A Novel Method of SOT-MRAM Switching

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Three-terminal memory cell structures based on a magnetic tunnel junction (MTJ) are promising candidates for future generations of magnetic memory [1]. In particular, three-terminal devices with spin-orbit torque (SOT) switching have already been proposed [2]. Typically, a SOT memory cell is an MTJ fabricated on a heavy metal channel with large spin-orbit interaction, wherein the free layer is in direct contact with the heavy metal channel. Spin torque generated by a current through the channel induces the magnetization switching. However, one shortcoming is that an external magnetic field is required to provide deterministic switching [3]. The second shortcoming of this memory type compared to the conventional spin transfer torque memory is that it demands more space and thus leads to a lower area density because of the second transistor required for writing [1]. In this work we propose an external magnetic field free method of soft magnetic layer switching based on two consecutive orthogonal sub-nanosecond in-plane current pulses. We investigate the proposed method by means of extensive micromagnetic simulations and discuss a possibility of using this method in building 1Transistor-1MTJ memory cells in a cross-point architecture.

In the proposed method the soft magnetic layer switching is governed by the torques generated in the metal channel by charge currents (Fig.1). The first pulse is necessary for tilting the magnetization of the free layer from its stable state in order to create a small initial angle. The second pulse is used for switching the free layer to a new state (Fig.2). As our simulations show (Fig.3a), the switching probability for the proposed write scheme is 1, when the second pulse width is in the range 2.63-9.1ns. Furthermore, we demonstrated the absence of switching in the case of using only one of the two pulses, as this switching is an unwanted event and leads to the loss of information in half-selected cells in a cross-point architecture (Fig.3b, Fig.3c). Finally, potential memory cells architectures with this switching method are shown in Fig.4.

[1] D. Suzuki et al., Jpn.J.Appl. Phys. **54**, 04DE01 (2015).

[2] S. Fukami et al., INTERMAG BB-06 (2015).

[3] L. Liu et al., Phys.Rev.Lett. **109**, 096602 (2012).

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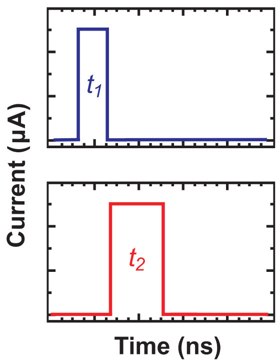
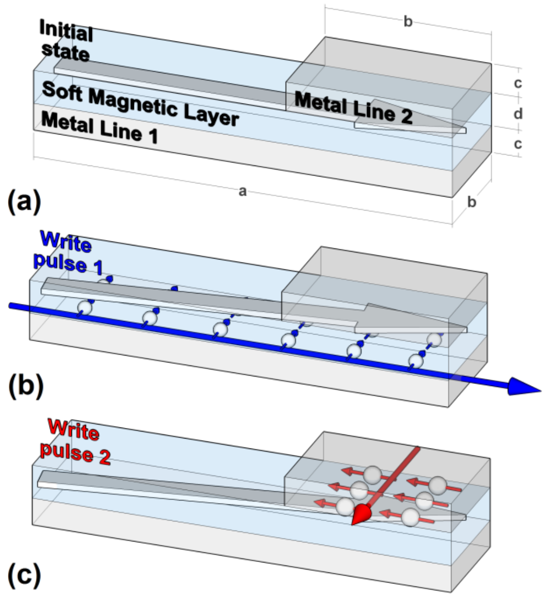
Figure 1. Schematic illustration of the proposed method of soft magnetic layer switching. In (b), (c) The direction of the charge current is shown by big arrows, the direction of the spin current is given by small arrows.





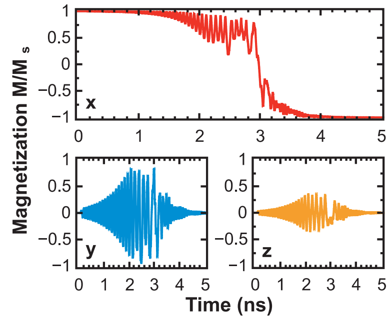


Figure 2. Magnetization components as a function of time for the "two write pulses" scheme: (top) *x*-component; (bottom - left) *y*-component; (bottom - right) *z*-component. The current is 10μA.

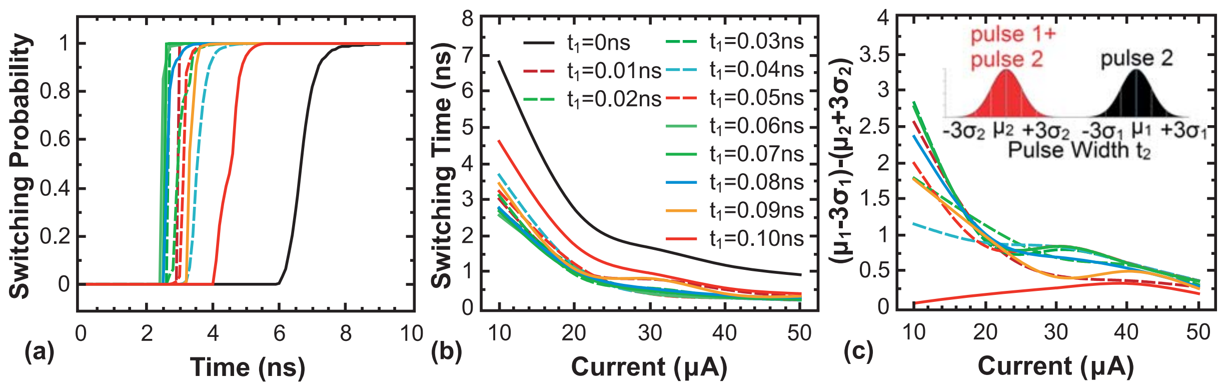


Figure 3. (a) Switching probability for the proposed scheme as a function of time for different values of pulse width t_1. For estimating the switching probability, 250 simulations of switching were performed with each pulse width t_1; (b) Switching time as a function of current for different values of pulse width t_1; (c) The difference between the minimum value of the pulse width t_2 required to achieve a non-zero probability of switching by using the "write pulse 2" scheme (μ_1-3σ_1) and a value of the pulse width t_2 needed to achieve guaranteed switching with the "two write pulses" scheme (μ_2+3σ_2) as a function of current.

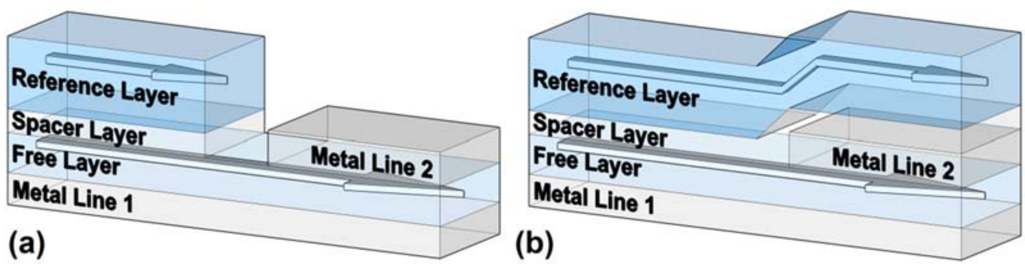


Figure 4. Schematic illustration of two memory cell structures with switching of the free layer based on the proposed "two write pulses" scheme.