Spin Drift-Diffusion Approach for the Computation of Torques in Multi-Layered Structures

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Nonvolatile magnetoresistive memories are an emerging solution for the typically increasing standby power consumption and leakages of shrunk CMOS devices. They possess high endurance and operation speed and have already been shown to be suitable for both SRAM and flash memory applications [1][2]. The design of novel devices for specific applications is nowadays supported by simulation tools.

We implemented a finite-element solver for computing the torques acting in magnetoresistive devices via the spin and charge drift-diffusion approach using the open source library MFEM [3]. The solver was tested against known analytical solutions [4] in order to confirm the accuracy of the results. The comparison for the spin accumulation is shown in Fig.1, while the torques are reported in Fig.2. Both show perfect agreement with the theoretical predictions. The angular dependence of the torque in a spin valve structure, with non-magnetic leads (NM) and a non-magnetic spacer layer between the magnetic free (FL) and reference (RL) layers, follows perfectly the shape predicted in a ballistic scenario in [5]. By using a long spin-flip length, the extracted value of the spin polarization parameter P coincides with the parameter $\beta_\sigma = 0.9$ entering the drift-diffusion equations (Fig.3). In systems with a lower spin-flip length, the extracted P reduces to a value of around 0.5, and the drift-diffusion approach allows to introduce dependences on other system parameters: The dependence on the diffusion coefficient in the NM layers is reported in Fig.4. Another advantage of the drift-diffusion approach is the straightforward possibility to compute the torques acting in all the ferromagnetic layers in realistic structures. In [6], the failure of writing of the cell at a high current density was linked to the destabilization of the RL. We investigated how the picture of the torques acting on the RL is modified in the presence of a pinned layer (PL) antiferromagnetically coupled to the RL. We show that, while writing the FL from parallel (P) to anti-parallel (AP) FL-RL configuration, the additional PL torque, initially stabilizing the RL along the $+x$ axis (Fig.5), also helps to reduce the torque destabilizing the RL at the end of switching (Fig.6). These findings suggest that the presence of the PL can help to prevent unwanted switching of the RL, but does not solve the issue completely. The computation of the torques acting in multi-layered structures and the understanding of their dependence on system parameters enables the efficient simulation of emerging magnetoresistive devices.

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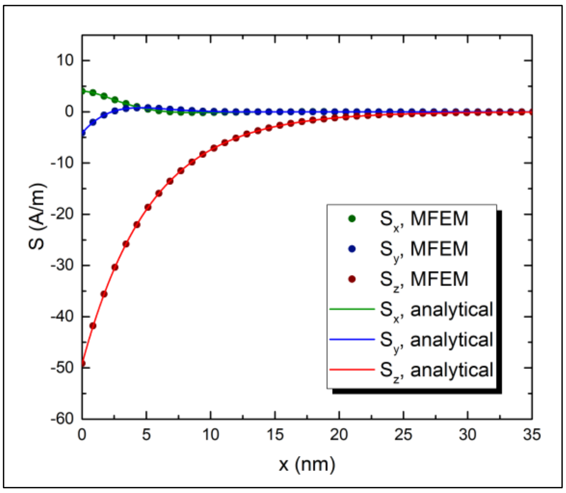

Fig.1: Comparison between the spin accumulation computed analytically (solid lines) and using our Finite Element solver (dots). The analytical solution is properly reproduced.

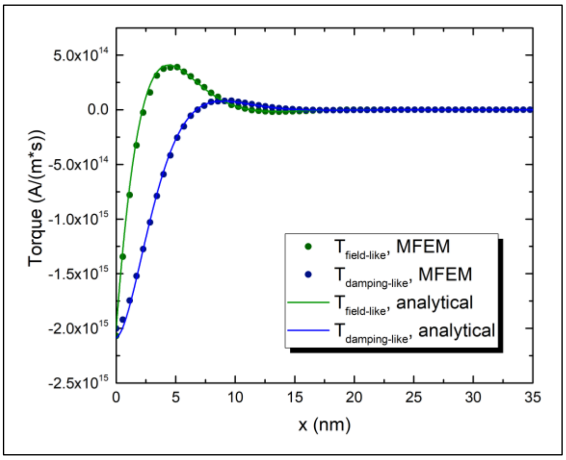

Fig.2: The torque computed using the numerical solution (dots) is in very good agreement with the theoretical one (solid lines).

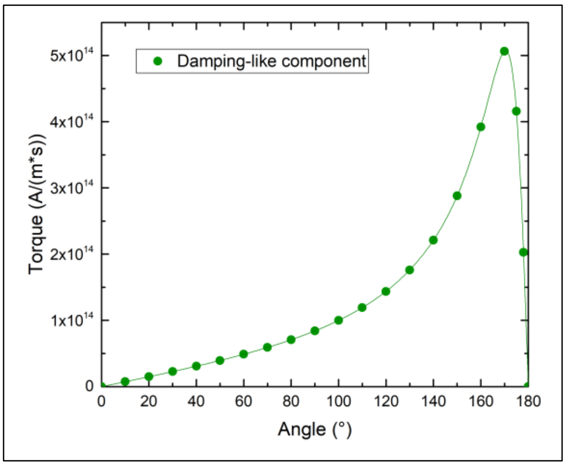

Fig.3: Angular dependence of the torque for a spin-flip length of 100 nm. The line represents a fit of the data with the equation reported in [5].

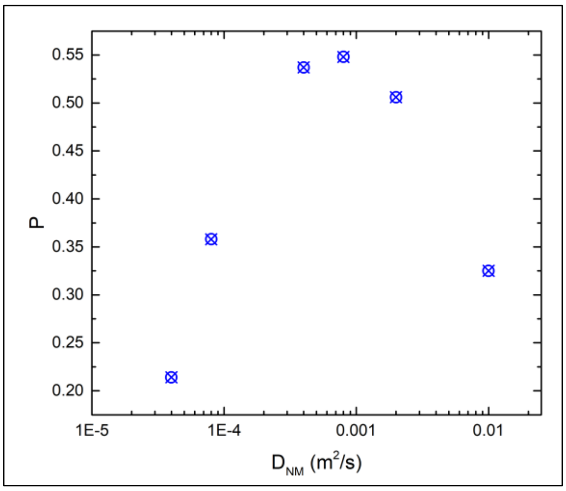

Fig.4: Dependence of the polarization parameter P, extracted from fitting the angular dependence of the torque, on the diffusion coefficient in the non-magnetic layers.

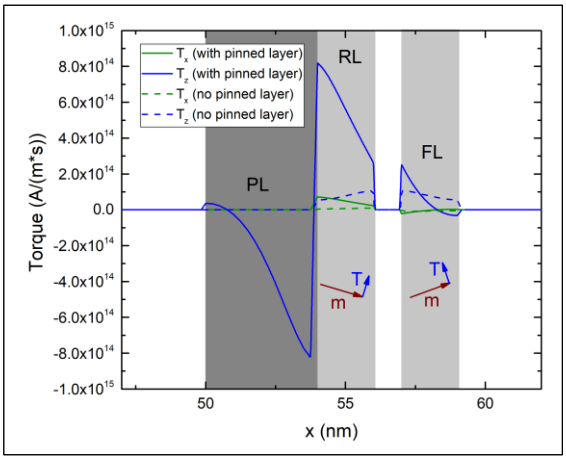

Fig.5: Damping-like torque in a multi-layered structure with quasi-parallel magnetization vectors in the FL and the RL. The solid lines are computed including PL, while the dashed lines do not include PL.

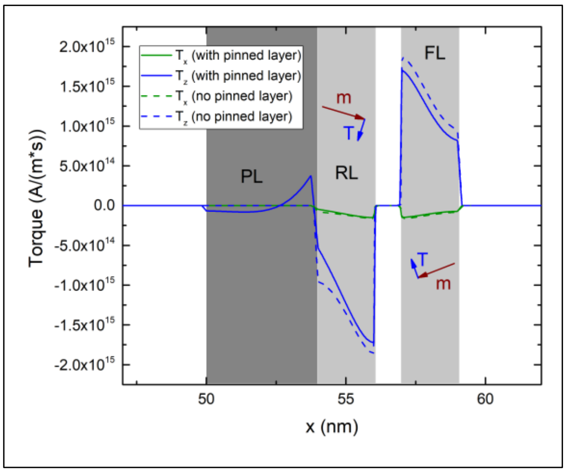

Fig.6 Damping-like torque in a multi-layered structure with quasi-antiparallel magnetization vectors in the FL and the RL. The solid lines are computed including PL, while the dashed lines do not include PL

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