From Physics to Product
From MRAM to Magnetic Logic Unit (MLU)

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Introduction

Since the discovery of Giant Magnetoresistance, spin-electronics has been a steadily expanding field of research and development which mainly benefited so far to the magnetic recording industry. More recently, magnetic tunnel junctions (MTJ) and the associated phenomena of tunnel magnetoresistance have been widely studied in order to produce non-volatile magnetic random access memories (MRAM) which offers significantly improved cyclability and access time compared to Flash memories.

The basic MRAM cell is the so-called Magnetic Tunnel Junction (MTJ) which consists of two magnetic layers sandwiching a thin (sub-nm) insulating layer (see Fig. 1). The magnetization of one of the layers, acting as a reference layer, is fixed and kept rigid in one given direction. The other layer, acting as the storage layer, can be switched under an applied magnetic field from parallel to antiparallel to the reference layer, therein inducing a change in the cell resistance. The corresponding logic state ("0" or "1") of the memory is hence defined by its resistance state (low or high), monitored by a small read current.

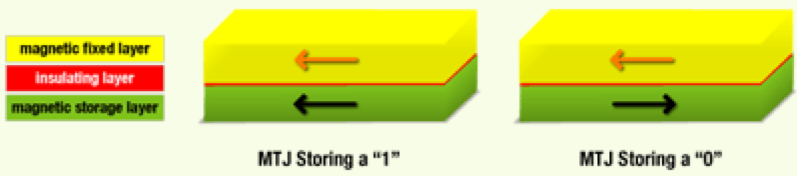

Fig. 1: Stored data follows the magnetization direction (parallel or anti-parallel) of magnetic layers in the MTJ.

A fully functional MRAM memory is based on a 2D array of individual cells, which can be addressed individually. In traditional architectures, each memory cell combines a CMOS selection transistor with a magnetic tunnel junction and three line levels, two of which are positioned in a cross point architecture.

Founded in 2006, Crocus-Technology [1] first developed Thermally Assisted Switching MRAM (TAS-MRAM) [2], using a thermal assistance during write to temporarily ease the pinned magnetization of a storage layer while applying magnetic field to switch its direction, thus changing the bit cell information. With pinning of the reference and storage layers being obtained by interfacial exchange coupling with an antiferromagnetic materials (AF) and heating of the storage layer produced by a pulse of current through the tunnel barrier, this TAS-MRAM provides both high thermal stability of the information within a large temperature operating range low power consumption.

In addition to TAS-RAM, Crocus has developed a new concept named Self-Reference (SR) [3] which is the heart of Magnetic Logic Unit (MLU) architecture. SR goes much further in resolving additional challenges and enabling new functionality and capability. The structure of SR MTJ is modified by the substitution of the base AF (that served to pin the reference layer in the fixed reference MTJ structure) with a magnetically free layer. As a result, the magnetization of this free layer is variable and subject to the magnetic field applied via the field line, and this layer is renamed as the sense layer.

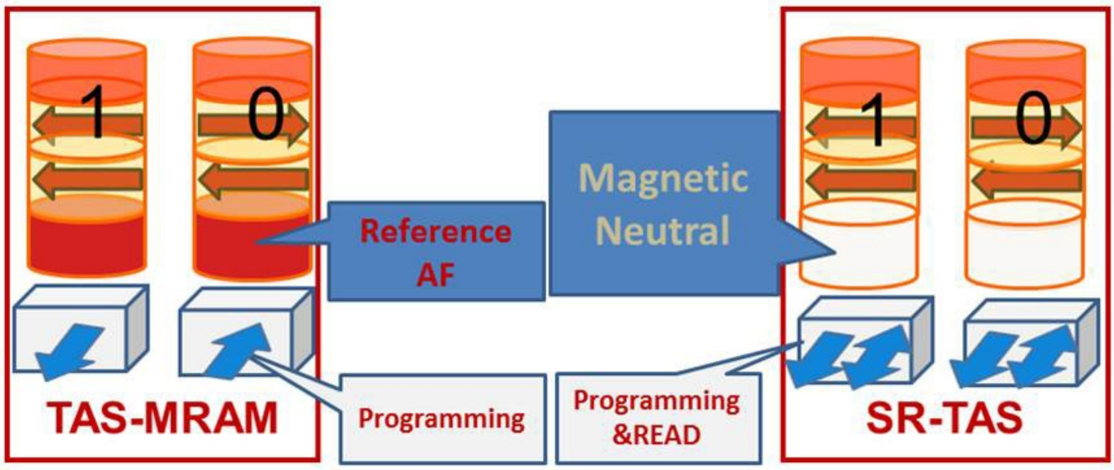

Fig. 2: TAS-MRAM with fixed reference (FR) vs SR-TAS with sense reference (SR)

In the SR case, read is achieved by measuring the MTJ resistance twice. The first measurement is performed with the sense layer aligned in one direction and the second measurement in the opposite direction. The alternative alignment of the sense layer is achieved by first driving a "north" current in the corresponding filed line followed immediately by a "south" current, which can be achieved in a 5 to 10ns time lapse [3].

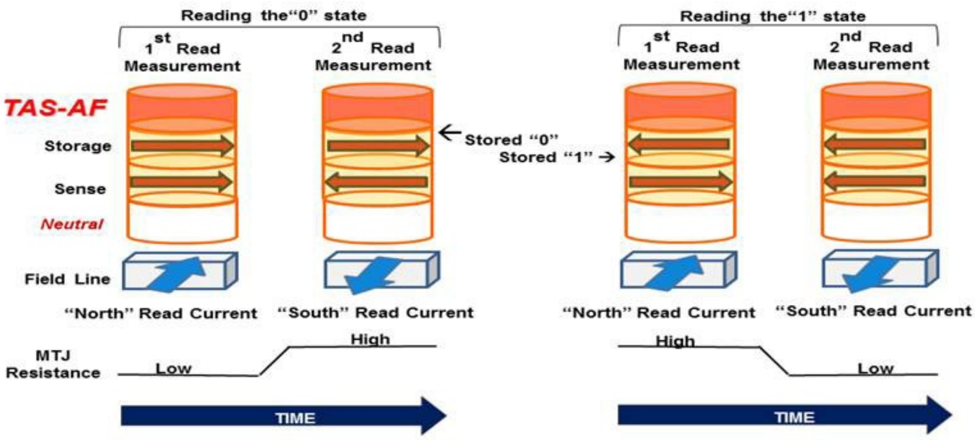

Fig. 3: MLU Read Sequence

Crocus is developing solutions based on its Magnetic Logic Unit™ (MLU). Crocus' MLUs read and write faster than Flash memory and have a smaller footprint. The company's Magnetic Logic Unit™ (MLU) architecture, based on its patented self-reference Thermally Assisted Switching™ (TAS) technology, enables a number of previously unachievable breakthroughs in magnetic memory implementation, including highly robust secure embedded memory, order-of-magnitude higher density hardware-based table searches (e.g., content addressable memory), high density multi-bit storage, and scaling to sub-20nm manufacturing. This enables Crocus' MLUs to offer significant advantages in performance, security and cost-effectiveness, making them ideal for use in mobile devices, smart cards, secure data servers and other embedded memory products. In addition, Crocus'

MLU™ architecture offers a highly reliable approach for building non-volatile memory (NVM) capable of operating at 250°C or higher, in comparison to Flash and other technologies that are effectively limited to 150°C or lower, making it ideal for extreme environment such as automotive, aerospace, energy exploration and defense.

This Talk will cover the description of Crocus as a start-up company within its academic and industrial eco-system. After the description of TAS-MRAM technology and its place in the quest for the universal memory, the technical and manufacturing challenges will be discussed in order to understand how to transform laboratory innovation on into a product ready for market. Then, the discussion will continue with the description of the Self-Referenced Bit-cell description the range of new applications it opens. The presentation will then be concluded with a discussion on the future of MTJ based devices.

References

[1] http://www.crocus-technology.com

[2] I. L. Prejbeanu, M. Kerekes, R. C. Sousa, H. Sibuet, O. Redon, B. Dieny, and J. P. Nozières, "Thermally assisted MRAM", J. Phys.: Condens. Matter 19, 165218, 2007.

[3] N.Berger, and J. P. Nozières, "Self-Referenced Magnetic Random Access Memory Cell", U.S. Patent 20110007561, issued January 13, 2011.