

The experimental study on 808nm LD end-pumped Nd:YVO₄ laser

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Abstract. It is discussed that the experimental output profile of 1064 nm beam of a laser diode (LD) end pumped Nd: YVO₄ laser. It shows that the output power is highly dependent on the focusing position of pump light inside Nd:YVO₄ crystal. Given the same beam waist (1mm) and the same cavity length (58mm), the relationship of output profile and the distance between coupling lens and crystal end is analyzed. When the coupling lens is 13mm away from the crystal end and the pump power is 58.8W, the output power is 20.25W. In this condition, the optical to optical conversion efficiency is 34.4%. The ZEM00 mode is acquired and M2 value is below.

Introduction

Since LD pumping technique has been significantly improved, solid state laser is developed rapidly. Because of the advantages of small volume, light weight, long life, high efficiency and tiny mechanical vibration, LD array pumping solid state laser is of great interest. Between end pumping and side pumping, end pumping offers better mode matching, and wavelength matching. Therefore, it becomes more and more important and developed rapidly[1, 2]. Meanwhile, Nd:YVO₄ is one kind of important laser material, which is especially suitable for LD end pumping[3]. It has two major advantages: 1.the absorbing bandwidth at 808 nm is 5 times wider than Nd:YAG[4]; 2. Nd:YVO₄ is naturally birefringent. Therefore the output is linearly polarized along π direction, avoiding additional heat birefringence. This article introduces a laser system based on LD end pumping technique using fiber coupling and Nd:YVO₄ is selected as laser material.

Theory Analysis

The energy level transition of Nd:YVO₄ generating 1064 nm light is a typical 4 level transition. It has been approved that[5]:

$$P_{th} = \frac{\pi h c (\omega_c^2 + \omega_p^2) \delta}{4 \sigma \pi \lambda_p \eta_p} \quad (1)$$

$$P_{out} = \eta_p \eta_a \frac{\lambda_p}{\lambda} \frac{T}{\delta} P_{in} \quad (2)$$

$$\eta_s = \eta_p \frac{h \nu_1}{h \nu_p} \frac{T}{\delta} \quad (3)$$

where P_{th} represents pumping power threshold, P_{out} represents output power, η_5 is the ratio of P_{th}/P_{out} , ω_c represents output beam waist, ω_p represents pumping beam waist, $h\nu_p$ is pumping photon energy, $h\nu_1$ is output photon energy, η_a is absorption efficiency of pumping light, σ represents the area of gain cross section, δ represents cavity loss, η_p represents quantum efficiency,

λ_p represents pumping wavelength, λ represents the wavelength of oscillating light, P_{in} represents the pumping power at the surface of laser material. Cavity loss δ includes two parts: 1.output loss T , 2.internal cavity loss δ_f , which is related to crystal doping density, crystal length and the absorption loss of pumping light. When cavity is designed, T and δ_f are confirmed. Based on experiments, an empirical equation can be obtained [6]:

$$\delta_a(\rho, l, P_{in}) = C\rho l + C_1\sqrt{P_{in}} \quad (4)$$

$$\eta_a = 1 - \exp(-C_2\rho^b l) \quad (5)$$

where δ_a represents absorption loss, η_p represents the absorption efficiency of gain material to pump light, C , C_1 , C_2 and b are experimental constant. $C=0.04\text{cm}^{-1}$, $C_1=0.001\text{W}^{-1/2}$, $C_2=25$, $b=1.5$. Substituting Eq. 4 and Eq. 5 into Eq. 1- Eq. 3, it is obtained that:

$$P_{th} = \frac{\pi hc(\omega_c^2 + \omega_p^2)(T + \delta_f + C\rho l + C_1\sqrt{P_{in}})}{4\sigma\pi\lambda_p\eta_p} \quad (6)$$

$$P_{out} = \eta_p[1 - \exp(-C_2\rho^b l)] \frac{\lambda_p}{\lambda} \frac{T}{T + \delta_f + C\rho l + C_1\sqrt{P_{in}}} P_{in} \quad (7)$$

$$\eta_s = \eta_p \frac{h\nu_1}{h\nu_p} \frac{T}{T + \delta_f + C\rho l + C_1\sqrt{P_{in}}} \quad (8)$$

Eq. 4 approves that high doping density, big material volume, and high pumping power leads to high intracavity absorption loss. From Equation Eq. 6- Eq. 8, it can be concluded that with the same material length and the same output transmittance, doping density is inversely proportional to output power. Slope efficiency is determined by $\frac{C\rho l + C_1\sqrt{P_{in}}}{P_{in} \cdot \eta_h \cdot (dn/dT)}$. Therefore, higher slope efficiency requires shorter material length and lower doping density. With a high pumping power, thermal lens effect is not neglected to laser output. For end pumping laser, the theoretical focusing length of thermal lens is:

$$f_T = \frac{\pi \cdot K_c \cdot \omega_p^2}{P_{in} \cdot \eta_h \cdot (dn/dT)} \cdot \frac{1}{1 - \exp(-\alpha \cdot l)} \quad (9)$$

The thermal lens of gain material is mainly due to temperature vibration and refractive index change caused by thermal strain. For end pumping, the Nd:YVO4 crystal is located on copper heat sink. Therefore, the material ends are exposed to air and the side is contacted with copper. Copper has a much higher heat conduction coefficient than air. As a result, heat is accumulated at both ends of gain material, which leads to heat deformation, changing optical path length along propagation direction. To avoid end deformation, composite crystal (doping crystal bonding with undoping crystal) is selected. Undoping crystal has a higher heat conduction coefficient, which can act as heat sink. This structure can effectively improve temperature gradient inside gain material. Therefore, thermal lens caused by end deformation is reduced, stabilizing laser output and increasing output power.

Experimental Arrangement

Fig. 1 illustrates a schematic diagram introducing a 1064nm Nd:YVO₄ laser with plane-plane resonator, which is end-pumped by a 808nm laser-diode. A 3mm×3mm×10mm(2+6+2) size Nd:YVO₄ was used as laser medium, whose doping concentration is 0.3 at.%, with a dual anti-reflecting film of 808nm and 1064nm. The plane-plane resonator consisted of mirror M1 and Fabry-perot etalon M2. M1 was plated with an anti-reflecting film of 808nm and a total reflection film of 1064nm, while M2 had a reflectance of 45% along with selection of longitudinal modes. The nLight laser-diode module used here operated under continuous conduction mode, generating maximum 100W laser whose center wavelength was 808nm at 25°C. An optical fiber coupled between laser-diode and Nd:YVO₄ crystal, focusing 808nm laser into Nd:YVO₄ crystal face. The equipment employed a plane-plane resonator, maintaining the length of cavity as a constant to avoid affecting pump efficiency influenced by cavity length. The position of coupling lenses were changed step by step, while pump current was increased respectively at every position until the output power began to decline. Figure 2 described a set of inflexion points in output power curves, which were acquired as above mentioned.

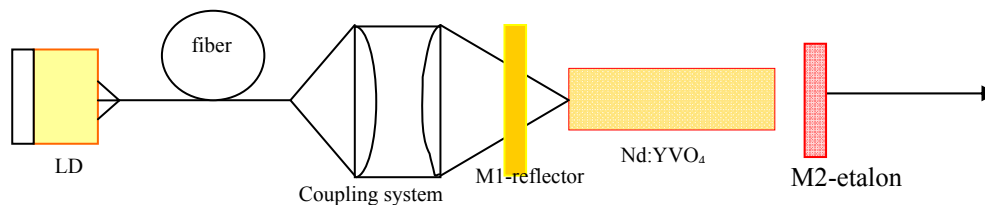


Fig. 1 experiment device

The crystal seated on a copper block with well thermal conductivity, using circulation water through inner channels to cool down. The laser pumped module was cooled by thermoelectric coolers, who were programmed and able to reach an accuracy of 1 °C. All well-designed methods ensured a stable, reliable, efficient, long-term working laser system.

Fig. 2 expresses input-output characteristics of laser system. The characteristics were established at different distances between laser-diode and the end face of Nd:YVO₄ crystal, which were 15.4mm, 14.2mm, 13mm separately, sharing a common beam waist of 2mm and common cavity length of 58mm. It could be found that when the pump current exceeded threshold current of 1.3A, the output laser power and the pump power had a consistent increase, reaching a maximum output power of 20.25W. There existed a rough linear rise of the output laser power with the pump power. However, the increasing rates of output power slowed down when the pump power reached a certain value. This phenomenon resulted in the thermal lens effect of temperature rising, which brought in an increase of cavity loss and led to a decreased output.

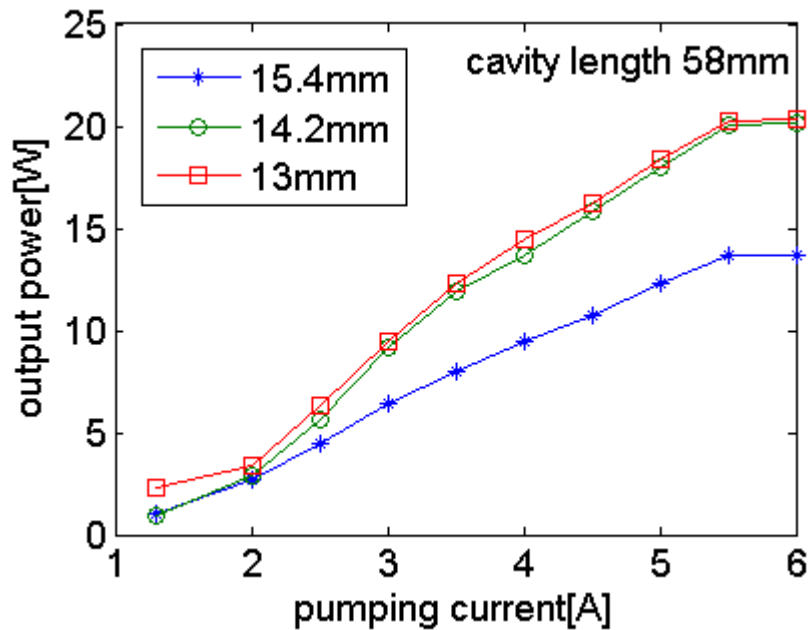


Fig. 2 input-output characteristics of 808nm LD end-pumped 1064nm Nd:YVO4 laser

An optimized result indicated that with a distance of 13mm and pumping power of 120W, an output laser of 20.25W at 1064nm obtained. At the same time, it achieved a slope efficiency of 16.8% and optical-optical efficiency of 34.4%, and M2 factor was less than 1.3. A laser spot was shown in figure 3, which was operated under 00 mode.

Conclusions

The thesis concentrates on some input-output characteristics of 808nm LD end-pumped 1064nm Nd:YVO4 laser. A series of experiments were studied and conclusions were presented as follows: changes of focal positions where pumped laser coupled into crystal had a great influence on output laser power. An optimized result indicated that with a distance of 13mm and pumping power of 58.8W, an output laser of 20.25W at 1064nm obtained as shown in Fig. 3. At the same time, it achieved optical-optical efficiency of 34.4%, and M2 value is below 1.3.

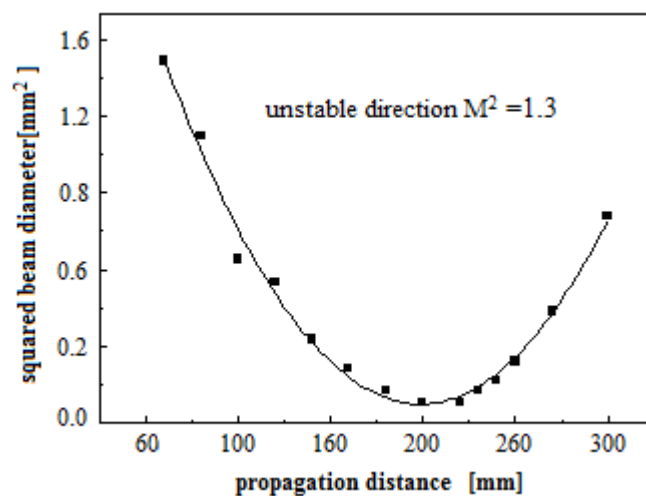


Fig.3 M^2 factor at output power 20.25w

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