CO_2-filled Hollow-Core Fiber Reference Gas Cells for Laser Frequency Stabilization at 2 μm

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Hollow-core photonic crystal fibers (HC-PCF) filled with a controlled gas pressure enable light-gas interaction over a long path in a very confined volume. As a result, they constitute an attractive solution for the realization of reference gas cells for laser stabilization onto molecular transitions that combine compactness and light weight in an all-fibered architecture that is particularly attractive for space applications. In the development of a frequency-stabilized seed laser at 2051 nm for a space-borne differential absorption lidar instrument, we have implemented a versatile modulation sideband locking scheme enabling a laser to be directly locked at an adjustable frequency detuning from the center of a CO_2 transition [1] in an all-fibered reference cell built around an HC-PCF.

Different configurations for the realization of tightly-sealed low-pressure CO_2 HC-PCF cells were investigated. The fabrication process relies on the permeation of gaseous helium through the walls of the silica fiber [2] to seal low pressure cells without contamination by ambient air. First cells were fabricated using a commercial hollow-core photonic bandgap fiber (HC-PBF) at 2 μm. To reduce the impact of interferometric noise, which was consequent with this fiber due to its multimode nature, a configuration made of a single-mode polarization-maintaining fiber spliced at the input of the HC-PCF and a multimode fiber at the output was adopted. An improved transmission profile was obtained using Kagomé HC-PCFs recently developed by Xlim and Glophotonics that operate with a different guiding mechanism based on inhibited coupling [3]. They typically provide quasi-single-mode propagation that leads to a smoother error signal for laser stabilization with strongly reduced interferometric noise (see Fig. 1). Different sealing approaches were considered with these large core (>50 μm) HC-PCFs, such as the use of an intermediate large mode fiber as well as end-caps. The different fabricated CO_2 cell configurations will be reviewed and their optical properties will be compared and discussed. Results of frequency stability of a 2051-nm laser obtained by modulation sideband locking with these different HC-PCF cells will be presented.

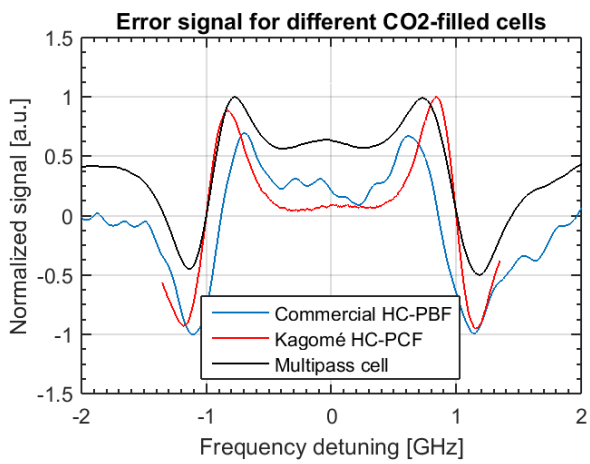

Fig. 1: Error signal of the modulation sideband locking method for laser stabilization at 1-GHz detuning from the center of the CO_2 R30 transition at 2051 nm obtained with different reference gas cells: a commercial HC-PBF (blue), a Kagomé HC-PCF (red), and a bulk multipass cell for comparison (black). A balanced detection was used with the two HC-PCF cells.

[1] S. Schilt, R. Matthey, K. Hey-Tow, L. Thévenaz, T. Südmeyer, *CEAS Space Journal* 9, 493–505 (2017).
[2] P. S. Light, F. Couny, F. Benabid, *Opt. Lett.* 31, 2538–2540 (2006).
[3] B. Debord, M. Alharbi, T. Bradley, C. Fourcade-Dutin, Y. Y. Wang, L. Vincetti, F. Gérôme, F. Benabid, *Opt. Express* 21, 28597-28608 (2013).