MRAM Markets and Applications

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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

	Latency	Density	Cost	HVM ready
DRAM	*****	***	***	*****
NAND	*	*****	*****	*****
MRAM	*****	*	*	***
3DXP	***	****	****	****
ReRAM	***	****	****	**
NRAM	***	**	**	*
Other	***	**	**	*

Memory Technology Comparison

Revised for Application

	Latency	Density	Cost	HVM ready
DRAM	*****	***	***	*****
SRAM	*****	*	*	*****
eFLASH	****	*	*	*****
MRAM	*****	*	*	***
3DXP	***	****	****	****
ReRAM	***	****	****	**

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.

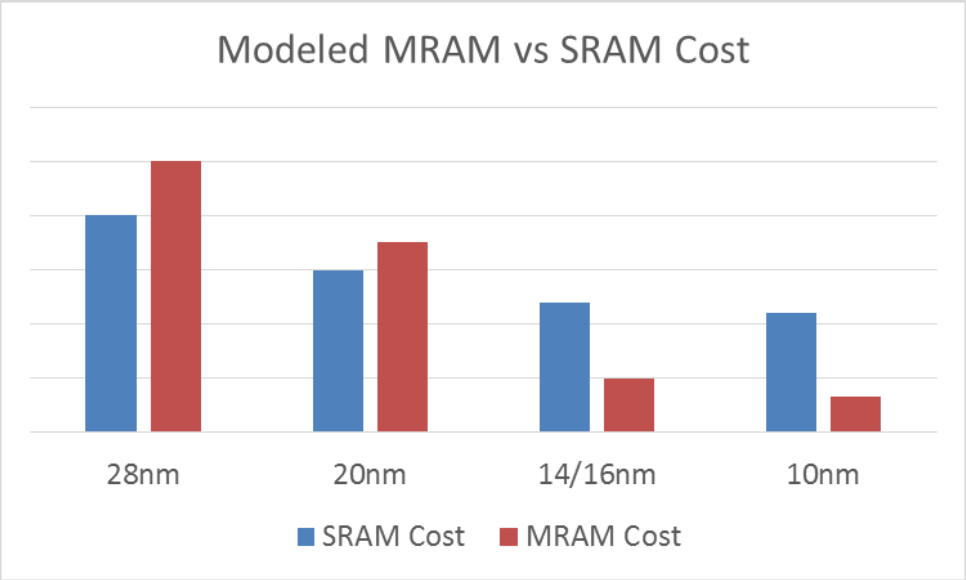
Standalone Applications

- 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

Potential Revenue Model

	MRAM Revenue Baseline	Notes/required milestone
2020	$325M	1Gb selling for revenue in 2019, DRAM-Like performance. Multiple IP sources for foundries
2022	$549M	Multiple foundries and 1+ Memory company in volume
2024	$928M	2+ memory companies in volume

- 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.