# Switching Current Reduction in Advanced Spin-Orbit Torque MRAM

Viktor Sverdlov, Alexander Makarov, and Siegfried Selberherr
Institute for Microelectronics, TU Wien, Gußhausstraße 27-29, 1040 Vienna, Austria
{Sverdlov|Makarov|Selberherr}@iue.tuwien.ac.at

*Abstract*—**Several paths to reduce the switching current by spin-orbit torques in an in-plane MRAM structure are analyzed. The switching by two orthogonal current pulses complemented with an interface-induced perpendicular magnetic anisotropy allows reducing the switching current and to achieve sub-500ps switching.**

***Keywords-Spin-orbit torque; MRAM; switching; perpendicural magnetic anisotropy***

## I. INTRODUCTION

Magnetoresistive random access memory (MRAM) based on spin-transfer torque (STT) switching possesses several important advantages: non-volatility, purely electric operation, long retention time, infinite endurance, and the capability to operate in harsh environments. It is also fast compared to other types of non-volatile memories: flash and phase change memory cannot operate at 10ns speed. This speed is sufficient to replace the main computer memory – DRAM. However, to compete with SRAM in the caches of hierarchical multi-level processor memory the switching must be further accelerated down to the sub-ns regime [1]. Spin-orbit torque (SOT) based MRAM is an electrically addressable non-volatile memory combining high speed and high endurance and is thus suitable for applications in caches [2]. Although the high switching current is not flowing through a magnetic tunnel junction but rather through a heavy metal line under it, the currents are still high, and their reduction is the pressing issue in the field of SOT MRAM development.

## II. METHOD AND RESULTS

The investigated memory cell is shown in Fig.1. It consists of an in-plane magnetized MTJ with its free layer lying on top of the heavy metal Line 1 of 3nm thickness. The dimensions of the free layer are $52.5\times12.5\times2\text{nm}^3$. Another heavy metal Line 2 with an overlap NM2 from the right side less or equal to the total free layer width 52.5nm serves to apply the second perpendicular current pulse and the spin-orbit torque associated with it. In this case only the current pulse through Line 2 with the complete overlap NM2=52.5nm is applied, the magnetization can be switched deterministically without an external magnetic field [3], provided the pulse is sufficiently long and the current is high enough. Switching by the current through Line 1 alone is not possible unless an external magnetic field is applied to break the mirror symmetry [4]. The torque due to the pulse through Line 2 switches the magnetization deterministically; however, the current is large. The reduction of the current by simply reducing the overlap NM2<52.5nm results in a smaller area where the torque is active and a longer switching time (Fig.2). This can be compensated by a larger current running through Line 2, as seen in Fig.3; however, this results in an unwanted current density increase. Next, we apply the current pulse through Line 1 just before the second pulse through Line 2 [5]. We assume equivalent pulses of 200ps duration. The first pulse through Line 1 creates an initial deviation of the magnetization from its equilibrium direction along the OX axis. This makes the torque from the second pulse efficient from the beginning thus removing the incubation period. The two-pulse scheme allows reducing the switching current by a factor of 3 as compared to single pulse switching of a similar duration. Fig.4 demonstrates that the optimal width NM2 of Line 2 is around 12.5 nm as its further reduction results in a high current density.

To further decrease the switching current, a perpendicular magnetic field typically developed at the MgO/CoFeB interface is introduced [6]. The perpendicular anisotropy compensates the large demagnetizing contribution when the magnetization is out of plane. However, the perpendicular anisotropy may compromise the temperature stability of the in-plane structure, when its value $K_1$ is too large. Fig.5 shows the time evolution of the magnetization projection on the direction OZ perpendicular to the structure, for several $K_1$, while Fig.6 displays a typical dependence of the in-plane magnetization along the easy axis.

In conclusion, the introduction of the perpendicular anisotropy $K_1$ into the two-pulse switching scheme allows reducing the switching current from 180µA to 30µA, while achieving fast sub-0.5ns writing suitable for cache applications.

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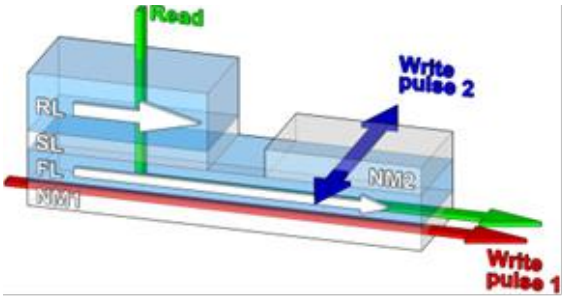

Figure 1. Schematic of the in-plane SOT MRAM cell. The free layer of an MTJ is grown above the heavy metal Line 1, through which the current pulse is applied. Line 2 serves to conduct the perpendicular current Write pulse 2.

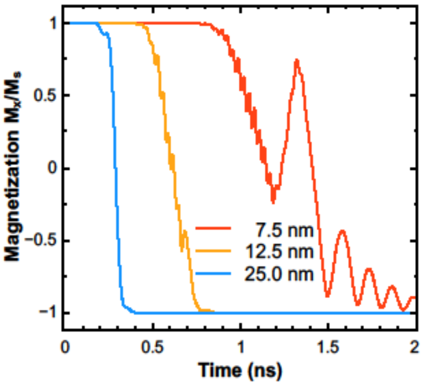

Figure 2. Time dependent magnetization evolution for several values of the second wire NM2 overlap. The current is scaled with NM2 and is equal to 180μA for NM2=25nm, 90μA for NM2=12.5nm, and 54μA for NM2=7.5nm.

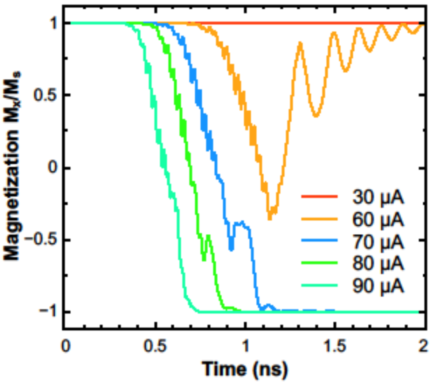

Figure 3. Time evolution of the magnetization for several values of the current through Line 2 with NM2=12.5nm. The current through Line 1 is zero.

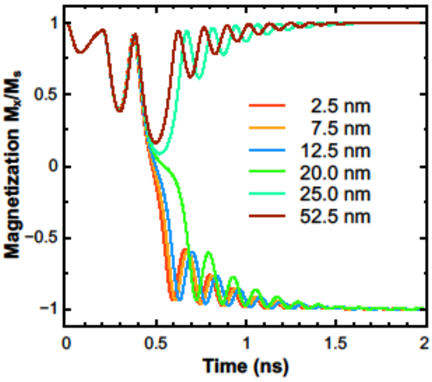

Figure 4. The magnetization dynamics for several overlap lengths NM2. Two consecutive perpendicular pulses with 30μA current and 200ps duration are applied.

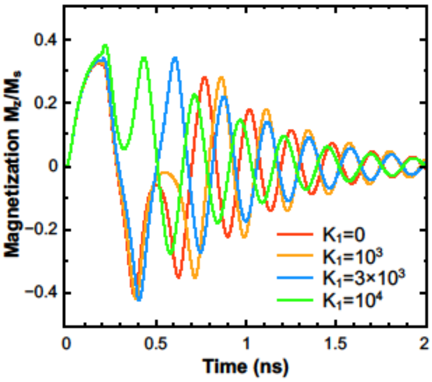

Figure 5. Time dependence of the magnetization projection on the perpendicular OZ axis, for several values of the interface-induced perpendicular anisotropy.

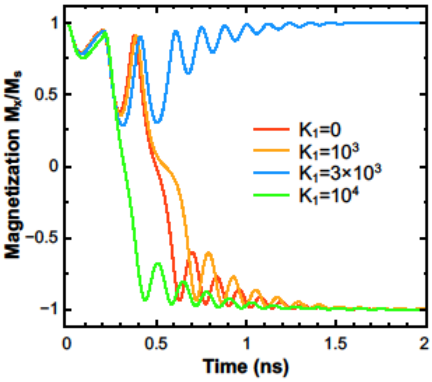

Figure 6. Adding perpendicular magnetization if a two-pulse scheme allows to reduce the current by a factor of 6 for sub-0.5ns switching.