MRAM Markets and Applications

Mark Webb

MKW Ventures Consulting, LLC
8/6/2018
MRAM Markets

- MRAM Overview compared to other Memories
- MRAM Technology/Shipment Status
- MRAM Embedded Markets and applications
- MRAM Standalone Markets and applications
- Cost and scaling model to increase penetration
- MRAM revenue/assumptions
## Memory Technology Comparison

### Generic NVM

<table>
<thead>
<tr>
<th>Memory Type</th>
<th>Latency</th>
<th>Density</th>
<th>Cost</th>
<th>HVM ready</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAM</td>
<td>*****</td>
<td>***</td>
<td>***</td>
<td>*****</td>
</tr>
<tr>
<td>NAND</td>
<td>*</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>MRAM</td>
<td>*****</td>
<td>*</td>
<td>*</td>
<td>***</td>
</tr>
<tr>
<td>3DXP</td>
<td>***</td>
<td>****</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>ReRAM</td>
<td>***</td>
<td>****</td>
<td>****</td>
<td>**</td>
</tr>
<tr>
<td>NRAM</td>
<td>***</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>Other</td>
<td>***</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
</tbody>
</table>
### Memory Technology Comparison
Revised for Application

<table>
<thead>
<tr>
<th></th>
<th>Latency</th>
<th>Density</th>
<th>Cost</th>
<th>HVM ready</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAM</td>
<td>*****</td>
<td>***</td>
<td>***</td>
<td>*****</td>
</tr>
<tr>
<td>SRAM</td>
<td>*****</td>
<td>*</td>
<td>*</td>
<td>*****</td>
</tr>
<tr>
<td>eFLASH</td>
<td>****</td>
<td>*</td>
<td>*</td>
<td>*****</td>
</tr>
<tr>
<td>MRAM</td>
<td>*****</td>
<td>*</td>
<td>*</td>
<td>***</td>
</tr>
<tr>
<td>3DXP</td>
<td>***</td>
<td>****</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>ReRAM</td>
<td>***</td>
<td>****</td>
<td>****</td>
<td>**</td>
</tr>
</tbody>
</table>
MRAM Compared to Other Technologies

- MRAM Advantages
  - Speed. It is the fastest new NVM
  - Maturity compared to other “new NVM”
  - Multiple manufacturers joining development
    - IP providers, Foundries, Memory Companies
    - This gets equipment suppliers engaged and spending money on development
    - Example: Samsung being involved pulls everything forward.
MRAM Compared to Other Technologies

- Disadvantages
  - Cost/Density
    - 10-20F\(^2\) planned, 50F\(^2\)+ is more typical today (More later)
  - Very limited shipments of STT (Spin-Transfer Torque)
    - Toggle ships today but doesn’t lead to cost effective applications
    - STT needed to achieve this and volume needed to make it mature
  - Even with STT, density projections cannot match ReRAM, 3D Xpoint
  - ROIC model for MRAM specific Fab tools is not clear
Technology Status

- Companies shipping measurable volumes of MRAM
  - Toggle today as it is a mature technology with sales
  - STT-MRAM provides higher density and is the future
- Everspin partnering with Global Foundries to ship stand alone and embedded
  - 28nm MRAM standalone being planned (40nm Shipping now)
  - 22nm embedded MRAM available in upcoming GF designs
- Multiple Companies licensing IP to improve performance and reliability
  - Numem, Spin transfer technologies
- All major logic companies and foundries are committing to MRAM
- IMO: MRAM future growth confidence is a “Tale of Two Markets”
Embedded Market

- Embedded Market is very attractive for MRAM!
  - E-Flash scaling issues limit density and cost reduction
  - SRAM scaling is slowing as finfet SRAMs require large $F^2$
  - MRAM power in embedded is better than SRAM
  - Merging NVM and SRAM is more efficient
  - Densities needed are near sweet spot MRAM density

- Multiple vectors all pushing for MRAM
Embedded MRAM Market

- All Logic companies see SRAM limitations and are actively looking to MRAM for solutions
- Foundries can offer this for multiple controller applications
- End result: Multiple Billion dollar companies are investing in MRAM
- MRAM appears to be ideal solution, not a solution in search of a problem (this is what we always look for)
MRAM Stand Alone Memory

- Standalone MRAM memory has more challenges than embedded
  - No short term path to MRAM being able to match DRAM on cost or density
  - NOR flash is a viable execute-in-place NVM in 256MB and below
  - Higher density NVM (>1Gbit) will use NAND due to extremely low cost
- ReRam and 3D Xpoint are lower cost and more dense for “NAND-DRAM Latency gap” applications
- Therefore MRAM is best applied to 256-1Gbit where DRAM like speed is desired, NVM needed, and cost is not a major issue
- MRAM Replaces battery/capacitor backed DRAM, Low density DRAM, NOR applications.
Standalone Applications

- **NVDIMMS**
  - Inherent speed and NV status replace DRAM without batteries/capacitor or backup algorithms

- **NVMe SSDs**
  - SSD with MRAM instead of DRAM can prevent data corruption without battery/Capacitor. Can provide caching options. MRAM+NAND SSD
  - SSD that is ALL MRAM can have very low latency (<10uS) and compete in markets with large monetary value for low latency

- **Mobile applications**
  - Mobile/phone market today has NOR-NAND-DRAM combinations along with SOCs that have embedded memory/SRAM.
  - MRAM could replace these and potentially enable space reduction
Cost/Cell Size Challenges

- MRAM cell size often ends up being larger than theoretical
  - To achieve high speed to compete with DRAM/SRAM, access transistor size grows
  - To achieve stable NVM with high reliability, storage node size grows.

- Cell size of 10-20F^2 becomes 50F^2+

- More advanced nodes allow increased speed at a given F^2.
  - This reduces the access transistor size “blowup”

- If MRAM cell size <1/3 SRAM cell size, this can tip conversion to MRAM in embedded markets
MRAM and SRAM Cost Model

MRAM Challenges
- MRAM is starting manufacturing at 28nm
- SRAM is in volume at 14nm and below
- MRAM must get to new nodes
- MRAM must scale $F^2$ at new node
How Can MRAM Achieve Breakthrough Growth?

- MRAM market is relatively small today
  - <$100M in annual sales, no embedded shipping in volume
- SRAM, DRAM, NOR/E-flash scaling is slowing
- MRAM must scale at 2x pace of these technologies to deliver competitive cost and performance
- This is achieved by spending 100s of Millions on R&D (like XP)
- Simple model shows 14nm MRAM is cost competitive with SRAM and provides faster NVM at a acceptable price. 22nm ramp needed to provide ramp vehicle
## MRAM Revenue Baseline

<table>
<thead>
<tr>
<th>Year</th>
<th>Revenue (M)</th>
<th>Notes/required milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>$325M</td>
<td>1Gb selling for revenue in 2019, DRAM-Like performance. Multiple IP sources for foundries</td>
</tr>
<tr>
<td>2022</td>
<td>$549M</td>
<td>Multiple foundries and 1+ Memory company in volume</td>
</tr>
<tr>
<td>2024</td>
<td>$928M</td>
<td>2+ memory companies in volume</td>
</tr>
</tbody>
</table>

- Revenue model for embedded will be decided over time
- Licensing/royalty is only modeled foundry embedded MRAM revenue
Summary

- MRAM Technology has unique attributes that allow it to excel in certain markets
  - Embedded Memory/SRAM/eFlash replacement
  - Low density (1Gb), high speed NVM
- Multiple IP providers plus multiple foundries and Logic companies will change the research spending and drive growth
- Revenue can approach $1B in 2024 with strong execution by all companies in the ecosystem.