**Double-end pumped efficient MHz self-mode-locked Pr:YLF green and red lasers**

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**Abstract:** We demonstrate an efficient tens and hundreds of MHz self-mode-locked green and red laser in a Pr3+:YLF4 crystal with V-type and Z-type cavity using a double-end-diode-pumped structure without the need of any additional components. Experimental results reveal that the laser system can be characterized in stable mode-locked operations. With an absorbed pump power of ~2.8 W, average output powers of more than 0.68 W for 522 nm green laser or more than 1.44 W for 639 nm red laser were obtained.

**Keywords:** Solid state laser, Blue diode-double-end pump, Pr:YLF crystal,visible laser source.

**1. Introduction**

The third-order nonlinear optical responses are closely related to the stimulated Raman

scattering (SRS) process and the Kerr-lensing effect [].

**2. Experimental Set-Up**

Figure 1 depicts the experimental setup for the self-mode-locked Pr:YLF red laser with a repetition rate of ~85 MHz using a double-end pumping scheme. The cavity configuration is a Z-type resonator with a total cavity length of ~1.8 m. The active medium is an a-cut 0.2 at. % Pr3+:YLF4 crystal with a length of ~8 mm. Both end surfaces of the Pr3+:YLF4 crystal were plano and uncoated. The laser crystal was wrapped with indium foil and mounted in a water-cooled copper holder. The water temperature was maintained around 18°C to eliminate thermal effect. The laser crystal was placed close to IM1, which is the input mirror for the pump on the left side. IM2 is the input mirror for the pump on the right side and was tilted to make the cavity longer. Both IM1 and IM2 had high transmission (>95%) at ~444 nm and high reflection (>99.8%) at 639 nm.

Each of the two pump sources was a ~1.8 W, ~444 nm laser diode with achromatic and collimation system, which is commercially available. Focusing lenses with 50 mm focal length was used to inject the pump beam into the laser crystal with an average pump size of approximately 60 μm, which is measured by using Spiricon M2-200.

HR1~HR3 were concave mirrors with radius of curvature of 300 nm and had high reflection (>99.7%) at 639 nm, which could provide positive feedback for 639 nm lasing. The output coupler (OC) was a coated plane mirror with a transmission of 3.5% at 639 nm. The distance between IM1 and IM2 plus the distance between IM2 and HR1 equals ~300 mm. The distance between HR1 and HR2 and the distance between HR2 and HR3 were both around 600 mm. The distance between HR3 and OC was ~300 mm. So the total cavity length was ~1.8 m.



Fig. 1. Schematic of a self-mode-locked Pr:YLF red laser

Moreover, for 639 nm self-mode-locked lasing operation, experiments with a V-type cavity and concave OC with a radius of curvature of 300 mm was conducted, making the cavity length ~0.3 m. The same V-type schematic using different IMs and OC for 522 nm lasing was also used to generate green self-mode-locked laser. For the 522 nm self-mode-locked laser, the two input mirrors IM1 and IM2 had a high transmission (>95%) for the pump (~444 nm), high reflection (> 99.9%) at 523 nm to support lasing and high transmission (> 60%) around 607 and 639 nm to suppress the high gain emissions at those wavelengths. The concave output coupler had a radius of curvature of 300 mm and transmission of 1.9% at 522 nm.

The mode-locked pulses were detected by a free space high sensitivity PIN photo detector unit (Menlo Systems, Inc. FPD310-FV with rise time 0.7 ns), whose output signal was connected to a digital mixed signal oscilloscope (Tektronix MSO 3054) with 500 MHz electrical bandwidth and a sampling interval of 0.4 ns. Meanwhile, the corresponding power spectrum is measured by an rf spectrum analyzer (GωINSTEK, GSP-930) with bandwidth of 3.0 GHz.

repetition rate of ~500 MHz was also obtained with a cavity length of ~0.3 m by using a V-type cavity and OC with radius of curvature of 300 mm.

a cavity length of ~0.3 m was also used to generate 522 nm self-mode-locked laser with a repetition rate of approximately 500MHz.

**3. Experimental results and discussions**

For the Z-type cavity with a total cavity length of ~1.8 m shown in Figure 1 operating at 639 nm, the optical cavity length was firstly set to be approximately 1.8 m, corresponding to a FSR of 83.3 MHz. Than the cavity alignment was optimized for generating the maximum average output power. The time trace of the output radiation revealed the laser to be operating in the self-mode-locked state. Thanks to the double-end pumping scheme, more than 1.44 W output power was extracted with a total laser slop efficiency of 57.3% with respect to the absorbed pump power. In the experiment, the left and right pump LDs were turned on in turn. The lasing performance for ~1.8 m Z-type cavity operated in self-mode-locked state at the wavelength of 639 nm was shown by the red dots and line depicted in Figure 2.

For the green self-mode-locked Pr3+:YLF4 laser operating at the wavelength of 522 nm, ~0.3 m V-type cavity was adopted using OC with a transmission of 1.9%, ~0.68 W average output power was obtained.

Note that once the pump power reaches the lasing threshold, the laser system instantaneously steps into a stable mode-locked operation without any mechanical perturbation. The locking mechanism is presumed to be the Kerr effect. However, the laser system has high stability over day-long operation and is insensitive to mechanical vibrations and air current. As a result, some auxiliary mechanism seems to exist in the locking process. Bai et al. [Novel self-mode-locking mechanism in narrow-band lasers] proposed a novel self-mode-locking mechanism in narrowband lasers based on the analysis of the gain-line splitting induced by an intra-cavity laser field. Although the present experimental results are fairly consistent with this mechanism, further identification is still needed.

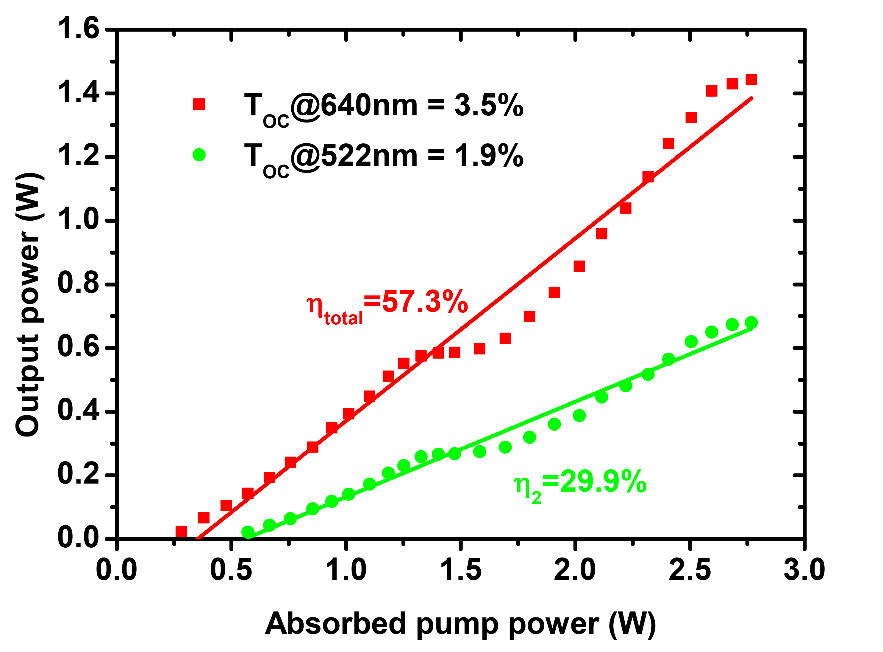


Fig. 2.

The mode-locked pulses were detected by a free space high sensitivity PIN photo detector unit (Menlo Systems, Inc. FPD310-FV with rise time 0.7 ns), whose output signal was connected to a digital mixed signal oscilloscope (Tektronix MSO 3054) with 500 MHz electrical bandwidth and a sampling interval of 0.4 ns.

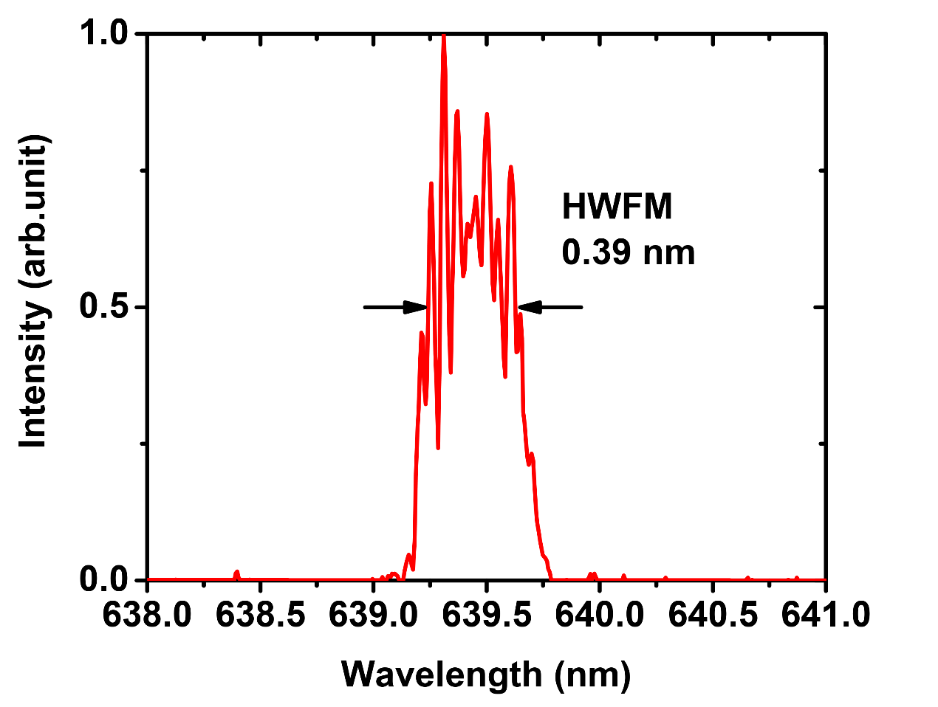


Fig. 3. optical spectrum of the mode-locking for 639 nm at cavity length of ~1.8 m

Hewlett Packard 8560E Series Optical Spectrum Analyzer with a resolution of 0.08 nm

As a result, the total cavity length was ~1.8 m, which coincides well with the repetition rate measured to be ~85 MHz shown in Figure 5(c).

Figures 4(c) and 4(f) show the pulse trains for the ~1.8 m-long cavity on two different time scales, one with time span of 5 ns, demonstrating mode-locked pulses, and the other with time span of 5 μs, demonstrating the amplitude stability. It can be seen that the pulse trains display full modulation, and the complete mode locking is achieved.



Fig. 4.

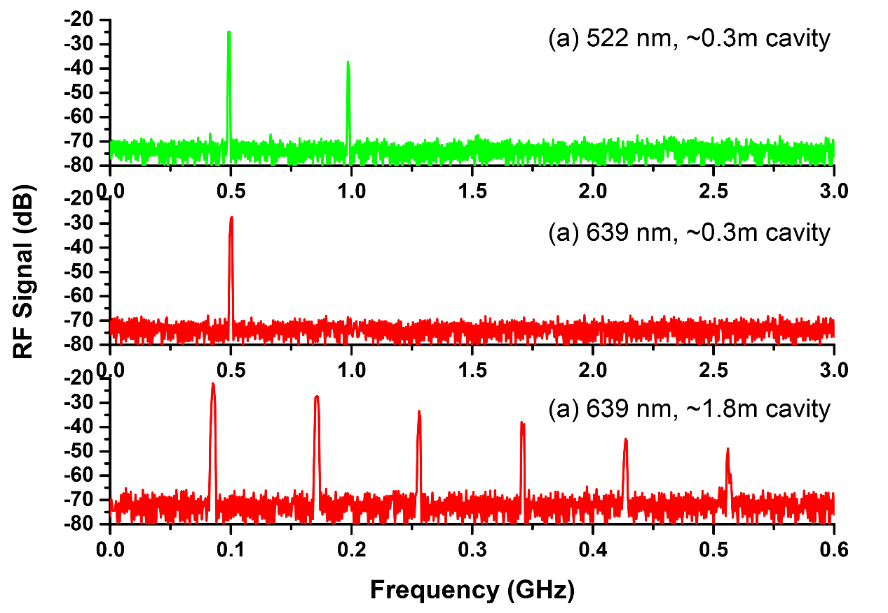


Fig. 5.

corresponding power

spectrum is shown in Fig. 3(c).

The laser was cw mode locked at ~85 MHz with only weak noise, and the difference between the peak of mode-locked frequency and that of relaxation oscillation frequency was experimentally found to be larger than 42 dBm.

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**References**

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