High repetition rate and frequency stabilized Ho:YLF laser for CO_2 differential absorption lidar

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Abstract: High repetition rate operation of an injection seeded Ho:YLF laser has been demonstrated. For 1 kHz operation, the output pulse energy reaches 5.8mJ and the optical-to-optical efficiency is 39% when the pump power is 14.5W.

OCIS codes: (140.3580) Lasers, solid-state; (140.3280) Laser amplifiers.

1. Introduction

Carbon dioxide (CO_2) has been recognized as one of the most important greenhouse gases. It is essential for the study of global warming to accurately measure the CO_2 concentration in the atmosphere and continuously record its variation. A Ho:YLF laser operating in the range of 2.05 μm can be tuned over several characteristic lines of CO_2 absorption. Experimentally, a diode pumped Ho:Tm:YLF laser has been successfully used as the transmitter of coherent differential absorption lidar for the measurement of CO_2 [1], where the repetition rate is 5 Hz and the pulse energy is 75 mJ. For coherent detection, high repetition rate is good for speckle averaging [2]. It will result in a low pulse energy requirement and highly precise measurements. However, a diode pumped Ho:Tm:YLF laser can not operate in high repetition due to the large heat loading and up-conversion. A Tm:fiber laser pumped Ho:YLF laser with low heat loading can operate in high repetition rate.

We have setup a theoretical model to simulate the performance of Tm:fiber laser pumped Ho:YLF lasers. For continuously wave (CW) operation, the high pump intensity (small beam size) is good for efficiency. For Q-switched operation, the optimal energy extraction relies on the pump intensity, pump volume, and pump duration (inversely proportion to the repetition rate). When the pump power from a Tm:fiber laser is 30 W, CW and Q-switched Ho:YLF lasers with different linear cavity configurations have been designed and demonstrated [3,4]. The CW slope and optical-to-optical efficiencies reach 65% and 55%, respectively. The Q-switched pulse energy is 30mJ at the repetition rate of 100Hz.

In order to avoid spectral hole burning and make injection seeding easier, a four mirror ring cavity is designed for the high repetition rate and single frequency Ho:YLF laser.

2. Experiment

Figure 1 shows our experimental setup. Our laser system is frequency stabilized in a master-slave configuration. The master laser, also called seed laser, is a CW operated single frequency Ho:YLF laser. The slave laser is a Q-switched Ho:YLF laser in a four-mirror ring-cavity configuration which is end-pumped by a Tm:fiber laser. The maximum output power of the Tm:fiber laser is 40W at the random polarization. Only 15W of pump power reaches the laser crystals along the π-polarization. In order to avoid damaging laser crystal, there are two laser crystals in the slave laser. The pumping beam first passes through a low doping concentration crystal (3cm length and 0.5% Ho:doping concentration) and then the high one (2cm length and 1% Ho:doping concentration). The optimal repetition rate of the designed slave laser is 1 kHz, considering the speed of data acquisition and signal processing. The cavity length is 1.88m. Cavity mirror M_4 is a flat mirror coated for high transmitted pump wavelength and high reflected laser wavelength. Cavity mirror M_5 is a concave mirror with a high-reflection coating for both pump and the laser wavelengths. Cavity mirror M_6 is a concave mirror coated for high transmitted pump wavelength and high reflected laser wavelength. The concave mirror M_7 reflects the extra pump beam back to the laser crystals for further absorption. The optimal output coupler has a reflection of 50%. The pump beam and laser beam are mode-matched in the laser crystals. The beam waists through the laser crystals is about

0.47mm in radius. The coolant temperature of laser crystals is 8.2^{o}C. The single passing diffraction efficiency of the Q-switcher is about 27%. The coolant temperature of the Q-switcher is 10^{o}C. For the master laser, the CW output power is 50mW. The online wavelength is 2050.967nm and the offline wavelength is 2051.023nm. Three Faraday isolators are inserted between the master laser and the slave laser for protecting the seed laser. For improving the success rate of injection seeding, the seed laser beam and laser beam are mode-matched in the laser crystals. Detector D_1 is to monitor the pump power. Detector D_2 is to capture the resonant signal for controlling the piezoelectric transducer (PZT).

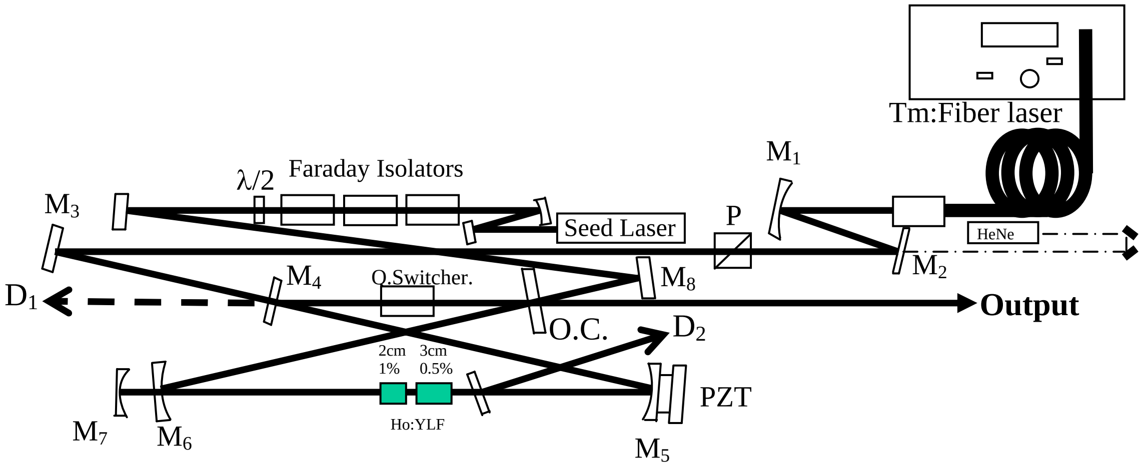

Fig.1. Experimental setup.

3. Laser performances

Fig.2 shows the laser performances from 1 kHz to 10 kHz operation. For 1 kHz operation, the output pulse energy reaches 5.8mJ, the pulse length is about 100nS, and the pump power measured by detector D_1 is 14.5W. For 10 kHz operation, the output pulse energy is 0.73mJ, and the pump power measured by detector D_1 is 15.8W.

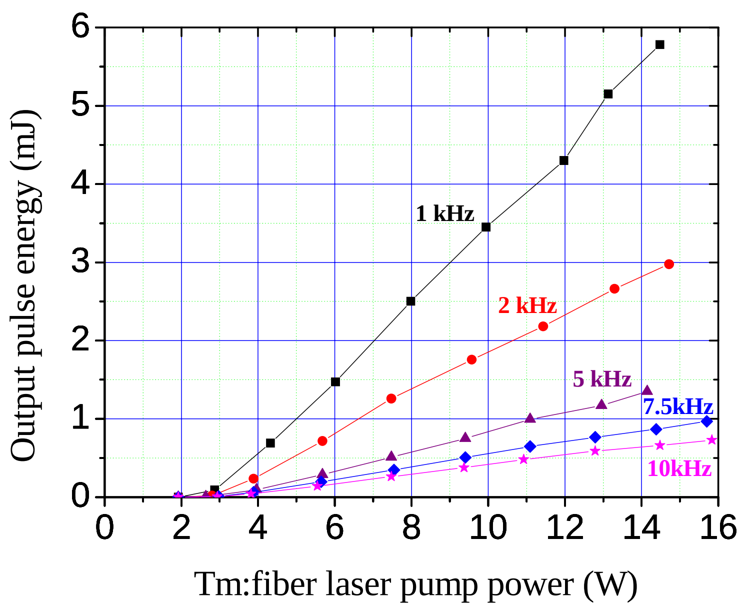

Fig.2. Output pulse energy versus pump power at different repetition rates.

If the operation rate is lower than 1kHz, the laser system has a Q-switcher hold-off problem when the pump power from Tm:fiber laser reaches maximum. After two cascaded Q-switchers are inserted into the ring cavity for improving hold off, at 500Hz operation the output pulse energy is 9.3mJ when the pump power measured by detector D_1 is 14.14W. For 100Hz operation, the output pulse energy can reach 30.8mJ when the pump power measured by detector D_1 is 12.86W.

Fig.3 shows the optical-to-optical efficiency at the different repetition rates. The optical-to-optical efficiency increases with the repetition rate. The maximum optical-to-optical efficiency for Q-switching mode approaches the CW optical-to-optical efficiency of 47%. The optimal repetition rate corresponds to the knee of optical-to-optical efficiency curve. It is close to 1 kHz. The optical-to-optical efficiency at a 1 kHz repetition rate is 39%.

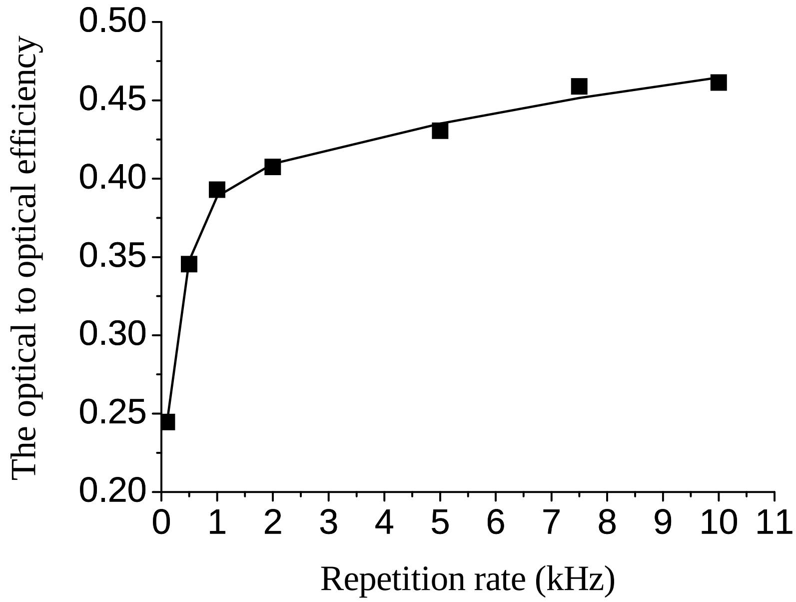

Fig.3. Optical-to-optical efficiency versus repetition.

A modified ramp-and fire technique is used for injection seeding. The seeding wavelength can be tuned by changing the voltage of PZT inside of seed laser. Due to the PZT hysteresis, the wavelength tuning is not linear with the voltage. The temperature tuning around center wavelength is +/-0.07nm.

4. Conclusion

Frequency stabilized Ho:YLF laser with high repetition rate has been designed and demonstrated for CO_2 differential absorption lidar. For 1 kHz operation, the output pulse energy reaches 5.8 mJ. It can meet the requirement of the coherent detection of CO_2 differential absorption lidar. So far, our seeding success rate has not reached 100%. In the future, we will test different methods for improving the seeding success rate.

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