§5. Development of a Coaxial Laser Beam Combing Device based on Terbium Scandium Aluminum Garnet (TSAG) Crystals

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A laser Thomson scattering system is one of the reliable methods for measuring the electron temperature and electron density in fusion plasma. One of the method to increase the repetition rate of the Thomson scattering measurement is the multi-laser system. Laser pulses emitted from several number of laser amplifiers are combined by beam combiner in multi-laser system. In this case, we can increase the repetition rate of Thomson scattering system as the number of the laser system. The problem of this system is thermo-optic effects in the beam combiner. Electro-optic and Magneto-optic effects based on polarization switching co-axial beam combiners are proposed in previous studies (1-3). Those beam combiner show the large thermo-optic effects at the high repetition rate operation due to the heat generation in the optical medium.

In this study, we investigated the terbium scandium aluminum garnet (TSAG) crystals based Faraday rotator for the beam combiner of the Thomson scattering system. TSAG crystal material is the recently developed transparent crystals which have large magneto-optic coefficient. Also this material has the good thermal properties supporting the high average power laser operation. Thirdly, large size TSAG crystals can be fabricated by recent crystals technology. Those three factors are suitable for the high average power beam combiner. we show the characteristics of the thermally induced depolarization (a kind of the magneto-optic effect) in TSAG crystals based Faraday rotator. Suppression of the thermally induced depolarization is the most important issue for this type of beam combiner.

Figure 1 shows the experimental set up for the measurement of the thermally induced depolarization in TSAG crystals based Faraday rotator. We used the cw fiber laser with a linearly polarized power of up to 1500 W as a radiation source. The beam diameter at the TSAG crystal rod and the wavelength of the laser are 2.4 mm and 1076 nm, respectively. A calcite wedge and Glan prism were set in the crossed-Nicols arrangement. Fused silica wedges were used to attenuate the laser radiation into the Glan prism polarizer. The intensity distribution of depolarized and polarized radiation transmitted through the second polarizer was measured by the CCD camera.

The laser power dependence of the depolarization ratio in the TSAG-crystal-based FARADAY DEVICE is shown in Fig. 2. In this experiment, a depolarization ratio γ of 2.9×10^{-4} was observed at a laser power of 1470 W using TSAG with its crystal axis in the <001> direction. From these results, the isolation ratio was calculated to be 35.4 dB. For the case of TSAG with its crystal axis in the <111> direction with a magnetic field, a γ value of 3.2×10^{-4} was observed for a laser power of 196 W. This isolation ratio was calculated to be 34.8 dB. TSAG with <001> orientation can be used for laser powers that are 7.5 times higher than those associated with the <111> crystal..

In LHD, we use the 1.6 J x 30 Hz laser. The average power is 48 W. By using TSAG crystals based beam combiner, we can combine five 1.6 J x 30 Hz lasers coaxially.

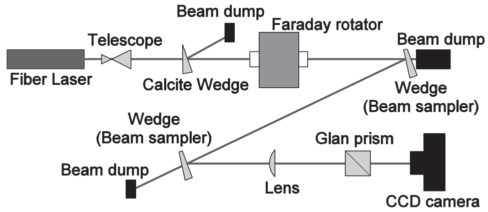

Fig. 1. A schematic diagram of the experimental set-up for the thermal birefringence measurement in TSAG crystal based Faraday rotator.

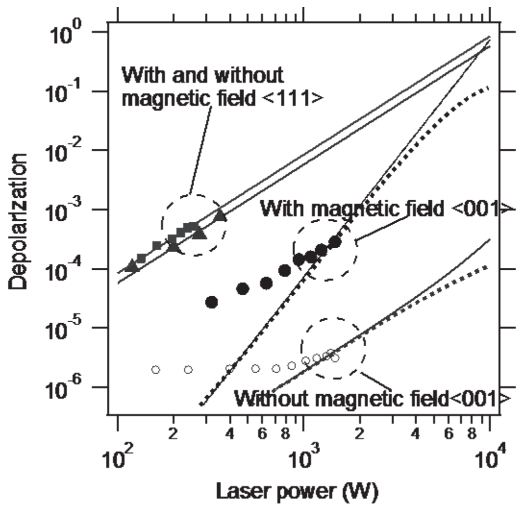

Fig. 2. Experimental results of depolarization as a function of laser power. Open circles show the results for terbium scandium aluminum garnet (TSAG) with <001> crystal orientation in the absence of a magnetic field. Closed circles show the results for TSAG with <001> crystal orientation in the presence of a magnetic field. Triangles show the result for TSAG with <111> crystal orientation in the absence of a magnetic field. Squares show the results for TSAG with <111> crystal orientation in the presence of a magnetic field. Solid lines show the theoretical curves. Dashed lines show the numerical calculations.

1) Yoshida H., et al., Rev. Sci. Instrum. 66 143 (1995).
2) Walsh M. J. et al., Rev. Sci. Instrum. 75 3909 (2004).
3) Yasuhara R., et al., Plasma and Fusion Research, 7, 2402030 (2012).