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An Intracavity Frequency Doubled Nd:YVO_4 Red 671nm Laser Based on LBO Crystal

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Abstract: Laser diode pumped solid-state lasers, which have the advantages of high efficiency, compactness, stability, long lifetime and high beam quality etc, are called all-solid-state lasers. The all-solid-state lasers are widely used in military, industrial, medical, scientific research and information fields. Among the many laser crystals suitable for them, the Nd:YVO_4 crystal has attracted much attention because of its excellent properties. At the same time, considering the high damage threshold of the nonlinear crystal LBO, using LBO crystal to realize the frequency doubling output of 1342nm fundamental frequency light of Nd:YVO_4 laser is an ideal choice. In this paper, an intracavity frequency doubled Nd:YVO_4 red 671nm laser based on LBO crystal is reported, and the parameters of this laser are theoretically analyzed. By using a type II noncritically phase-matched LBO crystal, the operation of a red light laser is realized. The output power of 1.16W at 671nm and optical to optical conversion efficiency of 10.5% were obtained at the pump power of 11.0W. The instability of the output power of this laser is less than 1%, and the output mode of it is TEM_{00} mode. In the experiment, the V-shaped folded cavity structure is used to improve the mode discrimination ability of the laser. Meanwhile, the reflector at the tip of the V-shaped cavity is used as the output mirror to ensure that the fundamental frequency light passes through the frequency doubling crystal twice, which improves the frequency doubling efficiency to a certain extent. This laser has high stability and can meet the needs of many fields for low power lasers, and the configuration of this source makes it very suitable in some kindred systems.

Keywords: Laser Diode, Intracavity Frequency Doubled, Nd:YVO_4 Crystal, LBO Crystal

1. Introduction

Laser diode pumped solid-state laser (DPSL) is called all-solid-state laser. These kinds of lasers have the advantages of high efficiency, compactness, stability, long lifetime and high beam quality etc. They are widely used in military, industrial, medical, scientific research and information fields [1-5]. Among many laser crystals suitable for DPSL, Nd:YVO_4 crystal has attracted much attention because of its excellent properties. It has become an ideal working material for small and medium power DPSL devices [6-8]. The $^4F_{3/2}$-$^4I_{11/2}$ level transition of Nd:YVO_4 crystal can produce 1.34μm laser. The stimulated emission cross section at this wavelength is $(6\pm1.8)\times10^{-19}cm^2$, which is comparable to the emission cross section ($4.6\times10^{-19}cm^2$) of Nd:YAG crystal at 1.06μm. So it is easy to achieve 1.34μm laser oscillation. Also, 1.34μm laser can obtain 671nm red light by frequency doubling technology. This wavelength corresponds to the maximum spectral sensitivity of the color holographic photosensitive adhesive layer and can be used as pump light of other lasers such as Cr: LiSAF. To a large extent, 671nm red laser can also replace expensive and complex krypton ion laser, and can be applied in color display, medicine and other fields [9-11]. Recently, the single-frequency 671nm lasers by second harmonic generation of the Nd:YVO_4 lasers at 1342nm have been demonstrated [9-10]. In this paper, on the basis of comprehensive consideration of various parameters, we designed a LD (Laser Diode) end-pumped Nd:YVO_4/LBO intracavity frequency doubled red laser. The output power of 671nm laser reaches 1.16W. The laser has high stability and can meet the needs of many fields for low power lasers. This research is the sequel to our earlier works [11-13].

2. Experimental Scheme

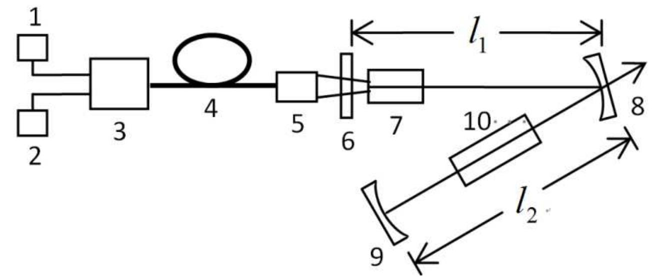

Figure 1. *Schematic structure of the 671nm Nd:YVO_4/LBO intracavity frequency doubled laser: (1) Electrical source of LD, (2) Temperature controller of LD, (3) LD, (4) Coupling fiber of LD, (5) Optical coupling system, (6) Plane mirrorM_1, (7) Nd:YVO_4 crystal, (8) Plane-concave mirror M_2, (9) Plane-concave mirror M_3, (10) LBO crystal.*

As shown in Figure 1, the pump light source LD used in the experiment is SDL-3460-P6 produced by SDL Company of the United States with optical fiber coupling output. The output aperture of the optical fiber is 600μm, the numerical aperture of the optical fiber is 0.37, the maximum output power of the LD is 16 W, and the peak wavelength is 808.9 nm. The focal length of the optical coupling system is about 30mm, and the waist radius of the LD beam passing through the optical coupling system is 120μm. Figure 1, whose radius of curvature is 100mm, is a concave mirror. The Nd:YVO_4 crystal, whose size is 3mm×3mm×5mm, is cut by a axis, with the length of light direction 5mm, the doping concentration of Nd^{3+} is about 0.7%. The size of the LBO crystal is 3mm×3mm×10mm, with the length of light direction 10mm. And the cutting direction of the LBO crystal is along Z axis, so as to achieve the type II non-critical phase-matching. In the experiment, Nd:YVO_4 crystal is fixed on the copper clamp and the copper clamp is cooled by the purified water. At the same time, the purified water is cooled and the temperature of cooling water is controlled by HX-10555 Constant Temperature Circulator. The temperature can be regulated between 10 and 40 centigrade degrees and the temperature control precision is (±0.2°C). In order to ensure the close contact between crystal and copper clamp, the side of crystal is wrapped with indium sheet, and the thermal conductivity of indium sheet is very good, so that the heat on crystal can be quickly transferred to copper clamp and the circulating water can take the heat away. The cooling device is fixed on the five-dimensional adjusting frame to accurately adjust the crystal position and ensure that the pump light is π polarization to Nd:YVO4 crystal, so that the pumping is more effective. LBO crystals are heated by tubular ceramic resistors. The temperature of phase matching is controlled precisely by a temperature controller. The temperature control accuracy is (±0.1°C). In order to suppress the 1.06μm spectral line oscillation with the strongest gain in Nd:YVO_4 crystals, planar mirror M_1 coating not only satisfies 1.34μm total reflection and 808nm high transmittance, but also 1.06μm high transmittance; Nd:YVO_4 crystal both ends are coated with 1.34μm antireflectivity film to reduce the reflective loss in cavity; plane-concave M_2 coating on 1.34μm high reflection and 671nm high transmittance. The plane-concave mirror M_3 is coated with high anti-dichroic reflective film of 1.34μm and 671nm. The 1.34μm laser passes through LBO crystal twice, and the 671nm red light is output through the plane-concave mirror M_2.

3. Cavity Design and Analyses

Firstly, the problem of calculating stable region is discussed. In order to improve the mode discrimination ability of laser, V-shaped folded cavity is used instead of linear cavity. However, when the radius of curvature and the length of cavity are fixed, the stable region of folded cavity is smaller than that of flat-concave cavity. According to our previous theoretical research on the characteristics of stable region of flat-concave cavity and three-mirror folding cavity [11-12], the length of straight arm l_1 is selected as 65mm. After inserting LBO crystal, the reciprocating matrix of three-mirror folding cavity is rewritten. Through numerical calculation, the folding arm l_2 can be selected in the range of 50mm-80mm or 150mm-175mm. Taking into account the requirement of increasing the module volume and energy storage, the length of folding arm is selected as 160mm.

Secondly, the cavity mode matching problem is analyzed. In order to improve the optical-optical conversion efficiency and stability of lasers, it is necessary to seriously consider the cavity mode matching between pumped and oscillating light. Theoretical analysis has previously been done on this problem [13]. If the waist radius of the pump beam is too small, not only the laser crystal will be damaged easily, but also the coupling efficiency will be low due to the large divergence angle. If the waist radius of the pump beam is too large, the overlap efficiency of the pump beam and the oscillating beam will also be reduced, because when the waist radius of the pump beam is too large, the pump energy can not be effectively coupled to the volume of the oscillating mode. On the basis of extensive experimental research on 1.34μm fundamental frequency light [11-12], combined with the existing experimental conditions, the pump optical coupling system is redesigned. After the LD output light is shaped by the coupling system, the waist spot radius of the pump light is 120μm, and the theoretical value of the waist spot radius of the oscillating light beam at the plane mirror M_1 is about 139μm, so that the principle of higher overlap efficiency is manifested when the two beams are coupled. Moreover, the waist size of the pump beam is small, which meets the requirement of transverse mode identification. In this experiment, the position of the waist size of the pumped beam is also a key concern. According to the cavity mode matching theory [13], we calculated the optimum position of the waist of the pumped beam in the crystal, which is about 0.7mm from the front end of Nd:YVO_4 crystal. This distance is the distance to ensure the minimum threshold of the laser.

Thirdly, the problem of crystal position is taken into account. Considering that the beam waist of oscillating light is close to the plane mirror M_1, the distance between Nd:YVO_4 crystal and plane mirror M_1 should be as small as possible, but if the distance is too small, the adjustment and movement of plane mirror M_1 and Nd:YVO_4 crystal will be inconvenient. The author believes that the distance is generally selected within 3-8mm, and the distance selected in this experiment is about 5mm. LBO crystal is placed at the waist of the cavity mirror M_2 and M_3. The waist position can be determined by observing the operation of the fundamental frequency light. It is found that the waist position of the fundamental frequency light beam is about 85mm from the cavity mirror M_3.

4. Experimental Results and Discussions

Figure 2 shows the relationship between the output power of red light and the pump power.

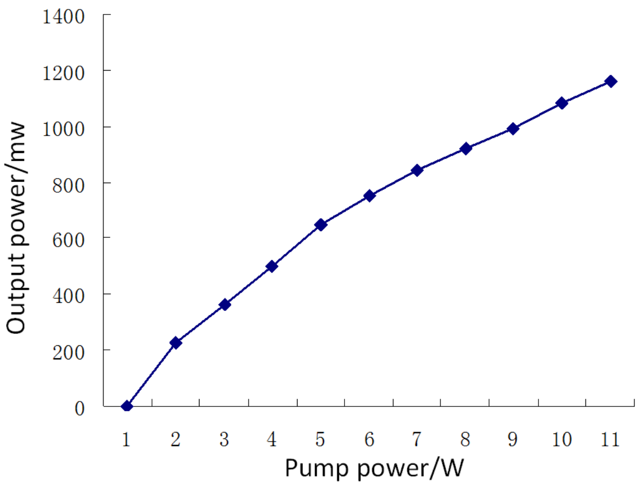

Figure 2. *Red light output power as a function of input power.*

Experiments show that when the temperature of LBO crystal temperature controller is adjusted to 41°C, the red light conversion efficiency is the highest, which is higher than the theoretical value of 36.2°C. The reason is that the temperature of the ceramic resistance is controlled by the temperature controller, and there is a temperature gradient between the ceramic resistance and the crystal.

The pumping threshold of the laser is about 320mW. When the pumping power is 11.0W, the output power of red light is 1.16W and the optical-optical conversion efficiency is 10.5%. The transverse mode of the laser is proved to be TEM_{00} mode by far-field observation. The stability of the laser is measured. When the output power of the laser is 1.16W, the laser is continuously monitored for 15 minutes. The instability of the output power of the laser is less than 1%.

The red light output power of 1.16W obtained by experiment is not the maximum output power. If the input power is increased, the output power will be increased, but the stability and optical-optical conversion efficiency may be reduced. We believe that this is a good point of work and can meet the needs of many fields. The author believes that our comprehensive consideration of laser parameters can provide reference for the design of similar lasers.

5. Conclusions

From above, the output characteristics of 1.34μm fundamental frequency light and 671nm doubled frequency light are studied experimentally. The theoretical basis for the selection of laser parameters is analyzed, and the general principle for the selection of cavity parameters is proposed. A satisfactory experimental result is obtained. When the pump power is 11.0W, the output power of 671nm laser is 1.16W and the optical-optical conversion efficiency is 10.5%. This kind of laser, which has high stability, can meet the needs of many fields.

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