Diode-pumped, 6-mJ, Repetitively Q-switched Tm, Ho:YLF Laser for Clear Air Turbulence Detection

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Abstract

We report on a diode-pumped, Thulium, Holmium:YLF ring laser which has produced over 4.5 W of CW power, 6 mJ of Q-switched pulse energy at a 100 Hz repetition rate, and over 3 mJ at 1 kHz repetition rate, all with a pump power of 14 W.

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It has long been recognized that the detection and avoidance of Clear Air Turbulence can benefit both military and civilian airfleet operations in terms of passenger safety and comfort, as well as economic and mission performance. Among a variety of lidar systems under development, we are currently constructing a 2 µm Q-switched Tm,Ho:YLF laser transmitter/ coherent receiver system specifically designed for CAT detection. Within this program, goal detection ranges are up to 20 km with real-time data update rates. This leads to a performance specification for the 2-µm laser system of 5 mJ at a repetition rate of 200 Hz with a 200 ns pulse duration. Towards this goal, we have recently demonstrated efficient operation of a Tm,Ho:YLF laser pumped by a 20-W fiber coupled CW laser diode array. We have obtained ~6 mJ of Q-switched pulse energy at repetition rates of 50 - 200 Hz and over 3 mJ at a 1 kHz repetition rate. In CW operation we have obtained over 4.5 W of power. In all cases the lasing mode was TEM_{00}.

Laser performance in Tm,Ho:YLF is critically affected by the temperature of the crystal medium. This is due to the strong temperature dependence of up-conversion rates and thulium to holmium energy transfer rates. During CW operation, without correct thermal management within the crystal, CW output powers are seen to “roll-over” at high pump powers as the pumped region center temperature becomes too high. In Q-switched operation, pulse energies also decrease due to inter pulse depletion of the inversion by up-conversion and other heating effects. These effects can be offset by using quasi CW diode pumping, but this effectively limits the maximum Q-switched repetition rate obtainable. We have examined and tested a variety of standing wave single end-pumped cavities, crystal lengths, and holmium concentrations. Based on these experiments, we came to the conclusion that thermal management is key to efficient and high power/energy operation of this medium. With this in mind, we decided to use a ring cavity configuration utilizing the double end-pumped geometry as shown in Figure 1.

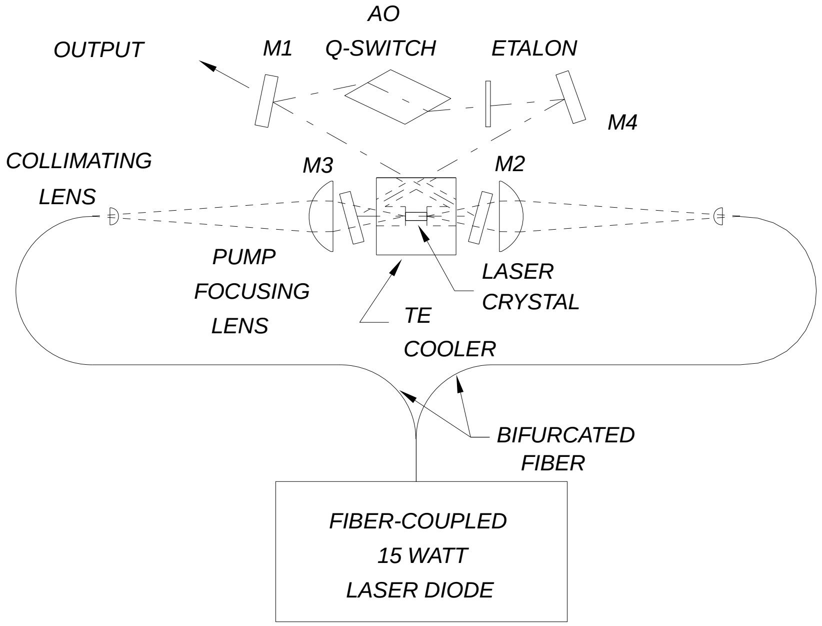

Figure 1. Schematic of the Tm,Ho:YLF Q-switched ring laser.

The 2-µm laser cavity contains a 10-mm long, 4-mm diameter 6% Tm, 0.5% Ho:YLF crystal mounted in a TE-cooled heat sink inside a purgeable enclosure. A single 20-W laser bar was used as the pump source, whose output was coupled to a bifurcated fiber bundle, i.e. the bundle was split into two separate smaller bundles each of which were imaged into either end of the YLF rod through HR/HT flat mirrors. By this means we could spread the absorbed pump power over the entire length of the rod, thus minimizing the thermal load at any given point inside the crystal. The hot sides of the TE-cooler were cooled to -40°C using a Fluorinert chiller, allowing the YLF crystal block to be cooled to as low as -63°C (210 K). The remainder of the ring resonator was a flat output coupler (6.8% T) and a 50-cm curved high reflector. Unidirectional operation of the ring laser was achieved by retroreflecting one of the output beams. A Brewster-angled acousto-optic Q-switch was inserted in one leg of the cavity.

Initially we investigated the CW operation of the laser and optimized the cavity configuration and pump imaging to obtain good TEM_{00} mode performance and maximum CW output. Figure 2 shows the output of the unidirectional ring laser as a function of pump power(delivered to the crystal) and crystal block temperature. As can be seen the laser performance improves significantly with cooling, yielding a maximum power of 4.65 W at a pump power of 14 W. This represents an optical conversion efficiency of over 33% and a slope efficiency of ~40%.

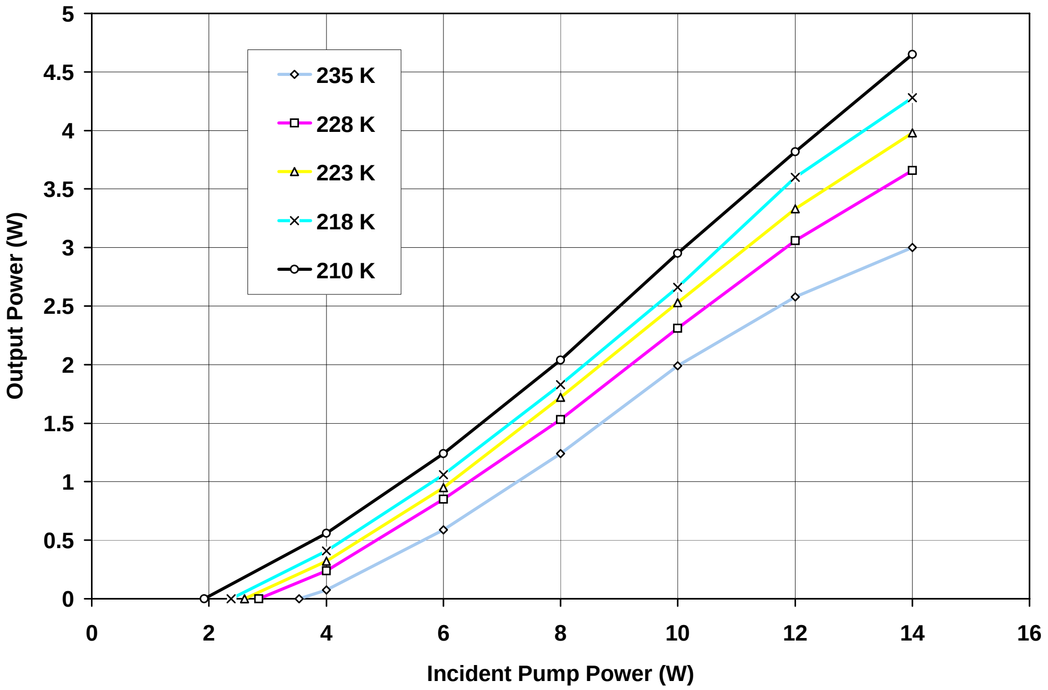

Figure 2. CW performance of ring laser as a function of crystal block temperature.

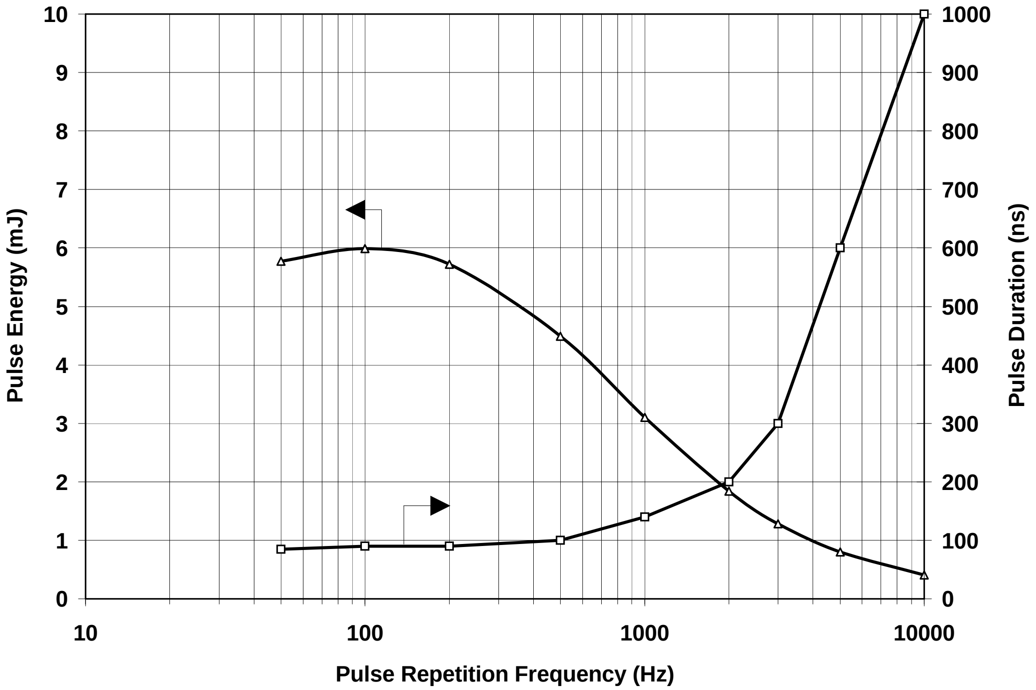

Figure 3. Q-switched performance of the Tm,Ho:YLF ring laser.

Figure 3 shows the Q-switched performance of the laser at 210 K. The maximum pulse energy of 6.0 mJ occurs at a repetition rate of 100 Hz. The pulse duration in this case was 90 ns. At 1 kHz repetition rates pulse energies were still over 3 mJ, offering the prospect for higher repetition rate operation as signal processing speeds improve.

Seeding of this cavity with a CW single frequency Tm,Ho:YLF laser to achieve single frequency operation is currently on going. We are planning to adopt a two stage TE-cooler design to cool the crystal block. The system design is also being ruggedized and incorporated into the remainder of the lidar system under development.