Improved Lifetime of Miniaturized Vapor Cells in Atomic Clocks

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CSEM has successfully solved lifetime issues of MEMS-based rubidium vapor cells and has demonstrated lifetime estimations of 10-20 years.

CSEM has developed and improved over the past years the technology for miniaturized atomic clocks. One of the key components of an atomic clock is the vapor cell which contains minute amounts of an alkali metal, in our case rubidium (Rb).

We have developed a method to batch-fabricate vapor cells on a wafer scale with a very high yield (Figure 1). The fabrication comprises pipetting of dissolved rubidium azide (RbN_3) into cavities etched into a silicon wafer and closed on one side with a glass wafer, and sealing the cavities by anodic bonding under Ar atmosphere with a second glass wafer. Irradiation under UV light results in decomposition of the inert RbN_3 according to

$$2\,RbN_3 \rightarrow 2\,Rb + 3\,N_2$$

One of the characteristics of this fabrication method is that the quantity of metallic Rb inside the vapor cell is directly related to the N_2 partial pressure. Since the latter one must be limited, we have below 1 µg of metallic Rb inside a vapor cell which is much less than in the vapor cells of most competitors. As a result we have very quickly encountered lifetime issues with our vapor cells. The spectroscopic absorption signal of the Rb atoms disappeared after operation times of some days or even after only a few hours at a working cell temperature of 100°C.

In-situ and non-destructive Raman spectroscopy was developed [1] in order to evaluate the residual partial pressures of nitrogen, oxygen, and hydrogen inside the cells at different states of accelerated thermal aging. Careful observation of condensed metallic Rb droplets inside the vapor cell and software-based monitoring of the droplet size allowed us to estimate the evolution of metallic Rb quantity. Hence we could show that the aforementioned partial gas pressures did not change during accelerated aging, but the quantity of metallic Rb decreased. This let us to the conclusion that the vapor cells are leak tight, and that the mechanism of diminishing Rb quantity must be related to Rb diffusion into the borofloat glass. To support this hypothesis we developed different types of molecular vapor deposition (MVD) diffusion barrier coatings.

Figure 1: Rubidium vapor cell of 4×4 mm² and 1.6 mm thickness including Pt resistive heaters on both cell windows.

Figure 2 shows that an appropriate diffusion barrier stops the diffusion of Rb into glass very efficiently. The rate of diffusion of the Rb in the glass is expected to follow Arrhenius' law describing the temperature dependence of reaction rates. According to Arrhenius' law the reaction rate depends on the thermal activation energy of the process, a parameter that can be considered as an energetic barrier to be overcome for a reaction to proceed. Accelerated aging tests at several high temperatures are ongoing to estimate the activation energy of the rubidium consumption process. At this stage only a preliminary estimation is possible due to the excessively long test times involved. The estimation yields an Rb consumption of ≤0.01 µg Rb per year at the working cell temperature of 100°C (see Figure 3). Hence lifetime of CSEM's vapor cells exceeds 10-20 years, matching thus industrial standards.

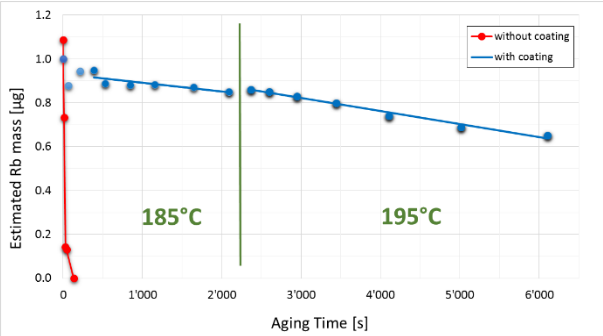

Figure 2: Rb consumption in vapor cells without (red graph) and with (blue graph) protective coating.

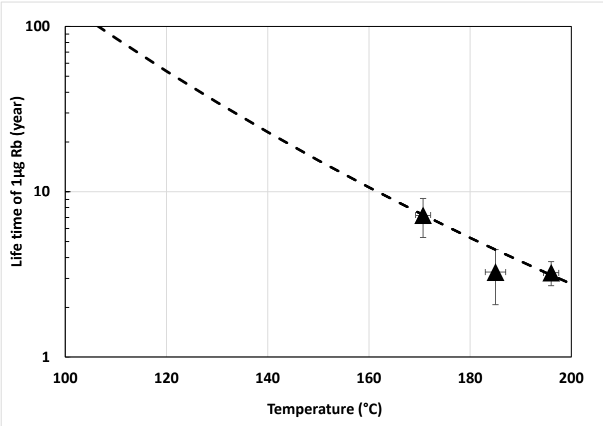

Figure 3: Arrhenius plot for the Rb consumption rate, preliminary estimate of the activation energy 50-60 kJ/mole.

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[1] J. Gobet, *et al.*, "Nondestructive Raman Spectroscopy for Hermetic Package Reliability Analysis", CSEM Scientific and Technical Report (2015), 30.