§27. Measurement of Temperature Dependence of the Thermo-optic Effect in Cryogenically Cooled Yb:YAG Ceramics

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A high-energy pulsed laser with high repetition rate is strongly desired for a laser Thomson scattering diagnostics in the plasma fusion experiment. One of the solutions for realizing a high-energy and high-average-power laser operation is a diode-pumped solid-state laser (DPSSL) with a large laser gain medium. In such laser system, the thermo-optic effect is one of the limiting factors for increasing the repetition rate and output beam quality. This effect strongly depends on the thermal properties of the laser gain medium.

Cryogenically cooled Yb:YAG ceramics are the most promising material for high-average-power and high-energy laser systems[1)]. They have good thermal properties at low temperatures, preferable spectroscopic properties, and can be manufactured in large sizes. Recently, high-average-power operation attained by using cryogenically cooled Yb:YAG materials.

We evaluate the improvement of the thermo-optic effects in cryogenically cooled Yb:YAG ceramics by simultaneously measuring the temperature dependences of thermo optic coefficient and thermal expansion in YAG ceramics from 73 K to 296 K[2)].

Figure 1 shows the undoped YAG ceramics (Konoshima Chemical Co., Ltd.,) used for measurement. Undoped YAG ceramic flats were diffusion-bonded to the ends of a 15.7-mm-long piece of undoped YAG ceramic to form a Fizeau interferometer. A part of the outer surface of each of the flats is antireflection- (AR-) coated at the laser wavelength for the vacuum path of the interferometer. The sample was placed in a vacuum chamber and attached to the cold finger of the temperature-controllable cryostat (Iwatani HE05) with thermal conductive paste (Dotite, Fujikura Kasei Co., Ltd.,) to improve the thermal contact. Two Fizeau interferometers, one with a vacuum path and the other with a YAG ceramic path, were illuminated through the half mirror by a He–Ne laser operating at 633 nm. The reflection that formed the Fizeau fringe was observed after the half mirror. After the beam passed through a pin-hole, the intensities of the reflected fringes were recorded by photo-detectors 1 and 2 as the temperature was varied while the cold finger was heated. The temperature was measured by a calibrated Kp-Au thermocouple on the material surface with a nano-voltmeter (34420A, Agilent).

Figure 2 shows the results for the temperature dependence of the thermal expansion coefficient α and the thermo-optic coefficient dn/dT that we obtained for the undoped YAG ceramics. α and dn/dT decreased when the temperature of the YAG ceramics was decreased. α decreases to $4 \times 10^{-7}\,K^{-1}$ at 73 K, which is 1/15 times lower than the value of α at 296 K. The dn/dT value of YAG ceramics also decreased to $8 \times 10^{-7}\,K^{-1}$ at 73 K, which is 1/10 times lower than that at 296 K. The α and dn/dT values measured in this work are in reasonable agreement with the previous work on the YAG crystal and YAG ceramics.

In this work, we have quantitatively substantiated the improvement of thermo-optic characteristics in Yb:YAG ceramics at cryogenic temperature by the measurement of their thermal properties. Our measurements will contribute to the development of a high-energy and high-power laser system based on cryogenically cooled Yb:YAG ceramics.

Fig.1 A photograph of the diffusion-bonded YAG ceramic sample for the measurement of dn/dT and the temperature dependence of the thermal expansion coefficient[2)].

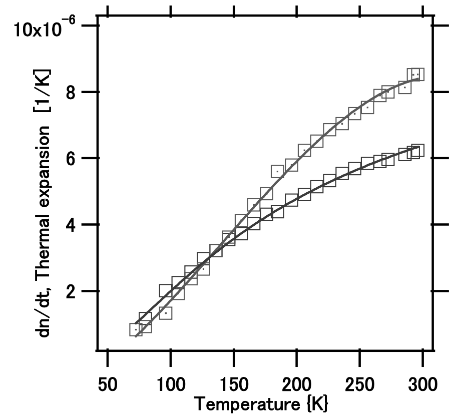

Fig.2 The temperature dependence of the thermal expansion coefficient and the thermo-optic coefficient dn/dT[2)].

1) Kawanaka, J., et al. :Laser Phys. 20(5), 1079–1084 (2010).
2) Yasuhara, R, et al. : Optics Express, Vol. 20, Issue 28, pp. 29531-29539 (2012).