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Characterization of spin pumping effect in nanometer-sized lateral devices

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Abstract

Magnetization dynamics was investigated for microfabricated lateral devices consisting of a rectangular Permalloy (Py) element, a Cu wire, and a Pt wire, which were located on a coplanar waveguide, in order to clarify the spin pumping effect in nanometer-sized lateral devices. The distance between the Py element and the Pt wire (*d*) was changed in the range from 100 nm to 2 µm. We observed the enhancement of Gilbert damping constant for the devices with *d* < 400 nm, and Gilbert damping constant gradually reduced with increasing *d*. We discuss the spin injection into the Cu wire from the viewpoints of the spin pumping and the spin absorption due to the Pt wire.

1. Introduction

Spintronics, which simultaneously utilizes the properties of electron spin and charge in devices, provides us with excellent device performance such as nonvolatility, high-speed data processing, and reduced electric power consumption. Thus, spintronic devices have a potential to substitute for existing semiconductor-based electronic devices. In order to realize high performance of spintronic devices, it is necessary to understand the spin transport properties in ferromagnetic and nonmagnetic materials. An effective way for spin injection into several materials is spin pumping [1]: magnetization precession in a ferromagnet emits a pure spin current into an adjacent nonmagnetic material through the interface. In contrast to other electrical spin injection methods based on the electric current flow, the use of which are strongly limited due to the impedance mismatch problem [2], the spin current generated by the magnetization dynamics does not require the flow of net charge currents, which enables us to do effective spin injection free from impedance mismatch problem. In this study, we investigated the enhancement of Gilbert damping in lateral devices consisting of a Permalloy (Py) element, a Cu wire, and a Pt wire, which were located on a coplanar waveguide (CPW) in order to examine the spin pumping effect in well-controlled nanometer-sized devices.

2. Experimental procedures

Figure 1 shows a schematic illustration for the nanometer-sized lateral device. The devices were fabricated on a thermally oxidized Si substrate employing sputtering, electron beam lithography, Ar ion etching and a lift-off technique. First, a 10-nm-thick Py element (2 µm x 50 µm) was prepared on a 40-nm-thick Au CPW. Then, a 10-nm-thick Pt wire with 100 nm wide was prepared. The distance between the Py element and the Pt wire (*d*) was changed in the range from 100 nm to 2 µm (edge to edge). Finally, the 30-nm-thick Cu nonmagnetic wire was placed as a bridge between the Py element and the Pt wire.

The broadband ferromagnetic resonance (FMR) measurements were performed with a vector-network analyzer and CPW. The RF magnetic field was applied to the Py element by injecting the RF power into the CPW. An external static magnetic field (*H*) was applied along the film plane. All the measurements were carried out at room temperature.

3. Experimental results

Figure 2 shows the FMR spectra measured at H = 1800 Oe for devices with d = 200 nm and without a Pt wire. The peak frequency gradually shifted as H was changed, which was interpreted by the Kittel's relationship. Compared with the device without a Pt wire, the linewidth broadening was clearly observed for d = 200 nm. Figure 3 shows the H dependence of the linewidth of resonant peak (Δf) in the FMR spectra for the devices with d = 200 nm and without a Pt wire. As seen in Fig. 3, Δf for d = 200 nm is larger than that of the device without a Pt wire in this H range, which suggests the enhancement of Gilbert damping parameter (α) by connecting the Pt wire to the Cu wire. From the liner fitting to the data in Fig. 3 using the equation of

$$\Delta f = \frac{\alpha\gamma}{2\pi}(2H + H_C + 4\pi M) + f_0 \ , \qquad (1)$$

the values of α were obtained to be α = 0.0103 and 0.0096 for the devices with d = 200nm and without a Pt wire, respectively. The values of α as a function of d are shown in Fig. 4. The α decreases gradually with increasing d. In the case of the spin pumping in a tri-layered system with Py / Cu / Pt [3], the α enhanced as the Cu layer thickness was reduced, because of the spin absorption effect in Pt layer, which came from the large spin-orbit interaction in Pt and it led to the spin relaxation in Cu. In the present case, the d dependence of α is roughly expressed as

$$\alpha = \alpha_0 + \left[1 + g^{\uparrow\downarrow} C \frac{1 + tanh(d/\lambda_{sd}) gC}{tanh(d/\lambda_{sd}) + gC}\right]^{-1} \times g^{\uparrow\downarrow} D \ , \qquad (2)$$

where $g^{\uparrow\downarrow}$ is the spin-mixing conductance, g is the conductance per spin of the Cu-Pt interface, C is a parameter related to spin-scattering, D is a parameter related to the magnetic properties, and α_0 is the bulk Gilbert damping constant. Then, our experimental results plotted in Fig. 4 by red markers are fitted using the equation (2). From this fitting, we obtained the spin diffusion length λ_{sd}~ 600 nm, which is in the same order of magnitude reported in previous experiments [4].

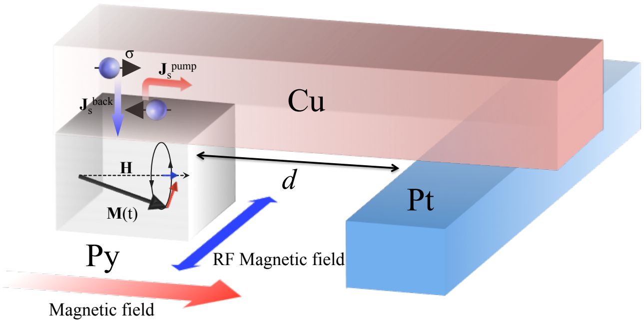

Fig. 1 A schematic of the device. A pure spin current is emitted into the Cu wire, which is driven by spin pumping.

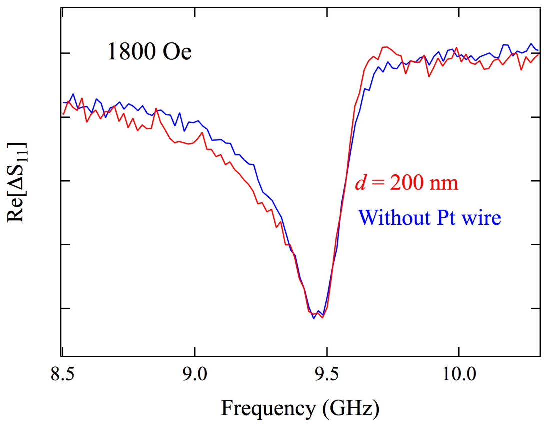

Fig. 2 FMR spectra for devices with d = 200 nm and without a Pt wire. The spectra were measured at H = 1800 Oe.

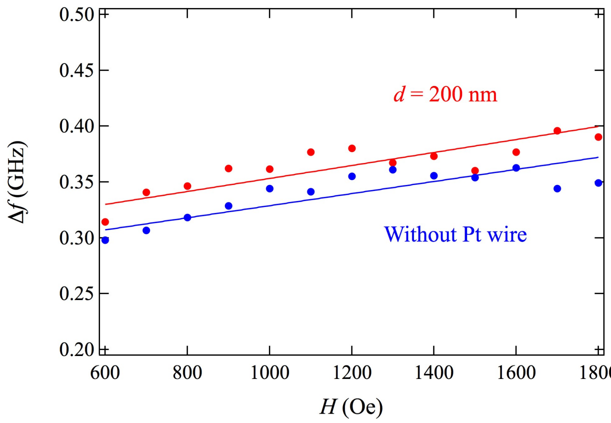

Fig. 3 External static magnetic field (H) dependence of the linewidth of resonant peak (Δf) of FMR spectra for the devices with d = 200 nm and without Pt wire. The solid lines are the fittings to the experimental data.

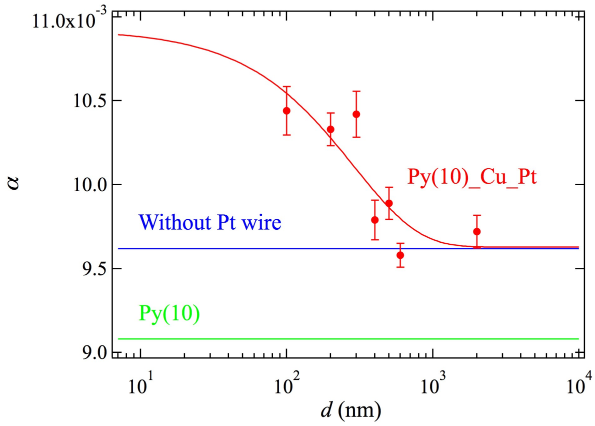

Fig. 4 Distance between the Py element and the Pt wire (d) dependence of Gilbert damping constant (α). All the devices were fabricated on the identical substrate.

4. Conclusions

The broadband FMR was measured for nanometer-sized lateral devices, which consists of a Py element, a Cu wire, and a Pt wire located on a CPW, where d was varied in the range from 100 nm to 2μm in order to characterize the spin pumping and spin absorption effect. For the devices with small d (d < 400 nm), the linewidth broadening in FMR spectra was observed. The values of α decreased gradually with increasing d, and the d dependence of α would be interpreted with in the framework of the spin pumping theory.

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