Proposal of an eXtremely simple MRAM (X-MRAM) using magnon emission/absorption and spin-disorder scattering for readout

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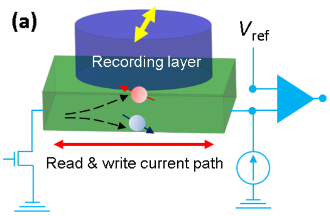
Spin-transfer torque (STT) MRAM has been intensively studied for high speed non-volatile random access memory applications. However, perpendicular STT-MRAM has a very complex stacking structure involving about 30 layers. These include a synthetic antiferromagnetic superlattice and a CoFeB layer for the reference layer, an MgO tunnel barrier, a CoFeB/Ta/CoFeB tri-layer for the recording layer, a second MgO layer, and other supporting layers. Furthermore, STT-MRAM has fundamental problems of large writing energy and junction breakdown due to the large writing current. While spin-orbit torque (SOT) MRAM, which utilizes the spin Hall effect for data writing, can avoid those problems, it requires an additional spin Hall layer and three terminals for data writing and reading. In this work, we propose an eXtremely simple MRAM (referred as X-MRAM) that requires only two layers and two terminals for data writing and reading. Figure 1(a) shows the schematic structure of X-MRAM, which consists of a ferromagnetic layer and a spin Hall layer. For data writing, a bipolar pulse current is applied in plane for SOT magnetization switching induced by the spin Hall layer. For data reading, a smaller bias current can be applied, and a sensing amplifier is used to determine the magnetization direction of the ferromagnetic layer by mean of the unidirectional magnetoresistance effect (UMR). Figure 1(b) shows the difference between STT-MRAM, SOT-MRAM, and X-MRAM. For UMR to be readable in X-MRAM, a giant UMR ratio of over 1% is required. However, conventional UMR based on the GMR-like interfacial or bulk spin-dependent scattering mechanism is as small as ~0.002% and cannot be used for readout. Here, we ulitize magnon emission/absorption and strong spin-disorder scattering in the ferromagnetic layer to obtain a UMR ratio larger than 1%, as shown in Fig. 1(c). For a demonstration of such a giant UMR, we fabricated a bilayer of GaMnAs ferromagnetic semiconductor / BiSb topological insulator. Figure 1(d) and 1(e) show a representative UMR curve and the temperature dependence of the UMR ratio of this bilayer. We observed a giant UMR ratio up to 1.1% in this bilayer, demonstrating the feasibility of X-MRAM.



(b)	STT-MRAM	SOT-MRAM	X-MRAM
Write	STT (~ 10 ns)	Type-z SOT (~ 0.5 ns)	Type-y SOT (~5 ns)
Read	TMR (~ 3 ns)	TMR (~ 3 ns)	Magnon-based UMR (10-100 ns)
Stack	~30 layers	~30 + 1 layers	2 layers
Terminals	2 terminals	3 terminals	2 terminals

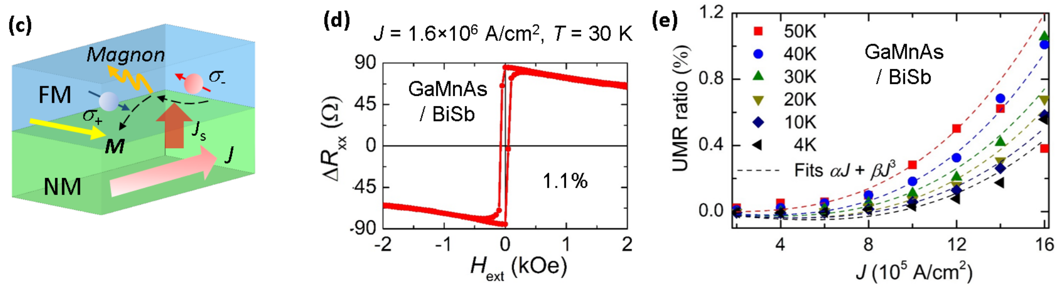


Fig. 1. (a) Schematic structure of X-MRAM. **(b)** Difference between STT-MRAM, SOT-MRAM, and X-MRAM. **(c)** Magnon emission/absorption and strong spin-disorder scattering mechanism for giant UMR. **(d)** Demonstration of a giant UMR of 1.1% in a GaMnAs/BiSb bilayer. **(e)** Temperature dependence of the UMR ratio of the GaMnAs/BiSb bilayer.