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# Experiment Study of Influence on Laser Beam Quality Induced By Thermal Lens Effect and Depolarization Effect

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**Keywords:** thermal lens effect, thermal double refraction, depolarization effect, Nd:Glass laser

**Abstract.** For high power and repetitive Nd:Glass laser, there would appear serious thermal effect due to the significantly-enhanced pumping optical power density in laser rod, which would induce thermal double refraction, phase distortion, thermal focusing, thermal depolarization, etc. Thus, the laser output power and beam quality would be influenced severely. Influence of thermal lens effect and depolarization effect caused by thermal stress double refraction on laser beam were studied in this paper for high power and repetitive laser. In the experiment of thermal lens effect, change of the laser spot by thermal lens effect was recorded after a $TEM_{00}$ He-Ne laser beam passing through the Nd:Glass rod pumped by Xe lamp, and the corresponding optical compensator was applied to eliminate the thermal lens effect to improve the beam quality. Configuration of polarizer was designed in our experiment to research the depolarization effect caused by thermal stress double refraction. First, emergent light distribution and loss factor caused by double refraction was calculated according to the theoretical model. Then the exiting cone-shaped polarized light intensity distribution was obtained through the experiment. It could be obtained from the experiments that thermal lens effect and depolarization effect caused by thermal double refraction would reduce the output laser beam quality to varied extents. As the number of laser pulses increased, thermal effects began to emerge and the output laser energy apparently decreased; when the thermal effects steadied, the output energy would be tending towards stability.

## Introduction

Nd:Glass laser was widely used in the fields such as nuclear fusion, material modification, laser peening, etc. due to its merits of high energy and high peak power[1-3]. However, For high power and repetitive Nd:Glass laser, there would appear serious thermal effect due to the significantly-enhanced pumping optical power density in laser rod, which would induce thermal double refraction, phase distortion, thermal focusing, thermal depolarization, etc[4]. Thus, the laser output power and beam quality would be influenced severely. Influence of thermal lens effect and depolarization effect caused by thermal stress double refraction on laser beam were studied in this paper for high power and repetitive laser. Influence of thermal lens effect and depolarization effect caused by thermal stress double refraction on laser beam were studied in this paper for high power and repetitive laser. Optical compensator was applied to eliminate the thermal lens effect and phase hysteresis method was applied to compensate the double refraction. It could be obtained from the experiments that thermal lens effect and depolarization effect caused by thermal double refraction would reduce the output laser beam quality to varied extents. As the number of laser pulses increased, thermal effects began to emerge and the output laser power apparently decreased; when the thermal effects steadied, the output power would be tending towards stability.

## Thermal Lens Effect and its Elimination with Optical Compensator

For high power and repetitive Nd:Glass laser, the Nd:Glass rod was usually cooled by cooling water because it would give off great heat during operation. In such case, the heat inside the rod would be conducted to the surface along the radial direction, thus producing great temperature gradient in the

cross-section of Nd:Glass rod. So, there would appear thermal stress inside the rod because expansion of the Nd:Glass core would be restricted by the external part, which would lead to refractive index variation in the rod. This variation was related not only to the radial position in the cross-section, but to the direction. The unequal refractive index variations along radial and tangential directions would cause thermal stress double refraction, that is, in the center of the rod, the temperature was high and the refractive index was large, while in the surrounding part, the temperature was low and the refractive index was small. When laser beam passed through this heat-inhomogeneous rod, it would be self-focusing and the laser spot quality would be damaged severely, somewhat like the beam passing through a lens, as a result, this phenomenon was called the thermal lens effect. In order to eliminate the thermal lens effect, optical compensator was applied in our research to improve the beam quality. In such circumstances, the laser rod acted as a lens, and the parallel laser beam would become a focused beam after it passed through the rod, then we could insert into the laser resonator an optical compensator like a special-designed lens whose focus point coincided at the focus point of the thermal lens. It was proved effective in our experiment to compensate high-order mode oscillation and power loss by this method.

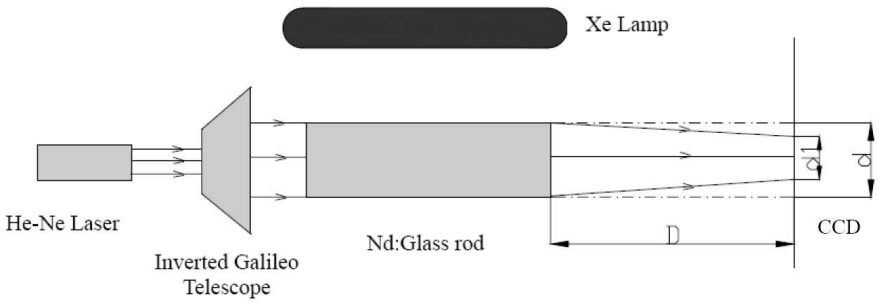
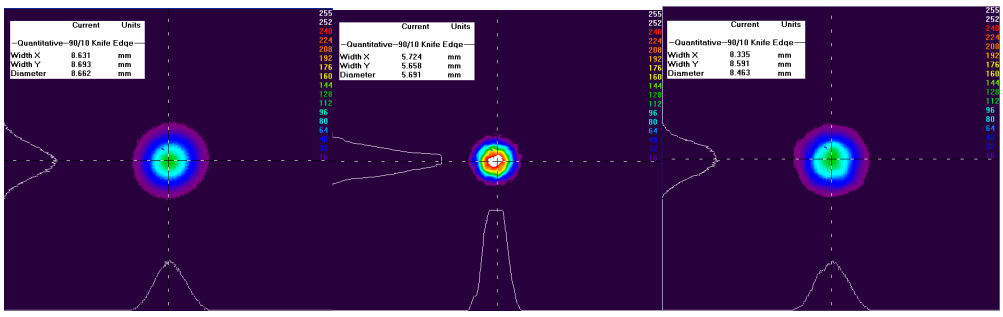



Fig. 1 Experiment setup for thermal lens effect research

Fig. 1 showed our experiment setup to study thermal lens effect. At first, turn off the Xe lamp, and let a He-Ne laser beam with a $TEM_{00}$ mode fill and pass through the Nd:Glass rod after expanded and collimated by a inverted Galileo telescope. If the rod had a diameter $d$, we could see a laser spot with a diameter $d$ on the CCD of a beam profiler with a distance $D$ from the right side of the rod in Fig. 1, where $d \ll D$. Next, turn on the Xe lamp and let Nd:Glass rod pumped. It could be seen that the beam spot on the CCD would become small due to the thermal lens effect. When the thermal lens effect had stabilized, the spot would also have a stable diameter $d_1$. Then, insert an adjustable lens between the inverted Galileo telescope and the rod. After that, adjust refractive index and focal length of this lens and observe variation of the spot on the CCD. When diameter of the spot again became $d$, it could be considered that the inserted lens had compensated the thermal lens effect and the focal length of the inserted lens was the same as that of the thermal lens. Besides, convergence could also be obtained. Supposing $\Delta d = d - d_1$, then convergence $\eta$ would be

$$\eta = \Delta d / D . \tag{1}$$



(a) (b) (c)

Fig. 2 Laser spots recorded by laser beam profiler

(a). Laser spot before pumping; (b). Laser spot after stabilization of thermal lens effect; (c). Laser spot after stabilization of thermal lens effect with an optical compensator inserted.

The corresponding experiment results were shown in Fig. 2. It could be measured that the spot before pumping was 9.662mm in diameter. When the thermal lens effect had stabilized, the spot had a stable diameter of 5.691mm. In our experiment, $D = 3\text{m}$ , then we could obtain $\eta = \Delta d / D = (d - d_1) / D = 1.32\text{mrad}$ according to Eq. (1) the convergence and could also obtain the focal length of the thermal lens

$$f \approx d / \eta = 7.32\text{m} . \tag{2}$$

From this experiment, it could be observed that thermal lens effect had obvious damage to the beam quality. And it could also be observed from the comparison between Fig. 2(a) and Fig. 2(c) that the thermal lens effect could be eliminated to improve the beam quality with a compensating lens.

**Depolarization Effect caused by Thermal Stress Double Refraction**

Influenced by stress double refraction, laser beam would degenerate from ideal linearly polarized light into non ideal linearly polarized light, such as elliptically or circularly polarized light. This degeneration would influence severely the coherence of the laser. For our high power and repetitive Nd:Glass laser, linearly polarized light was essentially necessary for electrooptical Q switch, frequency multiplication and external modulation. If there was no double refraction, there would not be input power loss for the laser. However, marked change of beam shape, as by thermal stress double refraction, would reduce output power of the laser. Configuration of polarizer was designed in our experiment to research the depolarization effect caused by thermal stress double refraction, as shown in Fig. 3. A He-Ne laser beam filled and passed through the Nd:Glass rod which was put between two polarizers after expanded and collimated by a inverted Galileo telescope. Polarization directions of the two polarizers were mutually perpendicular. Thus in the ideal situation, no light could transmit onto the screen. However, the He-Ne laser beam in the rod would be depolarized due to the existence of thermal stress double refraction, and some emergent light would appear on the screen. This emergent light showed particular shape called cone-shaped polarized interferogram.

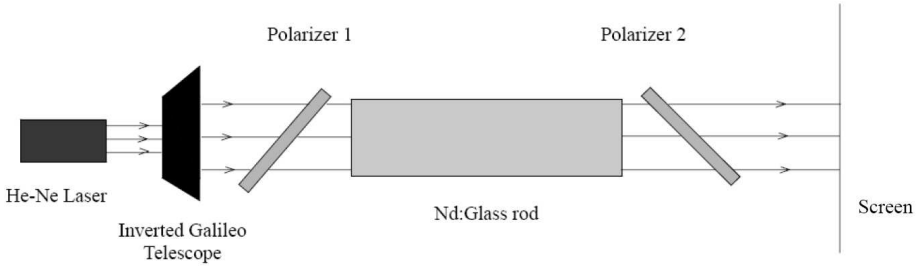



Fig. 3 Configuration of polarizer for research of the depolarization effect caused by thermal stress double refraction

From Fig. 3, the emergent light intensity could be derived from Eq. (3),

$$\frac{I_{out}}{I_{in}} = 1 - \sin^2(2\Phi)\sin^2(\frac{\delta}{2}) \tag{3}$$

where $\Phi$ was angle between direction of polarizer 1 and principal axis of the birefringence, $\delta$ was polarized phase difference of the emergent from the rod.

$$\delta = \frac{2\pi}{\lambda} L(\Delta n_{\Phi} - \Delta n_r) \tag{4}$$

After integral to all cross sections of the rod, we could obtain the total output light intensity and the loss factor as follows[5],

$$I_{out} = \left( \frac{3}{4} + \frac{\sin(C_T P_a)}{4 C_T P_a} \right) I_{in} \tag{5}$$

$$I_{depolarization} = 0.25\left(1+\frac{16}{C_T^2 P_a^2}\right). \quad (6)$$

Fig. 4 showed our obtained cone-shaped polarized interferogram which was accordance with the above equations.

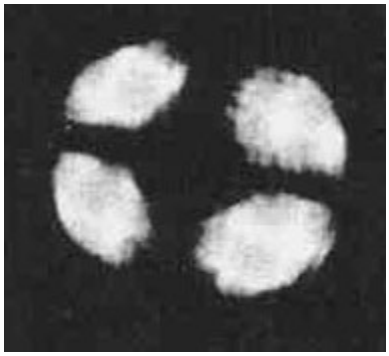


Fig. 4 The recorded cone-shaped polarized interferogram

**Influence of Composition Effects to Laser Quality**

It was obvious from our experiments, that thermal lens effect and depolarization effect caused by thermal stress double refraction would cause varying degrees of damage to the output laser beam quality for high power and repetitive Nd:Glass laser. In practical work, these two effects did exist simultaneously. Table 1 was our recorded output pulse energy from the 1st to the 10th laser pulses. Each test was run three times to take the mean to eradicate any discrepancies. Fig. 5 showed the plot of the mean pulse energy versus the number of pulses. It could be observer that thermal effects began to emerge and the output laser energy apparently decreased as the number of laser pulses increased; when the thermal effects steadied, the output energy would be tending towards stability.

**Summary**

Influence of thermal lens effect and depolarization effect caused by thermal stress double refraction on laser beam were studied in this paper for high power and repetitive laser. Experiment was designed to study thermal lens effect, and the optical compensator was applied to eliminate the thermal lens effect to improve the beam quality. Configuration of polarizer was also designed in our experiment to research the depolarization effect caused by thermal stress double refraction. First, emergent light distribution and loss factor caused by double refraction was calculated according to the theoretical model. Then the exiting cone-shaped polarized light intensity distribution was obtained through the experiment, which was accordance with the theoretical results. The research results showed that thermal lens effect and depolarization effect caused by thermal double refraction would reduce the output laser beam quality to varied extents. As the number of laser pulses increased, thermal effects began to emerge and the output laser energy apparently decreased; when the thermal effects steadied, the output energy would be tending towards stability.

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Table 1 The output pulse energy from the 1st to the 10th laser pulses

| Number of pulses | Output energy（J） | | | Mean energy （J） |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| **1** | 9.56 | 9.75 | 9.75 | 9.69 |
| **2** | 8.97 | 8.78 | 10.73 | 9.49 |
| **3** | 8.00 | 8.39 | 8.39 | 8.26 |
| **4** | 7.61 | 7.61 | 5.66 | 6.96 |
| **5** | 7.80 | 5.85 | 6.63 | 6.76 |
| **6** | 6.83 | 6.63 | 6.44 | 6.63 |
| **7** | 7.02 | 6.83 | 5.27 | 6.37 |
| **8** | 6.24 | 5.27 | 6.44 | 5.98 |
| **9** | 5.46 | 6.20 | 6.32 | 5.99 |
| **10** | 6.13 | 5.78 | 6.27 | 6.06 |

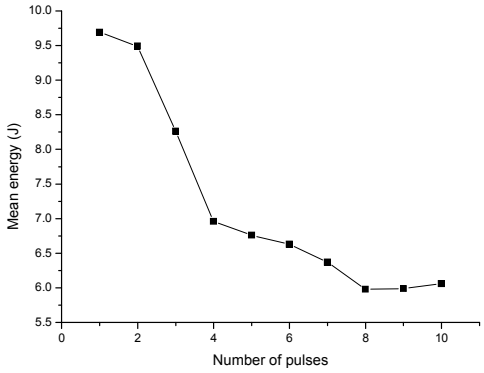


Fig. 5 Plot of the mean pulse energy versus the number of pulses

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