§23. Conceptual Design and Thermal Analyses of High Energy and High Repetition Rate YAG Laser for High Accuracy Thomson Scattering Diagnosticss

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For promotion of the deuterium experiments and the Large Helical Device (LHD) project for fusion research, higher performance plasma diagnosis and heating systems are important. Especially a high average power laser system with high pulse energy and high repetition rate is desired in laser Thomson scattering diagnostics. To develop an ideal laser source with good beam quality and high average power, thermal problems such as thermal lensing, thermally induced birefringence and thermal stress fracture in optics should be resolved.

Ytterbium (Yb) doped $Y_3Al_5O_{12}$ (YAG) ceramics is one of the most promising laser materials for the high power laser systems due to its high stokes efficiency over 90%. To design and develop high performance laser systems with Yb^{3+}:YAG ceramics, thermal properties of the sample are necessary. Thermal conductivity, thermal expansion and thermo-optic effects of ceramic YAG were measured as a function of temperature below and over room temperature [1),2)]. However, doping dependence of Yb-ion has not been studied well in spite of the fact that the thermal conductivity becomes lower with increasing doping concentration due to the size difference between Yb^{3+}- and Y^{3+}-ions.

In this work, we measure the temperature dependence of thermo-optic effects γ which includes both thermal expansion α and dn/dT of Yb:YAG ceramics for various doping concentrations. Thermo-optic effect γ can be expressed as follows:

$$\begin{aligned}\gamma &= 1 / nL \cdot d(nL) / dT \\ &= \alpha + 1 / n \cdot dn / dT \qquad (1)\end{aligned}$$

where L is length of the sample, and n is the refractive index of ceramic Yb:YAG. We prepared the undoped YAG and Yb:YAG ceramics with doping concentrations of 9.8 at.%, and 20 at.%, respectively.

Figure 1 shows the experimental setup of γ measurement. Each faces are polished with the surface accuracy of $\lambda/10$, and we formed a Fizeau interferometer with the reflected He-Ne laser light of the sample. The shift in the fringe due to temperature variation were recorded using a photodetector. This measurement was repeated 5 times for each sample.

Figure 2 shows the experimental results for each samples. As seen in Fig. 2, we find the thermo-optic effects increased with temperature for all the samples. For this measurements, the maximum measurement error was 0.45 ppm/K. From this study, a clear difference among the samples and doping dependence could not be observed.

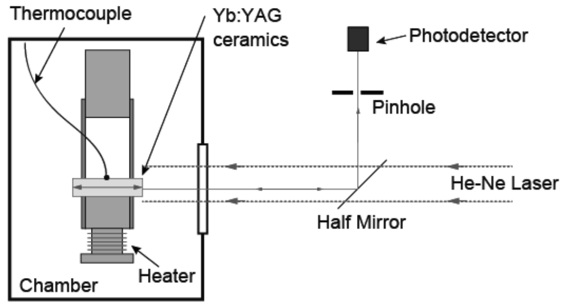

Fig. 1. Experimental setup of thermo-optic effect of Yb:YAG ceramics.

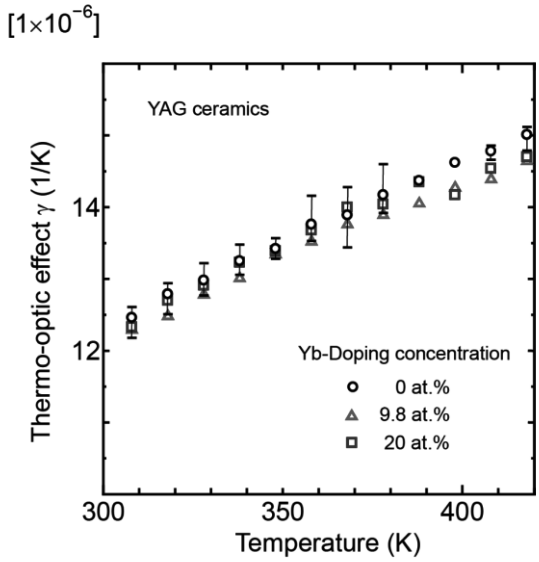

Fig. 2. Experimental results of thermo-optic effect γ for Yb:YAG ceramics.

In our future works, we will try to measure thermal expansion coefficients for each rod sample using wedge windows. In addition, we will measure the temperature dependence of dn/dT values for ceramics YAG using 1 μm probe laser which is the typical wavelength of high-average power laser systems. We believe that these thermal properties can be applied to analyze thermal effects in YAG ceramics and will be useful for designing high average power lasers.

1) Yasuhara, R. et al.: Opt. Express **20** (2012) 29531.
2) Furuse, H. et al.: Opt. Mat. Express **4** (2014) 1794.