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Observation of Spin-orbit torque generated by interface-generated spin current in a Py/Pt/Co system

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Abstract

We report an unconventional spin-orbit torque acting on the in-plane magnetized Py layer in Py/Pt/Co system. This new spin-orbit torque changes its sign with the polarity of the magnetization of Co, which has completely different symmetry observed in the conventional spin-orbit torques. We reveal that this current-induced torque originates from an additional interface-generated spin current, which is spin-orbit precession current, generated from the Pt/Co interface.

1. Introduction

Manipulation of magnetization vector using an electrical current is one of the important ways for information writing in magnetic random access memories (MRAMs) [1]. Current induced spin-orbit torque (SOT) is now intensively studied for the promising approach to achieve this [2,3]. SOT has been mainly observed in ferromagnetic metal (FM) / heavy metal (HM) bilayer structures, where the spin-orbit coupling related phenomena, such as the spin Hall effect (SHE) in adjacent HM [3] or the interfacial Rashba-Edelstein effect at FM/HM interface [4], play an important role for the mechanism of SOT. In this "conventional" SOT, the spin orientation $\boldsymbol{\sigma}^{\mathrm{con}}$ of the spin current or the spin polarized current injecting into the FM layer is described as follows;

$$\boldsymbol{\sigma}^{\mathrm{con}} \propto \boldsymbol{j_e} \times \boldsymbol{z}, \tag{1}$$

where $\boldsymbol{j}_{\mathrm{e}}$ represents the electrical current direction.

Recently, it has been theoretically predicted that the interfacial spin-orbit scattering at the FM/HM interface can generate an additional spin currents [4-7]. Among them, we focus on spin-orbit precession current (SOP current), which originates from the precession of electrons about the interfacial spin-orbit field during the interfacial scattering process [6,7]. The spin orientation of the SOP current $\boldsymbol{\sigma}^{\mathrm{SOP}}$ is governed by the polarization vector of the FM layer ($\boldsymbol{m}$) and shows "unconventional" symmetry compared to $\boldsymbol{\sigma}^{\mathrm{con}}$ expressed as;

$$\boldsymbol{\sigma}^{\mathrm{SOP}} \propto \boldsymbol{m} \times (\boldsymbol{j_e} \times \boldsymbol{z}). \tag{2}$$

In addition, it is expected that the SOP current can also exert the torque on magnetization via the spin transfer mechanism.

In this research, we focus on the SOP current generated at the Pt/Co interface and aim to observe the SOP current induced torque (SOP-torque).

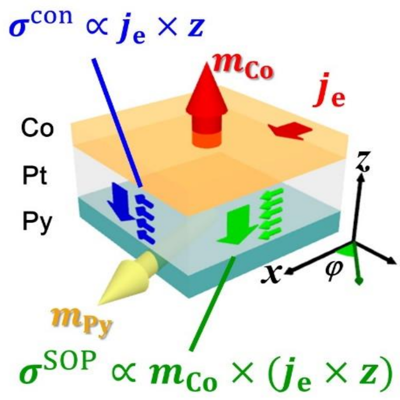

Figure 1: Schematic of Py/Pt/Co system. Two types of out-of-plane spin currents with different spin polarizations are generated by the electrical current injection. $\boldsymbol{m}_{\mathrm{Co}}$ and $\boldsymbol{m}_{\mathrm{Py}}$ correspond to the magnetization vector of the Co and Py layer respectively.

2. Sample preparation and method

In order to observe the SOP-torque generated from Pt/Co interface, we focused on the tri-layer system, where Pt/Co bilayer is deposited on the Py ($Ni_{80}Fe_{20}$) layer (Py/Pt/Co system). We deposited the following stack on thermally oxidized Si substrate by rf sputtering; Ta(1.4 nm) / Py (4.0) / Pt (1.0) / Co (0.5) / Pd (2.4) / MgO (2.0). The Co and Py layers correspond to a perpendicularly magnetized pinned layer and an in-plane magnetized free layer respectively. In this system, two types of the spin currents with different symmetries, the conventional spin current generated mainly by the SHE in Pt and the SOP current generated from Pt/Co interface, are injected into the Py layer and exert a current-induced torques. (Fig. 1) The current-induced torques were measured by the adiabatic harmonic Hall measurements using ac current application. [8,9]

3. Results

Angle-scan harmonic Hall measurements of Py/Pt/Co system with Co layer magnetized along +z and –z direction (+m_z^{Co} and –m_z^{Co} state respectively) are shown in Fig. 2. Measurements were held by rotating the magnetic field along the xy plane (azimuthal angle φ) [8,9]. The current was applied along x-axis with amplitude of I_{ac} = 10 mA. In both states, we observed a valley and peak signal near φ = 0 and

180 degree where $\boldsymbol{m}_{Py}$ points along x-axis (Fig. 2b). This signal corresponds to the conventional SOT generated mainly by the SHE in Pt layer. Meanwhile at the same time, we observed a clear difference between $+m_z^{Co}$ and $-m_z^{Co}$ state near $\varphi = 90$ and 270 degree. This antisymmetric behavior, which cannot be explained by the conventional SOT, indicates the presence of an additional current induced torque which we reveal it to be a SOP induced torque from its symmetry. Furthermore, we estimated that the magnitude of the SOP-induced torque is almost 30% of that of the conventional SOT.

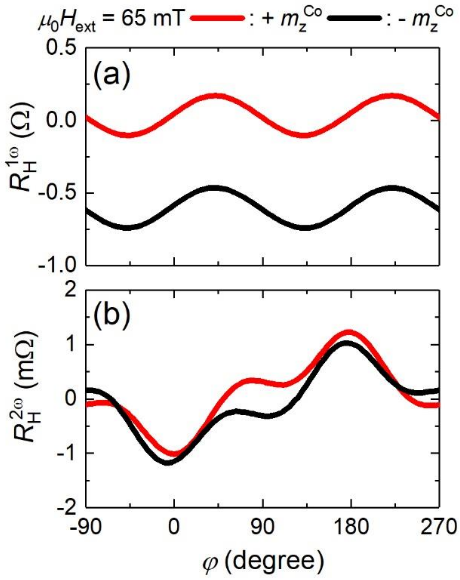

Figure 2: Angle-scan harmonic Hall measurement of Py/Pt/Co system. (a) First harmonic resistance Hall $R_H^{1\omega}$ and (b) second harmonic Hall resistance $R_H^{2\omega}$ measured under external field of 65 mT with + m_z^{Co} (red line) and – m_z^{Co} (black line) states.

4. Conclusions

We observed the unconventional current-induced SOT in Py/Pt/Co tri-layer structures in addition to the conventional SOT generated mainly by the SHE-induced spin current in Pt layer. From the symmetry, we revealed that this additional torque originates from the interface-generated spin current, which is SOP current, generated at the Pt/Co interface. Present result offers not only the new mechanism of SOT but also a new perspectives for SOT-induced magnetization switching using the coexistence of the two different spin currents.

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