Thermal Lensing Spectroscopy Analysis of Er:YAG Crystal Rod

Thermal Focal Length Measure

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Abstract—**The output efficiency of Er：YAG laser is low and thermal lens effect is apparent, so it brings about great affection on quality and stability of light beam. This article has given a simple method to survey thermal lens focal length, which use CCD vidicon to extract facula data in order to fitting Gaussian beam, and then calculate equivalent thermal focal length according to changes of Gauss beam. Experiment results show that thermal lens also makes extensive effect in low-power, and if higher the pumping power, smaller the thermal focal length. The results of experiment in accordant with that of theory.**

Keywords—Er:YAG; thermal lens effect; gauss beam; thermal focal length measure

Ⅰ. TNTRODUCTION

Erbium lasers (Er:YAG laser) emit laser at a wavelength of about 2.94 micrometers which can be strongly absorbed by water and hydroxylapatite, so it has been widely used in medical area like surgery and dental tissue ablation. However the output efficiency of Er:YAG which using lamp as pump is low (efficiency less than 3%), thermal lens effect is too important to ignore in research, work out the "thermal lens effcet" focal length exactly and make compensation on lasers have important practical significance. This article will make theoretical research and numerical analysis to the thermal lens effect of erbium laser on high pulse repitition frequency (HPRF), and finally the experiments are carried out to validate the analysis.

Ⅱ. THEORETICAL ANALYSIS

If the repetition frequency of laser rod greater than 5pps, the pluse interval period shorter than thermal time constant obviously and the result is temperature will not reduce between two pluses. Consequently, when the input power equal, temperature distribution of the rod same to continuous running[1].

Laser rod absorbs pumping light will generate quantity of heat which cooled by cooling liquid flow through rod surface. For convenience, suppose rod inner is homogenous in heating, when L≫ r_0, radial temperature distribution in cylinder can be got by one-dimensional heat equation, that is

$$\frac{d^2T}{dr^2}+(\frac{1}{r})(\frac{dT}{dr})+\frac{Q}{K}=0 \qquad (1)$$

Temperature field distribution in crystal rod could be obtained by formula one.that is

$$T(r)=T(r_0)+(\frac{Q}{4K})(r_0^2-r^2) \qquad (2)$$

where L is the length of rod, r_0 is radius, Q is heat productivity in unit volume and K is heat conductivity.

Stress in the rod generated by temperature could change refractive index through photoelastic effect. The direction of cylinder axis of Er:YAG crystal rod is [111], crystal grows along that direction. So it is an interesting promble of refractive index in [111] direction. The refractive variable quantity on radial and tangential are shown as following[2,3],

$$\Delta n_r=-\frac{1}{2}n_0^3\frac{\alpha Q}{K}C_r r^2 \qquad (3)$$

$$\Delta n_\phi=-\frac{1}{2}n_0^3\frac{\alpha Q}{K}C_\phi r^2 \qquad (4)$$

In the above expressions, α is coefficient of heat expansion, and C_r and C_ϕ are functions of elasto-optical coefficient of Er:YAG .

According to formula 3 and 4, refractive index of crystals caused by temperature has a quadratic relationship with radius r, the beams of light propagate along rod axis will appear quadratic space phase change , this kind of perturbation equal to spherical lens effect. Furthermore consider influence of stress and end effect, the equivalent thermal lens focus is[4]

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$$f = \frac{K\pi r_0^2}{P}\left[\frac{1}{2}\frac{dn}{dT} + \alpha n_0^3 C_{r,\phi} + \frac{\alpha r_0(n_0-1)}{L}\right]^{-1} \quad (5)$$

The focus f refers to the length from end face to focal point and where P is total power dissipated by rod, n_0 is refractive index of the crystal and dn/dT is thermal refractive index coefficient.

III. MEASURING METHOD OF THEMAL FOCUS

As the effect of thermal lens, the Gauss beam which pass through the crystal rod will change, and by measuring that changes could calculate equivalent thermal focal length. Experiment facilities is showing as following.

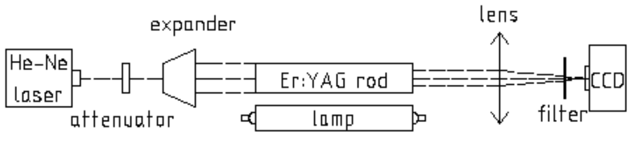

Fig 1 schematic diagram of measuring thermal lens focal length

The origin point is the intersection of optical axis and lens, then based on the transimission theory of Gauss beam, spot size of practical beam at the position of Z is as following,

$$w^2(z) = w_0^2 + \frac{\lambda^2(z-z_0)^2}{\pi^2 w_0^4} \quad (6)$$

Where z_0 is beam waist position, w_0 is beam waist width and λ is laser wavelength.

The curve fitting formula of beam waist width w which measured along propagation axis by CCD is[5]

$$w^2 = Az^2 + Bz + C \quad (7)$$

Where A , B and C are all fitting coefficient.

According to Formula 6, after lens focus the beam waist width w_0' and position z' are the following respectively,

$$w_0' = \sqrt{C - \frac{B^2}{4A}} \quad (8)$$

$$z' = -\frac{B}{2A} \quad (9)$$

According to the changes of Gauss beam after through lens[6]

$$\frac{w_0^2}{w_0'^2} = \frac{f-z}{f-z'} \quad (10)$$

$$\frac{\pi^2 w_0'^2 w_0^2}{\lambda} = (z + z' - \frac{zz'}{f})f \quad (11)$$

Among them f is the lens focal length, w_0 and z are the beam waist width and position before through pass lens respectively.

Then calculated with formula 10 and 11 could get the following,

$$w_0^2 = \frac{w_0'^2}{(1-\frac{z'}{f})^2 + \frac{\pi^2 w_0'^4}{\lambda^2 f^2}} \quad (12)$$

$$z = \left[1 - \frac{(1-\frac{z'}{f})}{(1-\frac{z'}{f})^2 + \frac{\pi^2 w_0'^4}{\lambda^2 f^2}}\right] f \quad (13)$$

Meanwhile by formula 10, the thermal lens focal f' could be got, that is

$$f' = \frac{w_1^2(d-z_2) - w_2^2(z_1-d)}{w_1^2 - w_2^2} \quad (14)$$

Where w_1 and z_1 are the beam waist width and position before through lens when pumping lamp isn't work., while w_2 and z_2 are the beam waist width and position after through lens when pumping lamp work steadily, and d is the length from crystal rod end face to lens.

IV.EXPERIMENTAL RESULTS

According to above method, the platform could been built as shown in Figure 2 .

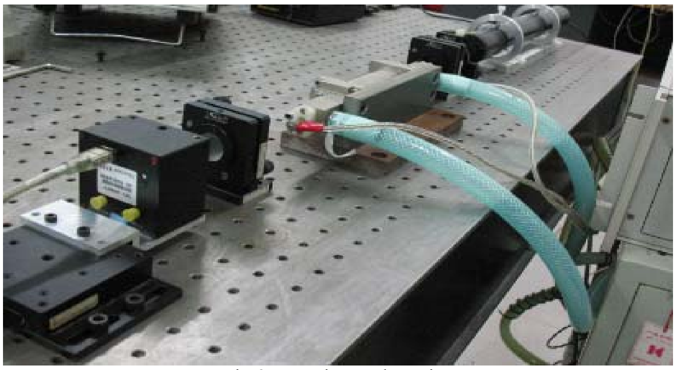

Fig 2 Experimental Device

The system adopts xenon lamp as single pump and circulating water to chilling. He-Ne laser outputs beam at the wavelength of 594nm, and after the beam through attenuator and 2.5 times beam expander device, it passes through Er:YAG crystal rod at the size of $\phi 4\times 110$ mm, then use C_aF_2 thin lens to gather and imaging on CCD. In order to eliminate other disturbance light, the front of CCD has mount narrow band pass filter which centre wavelength is 594nm. Adjust one-dimensional optical stages of mounting CCD, then facula images of different sections can be acquired. On the same section, acquisition facula images in different pumping power change obviously and reflect thermal lens effect well, as illustrated in Figure 3.

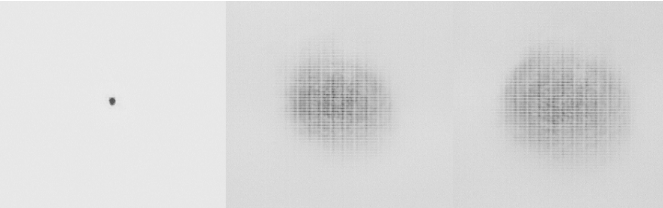

Fig 3 Acquisition facula images o the same section when pumping power are 0W, 15W and 30W separately(pictures for color reversal effect）

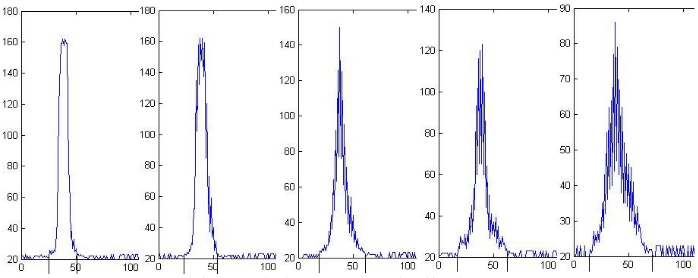

Fig 4 Relative Energy Distribution

Figure 4 shows facula relative energy distribution picture collected in the situation of pumping power at 15W and 0.5 mm intervals, which abscissa is pixels and one pixel is 3.2 μm . The beam waist width and position of Gauss beam can be fittd by above picture. Thermal focus in different puming power has got by experiments and shown as Fig5.

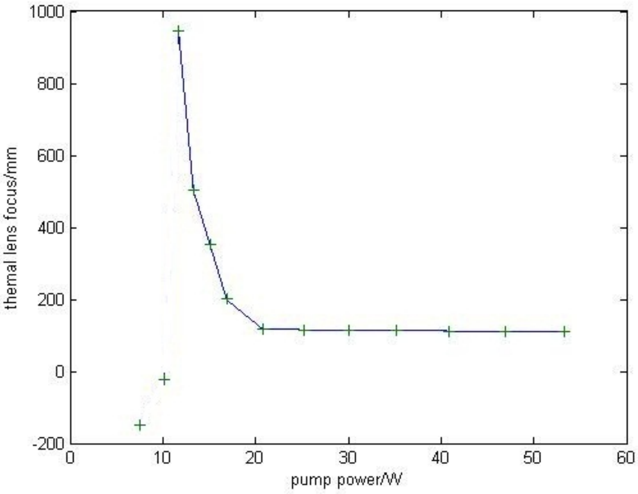

Fig5 Themal lens focus dependence with pump power

Ⅴ.CONCLUSION

Generally, measuring thermal focus with the method of using CCD to fitting Gauss beam is in accord with theory. When pumping power is higher than 20W, equivalent thermal lens focal length of Er:YAG crystal rod changes slightly with the change of pumping power, hereby, through decorating end faces to compensate it, the thermal lens effect can be solved easily and steadily. When pumping power is less than 10W, owing to rod surface temperature is higher than center, so it causes negative lens effect and thermal focus is a negative value.

REFERENCES

[1] T.J. Gleason,J.S. Kruger,R.M.Curnutt:Appl.Opt.12,2942
[2] J.D.Foster,L.M. Osterink:J.Appl.Phys.41.3656
[3] W.Koechner,D.K.Rice:IEEE J.QE-6,557
[4] Solid-state Laser Energineering/[U.S.A]Koechner, W. ; Trans.Sun Wen, Jiang Zewen, Cheng Guoxiang. Beijing: Science Press, 2002.363-364
[5] YANG J,LIU ShH,WAN PTetal. 3D numerical study on laserbending of sheetmetal [J].LaserTechnology, 2003, 27(2): 97~100(inChinese).
[6] Chen Yuqing, Wang Jinghuan. The Principle of Laser. Hangzhou:Zhejiang University Press, 1992.5