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LD-pumped actively Q-switched Tm,Ho:YLF laser at room temperature

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Abstract

We have investigated acoustic-optical Q-switched Tm,Ho:YLF laser end-pumped by a laser-diode. At room temperature, a 2.067 μm wavelength pulsed output is realized. Average output power, single pulse energy and pulse-width are measured at different incident pump powers and pulse repetition frequencies. When the incident pump power is 2.8 W, a maximum average output power of 189 mW is obtained at the repetition frequency of 9 kHz, and this corresponds to an optical conversion efficiency of 6.8%. The maximum single pulse energy of 65μJ, the shortest pulse-width with full-width at half-maximum (FWHM) of 138 ns and the maximum peak power of 470 W are obtained at the pulse repetition frequency of 1 kHz.

Keywords: Lasers and laser optics; Laser-diode pumped; Tm,Ho:YLF crystal; Actively Q-switched

1. Introduction

Eye-safe diode-pumped thulium (Tm) and holmium (Ho) lasers operating at 2 μm are regarded as promising sources for use in Doppler wind sensing, differential absorption radar (DIAL) water vapor profiling, and low altitude wind shear detection. Additional applications for which short duration optical pulses at 2 μm are required include altimetry, topographic, and nonlinear optical studies. Tm- and Ho-doped solid-state lasers have been of interest for many years [1–10], and many different hosts and transitions have been reported to laser, because Tm and Ho laser is potential for good 2 μm laser efficiency, which is a direct result of its high quantum efficiency and long storage lifetime. Broad Tm absorption lines provide strong coupling for the AlGaAs pump laser to the $^3H_4$ level. The high quantum efficiency results from the decay route of the Tm $^3H_6$ level. The Tm $^3H_4$ excited state cross relaxes with another nearby Tm ion to yield two Tm $^3F_4$ states. The meta-stable Tm $^3F_4$ excitation has been shown to be highly mobile. Approximately one half of the Tm $^3F_4$ excitation is promptly transferred to Ho $^5I_7$. These lasers are conductive to operation in Q-switched mode due to the 12 ms fluorescence lifetime. However, in many hosts studied to date up-conversion is a deleterious influence, manifest as an effective lifetime reduction, with concomitant reduction of the energy storage capacity and loss of conversion efficiency.

Of the 2 μm lasers based on the Ho $^5I_7-^5I_8$ transition most of the laser-diode pumped Q-switched studies to date have explored singly and doubly doped yttrium–aluminum–garnet (YAG) due to lower continuous wave (CW) thresholds when compared to YLF. For high pulse energy applications, however, the lower gain cross sections of the singly doped materials when compared with the doubly doped materials which use the Ho transition may make amplification beyond a few tens of mJ difficult [10].

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The energy transfer dynamics and the extent of up-conversion losses are often more influential than the threshold pumping level in determining the laser performance when Q switched. While the presence of Tm reduces the Stokes losses, the resonant Tm–Ho transfer time in YLF is at least 1 μs. Although this is faster than observed in Tm,Ho:YAG, it is longer than the typical pulse buildup time and consequently only that fraction of the excitation energy stored in the Ho $^5I_7$ upper laser level is accessible when Q switching. For a given pump power one can access a greater fraction of the excitation energy in a YLF host which, in conjunction with reportedly reduced up-conversion losses in YLF, would favor Tm,Ho:YLF over co-doped YAG. Furthermore, YLF is chosen as a host crystal because of its long pump integration time, excellent optical damage resistance, lack of thermal induced birefringence, and linearly polarized output. We have conducted some experiments and reported the characteristics of CW Tm,Ho:YLF lasers [11–14]. In this paper we demonstrate the experimental results for an acoustic-optical Q-switched diode-end-pumped Tm,Ho:YLF laser. Average output power, single pulse energy and pulse-width are measured at different incident pump powers and pulse repetition frequencies.

2. Experimental setup

The experimental setup is shown in Fig. 1. The pump source for these experiments is a 3 W CW Coherent Inc. laser-diode (S-79-3000-200-H/L), temperature tuned to a 792 nm absorption peak of Tm,Ho:YLF crystal. The highly divergent output of the laser-diode is collected by an 8 mm focal length collimating lens followed by a cylindrical lens with a focal length of 100 mm to reshape. This laser beam then is focused onto the Tm,Ho:YLF crystal using a lens with a 50 mm focal length. With this arrangement the pumping beam can be focused to a spot size of approximately $100 \times 100\,\mu m^2$ at the entrance face of the laser crystal. The total transmission efficiency of the beam-reshaping system is about 91% at 792 nm. The Tm,Ho:YLF laser crystal from II–VI corporation has dopant concentrations of 6% Tm, 0.4% Ho with dimensions of $5 \times 5 \times 2.5\,mm^3$. The crystal is oriented with the *c*-axis parallel to the polarization direction of the pump beam to utilize the higher π spectrum absorption. Because both the pump and laser cross sections are considerably enhanced in the π polarization, we should specify the preferred orientation of the laser element in any optical arrangement.

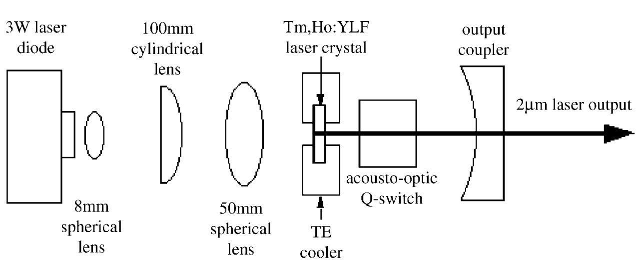

Fig. 1. Schematic diagram of LD-pumped Q-switched Tm,Ho:YLF laser.

A plane-concave resonator is employed to make the system very simple and compact. The near hemispherical resonant is formed between the planar crystal front face and the output coupler. A dichromatic coating on the front face is high transmitting at 792 nm, but is totally reflecting at 2 μm. The other face is only polished and uncoated at both pump and output wavelengths. To efficiently remove the heat generated with incident pump power from the crystal, the crystal is wrapped with indium foils and held in a brass heat sink. The temperature of the heat sink is held at a constant 293 K with a thermoelectric cooler. The QSGSU-6Q acoustic-optical modulator (The 26th Electronics Institute, Chinese Ministry of Information Industry), the effective length of which is 44 mm, is located between the crystal and the output coupler but near the crystal. The optical polarization and acoustic wave-vector are mutually orthogonal for optimum scattering. Both ends of the modulator are antireflection coated at 2067 nm, and its intrinsic diffraction loss is ~85% which is adequate to prevent lasing action. The modulate repetition rate is tunable from 80 Hz to 10 kHz.

The average output power P_{av} is measured with an LPE-1B power (Institute of Physics, Chinese Academy of Science). The pulse width t_p and the pulse repetition frequency are observed with a TDS3032B digital oscilloscope (Tektronix Inc., USA) and a room temperature mercury cadmium telluride photoconductive detector with a response time of 1 ns. Using the formulas $E = P_{av}/f$ and $P = E/t_p$, the single pulse energy E and the pulse peak power P can be obtained [15].

3. Results and discussion

Output couplers with transmissions of 1.26, 2.0, 2.97, 4.75, 6.0, and 10% have been used, with 2.0% giving the best results for the continuous conditions. The following experimental results are obtained with the output coupler with a transmission of 2%, and the radius of curvature of the output coupler is 10 cm.

The average output powers of the laser for Q-switching operation as a function of incident pump power at different pulse repetition frequencies as well as in the continuous mode to give a direct comparison are shown in Fig. 2. From the results of the experiment, it is noted that the average output power increases with the pulse repetition frequency for the same incident pump power. When the incident pump power is 2.8 W, a maximum average output power of 189 mW is obtained at the repetition frequency of 9 kHz, and this

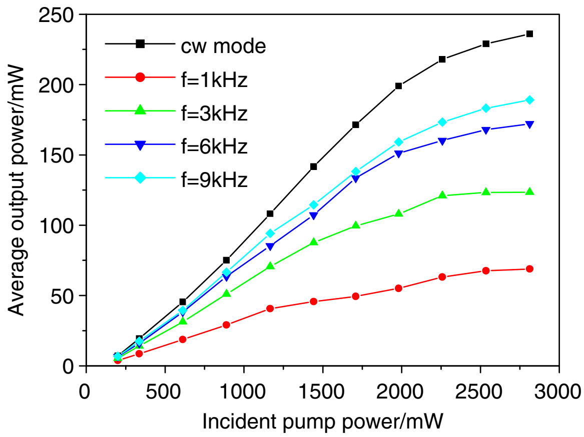

Fig. 2. Average output power as a function of incident pump power for different repetition frequencies.

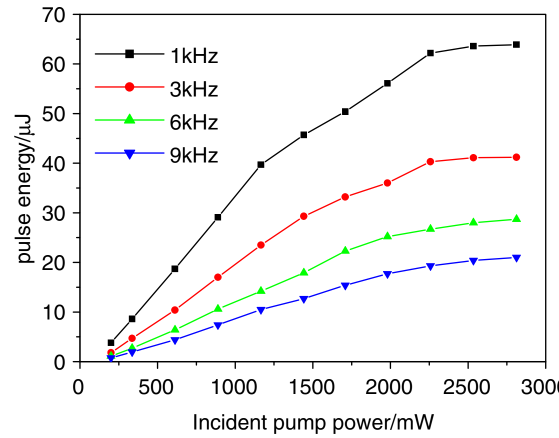

Fig. 3. Pulse energy as a function of incident pump power for different repetition frequencies.

corresponds to an optical conversion efficiency of 6.8%. When the pulse repetition frequency is changed to 1 kHz, the average output power is 70 mW at the incident pump power of 2.8 W. The average output power is seen to begin to saturate above 1.7 W of incident pump power. We believe the saturation effects to be a result of thermal population of ions in the lower transition level of a quasi-three-level system.

Fig. 3 shows the variations of single pulse energy with the incident pump power at different pulse repetition frequencies, calculated on the basis of the measured results of average output power and pulse repetition frequency. It is noted from Fig. 3 that the larger pulse energy can be accessed at the lower pulse repetition frequency. With the increase of the pulse repetition frequency, the pulse energy decreases. The largest pulse energy of 65 μJ is accessed at the pulse repetition frequency of 1 kHz. The peak power reaches its highest value of 470 W when the incident pump power reaches its largest value of 2.8 W, calculated on the basis of the measured results of single pulse energy and pulse-width.

Fig. 4 shows the pulse-width as a function of the incident pump power at different pulse repetition frequencies. It is noted that the pulse-width decreases as the incident pump power increases, and the effect of incident pump power on the pulse-width decreases when the pulse repetition frequency is kept a small value. Fig. 5 shows the measured Q-switched pulse-widths as a function of the pulse repetition frequency at the incident pump power of 1.7 W. When pulse repetition frequency is changed from 80 Hz to 10 kHz, the resulting laser pulse-width increases almost linearly from 136 to 205 ns. Fig. 6 shows the single pulse energies as a function of the pulse repetition frequency when the incident pump power is maintained at a fixed level of 1.7 W. It is noted from this figure that the largest pulse energy of 45 μJ can be achieved at the lower pulse repetition frequency of 1 kHz, the pulse energy decreased from 45 to 15 μJ with the increase of the pulse repetition frequency from 1 to 10 kHz, and at sufficiently low pulse repetition frequency ($f \ll 1/\tau$) the pulse energy will saturate.

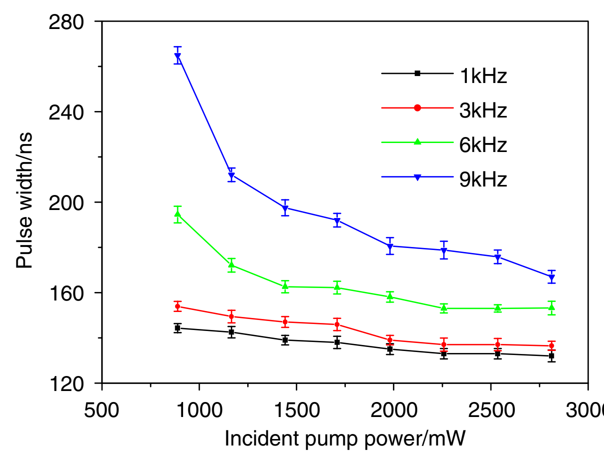

Fig. 4. Pulse-width as a function of incident pump power for different repetition frequencies.

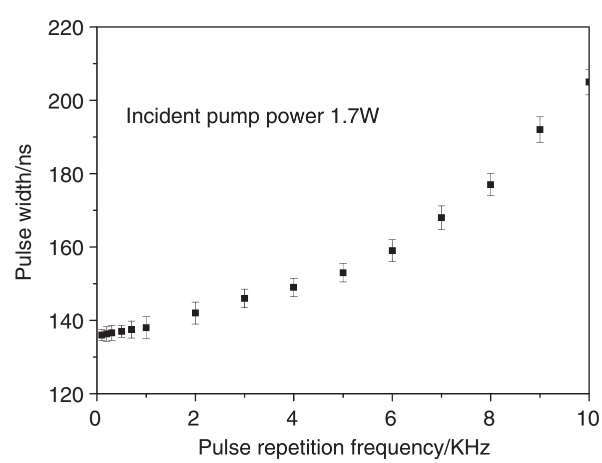

Fig. 5. Pulse-width as a function of pulse repetition frequency at the incident pump power of 1.7 W.

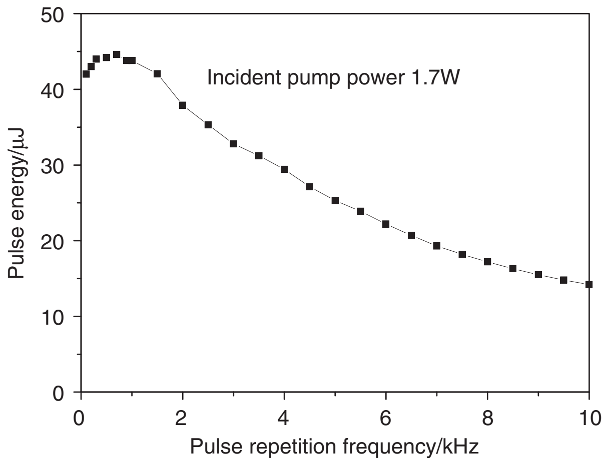

Fig. 6. Single pulse energy as a function of pulse repetition frequency at the incident pump power of 1.7 W.

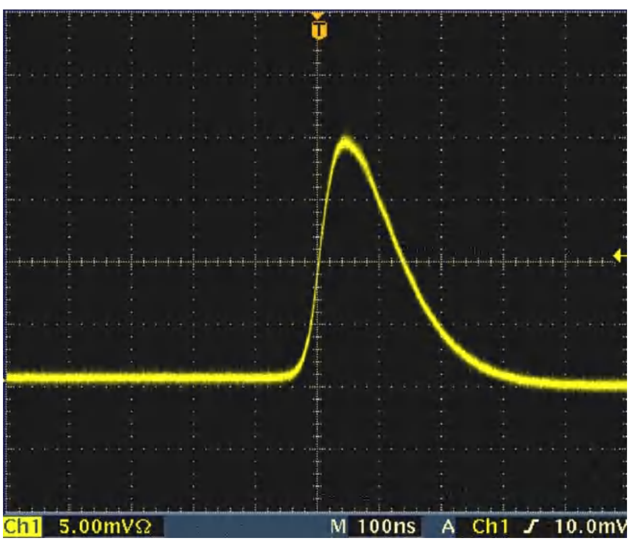

Fig. 7. Oscilloscope trace of the shape of a single pulse Q-switched at 1 kHz.

Fig. 7 shows the shape of a single Q-switched pulse at the pulse repetition frequency of 1 kHz, and FWHM width is 138 ns. Fig. 8 shows a consecutive pulse train of laser output operating at 1 kHz. The pulse-to-pulse amplitude fluctuation of the Q-switched pulse train is measured to be less than ±5%.

4. Conclusions

In summary, we have investigated acoustic-optical Q-switched, room temperature Tm,Ho:YLF laser pumped by a laser-diode. A 2.067 μm wavelength pulsed output is realized. Average output power, single pulse energy and pulse-width are measured at different incident pump powers and pulse repetition frequencies. At the incident pump power of 2.8 W, a maximum average output power of 189 mW is obtained at the repetition frequency of 9 kHz, and this corresponds to an optical conversion efficiency of 6.8%. The maximum single pulse energy of 65 μJ, the shortest pulse with FWHM width of 138 ns and the maximum peak power of 470 W are obtained at the repetition frequency of 1 kHz.

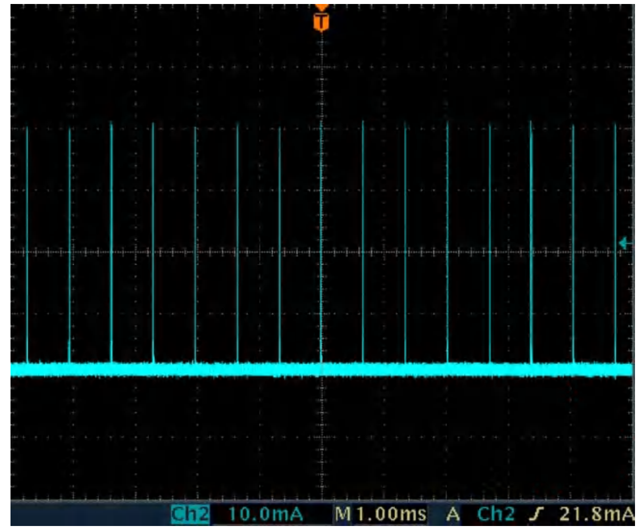

Fig. 8. Pulse train on the oscilloscope at 1 kHz.

Acknowledgements

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