Micromagnetic Modeling of SOT-MRAM Dynamics

Nils Petter Jørstad[1,2], Simone Fiorentini[1,2], Wolfgang Goes[3], Siegfried Selberherr[2], Viktor Sverdlov[1,2]

[1] *Christian Doppler Laboratory for Nonvolatile Magnetoresistive Memory and Logic at the*
[2] *Institute for Microelectronics, TU Wien, Gußhausstraße 27-29, A-1040 Wien, Austria*
[3] *Silvaco Europe Ltd., Cambridge, United Kingdom*

Spin-orbit torque magnetoresistive random access memory (SOT-MRAM) devices offer an attractive alternative to traditional memory devices due to their non-volatility, low power consumption, high switching speed and endurance [1]. These devices are composed of a magnetic tunnel junction (MTJ) and a SOT heavy metal (HM) layer. Applying a current across the HM layer generates bulk and interfacial spin torques acting on the ferromagnetic (FM) free layer (FL) in the MTJ, originating from the strong spin-orbit coupling present in HM layers, enabling manipulation of the FL magnetization. The symmetry of the SOTs introduces challenges for designing SOT-MRAM cells with perpendicular magnetization orientation required to achieve appropriate densities for memory applications. Several solutions have been proposed and demonstrated, some requiring external magnetic fields, additional symmetry breaking layers, or combination of SOT with spin-transfer torque (STT) [1,2]. To overcome the engineering challenges and to accelerate the development and adoption of SOT-MRAM devices, there is a demand for software capable of fast and accurate exploration of the design space of these devices.

We present results from a finite element micromagnetic simulator, devoloped with the goal to simulate FL magnetization reversal in realistic multi-layer, multi-terminal SOT- and STT-MRAM devices. The spin torques acting on the FL are calculated from solving coupled spin and charge drift-diffusion equations with appropriate boundary conditions. The HM layer receives special attention to accurately model spin torques originating from both bulk and interfacial spin-orbit coupling, constituting the spin Hall effect and the Rashba-Edelstein effect, respectiviely.

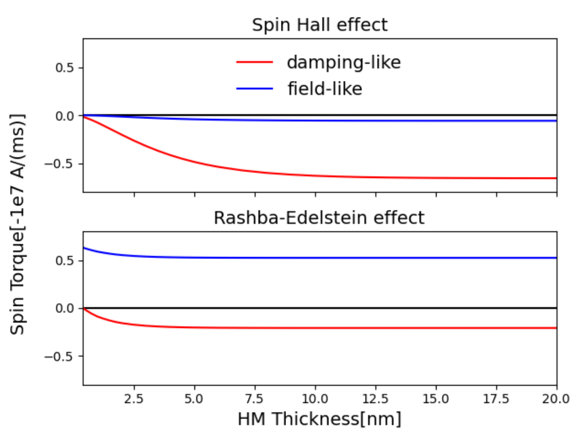

Figure 1: The calculated spin torques arising from the spin Hall effect and the Rashba-Edelstein effect as a function of the HM layer thickness. The material and simulation parameters were taken from [3].

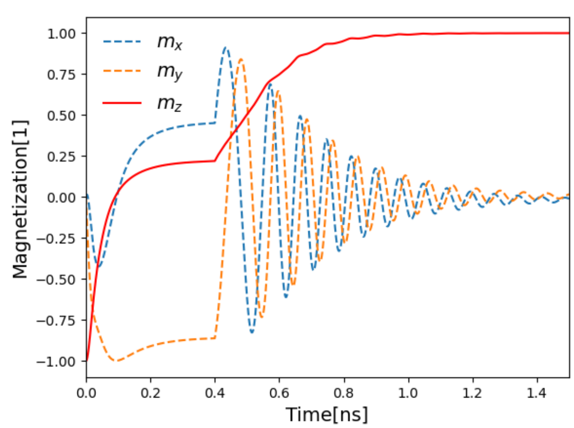

Figure 2: Switching simulation of the FL magnetization in a SOT-MRAM cell. The switching is initiated with a 0.4 ns SOT pulse and completed with STT. Material parameters consistent with CoFeB and Pt were used for the FL and HM layer, respectively.

References

[1] Q. Shao, et al.: Roadmap of spin–orbit torques. IEEE Trans. Magn., 57, 1–39 (2021).

[2] E. Grimaldi, et al.: Single-shot dynamics of spin–orbit torque and spin transfer torque switching in three-terminal magnetic tunnel junctions. Nat. Nanotechnol., 15, 111–117 (2020).

[3] P. M. Haney, et al.: Current induced torques and interfacial spin-orbit coupling: Semiclassical modeling. Phys. Rev. B, 87, 174411 (2013).