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RESEARCH ARTICLE

A 123 W Nd:YVO_4 slab laser with high beam quality output

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Abstract The laser diode (LD) partially end-pumped slab laser with hybrid resonator is a kind of novel solid-state laser that can achieve high power with high beam quality. Using this configuration, taking Nd:YVO_4 as the slab gain media, a 123 W output was obtained when the pumping power was 265 W, and the optical-to-optical efficiency and slope efficiency were 46.4% and 52.4%, respectively. The beam quality M^2 factors in the unstable direction and the stable direction were 1.3 at the output power of 98 W.

Keywords laser diode (LD), slab laser, Nd:YVO_4, hybrid resonator, 1064 nm laser

1 Introduction

Diode end-pumped solid state lasers have been shown to be compact, efficient sources with high beam quality [1]. However, power scaling and beam quality in the traditional rod lasers are limited by the thermal lensing and the thermal fracture damage of the lasing gain medium. How to obtain a high output laser with high beam quality has always been a focus.

Nd^{3+} doped laser crystals are common gain material in high power 1.06 μm lasers, such as Nd:YVO_4, Nd:$GdVO_4$, Nd:YAG, and so on. In 2005, Minassion et al. [2] obtained 40 W of predominantly TEM_{00} output and 34 W TEM_{00} output ($M_x^2 = 1.05$, $M_y^2 = 1.1$) with pumping power of 81 W by using side-pumped grazing-incidence Nd:$GdVO_4$ slab laser. In 2008, Xiao et al. [3] achieved a 280 W laser output with side-pumped Nd:YAG planar waveguide structure and beam quality factor M^2 was 1.5 in the width direction. Partially end-pumped slab lasers with hybrid resonators are also considered to be suitable for power scaling at high beam quality and efficiency [4]. In 2004, Shi et al. [5,6] used this configuration and obtained a 110 W 1064 nm output laser with high beam quality. Some universities and institutes in China have also done some researches on this configuration. In 2005, Tsinghua University presented a 1064 nm slab laser with the output power of 16 W [7]. In 2008, a 41.5 W output at 1064 nm using the configuration was reported by Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences [8]. In the same year, Zhu et al. [9] in EdgeWave GmbH, Germany, demonstrated a compact and efficient Nd:YVO_4 hybrid slab laser that was partially end pumped at 880 nm, and a maximum output power of 165 W at 1064 nm with high beam quality was obtained.

In this paper, a compact, partially end-pumped Nd:YVO_4 slab laser pumped at 808 nm by laser diode (LD) stacks was experimentally investigated, and a 123 W output was obtained when the pumping power was 265 W, the optical-to-optical efficiency and slope efficiency were 46.4% and 52.4%, respectively. The beam quality M^2 factors in both the unstable direction and the stable direction were 1.3 at the output power of 98 W, which has come up to an international advanced level.

2 Experimental setup

Figure 1 is the schematic diagram of the LD end-pumped Nd:YVO_4 slab laser. The central wavelength of the LD was 808 nm and the emission from each diode laser bar was individually collimated by micro lens. After the coupling system, which was the same as that in Refs. [5] and [9], a 12 mm×0.4 mm homogeneous pumping line was obtained and coupled into the Nd:YVO_4 crystal through its end face. The Nd:YVO_4 laser crystal with the size of 12 mm×10 mm×1 mm was 0.3% doped and mounted between two water-cooled heat sinks with two large faces (12 mm×10 mm). Indium foil was used for effective and uniform thermal contact and cooling. Only two end faces (12 mm×1 mm) of the slab crystal needed to be polished and coated for passing the pump radiation (808 nm) and laser beam (1064 nm). Both the LD stacks and laser crystal were temperature controlled by circulating water.

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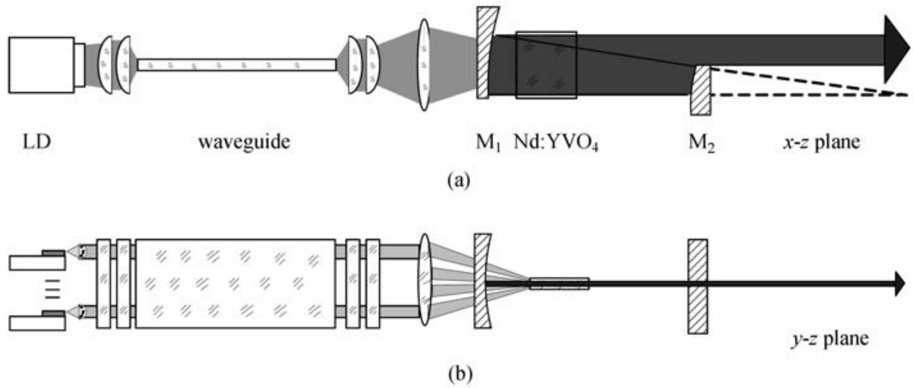

Fig. 1 Experimental setup of LD end-pumped Nd:YVO_4 slab laser with hybrid resonator. (a) Horizontal direction; (b) vertical direction

A spherical mirror (R_1 = 500 mm) and a cylindrical mirror (R_2 = −350 mm) were used as resonator mirrors. Both mirrors were coated for high reflectivity ($R > 99\%$) at 1064 nm and high transmission ($T > 90\%$) at 808 nm. M_1 and M_2 built up a plane-concave stable resonator in the y direction and an off-axis positive confocal unstable resonator in the x direction. The magnification of the unstable resonator was $M = -R_1/R_2 = 1.4$, and the output coupling was $T = (1 - 1/M) \times 100\% = 30\%$. The distance between the two mirrors was approximately 80 mm. M_2 was cut and polished at one edge where the laser beam was coupled out.

3 Results

The output power as a function of LD pump power is shown in Fig. 2, where the pumping power was 265 W, the maximum output power of 123 W was achieved with the slope efficiency η_{slope} of 52.4% and optical-to-optical efficiency $\eta_{\text{o-o}}$ of 46.4%.

To measure the beam quality, a lens with a focal length of 350 mm and a thin knife were used to get the beam diameters at different positions. Using M^2 factor, the propagation of the high order laser beam can be described as [10]

$$d(z)^2 = d_0^2\left[1 + \left(\frac{4M^2\lambda z}{\pi d_0^2}\right)^2\right], \qquad (1)$$

where d_0 is the diameter of beam waist, $d(z)$ is the beam diameter at point z, λ is the wavelength, and z is the distance to the beam waist. According to Eq. (1), the squared beam diameters at different positions in both directions at output power of 98 W were fitted as shown in Fig. 3. The beam quality M^2 factors in the unstable direction and the stable direction were 1.3.

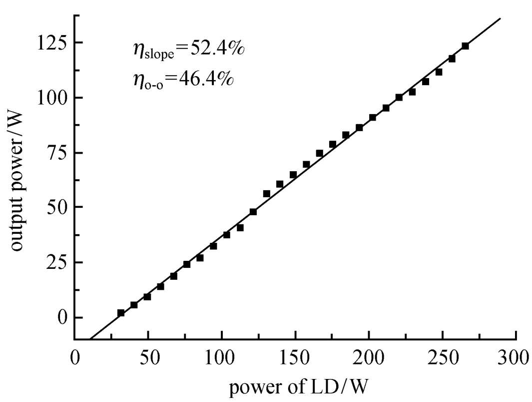

Fig. 2 Output power as a function of LD pump power

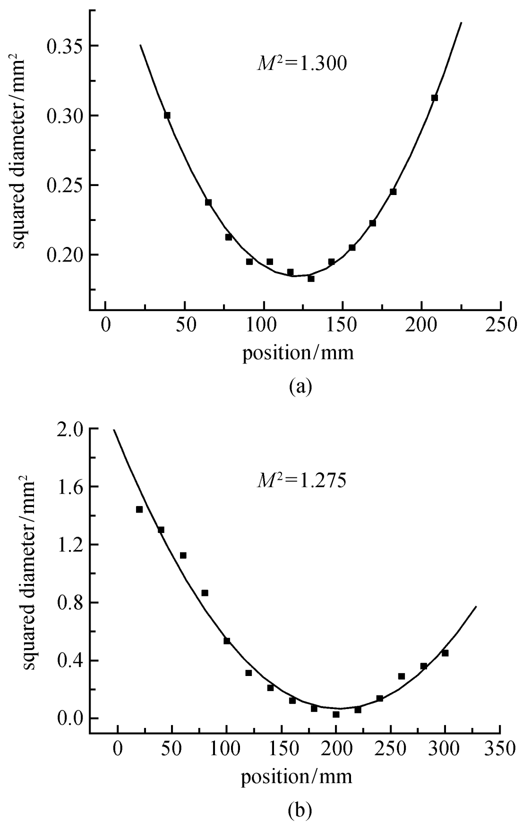

Fig. 3 M^2 factor at output power of 98 W. (a) Unstable direction; (b) stable direction

We measured the stability of LD end-pumped slab laser at an output power of 98 W for 45 min, and the results are shown in Fig. 4. No obvious fluctuations were observed. The stability was about 1%.

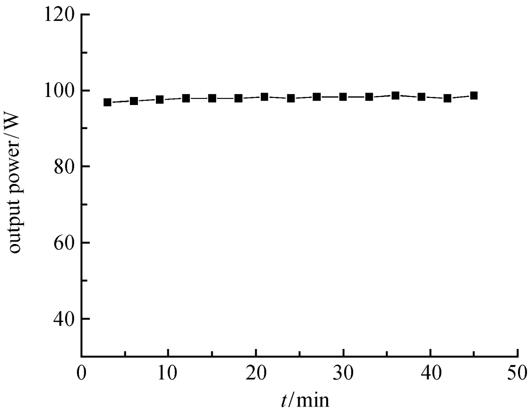

Fig. 4 Time stability at output power of 98 W

4 Conclusion

In conclusion, a 123 W continuous wave 1064 nm laser was generated with the pumping power of 265 W, the slope efficiency and optical-to-optical efficiency were 52.4% and 46.4%, respectively. At the output power of 98 W, the beam quality M^2 factors were measured to be 1.3 both in the unstable direction and the stable direction, and the stability was about 1%.

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