§19. Fundamental Study of High Energy Laser System for Plasma Diagnosis and Heating

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A high average power laser system which has both high pulse energy and high repetition rate is strongly desired for many applications such as laser Thomson scattering diagnostics. Higher performance plasma diagnosis and heating systems are required to prompt the deuterium experiments and the Large Helical Device (LHD) project for fusion research. Thus, the advanced high energy laser systems are one of the key technologies to achieve this.

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%. Additionally, cryogenically cooled (under 100 K) Yb^{3+}:YAG becomes a true four level laser material. Thermal conductivity, thermal expansion and thermo-optic effects of single crystal Yb^{3+}:YAG were widely measured as a function of temperature, and they have superior improvements [1]. However, experimental results of these thermal properties for Yb^{3+}:YAG ceramics sample are not enough. The thermal conductivity of YAG ceramics is lower than that of the single crystal at low temperature because of scattering at grain boundaries [2]. Also, it is well known that the thermal conductivity becomes lower with increasing doping concentration due to the size difference between Yb^{3+}- and Y_3-ions. These characteristics are very important to design and develop high performance laser systems with cryogenic Yb^{3+}:YAG ceramics.

In this work, we are trying to measure the temperature dependence of thermal properties of Yb^{3+}:YAG ceramics for various doping concentrations. For the measurements of thermal conductivity, we prepared undoped YAG and Yb^{3+}:YAG ceramics whose doping concentrations of 2%, 7%, 9.8%, and 20%, respectively. Thermal conductivity was measured using a steady state heat flow method [3]. The temperature of the ceramics was adjusted using a temperature controlled cryostat in NIFS laboratory. The stycast 2850FT which is thermally conductive epoxy glue, was used to attach the ceramic to an oxygen free copper. The cross section of the sample was 5 x 5 mm^2, and the thickness d were 15 mm, or 20 mm.

Figure 1 shows the experimental results for 0, 5, 9.8, and 20% Yb^{3+}:YAG ceramics. As mentioned above, the thermal conductivity increased with decreasing temperature for all doping concentrations. We also found that the thermal conductivity becomes lower with increasing doping concentration.

Figure 2 shows the microstructure image of Yb^{3+}:YAG ceramics by using a laser microscope. The average grain size was estimated by linear intercept method [4] as

$$\bar{D} = 1.56\frac{C}{MN},$$

where C is the length of the measured line, M is the optical magnification, and N is the number of grains on the line. The grain size was estimated about 2.0 μm for all the doping concentration samples.

We have also measured the thermal expansion coefficient (α) and thermo-optic coefficient (dn/dT) of YAG ceramics [5]. From these results, we have evaluated the thermo-optic characteristics in cryogenically cooled Yb^{3+}:YAG ceramics, and this will be used for designing high performance laser systems.

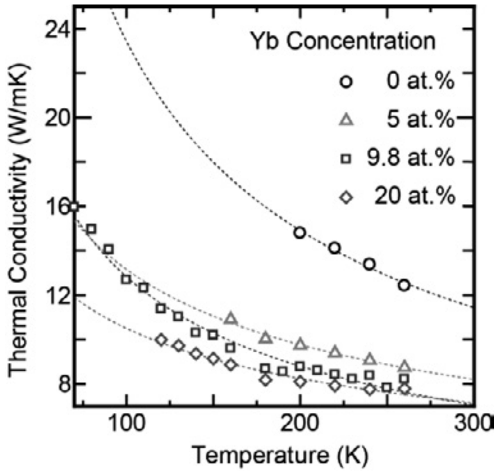

Fig. 1.Temperature dependence of Yb^{3+}:YAG ceramics.

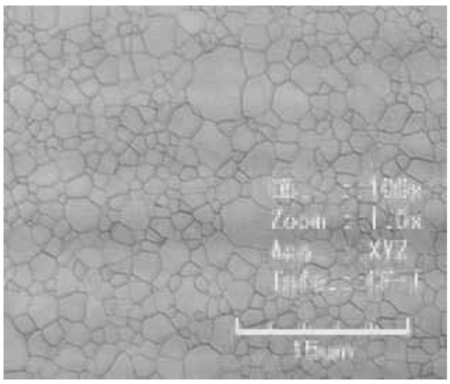

Fig. 2. Microstructure image of the Yb^{3+}:YAG ceramics.

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2) Yagi, H. et al.: Ceramics International **33** (2007) 711.
3) Iwamoto, A. et al.: Adv. Cryo. Eng. **49** (2004) 643.
4) J.C. Wurst, et al.: J. Am. Ceram. Soc. 55 (1972) 109.
5) Yasuhara, R. et al.: Opt. Exp. **20** (2012) 29531.