Record Efficiencies And Power Scalabililty In Diode-Side-Pumped Nd:YLiF$_4$ Lasers Using Double-Beam Mode-Controlling

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Abstract: In this work we present the novel results on the DBMC design, demonstrating its power scalability with a two gain medium cavity and a new record in optical-to-optical efficiency of 58.2%.
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1. Introduction

In the past few years, a large effort has been made by the academic community aiming at the development of new laser sources capable of providing diffraction limited beam quality, high power and high efficiency at reduced cost and complexity. Additionally, power scalability is another very desirable feature in the solid state lasers engineering field. Normally, for efficiency and beam quality end-pumped designs are preferred because the directional emission of the pump diodes allows for a good overlap between the pump beam and the laser's fundamental mode of oscillation, therefore high efficiencies and diffraction limited beam quality can be achieved. The highest optical-to-optical efficiency in a Nd:YLF end-pumped design of 50%, was achieved for the 1047 nm emission line (which has a higher emission cross section than the 1053 nm transition) [1]. Nevertheless, power scalability cannot be easily obtained with end-pumped lasers and expensive, time consuming approaches are required to achieve high output power [2].

The double-beam mode-controlling (DBMC) technique has proven its advantages for Nd:YLF and Nd:YVO lasers, based on a side-pump architecture, providing 53.6% of optical efficiency (63.5% slope efficiency) with diffraction limited beam quality. Additionally, this robust and compact cavity design can be easily operated at kHz-level repetition rate with mJ-level per-pulse energy in Q-switching mode [3 - 7].

In this work we present novel results on the DBMC design demonstrating, in two separated experiments, its power scalability and a new record efficiency.

2. Experimental setup

Fig. 1 shows two experimental setups

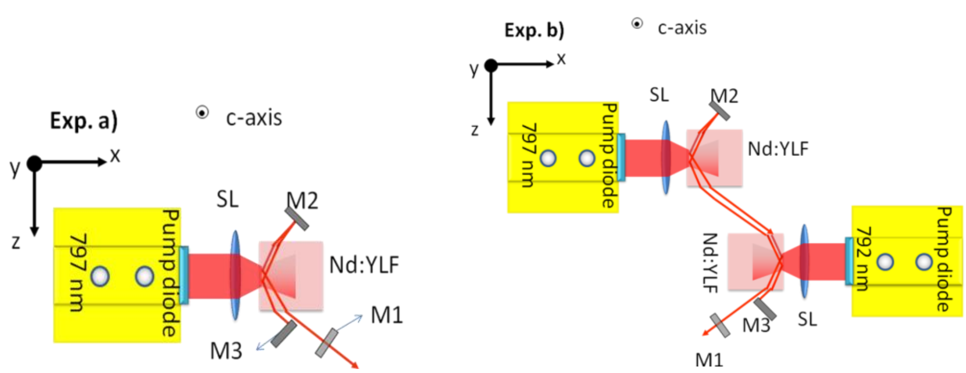

Fig. 1. A) Experimental setup classical DBMC laser and b) the experimental setup for a DBMC laser containing 2 gain media inside a single cavity to demonstrate power scalability of DBMC lasers.

Two a-cut crystals of dimension 13x13x3 mm^3 with 1 mol% neodymium doping and c-axis orientation parallel to the *y* direction (fig. 1) were placed inside a copper heat sink with water cooling on both facets. Qcw excitation by a diode bar was performed with a duty cycle below 5% to avoid thermal fracture. In experiment a), a single crystal slab was placed inside the resonator (setup fig. 1a)) and in the experiment b) (fig. 1b) and a second crystal slab along with an additional pump diode were placed inside a single cavity in order to demonstrate the power scalability of the DBMC design.

M2 is a concave mirror with radius of curvature ranging from 3 m to 10 m for experiments a) and b), respectively. M3 is a flat high reflection mirror at 1053 nm and M1 is a flat partial reflection mirror with T = 35% and T = 25% for exp. a) and b), respectively, at 1053 nm. The two pump diode bars were qcw operates at a duty cycle of less than 5% to avoid thermal fracture of the crystals. The diode bar used in experiment a) had its peak emission at 797 nm and was equipped with a volume Bragg gratings (VBG) to narrow its emission line, which increases the absorption efficiency of the pump light by the Nd:YLF crystal slab, the additional diode bar used in experiment b) had a peak emission at 792 nm. Both diode beams had a spot sizes of approximately 4 mm width and 0.1 mm height when focused into the two crystals by f = 20 mm spherical lenses.

3. Results and discussions

The measured laser performance of the two tested laser designs is presented in fig. 2. Since only one diode could achieve 115 W, when the amplifier stage was added, the driver's current was limited to 40 A, therefore in the exp. b, the overall absorbed pump power was 68 W. This setup was conducted only to prove the power scalability of this design. A slightly reduced overall output power is observed in the power scaled laser scheme due to the 16 air/crystal interfaces and 8 total internal reflections at the pump facets. The losses in this setup are high (7.5%), as expected. In a MOPA configuration the intra cavity losses can be in partly avoided, because of the single pass through the amplifier, leading to a better overall performance the lower gain of the Nd:YLF does not allows for a good screening of the inverted population with a single pass through the active medium[8].

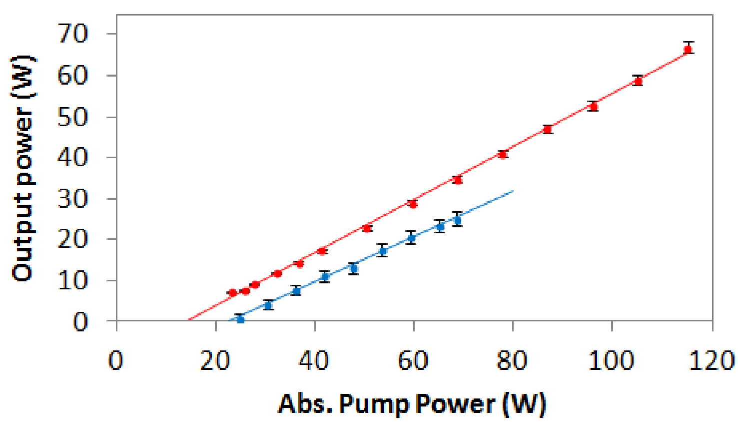

Fig. 2. Experimentally obtained laser performance of the classical DBMC side pumped laser of exp. *a* (red) and the performance of the power scaled DBMC side pumped laser of exp.*b* (blue)

From fig. 2 (red data series) we obtain a slope efficiency of 65%. At 115 W of absorbed peak power, the laser delivers 67 W peak fundamental mode output power, resulting in 58.2% of optical-to-optical efficiency which is, to the best of our knowledge, the highest efficiency ever reported for a Nd:YLF laser considering even longitudinal pump schemes. These results highlight three remarkable advantages of the side-pumped DBMC laser scheme versus longitudinal pumped laser schemes; Firstly the efficiency of the side pumped DBMC laser is not suppressed by its weaker mode overlap between pump and laser mode. Secondly the Side-pumped DBMC laser scheme easily allows power scaling, as demonstrated, and thirdly single mode laser operation is still preserved while using the DBMC laser scheme. Future investigation of the DBMC laser technology might improve the overall efficiency of the system.

From fig. 2 (blue data series) we obtain a slope efficiency of 56%. At 68 W of absorbed power, the laser delivers 25.2 W peak power of fundamental laser beam, resulting in 36.8% of optical - to - optical efficiency, which is very high considering a Nd:YLF laser and the losses.

4.References

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