

Hybrid fiber/bulk laser development at 2.05 μm for space-based CO₂ monitoring by lidar

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ABSTRACT

This paper presents the development of a 2.05 μm hybrid laser system dedicated to space-based CO₂ monitoring using the Differential Absorption Lidar (DIAL) technique. Based on a mission concept inspired by prior work and ongoing efforts for Greenhouse Gas (GHG) monitoring by lidar, we derived instrumental specifications at the laser level to guide its development. By synergistically combining the compactness and alignment-free nature of fiber-based systems with the high-power capabilities of free-space approaches, we propose a so-called hybrid laser architecture that represents a significant asset for space missions compared to classical free-space oscillators. We detail the laser design and discuss the technical choices made to achieve the required optical performance and space compatibility. To this end, minimizing the number of distinct components and using mature technologies helps mitigate risks for space demonstration. According to preliminary results, simulations and previous developments, we propose a lidar system capable of delivering pulse energies exceeding 30 mJ at a repetition rate of 500 Hz, while meeting the spectral and beam quality requirements for DIAL measurements. The present study is carried out within the framework of the Horizon Europe HALLOA (Hybrid Amplifier Laser for Lidar OperAtions) project.

Keywords: Lidar, Carbon Dioxide, DIAL, Hybrid laser, Optical fiber, Free-space amplifier

1. INTRODUCTION

The development of a Differential Absorption Lidar (DIAL) for monitoring greenhouse gas emissions from space poses significant technical challenges. This often requires a complex laser design, introducing substantial mechanical constraints. We tackle this issue by designing and developing a so-called hybrid laser architecture that synergistically combines the benefits of compact, alignment-free fiber-based systems with the high-power capabilities of free-space approaches.

The 2.05 μm spectral band is well-established for space-based CO₂ lidar measurement and is also particularly attractive for hybrid architecture that benefits from Tm-doped fibers which allow for a simple pumping scheme using double-clad and multimode pump diodes, and free-space Ho:YLF amplification that reaches its highest emission cross section at 2.05 μm . For DIAL applications, fiber amplification is mostly limited by Stimulated Brillouin Scattering (SBS) to tens of watts peak power in single-mode fiber and hundreds of watts for LMA (Large Mode Area) fiber representing respectively ten to one hundred μJ for 200 ns pulses. This performance is about two or three orders of magnitude below the requirements for an Integrated-Path Differential Absorption (IPDA) space mission (set to 40/55 mJ at a rep. rate of 50 Hz at 2.05 μm according to the A-SCOPE evaluation [1]). Bulk amplification in Ho:YLF crystal is performed using a pump fiber laser at 1.94 μm in a single-pass end-pumping scheme which strongly relaxes the mechanical constraints (no oscillation and no moving parts). In previous works from ONERA and LMD [2,3], with a moderated effort on the bulk part, we reached up to 10 mJ pulse energy, limited by crystal's LIDT (laser-induced damage threshold).

The present study is carried out within the framework of the Horizon Europe HALLOA project [4] and aims to design a hybrid laser system suited to the requirements of a space mission including optical performance (energy, repetition rate, pulse duration, spectral purity, etc.) as well as compatibility with the space environment (radiation, vibration and thermal cycling). Based on A-SCOPE heritage, we designed a lidar mission for CO₂ DIAL/IPDA (main product), H₂O and wind (secondary products) measurements to provide a top-notch evaluation of carbon emissions. The laser system features a

stabilized wavelength with a switching module for $\lambda_{ON}/\lambda_{OFF}$ measurements, a fiber pre-amplifier (including a specific wavelength stabilized pump diode development [5]) reaching tens of μJ for 200 ns pulses and two bulk amplifiers to achieve 30 mJ. Special attention is paid on the fiber part to demonstrate its compatibility with space environment supported by experimental evaluation under representative conditions. This work is a step toward a potential future lidar mission dedicated to CO_2 emissions inventories.

2. LIDAR MISSION AND LASER SPECIFICATIONS

The conventional technique considered for space-borne CO_2 lidar is the IPDA, i.e. an integrated column measurement using the ground reflectivity [6]. This usually guarantees a high signal to noise ratio on the lidar return power and enable reaching the required challenging precision on CO_2 concentration measurement. However, sources and sinks of CO_2 are located at the surface so that much of the variability in the concentrations lies within the lower troposphere, and even in the atmospheric boundary layer (first kilometer above the surface). Therefore, a space-borne CO_2 lidar should provide a measurement ideally within the boundary layer (DIAL configuration) or at least some information on the vertical structure of the atmosphere or the horizontal wind speed in addition to the column integrated measurement (IPDA). This is particularly important to reduce the uncertainty on surface flux estimates by atmospheric inversion [7]. Similarly, the required precision on IPDA measurement is usually more stringent (around 1 ppm, i.e. 0.25 % [6,8]) compared to the precision of a mean DIAL measurement in the boundary layer (around 4 ppm, i.e. 1%).

This defines the possible different scenarios for space-borne CO_2 lidar measurement. The target is DIAL measurement in the first kilometer of the atmosphere, i.e. in the boundary layer (ABL) using aerosol scattering, the breakthrough scenario is IPDA measurement using the ground reflectivity plus information on the vertical structure of the atmosphere (typically the ability to measure the ABL height and the horizontal wind speed profile) and the threshold scenario is a standard IPDA measurement with the typical specifications of ACDL (CO_2 lidar mission, 2022) or MERLIN (CH_4 French-German lidar mission [9]). The different scenarios are summarized in Table 1.

The numerical simulations use standard atmospheric conditions for temperature, pressure, humidity and particles extinction and backscatter coefficients from the ESA RMA model. The nominal conditions correspond to cloud-free condition, a flat terrain and a ground reflectivity of 0.03 sr^{-1} (surface albedo of 0.1). The solar zenith angle is 80° (background estimate) for a sun-synchronous 6:00–18:00 orbit (similar to the MERLIN mission). The laser Line Of Sight (LOS) is oriented 20° off-nadir across the orbit track, similar to the ADM-Aeolus mission scheme.

Table 1 : Lidar mission observation objectives

	Target	Breakthrough	Threshold*
CO_2 lidar measurement	DIAL	IPDA	IPDA
Additional measurements	Aerosol/clouds backscatter profile Boundary layer height Surface reflectivity Canopy structure Horizontal wind speed H_2O profile	Aerosol/clouds backscatter profile Boundary layer height Surface reflectivity Canopy structure Horizontal wind speed -	Clouds - - Surface reflectivity Canopy structure - -
Precision	4 ppm (1%) for DIAL < 1 ppm for IPDA	< 1 ppm	1 ppm
Accuracy	< 0.4 ppm for DIAL < 0.1 ppm for IPDA	< 0.1 ppm	0.1 ppm
Horizontal resolution	50 km	50 km	50 km
Vertical resolution	1 km for DIAL ** weighted column for IPDA	weighted column	weighted column

* Correspond to the A-SCOPE specifications of a CO_2 lidar mission

** This means a mean CO_2 concentration measurement in the first kilometre of the atmosphere, i.e. in the atmospheric boundary layer. In the free troposphere, the vertical resolution should be lower depending the content of particles

Based on the targeted scientific objectives, lidar performance models, and existing literature, a set of realistic but challenging instrumental parameters was derived and is summarized in Table 2. The telescope parameters are similar to the Aeolus mission. The optical filter bandwidth was reduced to the minimum possible given the spectral separation of 0.25 nm between λ_{ON} and λ_{OFF} wavelengths, that is to say 0.3 nm, to reduce the background noise. To be shot noise limited, one may assume that the detector Noise Equivalent Power (NEP) is lower than $0.5 \text{ fW/Hz}^{1/2}$ which is realistic but suppose a cooling at low temperature of HgCdTe avalanche photodiode [10]. Other possibility to obtain such NEP relies on parametric conversion from the 2- μm domain to the visible at 0.7 μm where standard low noise internally amplified detectors exist but will decrease the total efficiency of the system (standard efficiency for the conversion is 20%) [11]. Laser performance is similar to those encountered in A-SCOPE [1]. However, a different trade-off between pulse energy and repetition frequency have been chosen since pulsed fiber amplifiers operate better at higher repetition rate. Also, for wind speed retrieval using heterodyne detection, beam quality is an important parameter that strongly affects the measurement quality making it a more stringent parameter than in the A-SCOPE evaluation.

Table 2 : Lidar instrumental requirements at the different objective levels

	Target	Breakthrough	Threshold
Detection			
Telescope diameter	1.5 m	1.5 m	1 m
Optical filter bandwidth	0.3 nm	1 nm	1 nm
Overall transmission	60%	60%	60%
Detector NEP	$0.5 \text{ fW/Hz}^{1/2}$	$5 \text{ fW/Hz}^{1/2}$	$50 \text{ fW/Hz}^{1/2}$
Laser divergence	0.2 mrad	0.4 mrad	0.4 mrad
Telescope field of view	0.3 mrad	0.6 mrad	0.6 mrad
Laser			
$\lambda_{ON}/\lambda_{OFF}$ pulse energy	30 mJ / 10 mJ		
$\lambda_{ON}/\lambda_{OFF}$ pulse separation	< 300 μs		
Shot-pair rep. rate	500 Hz	100 Hz	100 Hz
λ_{ON} shift from R30 line	3.6 GHz		
Beam quality	$M^2 < 1.2$		$M^2 < 2$
Pointing stability	< 120 μrad at 10 s - Allan deviation		
Polarization	Linear – PER $\geq 20\text{dB}$		
Pulse duration	200 ns		
Frequency stability	< 100 kHz at 10 s - Allan deviation		
Spectral purity	> 99.95% within 1GHz		
OSNR (cross-talk)	> 40 dB		

3. LASER DEVELOPMENT AND TECHNICAL CHOISES

Based on laser requirements derived from mission and instrument objectives, the main technical choices for the laser system are presented and discussed hereafter. These concerns the seeding chain for frequency stabilization and wavelength switching, the fiber amplifier and the free-space amplifier. A general scheme of the complete laser system is provided on Figure 1.

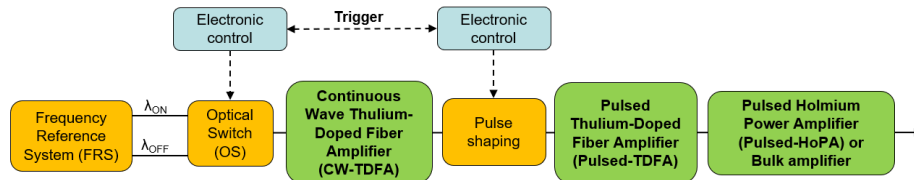


Figure 1 : General scheme of the HALLOA laser. Yellow boxes denote non-amplifying modules, green boxes denote optical amplifier and blue boxes denote electronic modules.

Seeding chain

The seeding chain provides continuous wave optical power to the subsequent amplifiers. This module ensures wavelength stabilization through the Frequency Reference System (FRS) as well as wavelength switching through the Optical Switch (OS) for DIAL operations.

The FRS relies on a master laser locked to the R30 CO₂ line center using a low-pressure CO₂-filled gas cell as an absolute frequency reference and the Pound-Drever-Hall technique [12] with external modulation. Two slave lasers (λ_{ON} and λ_{OFF} wavelengths) are locked to dedicated wavelength positions for the CO₂ space lidar application using beat notes between the master laser and a small portion of the λ_{ON} and λ_{OFF} seeders and using offset locking technique (Figure 2). The three seeds are semiconductor lasers associated with an external cavity to ensure a narrow linewidth emission (below 100 kHz). This feature is essential for coherent detection, hence for the wind speed retrieval, as it permits a high contrast in the heterodyne spectrum [13]. It is also an important feature to avoid bias on CO₂ retrieval with direct detection although less stringent (set to 50 MHz in A-SCOPE). The PDH technique with external modulation represents ease of use and is based on mature technologies (electro-optic phase modulator, moderate bandwidth detectors (~100 MHz class), and optical fibers and couplers). It therefore represents a low risk regarding space demonstration and qualification.

The offset locking technique relies on the frequency stabilization of the beat note between the master laser and the slave lasers. Thus, the master laser provides its stability to the slave lasers. This technique allows an offset as high as the detectors and electronic bandwidth allow. DIAL operation requires close λ_{ON} and λ_{OFF} wavelengths separated by a few GHz. In our case, the frequency shift limitation is driven by the photodiode bandwidth (15 GHz) but is enough to stabilize the λ_{OFF} laser outside the R30 line.

This architecture can be all-fibered which represents a major advantage for compactness and robustness. Furthermore, most of the components type are already flight-proven thus limit the risk of failure during qualification tests. This technique has already demonstrated the frequency stability requirement mentioned above [14].

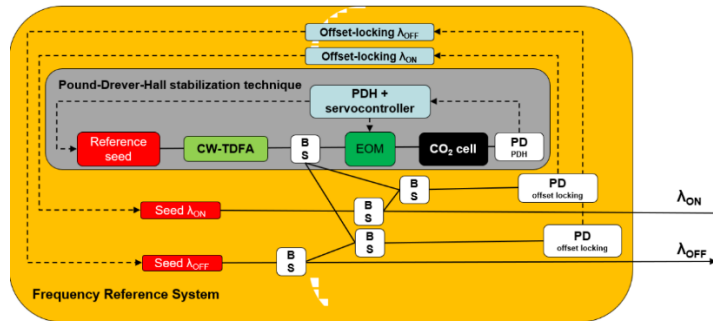


Figure 2 : Frequency Reference System (FRS) including the PDH stabilization (grey box) and the offset locking (yellow box). BS: fiber-coupled beam splitter, EOM: Electro-Optic Modulator, PD: photodiode.

The optical switch (OS) ensures wavelength switching between the λ_{ON} and λ_{OFF} wavelength for the DIAL operation. It consists of two (or more) fiber-optic inputs from the FRS in a continuous wave regime, and one output which sequentially lets pass each wavelength while blocking the other. The output signal is then sent through the amplifiers. A general scheme of the OS is provided in Figure 3.

The requirements for the OS are derived from the laser requirements summarized in Table 2. There are two key features for the OS: the switching time, i.e. the time delay to switch from one wavelength to the other, and its isolation (also called cross-talk) which is its ability to attenuate the blocked wavelength. The switching time requirement is derived from the pulse pattern (pulse pairs separated by 2000 μ s and $\lambda_{ON}/\lambda_{OFF}$ pulses separated by 300 μ s). The minimum time between two pulses is 300 μ s, so the wavelength switching time needs to be lower. The requirement is set to 30 μ s which is 10% of the limit that avoids any disturbance between pulses and provides margin for DIAL operations. The extinction ratio is derived from the optical signal-to-noise ratio (OSNR) requirement (>40dB) which represents the contrast between the active wavelength (at its peak) and the background. For the OS, this requirement can be understood as the contrast between the active wavelength and the blocked one. The OSNR requirement is simply applied to the isolation of the OS.

The mechanical-based system relies on MEMS (micro-electromechanical systems) with a micro-mirror that deflects the beam through different optical inputs/outputs. It provides very high extinction (>70dB) but the switching speed is usually

limited to milliseconds, suffers from a limited lifetime (up to $\sim 10^{10}$ cycles) and potential sensitivity to vibratory environments which makes this solution too risky for space applications.

The optical-based approach is mostly used in lidar applications and can rely on Electro-Optic Modulator (EOM - deflector, interferometer or polarization variator) or Acousto-Optic Modulator (AOM).

The EOM approach are widely used for the ease of use and low cost. It relies on an electro-optic material which varies the refractive index when a voltage is applied and then deflects, shift the phase or turn the polarization of the optical beam to vary the output intensity. It features low switching time (down to nanoseconds), moderate optical losses (~ 1.5 dB per stage) but relatively low extinction (~ 20 dB). Furthermore, the extinction is impacted by the external environment (mostly temperature) and must be stabilized with more or less complex feedback loop.

The AOM approach uses two AOMs (one per wavelength) as intensity modulators associated with a fiber coupler. The AOMs operate in opposition, one transmits while the other blocks. Both signals are merged through the OS output using a 50:50 fiber coupler. The AOM features a switching time in the order of tens of nanoseconds with an extinction better than 45 dB (up to 70 dB using appropriate drivers). Within the HALLOA project this last solution has been retained as it allows reaching the requirements expressed in Table 2 with a good margin, is easier to handle than the EOM (mainly regarding feedback loops required to maintained the isolation) and is acknowledge to be a very reliable component already demonstrated to space environment. The drawback of this technique is the high optical losses which represents about 7 dB (4 dB AOM and 3 dB optical coupler) which is compensated by the subsequent CW (Continuous Wave) amplifier. This solution combines high performance and reliability with simplicity and moderate number of components.

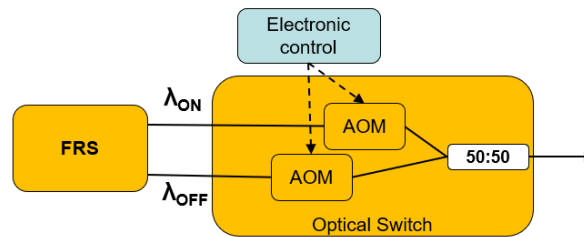


Figure 3 : Scheme of optical switch module using AOM as intensity modulator

Fiber amplification and pulse shaping

Fiber amplification takes as input the OS output and delivers amplified bell-shaped pulses. The fiber amplification architecture is similar to the one reported in [15] with one CW-amplifier followed by an intensity modulator for pulse shaping and two pulsed amplifiers. Pulse shaping is ensured by an AOM placed between the CW-amplifier and the 1st stage pulsed-amplifier. Pulse pattern as well as pulse shape can be easily modified as it is ruled by the voltage drive applied to the AOM. It provides a widely versatile system, operable under a variety of settings optimized to various observation requirements (e.g. short pulse for high spatial resolution, high Pulse Repetition Frequency (PRF) for high temporal resolution, or high energy for long-range measurement).

For DIAL applications, single mode operation is required and due to the single-frequency nature of the laser source, power scaling is limited by Stimulated Brillouin Scattering (SBS) around 50 W peak power in single-mode fibers. This limit can be circumvented initially by using a Large Mode Area (LMA) fiber, which allows reaching a peak power around 250 W. Secondly, it can be circumvented by broadening the Brillouin spectrum, for example by applying a stress gradient on the fiber. These techniques permit reaching the kW level in previous work [15]. However, the stress gradient method appears to be too risky for space applications due to possible mechanical deterioration of the fiber. Therefore, the final laser design only includes the use of LMA fiber for power scaling.

Fiber amplification at 2.05 μm can be done using thulium (Tm) doped fiber or holmium (Ho) doped fiber, both with different pumping schemes. Ho is usually pumped in-band with a 1.94 μm Tm: fiber laser and Tm can be pumped in-band with an erbium laser or by laser diodes emitting at 793 nm to benefit from the cross-relaxation process. For both, in-band pumping represents too complex solution as it requires an additional pump laser (with additional components to be space-qualified). Even if better, but still limited, performance regarding peak power could be reached with in-band pumping (especially in case of core-pumping), the simplicity of 793 nm pumping represents a major advantage for space demonstration and qualification as it significantly limits the number of different components. For DIAL applications from space, Tm-doped fiber using 793 nm laser diode pumping appears to be the best choice to successfully qualify the laser.

Additional information on the fiber amplifier architecture and performance can be found in the ICSO 2026 paper [16]. In the framework of the HALLOA project, the Tm fiber amplifiers are subject to representative environmental testing (radiation, vibration and thermal cycling) at component and full-scale level. Methodology and preliminary results can be found in the ICSO 2026 paper [17].

Free-space amplification

The bulk amplifier enables to close the gap between the peak power limitation encountered in the fiber amplifiers (hundreds of W) and the targeted peak power (150 kW to reach 30 mJ for a 200 ns pulse). Free-space amplification utilizes end-pumped Ho:YLF crystals. Pumping is ensured by a commercially available fiber laser emitting at 1.94 μm , with an electro-optical efficiency on the order of 20% (Futronics Laser GmbH). The use of YLF lattice is motivated by the highest emission cross-section at 2.05 μm , a particularly long upper-level lifetime, as well as the lowest upconversion rate among the most common matrices [2,3]. Upconversion is a phenomenon that limits the population of the excited state. By limiting the crystal doping, the upconversion rate is simultaneously reduced, but at the cost of lower pump absorption. A series of crystals are then used to obtain a gain medium with a total length of tens of cm. Numerical simulation of our system shown an optimization of the doping around 0.5 at%. This architecture is made possible thanks to the use of a fiber pump laser with good spatial quality to keep both beams well overlapped during the propagation. We can notice that the pump laser is built with a Tm-doped fiber laser and pumped at 793 nm as for the fiber amplifier which is in line with the limitation of different components for the complete laser system.

One important limitation in such an architecture is the Laser Induced Damage Threshold (LIDT), especially on crystal faces. With anti-reflection coatings, the LIDT is approximately around 5 J/cm² according to most suppliers and [14] but depends on pulse duration and PRF. This limitation requires using wider beams to remain under this limit, but it would also limit the gain and thus require a longer crystal length. To overcome this limitation, a solution is to cut the crystals at Brewster angle to avoid using AR coatings. In this case, the LIDT is over 35 J/cm² for 50 ns pulses according to [14] and permits to reach the pulse energy with a total of about 27 cm-long active medium. However, a Brewster angle cut imposes the use of a linearly polarized pump beam to avoid high reflection on s-polarization. Using a non-polarized laser can be done by separating the two orthogonal polarizations as in [18]. As a non-polarized pump laser is less expensive and less sensitive to back reflection, this solution represents an important asset for space qualification. Furthermore, the YLF lattice is birefringent and exhibits a polarization dependent emission cross section. By matching the signal and beam linear polarization and using an-cut Ho:YLF crystal, we optimize the amplification efficiency.

Figure 4 presents a schematic diagram of the bulk amplifier's optical setup. The amplifier consists of four Ho:YLF crystals doped at 0.5 at%. The first two crystals have anti-reflection coated faces, while the remaining two have Brewster-angle-cut faces. The unpolarized pump beam is split into two linearly polarized beams using a polarizer. A 45° dichroic mirror, which reflects at 1.94 μm and transmits at 2.05 μm , is used to combine pump beam 1 with the fiber amplifier's output beam before entering crystal no. 1. Another dichroic mirror, with opposite spectral properties, combines pump beam 2 with the 2.05 μm signal coming from the first three amplification stages. Afocal optical systems adjust the sizes of the pump beams to match the required beam waists inside Ho:YLF crystals no. 1 and no. 4. The beam waists of both the 2.05 μm signal from the fiber amplifier and the 1.94 μm pump beam 1 must be 250 μm at the center of crystal no. 1. Concave mirrors are used to refocus the 2.05 μm and 1.94 μm beams to maintain 250 μm waists at the centers of crystals no. 2 and no. 3. After crystal no. 3, and for pump beam 2, additional afocal optical systems expand the beams to obtain 400 μm waists at the center of crystal no. 4. A final dichroic mirror is used to separate the amplified 2.05 μm beam from the residual pump beam. The residual pump beams, transmitted through the dichroic mirrors, are collected by beam dumps.

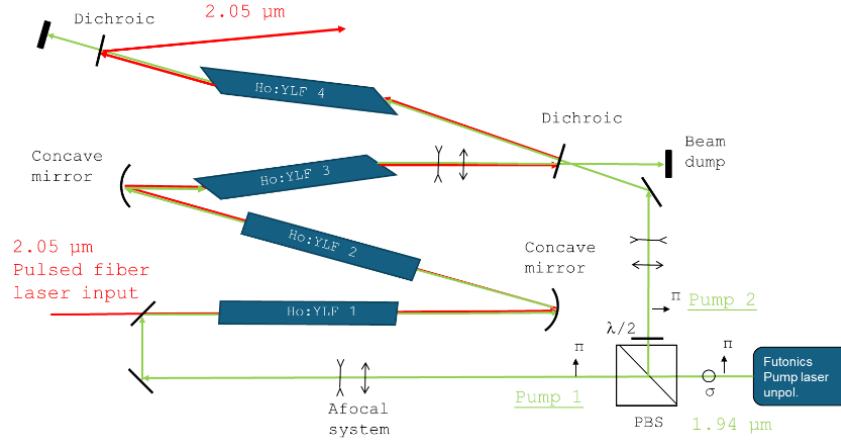


Figure 4 : Bulk amplifier design. π and σ denotes the polarization axes of the YLF crystals and are respectively parallel and perpendicular to the reflection plan. PBS: Polarization Beam Splitter

4. PERFORMANCE EVALUATION

The characterization of the performance of the frequency stability requires to use two identical and independent systems. Two seeds have been locked to R30 absorption line center using two identical PDH systems. The two seeds are then optically mixed to obtain a beat note which frequency is monitored with a frequency counter. The frequency of one seed is shifted by 50 MHz using an AOM in order to monitor positive and negative frequency deviations. The locking stability is characterized by the Allan variance of the beat note frequency divided by two (or a standard deviation divided by $\sqrt{2}$). It shows an Allan deviation under 10 kHz over 10^4 s.

The OS is characterized in terms of switching time and extinction ratio. The switching time is measured by monitoring the OS output rise and fall times when only one diode is switched on. It allows to monitor the time scale necessary to switch from one wavelength to the other with a simple setup. We found the switching time to be 70 ns from 0% to 90% and 5 μ s to 100% (far below the requirement) but this measurement was limited by the photodiode response. Isolation is measured using an optical spectrum analyzer with a dynamic range larger than 80 dB (Yokogawa - AQ6375). The extinction is calculated using the contrast between the spectra when the AOM is switched on and off. It shows for the arm 1 an isolation of 64 dB and 65 dB for the arm 2, which is 25 dB higher than the specification.

The fiber amplifier preliminary results shown a pulse energy higher than 50 μ J without SBS or self-lasing between the pulses. The detailed characterization is foreseen for the coming months.

The bulk amplifier is still under development. Numerical simulation predicts a pulse energy of 37 mJ for λ_{ON} and 12 mJ for λ_{OFF} , slightly higher than the requirement and using 30% margin on the pump laser. Main laser parameters are summarized in the table below.

Table 3 : Main laser performance

Laser parameter	Value
Frequency Reference System	
Frequency stability	<10 kHz at 10 s - Allan deviation
Optical Switch	
Switching time	< 100 ns (0-90%) < 5 μ s (0- 100%)
Extinction ratio	> 60 dB
Fiber amplifier	
Energy	50 μ J / 50 μ J
Stages	1 cw – 2 pulsed

Free-space amplifier	
Energies (<i>simulation</i>)	37 mJ / 12 mJ
Crystals number and total length	4 – 28 cm
Pump power	60 W (up to 90W)
PRF (double pulse)	0.5 kHz – 3kHz
Pulse duration	200 ns

5. CONCLUSION

This paper presents the development of a hybrid laser system dedicated to space-based CO₂ monitoring using the Differential Absorption Lidar (DIAL) technique. First, we outline the lidar mission concept for CO₂ monitoring at 2.05 μm . Inspired by prior work and ongoing efforts in GHG monitoring, the concept aims to enable direct measurement of near-surface CO₂ emissions via aerosol scattering (range-resolved measurement). Additionally, it targets secondary products such as horizontal wind speed, atmospheric structure, and H₂O mixing ratio to ensure a robust evaluation of CO₂ fluxes. Based on this concept, instrumental requirements were derived for the lidar design (including telescope size and detection parameters), with particular emphasis on the laser subsystem. Key specifications include a pulse energy of 30 mJ at a 500 Hz PRF, a 200 ns pulse duration, high frequency stability, and good beam quality. Special attention is placed on technical choices that balance performance requirements with space environment compatibility. Preliminary characterization shown suited performance for the FRS, the OS and the fiber amplifier (regarding pulse energy). Numerical simulations predict a pulse energy of 37mJ for the λ_{ON} wavelength and 12mJ for the λ_{OFF} wavelength at bulk amplifier output, slightly higher than the requirement while a 30% margin on the pump laser. Coming months will be dedicated to the complete laser assembly and characterization as well as the components and full-scale space demonstration of the fiber amplifiers.

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