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68% slope efficiency Nd:YLF laser with 91 W of peak power

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Abstract: We demonstrate two highly efficient Nd:$YLiF_4$ lasers, achieving the highest efficiencies for Nd:YLF side-pumped at 800 nm.

1. Introduction

When it comes to achieving a high beam quality, longitudinal pumping is usually preferred. However, transversely-pumped resonators that use a total internal reflection (TIR) at the pump facet of the crystal expose the center of the TEM_{00} mode to the area of highest inversion density, which not only contributes to a higher beam quality but offers higher efficiencies [1-3]. Side-pumping schemes also contribute to the power scaling, since the incident power is better distributed across the crystal. In 2015, TEM_{00} beam quality was achieved in a double beam mode controlling cavity (DBMC), using a quasi-continuous wave (QCW) 797 nm, volume Bragg grating (VBG) equipped diode to side-pump a Nd:YLF (yttrium lithium fluoride) crystal. This configuration resulted in a record 65% of slope and 63% of optical efficiency [4]. QCW pumping is also a good choice for passively q-switched cavities due to the reduction of timing jitter when compared with continuous-wave (CW) Q-switching [5,6].

Side-pumped Nd:YLF lasers that use a Brewster angle incidence (55.4º for the σ-transition) show very high efficiencies. The bigger angle takes advantage of the longer absorption length and lower absorption of the Nd:YLF, when compared to other Nd:doped crystals [6,7]. Despite Nd:YLF not being as efficient as other active media, such as Nd:YVO_4 (Yttrium Vanadate) and Nd:$GdVO_4$ (Gadolinium Vanadate), its long upper state lifetime, natural birefringence, and low-temperature variability of its index of refraction makes it a great alternative for applications such as LIDAR, Q-switched lasers and material processing [8-11]. The highest ever reported efficiency for an Nd:YLF crystal used an 863 nm pump diode in a single-bounce configuration, with intracavity cylindrical lenses. This configuration resulted in 76% of slope efficiency while operating with close to diffraction limited beam quality [12]. However, 863 nm lasers are expensive and somewhat difficult to come by, when compared to 800 nm diodes. Many Nd:YLF applications are made using the latter, more affordable option, which combined with highly efficient resonator design can lead to still respectable efficiencies.

Here we show the development of two single-bounce Nd:YLF lasers, one using a plane-concave resonator (PC) and another in a plane-plane resonator (PP) with intracavity cylindrical lenses, presenting the highest efficiencies ever reported for a Nd:YLF laser pumped into the 800 nm absorption band.

2. Experimental setup

An a-cut Nd^{3+}:$YLiF_4$ crystal with 1 mol% dopant was used as the active medium for both resonators. The crystal, with dimensions of 13x13x3 mm^3, was side-pumped at 797 nm by a VBG equipped diode (Northrop Grumman), with bandwidth of 0.5 nm. The diode had a peak output power of 150 W and operated with a repetition rate of 5 Hz and pulse width of 350 μs. This duty cycle was set by the manufacturer and has to be maintained in order to get optimal bandwidth narrowing of the 797 nm emission line by the VBG. Both resonators used a Brewster angle incidence to obtain pure 1053 nm emission. The pump polarization was rotated, by a half waveplate (HP), to be parallel to the c-axis of the crystal, coinciding with the peak absorption cross-section in the π-polarization. To optimize the spatial overlap of the pump and laser beam, the pump power was focused by a spherical lens (SL), with f = 25 mm in the case of the PC resonator and f = 40 mm for the PP configuration, as shown in Fig. 1A and Fig. 1B. The absorbed power, after the focusing system, was 140.4 W.

2.1 Plane-concave resonator

The PC resonator employed a highly reflective (HR) concave mirror (M2) with a radius of curvature of 150 mm and a flat output coupler (M1) with 20% transmission, as shown in Fig. 1A. The overall length of this resonator was 10 cm producing a spot size inside the crystal of 946.3 x 236.25 μm in the horizontal and vertical directions, respectively. These values were calculated by simulations using the LASCAD software. The biggest downside to this design lies in the small spot size, which hampers the ability to improve beam quality.

2.2 Plane-Plane resonator

In order to increase the spot size in the horizontal direction, the high reflectivity mirror was replaced by an HR plane mirror (M3) and the overall length of the resonator was increased to 343 mm, while maintaining the 20%

transmission output coupler (M1). To avoid diffraction losses in the y-direction, two intracavity cylindrical lenses (CL), with f = 100 mm, were added between each mirror and the Nd:YLF, as shown in Fig. 1B. This cavity presented spot sizes of 4.5 mm x 280 μm, in the horizontal and vertical directions.

3. Results and discussion

Power measurements were made with two calibrated power meters (model PM10V1 from COHERENT and model S322C from Thorlabs) showing identical results. The PC resonator achieved 67.81 ± 1.04% of slope efficiency and 64.94 ± 2.02% of optical efficiency with a peak output power of 91.17 ± 2.84 W, as shown in Fig. 1A. While both resonators achieved near Gaussian beam quality in the y-direction, the PC configuration resulted in an M_x^2 value of 13.18 ± 0.23.

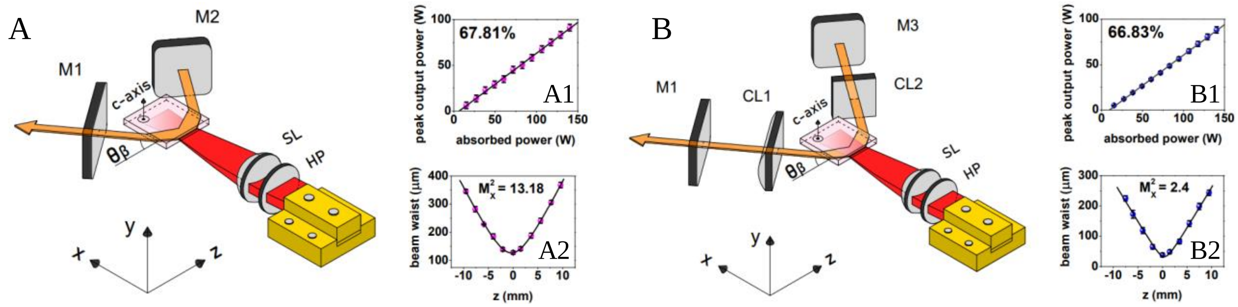

Fig. 1. A: Plane-concave resonator. A1: peak output power vs absorbed power of the PC resonator. A2: PC beam waist curve fit. B: Plane-plane resonator. B1: peak output power vs absorbed power of the PP resonator. B2: PP beam waist curve fit

With the PP resonator, a slope efficiency of 66.83 ± 0.64% and optical efficiency of 62.81± 2.51% were obtained with a peak output power of 88.18 ± 3.53 W. This configuration achieved a much better M_x^2 value of 2.4 ± 0.16, as shown in Fig. 1 B.

4. Conclusion

We report the highest efficiencies ever achieved for a Nd:YLF laser by pumping into the 800 nm absorption band. The first resonator achieved 68% of slope efficiency while presenting an M_x^2 value of 13.18. In the second configuration, we showed that it was possible to maintain this high efficiency while improving the M_x^2 to 2.4.

5. Acknowledgments

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