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Optics & Laser Technology 38 (2006) 626–630
Optics & Laser Technology
www.elsevier.com/locate/optlastec

Efficient diode-pumped intracavity frequency-doubled CW Nd : YLF laser emitting in the red

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Received 26 April 2004; received in revised form 20 December 2004; accepted 24 December 2004
Available online 3 March 2005

Abstract

We demonstrate an efficient continuous-wave diode-pumped Nd : YLF laser emitting in the red (660.5 and 657 nm) by intracavity frequency doubling with a LBO crystal. We obtained more than 1 W of average power (in two output beams) for 12 W of pump power with a TEM_{00} mode. This power is to our knowledge the highest obtained with a frequency-doubled Nd : YLF laser emitting in the red. Comparison between "a-cut" and "c-cut" crystals has been carried out in terms of performance and wavelength emission.

Keywords: Diode-pumping; Solid-state lasers; Intracavity frequency doubling

1. Introduction

For many years, red lasers, which emit around 650 nm, have been used in many applications such as holography [1], spectroscopy [2] and ophthalmology to repair cornea or macula [3] or to treat vascular malformation [4]. Krypton or dyes are usually used in these areas. Such laser systems exhibit a lot of problems. In fact, Krypton lasers have a shorter lifetime than diode-pumped lasers. Their air- or water-cooling systems induce problems concerning the power and beam pointing stability. Moreover, they have a low-power efficiency and cannot be compacted. On the other hand, the use of dye lasers is rather complicated and need to be maintained often. For all these reasons, we propose to develop a diode-pumped solid-state laser, emitting in the red after frequency doubling.

Unfortunately, there is no laser crystal which emits directly near 647 and 676 nm, the wavelength emission of a krypton laser. Consequently, we used a laser crystal which emits in the infrared, around 1300–1350 nm, and a nonlinear crystal for frequency doubling. For this purpose, neodymium-doped crystals are interesting as gain media because their transition between the level $^4F_{3/2}$ and $^4I_{13/2}$ generally leads to laser emission around 1300–1350 nm. Moreover, they can be diode-pumped with high-power laser diode around 800 nm. Emission wavelengths depend strongly on the matrix used. For example, Nd : YVO_4 laser emits at 1342 nm and frequency doubling at 671nm has already been demonstrated [5]. Its emission wavelength is close to one of the krypton ionized lines (676 nm). In the same way, an efficient Nd : $GdVO_4$ has been used to produce 2.4 W at 670 nm [6]. However, the other red line of the krypton ionized line (647 nm) is much more difficult to reach with frequency doubled Nd-doped solid-state lasers. In fact, it is rather difficult to find Nd doped crystals emitting below 1300 nm. Nevertheless, it will be useful to have a wavelength of emission nearest to 647 nm: the closer to the center of the visible spectrum, the better is

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0030-3992/$ - see front matter
doi:10.1016/j.optlastec.2004.12.013

the sensibility of human eye. In order to be as close as possible to this wavelength, we proposed to use Nd : YLF having a line at 1313 nm. Such a crystal has already been employed to pump another crystal (CrLiSAF) when inserted in a mode locked laser [7]. But a different line at 1321 nm was used, which corresponds to 660.5 nm after frequency doubling. This system was rather complicated (2 pumping diodes, 2 Nd : YLF crystals) with a limited efficiency: red power of 300 mW for a total pump power of 6 W. In this paper, we propose to investigate frequency-doubled Nd : YLF in the red at the watt level.

2. Experimental setup

The experimental setup is given in Fig. 1. The pumping source is an HLU30F400 system made by LIMO emitting up to 30 W at 800 nm. However, we limited the pump power to approximately 10 W (depending on the configurations, see Sections 3 and 4). The numerical aperture is 0.2, the output fiber diameter is 400 μm and central wavelength is 800 nm at 16 °C. Owing to two doublets having a focal length of 60 mm, the input beam is focused in the Nd^{3+} doped YLF crystal with a magnification of 1. The crystal is mounted in a copper heat sink whose temperature is controlled with a water circulation at 25 °C. The input face of the crystal was coated to obtain high transmission (HT) at 800 nm. Moreover, both end faces were anti-reflection coated at 1320 nm. We used a three mirror cavity, one plane (M_1) and two concave (M_2 and M_3) with 100 mm radius of curvature. All the mirrors have a high reflection in the 1300–1400 nm spectral range and high transmission ($T > 90\%$) at 1047 and 1053 nm, in order to avoid laser oscillations at these wavelengths. The Nd : YLF was put close to the plane mirror. M_2 was at 169 mm from the plane mirror M_1 and at 162 mm from M_3. The cavity has been designed for a waist of 185 μm in the Nd : YLF and another of 53 μm at 55 mm from M_2. To realize an efficient frequency conversion, the 10-mm-long nonlinear LBO crystal has been put at this place. LBO crystal is cut for noncritical phase matching in type II ($\theta = 0°, \Phi = 0°$). The crystal was heated at the right temperature (42 °C) by a water circulating system. The transmission of the mirrors M_2 and M_3 in the red (660 nm) is higher than 90%, leading to two red outputs (through M_2 and M_3).

3. "a-cut" Nd : YLF

We first studied the "a-cut" configuration corresponding to an Nd : YLF crystal with its optical axis (named the *c*-axis) perpendicular to the beam propagation axis. This crystal orientation has been firstly chosen because the absorption around 800 nm is approximately twice higher when pump polarization is parallel to *c*-axis [8]. In this configuration, Nd : YLF can emit on two principal lines depending on the polarization: 1321 nm (polarization parallel to *c*-axis, or π polarization) and 1313 nm (polarization perpendicular to *c*-axis, or σ polarization). The reported effective cross-sections are, respectively, 2.3×10^{-20} and $2 \times 10^{-20}\,cm^2$ [9]. The doping level of the 10 mm long crystal used in the experiment is 0.8%, leading to 90% of pump absorption. A classical problem met with diode-pumped solid-state laser in end pumping configuration is thermal lensing. This issue has already been addressed in some detail in the case of Nd : YLF for a wavelength around 1 μm, experimentally and theoretically [10,11]. An experimental study of this thermal lens around 1.3 μm was performed for our experimental setup. We used a classical method that consists in building a plano–plano cavity with variable length around the laser crystal. If the crystal is put near one plane mirror, the length between the two plane mirrors at the stability limit corresponds to the focal length of the thermal lens. It is important to note that for the π-polarization, the thermal focal length is negative and leads consequently to an unstable plano–plano cavity. As the gain is weak, such a cavity cannot produce laser radiation. Our

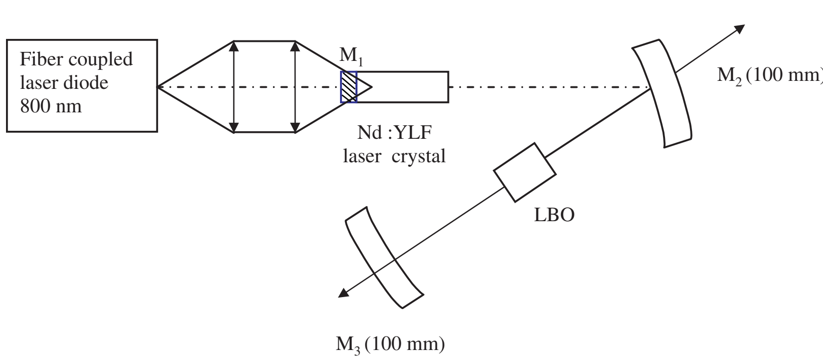

Fig. 1. Experimental setup of the intracavity frequency-doubled Nd : YLF laser cavity.