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Diode-pumped 671 nm laser frequency doubled by CPM LBO

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Abstract

A design of diode-pumped high-efficiency Nd:YVO_4/LBO red laser is reported. Using critical phase-matching (CPM) LBO, 671 nm red laser was obtained from 1342 nm light by intracavity frequency doubling. With an incident pump laser of 800 mW, using type-I and type-II CPM LBO, 97 and 52 mW TEM_{00} mode red laser outputs were obtained, with optical-to-optical conversion efficiencies of up to 12.1% and 6.5%, respectively. © 2002 Published by Elsevier Science Ltd.

Keywords: LBO; Critical phase-matching (CPM); Red laser

1. Introduction

It was well known that Nd^{3+} doped in YVO_4 can also emit 1342 nm in addition to 1064 nm. Furthermore, Nd^{3+} can have a high doped concentration and emit polarized light in YVO_4 [1], so Nd:YVO_4 is highly suitable for diode-pumping to generate 1342 nm laser, which can be frequency doubled to obtain 671 nm red laser.

There are already some papers on diode-pumped 671 nm red lasers [2–4], but all of them used type-II CPM KTP or NCPM LBO to generate the second harmonic wave. Among them, with a fiber-coupled 10 W diode array, Zhang et al. used type-II KTP to achieve 671 nm output of about 70 mW [2]; also Zhang et al. used type-I NCPM LBO ($T \approx 5^\circ$C) and a V-shaped folded cavity to obtain 502 mW output, with optical-to-optical conversion efficiency up to 8.3% [3]; Agnesi et al. used type-II NCPM LBO ($T \approx 38^\circ$C) and a V-shaped folded cavity to obtain 430 mW output [4].

Analysis has shown that KTP has a low second harmonic generation (SHG) efficiency and bad beam quality due to its large walk-off angle, while NCPM LBO requires strict temperature control and is very hard to be a commercial product [5], especially for type-II NCPM LBO which has the highest efficiency, however, it strongly requires dry surroundings due to its work temperature being lower than room temperature. As to CPM LBO, we have not found any reports on it for 1342 nm frequency doubling in diode-pumped Nd:YVO_4 red lasers.

In this paper, type-I and type-II CPM LBO was used for 1342 nm intracavity frequency doubling. By reasonable design, high SHG efficiency and good beam quality were obtained.

2. Characteristics of CPM LBO for 1342 nm frequency doubling

We have calculated some important parameters of different CPM crystals. Critical phase-matching angle (θ, ϕ), effective nonlinear coefficient (d_{eff}), walk-off angle (ρ) and acceptance angle of CPM LBO (I), LBO (II) and KTP (II) are listed in Table 1.

Data listed in Table 1 showed that although LBO has less d_{eff} than KTP, its little walk-off angle and large acceptance angle can make LBO's effective work length (L) very long for 1342 nm frequency-doubling. Based on the formula [6]

$$L = 1.16\omega/\rho, \qquad (1)$$

where ω is the radius of fundamental wave beam through LBO.

Formula (1) has shown that when ρ is very small, lowering ω also can have large L. In the meantime, small ω can increase the power density of fundamental wave through LBO to increase SHG efficiency.

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Table 1
Comparisons of three different CPM crystals for 1342 → 671 nm conversion

Items CPM	Process (1342–671)	CPM angle (θ, ϕ)	d_{eff} (pm/V)	Walkoff angle ρ (mrad)	Acceptance (mrad m)	L (mm)
LBO (I)	e+e—o	$86.1^\circ, 0^\circ$	0.817	3.45	24.29	34.1
LBO (II)	e+o—e	$3.6^\circ, 0^\circ$	0.645	3.25	26.07	35.9
KTP (II)	o+e—o	$58.9^\circ, 0^\circ$	2.84	44.3	1.69	2.6

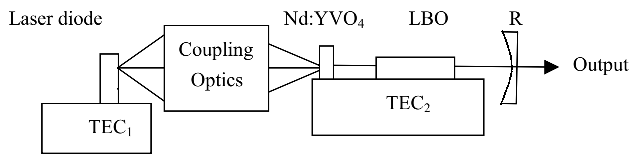

Fig. 1. The setup of diode-pumped red laser.

3. Experimental setup

Based on the above analysis, the optional parameters were designed by computer programming. The equipment is shown in Fig. 1.

A laser diode with maximum output 1 W, a central emitting wavelength of 806.4 nm at 23°C and a divergent angle of $7.2 \times 33.6\ \text{deg}^2$ was used as the pumping source. After going through the coupling optics, light emitted from the LD was reshaped to high-quality pumping light (with an ellipticity of 0.91, beam waist's radius is about 95 μm) and was injected into $Nd:YVO_4$ (1.3 mm thick, doped 3.0 atm.%). Left facet of $Nd:YVO_4$ was coated with 808 nm antireflection (AR) and 1342 nm high reflection (HR) coatings as all reflective mirrors and right facet with 1342 nm AR; the concave surface of the output mirror R ($\rho = 50$ mm) was coated with 1342 nm HR, 671 nm AR and 1064 nm AR ($T@1064 > 90\%$), plane facet with 671 nm AR; and two facets of LBO ($2 \times 2 \times 10\ \text{mm}^3$) both with 1342/671 nm AR coatings. When the coatings unavoidably affected each other, the requirements on 1342 nm radiation had the priority. Total resonator was about 30 mm long.

Laser diode $Nd:YVO_4$ and LBO were strictly temperature controlled by TEC_1 and TEC_2, respectively. The current of TEC_1 was adjusted to make the central wavelength emitted from the laser diode coincide with the absorption peak of Nd^{3+} in order to utilize the pumping light very well. $Nd:YVO_4$ and LBO were cooled by the same cooler-TEC_2 to reduce thermal effect of $Nd:YVO_4$ and keep the phase-matching condition of LBO from changing with surroundings.

4. Results and discussions

In the same setup, type-I and type-II CPM LBO were used for 1342 nm frequency doubling, respectively. After 808 and 1342 nm light were filtered, the 671 nm laser output power was measured. The red laser's power as a function of pumping light is shown in Fig. 2.

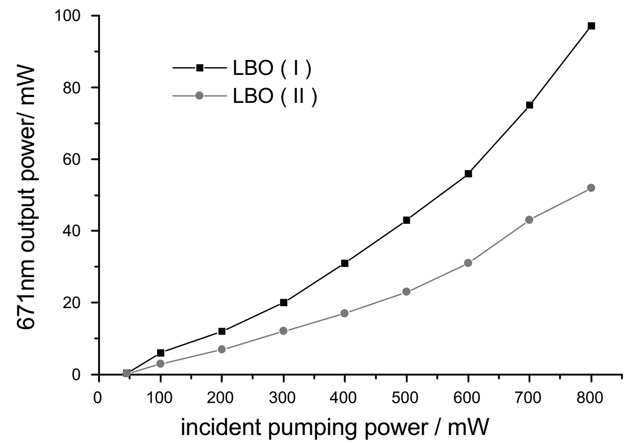

Fig. 2. 671 nm output as a function of pump power.

Fig. 2 shows the thresholds of pump power were both about 40 mW under the two conditions. But above the threshold, CPM LBO (I) is markedly better than LBO (II). When the pump light of 800 mW was injected, 97 and 52 mW 671 nm outputs were obtained by CPM LBO (I) and CPM LBO (II), respectively, and no saturation appeared.

Although CPM LBO (I) and LBO (II) have close values of $d_{eff}L$, but because LBO is a biaxial crystal and a birefringent effect exists in the type-II phase-matching process, when polarized light goes through it, its degree of polarization decreases, which reduces the SHG efficiency.

The TEM_{00} spacial energy distribution for the 671 nm LBO (I) laser in the far field was recorded by a beam profiler and is shown in Fig. 3.

5. Conclusions

For the first time, type-I and type-II CPM LBO were used for 1342 nm intracavity frequency doubling of a $Nd:YVO_4$ laser. By reasonable design, high SHG efficiency and good beam quality were obtained. With 800 mW incident pump laser, using type-I and type-II CPM LBO, 97 and 52 mW TEM_{00} mode red laser outputs were obtained, the optical-to-optical conversion efficiencies are up to 12.1% and 6.5%, respectively. Furthermore, the power would be increased by a big margin if a folded cavity was used. We

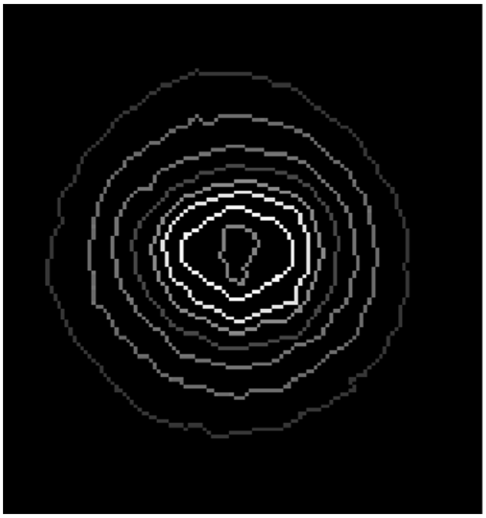

Fig. 3. The spacial energy distribution for the 671 nm laser (type-I CPM LBO).

can conclude that type-I CPM LBO is the best option for 1342 nm frequency doubling to obtain 671 nm output in diode-pumped $Nd:YVO_4$ red lasers.

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