Thermal lens compensation of Nd:YAG rod laser using a solid element of negative temperature coefficient of refractive index

Norihiro Takeuchi, Hidetsugu Yoshida, Hajime Okada, Hisanori Fujita, and Masahiro Nakatsuka

INTRODUCTION

In high power solid-state-laser systems, one of the major problems is the thermal effect, which occurs in optically pumped laser materials. Heating of the laser medium causes thermal distortions, leading to degradation of beam quality. The main thermal effects in laser rods are thermally induced birefringence and thermal lensing effects. High efficiency, high power and good output beam quality can be achieved by proper compensation of thermal lens effect.

In this report, the experimental results of study on the compensating of thermal lens are presented.

EXPERIMENTS

The thermal lens effect occurs owing to the refractive-index and stress-dependent variations by temperature distribution, and end-surface expansion. In the case of the uniformly pumped laser rod, the focal length $f$ of the thermal lens is given by

$$ f = \frac{K}{P_a} \left( \frac{1}{2} \frac{dn}{dT} + \alpha C_{1.70} \frac{n_0}{L} + \frac{\alpha r_0 \left( n_0 - 1 \right)}{L} \right)^{-1}, $$

where $K$ is the thermal conductivity, $A$ the rod cross-section, $P_a$ the absorbed power in the rod, $dn/dT$ the thermal coefficient of the refractive index, $\alpha$ the thermal expansion coefficient, $C_{1.70}$ the photoelastic coefficient, $n_0$ the refractive index of rod, $r_0$ the rod radius, and $L$ the rod length. [1]

The first term, $dn/dT$ factor constitutes the major contribution with about 75%, the stress dependent variation with about 20%, and the effect of the end surface expansion with about 5%. The conventional compensation techniques of thermal lens effects are,

1. Polishing one or both rod surfaces concavely.
2. Inserting a concave lens in the resonator.
3. Proper designing of a resonator adequately.
4. Keeping operational temperature very low.

Method 1-3 are static compensation techniques and limit the beam quality because the beam divergence and quality change with pumping power. Method 4, the active material must be kept in vacuum to prevent the dew condensation.

We have demonstrated that the dynamic compensation of thermal lens is independent of the pumping conditions. Our main attention was on $dn/dT$ term, which was main factor to cause the thermal lensing. This method is inserting solid compensating elements (CE) which has negative $dn/dT$ between the two Nd:YAG rods. The temperature profile generated by the radial cooling of the rod induces the desired thermal lens in the compensating elements (CE) between the two rods.

No heat is generated in the CE. The temperature gradient in the rod transferred to the CE by thermal contact, induces concave thermal lens, which can cancel convex thermal lens in the laser rod. A collimated He-Ne laser beam passes through the laser rod. The beam diameter, which determines the focal length of rod, was measured with a CCD camera. Figure 1 shows the experimental layout of thermal lens compensation. Total pumping length of two Nd:YAG rods is 90mm. The CE is transparent organic resin such as polymethyl methacrylate (PMMA), polycarbonate (PC), and cyrclo olefin polymer (COP) having large negative $dn/dT$ to generate the thermally induced concave lens effect. Table 1 shows the physical and thermal properties of a Nd: YAG and three CE’s. The thermal conductivity of organic resin is about 60 times less than that of the Nd:YAG crystal. For PMMA, the negative $dn/dT$ ($1\times10^{-4}/K$) value is about 16 times higher than that of the Nd:YAG crystal. [2] Transmittance includes Fresnel

<table>
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<th>Refractive index</th>
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<td>89</td>
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<td>Density[g/cm³]</td>
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<td>Specific heat[J/gK]</td>
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<tr>
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<td>0.0021</td>
<td>0.0023</td>
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<td>Softening temperature [°C] (1.80MPa)</td>
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<tr>
<td>$dn/dT [K^{−1}/K]$</td>
<td>0.73</td>
<td>-12</td>
<td>(-12)</td>
<td>(-21)</td>
</tr>
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</table>

Fig. 1 Experimental layout of thermal lensing

Table 1 Physical and thermal properties of Nd:YAG and CE
loss on its surface that can be reduced with an index matching liquid.

Figure 2 shows the beam profile of thermal lens compensated Nd:YAG rods with and without 5-mm thick PMMA at 5 to 40 Hz of repetition rate.

The focal beam size of the conventional rod without a CE changed from 4.5 to 1.75 mm in 1/e² at 40 Hz. On the other hand, the compensated Nd:YAG rod, the focal spot-size was improved and focal beam size with 5-mm thick PMMA was slightly enlarged at 40 Hz. Figure 3 shows the dioptr power as a function of pumping input power for the thickness of CE’s (a) the PC, (b) the PMMA and (c) the COP, respectively. In Fig. 3, the solid line is experimental results without CE. The thermal lens was almost compensated with 4 to 5 mm thick CE plate sandwiched between the two rods. The observed optimum thickness of CEs, PMMA, PC, and COP, for a 90-mm long Nd:YAG rod are 4.7, 4.7 and 2.7 mm, respectively. The values of dth/dT for PC and COP which shown in Table 1 were derived from this experimental results.

A radial temperature distribution of the laser rods is transferred to the PMMA through heat contact. It is important to keep the temperature of cylindrical surface of the CE at low level. Index matching liquid was immersed in a gap between rod and CE, in several microns, for avoiding Fresnel losses at surfaces of CE and also the lens effect of an expanded end surface of CE. Technical problem will be how to seal off stably the thin liquid layers between rod and CE.

CONCLUSION

We demonstrated the compensation of thermal lens effect regardless of pumping conditions by inserting a solid CE having negative dth/dT property between two rods. This scheme of thermal compensation of rod systems is an ultimate method because of its dynamic compensation feature independent of the pumping power level. In the future, more compatible materials are expected with a high thermal resistance working at a high temperature.

REFERENCES