Novel Spin Memory and Logic: Physics and Materials

Jian-Gang (Jimmy) Zhu

Data Storage Systems Center, Carnegie Mellon University, Pittsburgh, PA, USA

INTRODUTION

The utilization of spin transfer torque (STT) in magnetoresistive random access memory (MRAM) results in substantial reduction of switching current threshold, enabling the scaling of the memory technology [1-4]. mLogic, a proposed all spin logic design, uses spin Hall effect (SHE) for switching the logic states with fanout capabilities [5]. New spin based physical phenomena have been explored for novel device design to advance the current IC technologies with improved performance and viability.

In this paper, we present a spin based micromagnetic modeling to investigate new schemes that adding to both STT MRAM and mLogic designs to improve some of the key performances and make the technologies more viable and competitive in their possible commercialization.

SIMULATION RESULTS AND DISCUSSIONS

Further reduction the switching current threshold without degrading thermal stability is important for the STT-MRAM technology in gaining technology viability. Recent Resonance STT MRAM design addes an antiferromagnetic material (AFM) based magnetic multilayer stack to the current memory stack [6]. In this design, a rotating spin transfer torque with frequency matching the ferromagnetic resonance frequency of the free layer is added to the conventional STT during state-switching, significantly reduces the switching current threshold, in particular for the parallel-to-antiparallel switching. Figure 1 shows the Resonance STT MRAM design and the calculated switching current threshold as a function of AFM stack rotating frequency which is in proportion to the current through the AFM stack. The perpendicular spin polarized current through the antiferromagnetic layer results in steady circular precession of the antiferromagnetic spins around the spin polarization direction. With the addition of the rotating spin transfer torque, the switching current threshold of the memory element can be significantly reduced and the switching current reduction resembles similar behavior as microwave assisted magnetic recording (MAMR) as showing in the figure.

The spin current excited antiferromagnetic spin precession can occur in both collinear and frustrated antiferromagnets. Figure 2 shows the spin precession by perpendicularly polarized spin current in a frustrated antiferromagnet where antiferromagnetic coupled spins reside on a triangular lattice. The spins rotates synchronously in exactly the same rate and each spin has either + or – 120^o phase difference, or relative angle, with its six nearest neighboring spins.

In the paper, improved designs of mLogic and relative physics and materials study will be presented as well.

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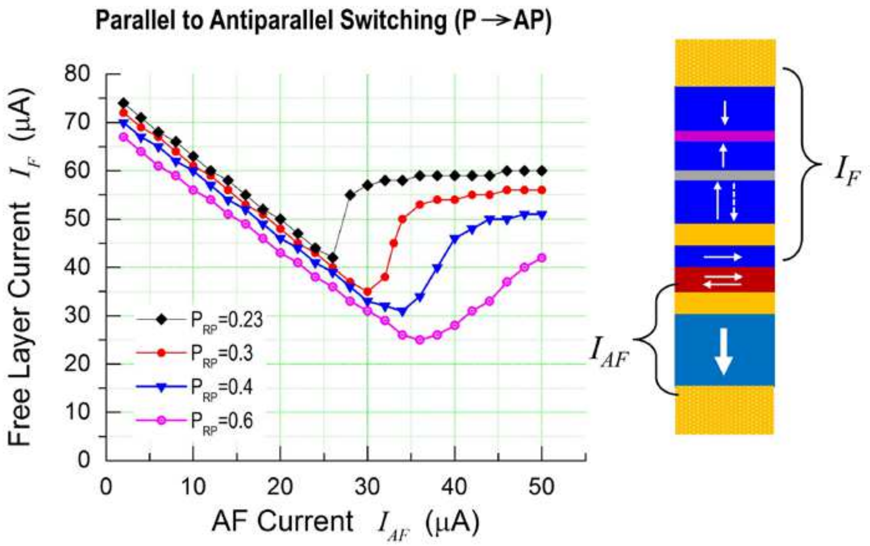

Fig. 1 *Right*: Design of the Resonance STT MRAM. *Left*: Calculated switching current threshold as a function of spin current level in the antiferromagnet-based stack that generates rotating spin transfer torque. The frequency of the rotating STT is proportional to the current level in the AFM stack.

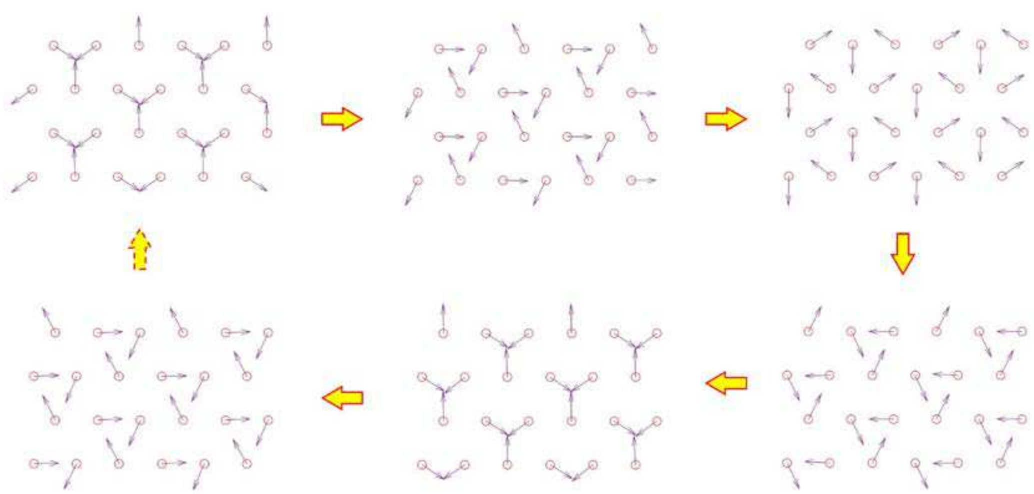

Fig. 2. Simulated spin transfer torque induced spin oscillation in an antiferromagnetic material of triangular lattice. Each subsequent frame represent a 30° counter-clockwise spin rotation (1/12 period).