

Single-mode, high repetition rate, compact Ho:YLF laser for space-borne lidar applications

Yingxin Bai^{1*}, Jirong Yu², Teh-Hwa Wong¹, Songsheng Chen², Mulugeta Petros², and Upendra Singh²

¹Science Systems & Applications, Inc. One Enterprise Parkway, Suite 200, Hampton, VA 23666

²NASA Langley Research Center, 5 N. Dryden Street, Mail 468, Hampton, VA 23681

*Corresponding author:yingxin.bai-1@nasa.gov

Abstract: A single transverse/longitudinal mode, compact Q-switched Ho:YLF laser has been designed and demonstrated for space-borne lidar applications. The pulse energy is between 34-40 mJ for 100-200 Hz operation. The corresponding peak power is >1 MW.

OCIS codes: (140.3070) Infrared and Far-infrared lasers; (140.3570) Lasers, Single-mode; (280.3640) Lidar

1. Introduction

The study of global warming requires the precise and accuracy measurement of greenhouse gases concentrations in the atmosphere from space. The carbon dioxide (CO₂) is one of the principal greenhouse gases. It has been significantly increased during past decades. NASA satellite mission ASCENDS (Active Sensing of Carbon dioxide Emissions over Nights, Days and Seasons) is to measure the sources, distribution and variations of carbon dioxide gas with very high precision (<1 ppm) all over the Earth [1]. Integrated Path Differential Absorption (IPDA) lidar is a new approach for global observation of atmospheric carbon dioxide to achieve the unprecedented accuracy. It needs a highly efficient and compact laser as the transmitter due to the limited power, volume, and weight [2].

Ho:YLF laser is capable of generating giant pulses because of its long upper level life time and large emission cross-section. Its wavelength can be easily tuned over the absorption line of CO₂, $\lambda_{R30}=2050.967$ nm. For the direct detection IPDA lidar, the desired 2 μ m Ho:YLF laser should generate 34-40 mJ pulses at the repetition rate of 100 to 200 Hz, with short pulse length (<100 ns) and limited power supply (<800 W). In-band pumped Ho:YLF laser has high efficiency and the ability to operate in high repetition rate (>1 kHz) [3].

Supported by NASA's Earth Science Technology Office (ESTO) Advanced Components Technology (ACT) program, a single transverse/longitudinal mode, compact Q-switched Ho:YLF laser has been designed and demonstrated at Langley Research Center, where a 40 W Tm: fiber is used as the pump source. Such a laser can be packaged in a 4 in x 16 in board and sealed in a Nitrogen filled canister for eliminating water vapor absorption.

2. Experimental setup

The laser system configuration is shown in Fig.1. The oscillator is a four mirror ring cavity laser where a 6 cm length 0.5% Ho:YLF crystal is the active medium, the reflectivity of output coupler is 35%. The cavity length is 1.1 meter. The unused pump power from the oscillator is focused to a 2 cm length 0.5% Ho:YLF crystal for amplification. The total pump power for the system is 40 W from a Tm: fiber laser. The wavelength of pump laser is 1.94 μ m at linear polarization.

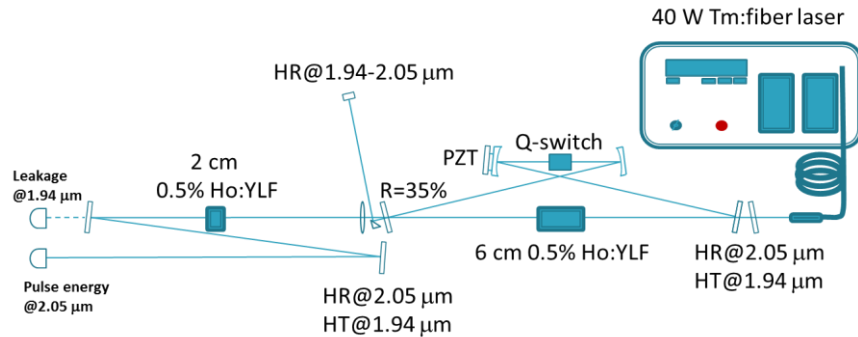


Fig. 1. Tm: fiber laser pumped Ho:YLF Laser system. The laser oscillator is in a bow tie configuration which is located in a 4 in x 16 in area. The mirror inserted between the pump laser and the oscillator is to compensate the astigmatism of pump beam and protect Tm: fiber laser from the damage by 2 μ m pulses.

3. Laser oscillator performances

In order to obtain the optimal laser performance, the laser beam and pump beam are mode-matched in the active medium. The mode-matching is also helpful for laser to operate in a single transverse mode. For the short pulse output and single longitudinal mode operation, a short length ring cavity is designed. An external mirror forces the laser to operate in a unidirectional travelling mode and avoids the spectral hole burning. The maximum diffraction loss of Q-switch is about 68% (Bragg diffraction). The left figure in Fig.1 shows when 36 W pump power is applied the oscillator can generate 40 mJ pulses (4 W) at 100 Hz or 34 mJ pulses (6.8 W) at 200 Hz. It implies that 200 Hz operation is much higher efficiency than 100 Hz operation. The middle figure in Fig.1 shows the beam profile of output laser pulses. The X-profile of beam (horizontal direction) is almost perfectly fitted by a Gaussian profile. The Y-profile of beam (vertical direction) has a difference from a Gaussian profile. It might be attributed to the asymmetry of Bragg diffraction within the Q-switch crystal. The full divergence angle of output beam at $1/e^2$ intensity is 2.65 mrad. The corresponding beam quality, M^2 is <1.2 . The temporal and spectral profiles of output pulses are shown in right figures in Fig.1. The pulse width at the full width at half maximum (FWHM) is about 32 ns. The spectral width at FWHM is less than 20 MHz. The corresponding time bandwidth product is <0.64 .

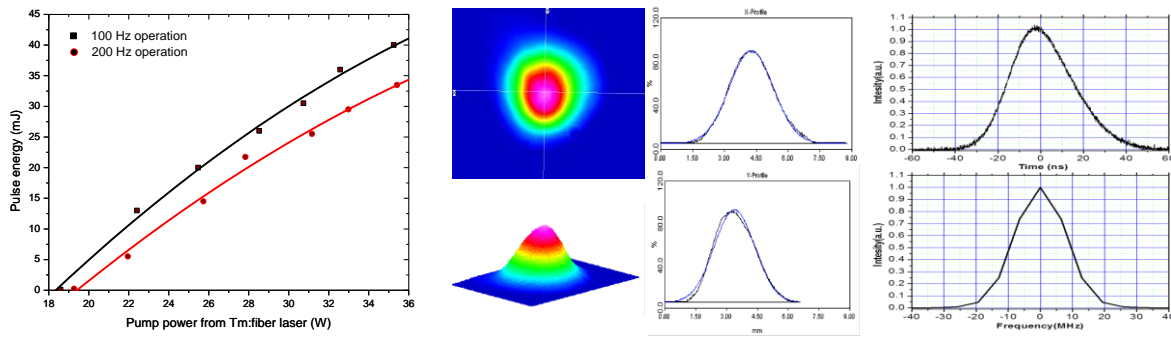


Fig. 2. The performances of laser oscillator. The left figure shows the oscillator output pulse energy via the pump power when the laser operate in 100 Hz and 200 Hz. The middle figure shows the output beam in a single transverse mode. The corresponding beam quality, M^2 is <1.2 . The right figure shows the output pulses in a single longitudinal mode. For a typical output, the full width at half maximum (FWHM) of pulse is 32 ns, the spectral FWHM obtained by Fast Fourier Transform is less than 20 MHz.

4. Laser amplifier performance

The unused pump powers from oscillator are 20 W (100 Hz operation) and 15 W (200 Hz operation), respectively. In order to efficiently use pump power, the leakage pump power is focused on a 2 cm 0.5% Ho:YLF crystal for amplification. The convex lens is located between the oscillator and amplifier with 25 cm effective focal length. For 100 Hz operation, 5-8 mJ energy can be extracted from amplifier. For 200 Hz operation, 3-5 mJ energy can be extracted.

5. Results and discussions

A single mode, high repetition rate, compact Q-switched Ho:YLF laser has been designed and demonstrated for CO₂ IPDA lidar. The output pulse energies from oscillator are 40 mJ for 100 Hz operation and 34 mJ for 200 Hz operation, respectively. The higher efficiency of 200 Hz operation than that of 100 Hz one is owing the upper level lifetime of Ho:YLF crystal (~ 14 ms). If the amplifier is added, the more energy can be extracted. The peak power exceeds 1 MW corresponding to 32 ns pulse. The near diffraction-limited beam and transform-limited pulse have been measured. Without adding amplifier, the energy requirement of space-borne IPDA lidar has been met. The future effort for this project is to complete injection seeding and package it for the field deployment.

6. References

- [1] Ken Jucks, "Active Sensing of CO₂ Emissions over Nights, Days and Seasons," Earth Science Decadal Survey Mission Symposium, (Washington, DC, 11-12 February, 2009).
- [2] James B. Abshire, Haris Riris, Clark J. Weaver, Jianping Mao, Graham R. Allan, William E. Hasselbrack, and Edward V. Browell, "Airborne measurements of CO₂ column absorption and range using a pulsed direct-detection integrated path differential absorption lidar," Applied Optics, Vol.52, 4446 (2013).
- [3] Yingxin Bai, Jirong Yu, Paul Petzar, Mulugeta Petros, Songsheng Chen, Bo C. Trieu, Hyung R. Lee, and Upendra Singh, "Single longitudinal mode, high repetition rate, Q-switched Ho:YLF laser for remote sensing," CLEO/IQEC, Baltimore, Maryland, CWH5, May 31-June 5, 2009.