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Influence of Surface Smoothing on Spin Seebeck Effect of $Ce_1Y_2Fe_5O_{12}$ Deposited by Metal Organic Decomposition

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Abstract

The spin Seebeck device have been fabricated using $Ce_1Y_2Fe_5O_{12}$ (Ce:YIG) film deposited by metal organic decomposition (MOD) method and annealed at various temperatures. The electromotive force was initially not observed, however after smoothing the surface of Ce:YIG film by mechanical polishing (MP), it appeared.

1. Introduction

Recently, studies of thermoelectric conversion technique are actively carried out. In Conventional thermoelectric conversion devices (Seebeck devices), it is a problem that the relation between thermal conductivity and electron concentration is a trade-off. On the contrary, high power conversion efficiency is expected in spin Seebeck devices because thermal conductivity and electron concentration can be designed independently [1,2,3]. Currently, $Bi_1Y_2Fe_5O_{12}$ (Bi:YIG) is mainly used as a magnetic insulating film by the metal organic decomposition (MOD) method. In order to increase the power conversion efficiency, it is necessary to search new materials. Most of materials used as a magnetic insulating film are magneto-optical materials. Accordingly, we focused on $Ce_1Y_2Fe_5O_{12}$ (Ce:YIG) which has approximately twice larger Faraday rotation than Bi:YIG [4]. There are a patent application of spin Seebeck devices using Ce:YIG by MOD method [5]. And in a doctoral thesis [6] spin Seebeck effect for Ce:YIG film formed by pulsed laser deposition was reported but no journal paper has been published so far. We deposited Ce:YIG by MOD method, and evaluated the relation between surface roughness and its spin Seebeck effect.

The structure of spin Seebeck devices is shown in Fig. 1. When magnetic insulating film/ metal junction is applied to temperature gradient, spin current is induced by spin Seebeck effect. Then, spin current which injected in metal layer converts into an electric field $\boldsymbol{E}_{\mathrm{ISHE}}$ by inverse spin-Hall effect. The electric field $\boldsymbol{E}_{\mathrm{ISHE}}$ is expressed as following equation.

$$\boldsymbol{E}_{\mathrm{ISHE}} \propto \boldsymbol{J}_S \times \boldsymbol{\sigma} \qquad (1)$$

where $\boldsymbol{J}_s$ and $\boldsymbol{\sigma}$, respectively, represent spin current direction and spin polarized direction [2].

2. Formation and Evaluation of Ce:YIG films by MOD

We used MgO (100), $SrTiO_3$ (STO) (100), and $Gd_3Ga_5O_{12}$ (GGG) (111) as substrate. The recipe of fabricating Ce:YIG film is shown in Table. 1. Ce:YIG was spin-coated on these substrates, following by decomposition and crystallization. The MOD process of Ce:YIG film was repeated 7 times to produce 200 nm thick film and finally annealed at 600˚C, 720˚C, 800˚C, 950˚C, and 1050˚C for 3h in pseudo air ambient (N_2:O_2=4:1). X-ray diffraction (XRD) spectra of Ce:YIG film on GGG (111) substrate is shown in Fig. 2. Anneal temperature dependence of XRD peak intensity of Ce:YIG (400) is shown in Fig. 3. Ce:YIG film is crystallized when anneal temperature is over 800˚C. The crystallinity of Ce:YIG on GGG (111) substrate is the best because the lattice constant of GGG (111), 12.375 Å, is closest to lattice constant of Ce:YIG (420) which is 12.52 Å[7] among of the used substrates. The spin Seebeck devices were completed after deposition of Pt film of 10 nm thick.

The electromotive force was measured using the systems shown in Fig. 4. Pictures of sample holder is shown in Fig. 5. Permanent magnet was used to prevent noise. DC voltage generated by spin Seebeck effect was converted to AC voltage by chopper circuit and function generator. The synchronized signal to the chopper was measured by Lock-in amplifier and recorded. However, we could not observe any electromotive force for all samples. We have evaluated surface roughness of Ce:YIG films on GGG (111) substance which were annealed 800˚C, 950˚C, and 1050˚C by atomic force microscope (AFM). The 3D mapping images of the Ce:YIG film by AFM is shown in Fig. 6 (a)~(c). The surface of Ce:YIG film were very rough. As anneal temperature is higher the surface roughness is increased.

3. Effect of surface roughness to spin Seebeck effect

We thought that the rough surface of Ce:YIG film suppress the inverse spin-Hall effect. Accordingly the Ce:YIG film surface was mechanically polished (MP) using diamond slurry with a diameter of 0.25 μm for 5 min. The 3D mapping images of Ce:YIG film after MP process is shown in Fig. 6 (d)~(f). Variation of Ra value after MP process is shown in Fig. 7. The Ra value of all samples decreased. After cleaning the polished surface in acetone and pure water the 10 nm thick Pt was deposited. The result of electromotive force by spin Seebeck effect is shown in Fig. 8. Here temperature gradient between substrate and platinum is 50˚C. The electromotive force of 5.5 μV, 3.2 μV , and 11.3 μV on anneal temperature 800˚C, 950˚C, were, respectively, observed. Ce:YIG annealed 1050˚C has the highest performance because it is best crystallized and most flat in all the samples. This is the first report concerning the spin Seebeck effect of Ce:YIG deposited by MOD method.

4. Conclusions

We have fabricated spin Seebeck devices using Ce:YIG by MOD method. Appropriate anneal temperature of Ce:YIG film by MOD method is over 800℃. The surface of as deposited Ce:YIG film is rough and no spin Seebeck effect was observed. However, after smoothing the surface by mechanical polish we have, for the first time, succeeded in observing the spin Seebeck effect for Ce:YIG film deposited by MOD method.

References

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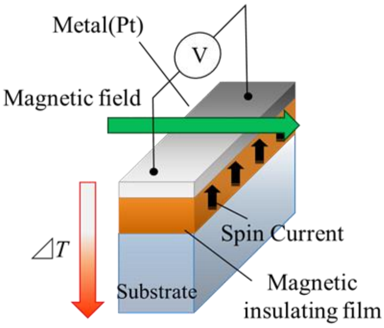

Fig. 1 Structure of spin Seebeck devices.

Table. 1 Recipe of fabricating Ce:YIG films by MOD method.

Process	Condition
1. Spin-Coating	500 rpm 5 s 3000 rpm 30 s
2. Drying	150˚C 3 min
3. Temperature rising	10 min
4. Pre-baking	500˚C 5 min
5. Annealing (N2:O2=4:1)	600~1050˚C 3 h

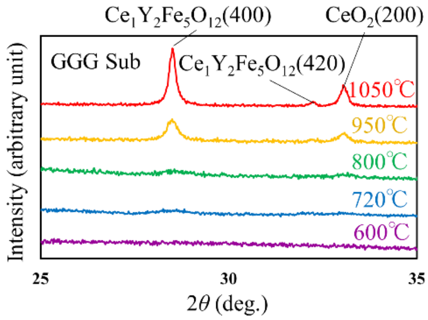

Fig. 2 XRD spectra of Ce:YIG films on GGG (111) annealed at various temperatures..

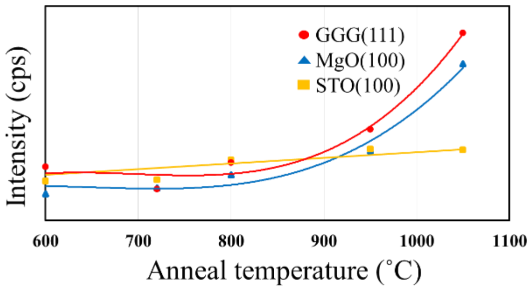

Fig. 3 Anneal temperature dependence of XRD peak intensity of Ce:YIG (400).

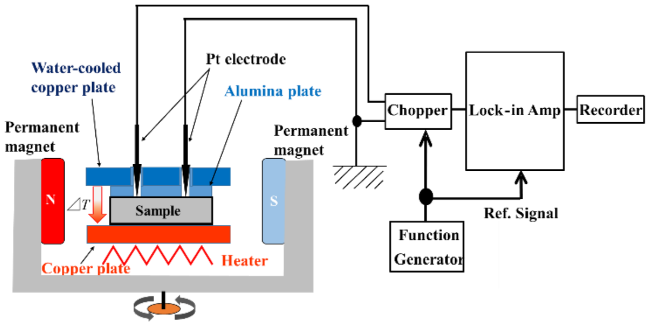

Fig. 4 Measurement system for electromotive force of spin Seebeck devices.

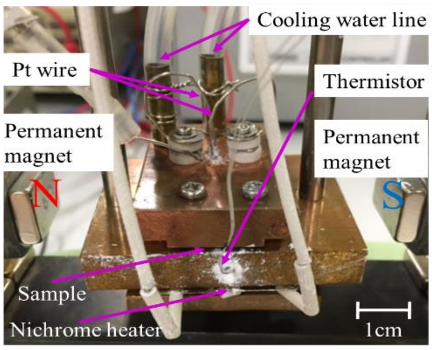

Fig. 5 Pictures of sample holder. Intensity of magnetic field is 700 G in middle of sample holder.

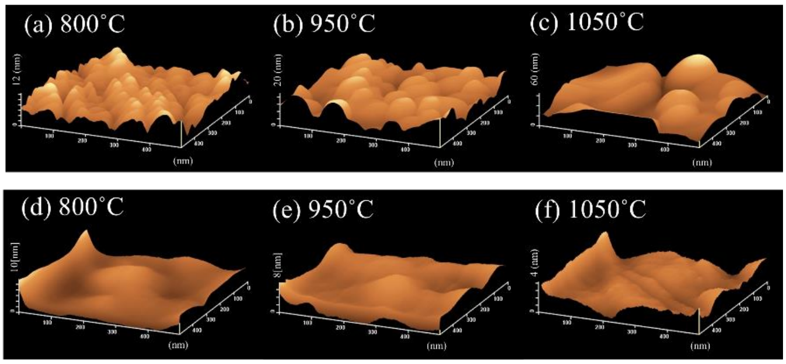

Fig. 6 3D mapping images of Ce:YIG films annealed 800˚C, 950˚C, and 1050˚C by AFM. (a)~(c) are before MP, (d)~(f) are after MP.

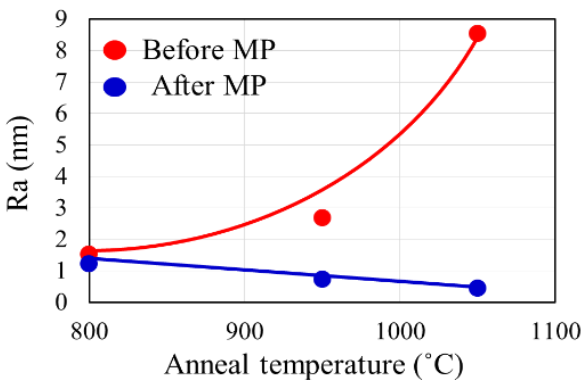

Fig. 7 Variation of Ra value after MP process.

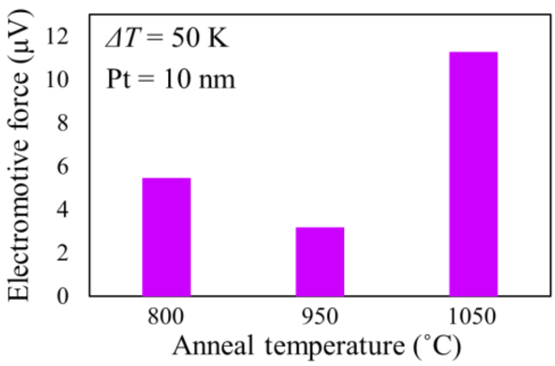

Fig. 8 Electromotive force of spin Seebeck devices using Ce:YIG.