Influence of Ferromagnetic Interlayer Exchange Coupling on Current-Induced Magnetization Switching and Dzyaloshinskii-Moriya Interaction in Co/Pt/Co Multilayer System

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1. Introduction

Spin-orbit torque induced current magnetization switching (SOT-CIMS) provides an energy-efficient way of manipulating the magnetization in the ferromagnetic layers, which may lead to potential applications in storage devices. We present a detailed study the relationship among interlayer exchange coupling (IEC), Dzyaloshinskii-Moriya interaction (DMI), and multilevel magnetization switching within a Ti(2)/Co(1)/Pt(0-4)/Co(1)/MgO(2)/Ti(2) (thicknesses in nanometers) patterned into micrometer-sized Hall-bar devices. Here, the Pt is used as a source of the spin current, and as a nonmagnetic spacer whose variable thickness enables the magnitude of the ferromagnetic IEC to be effectively tuned [1]. From anomalous Hall effect (AHE), anisotropic magnetoresistance (AMR) and spin Hall magnetoresistance (SMR) measurements, we found that the increase in Pt thickness (t_{Pt}) leads to the reorientation of Co-magnetizations from the in-plane to the perpendicular direction at $t_{Pt} \approx 1.3$ nm. Further increase in Pt thickness, over 3 nm, reduces the ferromagnetic coupling and, consequently, two weakly coupled Co layers become magnetized orthogonally to each other. From analysis of the Stokes and anti-Stokes peaks (Fig.1a) spectra measured by the Brillouin light scattering (BLS), we quantify the effective DMI (Fig. 1b), and explore its potential role in magnetization dynamics and multilevel magnetization switching. Experimental findings show four distinct resistance states under an external magnetic field and spin Hall effect related spin current (Fig.2). We explain this phenomenon based on the asymmetry between Pt/Co and Co/Pt interfaces and the interlayer coupling, which, in turn, influences DMI and subsequently impacts the magnetization dynamics. Numerical simulations, including macrospin, 1D domain wall, and simple spin wave models, further support the experimental observations of multilevel switching and help uncover the underlying mechanisms. Our proposed explanation [2], supported by magnetic domain observation using polar-magnetooptical Kerr microscopy, offers insights into both the spatial distribution of magnetization and its dynamics for different IECs, thereby shedding light on its interplay with DMI.

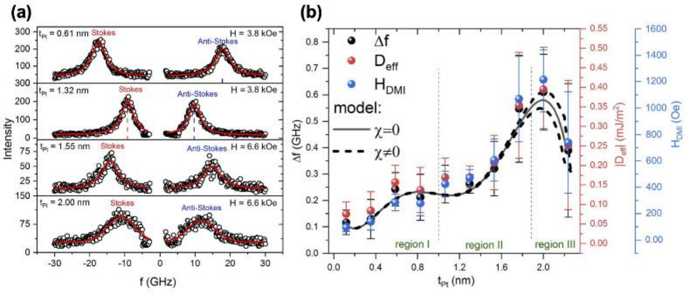

Figure 1. (a) BLS spectra of Stokes and anti-Stokes peaks and (b) extracted the effective DMI parameters (Δf, D_{eff},HDMI) as a function of Pt spacer thickness.

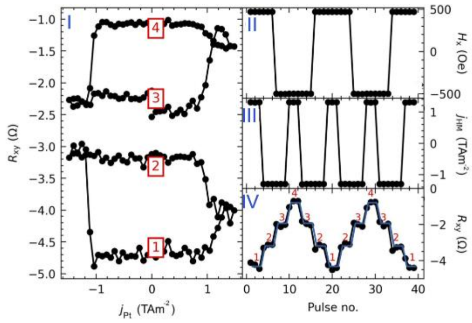

Figure 2. Four stable resistance (Rxy) states at $t_{Pt} = 1.55$ nm (I), obtained with the external magnetic field (II) and current pulses (III). Rxy levels in (IV) correspond to the Rxy levels of CIMS loops in (I).

References

[1] P. Ogrodnik et al., ACS Appl. Mater. Interfaces 13, 47019 (2021)
[2] K.Grochot et al., Sci Rep 14, 9938 (2024)

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