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Studies on He and Ne gas permeation in microfabricated cells using Al₂O₃ coatings

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The stability of cell-based atomic devices can be affected by the evolution of the cell inner atmosphere. The use of efficient gas permeation barriers is then of significant importance to enhance the performances of these instruments.

In a recent study¹, we have demonstrated the reduction of helium permeation through the borosilicate glass (BSG) and aluminosilicate glass (ASG) of MEMS vapor cells using Al₂O₃ thin-film coatings. Similarly to previous studies targeting a lower alkali consumption^{2,3}, 20 nm-thick Al₂O₃ layers were used.

Here, we report how helium permeation is influenced by the thickness of the Al₂O₃ coating⁴ deposited on BSG windows of the microfabricated cells. Coatings with thickness of 5, 10, 20 or 40 nm were tested. Permeation rates are derived from long-term measurements of the pressure-shifted transition frequency of a coherent population trapping (CPT) atomic clock. A strong reduction of He permeation, by about two orders of magnitude, is observed between 10 nm and 20 nm thicknesses whereas only a moderate reduction is obtained between 20 nm and 40 nm. For the best cell, with a 40 nm-thick coating, the He permeation rate is about 220 times lower than with uncoated BSG and only 1.8 times higher than for cells built with uncoated ASG windows.

Al₂O₃-coated cells with neon buffer gas have also been tested and showed a significant reduction of the permeation rate. A CPT clock, running the pulsed Symmetric Auto Balanced Ramsey (SABR) sequence⁵ in such Al₂O₃-coated Cs-Ne cell is demonstrated with a fractional frequency stability of 4×10^{-12} at 1 day. Despite a long-term still limited by light-shift effects, these results are comparable with those obtained from a Cs-Ne cell made with ASG windows⁵.

These results of more hermetic cells have motivated the development of Cs microcells filled with buffer gas mixtures for higher operation temperature. These cells rely on the break-seal approach described in Ref. ⁶. Successive openings of reservoir cavities yield tunability of the gas mixture turnover temperature to values higher than 80 °C. Studies are still in progress. Latest results will be presented at the conference.

¹ C. Carlé *et al.*, “Reduction of helium permeation in microfabricated cells using aluminosilicate glass substrates and Al₂O₃ coatings”, *J. Appl. Phys.*, vol. 133, p.214501, 2023.

² S. Woetzel *et al.*, “Lifetime improvement of micro-fabricated alkali vapor cells by atomic layer deposited wall coatings”, *Surf. And Coat. Techno.*, vol. 221, p.158-162, 2013.

³ J. M. Pate *et al.*, “Microfabricated strontium atomic vapor cells,” *Opt. Lett.*, vol. 48, p.383-386, 2023.

⁴ C. Carlé *et al.*, “On the reduction of gas permeation through the glass windows of micromachined vapor cells using Al₂O₃ coatings”, to be submitted 2024.

⁵ C. Carlé *et al.*, “Pulsed-CPT Cs-Ne microcell atomic clock with frequency stability below 2×10^{-12} at 10^5 s”, *Opt. Expr.*, vol. 31, p.8160-8169, 2023.

⁶ V. Maurice *et al.*, “Wafer-level vapor cells filled with laser-actuated hermetic seals for integrated atomic devices”, *Nature Micro. & Nanoeng.*, vol. 8, p.129, 2022.