

# MRAM TECHNOLOGY AND BUSINESS 2019

## Market & Technology Report - August 2019

*MRAM promises life beyond eFlash: the embedded MRAM market is taking off and is expected to reach \$1.2B by 2024.*

### KEY FEATURES

- Overview of the spectrum of (STT-)MRAM technologies, along with their manufacturing processes and related technical/economic challenges
- Description of three stand-alone and three embedded (STT-)MRAM applications
  - > Stand-alone:
    - industrial, transportation, defense and other applications requiring low-density memory chips
    - enterprise storage, including accelerators and SSD caching
    - persistent memory such as NVDIMM
  - > Embedded:
    - code/data storage memory, as an eFlash replacement
    - working memory, or "slow" SRAM, for ASSPs/ASICs such as AI edge accelerators
    - last-level cache memory, as eDRAM/SRAM replacements, in CPUs and mobile processors
- 2018-2024 market forecast for stand-alone and embedded applications in \$US, Gb and equivalents of 12" wafer starts
- Overview of the latest R&D developments and next-generation magnetic memories such as SOT-MRAM and VC-MRAM
- Overview of potential applications in the long term, including L1-L2 caching based on SOT-MRAM, execute-in-place (XIP) memory such as high-density NOR replacements at 2Gb and above, and storage class memory via STT-MRAM crosspoint architectures
- Mapping of the embedded and stand-alone MRAM supply chain with key partnerships
- Analysis of the ecosystem's maturity, challenges and strengths and description of the players' activities at different levels of the supply chain
- Presentation of the latest MRAM developments within the growing Chinese memory business

### EMBEDDED MRAM IS PICKING UP STEAM THANKS TO THE STRONG INVOLVEMENT OF TOP FOUNDRY/IDM PLAYERS AND EQUIPMENT SUPPLIERS

Nowadays, there is broad consensus in the computer memory industry that the 28nm/22nm silicon lithography nodes will be the last technology nodes for embedded Flash (eFlash). This is not because of fundamental scalability limitations, but because of economic barriers. Therefore a new embedded non-volatile memory (NVM) for code/data storage is needed. At the same time, scaling of volatile static random access memory (SRAM) is slowing down due to cell footprint degradation occurring at advanced nodes. A denser working embedded memory would therefore be highly desirable.

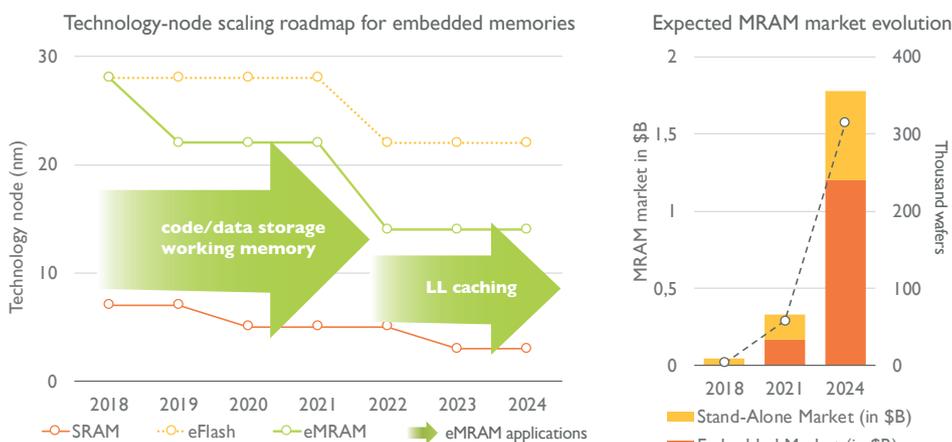
Among various emerging NVM technologies, spin transfer torque magnetoresistive RAM (STT-MRAM) is gaining significant momentum. It is poised to become the next embedded memory solution for a variety of integrated circuit (IC) products manufactured at the 28nm node and below. That includes low-power wearables and Internet-of-Things (IoT) devices, microcontroller units (MCUs), automotive, imaging and display ICs, edge artificial intelligence (AI) accelerators, and other application specific ICs (ASICs) and application specific standard parts (ASSPs).

In 2018, the embedded STT-MRAM market was still limited, with no volume shipments. 2019 is expected to be the year this market takes off. Samsung has recently started mass production of embedded STT-MRAM, and we expect other major foundry/integrated device manufacturers (IDMs) to enter the race soon. At the same time, multiple equipment suppliers like Applied

Materials, Tokyo Electron Limited (TEL), Canon, and Lam Research, and logic companies like Qualcomm, ARM and Synopsis are increasing their research spending on MRAM. This is further propelling the development of the embedded STT-MRAM business. Thanks to the support of a large number of leading companies, Yole Développement analysts believe the embedded memory market has the potential to reach \$1.2B by 2024, growing with a compound annual growth rate over this period (CAGR<sub>2018-2024</sub>) of 295%.

On the other hand, the stand-alone memory market is expected to grow less vigorously, with a CAGR<sub>2018-2024</sub> of 54%, and will remain below \$600M in 2024. So far, the growth has been driven by low-density (STT-)MRAM devices at 16Mb and below manufactured by a few key players, such as Everspin and Avalanche/Sony. In coming years, the stand-alone market will be mainly driven by enterprise storage applications. These include solid state drive (SSD) caching and storage/network accelerators, which are served by high-density STT-MRAM chips at 256Mb and above. The latter are typically sold to IDMs and system makers in the enterprise storage business. These companies require 12-18 months to develop new systems, so the ramp-up of STT-MRAM sales has taken a relatively long time. Notably, 1Gb 28nm devices from Everspin have recently moved into the pilot-production phase at GlobalFoundries. Their forthcoming availability in the market could trigger further growth of enterprise storage applications.

### Embedded memory technology trends & MRAM market evolution



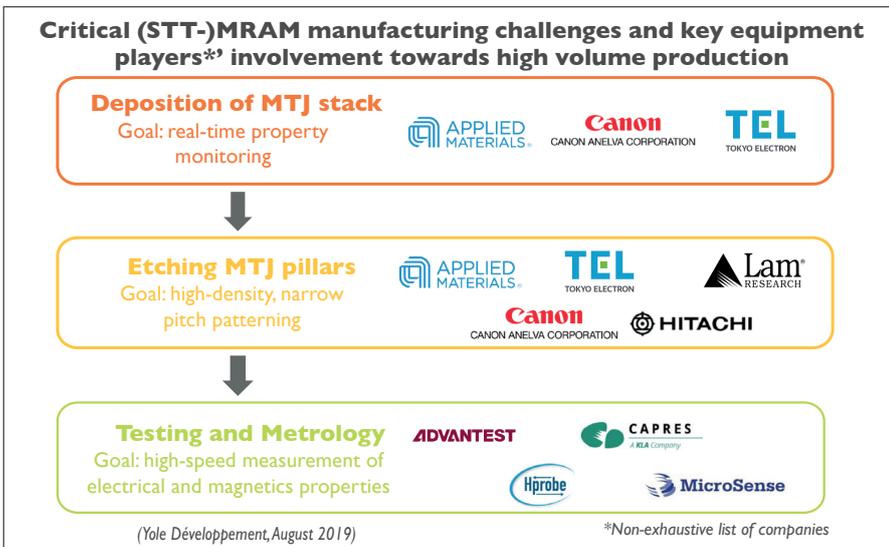
(Yole Développement, August 2019)

## EQUIPMENT SUPPLIERS ARE TACKLING THE CHALLENGES OF HIGH-VOLUME MANUFACTURING OF STT-MRAM

STT-MRAM combines the best attributes of conventional memory types in a single technology. It features the speed of SRAM and the non-volatility of eFlash with unlimited endurance. It can be added to process flows for logic chips without significant cost increase, offering a remarkable density gain over SRAM, together with low power consumption. However, a number of difficult technical challenges need to be tackled to fully exploit the potential of STT-MRAM and enable its high-volume production. Fortunately, equipment suppliers are working hard to solve such issues and are offering new solutions enabling continuous progress.

The magnetic tunneling junction (MTJ) – the fundamental element of the MRAM memory cell – consists of a delicate multi-layer stack comprising 20-to-30 different layers, whose thickness must be controlled with sub-nanometer precision. For reliable MTJ production, deposition systems capable of on-board monitoring of key material properties are needed, such as the Endura® Clover™ MRAM physical vapor deposition (PVD) tool recently announced by Applied Materials. Furthermore, the etch steps for patterning MRAM cells are among the most challenging in the manufacturing process. The CoFe and CoFeB layers used in the MTJ cannot be etched with conventional reactive ion etch (RIE) tools because such materials are not prone to form volatile compounds with plasma gases. RIE could also damage the stack. Hence, the industry has to implement suitable ion-beam etching techniques and optimize them to avoid the re-deposition of byproducts. For instance, Lam Research and TEL have developed chemically-enhanced ion beam etching tools.

Last but not least, metrology and testing are also critical steps and cannot be overlooked. They have to be performed multiple times during the device fabrication process to assess the material/device response to electrical and magnetic stimuli. Also in this framework, there are companies developing ad hoc solutions for fast measurements on wafers, as well as packaged devices.

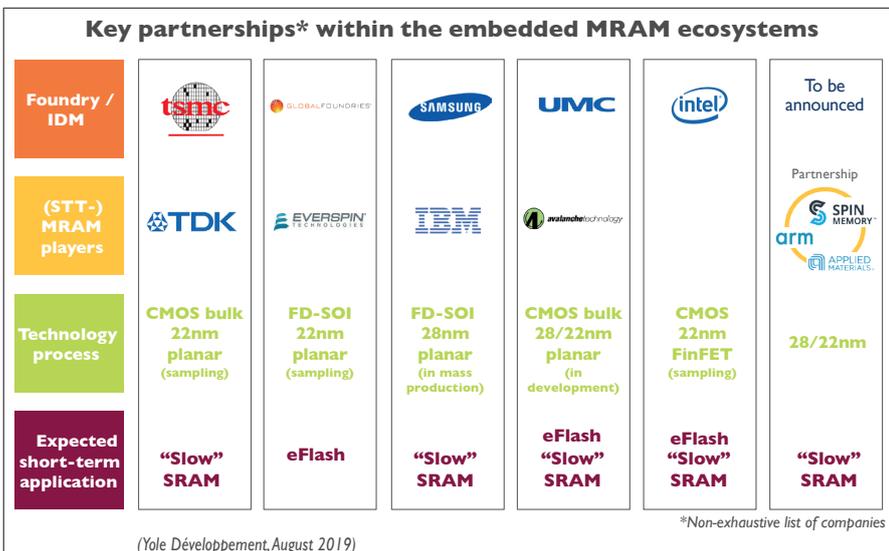


## EVERSPIN IS THE CLEAR LEADER IN THE STAND-ALONE MARKET. THE COMPETITION IS GETTING FIERCER IN THE EMBEDDED MRAM BUSINESS

Everspin is the clear leader of the stand-alone (STT-) MRAM market. It is the only supplier of toggle MRAM at 16Mb and below for applications requiring high reliability, such as industrial, transportation, defence and medical markets, which have for long been served by non-volatile SRAM (NVS RAM). It is also the only player supplying high-density STT-

MRAM for the enterprise storage market. Avalanche has started shipping stand-alone STT-MRAM parts from 1-32Mb, manufactured at Sony using 40nm lithographic processes. It is targeting the NVSRAM market, partially challenging Everspin's Toggle MRAM.

In the embedded business, foundry/IDM activities are advancing at a fast pace. Samsung is now in mass production on 28nm Fully Depleted Silicon On Insulator (FDSOI). Intel, after working silently on MRAM for several years, recently confirmed that its embedded MRAM, which uses a 22nm FinFET architecture, is ready for production. At the same time, TSMC is sampling on 22nm planar bulk silicon. Also, Gyrfalcon's MRAM-based AI chips, manufactured at TSMC, should enter volume production by mid-2020. GlobalFoundries will enter the market with embedded MRAM for replacing eFlash on 22nm FDSOI, and is working on an SRAM-like version for the subsequent 12nm FDSOI node. Seemingly, Intel is targeting eFlash replacement. Samsung and TSMC seem to be focusing primarily on embedded MRAM for replacing SRAM in applications where performance is not a priority. They are expected to enter the market with a "slow SRAM" implementation.



The overall MRAM ecosystem appears well developed and multiple companies, like NXP and Sony, are ready to adopt embedded MRAM in their IC products. We expect that 2019 will be the year of the MRAM market take off.

The new “MRAM Technology and Business” report by Yole Développement provides

an overview of embedded and stand-alone memory technologies. It details the market evolution for each application, the competitive landscape, the players’ dynamics, the challenges and the strategies in moving towards mass adoption of (STT-)MRAM.

**REPORT OBJECTIVES**

- Present an overview of the semiconductor memory industry with market insights and trends for different stand-alone and embedded technologies.
- Analyze embedded and stand-alone MRAM applications including: total addressable markets, roadmaps, market drivers, challenges and players’ objectives.
- Describe established and newly emerging magnetic memory technologies including: working principles, manufacturing methods, advantages and limitations, average selling price and time-to-market.
- Outline the latest activities for each key market player, as well as the current product development status.
- Provide roadmaps with technological nodes, chip density and price evolution.
- Analyze the MRAM ecosystems and its competitive landscape:
  - > Mapping of the entire supply chain
  - > Recent acquisitions, partnerships and funding
  - > Latest company news

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**Emilie Jolivet** is Director of the Semiconductor & Software Division at Yole Développement, part of Yole Group of Companies, where her specific interests cover package & assembly, semiconductor manufacturing, memory and software & computing fields. Based on her valuable experience in the semiconductor industry, Emilie manages the expansion of the technical and market expertise of the Semiconductor and Software Team. The team interacts daily with leading companies allowing semiconductor & software analysts to collect a large amount of data and integrate their understanding of the evolution of the market with technology breakthroughs. In addition, Emilie’s mission focusses on the management of business relationships with semiconductor leaders and the development of market research and strategy consulting activities inside the Yole group. Emilie Jolivet holds a Master’s degree in Applied Physics specializing in Microelectronics from INSA (Toulouse, France).

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  - Posting any Product to any other online service (including bulletin boards or the Internet);
  - Licensing, leasing, selling, offering for sale or assigning the Product.
- 6.3 If the Buyer would like to use data coming from the Products for presentations, press announcements and any other projects, the Buyer needs to contact Yole Développement's Public Relations Director (info@yole.fr) to get an official authorization and verify data are up to date. In return the Seller will make sure to provide up-to-date data under a suitable public format.
- 6.4 The Buyer shall be solely responsible towards the Seller of all infringements of this obligation, whether this infringement comes from its employees or any person to whom the Buyer has sent the Products and shall personally take care of any related proceedings, and the Buyer shall bear related financial consequences in their entirety.
- 6.5 The Buyer shall define within its company a contact point for the needs of the contract. This person will be the recipient of each new report. This person shall also be responsible for respect of the copyrights and will guaranty that the Products are not disseminated out of the company. In the context of Bundle and Annual Subscriptions, the contact person shall decide who within the Buyer, shall be entitled to receive the protected link that will allow the Buyer to access the Products.
- 6.6 Please note that whether in Bundles or Annual Subscription, all unselected reports will be cancelled and lost after the 12 month validity period of the contract.
- 6.7 As a matter of fact the investor of a company, external consultants, the joint venture done with a third party, and so on cannot access the report and should pay a full license price.

## 7. TERMINATION

- 7.1 If the Buyer cancels the order in whole or in part or postpones the date of mailing, the Buyer shall indemnify the Seller for the entire costs that have been incurred as at the date of notification by the Buyer of such delay or cancellation. This may also apply for any other direct or indirect consequential loss that may be borne by the Seller, following this decision.
- 7.2 In the event of breach by one Party under these conditions or the order, the non-breaching Party may send a notification to the other by recorded delivery letter upon which, after a period of thirty (30) days without solving the problem, the non-breaching Party shall be entitled to terminate all the pending orders, without being liable for any compensation.

## 8. MISCELLANEOUS

All the provisions of these Terms and Conditions are for the benefit of the Seller itself, but also for its licensors, employees and agents. Each of them is entitled to assert and enforce those provisions against the Buyer. Any notices under these Terms and Conditions shall be given in writing. They shall be effective upon receipt by the other Party. The Seller may, from time to time, update these Terms and Conditions and the Buyer, is deemed to have accepted the latest version of these terms and conditions, provided they have been communicated to him in due time.

## 9. GOVERNING LAW AND JURISDICTION

- 9.1 Any dispute arising out or linked to these Terms and Conditions or to any contract/orders entered into in application of these Terms and Conditions shall be settled by the French Commercial Courts of Lyon, which shall have exclusive jurisdiction upon such issues.
- 9.2 French law shall govern the relation between the Buyer and the Seller, in accordance with these Terms and Conditions.