Optimizing Unconventional Trilayer SOTs for Field-Free Switching

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Spin-orbit torques (SOT) provide rapid and energy-efficient manipulation of magnetic states in emerging spintronic devices [1]. Conventional SOTs, generated through the spin Hall effect (SHE) in the bulk and the Rashba-Edelstein effect (REE) at the interface in non-magnet (NM)/ferromagnet (FM) bilayers, have proven successful in switching logical states in SOT magnetoresistive random-access memory (SOT-MRAM). By utilizing perpendicular magnetic anisotropy, these devices can achieve sufficiently high densities to challenge conventional memories such as SRAM. However, due to the symmetry of conventional SOTs, reversing a perpendicular magnetic state is challenging without additional assistance, such as an external magnetic field. A promising approach involves leveraging unconventional SOTs in FM/NM/FM trilayers to break this symmetry [2]. By introducing a second FM layer below the NM, additional spin currents can be obtained through spin-orbit coupling (SOC) in the FM bulk and the FM/NM interface, offering enhanced control over the resulting SOTs compared to bilayers.

We investigate unconventional SOTs in trilayers to identify optimal configurations for achieving field-free switching of perpendicularly magnetized FMs. We consider a FePt/Cu/CoFeB trilayer with an in-plane electrical current and CoFeB magnetization along the high-symmetry direction, along which the bilayer torques vanish. In the FePt bulk, spin currents are generated through the anomalous Hall effect (AHE) and anisotropic magnetoresistance (AMR) [3]. We compute spin currents generated through the REE, by considering spin-dependent scattering from a Rashba SOC potential at the FePt/Cu interface. We include the three spin current contributions in a spin drift-diffusion model, and calculate the SOTs acting on the CoFeB layer. Figure 1 illustrates the dependence of the SOTs on the FePt magnetization direction, revealing a strong angular dependence of the torques. In particular the REE is most pronounced, when the magnetization aligns with the current direction, suggesting it could be the dominating mechanism for magnetization reversal in CoFeB/Ti/CoFeB trilayers [4]. Figure 2 depicts the thickness dependence of out-of-plane spin torques on the FePt and Cu thickness. We observe that AHE and AMR torques increase with FePt thickness, reaching saturation points based on the spin-diffusion length, similar to the SHE.

In conclusion, we demonstrate that FePt/Cu/CoFeB trilayers can generate unconventional SOTs acting on the CoFeB layer, tunable by the FePt magnetization direction. Our spin drift-diffusion approach enables the study and optimization of SOTs concerning materials, layer thickness, and magnetization directions. Ultimately, coupling the computed torques with the Landau-Lifshitz-Gilbert equation is essential for investigating the resulting magnetization dynamics in order to demonstrate deterministic field-free switching.

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References

[1] X. Han et al., Appl. Phys. Lett. 118, p. 120502 (2021).

[2] J. Ryu et al., Nat. Electron. 5, p. 217 (2022).

[3] T. Seki et al., Phys. Rev. B 100, p. 144427 (2019).

[4] Q. Yang et al., Nat. Commun. 15, p. 1814 (2024).

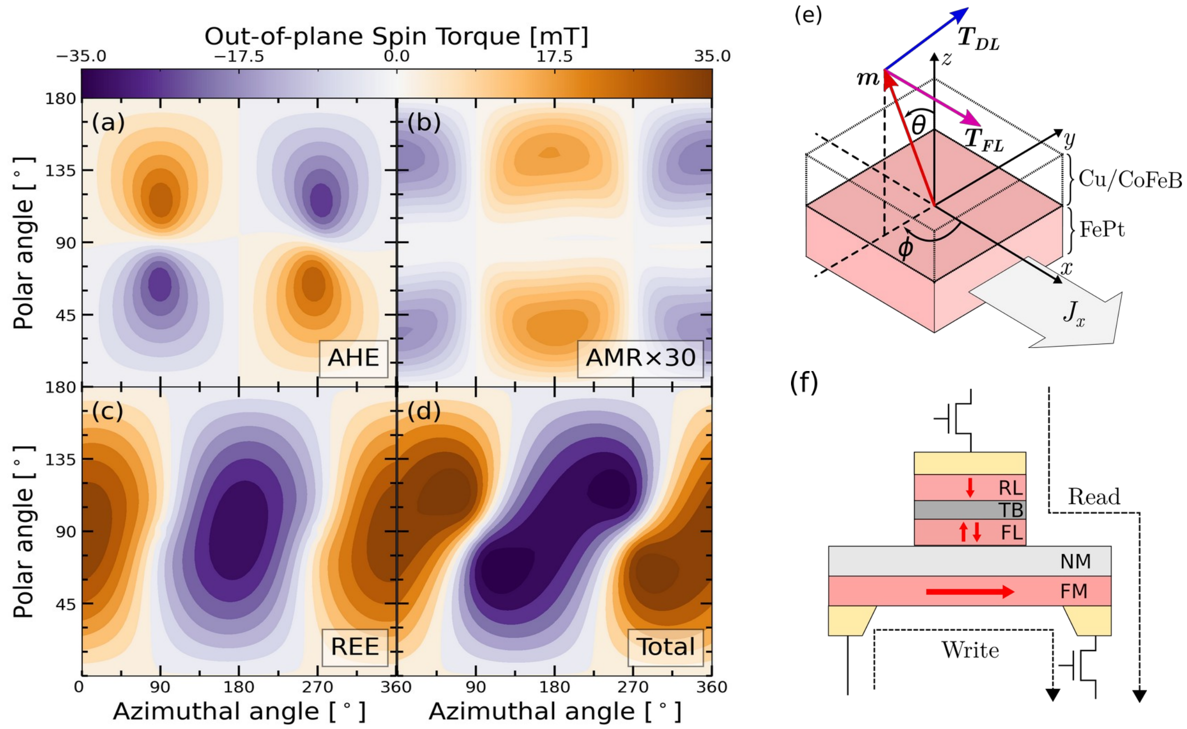

Figure 1: Out-of-plane spin torque in a FePt(10nm)/Cu(1nm)/CoFeB(1.2nm) trilayer, depicted in (e), as a function of the magnetization orientation of the FePt layer. A $5x10^{12}$ A/m² electrical current runs along *x*. The CoFeB magnetization is fixed along the *-y* direction, where conventional bilayer spin torques vanish. Panel (a), (b), (c), and (d) show the contributions from the AHE, AMR, REE, and total torque, respectively. A sketch of a SOT-MRAM cell based on the trilayer torques is shown in (f).

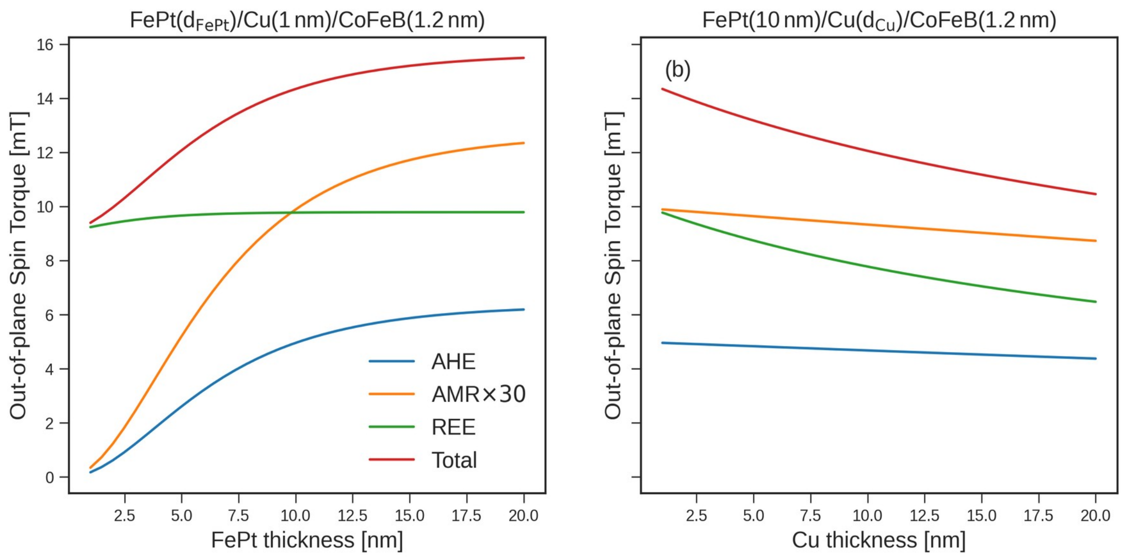

Figure 2: Dependence of the out-of-plane spin torque on the thickness of the FePt (a) and Cu layer (b) for the system depicted in Fig. 1(e). The FePt magnetization direction is given by θ = 60° and ϕ = 95°. The CoFeB magnetization direction is along -y.