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Nd:YLF laser pumped at 797 nm with 68% slope efficiency

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ABSTRACT

We demonstrate a $Nd:YLiF_4$ laser emitting at the 1053nm transition while side-pumped at 797nm by a VBG equipped diode. Initially, a plane-concave cavity is employed using a total internal reflection at the crystal pump face. The laser operated in QCW-mode and produced 68% of slope and 66% of optical efficiency with 67 W of peak output power, while having a multimode beam quality. These efficiencies are the highest ever reported for the $Nd:YLF_4$ pumped at 800nm.

Keywords: Lasers, neodymium, diode-pumped, $Nd:YLiF_4$, solid-state lasers

1. INTRODUCTION

Diode lasers have long been used as an efficient pump source for solid state lasers when compared to traditionally lamp pumped lasers. When it comes to make applications that require a high beam quality, diode end-pumping is usually preferred in contrast to diode side-pumping, since both, the pump- and laser beam, are propagating colinearly with good spatial overlap. For the same reason, these schemes can also achieve high efficiencies with ease. However, the power scaling of such configurations is limited by its lower fracture limit. This limitation can be overcome with side-pumped configurations, since the incident power is better distributed across the crystal. Although monomode operation in side-pumping configurations are harder to obtain than with longitudinal schemes, some cavity designs take advantage of the possibility of having an increased beam size inside the crystal to ensure good beam quality. Transversely-pumped cavities that presented 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 [1,2,3,4].

One of the first single-bounce configuration with TIR utilized a grazing incidence angle for a $Nd:YVO_4$ laser, this configuration has granted 64% and 72% of optical efficiency and slope efficiency, respectively [2]. Because of the lower absorption cross section of Nd:YLF crystals, when compared to vanadates, a bigger TIR - angle of incidence has to be used in order to better take advantage of its longer absorption length, for example, Brewster incidence angle (55.4º for σ-polarization at 1053 nm). This configuration has been used in several works throughout the years, generating good results in terms of efficiency for the Nd:YLF active medium [3,4,5,6,7]. The high intracavity intensities are prone for intracavity Raman conversion [8], and the quasi-continuous operation has achieved good results in Q-switching [9,10]. Using a 797 nm volume Bragg grating (VBG) equipped diode to side-pumped a Nd:YLF crystal in a double beam mode controlling cavity (DBMC), with an incidence at Brewster angle, record efficiencies of 60% and 65% of optical and slope efficiency were achieved in 2015 [11]. Slope efficiencies as high as 78.2% were achieved by direct pumping Nd:YLF at 863 nm wavelength in a single-bounce resonator [12]. However, 863 nm diodes with wavelength narrowed emission bands are hard to obtain.

Our previous work indicated that a single-bounce configuration, with incidence at Brewster angle, utilizing a 797 nm diode equipped with VBG to side-pumped a Nd:YLF crystal could achieve even higher efficiencies [13]. In this work we explore this configuration, and present the highest efficiency value ever reported for the traditionally pumped (800 nm pumping) Nd:YLF crystal.

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2. EXPERIMENTAL SETUP

Here we show the development a Nd:YLF laser, with a single-bounce configuration, emitting at the 1053 nm wavelength (σ – emission). The resonator consisted of two mirrors, a concave highly reflecting mirror (HR) and a flat output coupler, with a total internal reflection (TIR) at the pump face of the crystal. An a-cut $Nd^{3+}:YLiF_4$ crystal, with 1 mol% dopant, was used as the active medium for the resonator presented in this paper. The crystal, with dimensions of 13 mm x 13 mm x 3 mm, was side-pumped by a volume Bragg grating (VBG) equipped diode, with bandwidth (FWHM) of 0.5 nm at peak power, emitting at 797nm and resulting in a maximum absorbed pump power of 101.85 W. The laser diode was operated in quasi-continuous wave (QCW) with 5 Hz repetition rate and pulse width of 350 μs. These pulse parameters are necessary in order to maintain optimal bandwidth narrowing of the 797 nm emission line of the VBG equipped diode.

Since both, π- and σ- transitions of the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ emitting level are orthogonally polarized, one can obtain single wavelength oscillation by implementing some sort of polarization optics. In our case, where it is necessary to have the a- and b- axes (σ-polarization) in the same plane (horizontal plane), single oscillation of the 1053 nm laser wavelength was achieved by making an incidence at Brewster angle of 55.4º at both side-entrance facets of the crystal, as shown in Fig. 1.

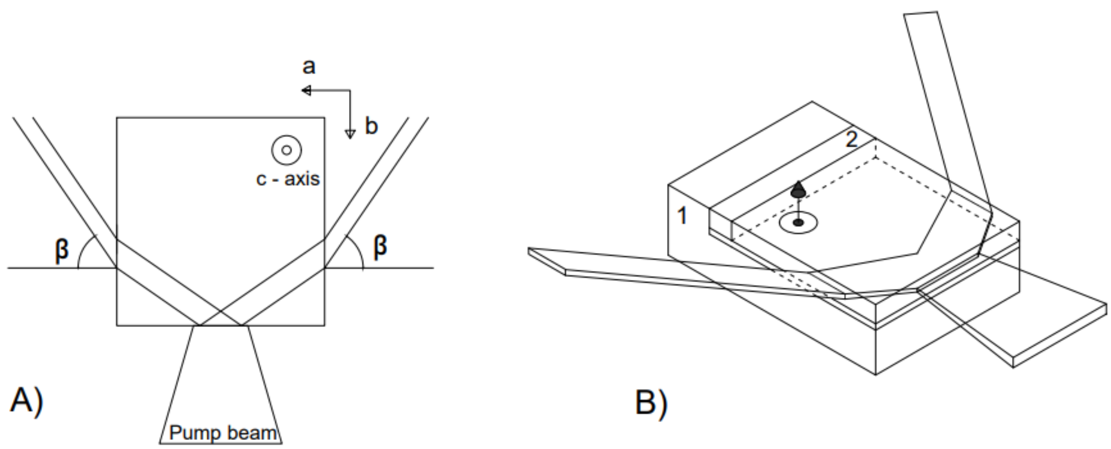

Figure 1. A: Laser beam with TIR and Brewster incidence at side-entrance facets. c, b and a are the crystals axis. B: isometric view of the Nd:YLF crystal in its support with pump- and laser beam. (1): Nd:YLF copper housing; (2): index matching material.

To reduce reflection losses at the end of the crystal, a material with an index of refraction close to the one of Nd:YLF (n_o = 1.4481 and n_e = 1.4704) was added between the crystal and its copper housing, as indicated in Fig. 1b. The pump laser polarization was rotated, by a half wave plate (HP), to be parallel to the c-axis of the crystal, coinciding with the peak absorption cross section in the π-polarization. In order 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, as shown in Fig 1 and Fig. 2.

Plane-concave resonator

The plane-concave resonator employed a highly reflective (HR) concave mirror (M2), with radius of 150 mm, and a flat output coupler (M1), with 20% transmission, as shown in Fig. 2.

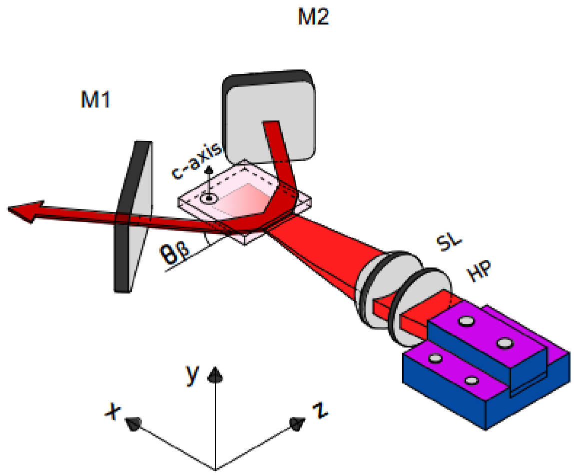

Figure 2. Scheme of the plane-convex resonator. M1: output coupler; M2: HR concave mirror; SL: spherical lens with f = 25mm; HP: half wave plate.

The overall length of this resonator was 10 cm, producing a spot size inside the crystal of 342,1 μm x 236.25 μm for a hypothetical TEM_{00} mode, in the horizontal and vertical directions, respectively. These values were calculated by simulations using LASCAD software.

3. RESULTS AND DISCUSSION

Power measurements were made with two calibrated power meters (model S322C from Thorlabs and model PM10V1 from COHERENT) which showed identical results. All the results presented here have passed through the correct treatment, based on errors theory, to give the appropriate uncertainties. Using the VBG equipped laser diode, which resulted in 101.85 ± 3.2 W of absorbed pump power, the plane-concave cavity achieved 67.94 ± 0.79% of slope efficiency and 66 ± 1.27% of optical-to-optical efficiency with a peak output power of 67.22 ± 1.29 W. The graph in Fig. 3 shows the curve of peak output power vs absorbed pump power for this cavity.

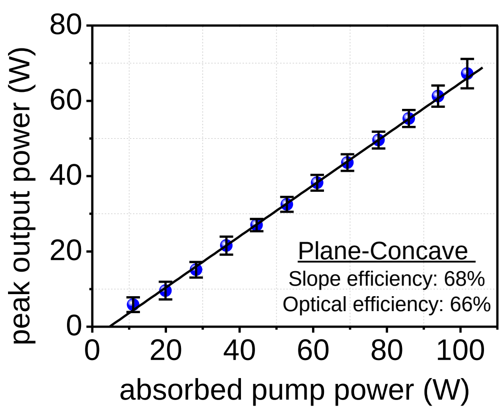

Figure 3. Curve of peak output power vs absorbed pump power for the plane-concave resonator.

Beam quality was obtained using a CCD camera (LBP series beam profiler by NEWPORT) to measure the beam waist of the laser beam 10 mm before and after the focus point produced by a 50 mm spherical lens. As shown in the graph of

Fig. 4. After making a non-linear curve fit of our data points, a M^2 of 12 x 1.48 was calculated in the x and y-direction, respectively.

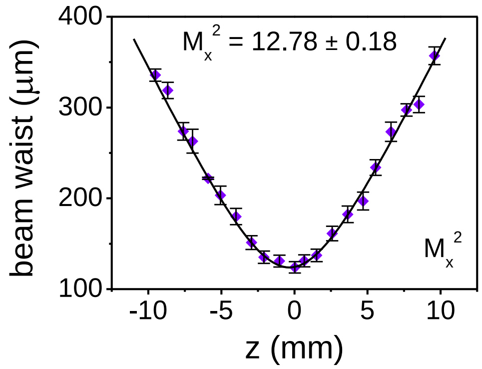

Figure 4. Experimental points and fitted curve of horizontal beam waist vs position of the plane-concave resonator operating at peak power.

Table 1 present a summary of the results produced by the cavity.

Table 1. Results of the plane-concave cavity.

	peak output power (W)	**optical efficiency (%)**	**slope efficiency (%)**	**M_x^2**	**M_y^2**
Plane-Concave Ressonator	67.22 ± 1.29	66 ± 1.27	67.94 ± 0.79	12.78 ± 0.18	1.48 ± 0.17

4. CONCLUSION

We report a Nd:YLF laser emitting at the 1053 nm transition with record efficiency, while side-pumped by a 797 nm VBG equipped diode. The configuration achieved 68% slope efficiency, with a peak output power of 67 W, and 66% of optical-to-optical efficiency, the highest values ever achieved for Nd:YLF lasers pumped within the traditional 800 nm pump band.

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