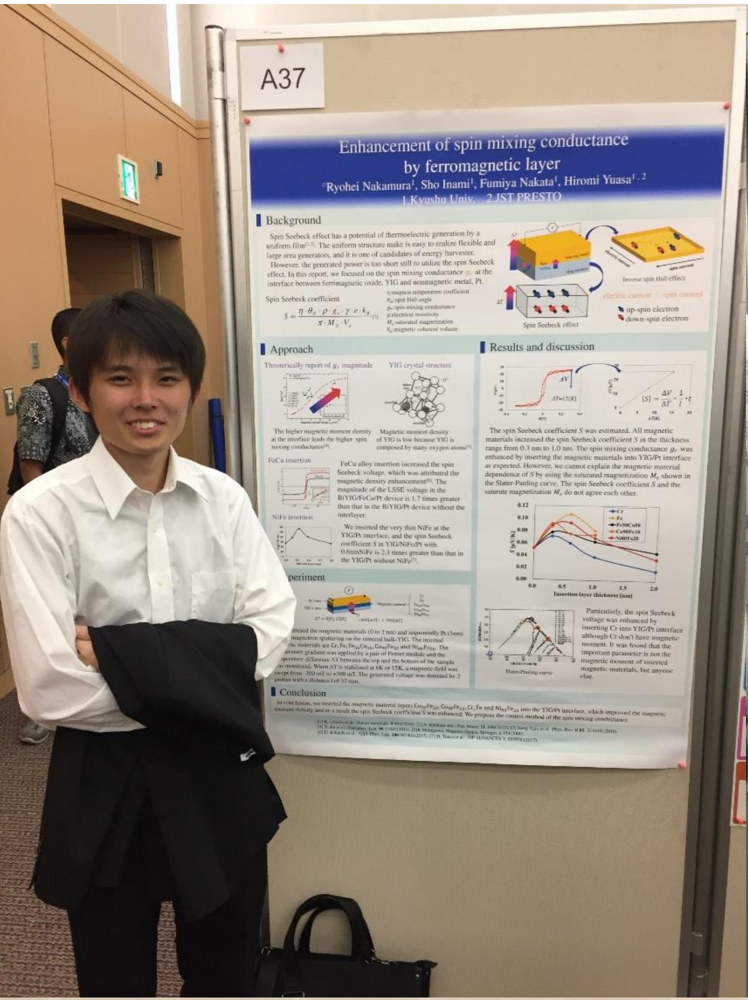
A37

Enhancement of spin mixing conductance by ferromagnetic layer

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Background

Spin Seebeck effect has a potential of thermoelectric generation by a uniform film[1,2]. The uniform structure make is easy to realize flexible and large area generators, and it is one of candidates of energy harvester.

However, the generated power is too short still to utilize the spin Seebeck effect. In this report, we focused on the spin mixing conductance g_r at the interface between ferrimagnetic oxide, YIG and nonmagnetic metal, Pt.

Spin Seebeck coefficient

$$S \propto \frac{\eta \cdot \theta_H \cdot \rho \cdot g_r \cdot \gamma \cdot e \cdot k_B}{\pi \cdot M_s \cdot V_a}\ [3]$$

Approach

Theoretically report of g_r magnitude

The higher magnetic moment density at the interface leads the higher spin mixing conductance[4].

YIG crystal structure

Magnetic moment density of YIG is low because YIG is composed by many oxygen atoms[5].

FeCu insertion

FeCu alloy insertion increased the spin Seebeck voltage, which was attributed the magnetic density enhancement[6]. The magnitude of the LSSE voltage in the BiYIG/FeCu/Pt device is 1.7 times greater than that in the BiYIG/Pt device without the interlayer.

NiFe insertion

We inserted the very thin NiFe at the YIG/Pt interface, and the spin Seebeck coefficient S in YIG/NiFe/Pt with 0.6nmNiFe is 2.1 times greater than that in the YIG/Pt without NiFe[7].

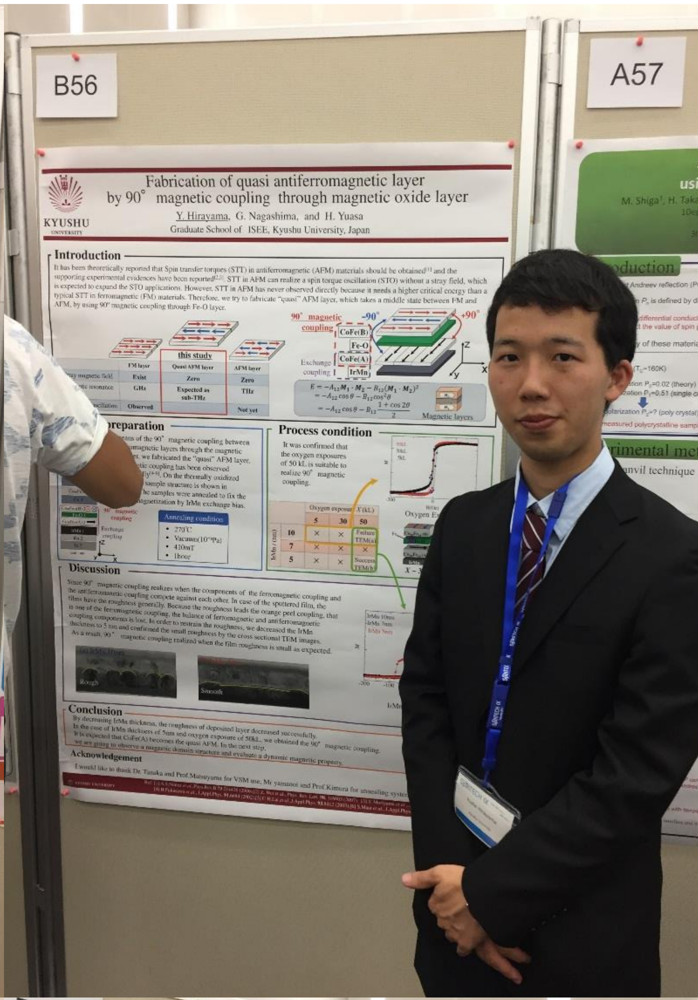
Results and discussion

$$|S| = \frac{\Delta V}{\Delta T} \cdot \frac{1}{l} \cdot t$$

The spin Seebeck coefficient S was estimated. All magnetic materials increased the spin Seebeck coefficient S in the thickness range from 0.3 nm to 1.0 nm. The spin mixing conductance g_r was enhanced by inserting the magnetic materials into YIG/Pt interface as expected. However, we cannot explain the magneric material dependence of S by using the saturated magnetization M_s shown in the Slater-Pauling curve. The spin Seebeck coefficient S and the saturate magnetization M_s do not agree each other.

Particularly, the spin Seebeck voltage was enhanced by inserting Cr into YIG/Pt interface although Cr don't have magnetic moment. It was found that the important parameter is not the magnetic moment of inserted magnetic materials, but anyone else.

Conclusion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Fabrication of quasi antiferromagnetic layer by 90° magnetic coupling through magnetic oxide layer

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Introduction

It has been theoretically reported that Spin transfer torques (STT) in antiferromagnetic (AFM) materials should be obtained[1] and the supporting experimental evidences have been reported[2,3]. STT in AFM can realize a spin torque oscillation (STO) without a stray field, which is expected to expand the STO applications. However, STT in AFM has never observed directly because it needs a higher critical energy than a typical STT in ferromagnetic (FM) materials. Therefore, we try to fabricate "quasi" AFM layer, which takes a middle state between FM and AFM, by using 90° magnetic coupling through Fe-O layer.

	FM layer	this study Quasi AFM layer	AFM layer
[illegible] magnetic field	Exist	Zero	Zero
[illegible] resonance	GHz	Expected as sub-THz	THz
[illegible]	Observed		Not yet

$$\begin{aligned} E &= -A_{12} M_1 \cdot M_2 - B_{12} (M_1 \cdot M_2)^2 \\ &= -A_{12} \cos\theta - B_{12} \cos^2\theta \\ &= -A_{12} \cos\theta - B_{12} \frac{1 + \cos 2\theta}{2} \end{aligned}$$

[illegible]preparation

[illegible] of the 90° magnetic coupling between [illegible] magnetic layers through the magnetic [illegible], we fabricated the "quasi" AFM layer. [illegible] coupling has been observed [illegible][4-6]. On the thermally oxidized [illegible] sample structure is shown in [illegible] samples were annealed to fix the [illegible] magnetization by IrMn exchange bias.

Annealing condition

- 270℃
- Vacuum(10⁻⁶Pa)
- 410mT
- 1hour

Process condition

It was confirmed that the oxygen exposures of 50 kL is suitable to realize 90° magnetic coupling.

		Oxygen exposure X (kL)		
		5	30	50
IrMn t (nm)	10	×	×	Failure TEM(a)
	7	×	×	×
	5	×	×	Success TEM(b)

Discussion

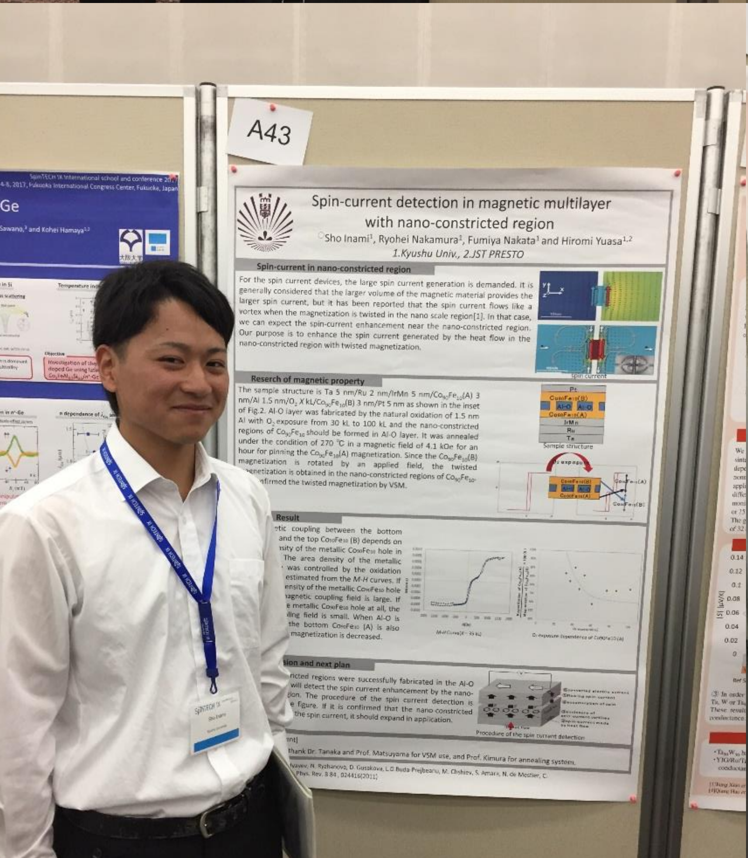
Since 90° magnetic coupling realizes when the components of the ferromagnetic coupling and the antiferromagnetic coupling compete against each other. In case of the sputtered film, the films have the roughness generally. Because the roughness leads the orange peel coupling, that is one of the ferromagnetic coupling, the balance of ferromagnetic and antiferromagnetic coupling components is lost. In order to restrain the roughness, we decreased the IrMn thickness to 5 nm and confirmed the small roughness by the cross sectional TEM images. As a result, 90° magnetic coupling realized when the film roughness is small as expected.

Conclusion

By decreasing IrMn thickness, the roughness of deposited layer decreased successfully.
In the case of IrMn thickness of 5nm and oxygen exposure of 50kL, we obtained the 90° magnetic coupling.
It is expected that CoFe(A) becomes the quasi AFM. In the next step, we are going to observe a magnetic domain structure and evaluate a dynamic magnetic property.

Acknowledgement

I would like to thank Dr. Tanaka and Prof. Matsuyama for VSM use, Mr yamanoi and Prof.Kimura for annealing system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Spin-current detection in magnetic multilayer with nano-constricted region

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Spin-current in nano-constricted region

For the spin current devices, the large spin current generation is demanded. It is generally considered that the larger volume of the magnetic material provides the larger spin current, but it has been reported that the spin current flows like a vortex when the magnetization is twisted in the nano scale region[1]. In that case, we can expect the spin-current enhancement near the nano-constricted region. Our purpose is to enhance the spin current generated by the heat flow in the nano-constricted region with twisted magnetization.

Reserch of magnetic property

The sample structure is Ta 5 nm/Ru 2 nm/IrMn 5 nm/$Co_{90}Fe_{10}$(A) 3 nm/Al 1.5 nm/O_2 X kL/$Co_{90}Fe_{10}$(B) 3 nm/Pt 5 nm as shown in the inset of Fig.2. Al-O layer was fabricated by the natural oxidation of 1.5 nm Al with O_2 exposure from 30 kL to 100 kL and the nano-constricted regions of $Co_{90}Fe_{10}$ should be formed in Al-O layer. It was annealed under the condition of 270 ℃ in a magnetic field of 4.1 kOe for an hour for pinning the $Co_{90}Fe_{10}$(A) magnetization. Since the $Co_{90}Fe_{10}$(B) magnetization is rotated by an applied field, the twisted [illegible]gnetization is obtained in the nano-constricted regions of $Co_{90}Fe_{10}$. [illegible]nfirmed the twisted magnetization by VSM.

Result

[illegible]etic coupling between the bottom [illegible] and the top $Co_{90}Fe_{10}$ (B) depends on [illegible]sity of the metallic $Co_{90}Fe_{10}$ hole in [illegible] The area density of the metallic [illegible] was controlled by the oxidation [illegible] estimated from the M-H curves. If [illegible]ensity of the metallic $Co_{90}Fe_{10}$ hole [illegible]agnetic coupling field is large. If [illegible]e metallic $Co_{90}Fe_{10}$ hole at all, the [illegible]ling field is small. When Al-O is [illegible] the bottom $Co_{90}Fe_{10}$ (A) is also [illegible] magnetization is decreased.

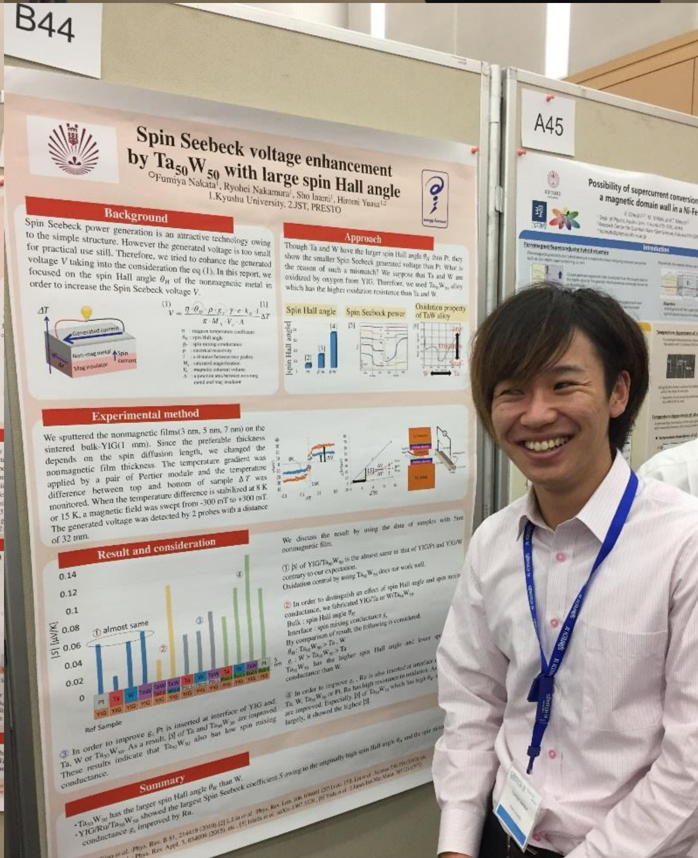
[illegible]sion and next plan

[illegible]ricted regions were successfully fabricated in the Al-O [illegible] will detect the spin current enhancement by the nano-[illegible]ion. The procedure of the spin current detection is [illegible]e figure. If it is confirmed that the nano constricted [illegible] the spin current, it should expand in application.

Procedure of the spin current detection

[illegible]ent]

[illegible] thank Dr. Tanaka and Prof. Matsuyama for VSM use, and Prof. Kimura for annealing system.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A45

Spin Seebeck voltage enhancement by $Ta_{50}W_{50}$ with large spin Hall angle

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Background

Spin Seebeck power generation is an attractive technology owing to the simple structure. However the generated voltage is too small for practical use still. Therefore, we tried to enhance the generated voltage V taking into the consideration the eq (1). In this report, we focused on the spin Hall angle θ_H of the nonmagnetic metal in order to increase the Spin Seebeck voltage V.

$$V \propto \frac{\eta \cdot \theta_H \cdot \rho \cdot g_r \cdot \gamma \cdot e \cdot k_B \cdot l}{\pi \cdot M_s \cdot V_a \cdot A} \Delta T \quad (1)\ [1]$$

Approach

Though Ta and W have the larger spin Hall angle θ_H than Pt, they show the smaller Spin Seebeck generated voltage than Pt. What is the reason of such a mismatch? We suppose that Ta and W are oxidized by oxygen from YIG. Therefore, we used $Ta_{50}W_{50}$ alloy which has the higher oxidation resistance than Ta and W.

Experimental method

We sputtered the nonmagnetic films(3 nm, 5 nm, 7 nm) on the sintered bulk-YIG(1 mm). Since the preferable thickness depends on the spin diffusion length, we changed the nonmagnetic film thickness. The temperature gradient was applied by a pair of Pertier module and the temperature difference between top and bottom of sample ΔT was monitored. When the temperature difference is stabilized at 8 K or 15 K, a magnetic field was swept from -300 mT to +300 mT. The generated voltage was detected by 2 probes with a distance of 32 mm.

Result and consideration

We discuss the result by using the data of samples with 5nm nonmagnetic film.

① |S| of YIG/$Ta_{50}W_{50}$ is the almost same as that of YIG/Pt and YIG/W contrary to our expectation.
Oxidation control by using $Ta_{50}W_{50}$ does not work well.

② In order to distinguish an effect of spin Hall angle and spin mixing conductance, we fabricated YIG/Ta or W/$Ta_{50}W_{50}$.
Bulk : spin Hall angle θ_H
Interface : spin mixing conductance g_r
By comparison of result, the following is considered
θ_H: $Ta_{50}W_{50}$ > Ta, W
g_r : W > $Ta_{50}W_{50}$ > Ta
$Ta_{50}W_{50}$ has the higher spin Hall angle and lower spin mixing conductance than W.

③ In order to improve g_r, Pt is inserted at interface of YIG and Ta, W or $Ta_{50}W_{50}$. As a result, |S| of Ta and $Ta_{50}W_{50}$ are improved. These results indicate that $Ta_{50}W_{50}$ also has low spin mixing conductance.

④ In order to improve g_r, Ru is also inserted at interface [illegible] Ta, W, $Ta_{50}W_{50}$ or Pt. Ru has high resistance to oxidation. A[illegible] are improved. Especially, |S| of $Ta_{50}W_{50}$ which has high θ_H [illegible] largely, it showed the highest |S|.

Summary

- $Ta_{50}W_{50}$ has the larger spin Hall angle θ_H than W.
- YIG/Ru/$Ta_{50}W_{50}$ showed the largest Spin Seebeck coefficient S owing to the originally high spin Hall angle θ_H and the spin mixing conductance g_r improved by Ru.