Diode-laser End-pumped Intra-cavity Frequency Doubling $Nd:YVO_4$ /LBO Continuous-wave 8W Green Laser

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Abstract A simple way to achieve 8W CW output green laser with intra-cavity frequency doubling in a $Nd:YVO_4$ laser doubly longitudinally pumped by two diode lasers is reported. With I-type non-critical-phase-match (NCPM) and temperature tuning of LBO crystal, a maximum of 8 W continuous-wave output at 0.532 μm has been obtained. With 28.9 W pump power, the optical-optical conversion efficiency is 27.7%.

Keywords $Nd:YVO_4$/LBO; Diode end-pumped; All-solid-state; Green laser

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0 Introduction

High-power diode-pumped compact visible lasers have attracted much attention[1~3]. Particularly in the recent years, all-solid-state multi-watt level intra-cavity-doubled green lasers are attractive for applications such as display, ophthalmology, printing, spectroscopy, material processing, biomedicine, underwater communications, and pumping ultra-short pulse laser systems. In addition, such lasers could also become critical components of an all-solid-state compact UV or femtosecond UV laser sources and optical parametric oscillators[4,5]. They have eventually become commercially available for replacing low-efficiency, cumbersome Ar^+ lasers and Hashlamp-pumped solid-state lasers in a variety of practical applications.

Owing to $Nd:YVO_4$'s strong and broad absorption lines at 808 nm and its large luminescence cross section at 1064nm, intra-cavity doubling of a diode-pumped $Nd:YVO_4$ laser with frequency doubling crystal has attracted much attention in the realization of a high power green laser source[6]. A variety of materials have been developed recently for various nonlinear applications that exhibit characteristics favorable for improved conversion efficiency of typical laser beams. Of these, KTP is rapidly becoming the material of choice for doubling 1064 nm radiation because of its relatively large nonlinear coefficient and temperature bandwidths[7]. LBO is another doubling crystal owing better characteristics in comparison with KTP. It has the highest damage threshold in all the commonly used inorganic NLO crystal and wide acceptance and small walk-off angle. Therefore, it is the best candidate for high average power SHG and other nonlinear optical processes. Although the effective SHG coefficient of LBO is smaller than that of KTP, it can be used as type I non-critical phase matching to minimize the walk-off effect and more longer LBO can be applied to compensate this shortcoming under high pumping power. It is also free from the gray tracking effect seem in KTP[8].

In this letter we report a maximum of 8.0 W CW output green laser obtained by intracavity frequency doubling with I-non-critical phase matching (NCPM), temperature tuning of LBO crystal in a $Nd:YVO_4$ laser doubly pumped by two laser diodes. To our knowledge this is the highest output power ever reported.

1 Experimental Setup

A cavity configuration of the LD two-end-pumped $Nd:YVO_4$ laser and the corresponding thermal lens equivalent resonator is shown in Fig. 1 and 2, The pump sources used in this system were two commercially available fiber-coupled diode-laser-arrays (Institute of Semiconductors, CAS) that deliver a maximum CW output power of 20 W at each fiber bundle end. The output beams from two 1.0 mm fiber bundle ends were focused, respectively, into the laser crystal with a spot radius of about 0.58 mm and numerical aperture of 0.12 by focusing optics. The $3 \times 3 \times 5$ mm^3, 0.5-at% Nd^{3+}-doped a-cut $Nd:YVO_4$ crystal (Fujian Castech Crystals) was antireflection-coated at 0.808 and 1.064 μm on both end surfaces. This laser crystal was wrapped with indium foil and was inlaid in a water-cooled copper block ensuring sufficient cooling for the pump-produced heat to be removed. The water temperature was maintained around 18℃. The $3 \times 3 \times 10$ mm^3 LBO (Fujian

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Castech Crystals) was AR - coated for 1 . 064 μm and 0. 532 μm on both end faces. LBO was placed in the stove of which temperature can be adjust and the control accuracy of the stove is ±0. 2℃. This kind of cavity consists of no other additional optical elements except for the laser gain medium and the frequency-doubling crystal and has a beam waist not at the end mirror face but inside the cavity where the frequency-doubling crystal is placed. So it is simple and adjusted easily. According to the corresponding thermal lens equivalent resonator, a set of perfect resonator parameters can be obtained.

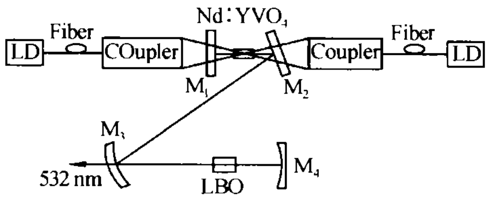

Fig. 1 Experimental setup of LD pumped Nd:YVO_4 laser

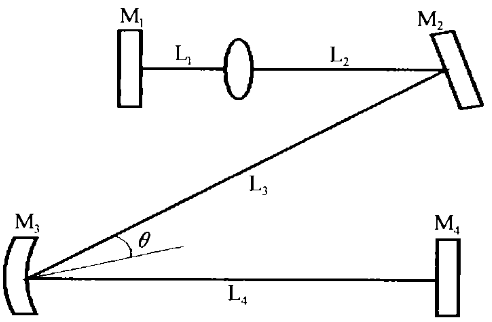

Fig. 2 The corresponding thermal lens equivalent resonator

2 Experimental Results and Discussion

In the experimental setup of laser system, M_1 and M_2 were flat mirrors, AR-coated at 808 nm on its outside surface nearing the focusing optics, HR-coated at 1.064 μm and HT-coated at 808 nm on the inside surface. M_3 and M_4 were concave convex mirror and concave mirror with radii of curvature of 150 and 50 mm, respectively. M_3 as the output couple mirror was HR-coated at 1. 064 μm and HT-coated at 0. 532 μm on the curved face, and AR-coated at 0. 532 μm on the convex face. M_4 was HR-coated at both 1.064 μm and 0. 532 μm. This kind of folding resonator has many characteristics, such as adjusting the mode parameter very neatly, having a large efficiency space inside the cavity for realizing double-pass frequency doubling and an easy one-end exporting, insulating the process of frequency doubling and laser gain medium. Also, it consists of no other additional optical elements except for the laser gain medium and the frequency-doubling crystal and has a beam waist inside the cavity where the frequency-doubling crystal is placed.

It was a key problem that needed to be solved in our resonator design when thermally induced focusing effect occurred. While the laser crystal Nd : YVO_4 having absorbed the pumping light, the thermal lens effect became sufficiently significant in affecting the resonator stability, performance and mode parameters everywhere inside the cavity. At the same time, there was a thermally induced astigmatism, which could also affect the output beam quality. Furthermore, to achieve a good output beam quality, the resonator must work at a TEM_{00} mode. And it is necessary to have a large mode volume in the laser gain medium (in the case of better match with the pumping mode) for a high intra-cavity power. Also, the laser must operate stably in the resonator cavity over a very wide pumping power range and working stability range large enough for an actual application. At the same time we need the conversion efficiency as high as possible for ensuring a great power green laser output. Consequently, we must consider the fact mentioned above during designing and analyzing the resonator cavity following the standard ABCD matrix. In continuous-wave (CW) end-pumping high-power solid laser cavity designing, the laser gain medium acts as a thermally induced self-focusing lens and can be treated as a thin lens with a focal length of f_T (Fig. 2)[9]. This kind of simplification is sufficiently exact for most practical purpose and is also widely accepted. According to the results of our numerical computation, a set of perfect resonator parameters was screened out, $R_3 = 150$ mm; $R_4 = 50$ mm; $L_1 = 10$ mm; $L_2 + L_3 = 310$ mm; $L_4 = 125$ mm, and the folding angle at mirror M_3 was smaller than $8°$[10]. In order to compensate for the thermally induced astigmatism, that was induced by the spherical face of mirror M_3. A main characteristic of this resonator was that the stability region of thermal focal length was found to extend from $f_T = \infty$ to 110 mm. So the stability operation condition was achieved by the insensitivity disturbance resulting from the thermal focal length of the mode volume in the gain medium.

In the experiment, First in order to get the best mode and highest output power at the wavelength of 1. 064 μm, Laser systmed was adjusted. Second run temperature control system and set the temperature at 150℃, then, put the stove (LBO inside) between the M_3 and M_4 mirror and adjusted its placement to reach the highest output power at 0. 532 μm. Finally, adjust the laser system again to obtain the highest output at 0. 532 μm[11]. During the experiment, it was found that 0. 532 μm green laser got its highest output power when the stove worked at about 148℃, but when the stove worked at the temperature more higher or lower than 148℃, the 0.532 μm green laser lost its power rapidly. it was also found the temperature band width of LBO was about 2℃.

The characteristics of 532 nm green laser power versus incident pump power are given in Fig. 3. Under an optimum mode-matching condition, in accordance with the theoretical result above, a maximum CW 0.532 μm green laser output power of 8 W was obtained with a pump power of 28.9 W corresponding to a green conversion efficiency of 27.7%.

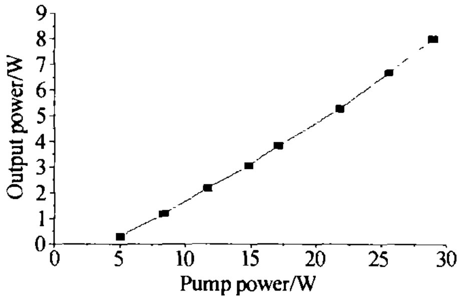

Fig. 3 Output power at 532nm as a function of diode pump power at 808 nm

3 Conclusion

A diode-laser two-end-pumped Nd : YVO_4/LBO intracavity frequency-doubled green lasers employed a simple four-mirror-folded cavity that consisted of no other additional elements in the resonator except for the laser gain medium and the frequency-doubling crystal were demenstrated. 532 nm green laser output power of 8W was reached at a pump power of 28.9 W, the corresponding optical-optical conversion efficiency being 27.7%. This system showed a good performance even in the large pumping power range.

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半导体激光端泵腔内倍频 Nd:YVO_4/LBO 连续波 8 W 绿光激光器

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摘 要 利用两个半导体激光二极管,双端泵浦 Nd:YVO_4 晶体,LBO 采用 I 类非临界相位匹配、腔内倍频.在 28.9 W 的泵浦功率下,获得了 8 W 连续波 0.532 μm 绿光输出,其光—光转换效率为 27.7%.

关键词 Nd:YVO_4/LBO;二极管端泵;全固态;绿光激光

Tian Feng was born in 1961. She received the B. S. degree in 1982 from Northwest University. She works in the foundation department of Ching'an University. Her major research fields include LD pumped all-solid-state lasers, nonlinear optics and the interaction between the laser and matter.