MRAM Technology and Market Trends

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Technology and Market Analyst, Yole Développement
Yole Développement - Fields of Expertise

**Life Sciences & Healthcare**
- Microfluidics
- BioMEMS & Medical Microsystems
- Inkjet and accurate dispensing
- Solid-State Medical Imaging & BioPhotonics
- BioTechnologies

**Power & Wireless**
- RF Devices & Technologies
- Compound Semiconductors & Emerging Materials
- Power Electronics
- Batteries & Energy Management

**Semiconductor & Software**
- Package, Assembly & Substrates
- Semiconductor Manufacturing
- Memory
- Software & Computing

**Photonics, Sensing & Display**
- Solid-State Lighting
- Display
- MEMS, Sensors & Actuators
- Imaging
- Photonics & Optoelectronics
## About Yole’s Memory Team

<table>
<thead>
<tr>
<th>Walt Coon</th>
<th>Mike Howard</th>
<th>Simone Bertolazzi, PhD</th>
<th>Ivan Donaldson</th>
<th>Emilie Jolivet</th>
</tr>
</thead>
<tbody>
<tr>
<td>VP of NAND and Memory Research</td>
<td>VP of DRAM and Memory Research</td>
<td>Technology &amp; Market Analyst Memory</td>
<td>VP of Yole Finance</td>
<td>Division Director Semiconductor &amp; Software</td>
</tr>
<tr>
<td>Experience: 20 years in Memory</td>
<td>Experience: 15 years in Memory</td>
<td>Experience: 8 years in Emerging Semiconductors and Devices</td>
<td>Experience: 14 years in Semiconductor Industry Strategy, Business Development, and IR</td>
<td>Experience: 9 years in Equipment, Manufacturing, Processing</td>
</tr>
<tr>
<td>At Yole: NAND</td>
<td>At Yole: DRAM</td>
<td>At Yole: Emerging Memory</td>
<td>At Yole: Manages all services and relationships for global financial clients</td>
<td>At Yole: Embedded Technologies, 3DIC &amp; Manufacturing</td>
</tr>
</tbody>
</table>
Memory Technologies

Focus of Yole’s NAND and DRAM Market Monitors (published every quarter)

Focus of MRAM Technology and Business 2019 and Emerging Non-Volatile Memory Report (updated every year)
Outline

- Overview of the Memory Market
  - Established and Emerging Memory
- (STT-)MRAM Technology - Overview
  - Comparison with Other Memory Technologies
- (STT-)MRAM Market and Ecosystem
  - Applications & Players’ Dynamics
  - Market Projections and Outlook
• NAND and DRAM account for ≈97% of the overall stand-alone memory market.
• Combined NAND and DRAM revenue was ≈ $160 billion in 2018, up 26% from 2017.

2018 Memory Market - Breakdown by Technology

Total Stand-Alone Market in 2018 ≈ $165 billions

Source: “Status of the Memory Industry” Report (May 2019), NAND and DRAM Memory Research Service by Yole
Emerging NVM Market - Overview

- Flash NAND and DRAM will maintain their leading position over the next five years thanks to new technical solutions enabling further scalability.
- Emerging NVM is gaining significant momentum, but will remain below 3% of the total stand-alone memory market.

Source: “Emerging NVM” and “Status of the Memory Industry” Reports by Yole
Emerging NVM Applications

Stand-Alone
- Industry & transportation, consumer electronics
- Enterprise SCM
- Client SCM
- Mass storage memory

Embedded
- NVM in MCU, SoC and ASIC/ASSP
- Cache in mobile devices
- Cache in high-end processors
- NVM for artificial intelligence

Industrial automation
- Journal
- Workstation
- NAND memory

Smart meters
- Databases
- Notebook
- NAND memory

Automotive
- Persistent memory (NVDIMM)
- Notebook
- General purpose

Increasing density

Source: “Emerging NVM” Report by Yole
Stand-Alone vs Embedded NVM

- Stand-alone memory will be the dominant market and is driven primarily by Storage Class Memory (SCM) enterprise and client applications (3D XPoint).
- Embedded applications are gaining momentum and will be reaching 16% of the emerging NVM market by 2023.

Emerging Memory Market CAGR 2018-2023 ~104%

Source: “Status of the Memory Industry” and “Emerging NVM” Reports by Yole
Opportunities for New Memories

Sources: “Emerging NVM” and “Status of the Memory Industry” (May 2019) Reports by Yole

Bubble size corresponds to the total accessible market (TAM) size in 2018.
# Memory Technology Comparison

## 2018 stand-alone commercial products performance

<table>
<thead>
<tr>
<th>Feature</th>
<th>STT-MRAM</th>
<th>PCM 3D XPoint</th>
<th>RRAM</th>
<th>DRAM</th>
<th>Flash NAND</th>
<th>Flash NOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-volatile</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Byte addressable</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Endurance (# cycles)</td>
<td>High (&gt;10⁹)</td>
<td>Medium (10⁷)</td>
<td>Low (10⁴)</td>
<td>High (10¹⁵)</td>
<td>Low (10⁵)</td>
<td>Low (10⁵)</td>
</tr>
<tr>
<td>Maximum density for products in 2018</td>
<td>256Mb (1 Gb ready)</td>
<td>128Gb</td>
<td>4Mb</td>
<td>16Gb</td>
<td>1Tb</td>
<td>2Gb</td>
</tr>
<tr>
<td>Cell size (cell size in F²)</td>
<td>Medium (6-30)</td>
<td>Small (4/2L)</td>
<td>Medium (6-30)</td>
<td>Small (6-8)</td>
<td>Very small (4/96L)</td>
<td>Medium (6-30)</td>
</tr>
<tr>
<td>Speed (Latency)</td>
<td>Fast (~10 ns)</td>
<td>Fast (10-100ns)</td>
<td>Medium (~100 ns)</td>
<td>Fast (~10 ns)</td>
<td>Slow (100,000ns)</td>
<td>Slow write (100,000ns)</td>
</tr>
<tr>
<td>Switching Power</td>
<td>Medium/Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>2018 price ($/Gb)</td>
<td>High ($10-100/Gb)</td>
<td>Low (≤ $0.5/Gb)</td>
<td>High ($100 - 1000/Gb)</td>
<td>Low ($0.97 Gb)</td>
<td>Very low ($0.03/Gb)</td>
<td>Medium ($10/Gb)</td>
</tr>
<tr>
<td>Key suppliers</td>
<td>Everspin, Avalanche</td>
<td>Micron/Intel</td>
<td>Adesto, Fujitsu</td>
<td>Samsung, Micron, SK hynix, Nanya</td>
<td>Samsung, Micron, Toshiba, WDC, SK hynix, Intel</td>
<td>Micron, Winbond, Macronix, Cypress-Infineon, GigaDevice</td>
</tr>
</tbody>
</table>
Memory Technology Comparison
2018 stand-alone commercial products performance

Data Storage

Yole Développement © 2019

Pricing position in 2018 ($/Gb)

Density position in 2018 (Gb)

5: best value
0: worst value

Working Memory

Endurance

Speed

Density

Price

Yole Développement © 2019

NAND
PCM
DRAM
NOR
STT-MRAM
RRAM

Yole Développement © 2019

NAND
PCM
DRAM
NOR
STT-MRAM
RRAM
Stand-Alone STT-MRAM Roadmap
Chip density and technology node scaling - Comparison with DRAM

- STT-MRAM will target enterprise storage (SCM) applications for a long time before trying to substitute DRAM.
Among established and emerging embedded memory technologies, STT-MRAM is promising as it offers a combination of persistence, low-power consumption, high speed and high endurance.
Embedded Memory Technology Highlights

- **eFlash scaling is reaching its end**: 28nm/22nm will be likely the last technology nodes.

- **SRAM scaling is also slowing down**: The cell footprint (# of $P^2$) degrades at advanced FinFET nodes.

- **STT-MRAM offers non-volatility together with low power consumption**, which is ideal for low-power MCUs, wearables and IoTs.

- **STT-MRAM offers a significant density gain over SRAM**. At advanced nodes ($\leq 1\times nm$) more than $\times 3$ gain.

→ Thanks to strong support of top foundry/IDM players and equipment suppliers, embedded STT-MRAM is poised to become the next embedded NVM solution for nodes $\leq 28$nm.
(STT-)MRAM Applications

Stand-alone

- Industry, transportation, and other
- Enterprise Storage
- Persistent Memory

Embedded

- Code/Data Storage (eFlash)
- “Working” Memory (Slow SRAM)
- Cache Memory (SRAM, eDRAM)

- Storage Accelerators
- Network Interface Cards
- Solid State Drives
  - Write caching, journaling, logs, data buffering and streams

- Persistent Memory for Servers

- MCU, ASSP, ASIC, SoC
- IoT / Wearables
- Display Driver ICs
- General Purpose
- Edge AI accelerator chips
- In memory computing

- Industrial automation
- Transport
- Aerospace
- Medical
- Gaming
- Network & Infrastructure

- NVSRAM
- NVDIMM

- NVSRAM Applications
- Tcon, memory buffers

- CMOS Image Sensors
  - Image memory buffer

- CPU
- Mobile AP

Required Speed/Density

2023+

2023+
The MRAM Ecosystem is Growing

An increasing number of players are involved in the MRAM arena

### MRAM IP and Design

<table>
<thead>
<tr>
<th>Company</th>
<th>Logo</th>
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<tr>
<td>Everspin</td>
<td><img src="https://example.com/everspin-logo" alt="Everspin Logo" /></td>
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<tr>
<td>Avalanche Technology</td>
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<td>SPIN Memory</td>
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<td>TDK</td>
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<td>IBM</td>
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<tr>
<td>HFC Semiconductor</td>
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<td>Synopsys</td>
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<td>NVE</td>
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<td>Inston</td>
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<tr>
<td>Numem</td>
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<tr>
<td>Shanghai Ciyu</td>
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</table>

### Embedded MRAM Manufacturers

**Players in mass production or close to mass production**

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<tr>
<th>Company</th>
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<tbody>
<tr>
<td>TSMC</td>
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<tr>
<td>GlobalFoundries</td>
<td><img src="https://example.com/globalfoundries-logo" alt="GlobalFoundries Logo" /></td>
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<tr>
<td>Samsung</td>
<td><img src="https://example.com/samsung-logo" alt="Samsung Logo" /></td>
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<tr>
<td>Intel</td>
<td><img src="https://example.com/intel-logo" alt="Intel Logo" /></td>
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<tr>
<td>UMC</td>
<td><img src="https://example.com/umc-logo" alt="UMC Logo" /></td>
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<tr>
<td>TowerJazz</td>
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</tr>
<tr>
<td>Crocus</td>
<td><img src="https://example.com/crocus-logo" alt="Crocus Logo" /></td>
</tr>
</tbody>
</table>

### Stand-alone MRAM Manufacturers

- **40nm, up to 128Mb**
  - Sony | ![Sony Logo](https://example.com/sony-logo) |
  - Avalanche Technology | ![Avalanche Technology Logo](https://example.com/avalanche-tech-logo) |
- **40nm, 28nm (256M, 1Gb)**
  - GlobalFoundries | ![GlobalFoundries Logo](https://example.com/globalfoundries-logo) |
  - Everspin | ![Everspin Logo](https://example.com/everspin-logo) |
- **Toggle Manufacturing**
  - SilTerra | ![SilTerra Logo](https://example.com/silterra-logo) |
  - Everspin | ![Everspin Logo](https://example.com/everspin-logo) |
- **Expected: 28nm, 22nm**
  - UMC | ![UMC Logo](https://example.com/umc-logo) |
# Embedded MRAM Business

Key partnerships and developments for leading players.

<table>
<thead>
<tr>
<th>Foundry / IDM</th>
<th>TSMC</th>
<th>GLOBALFOUNDRIES</th>
<th>SAMSUNG</th>
<th>UMC</th>
<th>Intel</th>
<th>To be announced</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(STT-)MRAM Players - Partners</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TDK</td>
<td>EVERSIPN</td>
<td>IBM</td>
<td>avalanche</td>
<td>arm</td>
<td>APPLIED MATERIALS</td>
</tr>
<tr>
<td><strong>Technology Process</strong></td>
<td>CMOS bulk 22nm planar (sampling)</td>
<td>FD-SOI 22nm planar (sampling)</td>
<td>FD-SOI 28nm planar (in mass production)</td>
<td>CMOS bulk 28/22nm planar (in development)</td>
<td>CMOS 22nm FinFET (sampling)</td>
<td>28/22nm</td>
</tr>
<tr>
<td><strong>Expected Short-Term Application</strong></td>
<td>“Slow” SRAM</td>
<td>eFlash</td>
<td>“Slow” SRAM</td>
<td>eFlash “Slow” SRAM</td>
<td>eFlash “Slow” SRAM</td>
<td>“Slow” SRAM</td>
</tr>
</tbody>
</table>
## Embedded MRAM Business

Challenges and developments by equipment suppliers

<table>
<thead>
<tr>
<th>Critical Challenges</th>
<th>Key Equipment Suppliers (Example of Tools)</th>
</tr>
</thead>
</table>
| • Deposition of MTJ stack  
  Goal: high-quality stacks via real-time property monitoring |  |
| • Etching of MTJ cells  
  Goal: high-density, narrow pitch |  |
| • Testing and Metrology  
  Goal: high-speed measurement of electrical and magnetics properties |  |
MRAM Market Projections

Market Forecast for Embedded and Stand-Alone (STT-)MRAM

- ~$0.58B for stand-alone MRAM in 2024
- ~$1.2B for embedded MRAM in 2024
- CAGR_{18-24} ~85%

New Report by Yole (August 2019)
Thanks to strong support of top foundry/IDM players and equipment suppliers, embedded STT-MRAM is poised to become the next embedded NVM solution for technology nodes ≤ 28nm.

The embedded STT-MRAM market has the potential to grow up to ~$1.2B by 2024, driven by code/data storage and “slow” working memory applications.

The stand-alone (STT-)MRAM market is expected to grow less vigorously than its embedded counterpart, with revenues up to ~$580M in 2024.

In the coming years, enterprise storage (SSD caching, storage and network accelerators) will be the leading stand-alone STT-MRAM applications.
Thank you for your attention
Questions?

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