

Deep blue Nd:LiYF₄ laser in quasi-continuous and continuous operation

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Abstract: In this work we present continuous and quasi-continuous operation of Nd:YLF operating at 908 nm and frequency conversion to 454 nm using LBO and BiBO nonlinear crystals with different sizes.

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1. Introduction

Lasers operating in the blue spectral range have been studied for many years around the world especially due to applications in data storage and display technology. RGB displays demand deep blue wavelengths to expand the color gamut which is the area inside a polygon formed by the linkage of three or more points (wavelengths), in the CIE 1976 diagram to obtain more combinations of colors. Data storage applications benefit from the lower wavelength to increase the storage capacity on compact disks.

One of the many possibilities to achieve blue wavelength is the intracavity frequency doubling of neodymium doped crystals operating on quasi-three level transition lines. Neodymium solid state lasers operating on the three level transition ${}^4F_{3/2} \rightarrow {}^4I_{9/2}$ generally use the highest fundamental stark level as lower laser level to generate photons between 900 nm and 950 nm, which can be efficiently converted to the blue spectral range between 450 nm and 475 nm by intracavity frequency doubling. A maximum blue output power of 14.8 W at 456 nm was reported using Nd:GdVO₄ [1]. Different wavelength with less output power in the blue have been demonstrated using other crystals such as Nd:YAG and Nd:YVO₄ [2,3]. In most cavity designs a folded mirror cavity was employed that produces two waists, one in the laser crystal and other smaller one in the doubling crystal, which improves the conversion efficiency for the SHG. In almost all cases the output power of these lasers is limited by the onset of resonator instability due to the strong thermal lens inside the active media.

A deeper blue emission at 451.5 nm and 454 nm may be achieved with neodymium doped yttrium-lithium-fluoride (Nd:YLF), which is a well known birefringent laser media (and therefore naturally polarized) that shows strong emission lines at 1053nm and 1047nm. Additionally it has another advantage for this specific application, which is its very weak thermal lensing due to the combination of a negative index lens and positive end face bulging. In Nd:YLF, the transition ${}^4F_{3/2} \rightarrow {}^4I_{9/2}$ generates photons of lower wavelength when compared to other neodymium doped crystals working also on the highest fundamental Stark level. The wavelength of the fundamental σ -polarization is 908 nm and of the π -polarization is 903 nm. The transition cross-section of both fundamental wavelengths is approximately 1×10^{-20} cm², which is roughly 15 and 20 times smaller than the respective cross-section at the four-level transition of 1053 nm and 1047 nm [4]. Laser action in continuous wave operation (cw) has been reported on both transitions with 1 W and 0.6 W at 908 nm and 903 nm, respectively [5]. Blue laser with 270mW in cw operation at 454 nm was obtained using an L cavity and a 5mm long LBO crystal [6].

In this work we present continuous and quasi-continuous operation of Nd:YLF operating at 908 nm and frequency conversion to 454 nm using LBO and BiBO nonlinear crystals with different sizes.

2. Laser setup

A linear cavity set-up with a curved pump mirror (ROC=100 mm) and another flat mirror, both highly reflective (R> 99.8%) at 908 nm and anti-reflection coated at 1047/1053 nm, 805 nm and 454 nm was employed (Fig.1). For the pump source, a fiber coupled diode laser of 50 W maximum output power was used whose fiber had 100 μ m diameter and NA of 0.22 (Apollo Instruments). Two doublets with focal length of 50 mm and 200 mm were used to focus the fiber output into the crystal providing a focus of 450 μ m spot size inside the crystal. For quasi-continuous operation (qcw) the diode laser was temperature tuned (31° C) to 805.7 nm using re-circulating

chiller. The Nd:YLF crystal, used during the qcw experiments, had dimensions of $3 \times 3 \times 10 \text{ mm}^3$ and a Nd^{3+} concentration of 0.7 at% in order to reduce the pump absorption and up-conversion losses inside the crystal. All crystals were AR coated at 454nm, 908nm, 1047/1053 nm and the pump wavelength of 806 nm. A total of 90% of the pump radiation was absorbed inside the crystal. A total of 90% of the pump radiation was absorbed inside the crystal.. Pulses of 2 ms duration and duty cycle of 3% were used. For continuous wave (cw) operation the diode laser was temperature tuned to 802 nm (20°C) and a 15 mm long crystal was used in order to decrease the total absorption to 83% and distribute the heat load more uniformly throughout the crystal. All crystals were AR coated at 454 nm, 908 nm, 1047/1053 nm and the pump wavelength of 806 nm.

The SHG was studied using two different type I nonlinear crystals, BiBO and LBO, as well as different lengths, 10, 15 and 20mm. The nonlinear crystal was placed near the flat mirror where the beam waist was smaller, around $125 \mu\text{m}$ for the 4 cm long cavity, in order to obtain a better conversion. Detection was achieved using a blue band-gap filter (BG40) and a thermopile detector (COHERENT Corp., model PS-19).

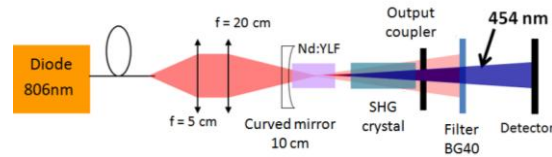


Fig. 1: Laser cavity set-up. A blue band gap filter (BG40) was used to block the infrared radiation from the detector.

3. Results

Laser operation at 908 nm was characterized using an intracavity Brewster plate on a rotation stage. Using the extra-cavity measured reflectivity of the Brewster plate as a function of rotation angle we determined the maximum output power as a function of effective reflectivity.

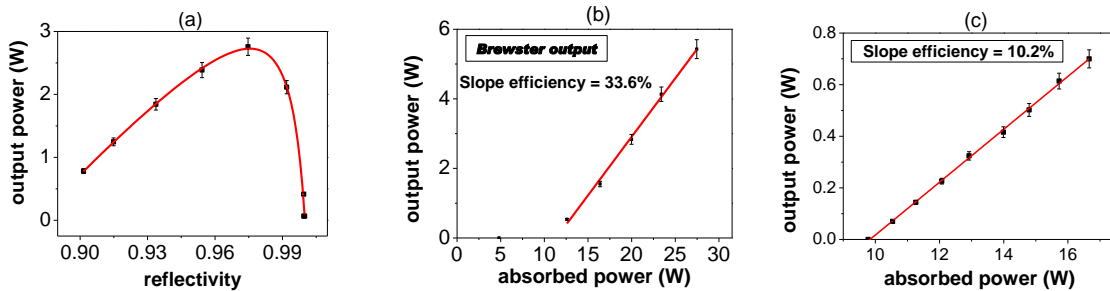


Fig. 2. (a)) output power as function of effective mirror reflectivity, (b) slope efficiency in qcw operation. (c): slope efficiency in cw operation.

In qcw operation a maximum peak output power of 5.5 W were achieved for a total Brewster plate reflectivity of 2.5%. The respective slope efficiency is 33.6%. In cw operation, using the longer crystal and pump wavelength of 802 nm, a slope efficiency of 10.2% and output power of 700 mW were achieved at 16.5 W of absorbed pump power (Fig. 2c).

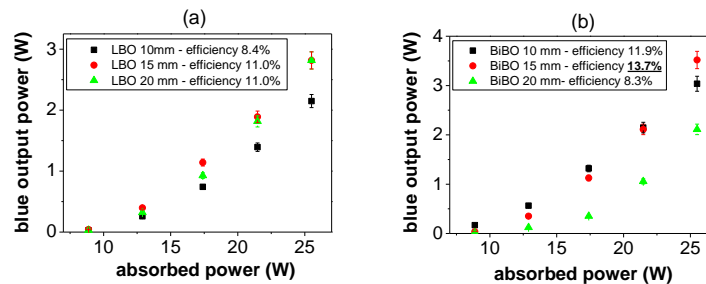


Fig. 3. Blue output power in qcw operation as a function of Nd:YLF absorbed pump power using crystals of different size, (a) LBO and (b) BiBO.

Using LBO we achieved the best results with crystal length of 15 mm and 20 mm. In this case the conversion efficiency was 11% (Fig. 3a). Using BiBO the best result was with a 15 mm long crystal and the efficiency was 13.7% (Fig. 3b).

In the cw regime, using the 15 mm-long BiBO crystal, 200 mW at 454 nm were obtained (Fig. 4a). The theory for the second harmonic generation for a gaussian beam using type I crystals results in a conversion efficiency Γ of [7,8].

$$\Gamma = \frac{P_{2\omega}}{P_{\omega}^2} = \frac{2\omega^2 d_{\text{eff}}^2}{\pi \epsilon_0 c^3 n_{\omega}^2 n_{2\omega}} L k_{\omega} h(\sigma)$$

$$h(\sigma) = \frac{1}{2l} \cdot \int_{-l/2}^{l/2} \int d\tau d\tau' \frac{\exp[-\beta^2(\tau - \tau')^2 - i\sigma(\tau - \tau')]}{(1+i\tau)(1-i\tau')}$$

$$\beta = \frac{\rho z_R}{w_0}, \quad l = \frac{L}{z_R}, \quad z_R = \frac{1}{2} k_{\omega} w_0^2, \quad k_{\omega} = \frac{2\pi n_{\omega}}{\lambda_{\omega}}$$

Where d_{eff} is the effective nonlinear coefficient, n is the refraction index, L is the nonlinear crystal length and w_0 is the beam waist inside the nonlinear crystal. The parameter σ is the normalized wave vector mismatch given by $\Delta k z_R$. The mismatch and walk off effects appear in the h function (where ρ is the walk off angle). Using this theory it is possible to simulate the conversion efficiency of a 15 mm long BiBO in function of different beam waists, Fig. 4.

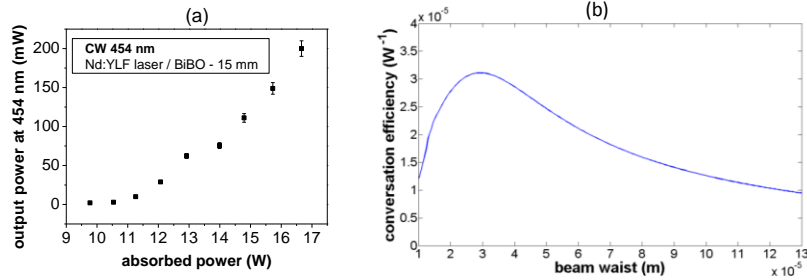


Fig. 4. (a) Output power in the blue during cw operation and (b) simulation of the conversion efficiency.

4. Discussion and conclusion

As in our experimental setup a linear cavity was used, the beam waist inside the nonlinear crystal was relatively large, around 125 μm , giving low conversion efficiency. In the literature a maximum of 270 mW was obtained in the deep blue using a Nd:YLF pumped at 792 nm and a 5 mm-long LBO as nonlinear crystal with a beam waist of 41 μm [4]. In order to obtain a higher power in the blue emission we intend to make a L cavity to achieve smaller waists. This should result in a 3 times higher efficiency. The qcw blue output power of 3.5 W was obtained in this research and it is the highest reported so far.

5. References

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