Single Crystals for Optical Isolator

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Currently, $Tb_3Ga_5O_{12}$(TGG)single crystal is used as Faraday rotator in the laser machinery the wavelength of which is <1100 nm. However, TGG has problems of not enough Faraday rotation angle, difficult crystal growth, very high price, and so on. In order to overcome these problems, we focused on $Tb_3(Sc,Lu)_2Al_3O_{12}$(TSLAG) single crystal and grew and characterized TSLAG crystals. In this paper, we report that TSLAG can be grown easily and has higher transparency, larger Faraday rotation angle, and extinction ratio, which are very important properties for Faraday rotator.

1. Introduction

In recent years, optical communication and laser machinery are widely used and use higher-power sources. This requires that power source be highly stabilized and prevented from destruction. The optical isolator is an important device that prevents optical feedback and keeps power source stabilized. In the IR region, $Y_3Fe_5O_{12}$(YIG) thin film is used as Faraday rotator of optical isolator. However, it cannot be used at shorter wavelengths (<1100 nm) due to its poor transparency. Because of this reason, $Tb_5Ga_3O_{12}$(TGG), which has high transparency and moderate Faraday rotation angle in the UV-visible-near IR region, is used as Faraday rotator in the range of <1100 nm[1)2)]. Nevertheless, TGG still has problems of not enough Faraday rotation angle, difficult crystal growth, very high price, and so on[3)]. In order to overcome these problems, we focused on $Tb_5Al_3O_{12}$(TAG), which melts incongruently[4)] and has high transparency and large Faraday rotation angle in the UV-visible-near IR region[5)].

In this investigation, we improve TAG and make it easy to grow by substituting Sc and Lu for Al in terms of ionic radii.

2. Ionic radii of cations in the garnet structure

In general, garnet structure is described as $\{C_3\}[A_2](D_3)O_{12}$. {C} means dodecahedral site, [A] means octahedral site, and (D) means tetrahedral site, respectively. Figure. 1 shows schematic of garnet structure.

The ionic radii of each cation of TAG are shown in Table 1. In this paper, ionic radius means Shannon's ionic radius[6)]. Table 1 shows that the ionic radius of Tb in the {C} site is 1.04 Å while that of Al in the [A] site is 0.535 Å, and this is very imbalanced. We considered this is the reason why TAG cannot keep garnet structure.

In this research, we created $Tb_3Sc_{2-x}Lu_xAl_3O_{12}$ (TSLAG)by substituting Sc and Lu for Al in the [A] site of TAG. Table 2 shows the ionic radii of each cation of TSLAG and the balance between them is improved compared with TAG.

3. Experimental

As starting materials, Tb_4O_7, Sc_2O_3, Al_2O_3, and Lu_2O_3 of 4N purity powder were used. They were weighted and mixed corresponding to the chemical formula of $Tb_3Sc_{2-x}Lu_xAl_3O_{12}$($0.05 \leqq x \leqq 0.2$), and charged in an Ir

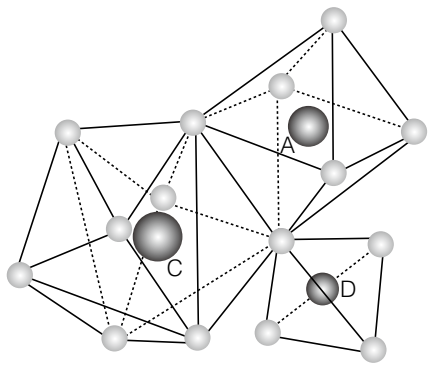

Fig. 1. Schematic of garnet structure.

Table 1. Each cations' ionic radii of TAG.

$\{Tb_3\}[Al_2]\ (Al_3)O_{12}$(TAG)	Element	Ionic radius(Å)
(D) site(tetrahedral)	Al	0.39
[A] site(octahedral)	Al	0.535
{C} site(dodecahedral)	Tb	1.04

Table 2. Each cations' ionic radii of TSLAG.

$\{Tb_3\}[Sc_{2-x}Lu_x]\ (Al_3)O_{12}$(TSLAG)	Element	Ionic radius(Å)
(D) site(tetrahedral)	Al	0.39
[A] site(octahedral)	Sc	0.745
[A] site(octahedral)	Lu	0.861
{C} site(dodecahedral)	Tb	1.04

1 : National Institute for Materials Science
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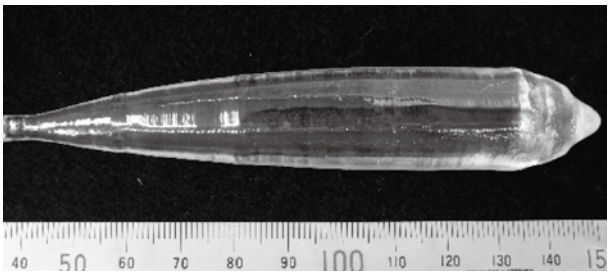

Fig. 2. TSLAG single crystal (x=0.05).

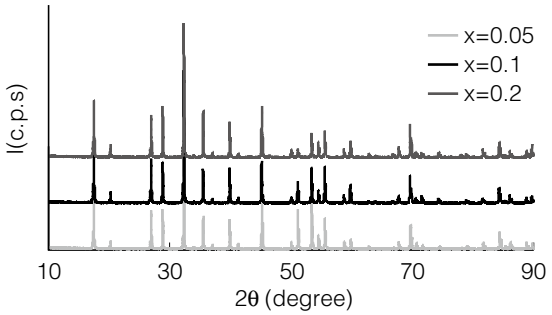

Fig. 3. Powder X-ray diffraction pattern of TSLAG.

crucible. TSLAG single crystals were grown by Czochralski method in the N_2 atmosphere. <111> oriented $Y_3Al_5O_{12}$(YAG) single crystal was used as a seed, and the pulling rate and rotation rate were fixed to 1 mm/h and 10 rpm, respectively.

The transmittance and Faraday rotation angle of grown crystals were measured through the cooperation of Kogakugiken Corporation. The phase identification of grown crystals was done by powder X-ray diffraction.

4. Results

The grown TSLAG(x=0.05) crystal is shown in Fig. 2. We succeeded to grow crack-free single crystal whose diameter is almost 1 inch.

Figure 3 shows the diffraction patterns of TSLAG (x=0.05, 0.1, 0.2) measured by powder X-ray diffraction. It shows that each crystal has only garnet phase.

Figure 4 shows the measured transmittance of TSLAG and TGG. The measurement was done under non-coating conditions. TSLAG has higher transmittance than TGG at all measured wavelengths, especially in the whole visible range (400 − 700 nm). This means that it is possible to provide high-performance optical isolator by using TSLAG at shorter wavelengths in which TGG has poor transmittance.

The measured Faraday rotation angles of TSLAG (x=0.05, 0.1, 0.2) are shown in Fig. 5. Measured plane was (111), and sample length was 20 mm. We found that TSLAG has up to 1.3 times larger Faraday rotation angle than TGG. Because of this, TSLAG needs smaller magnetic field to get same Faraday rotation angle as TGG. This means that magnet, as well as optical isolator, can be smaller. Especially, in-line type optical isolators used in laser machinery are required to be

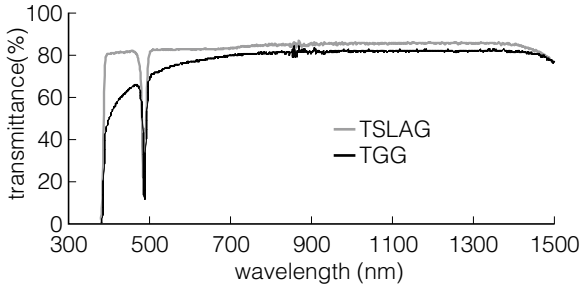

Fig. 4. Transmittance spectrum of TSLAG and TGG.

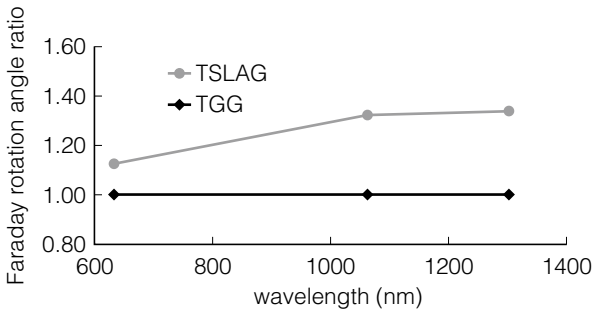

Fig. 5. Faraday rotation angle ratio of TSLAG and TGG (TGG value is 1).

smaller because the size of optical isolator influences size and layout of the other parts. For this reason, TSLAG whose Faraday rotation angle is larger than that of TGG is a very useful material.

5. Conclusion

We succeeded to grow TSLAG crack-free single crystal whose diameter is almost 1 inch. This is because of substituting Sc and Lu for Al of TAG. TSLAG has higher transmittance than TGG at all measured wavelengths, especially in the whole visible range (400 − 700 nm). We found that TSLAG has up to 1.3 times larger Faraday rotation angle than TGG.

In the future, we aim to grow larger single crystals and improve crystal quality.

References

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