Experimental Analysis of Quasi Three Level Nd:YLF Laser Operating at 908 nm With a Peak Output Power of 6.4 W

D. Geskus, J. Jakutis-Neto, N. U. Wetter
Centro de Lasers e Aplicações, IPEN/SP, Av. Prof. Lineu Prestes, 2242 São Paulo, SP, Brazil
Author e-mail address:d.geskus@alumnus.utwente.nl

Abstract: Nd:YLF laser at 908 nm, providing an QCW output power of 6.4 W at 33 W of absorbed pump power and a laser threshold of 3.2 W of absorbed pump power at 797 nm.

OCIS codes: (140.3530) Lasers, neodymium; (140.3580) Lasers, solid-state; (140.3480) Lasers, diode-pumped

1. Introduction

The development of high performance compact diode pumped laser sourced is ongoing, not only in increasing the output power, but also in expanding the spectrum. Here we report laser emission at 908 nm from Nd:YLF, this laser line exhibits reabsorption, hence an optimal design of the laser components is required to achieve the best laser performance. Therefore we have consecutively tested two similar crystals with different lengths into one laser cavity to find the preferred crystal length. In a second experiment a Brewster window is introduced into the cavity to find the optimal outcoupling efficiency. To date, laser performance with output powers of 1.43 W [1] and 5.5 W [2] at 908 nm has been demonstrated QCW mode. Despite the reabsorption of this transition, excellent CW laser operation has been demonstrated with an output power of up to 4.7 W [3].

The future goal of this project is to use this laser to drive an intracavity Raman laser, and to address new laser lines in the blue, using frequency doubling and sum frequency generation of the Raman and fundamental laser line. So far using the same scheme but operating the Nd:YLF laser at 1053 nm has resulted in laser emission in the yellow regime [4].

2. Experimental

Two characterizations have been performed. During the first characterization the preferred crystal length and pump wavelength is determined. Two 0.7% Nd doped YLF crystals with antireflection coated facets, having a length of 9 mm and 6 mm were mounted using indium foil into water cooled copper mounts. The temperature of the cooling water was set to 15 °C. During the two experiments the crystals were mounted consecutively in a 4.5 cm long linear cavity made by a flat outcoupling mirror having a transmission of OC = 1.14%, and a highly reflective concave mirror with a radius of r = 100 mm. The coating design of the concave mirror is designed to be highly transparent for the pump laser operating at 797 or 806 nm and in addition providing high transmission at 1053 nm to force laser oscillation at 908 nm. The laser emission was recorded via a long pass filter to reject the residual pump power. The pump source was a fiber coupled diode bar. The thermal load on the crystal was reduced by QCW pumping, here the pulse lengths were 961 μs and 600 μs at 979 and 806 nm respectively. An image of the pump fiber, having a core diameter of 200 μm and an NA of 0.22, was made using an AR coated doublet lens (f = 30 mm) to collimate the beam, and focused through the curved mirror into the crystal using another AR coated doublet lens (f = 50 mm). The minimal waist of the pump beam inside the crystal is estimated to be 150 μm. A schematic of the setup is shown in Fig. 1a.

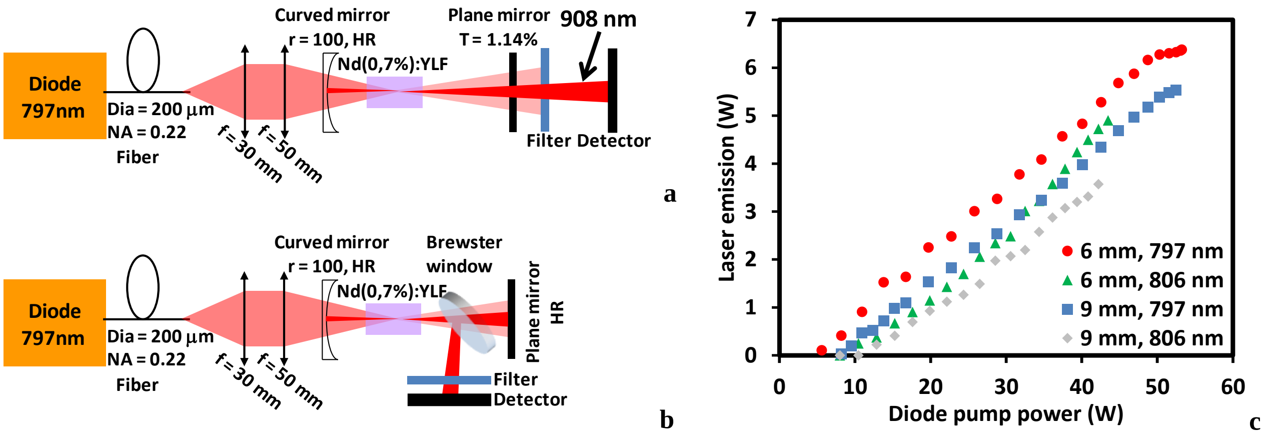

Fig. 1 a) Schematic representation of the used setup to determine optimal crystal length and b) optimal outcoupling efficiency. c) Measured QCW laser performance at 908 nm for different Nd:YLF crystal lengths (6 mm and 9 mm) and different pump wavelengths (797 nm and 806 nm).

In the second experiment a fused silica Brewster window is introduced into the non-pumped side of the cavity to determine the optimal outcoupling efficiency. In addition the flat outcoupling mirror is replaced by a highly reflective flat mirror. In this setup the outcoupling efficiency is controlled by the angle of the Brewster window. The laser power of two of the four reflections from the Brewster window are collected by a power meter, it is assumed that this is half of the outcoupled power by the Brewster window, hence the presented values are the double values that have actually been measured. An absorption efficiency of 70% at 979 nm was recorded in a separate experiment under non-lasing condition, no bleaching was observed during this measurement. The transparency of the second doublet lens and incoupling mirror was estimated to be 88%.

3. Experimental results I: Finding the preferred crystal length and pump wavelength

The laser performance of the two different laser crystals are presented in Fig. 1c, from this figure we see that the best laser performance is achieved using the shorter, 6 mm long, crystal under 797 nm pumping, resulting in a maximal output power of 6.4 W at an absorbed pump power of 33 W. For comparison reasons, the data in Fig. 1c is presented versus incident pump power, since the absorption of the pump light was not measured at 808 nm. The performance of the 9 mm long crystal is clearly reduced due to reabsorption processes, especially in the non-pumped side of the crystal. At the non-pumped side of the crystal fluorescence appeared when closing the cavity and initiating the laser oscillation, this is clearly caused by the reabsorption of the intracavity laser emission. The improved laser performance for pumping at 797 nm compared to pumping at 806 nm, is explained by the lower absorption cross-section at 806 nm. The observed rollover of the laser emission at the larges pump intensities is explained by an increased spectral width of the pump laser diode emission at these powers.

4. Experimental results II: Finding the optimal outcoupling efficiency

During this experiment the Brewster window was rotated over a range of 26° away from the Brewster towards smaller angles of incidence, hence varying the outcoupling efficiency (*T*) from nearly 0% to 8.9%. The measured laser performance, presented in Fig. 2a, reveals a low laser threshold of 3.2 W of absorbed pump power at the Brewster angle and increasing slope efficiencies for larger outcoupling efficiencies. Fig. 2b reveals an optimal outcoupling efficiency of around 3% to 4% at 32W of absorbed pump, resulting in an total extracted power of nearly 6 W. Remarkably this is lower than the maximum extracted power in experiment I, using only 1.14 % outcoupling efficiency. The possible cause for this discrepancy is the induced additional intracavity losses of the Brewster window.

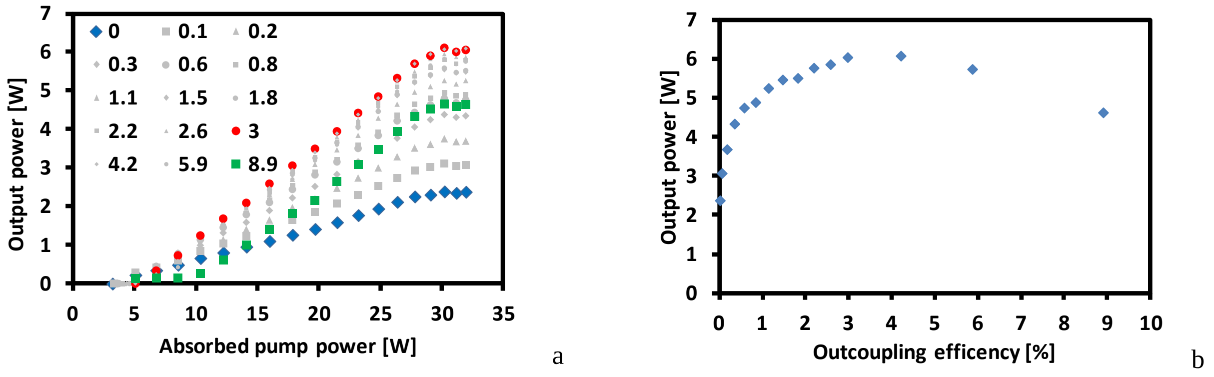

Fig. 2 a) The measured performance of the Nd(0.7%):YLF laser for various outcoupling efficiencies (labels provide the outcoupling efficiency in %), and b) The laser performance at maximum absorbed pump power of 32 W for the various outcoupling efficiencies.

An analysis according to the theory for laser devices exhibiting reabsorption [5] has been performed using the slope efficiencies, taken from the linear regimes of the experimental data shown in Fig. 2a. Commonly a linear representation is used for this type of analysis, however in this case the obtained data with low outcoupling efficiencies receive in the linearized analysis a large impact on the analysis, resulting in a reduced reliability of the analysis.

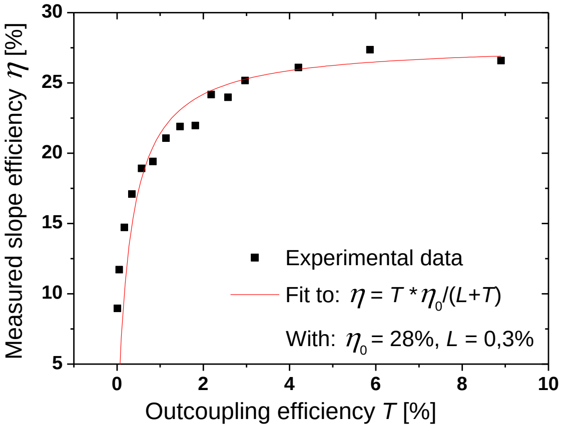

Fig. 3 Slope efficiency as function of the outcoupling efficiency by the Brewster window (dots). The solid line represents the fit to the theoretically expected laser behavior [5]. Here a fixed value for L of 0.3% was chosen, resulting in an internal efficiency η_0 of 28%.

Therefore a non-linear fit of the experimentally obtained slope efficiencies (η) at various outcoupling efficiencies (T) is performed to the theoretical laser behavior, see Fig. 3. The best fit of the measured data to the theory is found when choosing a fairly low intracavity loss value of $L = 0.3\%$. This value seems to be low, since in the former experiment having $T = 1.14\%$ resulted in a much higher output power of 6.4 W, which could only be explained by an even lower intracavity loss. Here the calculated intracavity loss using the specifications of the used mirrors from Layertec, having a specified reflectivity of R > 99.9%, and the specifications of the coatings of the crystal facets from Crystech, having a specified reflectivity of R = 0.05%, adds up to a total intracavity roundtrip loss of about 0.4 %. The internal efficiency (η_0) indicates the conversion efficiency of pump light into laser light, hence revealing the maximum achievable slope efficiency that can be achieved in such a laser. The internal efficiency strongly depends on the overlap between the pump beam and laser mode. Hera the fairly low internal efficiency of 28%, compared to earlier reported values of 33.6% [2], 43.3% [3] and 49% [1], is possibly caused by a non-optimal overlap between the pump beam and laser mode.

5. Conclusions and discussion

Laser emission from Nd(0.7%):YLF has been demonstrated, resulting in a maximal output power of 6.4 W at 908 nm with 33 W of absorbed pump power at 797 nm, resulting in an optical efficiency of 20%. In addition the optimal outcoupling efficiency between 3% and 4% is determined using an intracavity Brewster window to vary the outcoupling efficiency. Hence an improved laser performance is expected by increasing the outcoupling efficiency to a value around 3.5% using an outcoupling mirror, aided by the absence of the additional roundtrip loss caused by the Brewster window. Analysis of the data reveals a roundtrip loss of 0.3% and an internal laser efficiency of 28%. The internal laser efficiency can possibly be improved by better overlap between the pump beam and laser mode.

Acknowledgement: This research project is financially supported by CNPq project nr. 374365/2012-1

6. References

[1] S. Spiekermann, F. Laurell, "Continuous wave and Q-switched operation of diode pumped quasi-three level Nd:YLF Lasers," in Advanced Solid-State Photonics (ASSP), (2000).

[2] J. J. Neto, F. de Almeida Camargo, N. U. Wetter, "Deep blue Nd:LiYF$_4$ laser in quasi-continuous and continuous operation," in Advanced Solid-State Photonics (ASSP), San Diego, California, ATuA12, (2010).

[3] W. Liang, X. H. Zhang, Z. L. Liang, Y. Q. Liu, Z. Liang, "Efficient continuous-wave 908 nm Nd:YLF laser emission under direct 880 nm pumping," Laser Physics, **21** (2), 320-322 (2011).

[4] J. Jakutis-Neto, J. Lin, N. U. Wetter, H. Pask, "Continuous-wave Watt-level Nd:YLF/KGW Raman laser operating at near-IR, yellow and lime-green wavelengths, " Opt. Express **20** (9), 9841–9850 (2012).

[5] W.P. Risk, "Modeling of longitudinally pumped solid-state lasers exhibiting reabsorption losses, " J. Opt. Soc. Am. B, **5** (7) 1412-1423 (1988).