STT-MRAM: Emerging NVM

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Emerging Memory: Hierarchical Positioning

- **STT-MRAM**: targeted for DRAM, Storage-class-Memory
- **Embedded STT-MRAM**: for SRAM, e-Flash and e-DRAM
Emerging Memory / Target Markets

- **SRAM**: Scaling below 20nm will cause increase cell size and leakage—L2/L3SRAM(embedded)
  - **STT-MRAM is the Leading candidate**
    - Microprocessor, SOCs, Mobile SOC; Security applications; IOT

- **DRAM**: Scaling Challenge < 1Xnm – Stand alone and embedded
  - **STT-RAM is the leading candidate**
    - Performance and low cost

- **NOR Flash**: Legacy; > $2B TAM
  - STT-MRAM, ReRAM
Avalanche At-A-Glance

- Advanced Perpendicular MTJ (pMTJ)
  - Low write current (<100uA) @50ns pulse @55nm 32/64MBit Device
    (Achieved 50uA @2ns pulse @2X nm)
- Disruptive and Fundamental IP (185)
- Embedded and Discrete MRAM Solution
  - Storage, Telecom
- World Class Fab partners
  - 300mm Advanced Technology Nodes
- 32/64Mb SPI NOR/NvSRAM STT MRAM Silicon
  - CS Select Customers (Storage and Telecom)
- 1 Gb DDR4 STT MRAM Design

32/64Mb SPI/NvSRAM
Enabling STT MRAM through pMTJ

Highly scalable to 1x nm: low write current (<50 μA/0.3V) with sustainable high thermal stability $\Delta > 100$

Excellent write performance (sub ns)

High TMR ~200% (targeting 250 % in near future)

Thermally stable TMR up to 400°C > 60 min $\rightarrow$ compatible with standard CMOS (embedded)

High Endurance $> 10^{16}$ cycles and Rad Hard

Excellent Manufacturability & low cost (<1x nm)

pMTJ stack can be tailored for different applications through speed and cell size optimization
300 mm BEOL Integration: Scalable to 1x nm

- Advanced BEOL integration scheme developed and matured (40-50 nm) in world-class foundry
- Low cost adder with one single MTJ etch mask
- Scalable (<1x nm) MTJ BEOL integration process flow (portable to other IDM/foundry)
- MTJ thermally stable up to 400°C, compatible with embedded applications
- Note – MTJ below M1 as shown. Portable between any 2 metal layers
Current offerings with highest performance compare to Flash, EEPROM, FRAM, …

**Avalanche Quad SPI SPNOR™**

- **Key Features**
  - 32Mb 55nm STT-MRAM Technology
  - Dual/Quad SPI Interface (108MHz)
  - Byte Alterable (No Erase)
  - Fast Write > 3MB/s
  - Endurance > 100 Million Writes
  - Retention 20 Years at 85°C
  - Industrial Temp -45C to 85C

- **Applications**
  - Raid Storage
  - Power fail storage
  - Setup box and LCD display
  - Digital consumer applications

**Avalanche Quad SPI SPSRAM™**

- **Key Features**
  - 32Mb 55nm STT-MRAM Technology
  - Dual/Quad SPI Interface (100MHz)
  - No write
  - Fast Read & Write > 50MB/s
  - Endurance > 1 Trillion Writes
  - Retention > 20 Years at 85°C
  - Industrial Temp -45C to 85C

- **Applications**
  - Internet of Things (IOT)
  - Automotive Crash Recorder
  - Digital consumer application
  - Smart Meters

**10X Faster Program compared to SPI NOR FLASH and Byte Alterable**

Avalanche Quad SPI SPMEM based on proprietary pMTJ delivers faster program time (<32us per page), very high endurance (> 100 million) and 20 Years retention @85°C
**AvRAM™ – Ideal Embedded Memory**

**AvRAM™ Technology Delivers Cost and Performance Benefits**

- Smaller Die Size due to Smaller Cell Size
- Simplified System Architecture at sub nano-second performance
- Low voltage CMOS process; Low power consumption (Zero Leakage)
- Modular Integration with 1X CMOS design node and beyond
Avalanche STT-MRAM Architectural Roadmap

### Cell Size

<table>
<thead>
<tr>
<th></th>
<th>6-24 F²</th>
<th>4-10 F²</th>
<th>0.5 F²</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLC</td>
<td>Four-State MLC</td>
<td>3-D X-point Stacked MTJ</td>
<td></td>
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</tbody>
</table>

### Market

<table>
<thead>
<tr>
<th>NOR/Embedded/DRAM</th>
<th>DRAM/Enterprise SSD</th>
<th>Consumer/Data center</th>
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</table>

Avalanche STT-MRAM Architectures Enable Expanded Markets
THANK YOU
MRAM Into the Mainstream
Everspin - The Only Company to Deliver MRAM

- Private, VC funded, spinout from Freescale in 2008

- Delivering our first generation MRAM products with 7 years of consecutive growth and 60M units shipped at 50% gross margin

- Second generation product (Spin Torque) provides the opportunity for explosive growth. We are partnered with GLOBALFOUNDRIES to bring products on 300mm manufacturing to our customers

- Establishing MRAM as the leading emerging memory technology
Data *Instantly* Stored, *Instantly* Available

<table>
<thead>
<tr>
<th>HDD (Seek &amp; RL)</th>
<th>1ns 10ns 100ns 1us 10us 100us 1ms 10ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAND (tPROG)</td>
<td></td>
</tr>
<tr>
<td>CB-RAM, ReRAM, 3D XPoint &amp; PCM</td>
<td></td>
</tr>
<tr>
<td>Spin Torque (MRAM)</td>
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</tbody>
</table>

Minimum Time to Write

- No delays for Wear Leveling (no address translation, no write amplification and no garbage collection)
- Endurance Enables USEABLE Performance

**ST-MRAM 4KB Write Time**

- 4KB Stored in <100ns

**Total Write Times**

- Intrinsic Device & Interface Latency
<100ns Latency with ST-MRAM : A New Storage Tier

- Write Buffer/Cache for enterprise storage chassis & applications
  - Enables consumer class SSDs to become main storage platform
  - Enables the use of lower endurance TLC

- PCIe NVMe over fabrics without interrupting processors or disrupting CPU caches
  - True distributed and shared storage

- Metadata storage and file system journal

- Persistent memory/storage for SDS
  - HW support for SW RAID

- At speed data logging and persistent scratchpads
## Persistent DRAM – Closing the Computation and Storage Performance Gap without Batteries or Capacitors

**ST-MRAM is the only emerging memory technology to provide the speed and endurance needed for the 1\textsuperscript{st} tier in enterprise class storage systems**

<table>
<thead>
<tr>
<th>Characteristics*</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-MRAM</td>
<td>3D Xpoint</td>
</tr>
<tr>
<td>Supplier</td>
<td>Everspin</td>
</tr>
<tr>
<td>Latency R/W</td>
<td>10ns / 20ns</td>
</tr>
<tr>
<td>Endurance</td>
<td>$10^{10} - 10^{12}$</td>
</tr>
<tr>
<td>Status</td>
<td>Shipping 64Mb</td>
</tr>
<tr>
<td>Density</td>
<td>Gb</td>
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</tbody>
</table>

*Everspin estimate, supplier data
ST-MRAM ... Scaling Beyond eFLASH and eSRAM Intrinsic Limits!

- eFLASH and eSRAM are technology-limited at 40nm, 20nm, respectively.
- eSRAM is larger than the minimum logic transistor size.
- eMRAM bit cell tracks to the minimum logic transistor size starting with 28nm.
- A 28nm eMRAM MTJ can be applied in any CMOS technology (e.g. 40nm).
ST-MRAM is the Emerging Memory Ready to Use

- MRAM production experience and know-how
  - 300mm production with GLOBALFOUNDRIES = Quality and Quantity
    - Everspin branded products first targeted to enterprise storage
    - Embedded MRAM for consumer, industrial, automotive and IOT SoC products
- MRAM brings value as more than just memory
  - Persistent DRAM in write intensive storage applications
  - Versatility as embedded memory: *Compute, Code, Capture* all-in-one
- Card-based MRAM to allow for early adoption via reference designs
  - Ecosystem in place compatible with FPGAs and many controller IP products

*Moving MRAM into the Mainstream*
THANK YOU
Emerging Embedded Memory
Embedded Memory: Requirements

Reliable storage to fast analytics

Retention  Efficiency  Speed
Embedded Memory: Customer Usage

**Automotive**
- ADAS
- Engine Control
- Infotainment
- Battery monitoring
- Vision systems
- Navigation

**MCU**
- Smartcards
- Set-top boxes
- White goods
- Industrial Controls
- Touch sensors

**IoT**
- Wearables
- Intelligent sensors
- Gateways
- Smart TVs
- Smart Cities

**Storage**
- HDD and SSD storage controllers
- Storage arrays
- NV buffers/tiers
- NV caches

**Compute**
- Fast caches
- Persistent memory
- Server processors
- Network processors

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Embedded Memory: Technology

- Automotive
- MCU
- IoT
- Storage
- Compute

eFlash

Retention  Efficiency  Speed

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Embedded Memory: Time Horizon

- Automotive
- MCU
- IoT
- Storage
- Compute

eFlash: Sooner

eMRAM: Later

Retention | Efficiency | Speed
Embedded Memory: Customer Usage

**eFlash**
- Harsh Environment Reliability

**eMRAM**
- Power & Area Efficient
- Performance & Endurance

- Retention
- Efficiency
- Speed
GLOBALFOUNDRIES Embedded Memory
Solving your product challenges for the hyper-connected world.