SOLVING MANUFACTURING CHALLENGES AND 
BRINGING SPIN TORQUE MRAM 
TO THE MAINSTREAM
Everspin Company Highlights
Current Mainstream Memory is One-Dimensional.

- RAM is fast, but is also “Volatile”.
- FLASH is “Non-Volatile”, but is also slow, limited endurance, and requires high power.
- A complex system is required for “Persistent RAM” or “High-Integrity NVM”.

The Market for “Persistent RAM” and “High-Integrity NVM” will be ~$5B by 2019.

We address this market with Discrete and Embedded MRAM technology.

We are optimizing the memory for Embedded Integration (>20Bt TAM by 2018).

Magnetoresistive RAM, a.k.a. “MRAM”
Everspin Company Highlights

- The Market Leader in Advanced MRAM Products and Solutions
- Serves Large and Growing Markets ($2B+ Toggle & Spin Torque MRAM TAM in 2018)
- Well-Established OEM Relationships (Dell, Avago, Siemens, Bosch, BMW, Fujitsu...)
- Global, Cost Effective Operations
- 500+ Patents & Applications Worldwide, 350+ Patents Granted Worldwide
- Strong Financial Track Record and Privately Owned by Semiconductor VCs
- Proven Quality and Reliability, Qualified by Numerous Tier One (Fortune 50) Companies
- Increased R&D Focus on ST-MRAM in Advanced Technology Nodes (40/28nm and beyond)
- Mass-Proliferation of ST-MRAM through GLOBALFOUNDRIES Partnership
- Optimizing MRAM Technology for Embedded Integration
ST-MRAM background
64Mb in-plane ST-MRAM in Production
64Mb with pMTJ
256Mb and 1Gb ST-MRAM on 300mm
Manufacturing Summary
ST-MRAM Technology

Write with current passing through the MTJ

Higher memory density with shrinking MTJ bit size

Perpendicular MTJ (pMTJ) bits enable higher density compared to in-plane MTJ (iMTJ) bits
# In-plane vs Perpendicular ST-MRAM

## In-plane
- Magnetic thin films want to be in-plane magnetized (de-magnetization fields)
- Stable states defined bit shape: limits of shape anisotropy requires larger bits for good data retention
- The reference layer is pinned and the anti-parallel configuration of the SAF is intrinsically stable

## Perpendicular
- Few materials with stable magnetization direction perpendicular to the film plane
- Energy barrier is determined by the material and not shape of the bits. Can achieve high Eb with small bits
- Pinning is less effective and not used. It is possible to ‘break’ the SAF causing hard failure of the device
64Mb in-plane ST-MRAM in Production

200mm, 90nm node Si
ST-MRAM is in Production and Proven in the Market

Spin Torque MTJ bit (in plane)

- MTJ bit is integrated in the last 2 Cu layers
The programming voltage $V_{w}$ of an array of bits for a given write error rate is higher than the average switching voltage $V_{c}$.
High-speed switching of 64Mb ST-MRAM

- Large operating window of write voltages and pulse durations
- Transition to dynamical regime for pulses less than 15ns
- Perfect programming with sub-10ns pulses

64Mb in-plane, 90nm technology ECC-off
64Mb in-plane, 90nm technology ECC-off

- Large operating window of write voltages
- Good margin in both directions
64Mb iMTJ parts have better than 1e9 full memory cycles of endurance.
64Mb Perpendicular ST-MRAM

200mm, 90nm node Si
As expected, distributions are tighter with pMTJ bits
Switching Reliability of Large Arrays

CFB based free layers with increasing PMA

Excessive PMA causes unreliable switching for in-plane free layer

Switching reliability of fully perpendicular free layers exceeds that of in-plane free layers

In-plane free layer

In-plane free layer with excessive PMA

Perpendicular free layer

Write error rate (sigma) vs. Applied voltage (a.u.)
Switching distributions from integrated arrays

Large improvement for pMTJ

Very good distributions down to 50nm diameter
Achieving Zero bit fails with ECC On

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Shmoo Plot – Up Pulse vs Voltage(bit)

SEMICON Taipei  9/4/2015
300mm Development

256Mb In-plane ST-MRAM, 40nm node Si
1Gb Perpendicular ST-MRAM, 28nm node Si
First pass success on 300mm with In-plane MTJs

- Measured SGPC structures on first 256Mb wafers with MTJs

- Bit contact
  - Center shows good bit contact
  - Edge shows shorted and open bits
  - Oxide CMP optimization will address edge fails
Successful Demonstration of MTJ Device

Arrays on MTJs

High speed switching

![Graph showing resistance vs. field and switching probability vs. voltage](image)
Summary

- Fully-functional 64Mb DDR3 ST-MRAM 90nm node in production
  - In-plane MTJ material optimized for low Vc and good switching

- In-plane technology successfully transferred to GF 300mm for 256Mb product on 40nm node.

- Perpendicular MTJ development focus on 300mm
  - Several similarities in process and materials between iMTJ and pMTJ
  - 35% improvement in distributions compared to in-plane
  - Scaling to 1Gb product on 300mm, 28nm node Si
Part Two - Bringing MRAM to the Mainstream

- The MRAM Market Opportunity
- Everspin Takes MRAM to the Mainstream
  - MRAM is Proven and Shipping
- Embedded MRAM
- Conclusion
The Market for MRAM

- TAM compilation from Everspin, Semicast, Databeans, & MarketsMarkets

**Instantly Recoverable** Transportation Systems

**Power Fail Safety** for HDD and RAID

**Fault-Recoverable** Industrial Automation

**Secure & Reliable** Smart Grid

**More Reliable** Storage, File, & Backup Systems

**Rapid, Low Latency** Enterprise Storage & Networks

**Mainstream Persistent DRAM in** Consumer Applications

**Toggle MRAM (Field-Switched)**

**“Persistent SRAM”**

**“Persistent DRAM”**

**ST-MRAM (Spin Torque)**

- **256K MRAM**
- **1M MRAM**
- **4M MRAM**
- **16M MRAM**
- **64M QSPI (in dev)**
- **64M DDR3 (in test)**
- **256M (in dev)**
- **1Gb (in dev)**
- **4Gb (future)**

**$0.3B TAM (2015)**

- **$0.5B TAM (2016)**
- **$2.0B (2018)**
- **$3.5B (2019)**

9/4/2015
Expanding Market Opportunity as MRAM is Accepted and Proven

- **7 Yrs** MRAM Production
- **50 M** Cumulative MRAM Shipments
- **100+** Customer Apps
- **200+** Design Wins Per Year
- **500+** Everspin Customers

![Cumulative MRAM Shipments (Millions)](chart.png)

MRAM Adoption >30% CAGR '13-'18


SEMICON Taipei 9/4/2015
MRAM is Proven and Shipping

300mm Wafer Production of Everspin MRAM Products
ST-MRAM process transfer successful
Initial 256Mb 40nm product is functional
Acceleration of pMTJ based products in 28nm and smaller
Versatile embedded memory with eMRAM

Strategic Investment

DDR3 and DDR4 controller optimization
NVMe and storage protocol optimization
Evaluation platforms and technology demos

Meeting the quality and supplier excellence needs of leading storage, industrial, and automotive customers
ST-MRAM is Replacing Persistent DRAM Solutions by **Improving Latency** while Reducing Design Complexity and System Cost

**Example:**
Enterprise SSD

**OLD**
NAND Flash + Controller (Terabytes)
DDR SDRAM + Super Caps + Power Loss Circuitry (Gigabytes or Megabytes) (ms Latency)

**NEW**
NAND Flash + Controller (Terabytes)
Everspin’s DDR ST-MRAM (Gigabytes or Megabytes) (µs Latency)
Scalability & Versatility: eMRAM can Replace Multiple Embedded Memory Types through Bit Cell Design Optimization

**Versatility by Design:**
eMRAM is unique in that the bit cell design can be modified for optimization as a replacement for Embedded FLASH, DRAM, SRAM or a combination up to all three.

**As Embedded FLASH:**
eMRAM offers Better Endurance, Bandwidth, and Energy

**As Embedded SRAM, DRAM:**
eMRAM offers Smaller and with Non-Volatility

**As Embedded Flash + SRAM:**
eMRAM replaces program code + execute code + storage space with one memory
Where We’re Heading

**Penetrating Automotive**
125°C AEC-Q100 Grade 1, Cost-Down, QSPI
Reliability for Harsh Environments such as Auto, Aerospace, Transportation

**Persistent DRAM in Storage**
300mm Capacity, Gigabit+ Densities
Data Integrity and Security in Cloud Compute, Storage, and Server

**Embedding beyond Flash**
Major Foundry, Turn-Key Macro, Beyond 40nm
MCU, GPU, ARM serving IoT, Mobile, Networking, Auto, Industrial

- **2X**
  - Toggle MRAM Revenue by 2017

- **$100M**
  - ST-MRAM Revenue by 2018

- **21Bu**
  - eMRAM TAM by 2018

Source: IC Insights
Bringing MRAM to the Mainstream: Discrete and Embedded

- **MRAM is penetrating the discrete mainstream memory market.**
  - The Market for “Persistent RAM” will be >$2B by 2018.

- **MRAM is the ideal next-generation mainstream embedded memory.**
  - Market potential for Embedded MRAM is greater than 20 Billion units worldwide by 2018.
  - MRAM is scalable and versatile, beyond existing eFLASH (40nm) and eSRAM (20nm) solutions.

- **Everspin is the MRAM Company and the only company:**
  - To bring MRAM to the market, both discrete and embedded (7 years, 50Mu+)
  - With 200mm and 300mm (GLOBALFOUNDRIES) MRAM production lines
  - With a commercialized Spin Torque MRAM solution (64Mb) & roadmap to Gigabit density
  - Enabling embedded ST-MRAM (300mm, advanced technology nodes)
THANK YOU