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Incorporation tests of micromachined gas cell using new solid Rb source into atomic clock system
新規固体ルビジウム源を用いたマイクロガスセルの原子時計システムへの組込検証

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1. Introduction

We are developing an atomic clock chip that can be mounted on a board, targetting an innovative next-generation communication infrastructure[1]. In an atomic clock system, the microwave oscillator is stabilized by optically acquired coherent population trapping (CPT) resonance from a cell in which alkali metal gas such as Cs or Rb is sealed. A MEMS gas cell manufactured by the wafer process has received great attention from the viewpoints of downsizing and cost reduction since the 2000s[2]. However, in recent years, traditional glass tubes have been incorporated into many miniaturized atomic clock modules as the gas cells[3,4]. A glass-based gas cell is filled with an alkali metal gas and a buffer gas at an ideal partial pressure and pinched off by fusing. Therefore, although it lacks mass producibility, the ideal gas partial pressure in the cell can be semipermanently maintained. On the other hand, in the MEMS gas cell, there is a problem in maintaining the gas partial pressure over a long time.

The MEMS gas cell is manufactured by anodically bonding glass to a silicon cavity. The alkali metal gas is generated by activating a source material in the postsealing process. The following two processes are well known for such activation[5,6]:

$$BaN_6+ACl \rightarrow A+3N_2+BaCl, \quad (1)$$

$$18A_2CrO_4+5Zr_3Al_2 \rightarrow 36A+9Cr_2O_3+5Al_2O_3+15ZrO_2, \quad (2)$$

where an alkali metal element is represented by A. However, from (1) and (2), it is confirmed that reaction residues other than an alkali metal gas and a buffer gas (N_2) are generated. These residues cause the long-term fluctuation of gas pressure inside the cell owing to adsorption and deteriorate the long-term frequency stability.

A third process that does not leave any residue uses an azide of an alkali metal[7]:

$$2AN_3 \rightarrow 2A+3N_2. \quad (3)$$

The azide preferably produces only alkali metal gas and N_2. There is no residue in the reaction chamber if the amount of source is appropriate. However, it is difficult to synthesize the alkali metal azide at the laboratory level since explosive hydrogen azide must be used as an intermediate in the synthesis[8]. Therefore, we attempted to newly synthesize the alkali metal azide cooperatively with a chemical manufacturer. Here, we report the results of tests of the incorporation of the micromachined gas cell into an atomic clock system using the newly synthesized RbN_3.

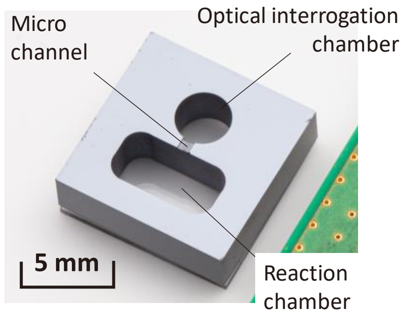

Fig. 1 Micromachined Rb gas cell

2. Fabrication of micromachined gas cell

Figure 1 shows the micromachined gas cell that we fabricated. As shown in this figure, the gas cell is cut into 1 cm squares. The gas cell has two cavities, a reaction chamber and an optical interrogation chamber that are connected by a microchannel. RbN_3 is placed in the reaction chamber, and after sealing, is irradiated with ultraviolet light to obtain an alkali metal gas. Ar and N_2 are used as buffer gases, and the partial pressure is adjusted by changing the internal pressure of the vacuum chamber for anodic bonding. The irradiation

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conditions are a power of 240 Wcm and an irradiation time of 1 h.

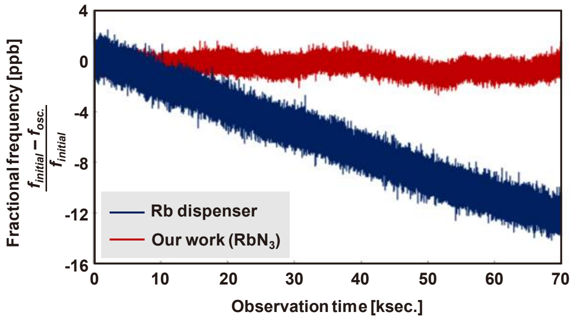

Fig. 2 Frequency fluctuation of the output signal of atomic clock system

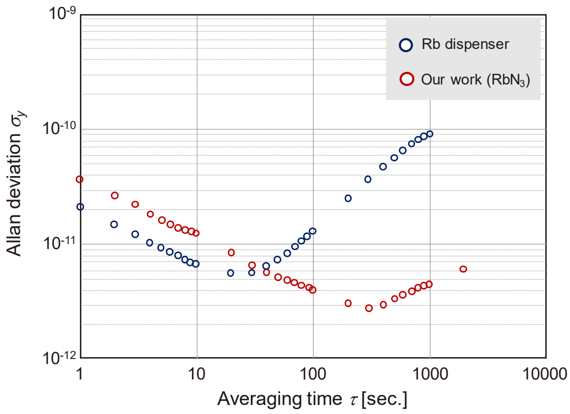

Fig. 3 Frequency instability

3. Incorporation test

The fabricated gas cell was evaluated on the atomic clock test bench constructed in our lab[8]. Here, for comparison, a gas cell in which Rb was generated by the (2) process was prepared. A mixture of the Rb compound and the inorganic reducing agent corresponding to the left side of (2) compressed in a tablet shape is commercially available as a Rb dispenser, and this was utilized in this study.

Figure 2 shows long time traces of the output frequency of the atomic clock system for gas cells using the Rb dispenser and RbN_3. From this figure, we see that when using the conventional dispenser, there is a slight linear frequency drift. This drift implies that the residue after decomposition adsorbs nitrogen of the buffer gas so that the pressure in the cell is gradually changed. On the other hand, when RbN_3 was used, the amount of residue was so small that no significant adsorption occurred, and the frequency fluctuation was suppressed. The frequency variation of the gas cell using RbN_3, compared with that using the dispenser, is about 1 to 2 ppb, but this is due to the temperature characteristics of the laser light source and was revealed by suppressing the pressure fluctuation in the gas cell.

Figure 3 shows the evaluation results of frequency stability using Allan deviation. This figure confirms that the use of RbN_3 suppresses the frequency drift due to the change in the gas pressure and that the long-term frequency stability over more than 100 s on average is apparently improved.

4. Conclusion

We are developing an atomic clock chip. One of the core parts of an atomic clock is the atomic resonator comprising a gas cell containing an alkali metal gas, and a pair of laser light sources and a photodetector to optically obtain resonance from the gas cell. There are two types of gas cell manufacturing methods: one that uses a fused glass tube and the other that uses a wafer process to seal the silicon cavity. The gas cell manufactured by the wafer process is highly mass-producible but has a problem with long-term stability. The cause of this problem is the residue of the solid source of the alkali metal gas in the postsealing process. The residue absorbs the buffer gas and decreases the internal pressure. We succeeded in independently synthesizing RbN_3 and applied it to an atomic clock system. It was shown that by using RbN_3, the frequency drift caused by adsorption can be suppressed and the long-term stability of frequency can be significantly improved.

Acknowledgment

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