Advances of Chip-Scale Atomic Clock in Peking University in 2021

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***Summary*—Chip-scale atomic clocks (CSACs) are widely used in portable and mobile applications, because of their small volume, low power consumption and high frequency stability. In order to make the physics package smaller and more power-saving, micro-electro-mechanical system (MEMS) technologies are introduced to fabricate the physics package, such as wire-bonding, anodic bonding, reactive ion etching (RIE). In the last year, we have made great progress in MEMS vapor cell fabrication. The MEMS vapor cell has the external dimensions of 3 mm× 3 mm × 1.2 mm. The Cs metal is filled in the MEMS vapor cell which can be seen through a microscope.**

Keywords—chip-scale atomic clocks; CSAC; MEMS; vapor cell

I. INTRODUCTION

The discovery of coherent population trapping (CPT) phenomenon [1, 2] is the basis for the chip-scale atomic clocks (CSACs) concept. Through the interrogation of the CPT signal, the frequency of the temperature compensated crystal oscillator (TCXO) can be locked to the transition of alkali atoms without the use of microwave cavity. CSACs are mainly composed of two subsystems, one is the physics package where laser interacts with alkali atoms and the CPT signal is produced. Another is the locking circuits that conveys the frequency stability of the atom transitions to the TCXO. Defense Advanced Research Projects Agency (DARPA) is the first to put forward the concept of CSACs [3]. The use of VCSEL and MEMS vapor cell make the volume of physics package smaller than the traditional TO packaged laser and glass blown vapor cell [4, 5]. Researchers have proposed different ways to fabricate vapor cells based on different MEMS technologies, such as Cu-Cu bonding vapor cell [6], anodic bonding vapor cell [7], low-temperature indium-bonded alkali vapor cell [8]. Silicon and glass have a similar thermal expansion coefficient [9] and they are generally anodically bonded together. Here we show the MEMS Cs vapor cell fabricated by anodic bonding. The MEMS vapor cell has a dimensions of 3 mm×3 mm×1.2 mm.

II. METHODS/RESULTS

The MEMS Cs vapor cell is consisted with a 300 μm thick top BF33 glass wafer, a 600 μm thick middle silicon wafer with micro-cavities and a 300 μm thick bottom BF33 glass wafer. The connections between the three wafers are performed by anodic bonding under piston pressure. The micro-cavities are filled with Cs and buffer gas. The design of the MEMS Cs vapor cell wafer is illustrated in Fig. 1. The micro-cavities on the silicon wafer have a diameter of 1.5 mm.

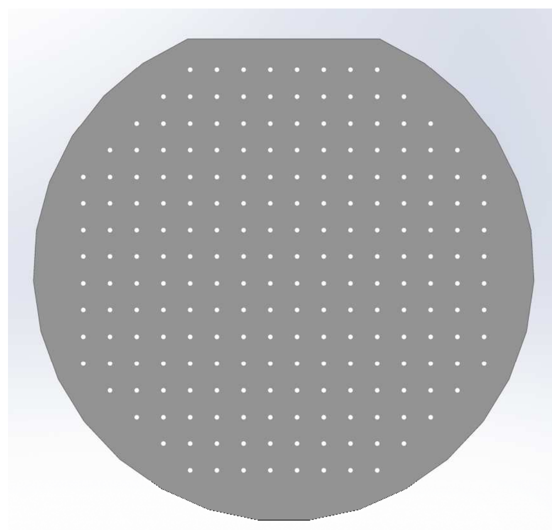

Fig. 1. The design of the MEMS Cs vapor cell.

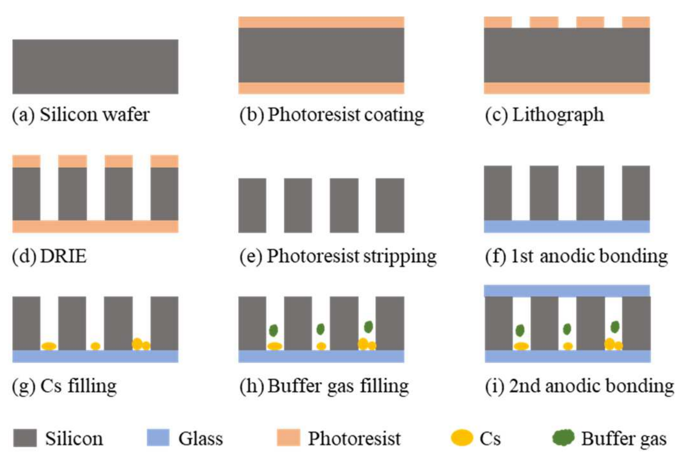

Fig. 2. The MEMS Cs vapor cell fabrication process.

The MEMS Cs vapor cell fabrication process is shown in Fig. 2. Anodic bonding has a high requirement for the bonding surfaces of the BF 33 glass and the silicon. The warp, the total thickness variation (TTV) and the surface roughness (Ra) of the silicon and glass wafers are required to be less than 20 μm, 1 μm and 1 nm, respectively. Contaminants on the surfaces of wafers will result in failure of anodic bonding. So, it is very important to clean the wafers before anodic bonding. The silicon and glass wafer are cleaned by standard radio corporation of America (RCA) cleaning process to remove impurities, as shown in Fig. 2(a). In Fig. 2(b), the photoresist is spin coated on the top and bottom surfaces of the silicon wafer. The photoresist on the top surface works as the mask during the deep reactive ion etching (DRIE). However, the photoresist on the bottom surface protects the tray from etching during DRIE. The photoresist is photo-lithographically patterned as shown in Fig. 2(c). Then, the silicon wafer is etched by DRIE and multiple micro-cavities are formed on the silicon wafer, as shown in Fig. 2(d). In Fig. 2(e), the photoresist is stripped from the top and bottom surfaces of the silicon wafer. The silicon wafer is cleaned again via standard RCA cleaning process before anodic bonding. In Fig. 2(f), the glass wafer and the silicon wafer are anodically bonded together under vacuum. The bonding temperature and the bonding voltage are 350 ℃ and 800 V respectively. Alkali metal Cs is dispensed in the micro-cavities as shown in Fig. 2(g). In Fig. 2(h), the anodic bonding chamber is evacuated firstly and then it is pressurized with buffer gas. At last, the 2nd anodic bonding is performed at vacuum as shown in Fig. 2(i).

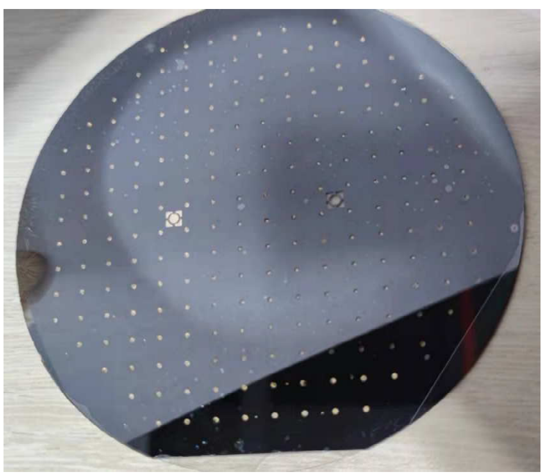

Fig. 3. The MEMS Cs vapor cell wafer.

The MEMS Cs vapor cell wafer is shown in Fig. 3. The gold-colored Cs can be seen in the micro-cavities. The Cs metal can be seen clearly through a microscope, as shown in Fig. 4.

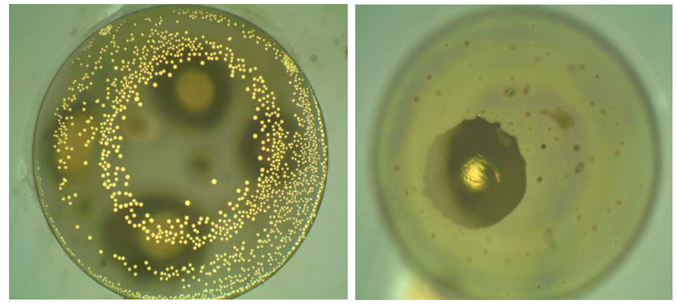

Fig. 4. The MEMS Cs vapor cell under the microscope.

III. Conclusions

Through the introduction of MEMS technologies of anodic bonding and DRIE, the MEMS Cs vapor cell is successfully fabricated by anodically bonding the BF33 glass and silicon wafer together. The Cs metal and buffer gas are sealed in the micro-cavities, which can be seen by a microscope. Compared to traditional glass blown vapor cell. The dimensions of the MEMS Cs vapor cell is greatly reduced to 3 mm×3 mm× 1.2 mm. There is no doubt that the volume of the physics package using the MEMS Cs vapor cell will be greatly reduced.

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