Available online at www.sciencedirect.com
ScienceDirect
Optics Communications 270 (2007) 296–300
OPTICS COMMUNICATIONS
www.elsevier.com/locate/optcom

High-power CW diode-side-pumped 1341 nm Nd:YAP laser

Zhu Haiyong [a,b], Huang Chenghui [a], Zhang Ge [a,*], Wei Yong [a], Huang Lingxiong [a], Chen Jing [a,b], Chen Weidong [a], Chen Zhenqiang [c]

[a] Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou, Fujian 350002, People's Republic of China
[b] Graduate University of the Chinese Academy of Sciences, Beijing 100039, People's Republic of China
[c] Institute of Optoelectronic Engineering, Jinan University, Guangzhou, Guangdong 510632, People's Republic of China

Received 28 April 2006; received in revised form 15 August 2006; accepted 29 August 2006

Abstract

A high-power CW diode-side-pumped Nd:YAP laser with linearly polarization at 1341 nm has been described. The laser characteristics including thermal lens and stability of flat–flat resonator were studied. By comparing the output powers at different resonator lengths and different output couplers, the *c*-axis polarized laser working at 1341 nm has been obtained with a maximum output power of 121 W at the pumping power of 555 W. The optical–optical efficiency is 21.8% and the optical slope efficiency is 40%. The *a*-axis polarized laser at 1339 nm has also been successfully obtained when the *c*-axis polarized laser had become instable with the increase of pumping power.

PACS: 42.55.Xi; 42.55.Rz

Keywords: Nd:YAP; 1341 nm; Diode-side-pumped; CW laser

1. Introduction

High-power 1.3 μm laser has attracted a great deal of attentions for its applications in laser medicine, fiber communications system, non-linear frequency conversion to produce visible radiation and so on [1–3]. The $^4F_{3/2}$–$^4I_{13/2}$ transition of neodymium doped crystal locates in this wavelength region. Among the various neodymium doped crystals, Nd:YAP crystal is an important candidate for high power 1.3 μm laser. It is because Nd:YAP crystal not only possesses high thermal conductivity and excellent optomechanical coefficient but also owns large product value (330×10^{-19} cm^2 μs) [4] of stimulated emission cross section σ and the fluorescence lifetime τ at 1341 nm, which is contributed to the low laser threshold and the high output power for the continuous wave laser. Moreover, the big natural birefringence of Nd:YAP may overcome the limitations on fundamental mode operation and depolarization losses caused by thermally induced stress birefringence and bifocals at high average powers[5]. Many experiments have shown that Nd:YAP crystal is one of the excellent laser materials at 1.3 μm [6–8].

The diagram of energy levels of Nd^{3+} in Nd:YAP crystal is shown in Fig. 1. The wavelength of the strongest line comes from the $^4F_{3/2}$–$^4I_{11/2}$ transition. The $^4F_{3/2}$–$^4I_{13/2}$ transition has two intense overlapped stark transitions: R1–X1 at 1339 nm and R2–X3 at 1341 nm [9]. The stimulated emission cross sections vary with polarization in the anisotropic Nd:YAP crystal [10]. For $^4F_{3/2}$–$^4I_{13/2}$ ($^4F_{3/2}$–$^4I_{11/2}$) transition of *b*-axis laser rod, the gain is greatest for 1341 nm (1079 nm) with the polarization of *c*-axis direction and greatest for 1339 nm (1064 nm) with the polarization of *a*-axis direction. Because the gain of *c*-axis polarized laser is much greater than that of *a*-axis polarized laser without polarization-selective optics, the oscillation in the laser cavity always obtained with *c*-axis polarized laser.

In this paper, we measured the thermal focal lengths of laser rod under different pumping powers and analyzed the stability of flat–flat resonator. By comparing the output

* Corresponding author. Tel.: +86 5913713114; fax: +86 5913714648.
E-mail address: zhg@fjirsm.ac.cn (G. Zhang).

0030-4018/$ - see front matter
doi:10.1016/j.optcom.2006.08.044

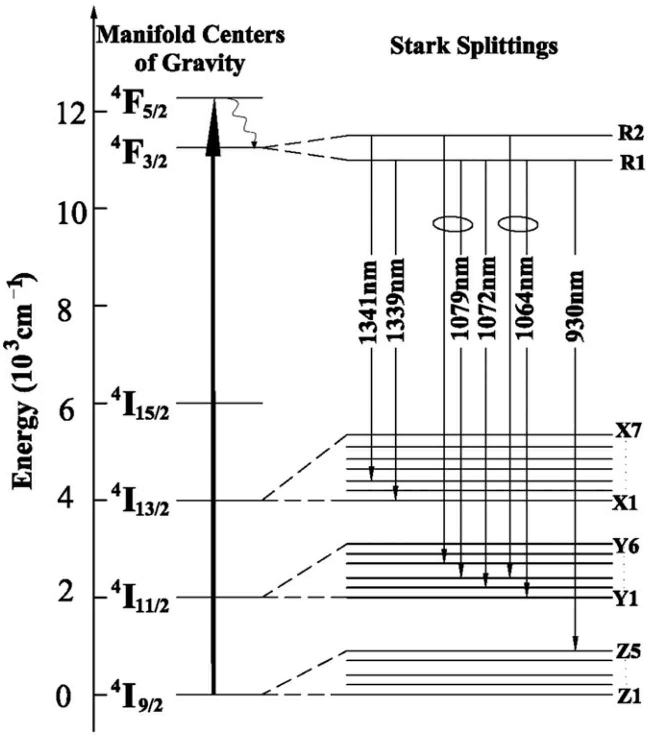

Fig. 1. The diagram of energy levels of Nd^{3+} in YAP crystal.

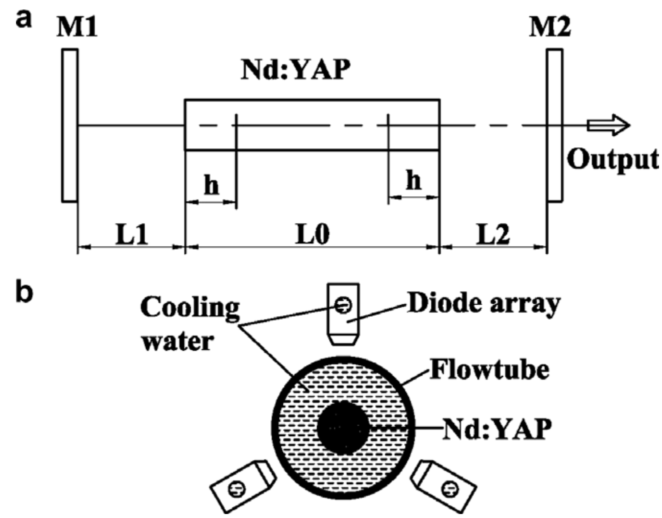

Fig. 2. Schematic diagram of the laser diode side-pumped Nd:YAP laser system: (a) Resonator configuration. (b) Diode-side-pump module cross-section.

powers at different resonator lengths and different output couplers, 121 W output power with *c*-axis polarized laser at 1341 nm was obtained at the pumping power of 555 W. We also have obtained the *a*-axis polarized laser at 1339 nm when the *c*-axis polarized laser had become instable with the increase of pumping power.

2. Experimental setup

The schematic diagram of the laser diode-side-pumped Nd:YAP laser is shown in Fig. 2. The resonator consists of two plane mirrors, M1 and M2. M1 is a high reflective mirror with reflectivity $R > 99.7\%$ at 1341 nm, and M2 is an output coupler with partial reflection coated at 1341 nm. They are both high-transmission coated ($T > 70\%$) at 1079 nm to restrain the 1079 nm strongest line. The activation medium is a *b*-axis cut Nd:YAP rod with 110 mm in length and 4 mm in diameter and with a Nd^{3+}doping concentration of 0.9 at. %. The two end surfaces of Nd:YAP rod were well polished and coated with antireflective film at both 1079 nm and 1341 nm. It is efficiently pumped by a diode-side-pumping module (from Beijing GK Laser Technology Co. Ltd.) which had three pump units arranged in a three-fold symmetry around the Nd:YAP rod. The current of the module turns from 20 A to 45 A, the working voltage vary from 26 V to 27.6 V. Both the module and Nd:YAP rod are cooled by re-circulating filtered water whose temperature was controlled to 20 °C.

The output power was measured with LPM-100 power meter. The output characteristics as the polarization and wavelength were measured with the Glan-Foucault prism and model 44 W grating monochromator, respectively.

3. Stability analysis

As shows in Fig. 2, Nd:YAP rod in the resonator can be considered as a thin lens with an effective focal length *f*. *h* is the distance from the principal plane of the thermal lens to the end surface of the Nd:YAP rod, which can be obtained by $h = L_0/(2n)$ [11], *n* is the refractive index of Nd:YAP rod. For the 110 mm length of Nd:YAP rod in our experiment, the values of *h* are calculated to be 29 mm. The stability of the resonator can be investigated by ABCD ray transfer matrix. Let $L_1^* = h + L_1$, $L_2^* = h + L_2$. Each optical element inside the resonator is characterized by its matrix. The beam radius of fundamental mode on the principal plane of the thermal lens is given as

$$\omega^2 = \frac{\lambda|B|}{\pi\sqrt{1-(A+D)^2/4}}, \quad (1)$$

where λ is the laser wavelength. The transition from the stable to the instable region is characterized by the condition that the size of the fundamental mode becomes infinite which means very high diffraction losses and thus vanishing laser action [12]. For example, we had calculated the Eq. (1) for three flat–flat resonators ($L_1 = L_2 = 4.5$ cm; $L_1 = 7.1$ cm, $L_2 = 6.9$ cm; $L_1 = 7.5$ cm, $L_2 = 4.5$ cm), which had been shown in Fig. 3.

Just as Fig. 3, with the decrease of the thermal focal length, the resonator has two stable regions. By defining $L^*_{max} = \max\{L_1^*, L_2^*\}$, $L^*_{min} = \min\{L_1^*, L_2^*\}$, the stability condition of resonator is $f \geqslant L^*_{max}$ and $\frac{L^*_{min}L^*_{max}}{L^*_{min}+L^*_{max}} \leqslant f \leqslant L^*_{min}$. For the symmetrical resonator ($L_1^* = L_2^* = L^*$), the two stable regions will combine into a wider continue stable region