2-Micron high-repetition rate laser transmitter for coherent DIAL measurements of atmospheric CO_2

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1. Introduction

To reduce their CO2 atmospheric emissions, companies consider carbon capture and storage as a breakthrough technology. Total, the French oil company, is testing a CO2 capture and storage process in Lacq (south of France). The project includes an integrated CO2 capture process, CO2 transportation via a 30 km pipeline and CO2 storage into a depleted gas reservoir. The Sentinelle project, which gathers both public research institutes like LMD-IPSL and companies, is dedicated to prevent any leak from the reservoir. The DIAL lidar is a perfect tool to make an efficient atmospheric CO2 monitoring above the sequestration site. The new COWI (CO2 and Wind) lidar was funded in the frame of the Sentinelle project to make DIAL measurements above the CO2 storage site in the beginning of 2012. 3D scanning, good CO2 concentration accuracy (4 ppm) and high time (1 min) and space (100 m) resolutions are required. To fulfil the monitoring requirements, a new high power, high repetition rate 2 µm laser transmitter has been developed. The COWI lidar will be a transportable coherent DIAL system with also a wind speed measurement capability. Combined gas concentration and wind velocity measurements will be used to make range resolved flux measurements [1].

The laser transmitter uses a Ho:YLF crystal pumped by a commercially available Tm:fiber laser from IPG-Photonics. CW and Q-switched Ho:YLF laser with different linear [2] or ring cavity [3] configuration have already been designed and demonstrated as much as 65 % and 55 % of slope and optical-to-optical efficiency, respectively. Single frequency Q-switched operation has also been reported recently [4]. The mean powers of these lasers were limited to few watts.
In this paper, we present the experimental set-up of the laser transmitter and show some results in continuous and pulsed mode operations. One of the main objectives is to increase the power in single frequency Q-switched operation to a few tens of watts with respect to the simulated characteristics of DIAL transmitter for CO2 measurements. First attempts to get single mode operation will be shown. The cavity injection seeding has been implemented thanks to two different techniques: the ramp and fire technique and the Pound-Drever-Hall technique.

2. Experimental set-up

The experimental set-up is shown in Figure 1. The laser is a four mirror 1 m long ring cavity with a 8 cm long 0.5 % Ho:YLF crystal. Cavity mirrors around the crystal are flat mirrors coated for high transmitted pump wavelength and high reflected laser wavelength. The third cavity mirror is a concave mirror coated for high reflected laser wavelength and mounted on a PZT. The fourth mirror is a concave mirror coated for partially reflected laser wavelength. The pump laser is a 100-W-linearly-polarized Tm:fiber laser at 1939 nm (from IPG Photonics). The pump beam size at the collimator output is 4.5 mm. An afocal system reduces the pump beam size to ~1 mm to end pump the crystal along the pi-polarization. That size matches the cavity waist inside the crystal. The quartz plate at the Brewster angle polarizes the laser and set the laser wavelength around the Ho emission band at 2050 nm. A mirror reflects one output beam into the cavity to ensure unidirectional operation. The acousto-optic modulator (AOM) is used to get the pulsed regime and to inject the seed-laser inside the cavity through the Bragg diffraction beam. The injection seeded operation will use a Pound-Drever-Hall technique [5] and will enable to get single frequency pulses at appropriate wavelengths to operate the DIAL system.

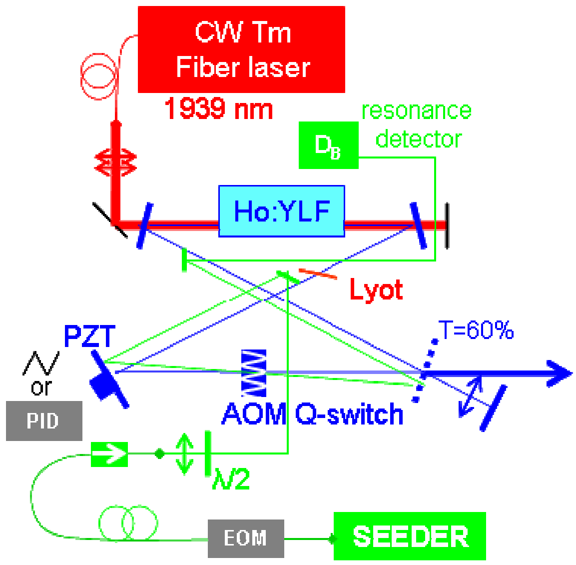

Figure 1. *Experimental set-up*

3. Laser performances

The laser naturally operates around 2064 nm and is randomly polarized. We use a quartz plate at Brewster angle to get a linearly polarized output beam. The quartz plate also acts as a Lyot filter to tune the laser wavelength around 2051 nm to reach the R30 CO2 absorption line.

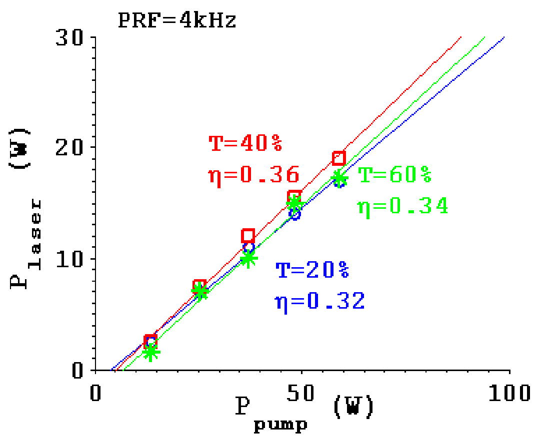

Figure 2. *Laser output power versus the pump power at 2051 nm, PRF=4 kHz, using different output couplers*

Using a T=20% output coupler, the laser delivers 18 W for 48 W of pumping in a CW operation with 50 % of slope efficiency. The threshold of the pump power is around 10 W. The laser performances in the Q-switch mode operation at 2051 nm, PRF=4 kHz and using different output couplers is shown in Figure 2. In the Q-switch regime, the laser power reaches 19 W for 60 W pump power. The slope efficiency reaches 36 % with the T=40 % output coupler. The pump power is limited to 60 W because of water vapour lines around 1940 nm. As the pump beam is absorbed, the pump efficiency decreases because of pump beam propagation perturbations. A dry air circulation around the pump path is currently developed to enable high pump power operation.

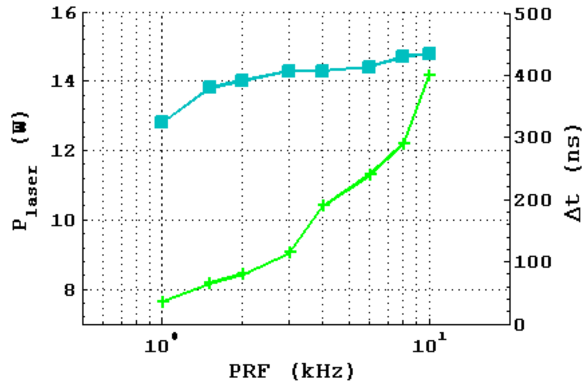

Figure 3. *Laser pulse duration (crosses) and power (squares) as a function of the pulse repetition rate for 48 W pump power.*

Between 2 and 10 kHz the average laser power is nearly constant around 14 W but the pulses energies vary from 13 mJ at 1 kHz to 1.5 mJ at 10 kHz (cf. Figure 3). As the pulse repetition rate increases, the crystal energy storage doesn't have the time to increase so the pulse energies decrease. Similarly, as the pulse repetition rate increases, the crystal gain gets lower so the pulse building time increases Below 2 kHz, the laser efficiency definitely goes down because the crystal gain starts to saturate. To take advantage of the wind speed measurement ability and make CO2 fluxes measurements, a trade-off between the pulse duration and the pulse repetition rate has to be found. The precision on CO2 mixing ratio relies on the number of independent samples in a range gate (the coherence time is limited by the laser pulse duration, see [6]) whereas the accuracy on velocity relies on the precision in the spectrum of the heterodyne signal. An optimum PRF of the laser seems to be between 2 and 4 kHz in order to keep a large number of temporal samples in a range gate and to keep, in the same time, a sufficient accuracy on velocity measurements [7].

3. Cavity injection-seeding

Single mode operation in the Q-switch regime is obtained thanks to injection-seeding techniques. A stable single frequency CW laser, locked to the center of the R30 CO2 absorption line, is injected into the ring cavity to ensure the single frequency operation (cf. Figure 1). The seeding is performed through the acousto-optic modulator first order. The cavity length is tuned thanks to the PZT so as to be resonant with the seeder wavelength. Two techniques are used to seed the power oscillator. The first technique is called 'the ramp and fire technique' [8]. The cavity length is swept thanks to the PZT. When the resonance peak is detected by the resonance detector, the ring cavity is Q-switched and seeded by the resonant seeder. Single frequency operation has been obtained thanks to the ramp and fire technique. However, as the laser pulse repetition frequency gets high (>2 kHz), the injection-seeding becomes difficult. At high laser pulse repetition rate, the PZT movement is very fast so the resonance is quickly lost. Morever, at high laser pulse repetition rate, the crystal gain is very low so the resonance peak becomes hardly detected and requires a higher seeding power. Another injection seeding technique is being implemented: the Pound Drever Hall technique [5]. Instead of being continuously swept, the cavity length is locked to a resonance position. The seeder frequency is phase-modulated by the electro-optic modulator (EOM). The demodulated resonance signal provides the error signal. A PID controller processes the error signal to adjust the cavity length at the resonance position. The PZT movement is limited close to the resonance position and the modulation-demodulation technique is very sensitive. This technique should be more appropriate for a high laser pulse repetition rate operation. The Pound Drever Hall scheme is currently being tested and the first results will be presented. We are also testing two different seeders: a DFB laser diode boosted by a fiber amplifier and a fiber laser from NP Photonics.

4. Conclusion

A high power, high repetition rate 2 µm pulsed laser operation has been demonstrated. The laser power reaches 19 W at a 4 kHz pulse repetition rate. According to DIAL simulations, the COWI laser fulfils the requirements for the CO2 monitoring above the sequestration site. A Pound Drever Hall injection seeding technique is being tested at high pulse repetition frequency.

5. Acknowledgements

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6. References

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