Compact Pulsed High Energy Er:glass laser

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ABSTRACT

Bulk Erbium-doped lasers are widely used for long-distance telemetry and ranging. In some applications such as coherent Doppler radars, laser outputs with a relatively long pulse width, good beam profile and pulse shape are required. High energy Q-switched Er:glass lasers were demonstrated by use of electro-optic (E/O) Q-switching or frustrated total internal reflection (FTIR) Q-switching. However, the output pulse durations in these lasers were fixed to relatively small values and extremely hard to tune. We report here on developing a novel and compact Q-switched Er:Yb co-doped phosphate glass laser at an eye-safe wavelength of 1.5 μm. A rotating mirror was used as a Q-switch. Co-linear pump scheme was used to maintain a good output beam profile. Near-perfect Gaussian temporal shape was obtained in our experiment. By changing motor rotation speed, pulse duration was tunable and up to 240 ns was achieved. In our preliminary experiment, output pulse energies of 44 mJ and 4.5 mJ were obtained in free-running and Q-switched operation modes respectively.

Keywords: Erbium, Er doped glass, Er:Yb co-doped glass, Q-switched laser

1. INTRODUCTION

Bulk erbium-doped lasers in the 1.5 μm "eye-safe" spectral region are the preferred coherent sources for laser sensing, velocimetry, laser imagery coherent Lidar, free space communications and laser-induced breakdown spectroscopy (LIBS)[1-5]. Among the 1.5 μm solid-state materials, Er:Yb codoped phosphate glass has been proved to be the most popular laser-active material for this region due to its excellent chemical durability, high-optical quality, and large energy storage. However, the relative small emission cross section and low thermal conductivity of Er:Yb co-doped glass have prevented researchers from obtaining high energy Q-switched output. Approaches for the reliable, Q-switched operation of an Er:Yb co-doped glass laser have already been reported in the literature [6,7]. Most of these approaches need special materials and expensive components such as specially designed electro-optic Q-switches or frustrated total internal reflection (FTIR) Q-switch shutter, and the pulse width were fixed and relatively short. In this paper, we report our recent work on using a rotating mirror approach to achieve Q-switched output pulses at wavelength of 1.5 μm with variable pulse width up to 240 ns.

2. EXPERIMENT SETUP

The Er:Yb co-doped glass laser configuration is shown in Figure 1. The laser resonator consisted of an output coupler mirror, a flat high reflector (HR) at 1.5 μm and a 5 mm thickness uncoated Er:Yb co-doped glass. The HR mirror was fixed to a motor shaft, which worked as an optical Q-switch. The laser gain medium was supported by a brass holder (not shown in Figure 1) serving also as a cooling sink. The gain medium was placed at Brewster angle. The output coupler which also worked as a pump mirror has 12% transmittance at the lasing wavelength of 1.5μm and 95% transmittance at pump wavelength of 976 nm. Co-linear pump scheme was used to maintain a good output beam profile.

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Three 30 W- IPG 976 nm laser diodes were combined together into one common fiber output through a fiber combiner. Up to 75 W peak power was delivered before the Er:Yb co-doped glass. The pump beam was focused into the gain medium by a lens with a focal length of 10 cm. The focal point has a spot size of 0.63 mm. Electrical power was supplied to the laser diodes by a custom-made current driver with adjustable pulse duration τ_p = 1-10 ms. Typical 976 nm pump pulse shapes with 1 ms and 10 ms pulse durations are shown in Figure 2.

The basic Q-switching technique for the rotating mirror laser is well known [8]. The system is Q-switched when the mirror rotates back into alignment (it is in alignment once each revolution). Rotating mirror Q-switches offer 100% dynamic loss and 0% insertion loss. The Q-switch speed can be tuned by rotating the mirror at various speeds.

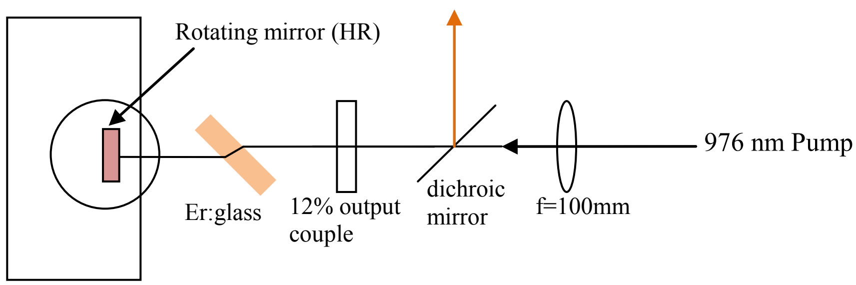
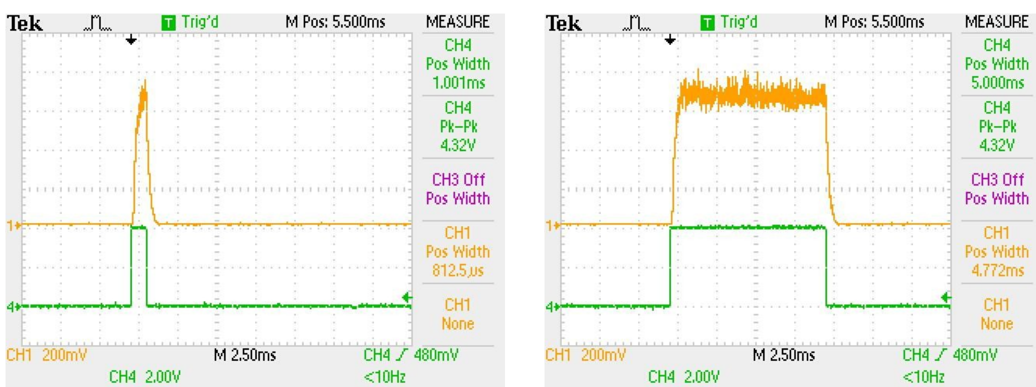


Figure 1: Q-switched Er:Yb co-doped glass laser experiment setup.



(a) (b)

Figure 2. Typical 976 nm pump pulse trains. The lower trace represents trigger signal, the upper trace represent 976 nm optical signal. (a) 1 ms pump duration; (b) 10 ms pump duration.

3. EXPERIMENTAL RESULTS

The output pulse energy as a function of input pump energy from the Er:Yb co-doped glass laser was measured in both free-running and Q-switched modes of operation. In free-running mode, the HR mirror was fixed. Pump duration was set to 10 ms. The output energy result for free-running mode is presented in Figure 3. A maximum output of 44 mJ and an optical slope efficiency of 15.8% were obtained. In a separate CW experiment, a slope efficiency of above 20% was obtained with the same gain medium [9]. The slope efficiency was getting lower here was mainly due to the thermal lensing effect, which was observed but not compensated in this laser cavity design. When further increased the pump pulse duration and peak power, a stable saturated output of 4.7 mJ/ms was achieved, which implied that the saturated maximum output in CW operation was 4.7 W for this laser cavity geometry. A sample output pulse train is shown in Figure 4. There were spikes at the beginning of lasing, followed by a stable output. After the end of pump pulse, the output intensity gradually reduced to zero within 1 ms.

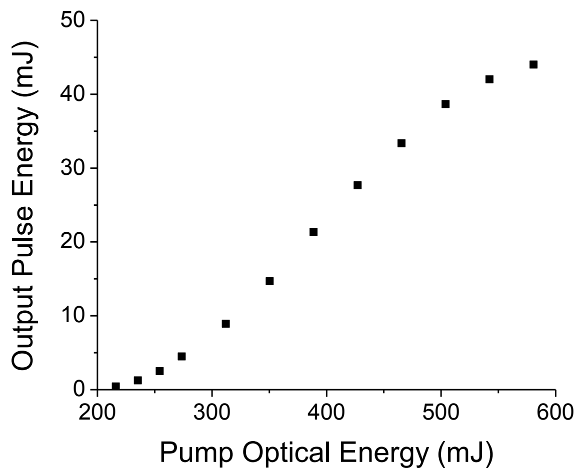


Figure 3: Output energy as a function of pump energy in a free-running Er:Yb co-doped glass laser.

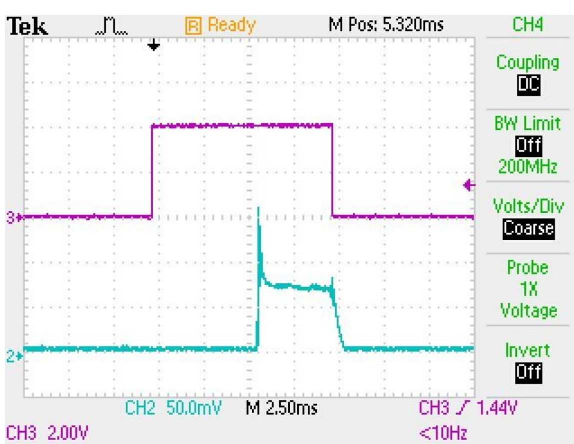


Figure 4: A sample output pulse train in free-running operation. Upper trace represents the pump trigger signal; lower trace represents the output optical signal.

In Q-switched mode, the output pulse energy vs. pump energy is plotted in Figure 5. Since the lifetime of Erbium fluoresces is around 8 ms, the pump duration was limited to be 8 ms for a better pump efficiency. Pulse energy of up to 4.5 mJ was obtained with 460 mJ pump energy. The saturation fluency for Er:Yb co-doped glass is 122 mJ/mm^2, which was measured in a separated experiment from a CW laser cavity [9]. The pump beam diameter inside the gain medium was 0.64 mm, thus the maximum extractable energy was 39.2 mJ. An energy extractable efficiency of 11.5% was achieved. It seemed that the output pulse energy was still not saturated (Figure 5) at our maximum pump level of 75 W. If further increasing the peak pump power, more pulse energy can be extracted. The optical slope efficiency for Q-switched operation was about 1.6%. Because it took relative long time to accumulate energy into Er:Yb co-doped glass, about 32% absorbed energy was wasted into Erbium self-relaxation. The optical slope efficiency can be further increased if more energy is pumped into the gain medium within the same pump duration.

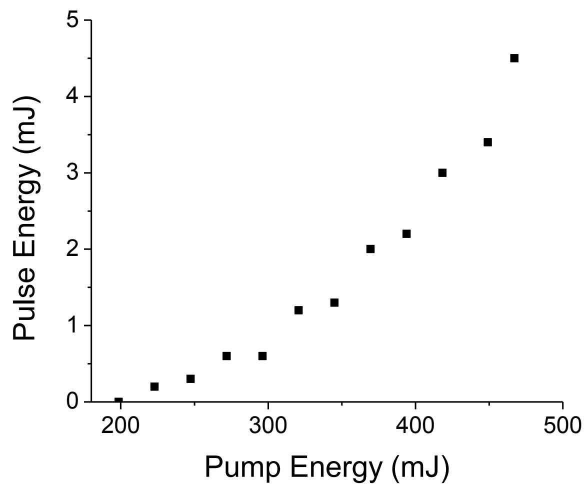


Figure 5: Q-switched output pulse energy as a function of pump energy within 8 ms.

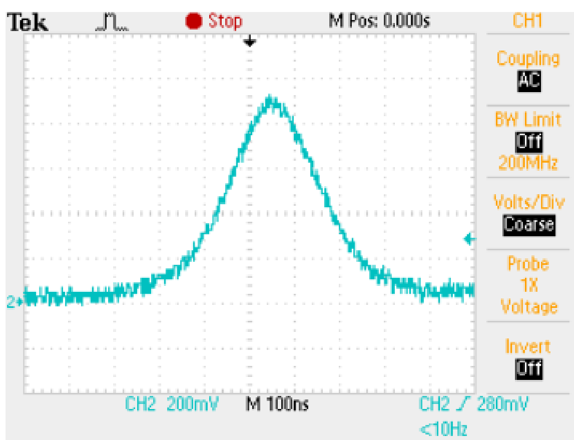


Figure 6: Output pulse train with a pulse width of 240 ns. The speed of motor was 50 revolutions/sec and the cavity length was ~20 cm.

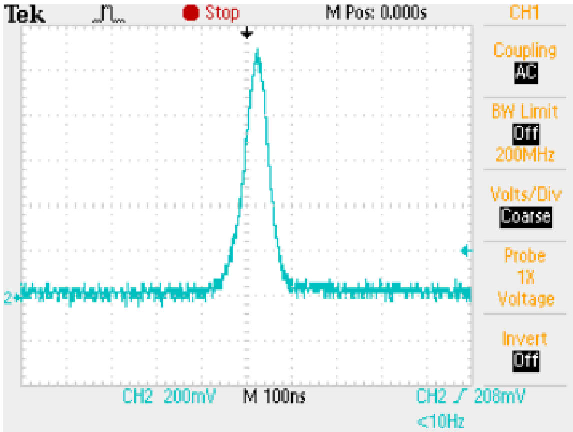


Figure 7: Output pulse train with a pulse width of 65 ns. The speed of motor was 100 revolutions/sec and the cavity length was ~10 cm

Various output pulse widths were obtained at different cavity lengths and motor rotating speed. Two sample pulse trains with pulse width of 240 ns and 65 ns are show in Figure 6 and Figure 7 respectively. Figure 8 shows an output beam profile image. Since the collinear pump method was used in this cavity design, a near diffraction limited beam profile was obtained.

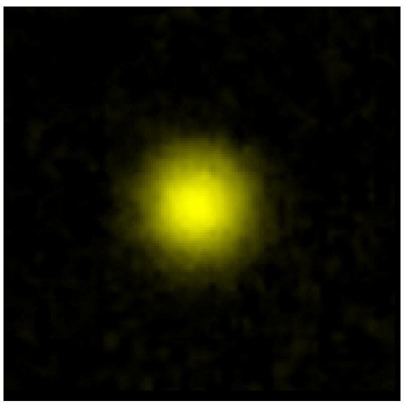


Figure 8: A sample output pulse beam profile

4. SUMMARY

We have developed a novel and compact Q-switched Er:Yb co-doped phosphate glass laser at an eye-safe wavelength of 1.5 µm. Pulsed output was realized by rotating mirror Q-switching technique. Good output beam profile and near-perfect Gaussian temporal shape were obtained. By changing rotation speed, pulse duration was tunable and up to 240 ns was achieved. In our preliminary experiment, at pump peak power of 75 W, output pulse energies of up to 44mJ and 4.5 mJ were obtained in free running and Q-switched operation modes respectively. Larger output pulse energies can be achieved in our future work.

ACKNOWLEDGEMENT

This work is supported in part by NASA SBIR contracts.

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