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Current Density Dependence of Asymmetric Magnetoresistance in Pt/Py Bilayers Under Various Magnetic Field Strength

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Abstract

It has been reported recently that an asymmetric magnetoresistance (MR) in Py/Pt bilayer originates from spin current injected from the Pt layer. Our study demonstrates that current density dependence of the asymmetric MR shows interesting behavior; it monotonically increases with current density up to a threshold, and increases more rapidly above the threshold. The external magnetic field dependence of asymmetric MR is investigated to reveal the origin of the threshold behavior.

1. Introduction

An asymmetric MR has been recently found to exist in the system of bilayers consist of ferromagnetic (FM) and non-magnetic (NM) metals, which can be attribute to either spin accumulation [1] or electron-magnon scattering [2]. As the current density increases, the asymmetric MR firstly linearly increases up to a threshold, and above the threshold it increases more rapidly [2]. The unique threshold current density behavior of asymmetric MR implies different origin of asymmetric MR below and above threshold current density.

To reveal the origin of the threshold behavior of asymmetric MR, we investigate the current density dependence of asymmetric MR under various magnetic fields. We find that the asymmetric MR below the threshold is not affected by the external magnetic field up to 8.9 T, which differs from the characteristic of GHz magnons. In addition, the threshold behavior is found to be suppressed while increasing magnetic field, which implies that much smaller energy scale of magnetization excitation is involved in the threshold phenomena of asymmetric MR.

2. Results and Discussions

Figure 1 illustrates the measurement configuration with a wire of Py (4.5 nm)/Pt (5 nm) bilayer. An electron current is applied along +x direction, which is defined as a positive current. The red and blue arrows in Figure 1 represent the spin of conduction electrons in Pt. Due to spin Hall effect in Pt, spin of conduction electrons in –y direction is injectd into the Py layer.

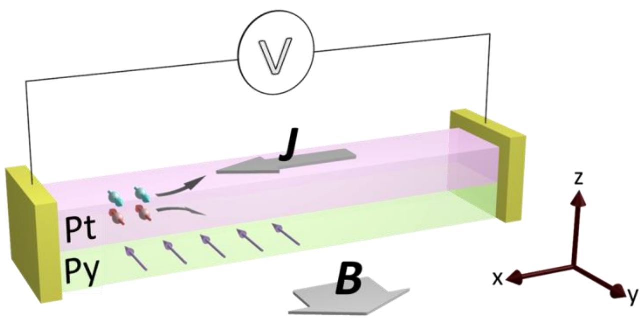

Figure 1 Schematic illustration of the Py (5 nm)/Pt (5 nm) bilayer wire with the definition of external magnetic field (B) and current density (J).

To understand the threshold behavior, we investigate the current density dependence of the asymmetric MR under various magnetic fields. The asymmetric MR is defined here as; $MR_{asym} \equiv [\Delta R(+B)-\Delta R(-B)]/R_{max}$. Measurement is performed at T = 10 K to suppress the thermal effects. Figure 2 shows the asymmetric MR as a function of current density under 0.1 T and 8.9 T. A constant slope in the

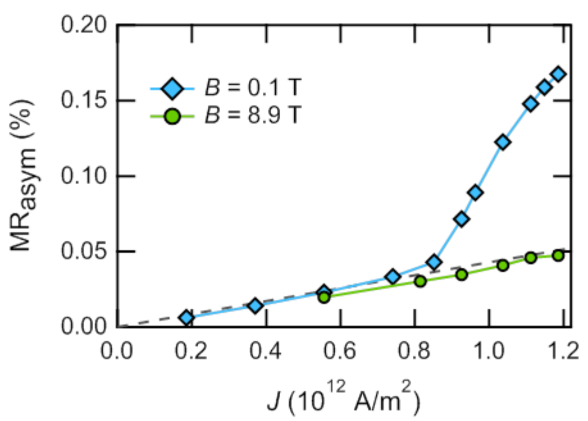

Figure 2 MR_{asym} with respect to J for B = 0.1 T and B = 8.9 T.

asymmetric MR is observed under either higher or lower fields. Note that that the asymmetric MR above threshold is suppressed by magnetic field of 8.9T, while the slope of asymmetric MR is almost constant even over threshold current density. The unique difference of magnetic field dependence for the current density below and above the threshold suggests that there are two different mechanisms involved in the asymmetric MR phenomena.

It is recently reported that the asymmetric MR originateds from the electron-magnon scattering due to THz magnon generated in a spin-flip process [2], which is consistent with our results: the linearly increasing asymmetric MR is not influenced by magnetic field up to 8.9 T, because THz magnons have an energy of a few meV which is much larger than the Zeeman energy induced by the magnetic field of 8.9 T (~1 meV computed from $g\mu_B B$ with g = 2). On the other hand, the fact that the threshold behavior is strongly affected by the external magnetic field can be explained by a GHz magnetization excitation induced by the spin torque effect.

3. Conclusions

The current density dependence of asymmetric MR is investigated under various magnetic fields. Below the threshold, the asymmetric MR is not affected by the external magnetic field up to 8.9 T, which implies the high energy THz magnon can be responsible for the asymmetric MR. On the other hand, the rapid increase of the asymmetric MR above the threshold is strongly suppressed by magnetic field. This result suggests that the magnetic excitations with a lower energy scale (GHz) are also involved with the THz magnon in the asymmetric MR above threshold. Our results suggest that the asymmetric MR has two origins: the reduction of magnetization due to GHz generated by spin-torque effect and electron-magnon scattering due to THz excited by spin-flip process.

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