glass wafer stacks assembled by anodic bonding has been widely adopted [2], but various solutions have been proposed to fill them with alkali vapor and buffer gas, each with its pros and cons. In many solutions, having pure alkali metal during sealing is avoided to prevent its reaction or evaporation. For this purpose, the alkali metal can be introduced inside the cell under a stable form (alkali chromate [3] or molybdate [4], azide [5] or chloride [2]), which can eventually be reacted by external irradiation in order to release alkali vapor. However, none of these techniques successfully meet the needs of all atomic devices. For instance, azide, due to its fixed stoichiometry, typically imposes large amounts of buffer gas, whereas alkali molybdate-based dispensers, which contain a Zr/Al getter, prevent gasses such as nitrogen from being used.

In this context, we propose a new technique to lift the limitations associated with current cell microfabrication techniques. It consists in transposing the make-seal and break-seal features commonly found in glass cell fabrication assemblies into wafer-integrated structures. Such structures allow connecting or hermetically isolating inner cavities [7]. This solution offers many advantages, such as the ability to use a single dispenser to fill tens of cells, to introduce gasses that were not compatible with the getter, or to target a higher vacuum inner atmosphere.

II. METHODS/RESULTS

We developed two types of seals. The first one, the make-seal, consists in a thin glass membrane that can be deflected to seal the port of an underlying microchannel. The deflection is achieved by locally heating and melting the membrane with a CO_2 laser as it undergoes a pressure difference. Hermetic sealing is achieved when the membrane touches and fuses with the glass substrate around the port of the channel, forming a ring-shaped sealing area. This structure can be made by standard micromachining processes such as anodic bonding, deep reactive ion etching and laser ablation.

We designed a wafer layout where a single source of alkali metal feeds an array of cells, each featuring a make-seal structure, through a network of microchannels (Figure 1). We used a cesium pill dispenser to act as a source and we monitored the establishment of the atomic density after activating the pill. After a while, a saturated vapor is obtained in the cells and cesium droplets are observed. The cells are then individually sealed using the make-seals. Finally, the cells are diced, resulting in 4 mm x 6 mm chips with pure Cs vapor and no dispenser.

The second type of seal, the break-seal, consists in a thin silicon wall separating an auxiliary cavity from the main cavity of the cell. The wall initially provides an hermetic seal

Figure 1: An array of microfabricated cells featuring make-seals connected to a common source of cesium (before sealing and dicing).

and can consequently be broken by various means. Here, we use an ablation laser to breach the wall without compromising the overall hermeticity of the cell.

To demonstrate this feature, we designed a layout where several auxiliary cavities surround the main cavity of the cell. Since the auxiliary cavities are blind holes, they can be filled with buffer gas at the first anodic bonding step, while the second bonding step defines the content of the main cavity of the cell, which in our case was evacuated. After introducing cesium vapor, we use the break-seals to release the content of the auxiliary cavities into the cell cavity.

Linear absorption and CPT spectroscopy is performed to assess the hermeticity, on the one hand, of the make-seal after the seal is made and, on the other hand, of the break-seal before the seal is broken on the long term.

III. DISCUSSION/INTERPRETATION

Combining make-seal and break-seal structures offer novel possibilities. We demonstrate here an immediate benefit: the ability to mitigate the major limitations imposed by pill-dispensers. While dispenser pills can be relatively costly, tedious to insert and cumbersome, we show that a single dispenser can be used to fill multiple cells. Besides, a quenching gas such as nitrogen can now be introduced within the cells without being absorbed by the pill [8].

Other use cases can be envisioned. For instance, for chip-scale atomic clocks based on microwave transitions, various gas mixture ratios can be obtained at the same time, providing cells targeting different operating temperatures [9].

External sources of atomic or molecular species can be envisioned providing new solutions when dispenser pills or stable reactants are not readily available or when electric discharge through the buffer gas prevents anodic bonding from being used.

IV. CONCLUSIONS

By transposing the techniques used in conventional vapor cell fabrication to microfabricated cells, we have proposed a more versatile way of making microfabricated vapor cells alleviating the shortcomings of current techniques. In the future, we will work on reducing the footprint of the make-seals and improving the yield by experimenting with different dimensions and materials. Next, we will focus on ultra-high vacuum regimes and we will investigate its ability to seal a cell under vacuum while minimizing outgassing, which is relevant for optical frequency references [10] and passively pumped cold-atom devices [11].

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