Research on the mechanism of high power solid laser

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Abstract. A laser resonator with a concave lens is designed to solve the thermal lens effect, in order to obtain the 1064nm laser with high power and high beam quality. At first we analyzed the selection of the compensation lens. Then high power laser beams are obtained with a Nd:YAG laser resonator we designed. So an output power of 48W at 1064nm is obtained, when the concave focus is 250mm and the output mirror transmittance is 20%,.

1 Introduction

Nd:YAG laser pumped by a laser diode has drawn more and more attention in recent years, because of its advantages of high power, high efficiency, low cost, long service life, etc. It can be used in many fields, such as industrial production, scientific research, medical diagnosis and environmental monitoring. With the development of solid laser application, there are higher requirements for the output power, beam quality and stability. As one of the most important factors, the thermal lens effect gets more attention in design of resonant cavity [1-9].

In order to obtain laser beams with high power and high beam quality, we should compensate the thermal lens effect of laser rod. In this paper, we select an appropriate lens to compensate the thermal lens effect of the laser rod, and get an optimal design of Nd:YAG laser resonator. The beam waist curves (at the principal planes of the laser rod) is studied theoretically and experimentally. Experiment results show that, using an appropriate concave lens and optimal design of the resonator, a high power and high beam quality laser can be achieved. We obtain an output power of 48W.

2 Optimal design of Nd:YAG laser

The existence of the thermal lens in solid state lasers severely affects the beam quality, the output power and the stability of the resonator. One method to compensate the thermal lens effect is adding a concave lens in the cavity. We use the theory of the dynamically stable resonator[10-19] to optimize the resonator with a compensate lens. The dynamically stable resonator meets the following conditions: (1) The diameter of the TEM00 mode should be limited by the active material. (2) The resonator should be insensitive to pump-induced fluctuations of the rod's focal length. (3) The resonator modes should be fairly insensitive to mechanical misalignments. Two configurations are discussed here, a plano-plano cavity and a plano-plano cavity with a concave lens. Fig. 1 shows the schematic of Nd:YAG laser cavity with a concave lens.
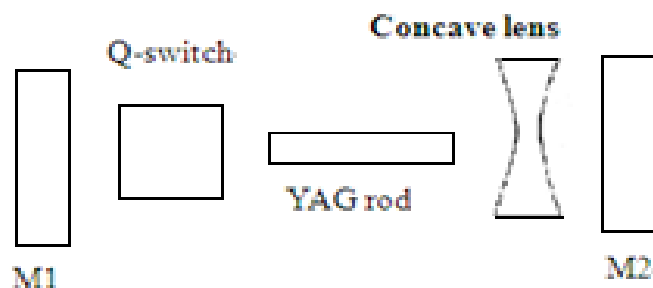

Fig.1. Schematic of Nd:YAG laser cavity

According to ABCD matrix theory, we calculate the beam radius wYAG at the principal plane of the laser rod (mode radius) with a concave lens (Fig. 2). Parameters used in calculation are: length

of the total cavity is 286mm, length of the YAG laser rod is 120mm, the distance between YAG rod end faces and the concave lens is 10mm and 90mm. The blank part of the figure is the unstable region. There are two stable regions in both cases. But only the above one is useful because the below one is narrow with a small thermal focus which is unrealistic. The low boundary of the above region in Fig. 2(a) is a line with thermal focus equal to 140 mm. And that in Fig. 2(b) is a curve with thermal focus from 70 mm to 120 mm which is smaller than the previous case.

For achieving high power, high pump current is better, corresponding to a smaller thermal focus. Thus, a shorter distance between YAG rod end faces and the concave lens is better here. We choose the distance equal to 25 mm for mechanical constraint. High pump current from 17 – 24 A is expected to be used in the experiment for getting high power laser with corresponding thermal focus from 140 mm to 260mm. Thus, we choose a concave lens with 250 mm focus length according to Fig. 2.

With the above resonator parameters, the curve between wYAG and the refractive power of thermal lens D (inverse of the thermal focal length) are calculated and shown in Fig. 3. For comparing, the curve of removing the concave lens is shown in the same figure.

It shows that the laser has two stable regions. When adding concave lens into the cavity, the two stable regions move right due to the compensation of thermal lens effects. Then the laser could operate at higher pump current (larger

D) result in higher laser power. Moreover, the resonator with a concave lens
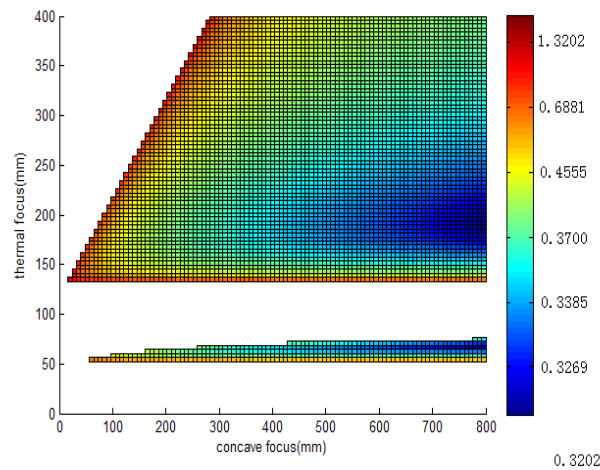
(a)
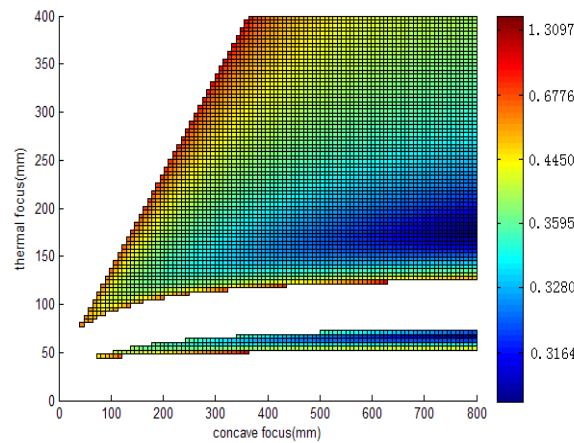
(b)

(a) the distance between the concave lens and the YAG rod end face is 90mm
(b)the distance between the concave lens and the YAG rod end face is 10mm

Fig.2. Stable region figure at different concave focus and thermal focus

has larger minimum beam radius $w_{\min}$ than the resonator without a concave lens. For achieving dynamic stability, lasers often operate at the state which w_{YAG} is equal to $w_{\min}$.
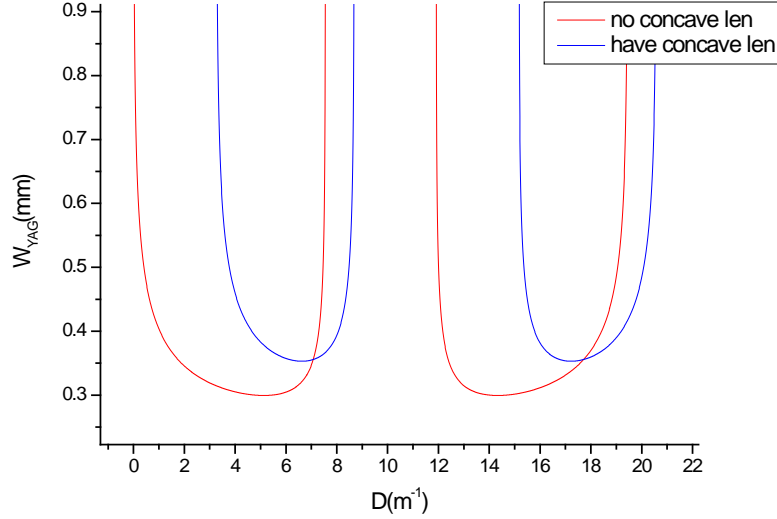

Fig.3. Refractive power versus beam waist radius at the main section of YAG laser rod

Figure 3 shows that the laser has two stable zones, the left corresponds to the second stable zone and the right corresponds to the first stable zone. When adding compensation lens into the cavity, both of the two stable zones move right. This makes the laser operating at high pump current to get high power laser. Because in the case of high pump current, the higher the LD pump power, the bigger the optical power of thermal lens. From figure 2 we can also see that after adding compensation lens the width of stable zone becomes narrow, the minimum beam waist radius increases accordingly.

Generally, the width of stable zone ΔD and minimum beam waist radius $w_{\min}$ satisfy the following relationship:

$$w_{\min}^{2} \cdot \Delta D = \frac{2\lambda}{\pi} \qquad (1)$$

The lasers have two stable areas and low pumping current is the first stable region while high pumping current is the second stable region. Experimental conditions limit the pump current can only be adjusted from 0A to 24A, and therefore, the laser can only work in the second stable area. In calculation we found that, At the left edge (low current position) in the second stable region, misalignment sensitivity is very large, which indicates that the laser will be very unstable and can not work effectively when it just goes into stable region. However, with the increasing of pump current, misalignment sensitivity decreases rapidly. In the middle and right part of the second stable area, misalignment sensitivity has been close to the value of the first stable area, which illustrates that the laser is able to function properly. We use CCD to record the speckle pattern of laser leaked out by holophote M2 along with the changing of pump current, when the pump power is 21A, the horizontal and vertical cross-sectional shapes of the speckle are close to Gaussian distribution.

The resonator will be insensitive to pump-induced fluctuations of the rod's focal length（dw_{YAG} /dD=0）. According to the first conditions of dynamically stable resonator, larger $w_{\min}$ would get better beam quality. The beam quality factor can be estimated by [20]

$$M^2 = \frac{d^2}{4w_t^2} \qquad (2)$$

Where, d is the diameter of laser rod, w_t is mode radius. Then submit the $w_{\min}$ and d=4mm, we obtain M^2=44.6 without concave lens and M^2=32.1 with a concave lens. It is visible that after adding a concave lens, beam quality will significantly improve.

3. Experimental research and analysis

The experimental setup is shown in Fig.1. A commercial laser diodes side-pumped Nd:YAG module is used. It consists of a 4-mm-diameter, 120-mm-long Nd:YAG crystal. Both of its end faces are flat and antireflection coated at 1064nm. M2 is a flat mirror with highly reflection at 1064nm, and M1 is the output coupler mirror with an 80% reflectivity at 1064nm. The concave lens is 250mm in focus length and both of its side faces are anti-reflection coated at 1064 nm.
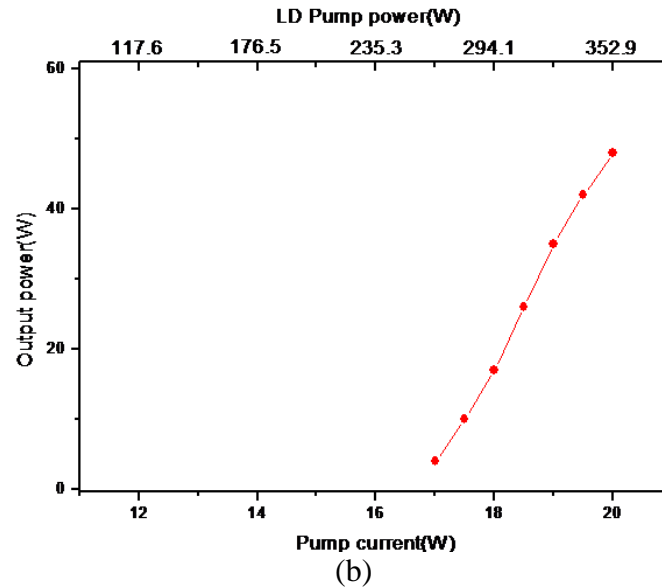
The performances of the laser with and without the concave lens are shown in Fig. 4. The slope efficiency of the laser with the concave lens is 60%, which is much larger than that without the concave lens, which is 22%. The output power increases linearly with the pump power. It obtains a maximum output of 48 W at a pump current of 20 A. However, the efficiency of the laser without the concave lens is becoming saturated when the pump current reaches 17 A.

4. Conclusions

In this paper, the method of using a concave lens to compensate the thermal lens effect is proposed. The theory of dynamically stable resonator is used in optimizing the laser cavity. Experiments are performed. The results show that a

(a)

(b)
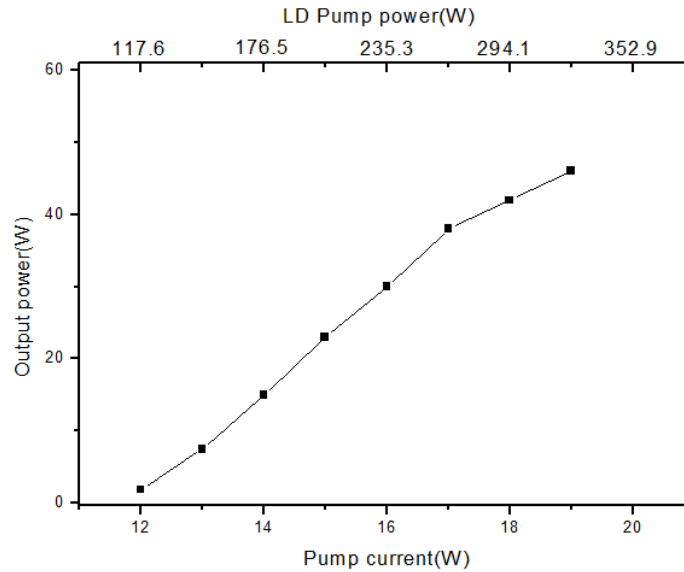
(a)the output power versus pump current without concave lens
(b)the output power versus pump current with a concave lens
Fig.4. The performances of the laser

laser with a concave lens has better performance than that without a concave lens. A maximum output of 48 W is obtained in our experiment.

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