Compact diode-side-pumped Nd:YLF laser with high beam quality

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Abstract. We describe the performance of a diode-side-pumped Nd:YLF laser using a compact cavity based on total internal reflection inside the gain media, showing the beam quality improvement with multiple pass configuration. With one pass through the crystal, high efficiency in multimode operation with 6W of output power for 17.1W of pump power is demonstrated. Using a second pass through the crystal, the beam quality was improved to fundamental mode with 3.8W of output power for 17.1W of pump power.

INTRODUCTION

Nd:YLF is an attractive host material for near infrared high power lasers, especially for Q-switched and amplifier applications where its long storage lifetime is an advantage. YLF has also superior thermo-optical characteristics because its natural birefringence eliminates thermal depolarization and its weak thermal lensing on the polarization corresponding to 1053nm keeps the high quality of the output beam [1]. This weak lensing observed under laser conditions is consequence of a refractive index decrease with temperature increase, creating a negative thermal lens, which partly compensates the positive thermal lens [2]. Applications for Nd:YLF lasers include pumping of other solid-state lasers, medical treatment, industrial material processing and LIDAR for pollution monitoring.

One of the most important elements in optimizing the efficiency and the beam quality of a solid-state laser is maximizing the overlap of the region in the active medium excited by the pumping source with the volume in the active medium occupied by the desired laser mode. Most often the desired laser mode is the lowest order or TEM_{00} mode.

Longitudinal pumping geometries provide optimal mode matching resulting in high efficiency and high beam quality. Using the longitudinal pumping scheme, slope efficiencies of 50% or greater can be achieved for Nd:YLF laser systems in fundamental output. However, the focused pump beam restricts the pump power due to the risk of fracture. Using a side pumping configuration, the pump power can be increased, but this configuration usually suffers from low efficiency when operating in TEM_{00} mode. To increase the efficiency and the beam quality it is necessary to guarantee a better overlap between pump beam and intracavity beam. This was demonstrated with $Nd:YVO_4$ [3] using a grazing incidence configuration inside the gain media, where the intracavity beam bounces at the pumped crystal surface. Using Nd:YLF, high efficiency and high beam quality in side pumped lasers was demonstrated by multiple pass configurations [4, 5, 6].

In this work we present a compact diode-side-pumped slab laser using Nd:YLF in a resonator based on total internal reflection inside the gain media. We describe the performance during cw and qcw (quase-continuous-wave) operation, showing the input-output power behavior and characterize the output beam quality. We have demonstrated that a Nd:YLF laser in a compact cavity using a configuration with one total internal reflection inside the crystal results in a high power multimode output. However, we have demonstrated that a second pass can improve the beam quality to fundamental mode.

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EXPERIMENTAL SETUP

An YLF crystal was grown by the Czochralski technique with neodymium concentration of 0.8mol%, resulting in absorption of $8cm^{-1}$ at 792nm for light polarized parallel to the crystal c-axis (π polarized light), as shown in figure 1. Then, a crystal slab was cut and polished with dimensions of 14 x 13 x 4 mm^3 with the c-axis orientation perpendicular to the large surface used for refrigeration.

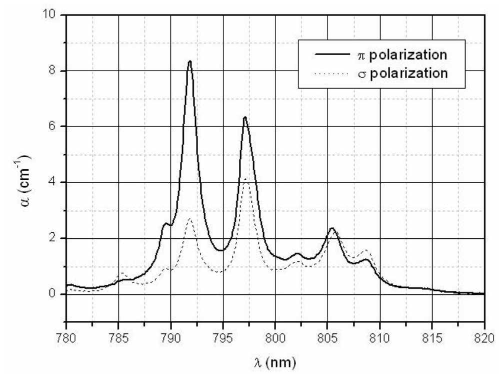


FIGURE 1: YLF absorption spectra for a Nd^{3+} concentration of 0.8mol%.

The crystal was side pumped by a 20W TM polarized diode bar thermally tuned to operate at 792nm and, thus, matching its emission spectrum with the highest absorption peak of the gain media. The diode temperature was fixed around 25°C by a thermoelectric cooling system. In order to achieve high absorption efficiency, the diode polarization was parallel to the crystal c-axis and the pump radiation was focused in the crystal by a 2.5cm focal length spherical lens. With the purpose of avoiding fracture due to thermal stress, the diode was operated mostly in the qcw regime with a diode pulse width of 2ms and a repetition frequency of 35Hz, resulting in a duty cycle of 7%. The heat was removed from the crystal through its bottom surface mounted on a water-cooled cooper heat sink with thermal grease at the interface, ensuring good thermal contact.

In order to demonstrate the improvement of beam quality in side pumped lasers with cavities based on multiple pass configurations, we have performed two experiments: first using a cavity with a single pass configuration and, later, a double pass configuration as shown in figure 2.

The first experiment was carried out using a simple configuration where the intracavity beam bounces at the pumped face in a single total internal reflection. A hemispherical cavity with a 30cm radius of curvature high reflector mirror and a flat output coupler with 7% transmission was used. The crystal was mounted at Brewster angle to minimize reflection losses at the entrance and exit surfaces of the crystal. The total size of the cavity was, approximately, 8 cm.

In a second experiment, the resonator was mounted using a double pass configuration with two total internal reflections at the pumped face. The same crystal was used with three mirrors: a folding mirror with 50cm radius of curvature, a flat output coupler with 15% transmission and a flat high reflector mirror. The size of this cavity was, approximately, 15 cm.

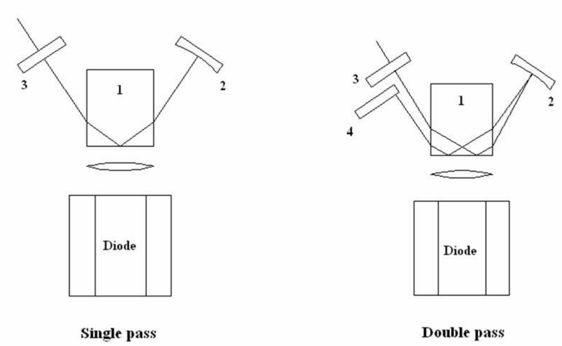


FIGURE 2: Schematic diagrams of the cavity configurations: 1) Nd:YLF crystal, 2) curved high reflector mirror, 3) flat output coupler, 4) flat high reflector mirror.

RESULTS AND DISCUSSIONS

The laser emission occurred at 1053nm. With one pass through the gain media, the laser presented an output power of 6.0 W for a pump power of 17.1 W, resulting in 35% optical to optical efficiency and 40% slope efficiency (figure 3). The output beam was multimode with M^2 of 43.3 x 2.15 in the horizontal and vertical directions, respectively. We also tried cw operation with improvement of the crystal refrigeration by thermal contact at the bottom and top crystals surfaces using indium foils. Near 18W of pump power the crystal fractured due to thermal stress.

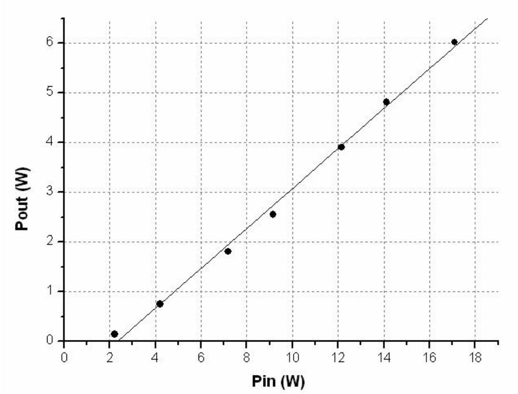
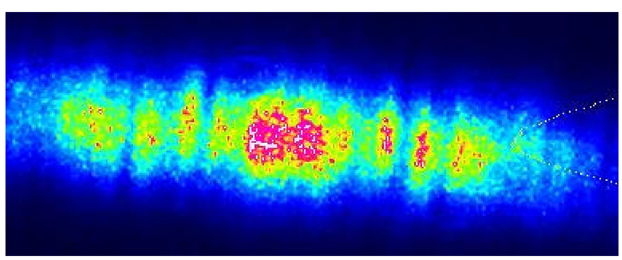
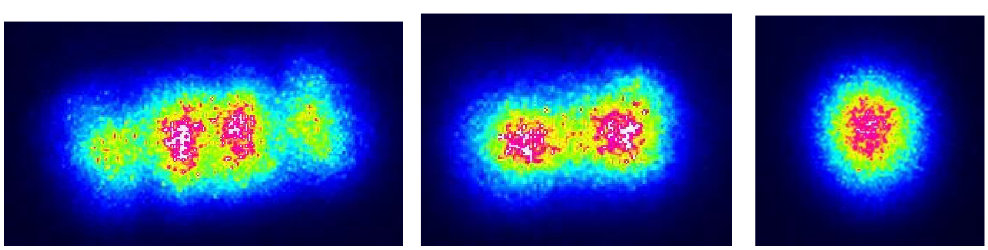


FIGURE 3: Output power versus pump power for the Nd:YLF laser in single pass configuration.

Using a second pass through the gain media increases the higher order mode threshold, thus improving the output beam quality. With two total internal reflections, different modes could be observed according to the cavity alignment (figure 4). For maximum output power, the laser presented a TEM_{30} output beam with M^2 of 6.2 x 2.2 in the horizontal and vertical directions, respectively, without significant loss of output power, 5.9W (figure 5), when compared with the single pass configuration. A TEM_{10} profile was observed at 4.4W of output power and a fundamental mode with M^2 of 1.5 x 1.4 in the horizontal and vertical directions, respectively, (figure 6) at 3.8W of output power. In this case, pump power was 17.1 W, resulting in 22% optical to optical efficiency and 28% slope efficiency (figure 5).



(a)



(b) (c) (d)

FIGURE 4: Beam profiles a) multimode output beam from single pass configuration; b) TEM_{30} mode obtained with double pass at the maximum output power of 5.9W; c) TEM_{10} mode obtained with double pass at 4.4W and; d) fundamental mode obtained with double pass configuration at 3.8W.

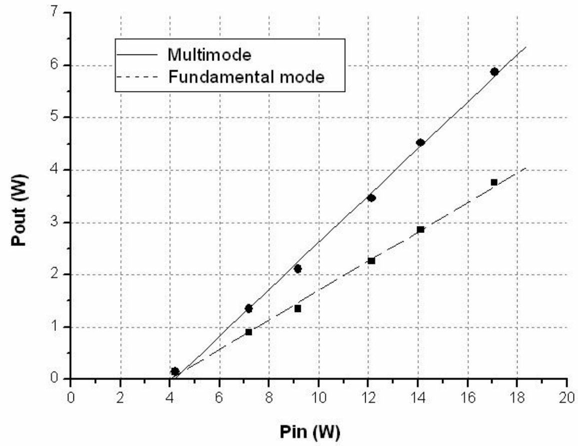
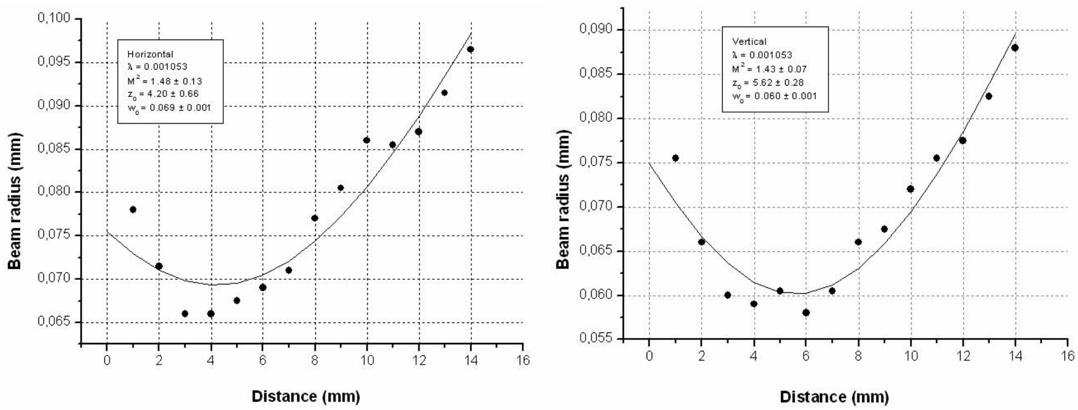


FIGURE 5: Power out versus pump power for the Nd:YLF laser in double pass configuration.



(a) **(b)**

FIGURE 6: Laser beam behavior for horizontal (a) and vertical (b) propagation.

CONCLUSIONS

Nd:YLF displays exceptional advantage in output beam quality because its natural birefringence and weak thermal lensing. However, in side-pumping configurations it usually presents low efficiency when operating in TEM_{00} mode. We have demonstrated that multiple passes through the gain media can improve the output beam quality. We showed a highly efficient diode-side-pumped Nd:YLF laser with one bounce at the pump face in multimode operation. The laser presented 6W of output power for 17.1W of pump power and an output beam with M^2 of 43.3 x 2.15 in the horizontal and vertical directions, respectively. Using a double pass configuration, the beam quality could be improved to fundamental mode with 3.8W of output power for 17.1W of pump power. The cavity presented is very compact and permits power scalability by using other diodes disposed laterally to the gain media.

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