Design Support for Ultra-Scaled MRAM Cells

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The design of advanced, single-digit shape-anisotropy MRAM cells [1] requires accurate evaluations of spin currents and torques in magnetic tunnel junctions (MTJs) with composite elongated free layers (FLs). For this purpose, we generalized the coupled spin and charge drift-diffusion approach previously successfully applied to nanoscale metallic multilayer structures [2][3] to accurately evaluate the spin and charge transport and the torques acting in an MTJ on a FL composed of several pieces separated by MgO tunnel barriers (TBs) [1].

To evaluate the charge current density, we model the TB as a poor conductor with a local resistance being dependent on the relative orientation of the magnetization across the TB. We demonstrated that the expected dependence of the current density flow on the magnetization state is reproduced [4].

To model correctly the spin current density, the coupled spin and charge drift-diffusion approach must be supplemented by *appropriate boundary conditions for the spin current at the TB interfaces*. With the addition of such conditions, the expected dependence of the torques on the relative angle between the magnetization vectors [5][6] is reproduced. Our approach can be generalized to model non-linear bias dependences of the torques as an on-demand feature by making the interface polarization parameters depend on the voltage. The observed voltage dependencies of both the damping-like and field-like torques are thereby properly reproduced.

The magnetization in elongated FLs of ultra-scaled MRAM cells during switching is highly nonuniform along the FL as the formation and propagation of a domain wall is expected. The additional torques acting in the presence of a domain wall are usually modeled by the Zhang and Li [7] expression. We demonstrate that, in the presence of a TB, the Slonczewski and Zhang and Li torques are *not additive* and must be treated on equal footing to correctly describe the torques acting on nonuniform magnetization in elongated FLs with several MgO TBs. Our simulations of the magnetization dynamics in composite elongated FLs agree well with recent experimental demonstrations of switching of ultra-scaled MRAM cells.

[1] B. Jinnai *et al., Proc. of the IEDM*, pp. 24.6.1-24.6.4, 2020.
[2] C. Abert *et al*., *Sci. Rep.*, vol. 5, p. 14855, 2015.
[3] S. Lepadatu, *Sci. Rep.*, vol. 7, p. 12937, 2017.
[4] S. Fiorentini *et al.*, *Sol.-St. El.*, vol. 186, p. 108103, 2021.
[5] J. C. Slonczewski, *Phys. Rev. B*, vol. 71, p. 024411, 2005.
[6] M. Chshiev *et al.*, *Phys. Rev. B*, vol. 92, p. 104422, 2015.
[7] S. Zhang *et al.*, *Phys. Rev. Lett.*, vol. 93, p. 127204, 2004.