21. A Dynamical Approach to Fast and Reliable External Field Free Perpendicular Magnetization Reversal by Spin-Orbit Torques

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Spin-orbit torque (SOT) magnetoresistive random access memory (MRAM) is a viable candidate for a non-volatile replacement of high level caches, as it delivers high operation speed complemented with large endurance. However, for a deterministic SOT switching of a perpendicularly magnetized free layer (FL) an external magnetic field is required. In a recent SOT-MRAM implementation on a 300mm wafer the field was created by a cobalt nanomagnet added to each memory cell [1]. The magnetic field free switching solutions are based on breaking the cell mirror symmetry, which can be performed by coupling the FL to a ferromagnet [2] or an antiferromagnet (AF) [3], by designing the crystal structure [4], or purely geometrically by shaping the device appropriately [5]. Recently, interesting field-free schemes based on stacking of ferromagnetic layers [6] and heavy metals with opposite Hall angles [7] have been demonstrated. However, dynamical approaches to induce the effective magnetic field were not explored. By means of extensive micromagnetic simulations, we demonstrate that an application of the two perpendicular current pulses in a Hall bar configuration results in fast, reliable, and magnetic field free perpendicular magnetization reversal of a rectangular FL. While the first current pulse forces the magnetization in-plane perpendicular to the long rectangle edge, the second pulse deviates the magnetization towards one of the elongated rectangle sides. Then, the magnetization experiences the shape anisotropy field which plays the role of an external field and makes the switching deterministic. The speed of switching is boosted, when the second current is applied not to the whole FL, but to a part of it. In this case, the FL part subject to SOT of the second current is quickly rotated in-plane along the long edges of the rectangle. The field from this part makes the rest of the FL to rotate about it, moving the magnetization deterministically from its in-plane orientation, thus completing the switching. We demonstrate that the dynamic scheme does neither require a perfect current pulse synchronization nor precise patterning of the second current line.

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