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# Giant field-like torque observed in a Py/W/Pt trilayer system

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**Abstract**

**We find comparable field-like torque to Oersted-field induced torque in Py/W/Pt multilayer system by means of spin-torque ferromagnetic resonance (ST-FMR). In the ST-FMR measurement, we observe disappearance of anti-symmetric voltage generated by sum of Oersted-field induced torque and field-like torque, meaning the torque has almost equal amplitude to that generated by the Oersted field, and opposite sign. This finding and further systematic study would lead us to unveil the origin of the field-like torque in spin-orbit materials.**

## 1. Introduction and Objective

Spin-orbit torque (SOT) via spin Hall effect [1] or Edelstein effect [2] is key ingredient for spintronics devices from the perspective for inducing magnetization reversal [3] which is central concept for MRAM. Therefore, many materials have been studied for generating SOT so far such as Pt, Ta, W [4, 5]. The amplitude of SOT is defined by charge-to-spin conversion efficiency, i.e. spin Hall angle (SHA) or spin torque efficiency (STE) in the bulk materials. Although the SHA and STE are determined by a just bulk materials parameter, we need to design new multilayered materials for more efficient or controllable SOT generation.

From the view point of spin-orbit engineering, an artificial lattice has a possibility to emerge novel SOT due to variable Berry curvature, especially multilayer consisted of spin Hall materials which have opposite sign of spin Hall angle each other. Here we focus on W/Pt multilayers for extracting SOT such as damping-like (DL) and field-like (FL) torques.

## 2. Methods

At first, we prepared several Py(5nm)/W(2nm)/Pt(1 or 5nm) multilayers by means of DC magnetron sputtering, where the number in ( ) corresponds to the thickness for each layer. After that, we fabricated conventional GSG-type waveguide devices for performing ST-FMR measurement by lithography and lift-off technique as shown in Fig.1. In the measurement, we injected RF current into the devices from RF signal generator, then separated RF and DC components by using bias-tee for detecting the sample voltage with applying magnetic field.

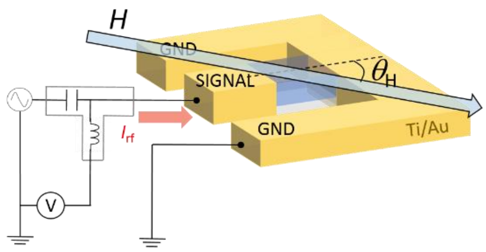


Fig. 1 Schematic image for the device and experimental setup. $\theta_H$ corresponds to applied-field angle. Except for field-angular dependence as shown in Fig. 4, we normally performed the ST-FMR measurement at 45 deg.

## 3. Experimental results

We compared different Pt thickness cases such as (a) Py(5nm)/W(2nm)/Pt(5nm) and (b). Py(5nm)/W(2nm)/Pt (1nm). The case (a) stands for W/Pt multilayer system which is focused in this study, while (b) means almost only W sample as a reference at this moment. Here applied power and frequency range are 6 dBm, and 5 to 12 GHz, respectively. The result for case (a) is shown in Fig. 2. The estimated efficiency is about -0.05. This means that the result comes from spin Hall effect in alpha-W whose SHA is reported as below -0.07 [5]. So there is no interesting effect from multilayer on the spin torque generation in this case.

On the other hand, we found surprising behaviors in Py(5nm)/W(2nm)/Pt(1nm) as shown in Fig. 3.

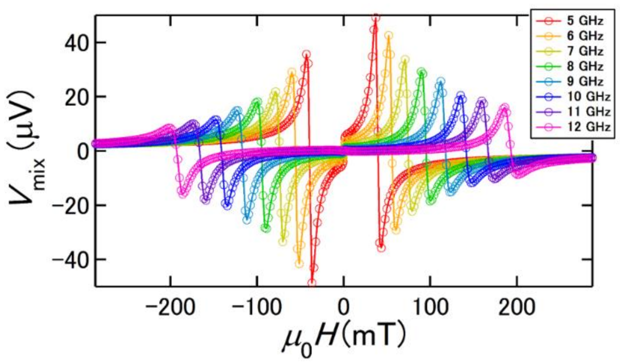


Fig. 2 Detected voltages as a function of the applied field for each frequency case in Py(5nm)/W(2nm)/Pt(5nm) trilayer.

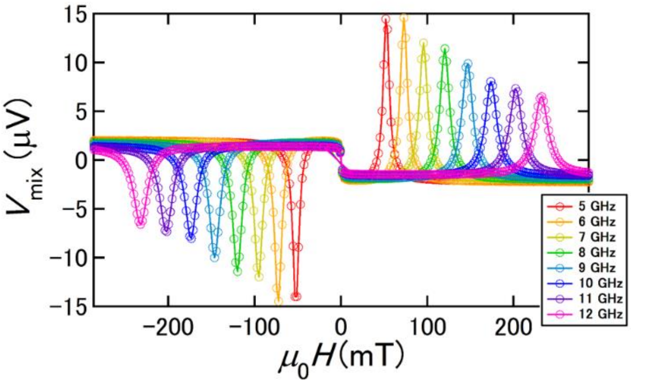


Fig. 3 Detected voltages as a function of the applied field for each frequency case in Py(5nm)/W(2nm)/Pt(1nm) trilayer.

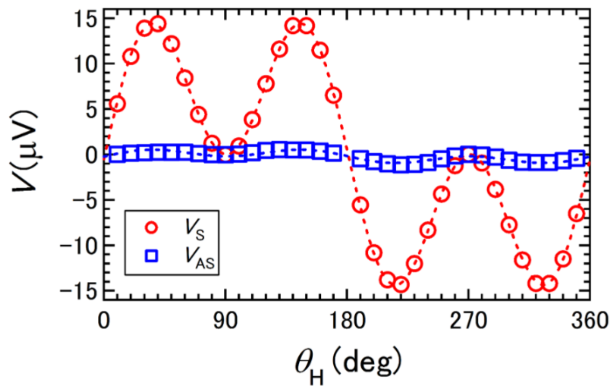


Fig. 4 Field-angular dependence of $V_S$ and $V_{AS}$ in the case of Py(5nm)/W(2nm)/Pt(1nm) trilayer.

The ST-FMR signals consist of almost 100 % symmetric voltage $V_S$ without any anti-symmetric one $V_{AS}$. Therefore one would doubt that this result is originated from spin pumping during the ST-FMR. We investigated in-plane field-angular dependence for both of $V_S$ and $V_{AS}$ as shown in Fig. 4. It is clear that $V_S$ doesn't show absolutely $\sin\theta$ dependence originated from the spin pumping effect, but $\sin 2\theta \cos\theta$ behavior from the ST-FMR. The field-angular dependence indicates that the spin pumping effect is negligible in the present measurements.

Moreover we measured RF power dependence of the voltages shown in Fig. 5. Applied power for obtaining Figs. 3 and 4 data was set to be 6 dBm which corresponds to about 4 mW. In this range, the voltages are monotonically changed, implying the FMR dynamics is adequately linear region. Therefore, we confirmed that these amplitudes of $V_S$, $V_{AS}$ are precisely coming from the ST-FMR signals.

Here we discuss the reason why $V_{AS}$ is almost zero in this Py(5nm)/W(2nm)/Pt(1nm) trilayer. Actually, the asymmetric signal $V_{AS}$ is originated from a sum of torques generated by the Oersted field and the FL field [6] as shown below.

$$V_{AS} \propto (H_{Oe} + H_{FL})\sqrt{1 + \mu_0 M_{eff}/\mu_0 H_R} \qquad (1)$$

Where $H_{Oe}, H_{FL}, \mu_0 M_{eff}, \mu_0 H_R$ mean Oersted field, FL field, effective magnetization of Py, resonance field, respectively. Therefore, zero $V_{AS}$ signal indicates that the FL torque and Oersted-field induced torque are cancelled out each other. FL torque generated from W is reported as negligible value by means of harmonic measurement [7]. So this comparable FL torque to Oersted-field induced torque is quite remarkable since the FL torque is usually much smaller than Oersted-field induced torque [8].

In this conference, we will discuss Py thickness dependence for extracting actual DL and FL torque quantitatively, and Pt thickness dependence for unveiling the origin of the large FL torque in this system.

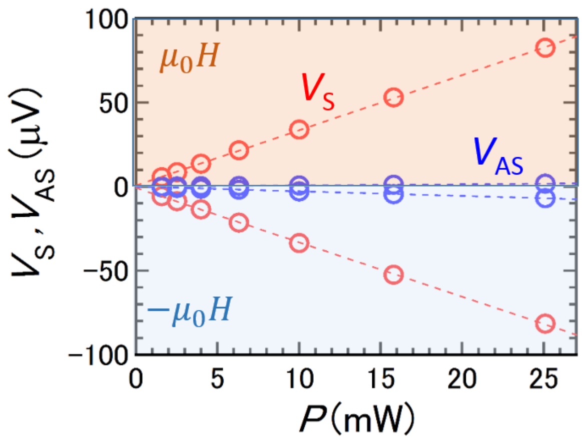


Fig. 5 Power dependence of $V_S$ and $V_{AS}$ for positive and negative field in the case of Py(5nm)/W(2nm)/Pt(1nm) trilayer.

## 4. Conclusion

Surprisingly large FL torque is revealed in a Py(5nm)/W(2nm)/Pt(1nm) multilayer. We find that the FL torque is drastically controlled by varying Pt thickness. This Py/W/Pt multilayered system has a key for understanding the origin of FL torque by studying thickness dependence systematically.

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