VOLTAGE-INDUCED MAGNETIC SWITCHING: TOWARDS THE LIMITS OF ENERGY EFFICIENCY AND SPEED IN SPINTRONICS

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Magnetoresistive random access memory (MRAM) based on spin transfer torque (STT) is entering volume production in the semiconductor industry. While STT-MRAM offers nonvolatile embedded memory operation with high endurance, its ultimate energy efficiency, speed and scalability are limited by its current-controlled write mechanism. In this talk we discuss novel device candidates, physics, and materials which may enable approaching the fundamental limits of speed and energy efficiency in spintronics. Building on the success of STT-MRAM, these emerging device candidates may not only address a broader cross-section of the memory hierarchy, but also enable new computing architectures with simultaneously ultralow-power and high-performance attributes, which are important for machine intelligence on both edge and cloud platforms.

We first review the recent progress and perspectives of voltage-controlled nonvolatile magnetic memory devices, which offer ultralow dynamic energy dissipation, as well as reduced standby power due to nonvolatile data retention. We discuss progress in the development of magnetic tunnel junctions using voltage-controlled magnetic anisotropy (VCMA) for switching, which exhibit the lowest power consumption MRAM cells to date (single-digit fJ/bit with precessional switching times ~1 ns [1-7]). The current device and materials-level challenges and opportunities are discussed, including biasing, VCMA coefficients, read disturbance, and write error rates. We evaluate array-level performance of this memory considering different use models within the memory hierarchy and under different workloads.

As a strategy to further reduce switching time, and improve energy efficiency and scalability of VCMA-based MRAM, we then examine the VCMA effect in new free layer structures containing antiferromagnetic materials. We show that the large exchange field present in such free layers allows for dramatic reduction of the switching time, down to < 10 ps, which is also expected to reduce the energy dissipation during writing. A micromagnetic framework is used to incorporate the VCMA effect and current-induced spin torques in the device model. To simulate the spin dynamics, two coupled Landau-Lifshitz-Gilbert equations are solved for the two opposite sub-lattices, coupled by an exchange field. The simulation results show that for sufficiently large applied electric fields which overcome the anisotropy, a high-frequency resonance is excited. This VCMA-induced anti-ferromagnetic resonance is used to switch the Néel vector by 180 degrees for voltage pulses shorter than 10 ps. In addition, we discuss the variation of switching behavior and optimum pulse width depending on voltage, external magnetic fields, damping, and exchange interaction. This proposed switching mechanism can enable ultralow-power voltage-controlled spintronic devices based on antiferromagnetic materials.

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