Efficient cw $Nd:LuVO_4$-BiBO deep-bluelaser

Wang Yang, Duanmu Qingduo

(School of Science, Changchun University of Science and Technology, Changchun 130022, China)

Abstract: $Nd:LuVO_4$, has attracted much attention because its larger absorption and emission cross sections than $Nd:YVO_4$ and $Nd:GdVO_4$. A more efficient pumping method was presented and researched, which was to pump the Nd^{3+} ions directly into the $^4F_{3/2}$ upper lasing level to improve the laser parameters such as decreasing the threshold and increasing the slope efficiency and reduce the amount of heat generated by the nonradiative processes. In this paper, the report a quasi-three-level $Nd:LuVO_4$ laser which is directly pumped by a laser diode at 888 nm. Achieved an output power of 2.5 W at 916 nm for an incident pump power of 18.6 W. The incident pump power at threshold of laser oscillation was 4.7 W, corresponding to the slope efficiency with respect to the incident pump power was 17.8%. For the same incident pump power, a maximum blue output power was 743 mW. The stability of the blue output power was better than 3%. The beam quality M^2 value is 1.12.

Key words: diode-pumped; direct pumped; $Nd:LuVO_4$ crystal; deep-bluelaser
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高效连续 $Nd:LuVO_4$-BiBO 深蓝激光器

王 洋,端木庆铎

(长春理工大学 理学院,吉林 长春 130022)

摘 要: $Nd:LuVO_4$ 晶体因具有相比于 $Nd:YVO_4$ 和 $Nd:GdVO_4$ 晶体更大的吸收和发射截面而受到广泛关注。一种高效的泵浦方式因此而产生:将 Nd^{3+} 离子直接泵浦到 $^4F_{3/2}$ 激光上能级来改善激光器参数,不仅可以减小激光器的阈值,提高激光器的斜效率,并且可以降低非辐射跃迁过程中所产生的热量。利用 888 nm 激光二极管直接泵浦 $Nd:LuVO_4$ 晶体,实现了准三能级 $Nd:LuVO_4$ 激光器。当入射泵浦功率为 18.6 W 时,916 nm 的输出功率为 2.5 W, 激光器的阈值功率为 4.7 W, 相应的斜效率为 17.8%。入射泵浦功率不变的情况下,获得的最大蓝光输出功率为 743 mW。蓝光输出功率的稳定性高于 3%。光束质量 M^2 的值为 1.12。

关键词: 二极管泵浦; 直接泵浦; $Nd:LuVO_4$ 晶体; 深蓝激光器

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作者简介: 王洋(1982-),女,博士生,主要从事固体激光器方面的研究。Email:58139414@qq.com

导师简介: 端木庆铎(1956-),男,教授,博士生导师,博士,主要从事光电子材料与器件、薄膜与微细加工技术方面的研究和开发。Email:duanmuqingduo@163.com

0 Introduction

High-power, high efficiency 910 nm lasers can be used in many applications, such as water vapor lidars and differential absorption lidars for ozone measurements, and also can be used as pump source for Yb-doped crystals and Yb-doped fibers. The quasi-three-level 910 nm continuous-wave laser emission was investigated for Nd-vanadate crystals in the past 20 years. A well-known representative is Nd:YVO_4, which has been widely used both in research and commercial devices. Another vanadate crystal, Nd:$GdVO_4$, which was confirmed to be superior to Nd:YVO_4 in thermal properties, was also investigated extensively. Recently another member from the vanadate family, Nd:$LuVO_4$, has attracted much attention because its larger absorption and emission cross sections thanNd:YVO_4 and Nd:$GdVO_4$[1]. Moreover, Nd:$LuVO_4$ crystal has a high damage threshold, and it is easy to process [2]. Some papers about Nd:$LuVO_4$ laser operating at 1.06 μm [3-5], 1.34 μm [6] and 0.9 μm have been reported recently.In all these papers the pumping is made in levels above the emitting level $^4F_{3/2}$ of Nd^{3+}, usually in $^4F_{5/2}$. This induces a parasitic upper quantum defect between the pump and the emitting laser levels, with negative influence on the laser parameters and on the generation of heat by non-radiative processes. Therefore, the performances are still limited and the full lasing potential has not been exploited yet. A more efficient pumping method was presented and researched [7], which was to pump the Nd^{3+} ions directly into the $^4F_{3/2}$ upper lasing level, based on the fact that increasing the quantum defect ratio, $\eta_{qd}=\lambda_p/\lambda_{em}$, between the pump wavelength λ_p and the laser wavelength λ_{em}, improves the laser parameters such as the threshold and slope efficiency and reduces the amount of heat generated by the nonradiative processes. Recently, the Nd:$LuVO_4$ lasers pumped at 880 nm has already been carried out[8], but to our knowledge, pumping at 888 nm is unimplemented in the quasi-three-level lasers.

In this paper, we report a quasi-three-level Nd:$LuVO_4$ laser which is pumped by a laser diode at 888 nm. The maximum output power of 2.5 W at 916 nm laser is obtained. Furthermore, we generate 743 mW of 458 nm blue laser output employing a type-I critical phase-matched BiBO crystal.

1 Experimental setups

The experiment setup of the fundamental 916 nm laser is shown in Fig.1 (a). The pump source was a fiber-coupled diode at 888 nm with a core diameter of 400 μm and a numerical aperture of 0.22, which provide a maximal power of 20 W. An optical system made of two achromatic lenses was employed in order to image the fiber endinto the Nd:$LuVO_4$ crystal. The waist of pump beams was measured to have a radius of nearly 210 μm. A conventional a-cut Nd:$LuVO_4$ crystal with the dimension of 3 mm×3 mm×10 mm and doping concentration of 0.5 at.% was chosen in the experiment. Both surfaces of the Nd:$LuVO_4$ crystal were antireflection (AR) coated at 916 nm and was wrapped in indium foil and clamped in a copper holder while the water temperature was kept at 15 ℃. The plane mirror M1 was AR coated at 888 nm, high reflectivity (HR) at 916 nm and AR at 1 066 nm and 1 343 nm to suppress the strong parasitical oscillation at there transitions.The plane mirror M2 was HR coated at 914 nm and AR at 888 nm. The plane mirror M3 was HR coated at 888 nm in order to increase the pump beam absorption efficiency. The plano-concave mirror M4 with a curvature-radius of 50 mm was HR coated at 916 nm. The plano-concave mirror M5 with a curvature-radius of 200 mm was employed as an output coupler, which was coated with a transmission of 4.3% at 916 nm. The experiment setup of the 458 nm blue laser is shown in Fig.1(b). All the elements were the same as the corresponding ones in the setup of fundamental 916 nm laser mentioned above. The plano-concave mirror M6 (ρ=50 mm) was employed as an output coupler, which is HR coated at 916 nm and AR at 458 nm. The plano-concave mirror M7 (ρ=200 mm) was coated for HR at 916 and 458 nm. An BiBO crystal cut for type-I critical phase matching in the principal plane **XZ** (θ=45.3°, φ=0°) with d_{eff}=2.46 pm/V) was chosen as the nonlinear crystal The size of the BiBO crystal is 2 mm×2 mm×10 mm and both end faces were coated for AR at 916 and 458 nm wavelengths. It was also cooled in the same manner as in the case of the Nd:$LuVO_4$ crystal. The distances of M1-M4 (or M1-M6), and of M4-M5 (or M4-M7) were 68 and 27, respectively.

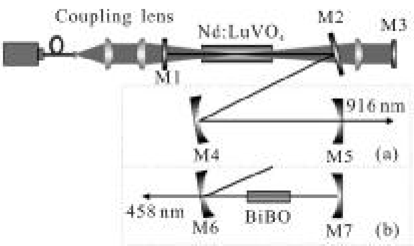

Fig.1 Experimental setup of the fundamental and the frequency-doubled laser

2 Results and discussion

Because of the very small absorption compared with the one around 888 nm, the first (to our knowledge) demonstration of an Nd:$LuVO_4$ laser pumped near 888 nm was realized with an Nd:$LuVO_4$-BiBO setup where the pump beam is very powerful and diffraction limited, ensuring a perfect overlap between the pump and the laser beams. Consequently, direct diode pumping of Nd:$LuVO_4$ at 888 nm represents a challenge that might be taken up if extremely high-brightness laser diodes are used in combination with relatively highly doped Nd:$LuVO_4$ crystal. The output powers at 916 and 458 nm versus the incident pump power is shown in Fig.2.

The Quasi-three-level Nd:$LuVO_4$ lasers have already been carried out in the near infrared and visible with neodymium-doped vanadate crystals pumped by a direct in-band diode pumping at 880 nm [9-12]. When the incident pump power is 18.6 W the laser yielded 2.5 W of continuous wave output power at

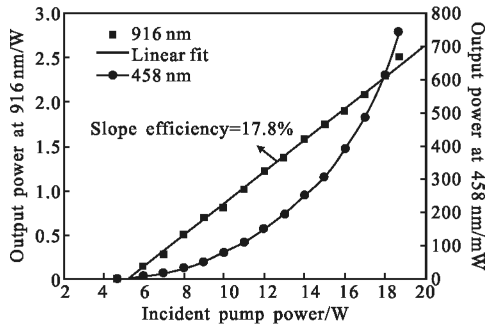

Fig.2 Output powers at 916 nm and 458 nm versus pump power at 888 nm

916 nm. The incident pump power at threshold of laser oscillation was 4.7 W and the slope efficiency with respect to the incident pump power was 17.8%. For the same incident pump power, a maximum blue output power was 743 mW. The far-field beam spatial profile of the 458 nm laser was measured by a Laser Beam Diagnostics. The beam quality factor M^2 is 1.12 measured by the knife-edge technique. Stability of better than 3.2% for 30 min is measured by Field Master-GS power meter as shown in Fig.3.

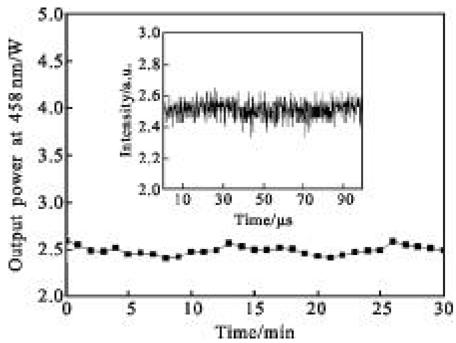

Fig.3 Stability of 458 nm laser for 30 minutes

However, as shown in Fig.3 inset, the noise of the blue laser is observed with a Si fast photo-diode. This is due to cross saturation in the laser crystal and sum-frequency in the doubling frequency crystal. In our experiments, because no ways (such as forcing operation of single frequency) are adopted to overcome this problem, the noise is always observed except very short time stability on the starting of the laser for longitudinal mode competing. The spectra were measured with a Spectrapro-500i spectrometer from Acton Research Corporation. The spectral linewidth (FWHM definition) is about 0.8 nm with the central wavelength at 458.1 nm.

3 Conclusion

In summary, we have demonstrated a diode-pumped Nd:$LuVO_4$ laser emitting at 916 nm with a maximum continuous-wave output power of 2.5 W for 18.6 W of incident pump power at 888 nm. Furthermore, intracavity second harmonic generation has also been demonstrated with a power of 743 mW at 458 nm by a BiBO nonlinear crystal. Further the use of more efficient nonlinear crystals, such as ppKTP or $KNbO_3$, should increase the blue power.Therefore, diode laser at 888 nm is a more suitable pump source for Nd:$LuVO_4$ lasers.

References:

[1] Sato Y, Taira T, Pavel N, et al. Laser operation with near quantum-defect slope efficiency in Nd:YVO_4 under direct pumping into the emitting level[J]. Appl Phys, 2003, 82: 844.

[2] Lv Y F, Yin X D, Xia J, et al. All-solid-state continuous-wave doubly resonant all-intracavity sum-frequency mixing blue laser at 488 nm[J]. Laser Phy, 2009, 6(12): 860-863.

[3] Lv Y F, Zhang X H, Xia J, et al. 981 nm Yb:KYW laser intracavity pumped at 912 nm and frequency-doubling for an emission at 490.5 nm[J]. Laser Phy, 2010, 7(5): 343-346.

[4] Lv Y F, Zhang X H, Xia J, et al. Dual-wavelength laser operation at 1064nm and 914nm in two Nd:YVO_4 crystals [J]. Laser Phy, 2010, 20(4): 737-739.

[5] Lv Y F, Zhang X H, Xia J, et al. 1 064 nm Nd:YAG laser intracavity pumped at 946 nm and sum-frequency mixing for an emission at 501 nm[J]. Laser Phy, 2010, 7(5): 335-338.

[6] Lv Y F, Xia J, Yin X D, et al. 1 085 nm Nd:YVO_4 laser intracavity pumped at 914 nm and sum-frequency mixing to reach cyan laser at 496 nm[J]. Laser Phy, 2010, 7(1): 11-13.

[7] Maunier C, Doualan J L, Moncorgé R, et al. Growth, spectroscopic characterization, and laser performance of Nd:$LuVO_4$, a new infrared laser material that is suitable for diode pumping[J]. J Opt Soc Am B, 2002, 19: 1794-1800

[8] Liu Jie, Yang Jimin, He Jingliang. Comparision of diode-pumped Nd:YVO_4, Nd:$GdVO_4$ and Nd:YAG lasers' characteristic[J]. Laser Journal, 2003, 24(5): 28-30. (in Chinese)

[9] Zhang H J, Zhu L, Meng X L, et al. Thermal and laser properties of Nd:YVO_4 crystal[J]. Cryst Res Technol, 1999, 34(8): 1011-1016.

[10] Fields R A, Bimbaum M, Fincher C L. Highly efficient Nd:YVO_4, diode-laser end-pumped laser [J]. Appl Phys Lett, 1987, 51: 1885-1886.

[11] Deshazer L. Vanadate crystals exploit diode-pump technology [J]. Laser Focus World, 1994, 30: 8893.

[12] Koechner W. Solid-State Laser Engineering [M]. 4th ed. Berlin: Ed-Springer-Verlag, 1995: 93.