Robustness of the Two-Pulse Switching Scheme for SOT-MRAM

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The downscaling of semiconductor devices has sustained a continuous increase in density and performance of memories. However, this has also been followed by an increasing power consumption. Besides charge, the spin is also an inherent property of the electron, which yields energy-efficient and nonvolatile alternatives to charge-based memories [1]. Spin-orbit torque magnetoresistive random access memory (SOT-MRAM) combines non-volatility, high endurance and high speed, and is thus particularly suited for applications in caches [2].

In this work, we demonstrate the robustness of a magnetic field-free two-pulse switching scheme previously proposed [3] to switch a perpendicularly magnetized free layer (FL) by SOT. The structure consists of a perpendicularly magnetized square FL (25x25x2 nm^3) grown on top of a heavy metal wire (NM1) with another heavy metal wire (NM2) partially on top of the FL (Fig. 1). Two orthogonal current pulses of duration T_1 / T_2 are applied through the wires NM1/NM2 (Fig. 2). τ is the delay/overlap between the pulses, which models the non-idealities of signal propagation leading to pulse synchronization failures. Considering perfectly synchronized pulses (τ=0), the switching is deterministic for a broad range of the second pulse duration (Fig. 3). A fast (~0.6 ns) switching time is obtained in the range of 30% - 50% of overlap between the NM2 wire and the FL (Fig.4). The impact of pulse delay/overlap on the magnetization is shown in Fig.5. A delay leads to an increase, while a short overlap can even reduce the switching time, as summarized in Fig. 6. Although a delay leads to a longer switching time, for a delay corresponding to as large as 50% of the pulses' durations (50ps /100ps), the switching time increases by only 10%, while for an overlap it improves by 10%. This shows that the scheme is extremely robust with respect to pulse timing variations, a very important feature for practical implementation.

[1] O. Golonzka *et al.,* Proc. IEDM, 36.2.1 (2018).
[2] S. Lee *et al.*, Proc. IEEE **104**, 1831 (2016).
[3] V. Sverdlov *et al.*, Solid-State Electron. **155**, 49 (2019).

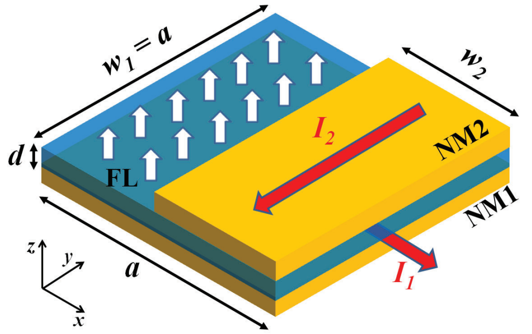

Fig.1: Two-pulse switching scheme applied to a perpendicularly magnetized square free layer with partial top heavy metal overlap.

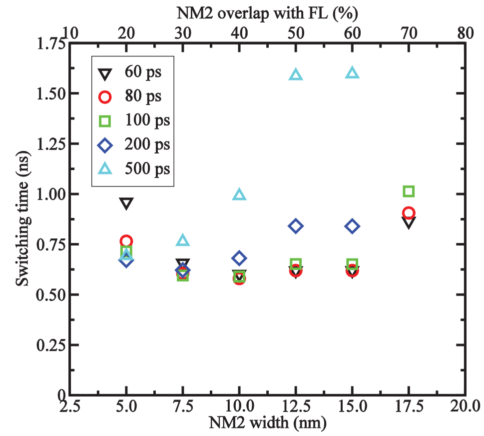

Fig.4: Switching times as function of the NM2 wire width (w_2), for several second pulse durations (T_2). T_1 = 100 ps and τ = 0.

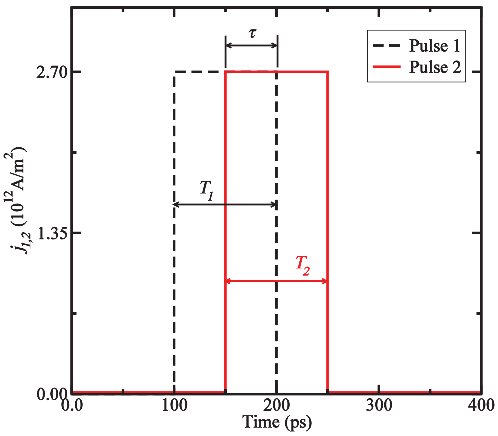

Fig.2: Current pulses applied to the bottom and the top heavy metal. T_1/T_2 is the width of the first/second pulse and τ is the delay/overlap between the pulses. A negative τ represents an overlap, while a positive value represents a delay between the pulses.

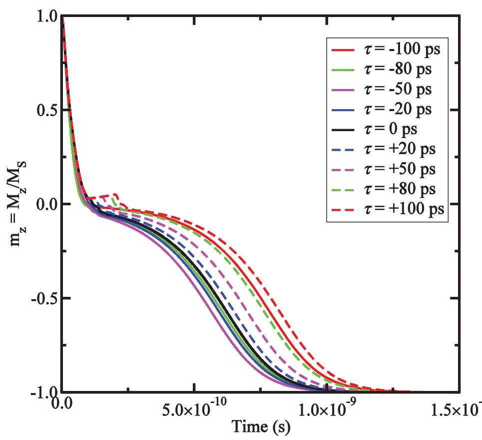

Fig.5 Magnetization as a function of time for several values of overlap/delay between the first and the second current pulse. A short overlap reduces the switching time. The switching is still reliable for a wide range of delay. T_1 = T_2 =100 ps.

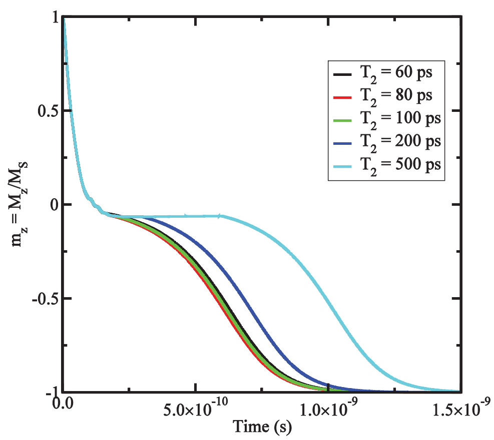

Fig.3: Average magnetization (z-component) of 20 switching realizations for w_2 = 10 nm. Reliable switching is observed for all T_2. T_1 = 100 ps and τ = 0.

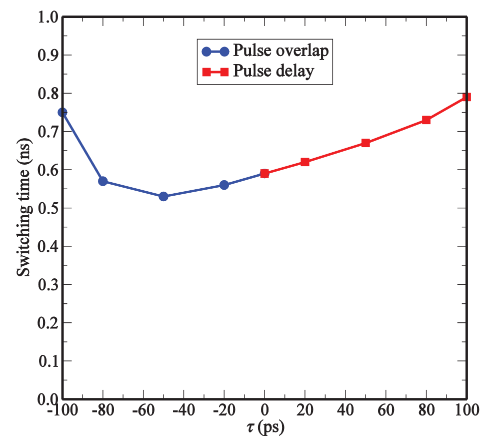

Fig.6: Switching time as function of the delay/overlap between the first and the second pulse. $\tau < 0$ represents an overlap and $\tau > 0$ indicates a delay between the pulses. T_1 = T_2 = 100 ps.