Spin Hall Magnetoresistance and Spin Hall effect in heavy metal, ferromagnet, antiferromagnet hybrid structures

Abstract

The development of new, energy-efficient storage and data processing based on electron spin is attracting widespread interest from the perspective of potential applications in so-called green IT. Heavy metals (HMs) demonstrating strong spin-orbital couplings, such as Pt and W, are being explored for use as sources of spin current. The spin current-generated SOT can switch the perpendicular magnetization of a FM layer in an external magnetic field collinear with the current, but this significantly limits its practical application. The solution to this problem is using an AFM layer, which, due to exchange bias coupling, can break the spatial symmetry of the system and makes it possible to switch the current magnetization of the ferromagnet without an external magnetic field. The dissertation describes contributions to the experimental investigation of thin-film spintronic heterostructures of the HM/FM, FM/HM/FM, and HM/FM/AFM types characterized by significant spin-orbital interactions. This thesis is based on four papers previously published in well-known scientific journals listed in the JCR database and one under preparation, in which the Author was the main experimenter.

The work is divided into two main parts, including a theoretical introduction and a discussion of the conducted experiments. The first part discusses the theoretical basis of the phenomena observed in the experiment, such as galvanomagnetic effects and effects related to spin-orbital interactions such as SMR, CIMS, SOC in HMs, SHE, and EB interaction.

The experimental part begins with describing the study of the HM/FM bilayer system using a series of samples in which the HM role was mainly W, Pt, and Au. At the same time, the FM layer was Co and CoFeB. The chapter discusses the results of determining the SMR and AMR contribution to magnetoresistance using the theoretical spin diffusion model. Next, we examined the SHA as a function of t_{Pt} in Pt(t_{Pt})/CoFeB(2) and [Pt/Ti]/Pt/CoFeB(2) systems (numbers in parentheses denote thickness in nanometers). Finally, we analyze the shape of the current switching loop in the Pt(4)/Co(1)/MgO(2) system using the phenomenological model considering the effect of DMI.

Then we focused on the trilayer Co(1)/Pt(0- 4)/Co(1) system, where the magnetization dynamics of the Co layers, AHE hysteresis loops, and spin-orbit interaction are discussed. The variable Pt thickness enables effective tuning of the ferromagnetic IEC. Spin Hall magnetoresistance SMR and anisotropic magnetoresistance AMR effects were analyzed based on the spin diffusion model. The effective SOT field (field-like (H_{FL}) and damping-like (H_{DL})) and the effective SHA as a function of the Pt thickness were determined and analyzed. The experimental results were compared with the predictions of the spin diffusion model. The asymmetry of Co/Pt and Pt/Co interfaces, IEC, and domain structure, enables both to achieve multilevel CIMS, potentially important for SOT memory applications.

The last section discusses the experimental results of SOT-induced CIMS in Pt(W)/Co/NiO heterostructures with varying thicknesses of W and Pt layers, a perpendicularly

magnetized Co layer, and an antiferromagnetic NiO layer. Using magnetization current switching, magnetoresistance measurements, and the AHE, the perpendicular and plane components of the EB were determined. An analytical model of the critical switching current as a function of HM thickness was then fitted to the obtained results for several nanodevices from both systems. As a result, the effective SHA and the effective perpendicular anisotropy were determined. In addition, the dependence of SMR as a function of Pt thickness was reproduced by fitting the theoretical model to the experimental data. Measurements by the field harmonic method allowed us to determine the SHA as a function of HM thickness in Pt(W)/Co(0.7)/NiO systems.

In addition, the technologies for fabricating Hall bar devices by the optical lithography are discussed, and methods for determining the SHA by angular and field harmonic methods are demonstrated, as well as the scheme of magnetization current switching experiments and methods of magnetoresistive measurements.

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