# Nanosecond Spin-Orbit Torque Switching of Three Terminal Magnetic Tunnel Junctions with Low Write Error Rate


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## Abstract:

**Recently we reported that a significant reduction of critical switching current $I_c$ can be achieved in tungsten-based three-terminal magnetic tunnel junctions with atomic Hf layer modification of the interfaces. This has stimulated additional work to further optimize these nanoscale structures to achieve still lower critical currents and higher speed switching for future cache memory applications. Here we report on a systematic study of the micromagnetic factors that determine both the intrinsic time scale of this nanosecond switching behavior and the degree of symmetry between the fast switching from parallel (P) to anti-parallel (AP) and the reverse. Using a modified geometry of the nanopillar magnetic tunnel junction structure we find that we are able to tune the relative speeds of reversal between two polarities. We have also designed a new spin Hall channel geometry to achieve a major reduction in channel resistance. This enables us to examine write error rates in the very high pulse current regime, $I >> I_c$. (See Figure 1.) The results of these studies further demonstrate the feasibility of this type of three-terminal spin-orbit torque device as a high speed, energy efficient, non-volatile memory solution.**


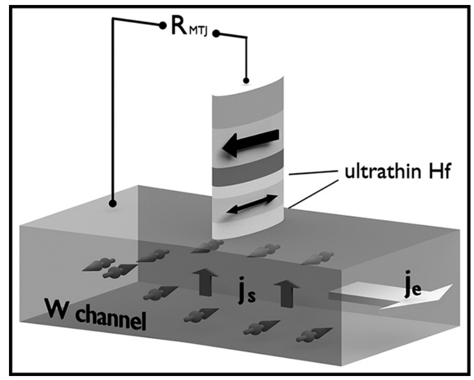


*Figure 1: Schematic picture of the three terminal MTJ and measurement technique.*

## Summary of Research:

One of the key advances in magnetic memory technologies is the utilization of the giant spin Hall effect to switch a nanomagnet free layer in a magnetic tunnel junction (MTJ) structure. While different areas of application set different standard for what an efficient memory cell should perform, faster operation with lower energy consumption is always desired. Three-terminal MTJs are good candidates for next generation memory application due to non-volatility and zero read disturbance characteristics. However, lower write current and faster (<1ns) write time are required for them to replace existing techniques. We have shown that with interface modification we can achieve very low write current using a tungsten-based MTJ structure with atomic layer of Hf "spacer" and "dusting" [1]. Here we demonstrate high speed operation of these nano-structures.

We fabricate a series of MTJ pillars on top of 4 nm of PtHf alloy spin Hall channels. We show that we can achieve fast pulse switching with characteristic time scale smaller than 1 ns (Figure 2 and Figure 3), and the write error rate can be driven down below $10^{-6}$, with high enough overdrive in the spin Hall channel. This extraordinary performance could potentially be due to fast domain nucleation process induced by various factors including Oersted field / field like torque / sample geometry.

Micromagnetic simulation shows that non-uniform initial state can be beneficial to switching, promoting switching speed in a preferred direction [2].

Our research shows that if we can utilize (or control) preferred non-uniform configuration and it is possible to achieve ultra-fast pulse switching in the MTJs.

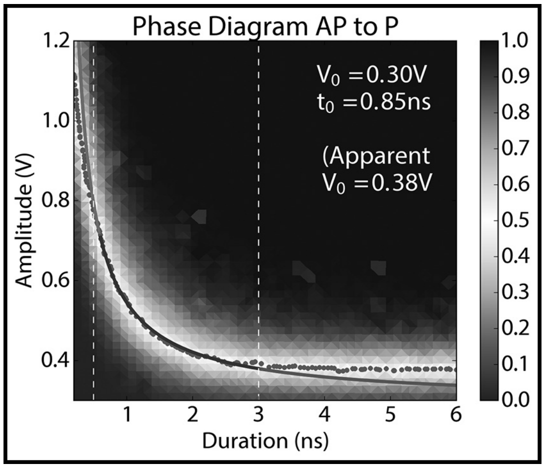


*Figure 2: Switching probability of the free layer with injection of voltage pulses at various durations. Switching polarity is from AP to P.*

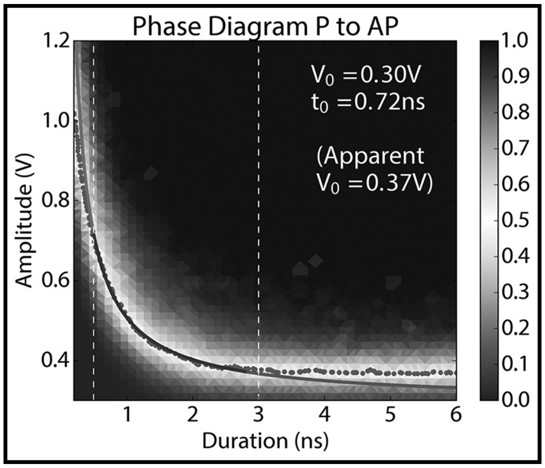


*Figure 3: Switching probability of the free layer with injection of voltage pulses at various durations. Switching polarity is from P to AP.*

## References:


[1] Shengjie Shi, Yongxi Ou, S. V. Aradhya, D. C. Ralph and R.A. Buhrman, Fast Low-Current Spin-Orbit-Torque Switching of Magnetic Tunnel Junctions through Atomic Modifications of the Free-Layer Interfaces. Phys. Rev. Applied. 9, 011002 (2018).

[2] Aradhya, S. V., Rowlands, G. E., Oh, J., Ralph, D. C. and Buhrman, R. A. Nanosecond-Timescale Low Energy Switching of In-Plane Magnetic Tunnel Junctions through Dynamic Oersted-Field-Assisted Spin Hall Effect. Nano Lett. 16, 5987-5992 (2016).