All-Fiber Molecular Frequency Reference at 2 µm based on a Versatile Laser Modulation Sideband Locking and a Hollow-Core Fiber Gas Cell

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Sensing of atmospheric trace gases is crucial for climate monitoring and to predict global climate changes. The required global coverage and spatial resolution have driven the studies of space-borne differential absorption lidar (DIAL) instruments to remotely monitor atmospheric gases from a satellite to ground. The performance of such instruments is notably determined by the frequency stability and accuracy of a low-power continuous-wave laser that seeds the pulsed laser transmitter. For a CO_2 DIAL, this reference laser needs to be stabilized with an adjustable frequency-detuning from the center of the probed molecular transition and the 2.05-µm spectral range is of high interest from a spectroscopic point-of-view [1].

We have developed an all-fiber modulation sideband locking set-up enabling a laser to be locked at a controlled frequency detuning from the center of the CO_2 R(30) transition at 2050.97 nm, selected for DIAL applications. The offset frequency can be directly tuned over a span ranging from some hundred MHz up to at least 3 GHz, which is the typical requirement for a space-borne CO_2 DIAL. The method is depicted in Fig. 1a. It consists of a distributed feedback (DFB) laser, followed by an intensity electro-optic modulator (EOM) driven by a radio-frequency signal at f_{EOM} provided by an amplified voltage-controlled oscillator (VCO). The EOM generates a pair of sidebands shifted by $\pm f_{EOM}$ that are coupled into a reference gas cell. The sidebands are dithered by modulating the VCO at a frequency $f_m \approx 40$ kHz to implement wavelength modulation spectroscopy (WMS). An error signal is produced by demodulating the reference cell transmission signal to servo-lock one of the sidebands at the center of the transition. As a result, the unmodulated laser carrier is detuned from the transition linecenter by the frequency offset f_{EOM}, which can be easily varied, thus making the system versatile.

In order to achieve a robust, mechanically-stable system with a light weight and small form factor, the reference gas cell is made of a hollow-core photonic crystal fiber (HC-PCF). The 11-µm air core diameter is filled with CO_2 at low pressure and sealed by fusion-splicing to standard optical fibers. The fabrication process relies on the permeation of gaseous helium through the walls of the silica fiber [2] to enable low pressure cells to be built and sealed without contamination by ambient air. The length of the HC-PCF (~3 m) and the CO_2 pressure (~20 mbar) have been selected based on spectroscopic simulations to maximize the WMS error signal. The corresponding CO_2 absorption line has a width of ~430 MHz and on-peak absorption of ~77% (Fig. 1b). In order to reduce the amplitude of interferometric noise in the HC-PCF transmission spectrum and in the corresponding error signal, a polarization-maintaining fiber and a multimode fiber have been respectively used as input and output fibers. The all-fibered gas cell is enclosed in a temperature-stabilized housing to minimize temperature-induced changes of the cell background signal. A balanced optical detection is also implemented to reduce the residual amplitude modulation resulting from the VCO modulation. The optical set-up is enclosed in a breadboard demonstrator of dimensions 25 cm x 25 cm x 5 cm realized for the European Space Agency (ESA).

The performance of the stabilized laser was assessed by optical beating with a coherent supercontinuum spectrum, generated in a nonlinear fiber from a fully-stabilized Er:fiber optical frequency comb (OFC) referenced to an H-maser. The frequency noise of the laser was obtained by analyzing the heterodyne beat signal using a frequency discriminator, showing a feedback bandwidth of ~2.5 kHz (Fig.1 c). The frequency stability of the laser is lower than 100 kHz in terms of Allan deviation for integration times over 1 s, determined by counting the beat frequency (Fig.1d). These results comply with the typical requirements for the reference seed source for a space CO_2 DIAL.

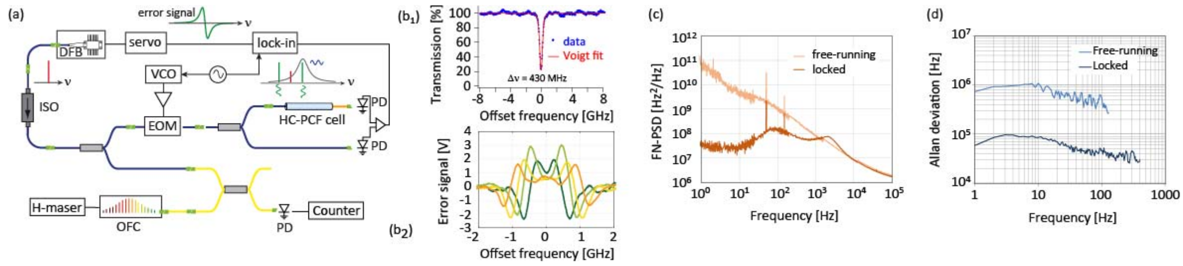

Fig. 1 All-fiber modulation sideband locking. (a) Scheme of principle (top) and optical frequency measurement with an OFC and a counter (bottom). (b1) Transmission of the HC-PCF gas cell (on CO_2 R(30) transition). (b2) Error signal for sideband locking at various EOM frequencies (500/700/900/1100 MHz, green to orange). (c) Frequency noise power spectral density (FN-PSD) of the free-running and locked laser. (d) Laser frequency stability.

References

1. G. Ehret, C. Kiemle, M. Wirth, A. Amediek, A. Fix, and S. Houweling, Appl. Phys. B **90**, 593–608 (2008).
2. P. S. Light, F. Couny, and F. Benabid, Opt. Lett. **31**, 2538–2540 (2006).

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