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Spin Polarization Characterization by Spin Hall Magnetoresistance in Ferrimagnetic Pt/$Co_{1-x}Tb_x$ bilayers

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Abstract

Rare earth-transition metal (RE-TM) ferrimagnets has received great attention for their small magnetic moments, fast dynamic behaviors. Here we study the spin transport behavior in Pt/$Co_{1-x}Tb_x$ bilayers by varying *x* and temperature, and find a spin polarization compensation point deduced by an anomalous behavior of spin Hall magnetoresistance (SMR) near the temperature compensation point of magnetization (T_M). We propose an easy and convenient way to access the spin polarization of the RE-TM ferrimagnets, which is crucial for the reading operation in their future applications of spin-orbit torque magnetic random-access memory (SOT-MRAM).

1. Introduction

Ferrimagnetic materials have emerged as potential candidates for realizing the functions of spintronic devices [1-3], especially for the rare earth-transition metal (RE-TM) ferrimagnets such as Co-Tb, Co-Gd and CoFe-Gd etc., which show promising perspective to the development of high-density, high-speed spintronics memory and logic devices.

However, most researches have been focused on the writing operation of the spin memory devices, few was related to the reading operation of it. Serving as the free layer of the MTJ, ferrimagnetic layer should promise significant and stable spin polarization, which claims a fully understanding of the spin-dependent transport mechanisms for the RE-TM ferrimagnets, especially for the spin polarization of them. In this work, we demonstrate a rapid spin polarization changing in the vicinity of T_C, and a spin polarization compensation point (T_P) near T_M in a 3 nm thick Co-Tb alloy layer. We report an anomalous temperature dependence of SMR which infers an underlying spin polarization behavior.

2. Experimental Procedure

Sample Fabrication

For this study, we prepare five samples of the $Co_{1-x}Tb_x$ alloys with each having different chemical composition *x*. The film stacks of SiN(2)/$Co_{1-x}Tb_x$(3)/Pt(3)/SiN(3) are grown on thermally oxide Si substrates using magnetron sputtering with a base pressure of 2×10^{-8} Torr, all thicknesses are in nm. The Tb concentration changes from 0.15 to 0.48. The film stacks are then fabricated into Hall bar devices with a width of 100 μm and length of 1500 μm using photolithography and ion milling.

Transport measurement

Magnetic properties are measured by anomalous Hall effect using a Quantum Design PPMS with magnetic field up to 9 T. Both the temperature and composition dependence of the anomalous Hall resistance (R_{AH}) are measured and the sign changes of R_{AH} are detected in both measurements.

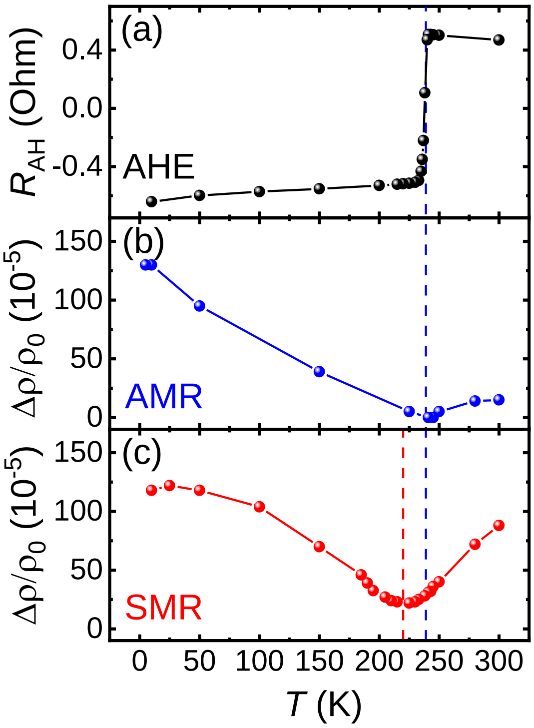

Fig. 1 Temperature dependence of the anomalous Hall resistance (a), SMR (b), and AMR (b) respectively. The blue dash line shows the T_M and the red dash line indicates the temperature where the SMR reaches its minimum.

Temperature dependences of the spin Hall magnetoresistance (SMR) and anisotropic magnetoresistance (AMR) are measured and separated by rotating the external magnetic field in two orthogonal planes according to the different angular dependence of SMR and AMR.

3. Results

To compare the spin-related transport effects of AHE, AMR and SMR, we carry out a series of transport measurements over a wide range of temperature between 5 and 300 K on the same device of sample of Pt/$Co_{0.59}Tb_{0.41}$ bilayers. R_{AH} is extracted from the hysteresis loops and summarized in Fig. 1(a), which precisely determine the T_M=238 K. The temperature dependences of the amplitudes of the AMR and SMR oscillations are extracted and plotted in Fig. 1(b) and (c), respectively. The detailed temperature dependence of these effects has been intensively explored and compared in a short range (200 - 250 K) where the composition is expected. SMR and AMR, plotted in Fig.1 (b) and (c) respectively, have similar temperature dependences, they all change non-monotonically. Above the T_M, they decrease, and then increase dramatically at lower temperature. What is abnormal is that the minimum points of AMR and SMR are separated a little with the AMR vanishing at T_M, and SMR has a minimum at 225 K.

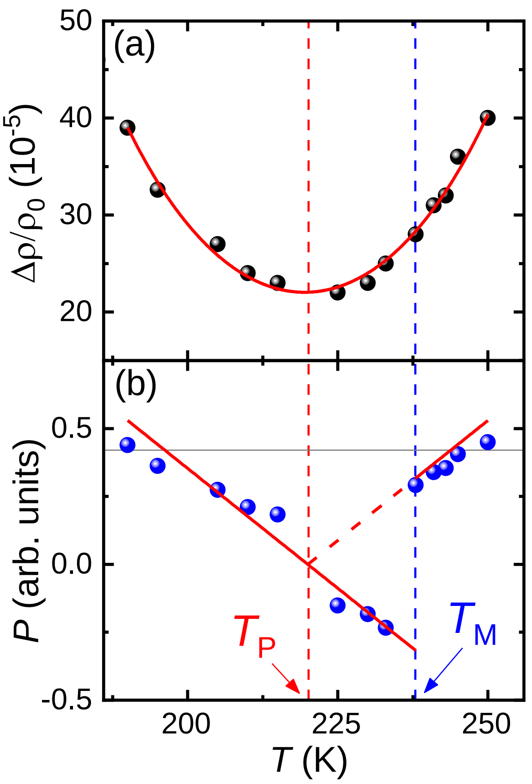

Fig. 2 (a) SMR measured as the function of temperature in the neighborhood of SMR minimum. The red curve is the fitting outcome. (b) The deduced spin polarization which gives the best fit. The light gray line indicates the Co polarization reported by the literature.

A longitudinal spin current absorption should be considered to character the effect of the ferrimagnetic $Co_{1-x}Tb_x$ layer. Because of the absorption of this longitudinal spin current by $Co_{1-x}Tb_x$ layer, the SMR amplitude tends to be decreased compared to the case in heavy metal/ferromagnetic insulator (HM/FI) system. The degree of this discrepancy depends on the spin polarization P of the ferrimagnetic layer: the smaller the P, the larger the decrease.

In light of this, we can attribute the anomalous temperature dependence of SMR near the T_M to the change of the spin polarization of the ferrimagnetic $Co_{1-x}Tb_x$ layer. Fig. 2(a) demonstrates the fitting outcome from this extended SMR model [4]. Fig. 2(b) shows the fitting parameter P which gives the best fit. The red solid lines in fig. 2(b) stands for the temperature behavior of P estimated from the fitting. The blue dots are the calculated P values at several temperatures. An abrupt sign change of P at T_M and a compensation point of P (T_P) at 220K are obtained from the fitting.

4. Conclusions

In summary, we have studied the spin Hall magnetoresistance in the Pt/$Co_{1-x}Tb_x$ bilayers, and found an anomalous temperature dependence of SMR in our samples that the SMR decrease dramatically near T_M and reach its minimum at another temperature near T_M. We attribute this phenomenon to the dramatically changed spin polarization of $Co_{1-x}Tb_x$ alloy which modulate the degree of the absorption for the longitudinal spin current flowing from Pt layer to $Co_{1-x}Tb_x$ layer. By fitting the anomalous SMR behavior with an extended SMR model, we deduce a temperature dependence of P. In light of this, we find a convenient mean to characterize the spin polarization behavior in the RE-TM ferrimagnets which is meaningful to the implementation of the ferrimagnets-based spin memory devices.

Acknowledgements

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