



## *Technology, Manufacturing and Markets of Magnetoresistive Random Access Memory (MRAM)*

**Brad Engel, VP- Product Development & Quality**



# Everspin – Electron Spin is Forever

## ❑ Industry-first and leading MRAM supplier

- Technology leader in **Toggle MRAM** and **ST-MRAM**
- Shipped over **2.5M** units with over **300** active customers to date
- Over 15 years of design and production experience with **MRAM**

Embedded Technology



Standalone Products



## ❑ Break through non-volatile memory products and IP

- 70 Products in 3 Memory Families
- Asynchronous x8, x16 and Serial SPI
- 600 Active Patents and Applications WW
- 176 Issued / 47 Pending US Patents

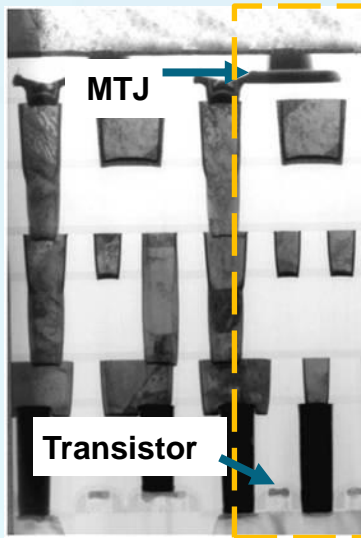
## ❑ Backed by leading VC Investors (*Spin-out from Freescale in June, 2008*)

## ❑ Global Footprint

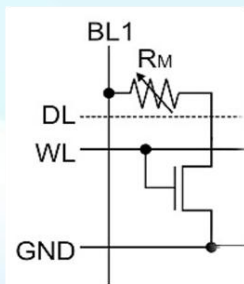
- Headquarters: Chandler, AZ, USA
- Manufacturing: USA, Singapore, Thailand, China
- Sales Offices: USA, Europe, China, Japan
- Design Center: Austin, TX, USA



# What is MRAM Technology?



Cross-sectional view



Circuit

- ❑ Simple 1 transistor + 1 MTJ memory cell
- ❑ Magnetic polarization stores data
- ❑ Resistance levels represent bit values compared to electron charge levels
- ❑ Highly reliable non-volatile memory
- ❑ Unlimited cycling endurance
- ❑ Low latency enabling instant on/off



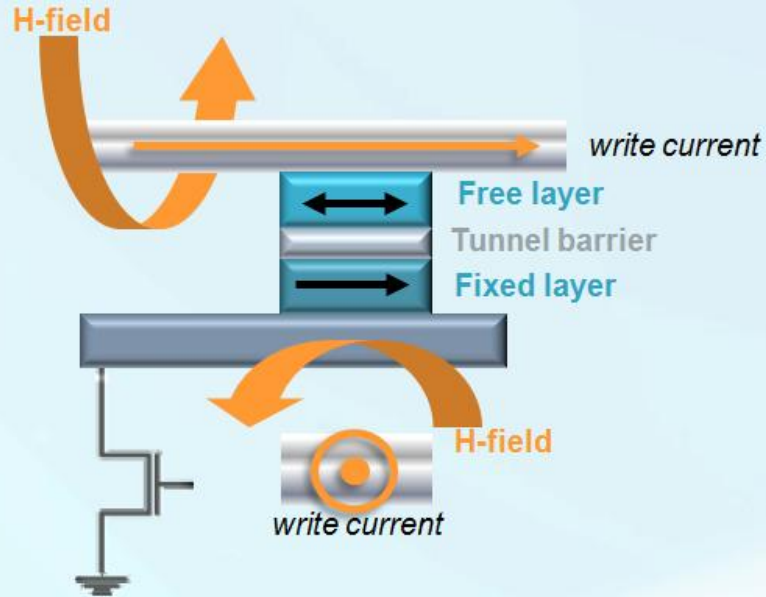
low resistance



high resistance

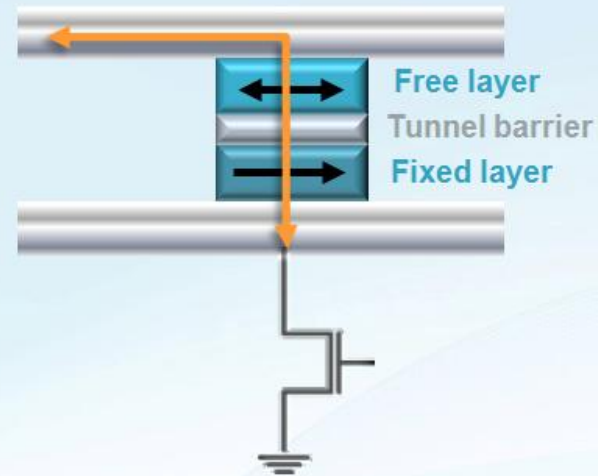
# MRAM - Technology Comparison

## Toggle Write



- ❑ Write accomplished by magnetic fields from current passing through bit and word lines.
- ❑ In volume production

## Spin-Torque Write



- ❑ Write accomplished by spin polarized current passing through the MTJ.
- ❑ In development

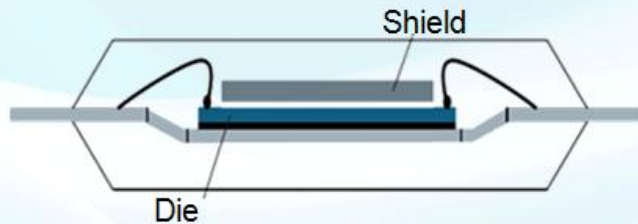
# Everspin MRAM Advantages

Parameter	Capability
<b>Non-volatile capability</b>	Data retention of the bit cell > 20 years
<b>Performance</b>	Symmetric read/write – 35ns / 40MHz Serial
<b>Endurance</b>	Unlimited cycling endurance
<b>CMOS integration</b>	Easily integrates into back-end process Compatible with embedded designs → No effect on CMOS Allows for flexible manufacturing
<b>Temperature range High Temp Storage</b>	-40°C < T < 150°C operation demonstrated Intrinsic reliability > 20 years lifetime at 125°C
<b>Soft error immunity</b>	Alpha radiation soft error rate too low to measure (<0.1 FIT per Mb) – Everspin partners offer radiation hardened MRAM
<b>Environmentally friendly</b>	No battery/caps, RoHS/REACH compliant, instant-on

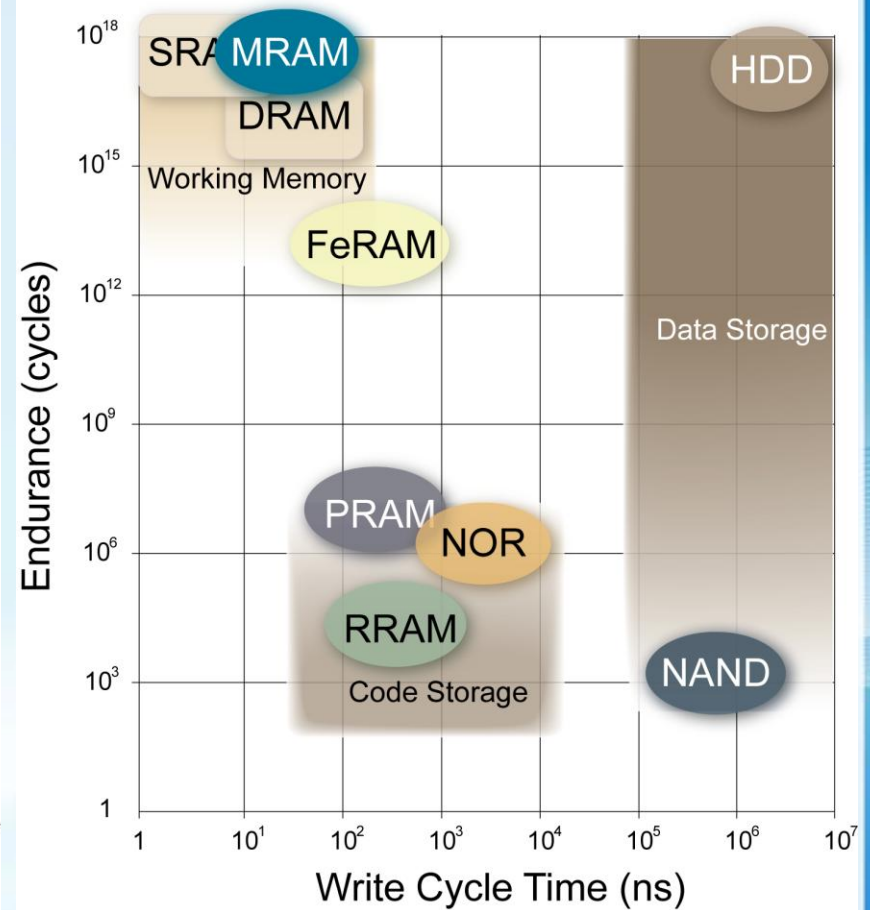
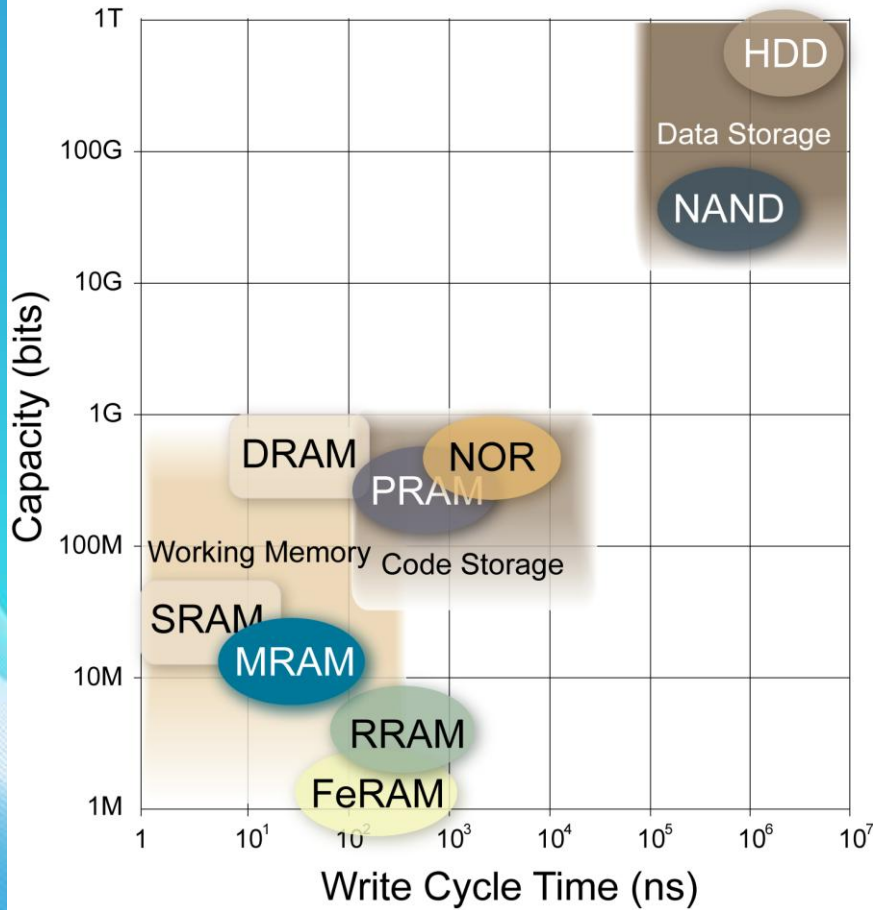


# How is MRAM made?

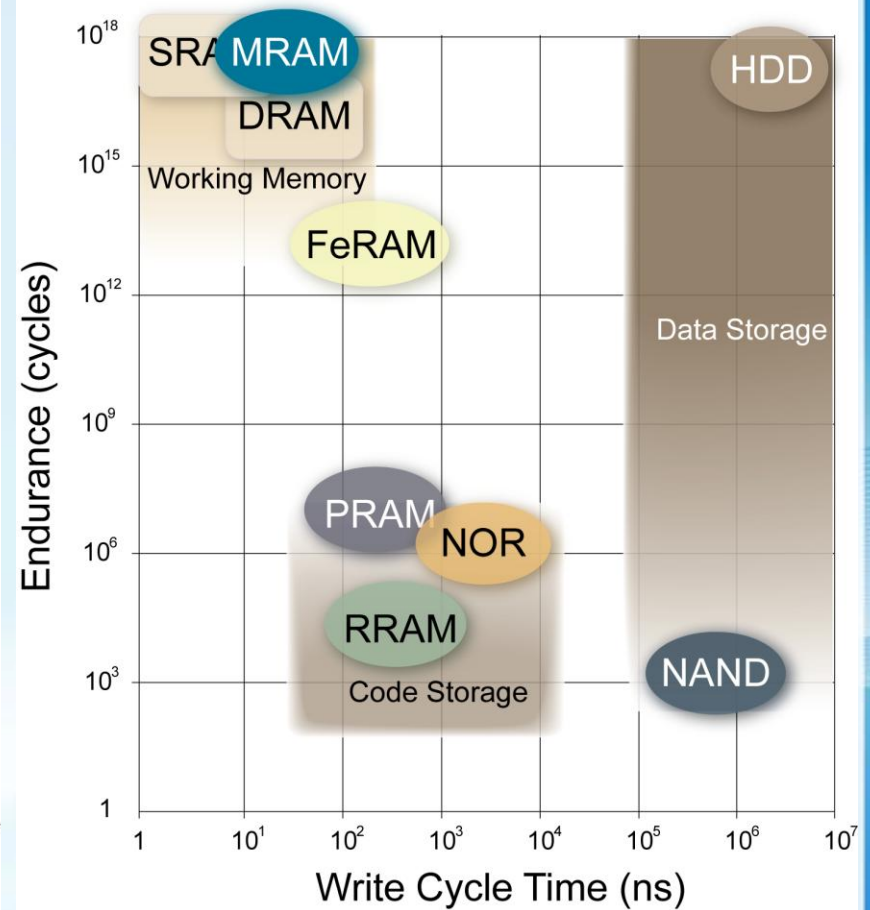
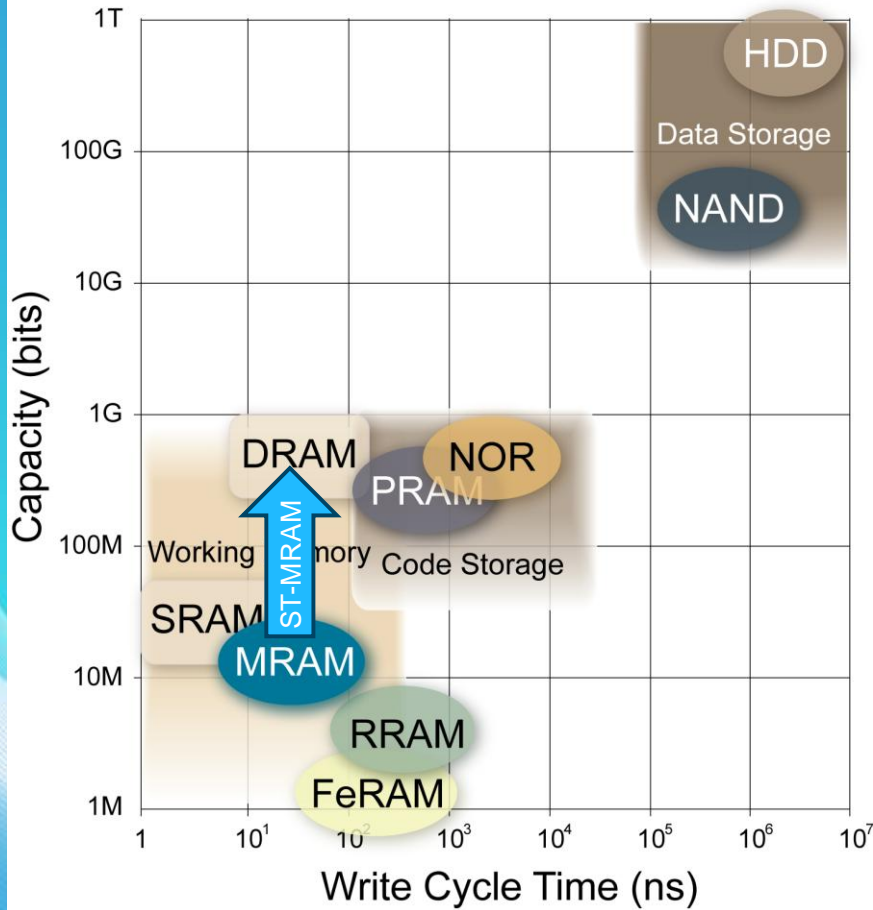
- ❑ **Leverage CMOS semiconductor ecosystem**
  - Everspin MRAM layer added to standard CMOS
  - Standard packages with protective internal shield
- ❑ **Common standard package types**
  - Drop in replacement fits footprints for existing printed circuit board designs
- ❑ **Pin for Pin functionally equivalent**
  - BBSRAM, SPI NVM, nvSRAM and FeRAM



# Memory Performance



# Memory Performance





# Current Toggle MRAM Products

## 16-bit I/O

<u>Part Number</u>	<u>Density</u>	<u>Configuration</u>	<u>Temp</u>
MR4A16B	16Mb	1M x 16	C,I,A
MR2A16A	4Mb	256K x 16	C,I,E,A
MR0A16A	1Mb	64K x 16	C,I,E,A

## 8-bit I/O

<u>Part Number</u>	<u>Density</u>	<u>Configuration</u>	<u>Temp</u>
MR4A08B	16Mb	2M x 8	C,I,A
MR2A08A	4Mb	512K x 8	C,I
MR0A08B	1Mb	128K x 8	C,I
MR256A08B	256Kb	32K x 8	C,I
MR0D08B	1Mb	128K x 8, 1.8v I/O	C
MR256D08	256Kb	32K x 8, 1.8v I/O	C

## SPI I/O

<u>Part Number</u>	<u>Density</u>	<u>Configuration</u>	<u>Temp</u>
MR25H40	4Mb	512K x 8	I, A
MR25H10	1Mb	128K x 8	I, A
MR25H256	256Kb	32K x 8	I, A

## 48-BGA

- x8 Asynchronous parallel I/O
- x16 Asynchronous parallel I/O
- x8 Asynchronous parallel 1.8V I/O



## 44-TSOPII, 54-TSOP

- x8 Asynchronous parallel I/O
- x16 Asynchronous parallel I/O



## 8-DFN

- SPI-compatible serial I/O
- 40 MHz; No write delay



## 32-SOIC

- x8 Asynchronous parallel I/O

## Temperatures

<b>Commercial</b>	0 to +70 °C
<b>Industrial</b>	-40 to +85 °C
<b>Extended</b>	-40 to +105 °C
<b>Automotive</b>	-40 to +125 °C



# MRAM Markets & Applications

## Storage Systems & Servers



## Industrial Automation & Robotics



## Automotive & Transportation



## Energy Management



## Telecom & Datacom



## Consumer, POS, Gaming



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# Toggle MRAM Used by Top Companies



**Siemens Recognizes Everspin Technologies for Perfect MRAM Quality - May, 2009**

**“After two years of high volume production and more than 100K systems in the field, we are very happy with the perfect quality and reliability of Everspin’s products in our industrial automation systems”**

<http://www.semiconductor.net/article/CA6658902.html>



**Everspin's automotive-temperature MRAM meets harsh environment demands in BMW S1000 RR racing bike**

*Everspin introduces AEC-Q100 MRAM products to serve broad automotive applications; 4Mb MRAM stores critical calibration data for BMW Motorsport Super Bike*



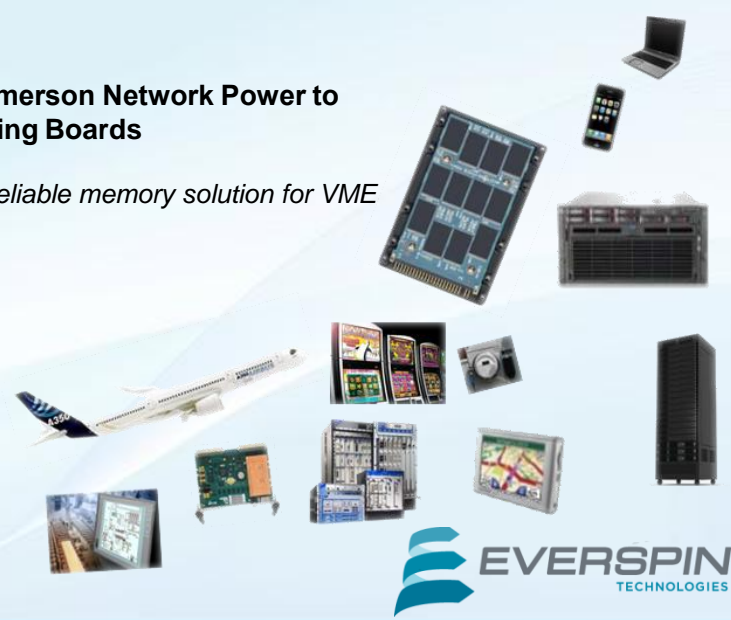
**Everspin Technologies' MRAM Selected by Emerson Network Power to Deliver Critical Storage for Industrial Computing Boards**

*Non-volatile MRAM technology provides a robust, reliable memory solution for VME and Compact PCI boards.*



**Everspin Technologies to provide Airbus with MRAM products for advance wide body aircraft**

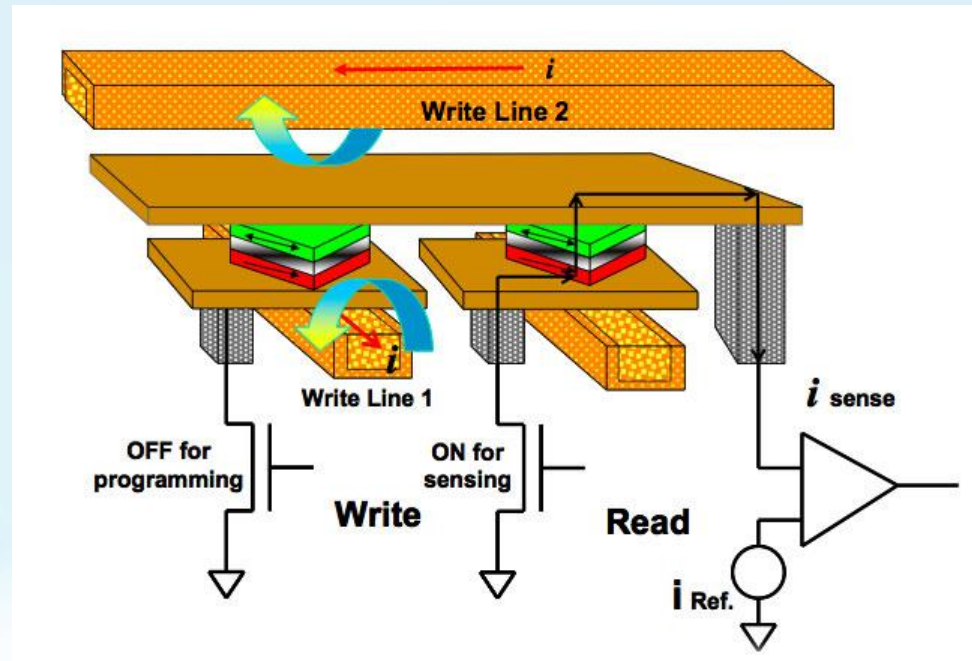
*Flight Control Computer on A350 XQB aircraft uses MRAM for critical program and data storage in extreme environment applications.*



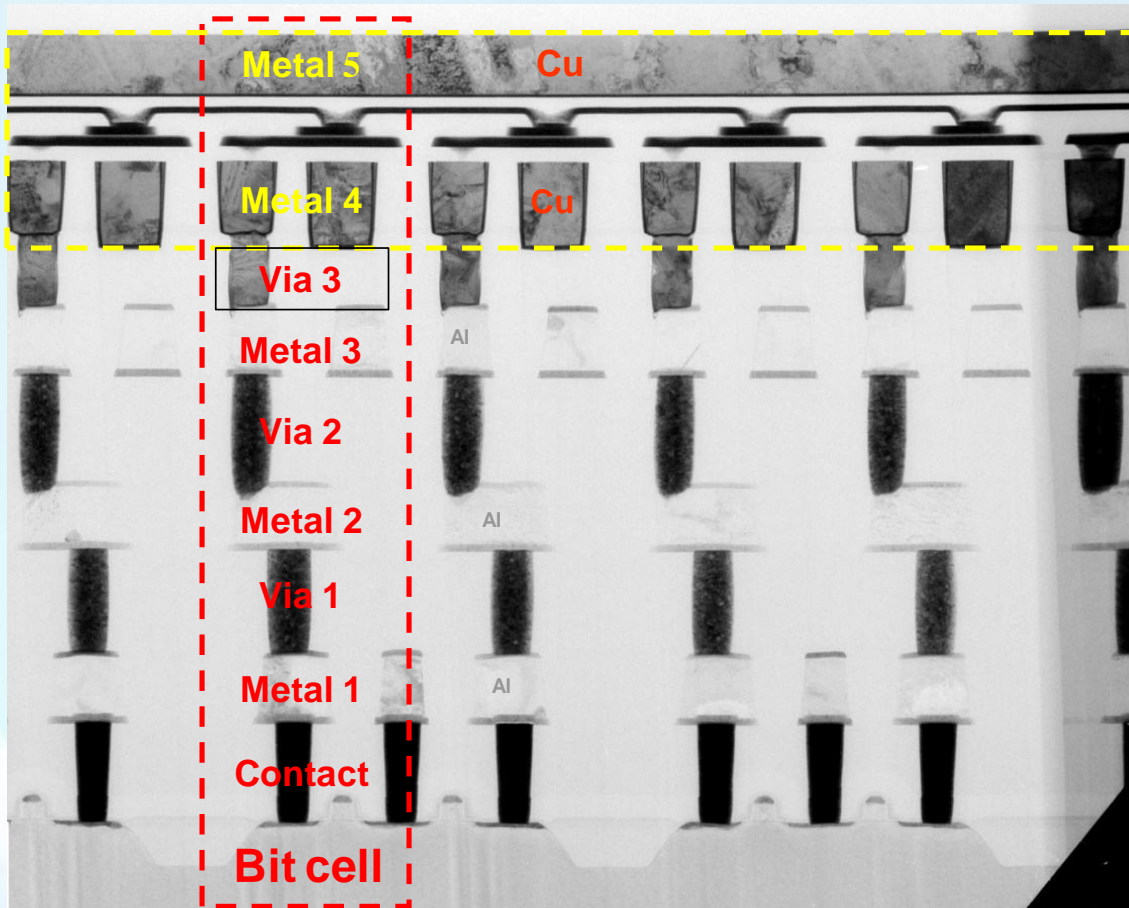
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# MRAM Writes and Reads

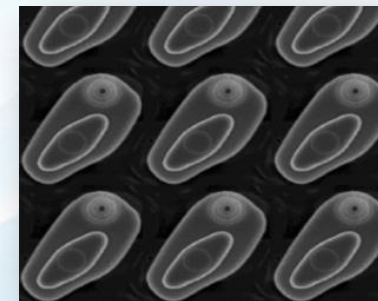
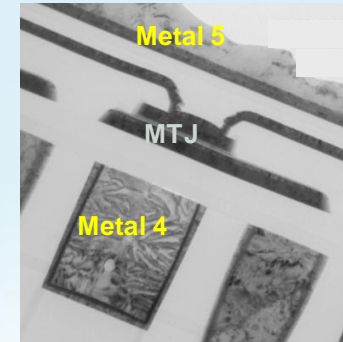
- Write Current Flows Down Write Line 1 & 2
- Magnetic Tunnel Junction (MTJ) At Cross-Point Is Polarized
- Polarization State Is Read By Selecting Pass Transistor to Sense Resistance of Specific MTJ



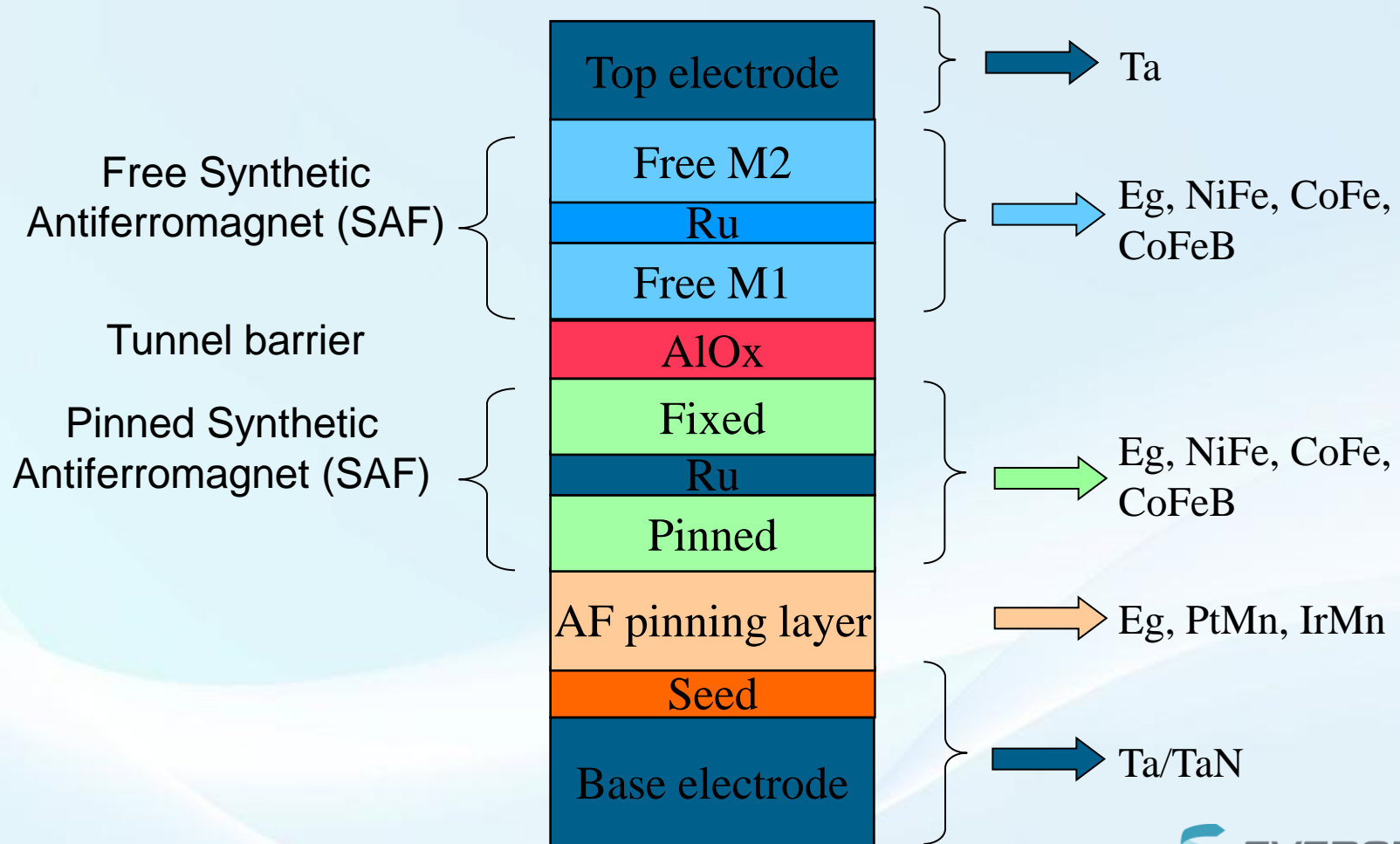
# MRAM Integration



MRAM  
module

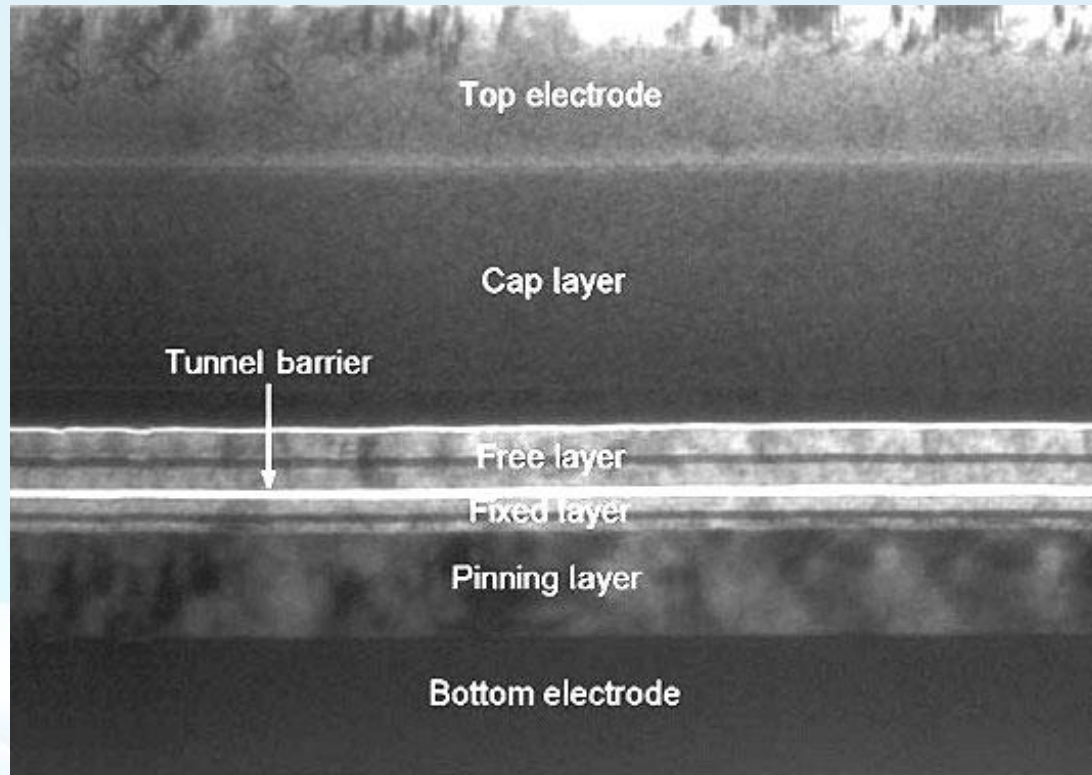


# MTJ Bit Materials



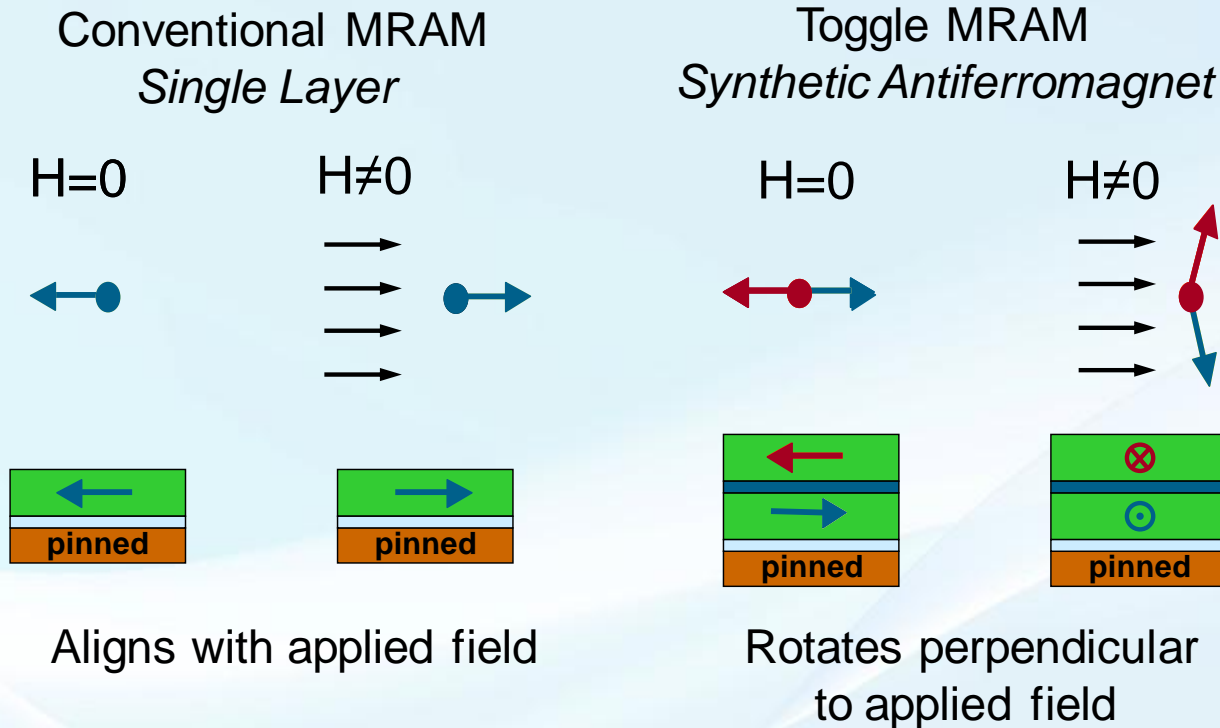
# MTJ Vertical Profile

- ❑ Ultra-thin layers require precision control for manufacturing



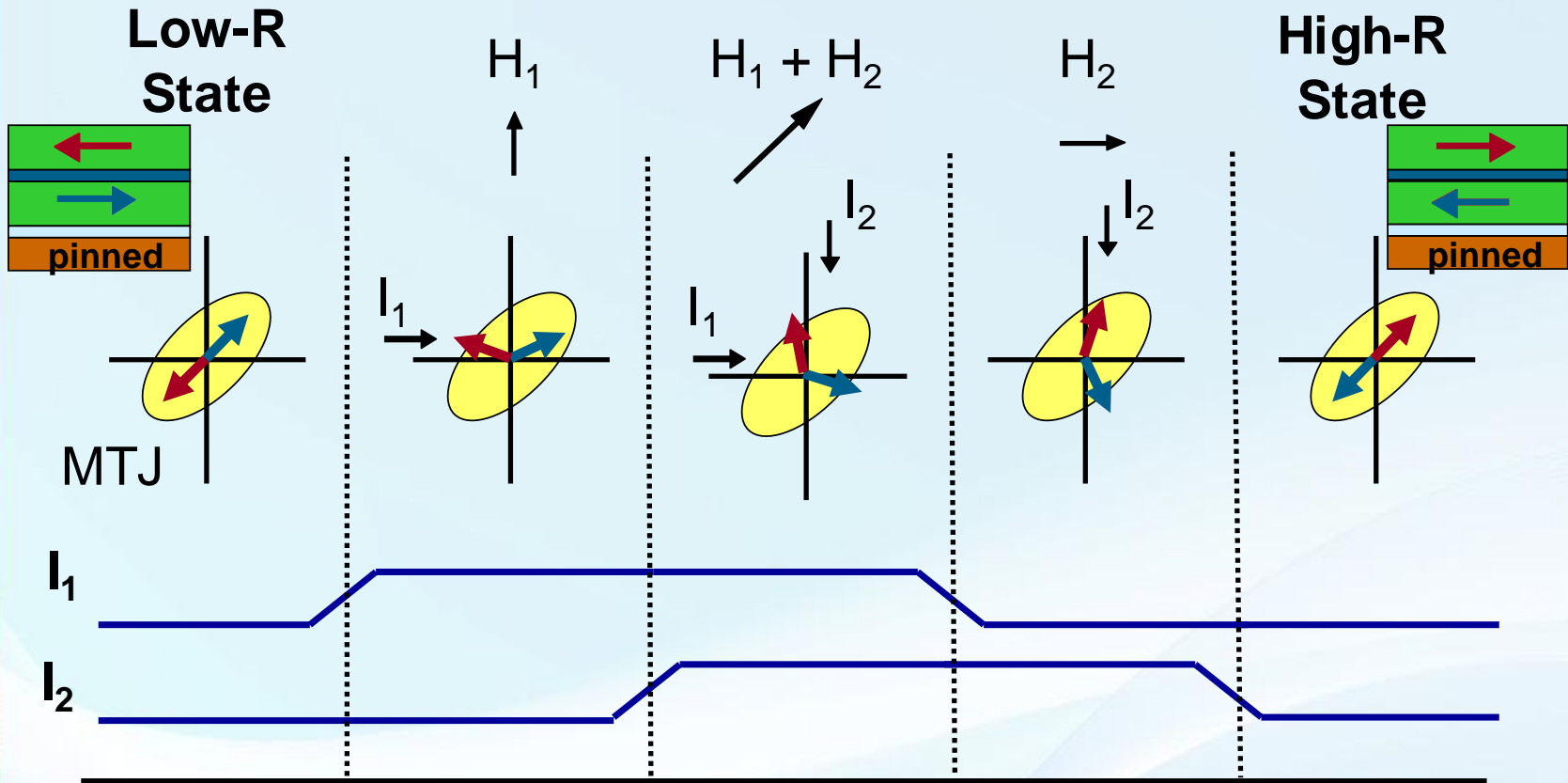
# Toggle MRAM: Write Mechanism

- Toggle MRAM is a unique approach that provides both robust switching performance and manufacturability
  - Response of synthetic antiferromagnetic free layer is the key.





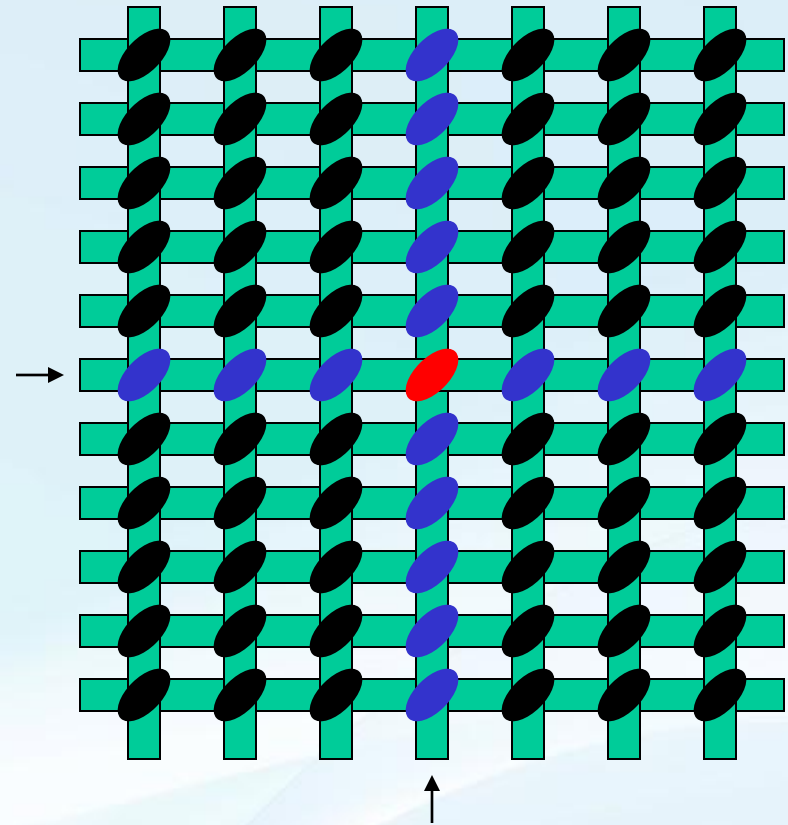
# Toggle Write Operation



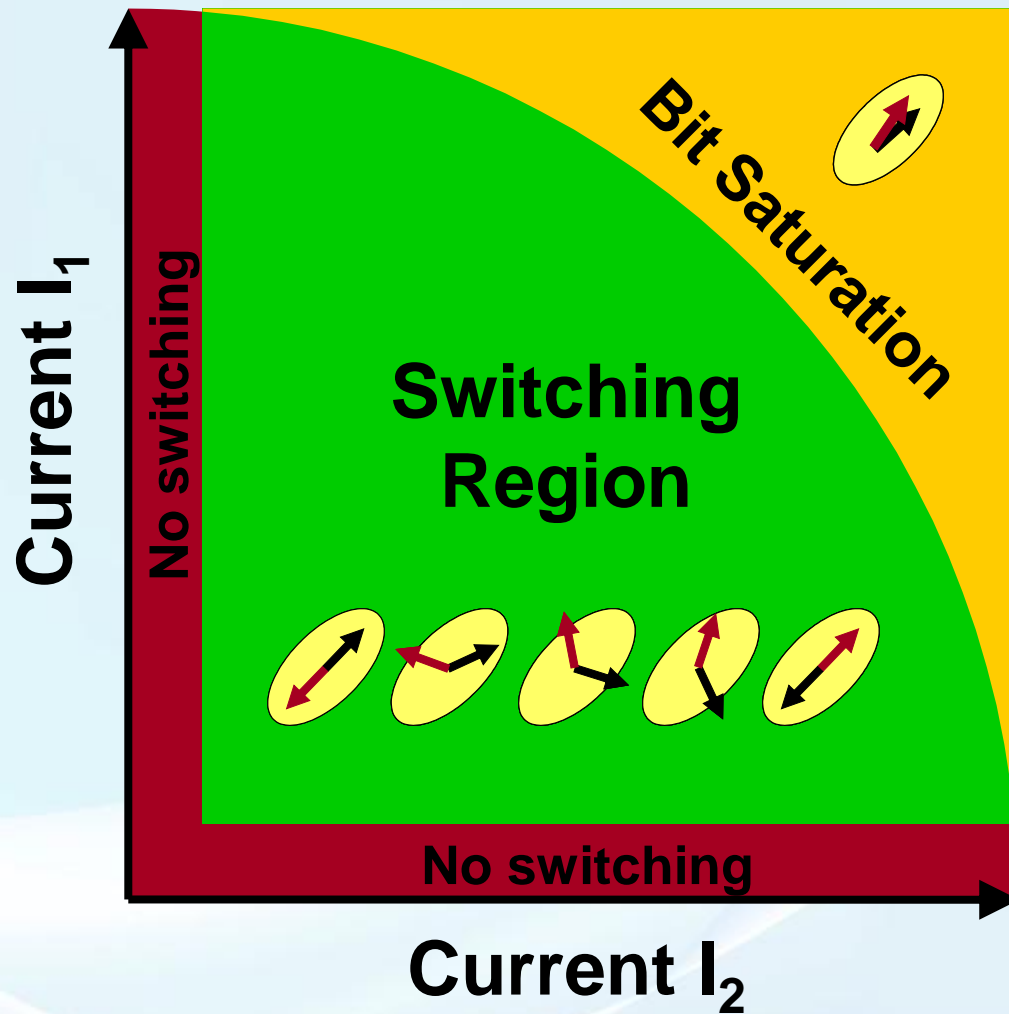
**Advantages: Eliminates disturb - Large operating window**

# Robust Toggle-Bit Selection

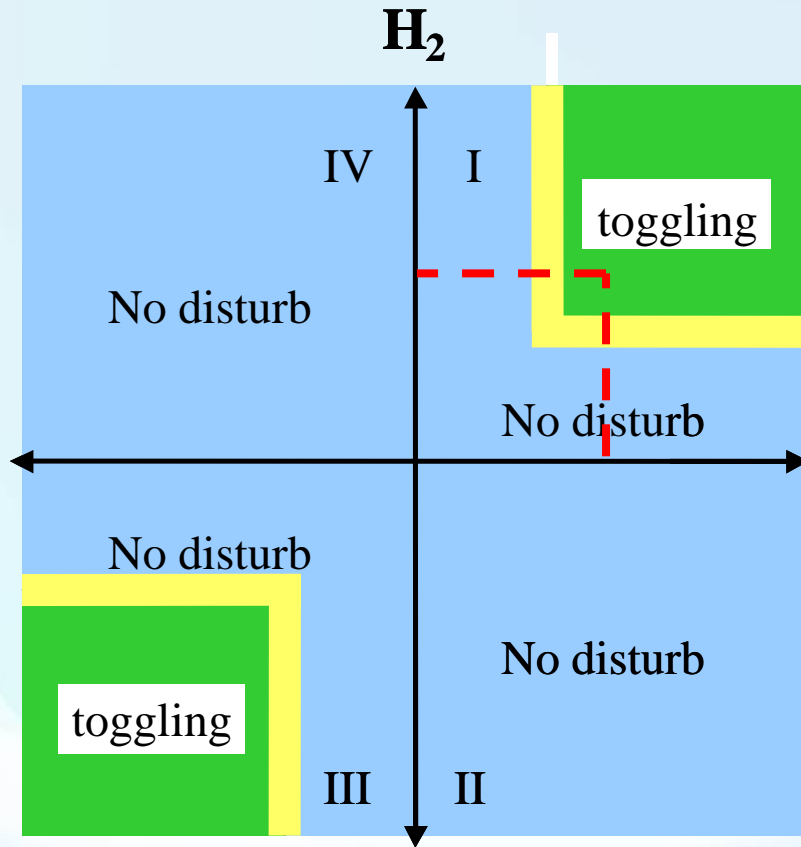
- ❑ Robust bit disturb margin
- ❑ All bits along  $\frac{1}{2}$ -selected current lines have increased energy barrier during programming



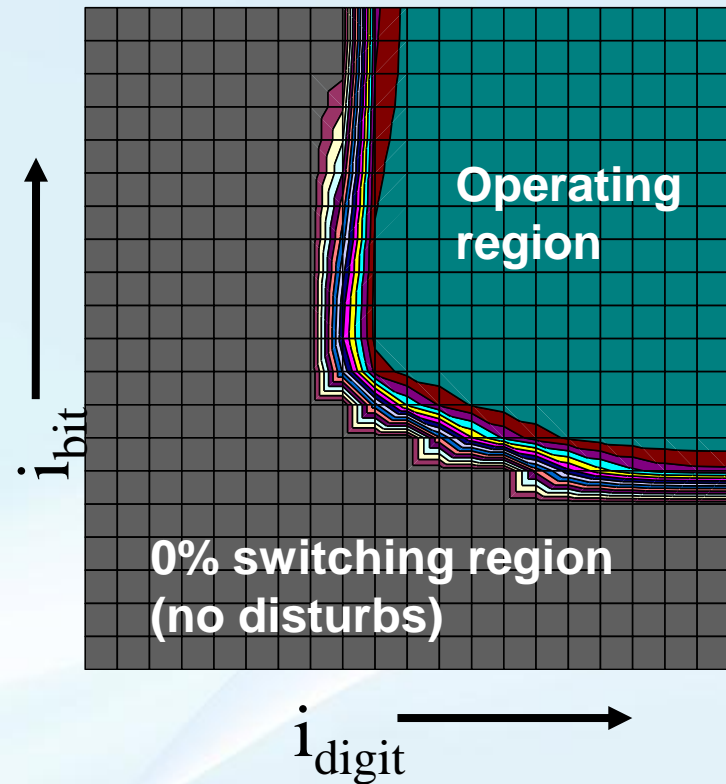
# Toggle Switching Characteristics



# Toggle-bit Array Characteristics

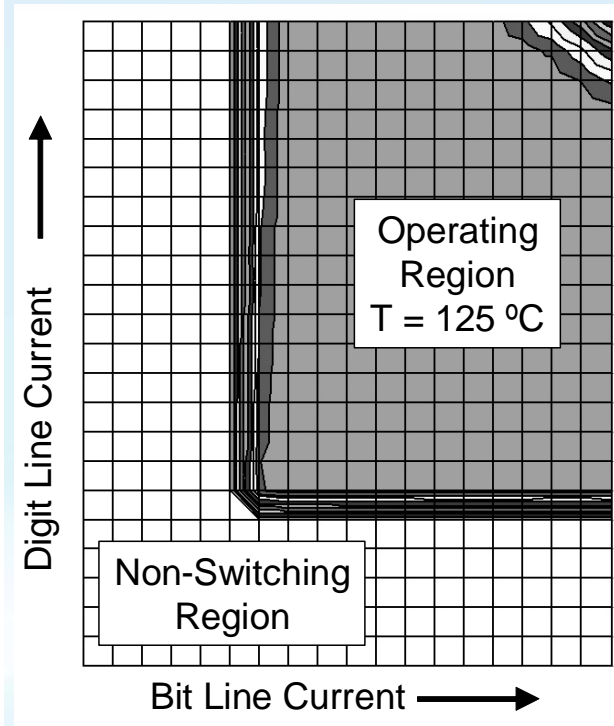
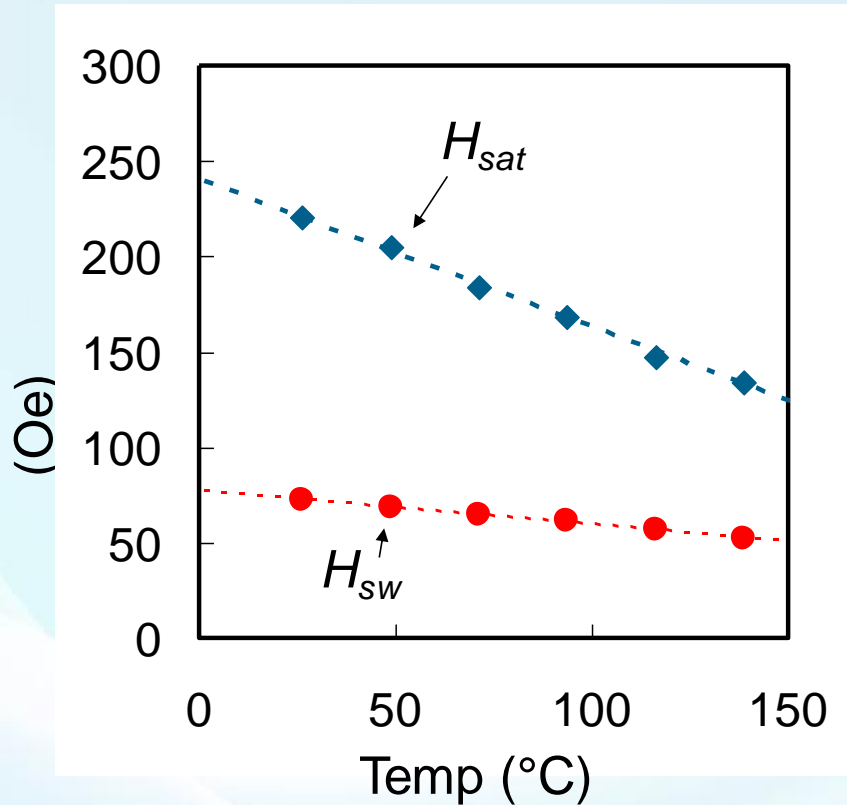


4Mb, March6N Toggle Map



# Write Operating Region at 125 °C

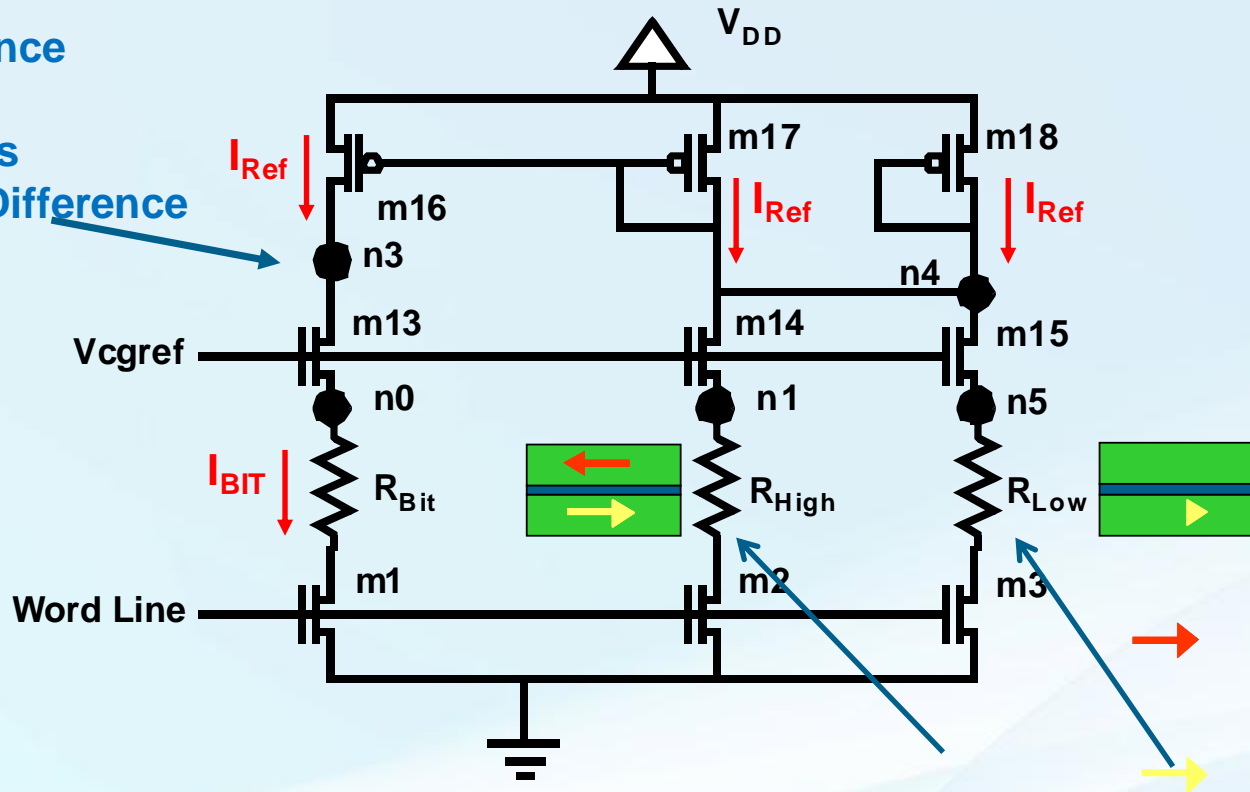
- Large write window at Automotive temperatures



•  $H_{sat}$ ,  $H_{sw}$  decrease linearly w/Temp, reducing window

# Read Sense Amplifier

Capacitance  
at node  
Integrates  
Current Difference



$$I_{Ref} = (I_{High} + I_{Low})/2$$

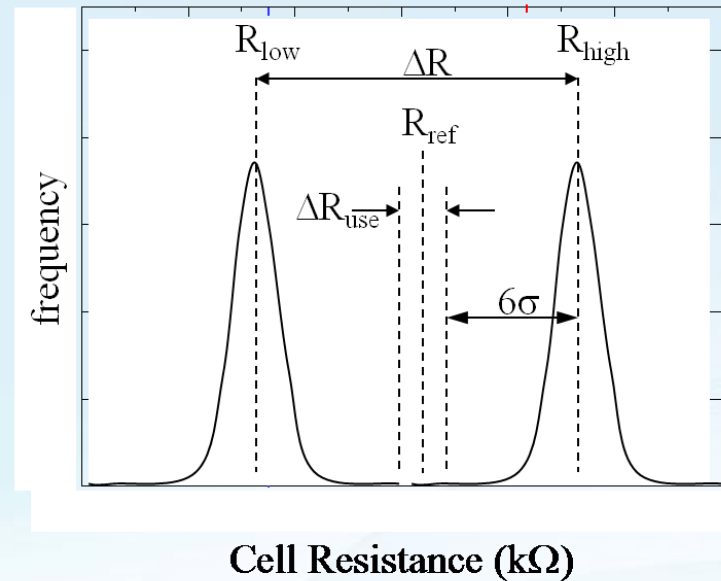
Local references created from two MTJ: one high and one low resistance state

# Magnetoresistance and Distributions

$$MR = \Delta R / R_{low}, \quad \Delta R = R_{high} - R_{low}$$

- ❑ **Signal =  $R_{cell} - R_{ref}$** 
  - $1/2$  of  $\Delta R$  available for sensing
- ❑ **Circuit works at finite bias**
  - MR is reduced by bias dependence of MR
- ❑ **Must sense all bits in the array**
  - Circuit must work with bits in tails of the R distribution

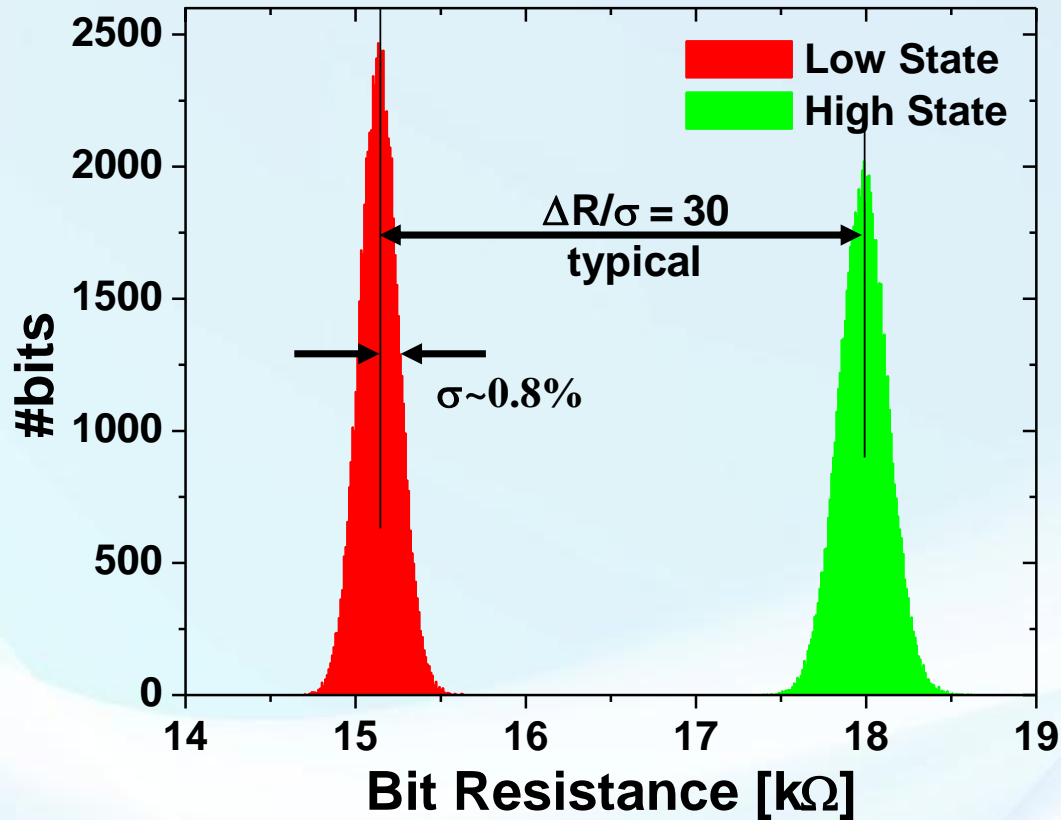
Array:  $R_{cell}$  Histogram



Resistance distribution reduces useable MR.

For six-sigma yield in the array, need:  $\Delta R/2 > 6\sigma$

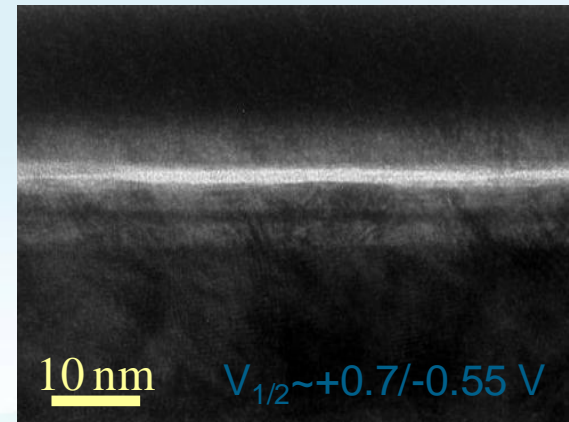
# Read Distribution within an Array



## Critical Factors:

1. Tunnel barrier quality
2. Pattern fidelity

Optimized for MRAM





# MTJ Deposition on 200mm Wafers

## Measured uniformity—200 mm

MR=45%,  $\sigma=2\%$

	43.9	44.5	44.6	44.8	44.5	43.1	
44.4	45.0	45.2	46.0	45.8	46.0	44.6	43.1
44.1	45.4	42.9	45.6		45.6	45.8	44.5
44.5	46.1	44.3	45.1	45.5	45.8	46.0	45.0
44.5	45.8	43.4	45.4	45.9	45.7	45.9	44.7
44.2	45.3	45.7	45.5	43.9	45.8	45.4	44.0
	44.1	45.3	45.9	45.6	45.0	44.7	
	43.4	44.0	44.8	44.1			

RA=10.4 k $\Omega$ - $\mu\text{m}^2$ ,  $\sigma=6\%$

		11.3	11.0	10.5	10.5	10.9	12.3	
11.7	10.3	9.74	9.88	9.65	9.80	10.2	11.5	
10.3	9.54	10.9	10.6		10.3	9.74	10.5	
10.1	9.68	10.4	10.8	10.8	10.7	9.85	10.7	
	9.80	10.9	10.5	10.8	10.5	9.86	10.2	
10.3	9.45	10.1	10.4	10.6	9.87	9.62	10.9	
	10.2	9.52	9.43	9.56	9.59	10.2		
		11.2	10.2	10.4	11.0			

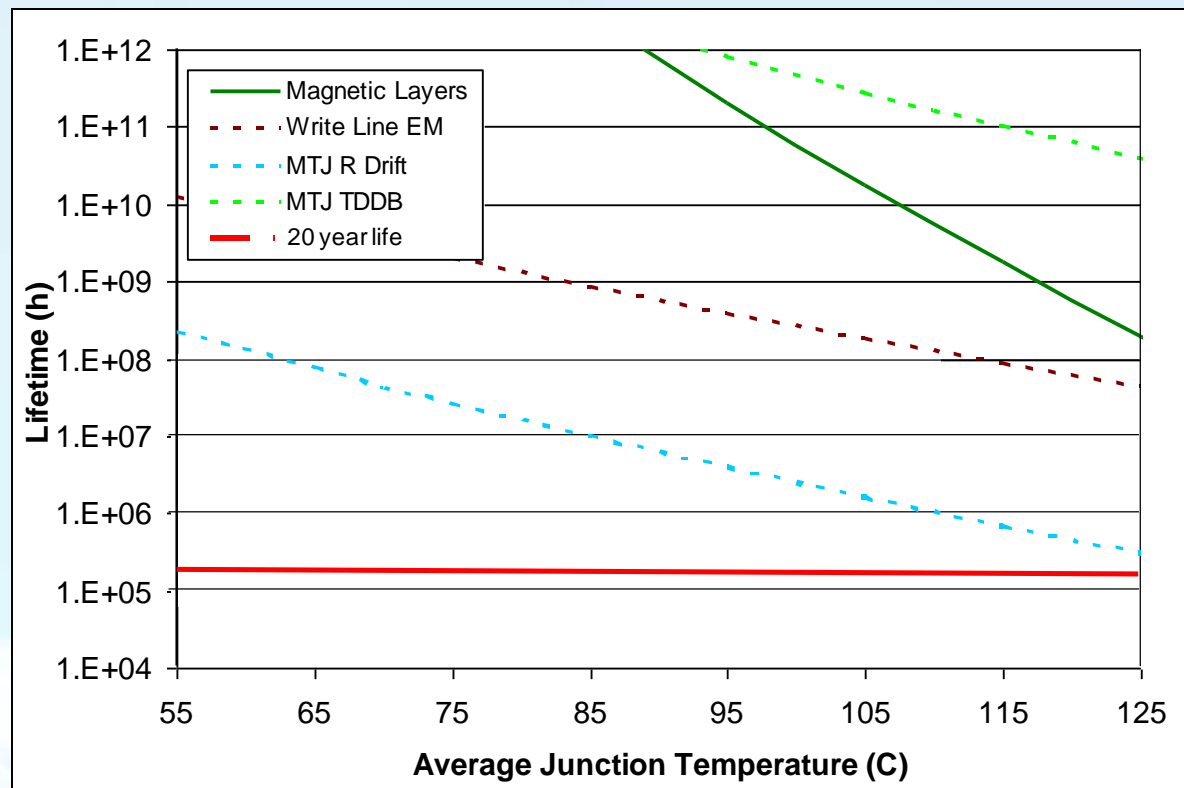
Manufacturable wafer level uniformity and wafer-to-wafer repeatability

- optimization of deposition tool, process, and material stack



# Toggle MRAM High Reliability

- ❑ Predicted lifetime from accelerated testing
- ❑ Robust reliability at Automotive temperatures



# Summary

- ❑ **MRAM is a highly reliable, high-performance, nonvolatile memory IC, with unlimited endurance**
  - Has the unique characteristics of a working memory while providing non-volatility
  
- ❑ **Current MRAM products are used in a wide variety of applications**
  - Data Storage, Industrial Control, Medical Systems, Transportation, Metering and Gaming
  
- ❑ **Everspin Continues MRAM leadership:**
  - Expanding MRAM into new markets and applications
  - On track to deliver the industry's first ST-MRAM

