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NUMERICAL SIMULATIONS OF A 2.05 µm Q-SWITCHED Ho:YLF LASER FOR CO_2 IPDA SPACE REMOTE SENSING

Jessica Barrientos Pellegrino*, Dimitri Edouart, Fabien Gibert, Claire Cenac

*Laboratoire de Météorologie Dynamique, Route de Saclay, 91128 Palaiseau Cedex, *Email: jessica.pellegrino@lmd.polytechnique.fr*

ABSTRACT

We report on numerical simulations of the performances of a 2.05 µm double pulse Q-switched Ho:YLF laser for the monitoring of CO_2 from space. A Q-switched Holmium laser set-up based on a MOPA configuration is proposed to fulfill the requirements of a IPDA space-borne measurement. Double pulse operation is considered to obtain a 250 µs delay time between the ON and OFF pulse emissions. Numerical simulations results show that up to 40 mJ ON pulse can be extracted from the Ho:YLF laser at a repetition rate of 350 Hz with an optical efficiency of 17 %.

1. INTRODUCTION

A particular interest is focused on space borne active remote sensing of greenhouse gases. Indeed, greenhouse gases (GHGs) measurements on a global scale are necessary to identify, locate and quantify GHGs sources and sinks in order to improve the comprehension of climate change. In this context, instruments able to detect, identify and quantify atmospheric trace gases such as CO_2, H_2O or CH_4 from space are required. Previous studies enable to identify the emitter specifications, in terms of emitted wavelength to address the most important greenhouse gases, output energy, frequency stability, and beam quality, were derived from the overall instrument error budget for such space borne measurements [1, 2[2]]. A peculiar aspect of the space borne monitoring of the atmospheric CO_2 dry-air mixing ratio, is a high accuracy on the ppm level or 0.25 % assuming a mean concentration of 400 ppm. To meet this stringent need, we have to address challenging technical requirements such as: (1) a transmitter delivering high energy pulses (higher than the mJ scale) at repetition rate (PRF) higher than hundreds of Hertz, (2) with a good spectral and spatial quality of the emitted radiation, (3) multiple wavelengths emission capability in single mode operation and (4) double pulse emission with a delay time between ON and OFF emissions of 250 µs [3]. Several approaches were investigated to fulfill such stringent requirements for space applications. Some of them are based on injection-seeded laser oscillators [4, 5] or on single mode optical parametric oscillator with optical parametric amplifier (OPO-OPA) source [6] at 2.05 µm for space CO_2 monitoring. Others approaches are based on injection-seeded optical parametric oscillators (OPOs) emitting around 1.57 and 1.6 µm, for CO_2 or CH_4 monitoring, respectively [7 - 9]. These examples are operating in a single pulse mode. However, to fulfill the need on the delay time between ON and OFF emissions, there are also developments and assessments studies on emitter operating in double pulse mode [10] or triple-pulsed mode [11] for DiAL measurement based on codoped Ho:Tm laser. These systems deliver high energy pulses but at a repetition rate lower than 50 Hz. Here, we propose a numerical study of the performances of a double pulse Q-switched Holmium laser with a repetition rate higher than 100 Hz dedicated to the atmospheric CO_2 monitoring from space.

2. Q-switched Ho:YLF laser SET-UP

As you can see on the Figure 1, the suggested Ho-doped fluorides laser set-up is based on a master oscillator-power amplifier (MOPA) configuration. This configuration enables to produce high energy level pulses (> 10 mJ) while maintaining a high spectral and spatial beam qualities as required for LIDAR applications. Ho-doped fluorides are more attractive laser materials than Ho:YAG as they have much longer upper laser level lifetimes (~ 14 ms) and higher peak emission cross-sections (1.6×10^{-20} cm^2 versus 1.2×10^{-20} cm^2) [12]. The typical emission bands of Ho-doped fluorides are more adapted to the monitoring of CO_2 from space. In addition, YLF and LLF thermal lens are weaker than YAG which enables to generate diffraction-limited beams even under intense end pumping.

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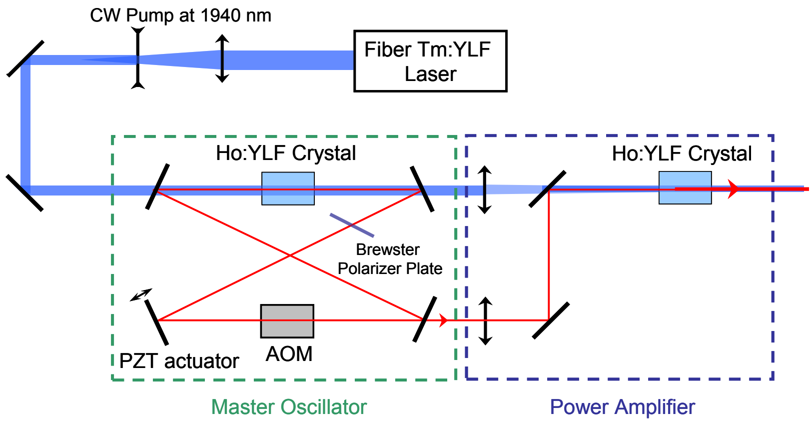

Figure 1: Ho-doped fluorides laser set-up proposed for double-pulse operation.

However, Ho:YLF and Ho:LLF have a stronger quasi-three-level nature than Ho:YAG [13].

The Ho:YLF master oscillator (MO) relies on a CW Tm fiber laser pump which has the main advantage to provide a simple and robust pumping architecture. A 0.5 at. % doped Ho:YLF crystal is put in a 1-m long ring cavity to limit up-conversion processes. This cavity configuration for the MO is expected to ease injection-seeding operation and avoid spatial hole burning to reach higher frequency stability. The PRF and the double pulse operation of the MO is controlled by the Q-switching rate of the acousto-optic modulator (AOM). Careful design and operation has to be done to avoid laser damage and reach the specified Ho:YLF emission wavelength around 2051 nm. This latter band is in competition with a second emission band around 2065 nm. It has been demonstrated that the laser emission frequency shifts with optical characteristics of the output coupler and could be further tuned to the specified wavelength by both accurate control of crystal temperature and selective spectral components inside the cavity [14]. YLF host crystal is birefringent and produces laser emission on both π and σ polarisations whatever the Tm fiber laser beam polarization is. Nevertheless, pumping on the π axis will be searched for more efficiency. The polarization of the emitted beam is chosen by inserting a Brewster polarizer plate inside the cavity. The Q-switched master oscillator is sequentially injection seeded to produce specific ON- and OFF- wavelengths, line width, pulse width, beam quality and adaptable pulse repetition rate [15]. To achieve space energy requirement, a power amplifier (PA) composed of a Ho:YLF crystal amplified the MO laser beam to energy level > 10 mJ.

3. NUMERICAL SIMULATION RESULTS

Double pulse operation, consisting in Q-switching the laser cavity two times in a row, has been simulated. We use a numerical model based on rate equations describing the dynamics of the laser manifolds involved in 2051 nm laser emission and quasi resonant pumping around 1940 nm [16]. Re-pumping during the delay time between ON and OFF pulses is considered in the simulations.

PRF (Hz)	ON pulse energy (mJ)	OFF pulse energy (mJ)	Optical efficiency (%)	Max. Fluence (J/cm^2)
100	14,5	4	3,5	5
250	14	3	8,5	5
350	13	3	11,5	5
400	12,5	3,5	13	4,5
500	12	4,5	15,5	4,5

Table 1 : Simulated MO parameter sets in double pulse operation to achieve asymmetric pulse energies. Length crystal : 50 mm.

Double-pulse operation assessment of the MO

As two pulses must be emitted in a row, high energy storage is required and an available pump power of 50 W is considered for the MO. To limit the maximal fluence to 5 J/cm^2, a 500 µm beam size is optimal in the MO. The simulation results show that MO laser performances slightly depend on the crystal length. As you can see in Table 1, High PRF operation is necessary to obtain high optical efficiency. Respective ON and OFF pulse energies depend on the intermediate cavity loss level after the first Q-switch. Assuming OFF pulse energies higher than 3 mJ to ensure good pulse energy stability, the maximal achievable ON pulse energy is limited to 15 mJ.

Most of the crystal gain is used to emit the high energy ON pulse (11-15 mJ). As a consequence, the OFF pulse is built with a low gain crystal and its duration is much longer than the other one.

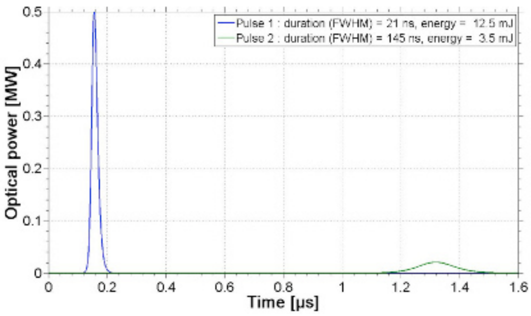

Figure 2 : Simulated pulse temporal profiles in double pulse operation.

ON pulse durations range between 17 and 27 ns and OFF pulse durations between 135 and 185 ns. Figure 2 displays an example of simulated pulse duration power profiles in double pulse operation. The first pulse is a high energy (12.5 mJ) and short pulse of 21 ns. Indeed, as it is generated with a high crystal gain, its built-up time is shorter than 200 ns. The second pulse is much longer (145 ns), has a low energy (3.5 mJ) and shows up after more than 1 µs delay time. This inability to generate short OFF pulses is a drawback of the double pulse operation. The AOM can be used to artificially shorten the OFF pulse duration but this will reduce the expected pulse energy and may affect the pulse spectral line width.

Double-pulse operation assessment of the MOPA set-up

Moreover, assuming these energy levels, a pulse amplifier gain between 2 and 3 is needed to answer the requirements for a space-borne measurement. So, MOPA set-up in double pulse operation has been simulated as a whole. Amplifying up to 40 mJ energy and keeping maximal fluence as low as 5 J/cm^2 is very challenging.

PA pump power (W)	PRF (Hz)	PA beam waist (µm)	ON pulse energy (mJ)	OFF pulse energy (mJ)	MOPA optical efficiency (%)
40	100	800	43	15.5	5.5
50	250	800	41	14	12
50	350	800	41	13.5	17
50	400	800	39.5	12.5	19

Table 2 : Simulated MOPA performances in double pulse operation.

All the MOPA parameters and resulting simulated performances that fulfill the pulse energy requirement and achieve the lowest maximal fluence (~ 6 J/cm^2) are gathered in Table 2. With 50 W pump for the PA stage and 800 µm beam size, the simulation shows that 40 mJ pulse energy is achieved at 350 Hz PRF with 50 mm long PA crystal length and 17 % optical efficiency. At 500 Hz PRF, 40 mJ pulse energy is obtained with 700 µm beam size but the maximal fluence reaches 8 J/cm^2. Pulse energies are not higher than 35 mJ with 800 µm beam size.

4. CONCLUSIONS

To fulfill the requirements of space-borne CO_2 monitoring, we propose a double pulse Q-switched Holmium laser based on a MOPA configuration. Double pulse operation is achieved by Q-switching the laser cavity two times in a row. The drawback of this method is the difference between the ON and OFF pulse duration that would probably affects LIDAR measurement. Nevertheless numerical simulations results are very promising. Indeed, they show that up to 40 mJ can be extracted from the Ho:YLF laser at a repetition rate larger than 100 Hz on the ON pulse while maintaining a maximal fluence around 5 J/cm^2. At 350 Hz PRF, an optical efficiency of 17 % is achieved. The development and the characterization of this emitter will start soon.

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