CW operation of diode side pumped Nd:YLF laser

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Abstract

Nd:YLF displays exceptional qualities as a laser material for CW lasers by its natural birefringence and weak thermal lensing; however it has the disadvantage of a low thermal conductivity and mechanical resistance. We describe the performance during CW operation of a diode side pumped Nd:YLF laser using a compact cavity with one pass through the gain media in a total internal reflection, demonstrating high efficiency and multimode output with 3.51W of output power for 11.9W of pump power at 792nm and 4.13W of output power for 17.6 of pump power at 797nm.

Introduction

Neodymium was the first of the trivalent rare earth ions to be used in a laser and remains among the most important active ions due to its several applications in industry, medicine and LIDAR. Some properties of YLF have shown to be superior to other host materials for certain applications. Nd:YLF has a longer fluorescence lifetime and a lower cross-section, which offers advantages in pulsed and Q-switched operation. YLF also has superior thermo-optical characteristics because of its natural birefringence that eliminates thermal depolarization and it has weak thermal lensing. However, YLF has a low thermal conductivity which limits the pump power due to the thermal stress that can lead to a fracture of the host material. The thermal conductivity of YLF ($0.06Wcm^{-1}K^{-1}$) is about a factor of two lower than YAG ($1.12Wcm^{-1}K^{-1}$) and its mechanical resistance is about a factor 5 lower than in YAG (30 MPa against 165 MPa). Longitudinal pumping geometries provide optimal mode matching, resulting in high efficiency and high beam quality. However, the focused pump beam restricts the pump power around 14W in YLF due to the risk of fracture. The pump power can be increased by use of a side pumping geometry, but this configuration usually suffers from low efficiency. However high efficiency in side pumped lasers was demonstrated in a tightly folded resonator configuration [1] and good beam quality was demonstrated by a multiple pass configuration [2].

We have already demonstrated that a Nd:YLF laser in a compact cavity using a grazing incidence configuration with one total internal reflection inside the crystal results in a output power of 4.7W for 20W of pump power [3]. In that case, the beam bounces at the pumped crystal surface maximizing the overlap of the excited region in the active medium with the volume occupied by the laser mode, optimizing hence the efficiency of the laser. Also, the laser action reduces the heat generation, because the bounce acts as an effective cooling mechanism for the pump surface where the highest temperature gradients are expected. However, we have already demonstrated that a second pass can improve the beam quality to fundamental mode with small loss of output power.

In this paper, we demonstrate higher efficacy in a similar cavity and show the transition from pulsed to CW operation until the fracture threshold.

Experimental Setup

The YLF crystal was grown by the Czochralski technique with a low neodymium concentration of 0.8mol% resulting in absorption of $8cm^{-1}$ at 792nm and $6cm^{-1}$ at 797nm for light polarized parallel to the crystal c axis (π polarized light). Then a crystal sample was cut and polished with dimensions of 15 x 13 x 2 mm^3 and the c axis orientation perpendicular to the large surface.

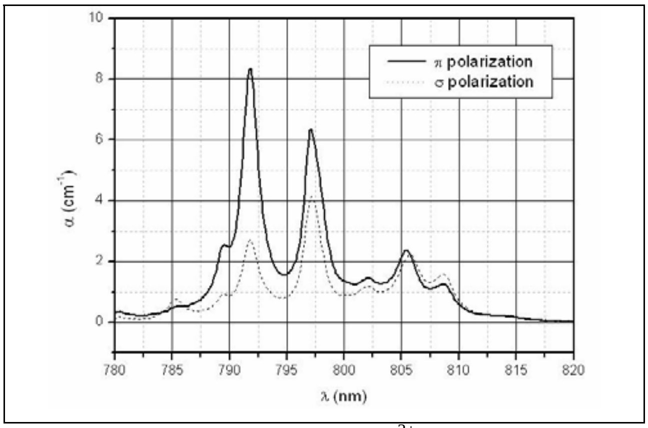

Figure 1: YLF absorption spectra with Nd^{3+} concentration of 0.8mol%.

In a first experiment, the laser was operated in pulsed regime with a diode pulse width of 2ms and a repetition frequency of 35Hz, resulting in a diode duty cycle of 7%. The crystal was side pumped by a TM polarized diode bar with the pump radiation focused in the crystal by a 24mm focal spherical lens. To achieve high absorption efficiency, its polarization was parallel to the crystal c axis. We have explored both high absorption peaks of the crystal, first using a 20W TM polarized diode bar emitting at 792nm and then a 50W TM polarized diode bar emitting at 797nm.

In a second experiment, the laser was operated CW. The pump was the 20W TM polarized diode bar with the pump radiation focused in the crystal using the same 24mm focal spherical lens in front of the diode. To match its emission spectra with the high absorption peaks of the gain media, the diode was thermally tuned to operate at 792nm or 797nm with temperatures fixed around 15°C and 30°C respectively by a thermoelectric cooling plate connected to a closed loop temperature stabilization circuit.

In qcw operation the crystal was already pumped above 25W without thermal damage. But at CW operation the active medium needs a better cooling mechanism to avoid fracture by thermal stress. The crystal was mounted on a cooper support between indium foils with circulating chilled water removing the heat from the top and bottom crystal surfaces.

The resonator, figure 2, was mounted using a simple configuration where the intracavity beam bounces at the pumped face in a single total internal reflection. It was used a high reflector mirror with 30cm radius of curvature and a flat output coupler with 7% transmission. The crystal was mounted at Brewster angle to minimize reflection losses at the entrance and exit surfaces of the crystal.

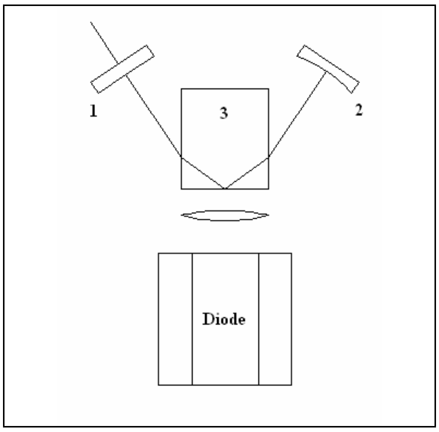

Figure 2: Schematic diagrams of the cavity configurations: 1) flat output coupler, 2) curved high reflector mirror, 3) Nd:YLF crystal.

Results and Discussions

The laser emission occurs at 1053nm in multimode output with M^2 approximately 16x5 in the horizontal and vertical direction. Because of the absorption peak at 792nm, a higher efficiency was obtained with the diode emission at this wavelength. With the pulsed operation of the first experiment, and pumping at 792 nm the laser presented an output power of 5.27 W for a pump power of 17 W resulting in 31% optical to optical efficiency and 37% slope efficiency (figure 3). With pumping at 797 nm, 8.58 W of output power were obtained for 27.7W of pump power, resulting in 31% of optical to optical efficiency and 36% of slope efficiency.

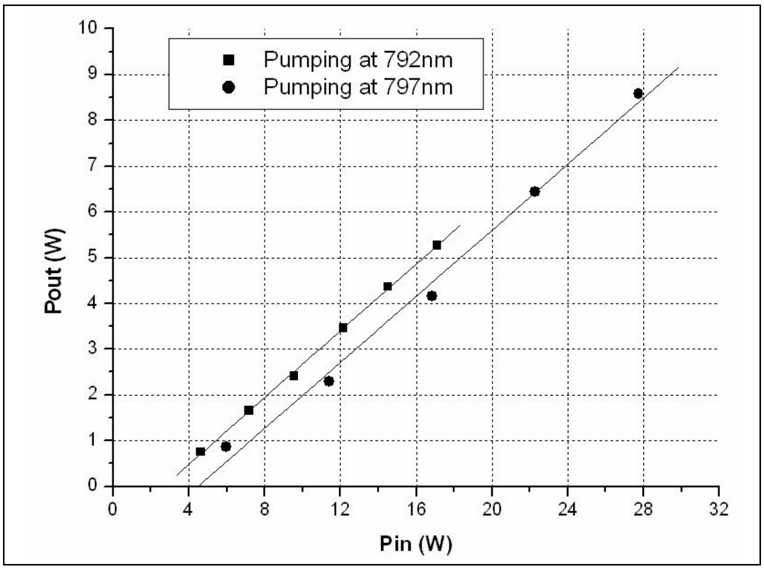

Figure 3: Power out versus pump power for the pulsed Nd:YLF laser with one pass through the crystal.

In CW operation, the pump emission at 792nm was restricted to 11.9W due to diode thermal tuning limitations, resulting in an output power of 3.51W in multimode operation with 29% of optical to optical efficiency and slope efficiency of 33%, figure 4. The experiment at 797nm was performed with the crystal damaged by heat load, leading to a decrease of the efficiency. At 797nm the pumping power could be increased to 17.6 W and 4.13 W of multimode output was achieved with 23% of optical to optical efficiency and slope efficiency of 28% before crystal fracture occurred due to thermal stress. The fracture occurred near the top face in the center of the crystal.

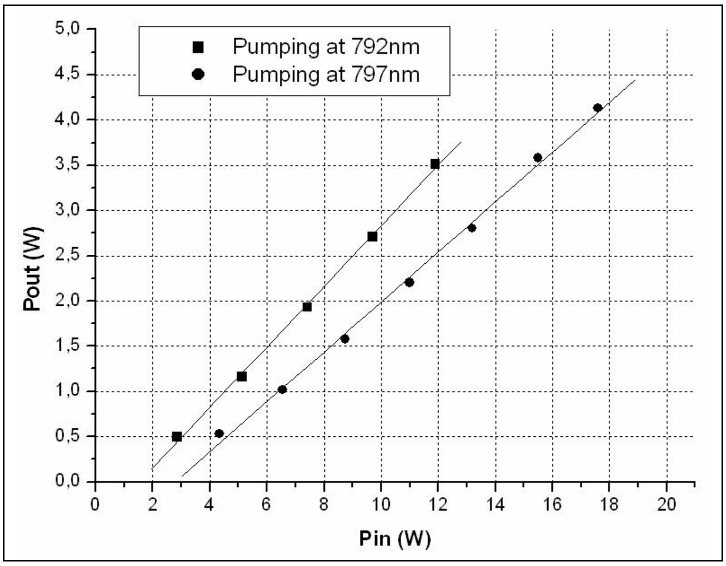

Figure 4: Output power versus pump power for the CW Nd:YLF laser with one pass through the crystal.

In order to explain the causes of the fracture, we have made a stress simulation. Nd:YLF is a four level system with absorption at 792 or 797nm and emission at 1053nm, this difference of energy is converted in heat inside the host material with thermal losses around 24%. The heat is distributed inside the crystal in a temperature gradient that implies in different regions of deformation and mechanical stress that can lead to a fracture of the host material. In a three dimensional finite-element simulation of stress by thermal generation, figure 4, we show that YLF presents compression near the pump region and expansion around it, principally at the upper and lower corners between the pump face and the refrigerated faces. The compression at the center of the crystal implies in a partial loss of contact of the refrigerated crystal surfaces with the cooling cooper support, which increases the heat load in the region and increases the risk of fracture near the crystal edge. In addition, an edge leads to a accumulation of the stress field density. In the case of an thermal expansion, as happens in i.g. isotropic crystals such as YAG, the edge angle increases to > 90 degrees, diminishing the force field. But YLF reduces the edge angle due to the compression of the pump face which implies in a strong increase of the stress and, consequently, in an increase of the fracture risk.

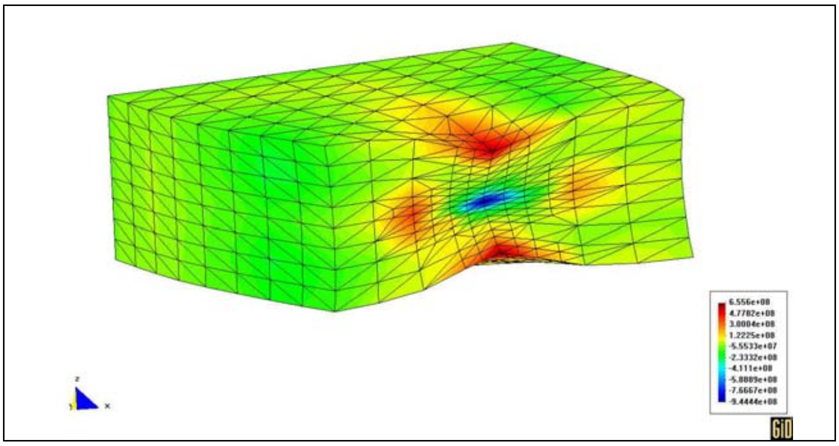

Figure 5: Simulation of thermal stress in YLF crystal with pump at the center of the front face. The thermal stress is amplified more then 300 000 times. Blue regions at the center indicate compression and red regions at the edges indicate expansion.

These considerations help to explain the fracture observed at the crystal's upper corner for relative low pump powers. In comparison, some oxide crystals can be pumped with more 30 times higher pump densities without fracture. This difference cannot be explained by mechanical strength factors alone.

Conclusions

Nd:YLF displays exceptional qualities as a laser material for CW laser, but has the disadvantage of a low thermal conductivity and low mechanical resistance. We have demonstrated that using a good cooling mechanism and CW side pumping, the fracture threshold is near to 18W. Using a compact cavity in pulsed operation with a simple pass through the active medium, we have obtained a maximum optical to optical efficiency of 31% at 792nm and 797nm. In the CW regime we have obtained a maximum optical to optical efficiency of 29% at 792nm.

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