Fast, Reliable, and Field-free Perpendicular Magnetization Reversal in Advanced Spin-Orbit Torque MRAM by Two-pulse Switching

Viktor Sverdlov[1], Alexander Makarov[2], and Siegfried Selberherr[2]

[1]*Christian Doppler Laboratory for Nonvolatile Magnetoresistive Memory and Logic at the*
[2] *Institute for Microelectronics, TU Wien, Gußhausstraße 27-29, 1040 Vienna, Austria*
Selberherr@TUWien.ac.at

The spin-orbit torque magnetic random access memory (SOT-MRAM) combines non-volatility, high speed, and high endurance. It is suitable for applications in caches to mitigate the increase of dissipated power and to facilitate instant-on architectures. However, its development is still hindered by the need of an external magnetic field for deterministic switching of perpendicular magnetic layers [1]. We demonstrate that the switching scheme by means of two orthogonal current pulses previously suggested for in-plane structures [2] allows achieving deterministic, fast (sub-500ps), and magnetic field-free switching in perpendicular free magnetic layers of rectangular shape [3].

A perpendicularly magnetized free layer of the dimensions $52.5\times12.5\times2\text{nm}^3$ is grown on top of a heavy metal wire NM1 of 3nm thickness (Fig.1). A NM2 wire with a non-complete overlap from the right side of the free layer serves to apply the second perpendicular current pulse and the spin-orbit torque associated with it. First, a 100ps short and 100µA strong current pulse is applied through NM1 (Fig.1). The consecutive perpendicular current pulse of varying strength and duration is applied through NM2. The time dependent magnetization dynamics for 20 realizations is shown in Fig.2. Although the NM2 current is large (1mA), it does not provide a deterministic switching as it only orients the magnetization in-plane. However, when the current is decreased to 200µA, the switching becomes deterministic, for all 20 realizations (Fig.3). If the current of the "Write pulse 2" is further reduced to the value of that in the "Write pulse 1", the switching becomes unreliable (Fig.4). However, if the width of NM2 is reduced to 12.5nm (width of NM1), the switching becomes deterministic again (Fig.5). Fig.6 shows the dependence of the switching time on the NM2 width, for several durations of "Write pulse 2". Importantly, for NM2 widths around 12nm the switching is not only fast, but also not very sensitive to the width and pulse duration fluctuations.

[1] S. Fukami et al., Nature Nanotechnol. **11**, 621 (2016)
[2] A. Makarov et al., Semicond. Sci. Technol. **41**, 113006 (2016)
[3] V. Sverdlov et al., Solid-State Electron., submitted (2018)

978-3-901578-32-8

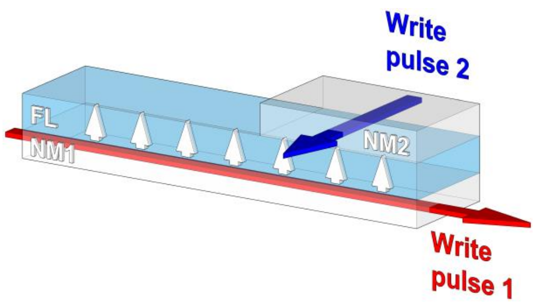

Fig.1: Perpendicular SOT-MRAM memory cell with a 52.5nm × 12.5nm × 2nm free layer. After the 100ps/100μA current pulse the second perpendicular pulse is applied.

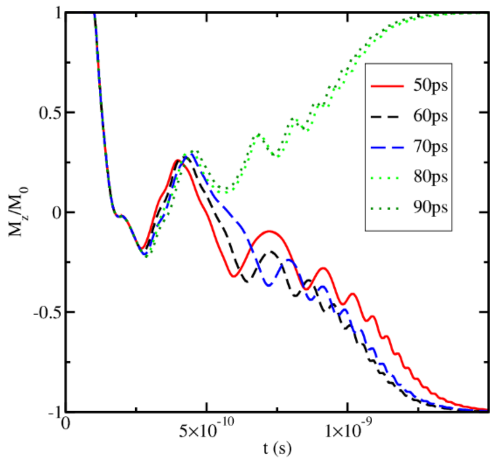

Fig.4: Randomly chosen realizations for a current of 100μA in the second pulse, for several pulse durations. Surprisingly, the switching fails for longer pulses. NM2 has a complete overlap with FL.

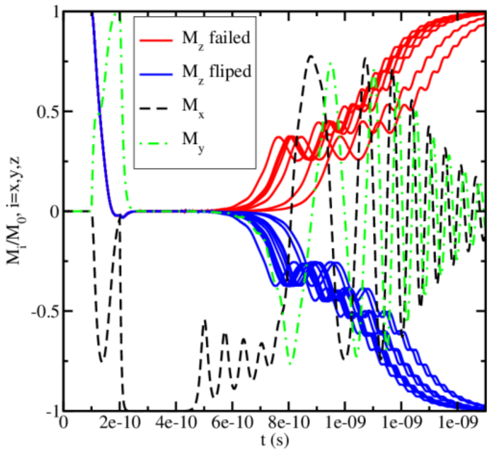

Fig.2: Time evolution of the magnetization in two-pulse switching (second pulse 1mA/200ps). 20 different switching realizations obtained after 100ps initial thermalization are shown.

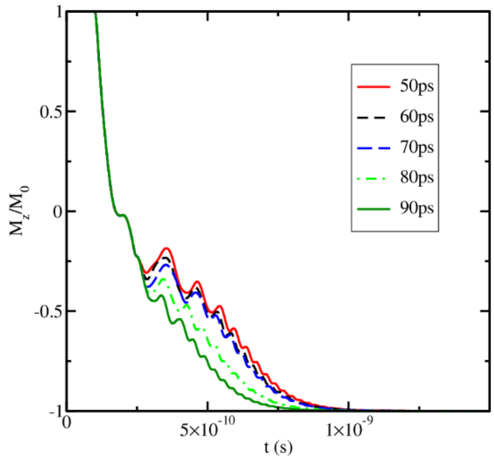

Fig.5: For equal wires NM1 and NM2 (NM2 has a partial overlap) and equal currents of 100μA the switching becomes fast and deterministic.

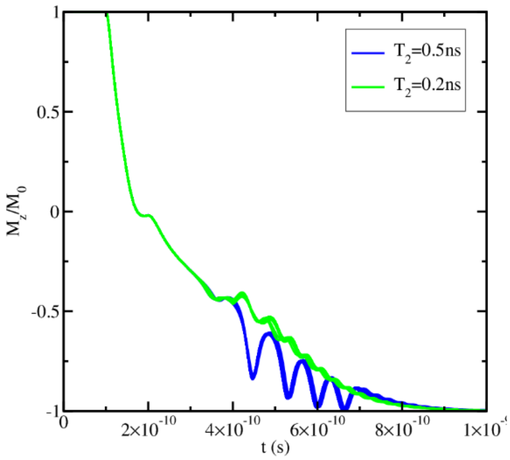

Fig.3: The current in the second pulse is 200μA. All 20 realizations switch evenly, almost without dispersion. The switching is deterministic. NM2 overlaps fully with FL.

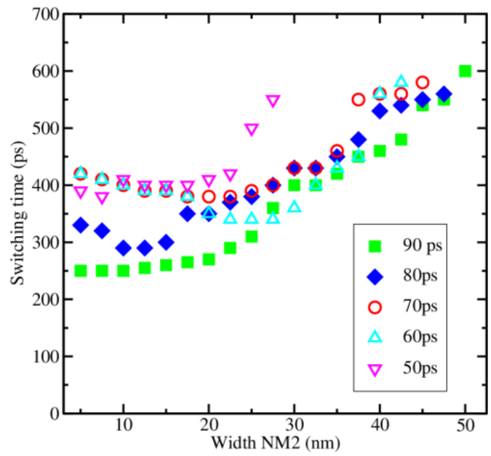

Fig.6: The switching time as a function of the NM2 width. The NM2 width of 12.5nm is optimal as it guarantees fast, robust, and deterministic switching.

978-3-901578-32-8