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Layer Thickness Dependence of Spin Orbit Torques and Fields in Pt/Co/AlO Trilayer Structures.

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Abstract

We measure the strength of two torques of even and odd symmetry via spin orbit interaction in Pt/Co/AlO with varying Pt thicknesses. Torque strength was measured by the effective field on the magnetization through an AC magnetization tilting technique. The even torque term is found to be stronger for increasing Pt thickness and closely related to the spin Hall effect and the bulk Pt layer. The odd torque is smaller than the even torque and exists for thin Pt thicknesses indicating its relation to the interface of Pt/Co.

Introduction

Magnetization control via spin orbit interaction [1][2] (SOI) in Pt/Co/AlO [3-5] and other similar trilayer structures have been attributed to the spin Hall effect [6-11] (SHE) as well as the Rashba effect [3-5][12-16]. It can be ascertained that through Rashba, and SHE there exists two distinct torques of odd and even symmetry [17] respectively about the magnetization. The even torque (τ_{even}) arising from the angular momentum exertion from a spin current [18][19] applied to the magnetization is represented by

$$\tau_{even} = \frac{I_S \hbar}{2e}(\hat{m} \times \hat{\sigma} \times \hat{m}) \propto (\hat{m} \times \hat{y} \times \hat{m}) \qquad (1)$$

where I_s is the spin current, m is the magnetization unit vector and σ is the spin unit vector. The odd torque resulting from the exchange interaction from a spin orbit coupled conduction electron and the local magnetization is given by

$$\tau_{odd} = \vec{H} \times \vec{M}, \qquad \vec{H} = \frac{\alpha_R}{\mu_B M} J(\hat{z} \times \vec{J_e}) \qquad (2)$$

$$\tau \propto (\hat{y} \times \hat{m})$$

where α_R is the Rashba or spin orbit parameter, J is an exchange coupling constant M is the saturation magnetization and μ_B is the Bohr magneton. Even and oddness is established by the order of magnetization vector product in eq. (1), (2). A further distinction between the τ_{odd} and τ_{even} is the physical origins stemming from bulk or interfacial aspects of the film which can be examined by varying thicknesses. In the present experiment, we attempt to measure the strength of the τ_{even} and τ_{odd} on the magnetization of Pt/Co/AlO in terms of an effective field H_L and H_T respectively by an AC induced magnetization tilting technique with several films of varying thickness [20].

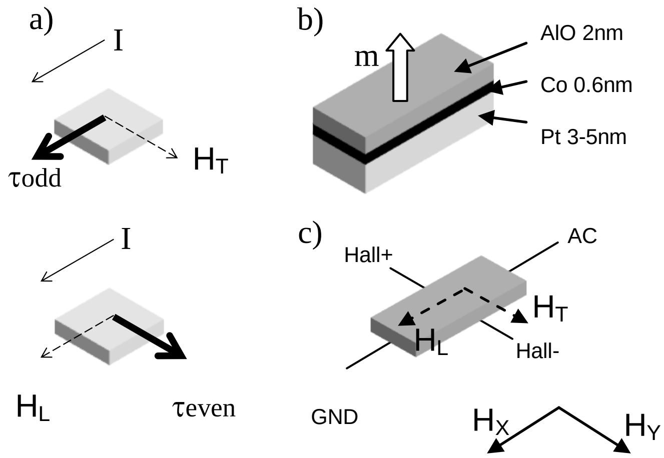

Fig 1. (a) orientations of τ_{odd} and τ_{even} and the associated field H_T, H_L orientations with respect to current. (b) the stack structure of Pt/Co/AlO with perpendicular magnetization. (c) Device configuration. H_{XY} are the orientations of the externally applied field.

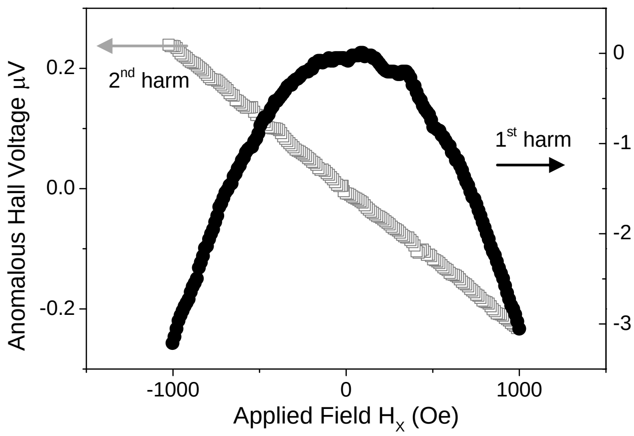

Fig 2. 1st and 2nd harmonic signals for Pt_3/Co/AlO measured with an external applied field in the x direction H_x. The 2nd harmonic signal was measured with a current amplitude of 10^8 A/cm^2 and a current amplitude of 5×10^7 A/cm^2 was used for the 1st harmonic.

Experiment

Pt, Co and AlO layers (bottom to top) were deposited onto an MgO (111) substrate through RF magnetron sputtering and shaped into 5 μm by 50 μm rectangles. Layer thicknesses were selected to be Pt 5 nm / Co 0.6 nm /AlO 2nm (Pt_5Co/AlO) and Pt 3 nm / Co

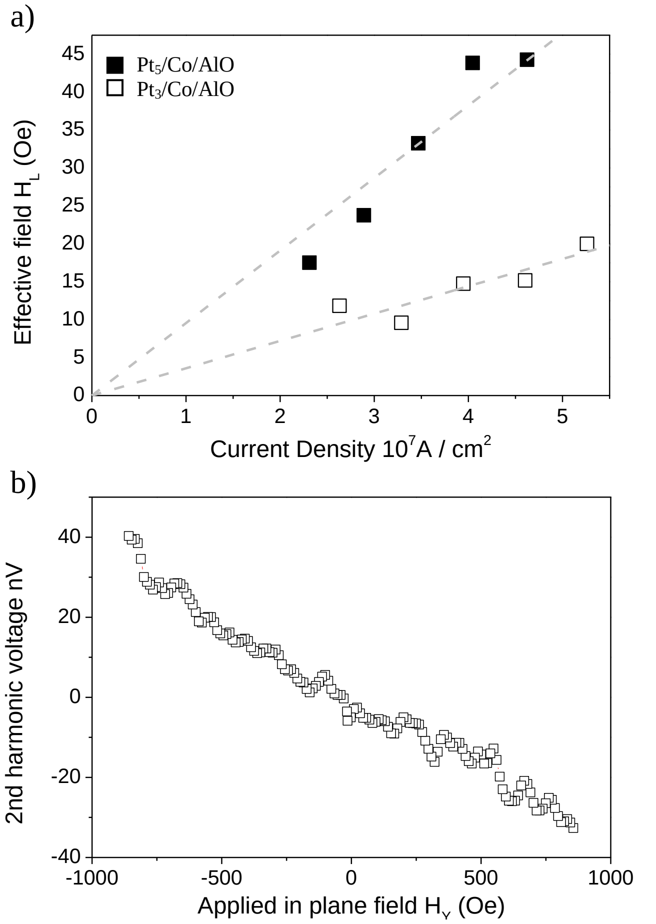

Fig 3. (a) comparison of the strength of the effective field H_L against the current amplitude. Values in tbl. 1 are calculated through the linear fit. (b) the 2nd harmonic signal of H_T. The strength of HT is significantly smaller than HL and exists only for $Pt_3/Co/AlO$.

	H_L	H_T
$Pt_3/Co/AlO$	45	11
$Pt_5/Co/AlO$	115	None detected

Tbl. 1. Values of the effective field measured for H_L and H_T for the samples with units of Oe cm^2 / 10^8 A.

0.6 nm / AlO 2 nm ($Pt_3/Co/AlO$). An AC current was applied longitudinally while the hall voltage was measured transversely Fig. 1c. The hall voltage signal contains a first harmonic signal corresponding to the AC current induced anomalous Hall voltage and a second harmonic component accounting for the tilting of the magnetization by H_L or H_T. To obtain the strength of $H_{L(T)}$, the 1st and 2nd harmonic hall voltages are measured by a lock in amplifier and an applied magnetic field $H_{x,(y)}$ is swept in the x (y) direction. The strength of $H_{L,(T)}$ can be given by [20]

$$H_{L(T)} = 2\frac{\partial V_{2\omega}/\partial H_{X(Y)}}{\partial^2 V_{\omega}/\partial H_{X(Y)}^2} \quad (3)$$

Discussion

For both samples, linear 2nd harmonic signal are observed for an applied field swept in the x direction which are then linearly fitted to determine the $(\partial V_{2\omega}/\partial H_X)$. Parabolic 1st harmonic are observed and fitted with a second order polynomial function to determine $\partial^2 V_{\omega}/\partial H_{X(Y)}^2$ from which H_L can be determined. Through several applied AC currents, it is determined that the longitudinal field H_L (associated with τ_{even}) is linear to the applied current and strongest at 115 Oe $cm^2/10^8$A for $Pt_5/Co/AlO$ and 45 Oe $cm^2/10^8$A $Pt_3/Co/AlO$ Fig. 3. The lower H_L found in $Pt_3/Co/AlO$ compared to $Pt_5/Co/AlO$ can be explained by the suppression of spin current generation by the spin Hall effect in Pt as the thickness approaches the spin diffusion length of 1.4 nm in Pt[9]. This affirms that τ_{even} measured by H_L is largely due to the spin Hall effect which is related to the bulk structure of the Pt layer and diminishes with decreasing Pt thickness. In $Pt_3/Co/AlO$, a transverse field H_T associated with τ_{odd} is detectable with an applied AC current of 1.2 10^8 A/cm^2 while no noticeable field is detected for $Pt_5/Co/AlO$. The lack of H_T in $Pt_5/Co/AlO$ layers is likely due to the current shunting from the Co and inhibiting any spin orbit torques associated with the Pt/Co interface. In addition to the two torques distinction with magnetization symmetry, the results also indicate that there is also a distinction between bulk and interface effects as well.

Conclusion

We measured the H_T attributed to the Rashba effect and τ_{odd}, as well as H_L attributed to the spin Hall torque and τ_{even}. H_L is strongest in $Pt_5/Co/AlO$ approximately 115 Oe $cm^2/10^8$A and in 45 Oe $cm^2/10^8$A $Pt_3/Co/AlO$. HT attributed to the Rashba effect and found to be Oe $cm^2/10^8$A in $Pt_3/Co/AlO$ at nonexistent in $Pt_5/Co/AlO$. We find that the H_L is related to the bulk structure of Pt while H_T originates from the interface between the Pt/Co. Additional measurements in varying thickness will be carried out to further examine these two torques and fields.

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