Room-temperature, diode-pumped Ho:Tm:YLF laser amplifiers generating 700 mJ at 2-μm

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Abstract

Q-switched, 400-ns pulses with output energy of 700 mJ at 2-μm, representing an optical-to-optical efficiency of 2%, was achieved from five diode-pumped Ho:Tm:YLF laser amplifiers at room-temperature.

Key Words

Optical amplifiers, Rare earth and transition metal solid state lasers, Diode laser arrays, Lidar.

Introduction

Laser remote sensing of the atmosphere from space platforms requires a new generation of reliable, all solid-state lasers capable of delivering high-power radiation in the eye-safe region. NASA Marshall Space Flight Center is coordinating the efforts to develop a reliable, long-life, eye-safe, space-qualified, solid-state coherent Doppler lidar for global atmospheric wind measurements. To support this effort, NASA Langley Research Center is developing a diode-pumped pulsed Ho:Tm:YLF laser transmitter capable of generating 500 mJ with a pulse repetition rate of 10 Hz in the eye-safe region near 2-μm. The other requirements are single-frequency with a line width of 2.5 MHz, and a pulse length greater than 180-ns for accurate wind velocity measurements. This activity is in support of fulfilling one of the primary goals of NASA's Mission to Planet Earth: a high-accuracy, unbiased, high-spatial-resolution global wind measurement from an earth-orbiting space platform for global climate change research and for improved numerical weather prediction.

The pulsed laser transmitter work consists of developing an injection-seeded, narrow spectral bandwidth, long-pulse, diode-pumped oscillator capable of generating about 50 mJ at 10 Hz with a near diffraction-limited. A narrow spectral bandwidth is required to detect the smallest Doppler shift. Long pulse lengths are required for the narrow, transform-limited bandwidth needed to measure wind velocity to ± 1.0 m/s. The second major task was to study, design, and build amplifiers with high gain to amplify the oscillator probe beam to achieve 500 mJ. This paper describes optimization of Ho:Tm:YLF amplifier assemblies in a single pass configuration.

Extensive theoretical modeling is required to identify the laser material and doping concentration for optimum gain at 2-μm. Using a model developed at NASA/LaRC, both the dynamics of the energy transfer processes and the laser amplification processes were modeled in order to predict the performance of the Ho:Tm:YLF laser amplifier. In a diode pumped Ho:Tm laser, usually the Tm $^3H_4$ manifold is optically pumped and the absorbed energy is then transferred to the Ho $^5I_7$, which is the upper level of the laser manifold. To determine the relation between the pump energy absorbed by the former manifold and the energy stored in the latter at the time of amplification, a laser dynamics code was developed. Requisite constants for the laser dynamics code were calculated using a quantum mechanical model [1]. To determine the relation between the energy stored in the Ho $^5I_7$ manifold and the gain of the laser amplifier, a laser amplifier model was developed to account for both the spatial and temporal variation of the laser pulse.

Experiment

The schematic for amplifier optimization is given in Fig. 1. A flashlamp-pumped Ho:Tm:Er:YLF oscillator provides a

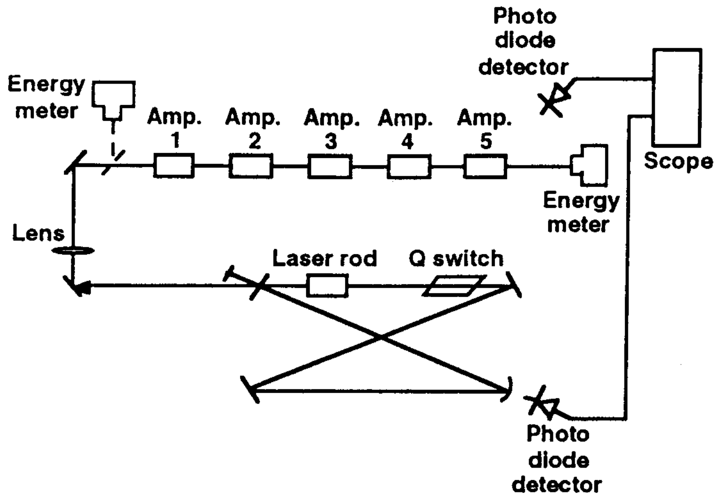

Figure 1. Schematics of the experimental arrangements for gain and pulse delay measurements. A flashlamp-pumped four meter ring resonator oscillator and five diode-pump amplifiers are shown.

Q-switched probe beam of approximately 50 mJ at 1 Hz. A 4-m ring configuration resonator yields ~400-ns-long pulses, necessary for the accurate wind measurements. To reduce the beam divergence through the amplifier chain a 10-meter focal length lens is placed at half a meter from the first amplifier. The amplifier head design, consists of five sets of laser diode arrays arranged circumferentially around each laser rod [2]. There are four diode arrays in each set which were arranged linearly along the length of the rod. In total, 20 diode arrays provide uniform transverse pumping of each laser rod. The laser rod has diffusion bonded ends. Only the middle 40 mm section, which is doped with Ho and Tm, is pumped by laser diode arrays. Undoped YLF (10 mm length) is bonded onto the ends of the laser rod. This 4 mm diameter and 60-mm in length rod is encased by a fused-silica glass flow tube with 5-mm inner diameter and a 7-mm outer diameter, respectively, and is continuously cooled at 16°C by flowing deionized water. Independently, all laser diode arrays are individually cooled through the continuous flow of water. As indicated in the schematic (Fig. 1.), probe energy is monitored just before the first amplifier while a photodiode placed near the oscillator records reference oscillator probe pulse parameters. Similarly, an energy meter and a photo diode are placed after the fifth amplifier to record energy and pulse length of the amplified output.

By varying the diode current, the pump energy of the individual amplifiers was adjusted. The total maximum pump energy applied to each amplifier was approximately 6.5 Joules. The cumulative pump energy for the amplifier chain is calculated by adding the pump energy for the individual amplifiers. Time of peak amplitude, pulse length, and energy of oscillator probe and amplifiers was recorded simultaneously as a function of pump energy.

Results and Discussions

Both measured and predicted single pass gain as a function of the total pump energy appears in Fig. 2. For calculating predicted gain, Ho concentration and a direct relation between the emitted and absorbed pump energy were used in the model. These were the only adjustable parameters used in the model calculations. With the direct relationship, the energy stored in the upper laser level was obtained using

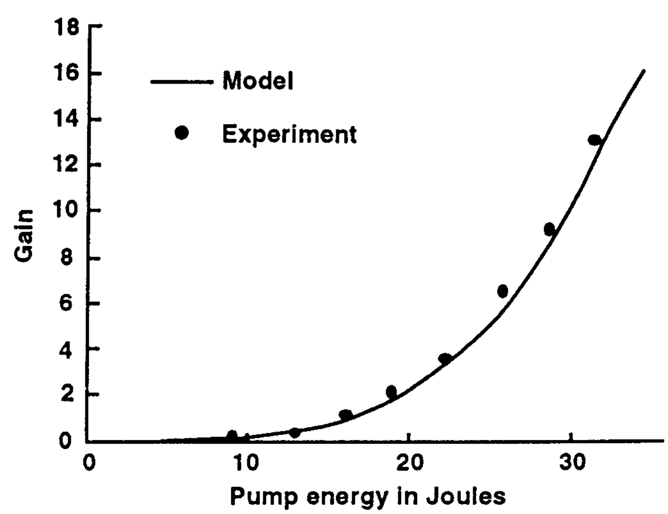

Figure 2. Theoretical and experimental gain of the five amplifiers are shown as a function of diode pump energies.

the dynamics code. Applying this stored energy, the gain was obtained using the laser amplifier code [3]. Agreement between the measured and predicted gain is well within experimental error. Another important observation which can be made from Fig. 2 is that, even for high pump energy, the cumulative gain is still in a non-saturating regime and is expected to increase linearly with an increase in pump energy. An optical-to-optical efficiency of 2% was obtained in this experiment. Higher pump and probe energies will allow more efficient extraction in a near-saturation regime and will improve the cumulative gain.

When observing the peak of the incident pulse and the amplified pulse simultaneously as a function of time, it can be seen from Fig. 3 that for pump energies exceeding 15 Joules, the peak of the amplified pulse occurs significantly before the peak of the incident pulse. This apparent negative pulse delay (or negative shift in the peak of the probe pulse after amplification) is a function of the pulse length and the gain of the amplifier, as shown in Fig. 3. In this figure, predicted and observed pulse delay appears as a function of the pump energy. The peak of the amplifier pulse precedes the oscillator probe pulse for gain exceeding 1 (amplification), and lags for gain less than 1 (absorption). Agreement between the experiment and the model is encouraging. While a negative pulse delay has been previously predicted for Nd:YAG laser amplifiers [4], the short pulse length of the laser described in this reference makes unambiguous measurement of the effect more difficult. In this paper, where the pulse length is 400-ns, the effect is more obvious. The apparent negative pulse delay is caused by the saturation of the laser amplifier [5]. Since the leading edge of the pulse is amplified more than the trailing edge, the peak of the amplified pulse is shifted toward the leading edge of the pulse.

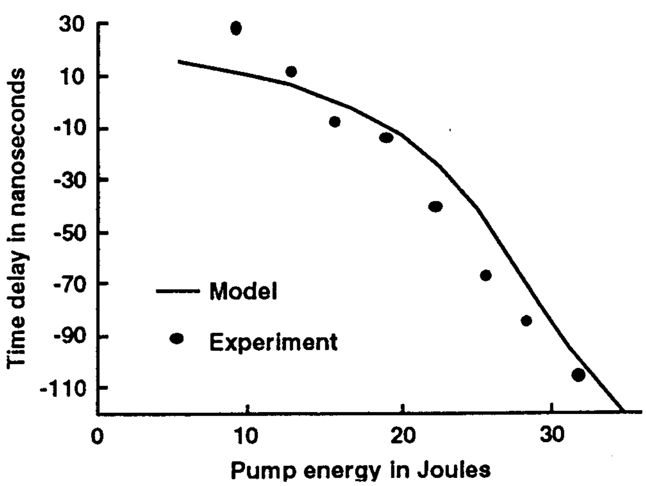

Figure 3. Theoretical and experimental pulse delay of the amplifiers relative to oscillator pump pulse are shown as a function of diode pump energies.

Conclusions

Optimization results of a room-temperature, diode-pumped Ho:Tm:YLF laser amplifier are reported. A maximum Q-switched output energy of 700 mJ/pulse at 2-μm is achieved by using five water-cooled, diode-pumped Ho:Tm:YLF amplifiers and 50 mJ of oscillator probe energy at 1 Hz. The energy reported here is at least an order of magnitude greater than reported so far for a diode-pumped 2-μm Ho:Tm:YLF laser system at room temperature. Agreement between the predicted and observed gain validates the amplifier model. An interesting but apparent negative pulse delay of the amplified pulse is observed. Excellent agreements between theoretical and experimental results are very encouraging and hold promise for designing and developing multi-Joule space-based 2-μm atmospheric wind lidar systems.

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