## Pushing the limits of energy efficiency and scaling in spintronics: voltage-control, spin-orbit torques, and microwave dynamics in magnetic tunnel junctions

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We will review recent progress and perspectives on future directions of spintronics focusing on two areas: (i) How to build spintronic memory devices with unprecedented energy efficiency, speed, and integration density, with an eye on applications in brain-inspired computing, (ii) How emerging device concepts in spintronics, which frequently emerge from a desire to build better memory elements, can be adapted to other types of devices that are important for IoT, with examples being spintronic oscillators, microwave detectors, and random number generators. We will discuss progress in the development of magnetic tunnel junctions controlled by electric fields, which exhibit the lowest power consumption MRAM cells developed to date (< 5 fJ/bit with write times < 1 ns), and discuss some of the current device and circuit-level opportunities and challenges for these devices [1, 2]. We then discuss random number generators using voltage- and spin-orbit-torque-controlled magnetic tunnel junctions, and some of their potential application areas [3, 4]. Finally, we point out recent results and opportunities in the development of high-performance microwave devices [5], based on engineering of interfacial anisotropy and spin-orbit interaction in nanostructures.

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