



SDC¹⁸

September 24-27, 2018
Santa Clara, CA

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The Long & Winding Road to Persistent Memories

Jim Handy, Objective Analysis

Tom Coughlin, Coughlin Associates

Outline

- ❑ Persistent Memory Types
- ❑ Market Drivers
- ❑ Support Requirements
- ❑ Outlook

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- ❑ Outlook

Persistent Memory Types

- ❑ PCM/XPoint
- ❑ MRAM
- ❑ ReRAM
- ❑ FRAM
- ❑ Others

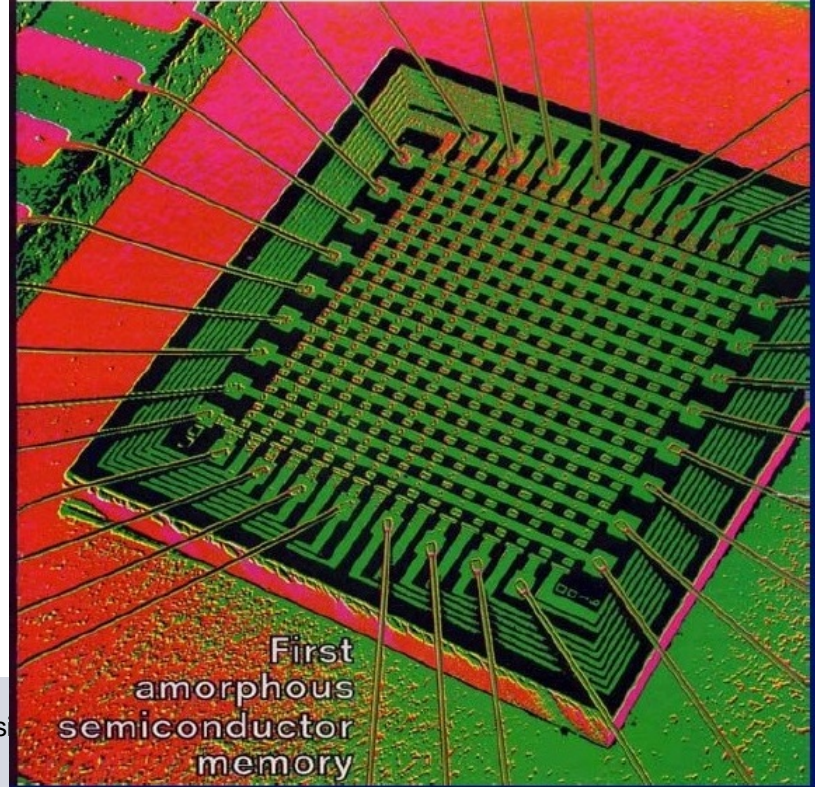
3D XPoint: A Long Time Coming

Amorphous semiconductors: jury still out 56
Designing low-noise bipolar amplifiers 82
The big gamble in home video recorders 89

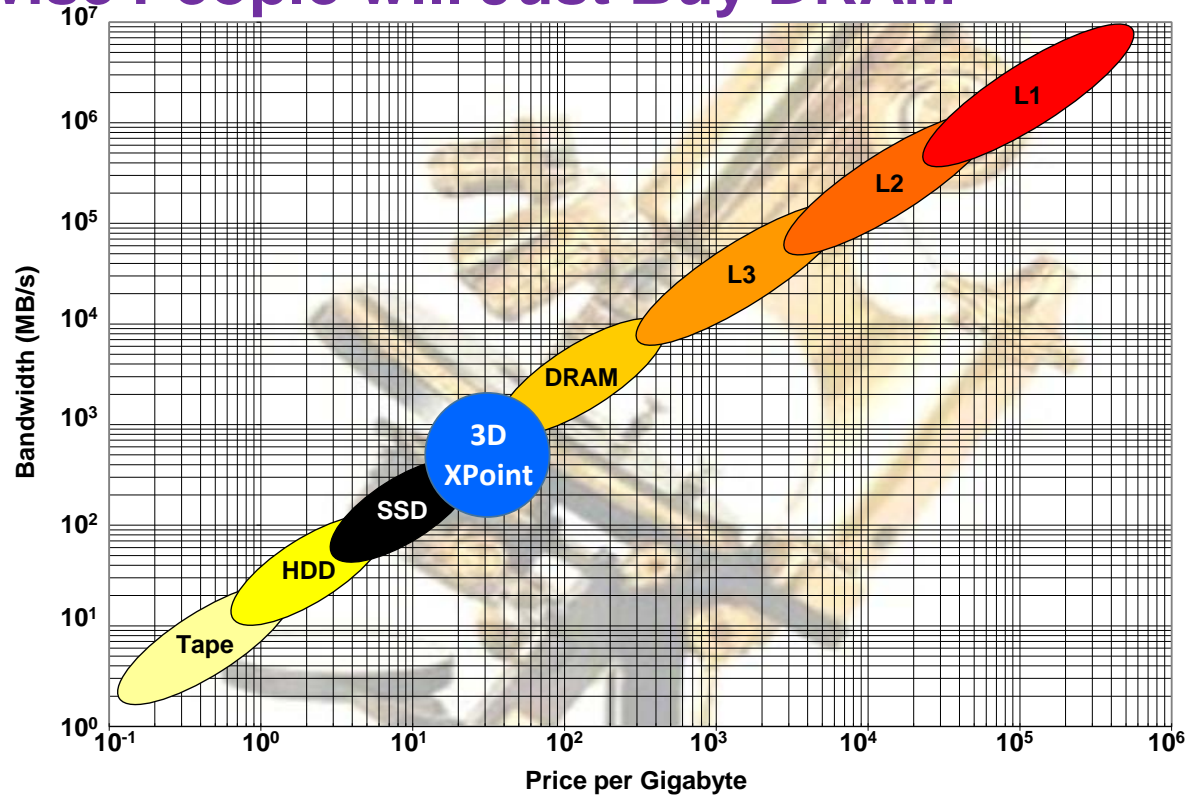
A McGraw-Hill Publication

September 28, 1970

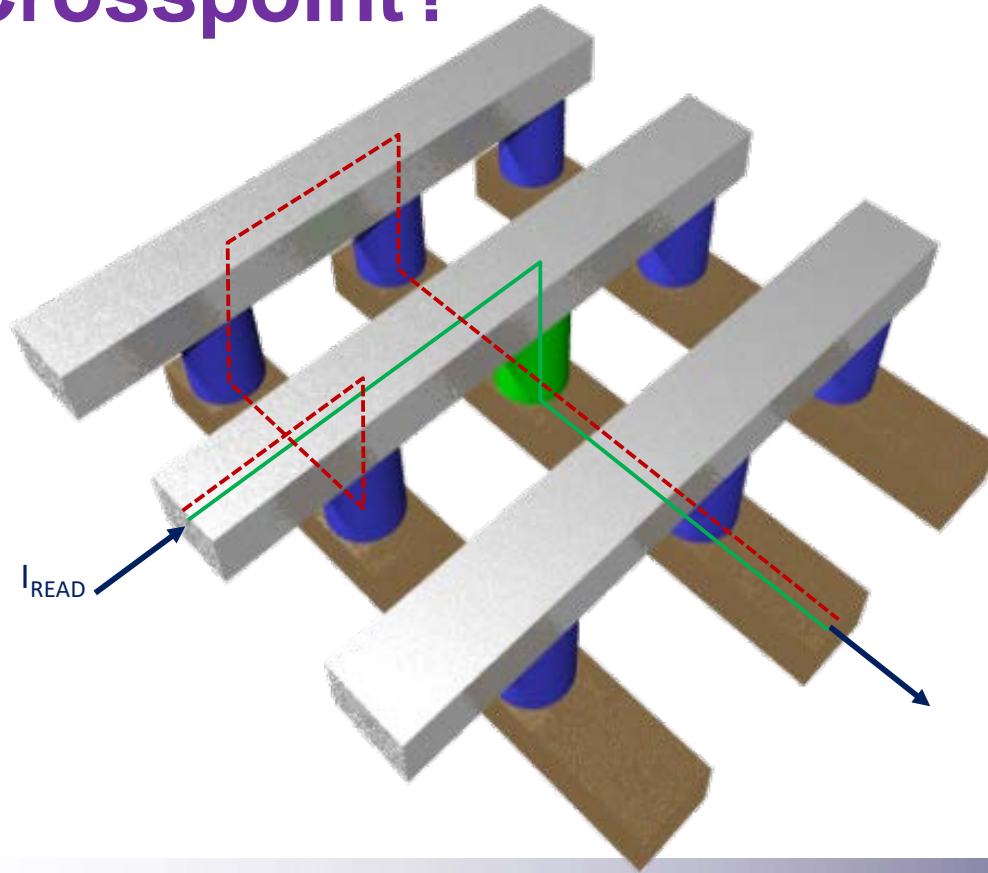
Electronics



3D XPoint Must Cost Less than DRAM Otherwise People will Just Buy DRAM

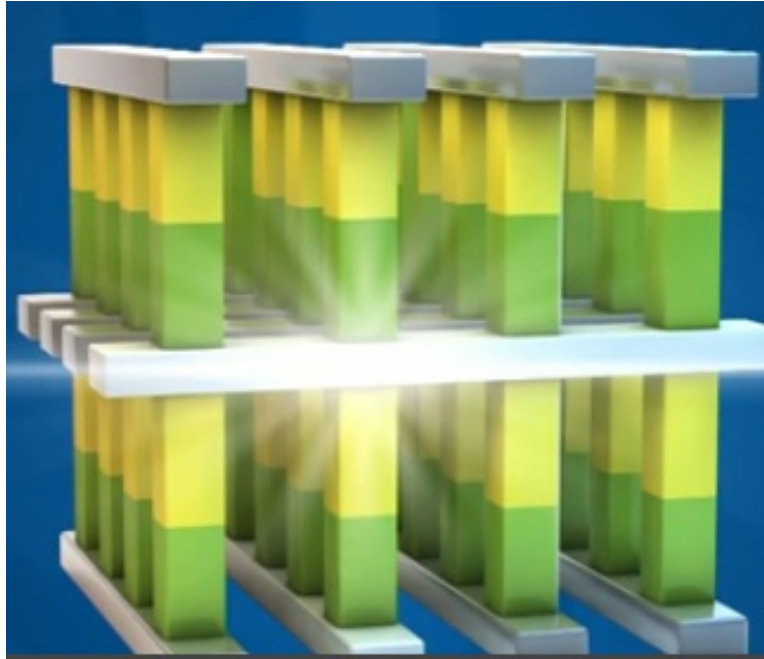


What is a Crosspoint?

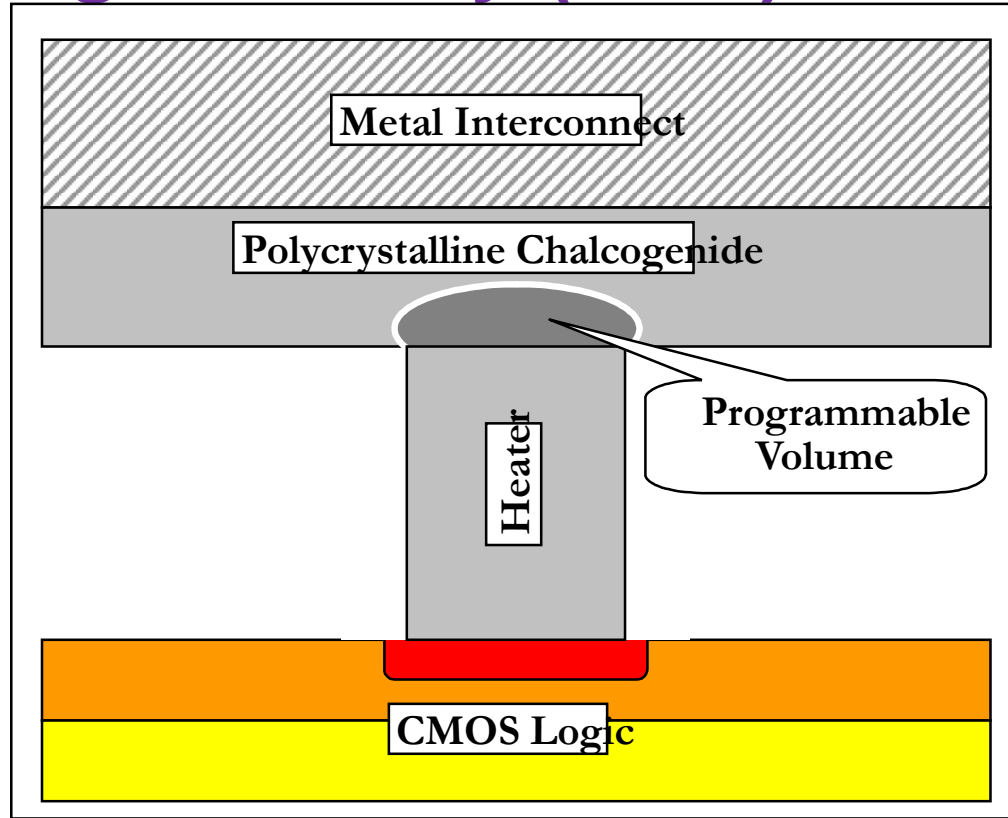


Crosspoint Arrays Can Be Stacked

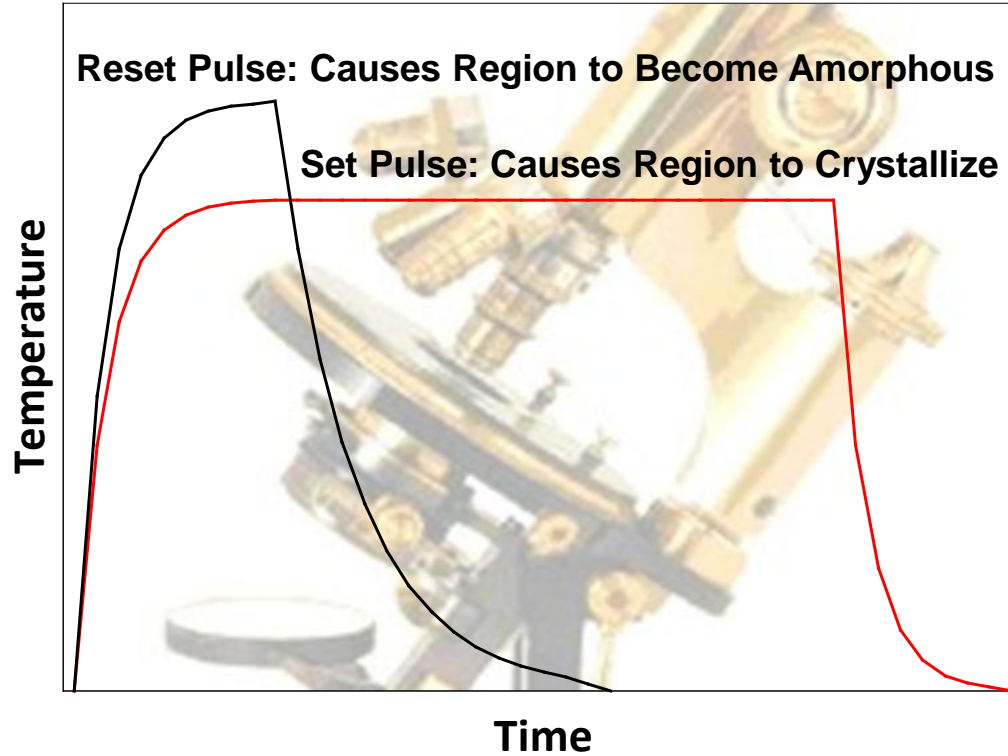
The Intel/Micron 3D XPoint Memory



Phase Change Memory (PCM)



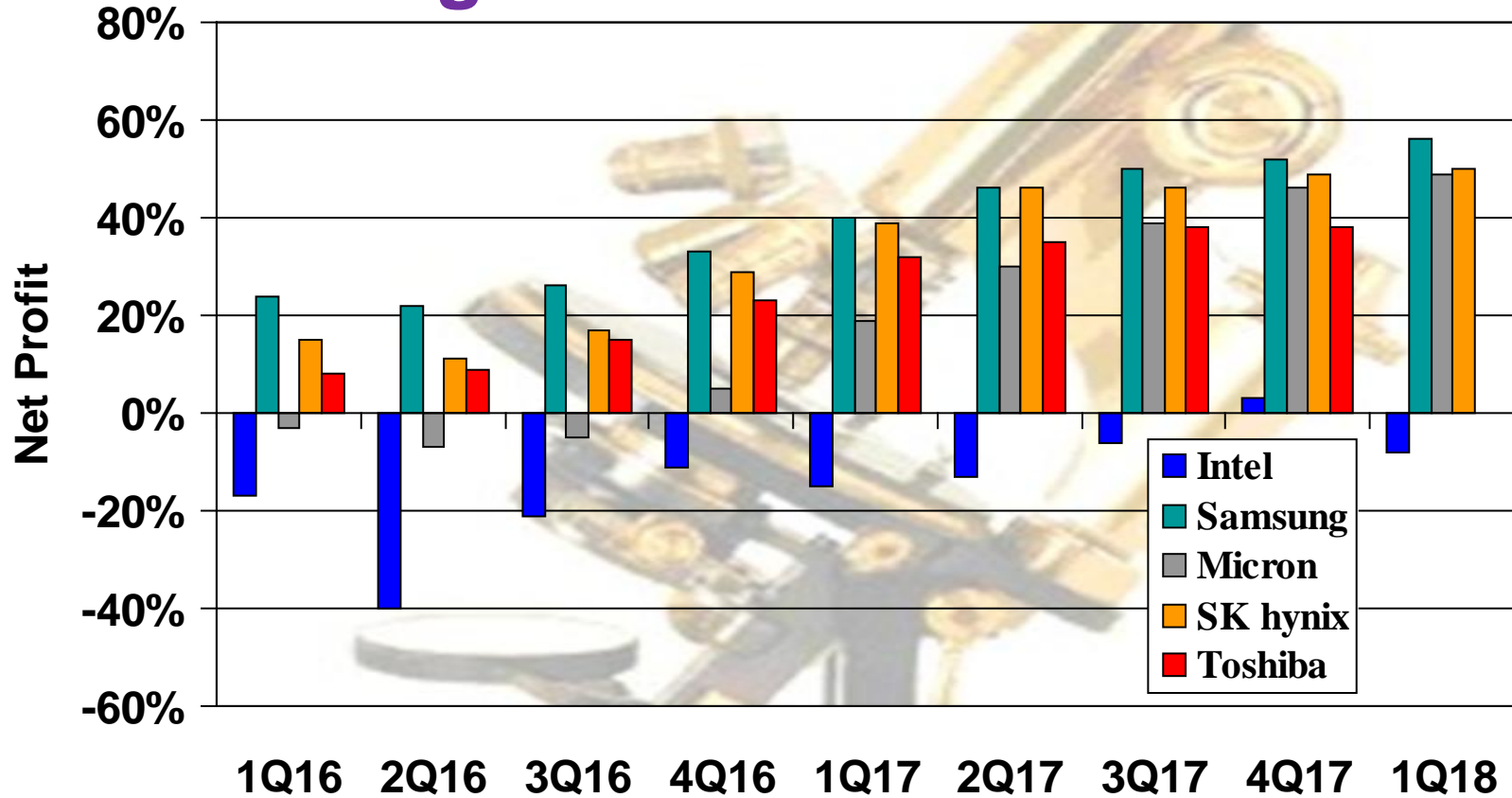
PCM Set/Reset Mechanism



NOR-Compatible PCM

- ❑ Shipped by both Samsung & Numonyx (Micron)
 - ❑ Both obsoleted it
- ❑ Well-understood materials
- ❑ Single current flow direction
 - ❑ Selector device is uncomplicated
- ❑ Today's markets:
 - ❑ Largely experimental & university projects

Intel Incurring XPoint Losses

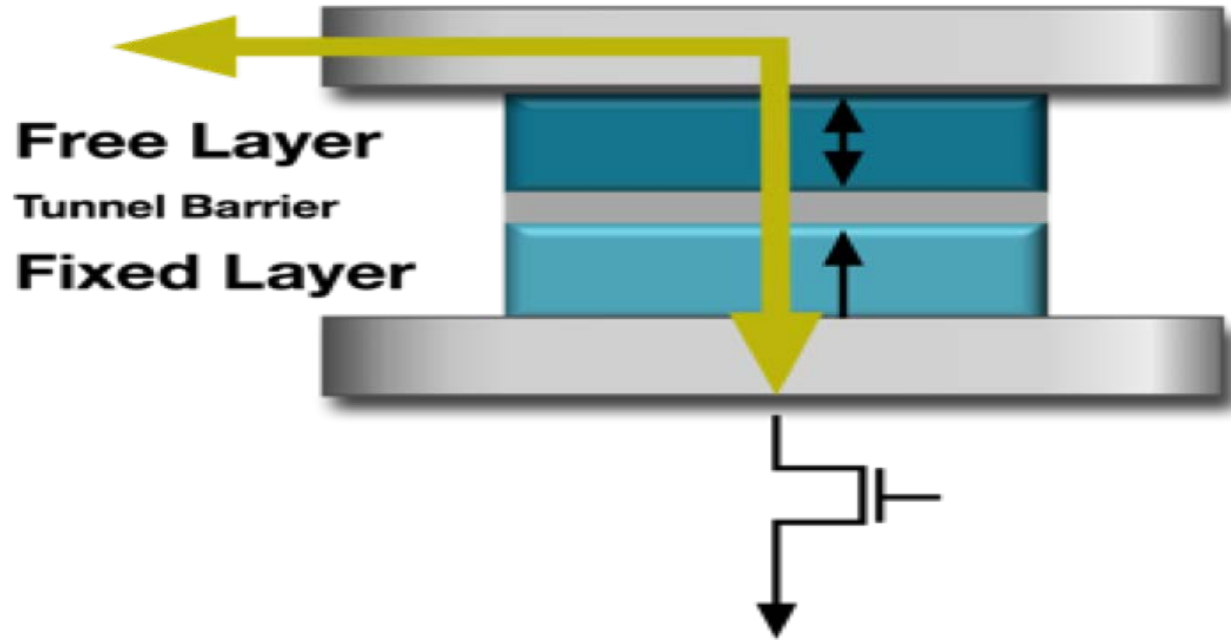


3D XPoint Report

- ❑ Objective Analysis
- ❑ The Why, How, and When of 3D XPoint Memory
 - ❑ Why Intel wants it
 - ❑ How it fits into the memory hierarchy
 - ❑ Impact on DRAM
 - ❑ When will it sell in volume
- ❑ Forecasts by application
 - ❑ NVMe SSD
 - ❑ DIMM format

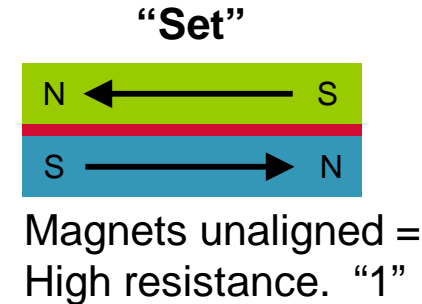
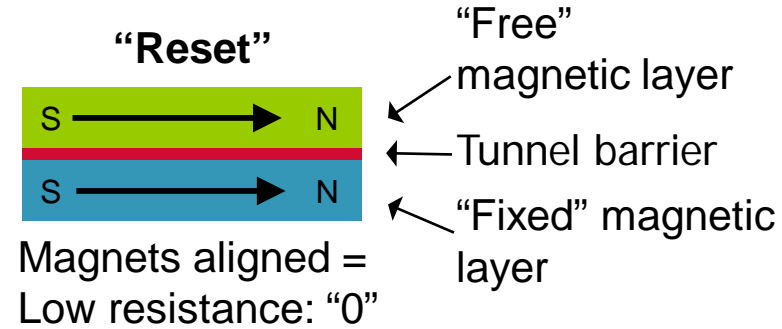
Now Available!

MRAM



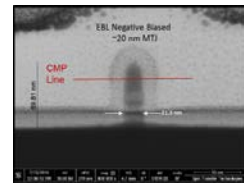
Toggle MRAM

- ❑ Offshoot of HDD head design
 - ❑ Magnetic tunnel junction: “MTJ”
- ❑ Magnetism determines tunnel barrier resistance
- ❑ Before STT there were scaling issues

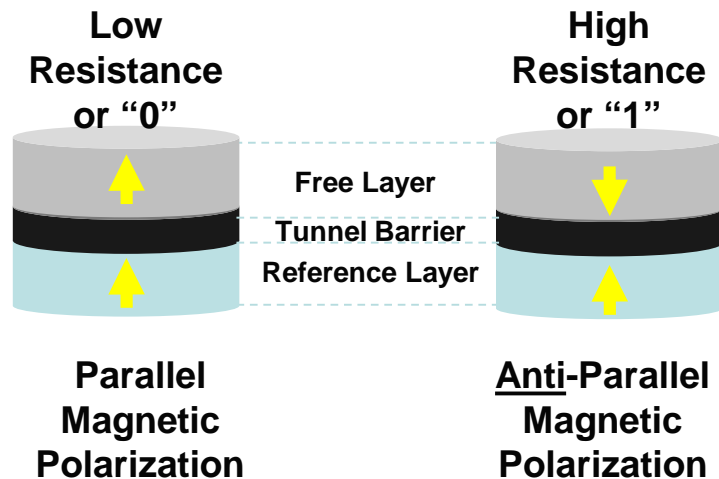


STT MRAM

- ❑ Solves scaling issues
- ❑ Being adopted in foundries
 - ❑ For embedded memories: SoCs
- ❑ Discrete memories will come later



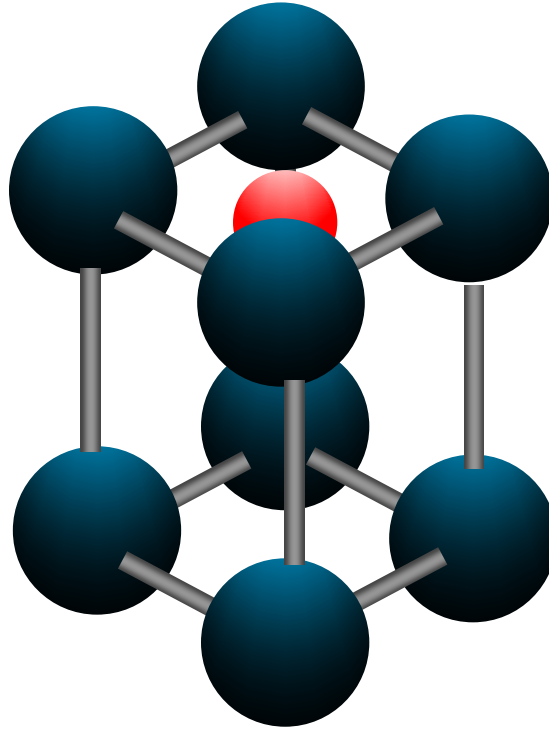
Perpendicular Magnetic Tunnel Junction (pMTJ)



MRAM Status

- ❑ Once considered a DRAM replacement
- ❑ Only one chip supplier: Everspin
 - ❑ Over 70 million units shipped
 - ❑ Converting from toggle bit to STT
 - ❑ Partnership with Global Foundries for 300 mm wafers
 - ❑ GF to engage embedded market
- ❑ Others trying to get in
 - ❑ Avalanche, Samsung, Spin Transfer, TDK, Toshiba, TSMC, UMC
- ❑ Today's markets: Space, high-uptime systems

Ferroelectrics: FRAM



FRAM Status

- ❑ Ramtron (Now Cypress)
 - ❑ Partnered with Fujitsu for high-volume applications
 - ❑ PZT – Lead Zirconium Titanate.
- ❑ Other renditions:
 - ❑ Thinfilm, organic FRAMs
 - ❑ Symetrix
- ❑ New HfO_2 approach from NamLab, Dresden
 - ❑ Uses well-understood materials (Hafnium Oxide)
- ❑ Today's markets:
 - ❑ RFID, other low write current applications

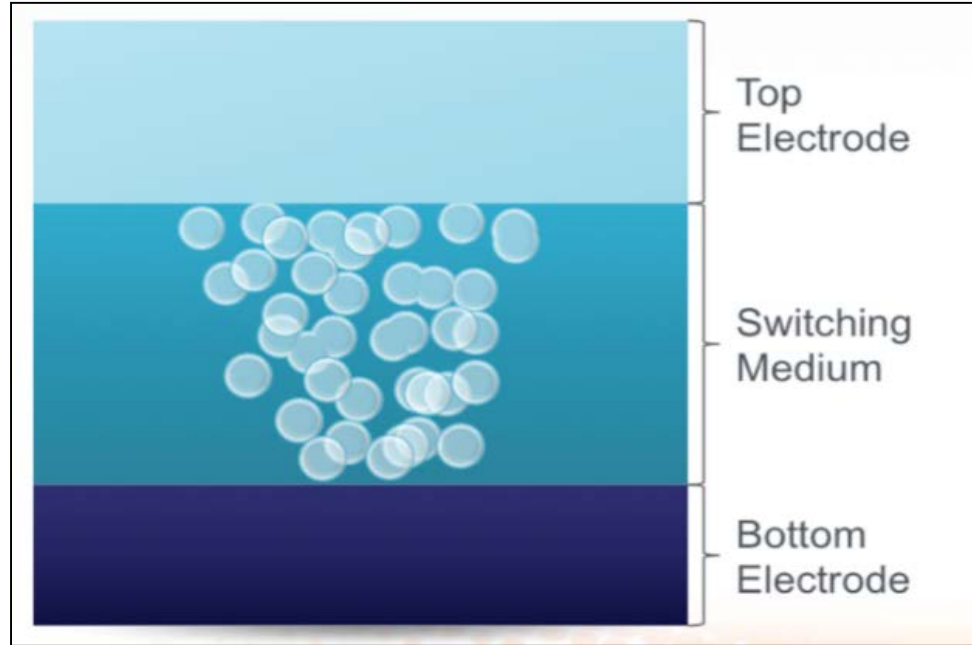
ReRAM

- ❑ What it is depends on who you ask
 - ❑ PCM
 - ❑ Memristor
 - ❑ CMOx
 - ❑ CBRAM
 - ❑ Carbon nanotubes

Let's examine each in turn

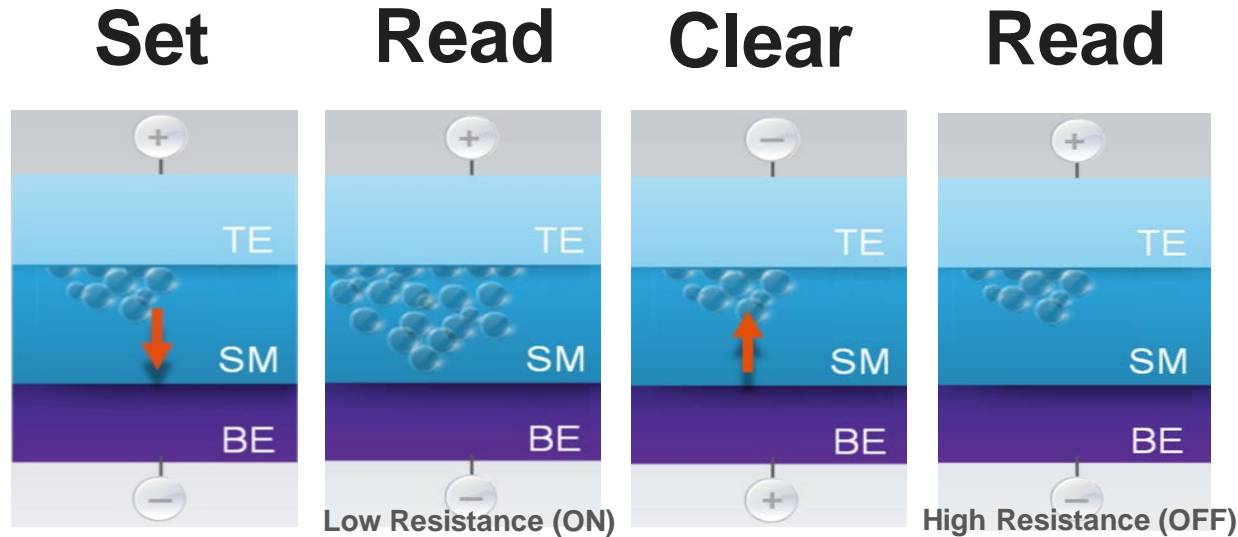
What /S a ReRAM?

- Any memory with a resistive bit



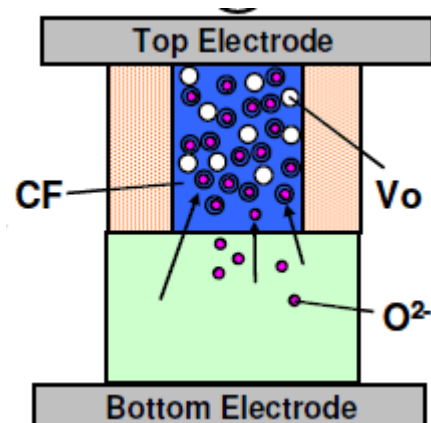
Programming/Reading ReRAMs

- ❑ Most require reversing the current
- ❑ Makes selector design difficult



CMOx

- ❑ “Oxygen Depletion” memory
 - ❑ Mechanism not well understood
- ❑ Unity pioneered it
 - ❑ Acquired by Rambus
 - ❑ Subsequently shut down
- ❑ Other research underway at universities and memory makers

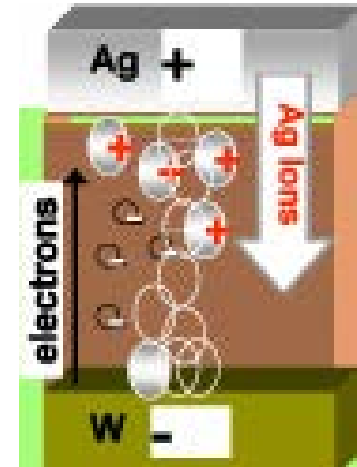


Memristor

- ❑ The “Missing” circuit element
- ❑ HP’s and HP’s alone
- ❑ Many claim that it’s really just a CMOx device
- ❑ Caused delays in HP’s “The Machine”
 - ❑ Was removed from the project two years ago
- ❑ Future is unclear

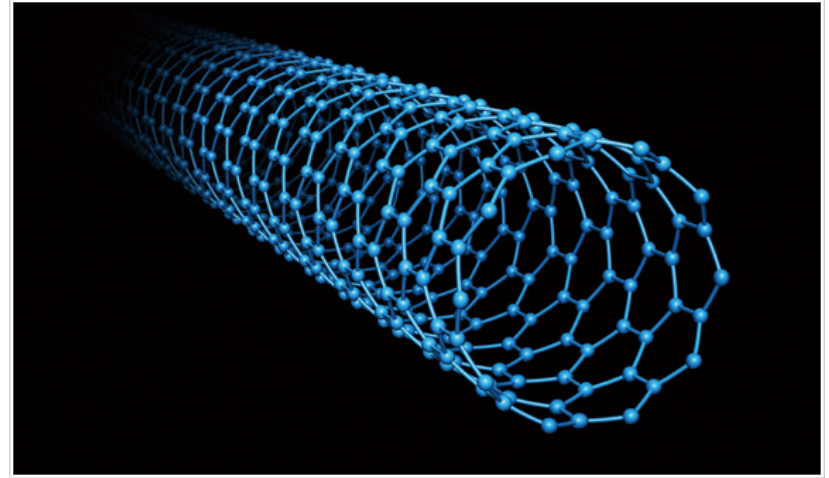
CBRAM

- ❑ Conductive Bridge
 - ❑ Silver filaments in glass
- ❑ Adesto currently shipping limited volume
- ❑ Other companies trying to get in
 - ❑ Contour – Acquired by WDC
 - ❑ Crossbar licensed to multiple foundries
- ❑ Today's markets:
 - ❑ High-radiation medical & space applications



Carbon Nanotubes

- ❑ A “Wonder Technology”
- ❑ Nantero
 - ❑ Recently-announced Fujitsu partnership
- ❑ University research



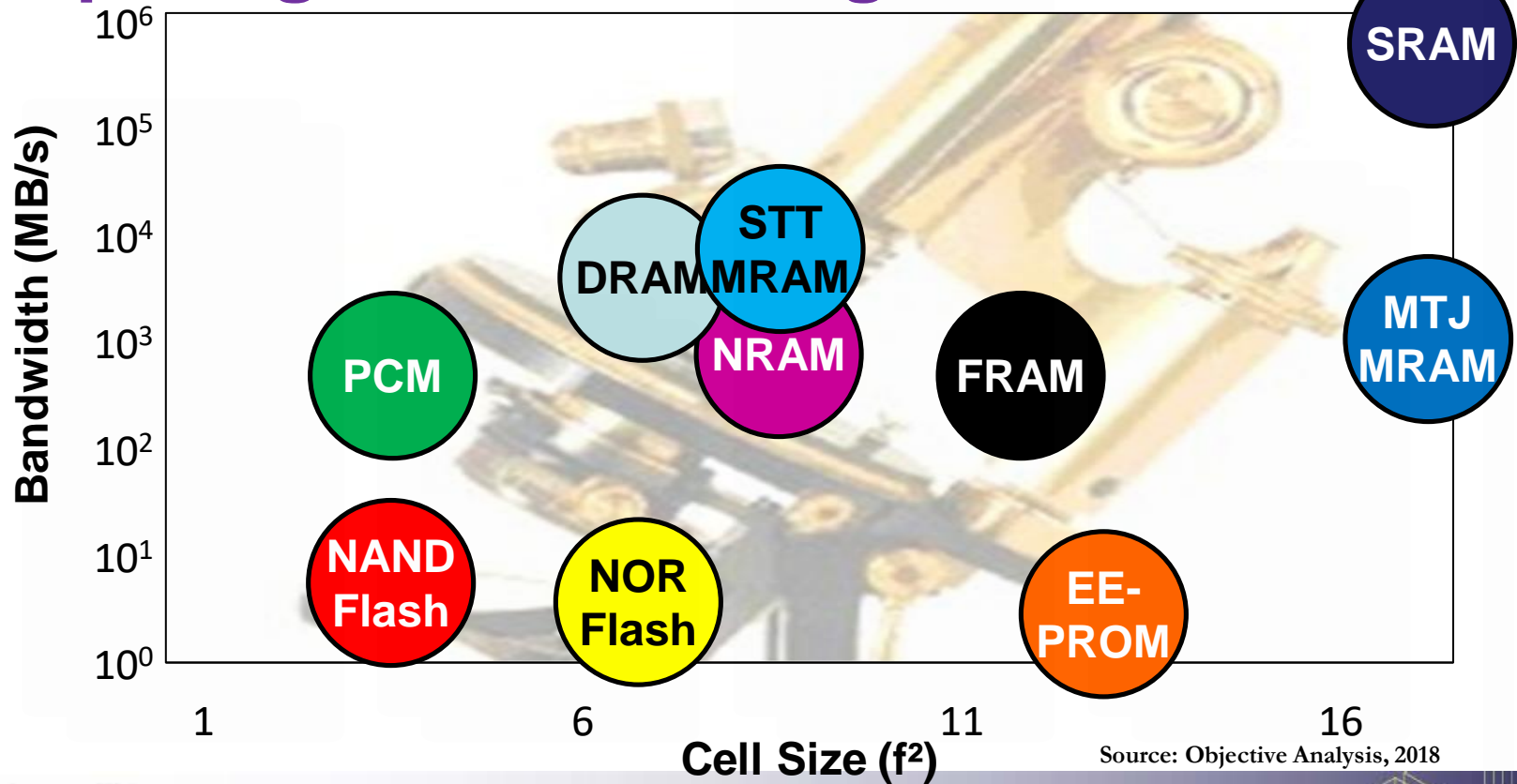
All Have Something In Common

- ❑ Small single-element cell
 - ❑ Some use diode select mechanism
 - ❑ Promise to scale past DRAM & NAND flash
- ❑ Nonvolatile
- ❑ Write in place
 - ❑ No “Block Erase”
 - ❑ More symmetrical read/write speeds
- ❑ New materials

Memory Attributes By Technology

	Units	SRAM	DRAM	NOR Flash	NAND Flash	MTJ MRAM	ST-MRAM	FRAM	PCM	RRAM
Byte Read Time	ns	2	10	25	10,000	35	<10	55	16	10
Byte Write Time	ns	2	10	5,000,000	200,000	35	<10	55	30	10
Standby Current	mA	<1	45	<1	<1	<1	<1	<1	<1	<1
Read Current	mA	20	220	20	25	30	15	<10	15	15
Write Current	mA	20	240	50	25	30	15	<10	20	20
Endurance	P/E Cycles	Infinite	Infinite	10 ⁵	10 ⁴	10 ¹¹	10 ¹³	10 ¹⁴	10 ⁶	10 ⁶
Retention	Yrs @ 55°C	0	10 ⁻⁹	>10	>10	>20	>20	>10	>10	>10
Scaling Limit	nm	5	10?	45?	14	65	5	5	5	5
Cell Size	f ²	50	6-8	6-8	4 effective with MLC	35-40	8-9	8-20	4	4
Select Device	N/A	Transistor	Transistor	Transistor	Transistor	Transistor	Transistor	Transistor	Diode	Diode
MLC Capability	Bits/ Cell	1	1	2	4	2	4	1	4	TBD
SEU Immune	N/A	No	No	No	No	Yes	Yes	No	Yes	Yes
Self Refresh	N/A	No	No	No	No	Yes	Yes	No	Yes	Yes

Comparing the Technologies



Source: Objective Analysis, 2018

New Persistent Memory Report

- ❑ Coughlin Associates/Objective Analysis
- ❑ Examines the PM Ecosystem
 - ❑ Technologies (PCM, ReRAM, MRAM, FRAM, +)
 - ❑ Companies
 - ❑ Markets
 - ❑ Support requirements
- ❑ Forecasts PM consumption
 - ❑ Embedded PM
 - ❑ Discrete PM
- ❑ 161-page report, containing 31 tables and 111 figures

**EMERGING MEMORIES
POISED TO EXPLODE**
An Emerging Memory Report



COUGHLIN ASSOCIATES
San Jose, California
July 2018

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<http://www.tomcoughlin.com/techpapers.htm>

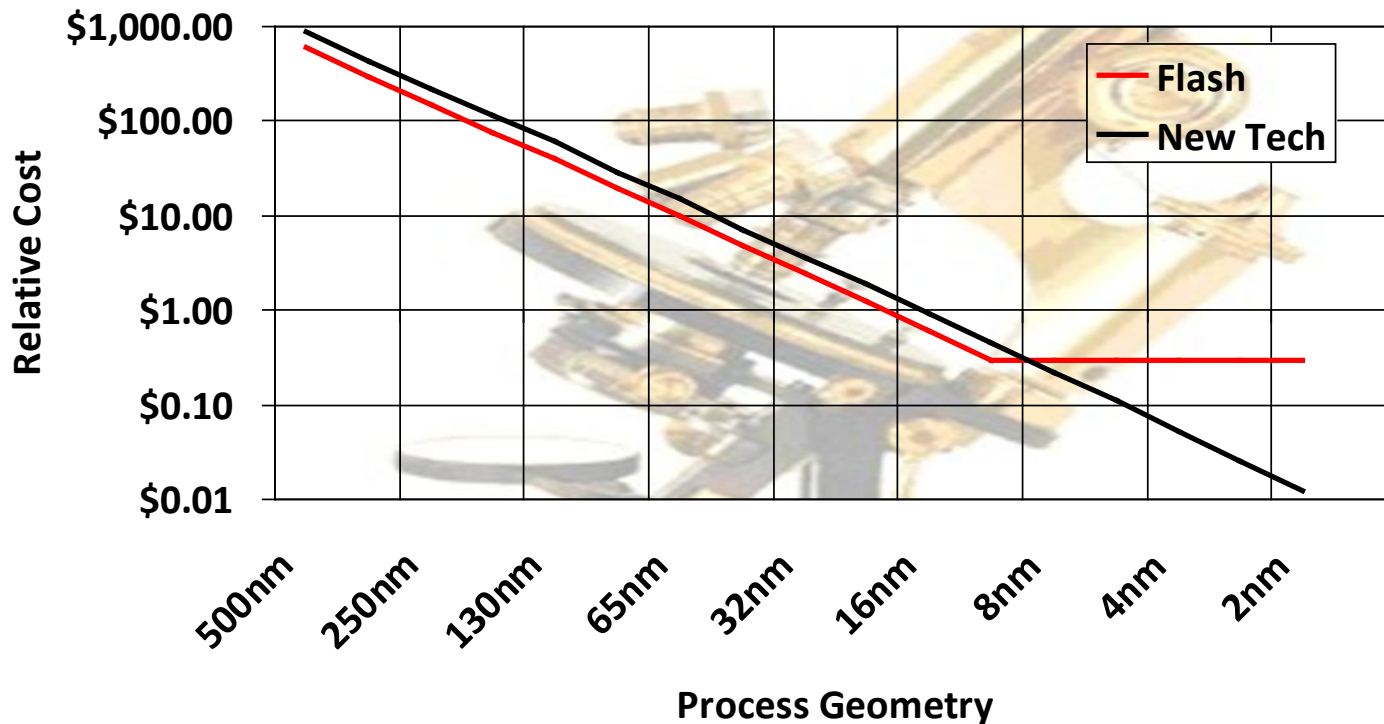
Outline

- ❑ Persistent Memory Types
- ❑ **Market Drivers**
- ❑ Support Requirements
- ❑ Outlook

Market Drivers

- ❑ PM vs. RAM
- ❑ PM in SoCs
- ❑ The economies of scale

The Vision: Replace Existing Technologies



What Dictates Memory Cost?

- ❑ Cost per megabyte depends on:

- ❑ Wafer cost

- ❑ Megabytes per wafer

- ❑ Yield

- ❑ Megabytes per wafer driven by bit size

- ❑ Shrinking bits allow cost reductions

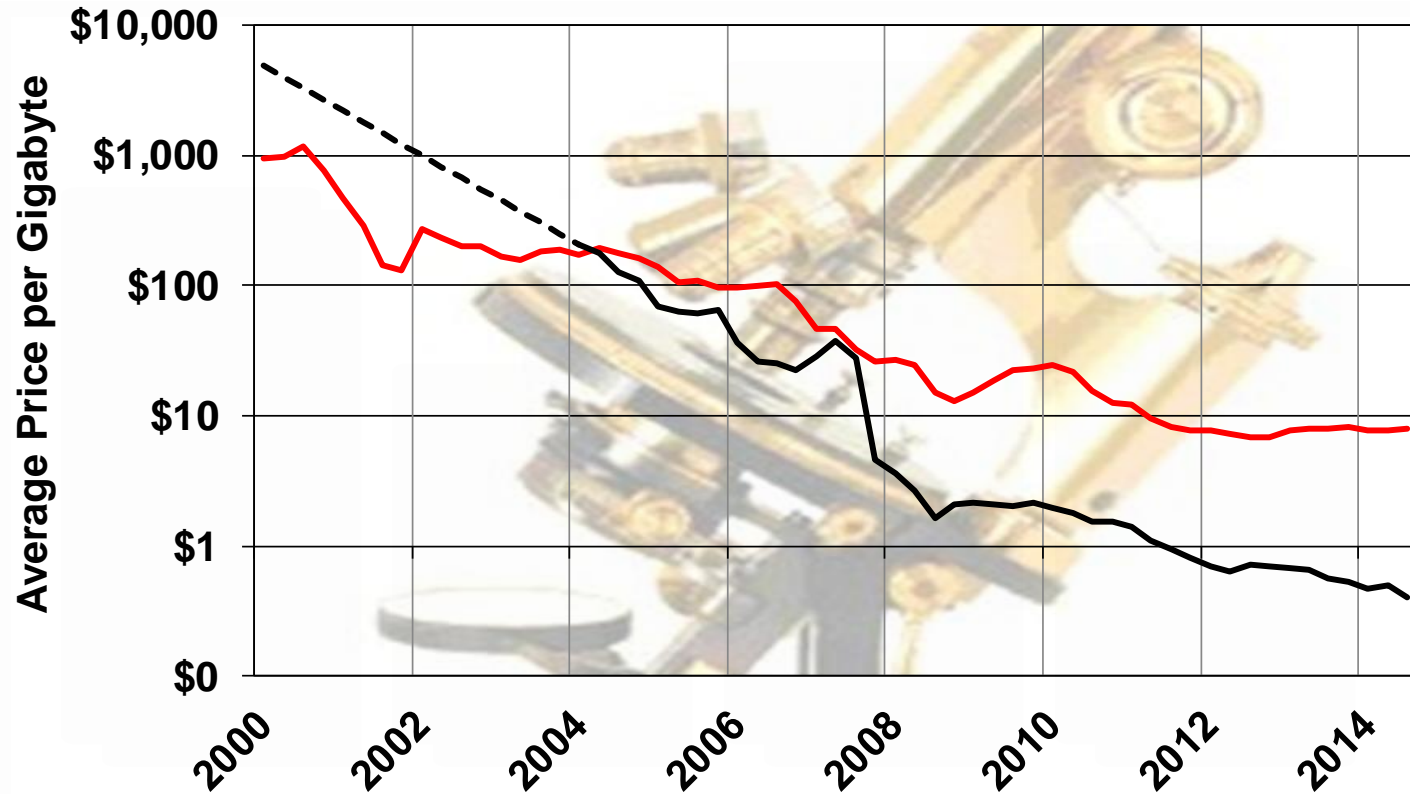
- ❑ Manufacturers shrink processes to drive this



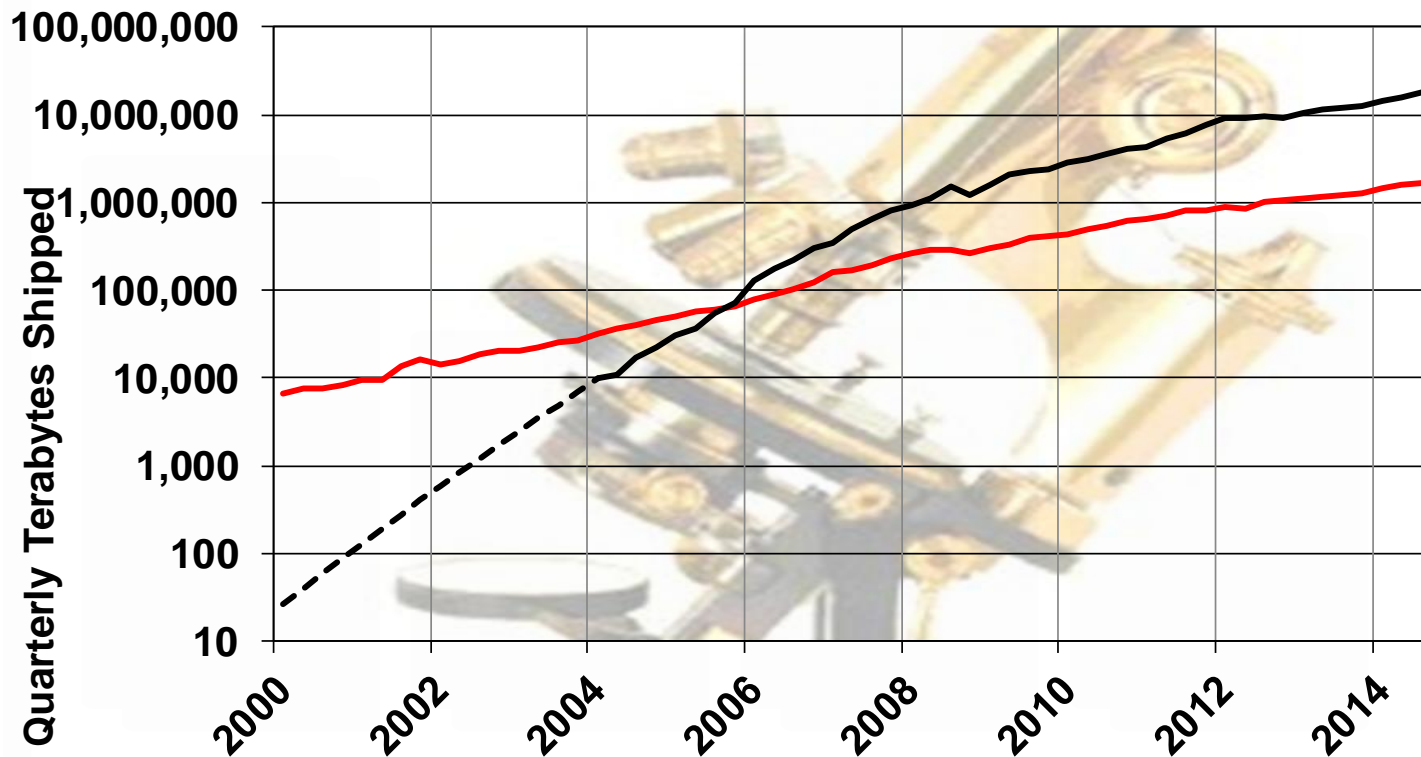
**Scale
determines
wafer cost
& yield**

This is Moore's Law in Action!

NAND \$/GB > DRAM's Until 2004



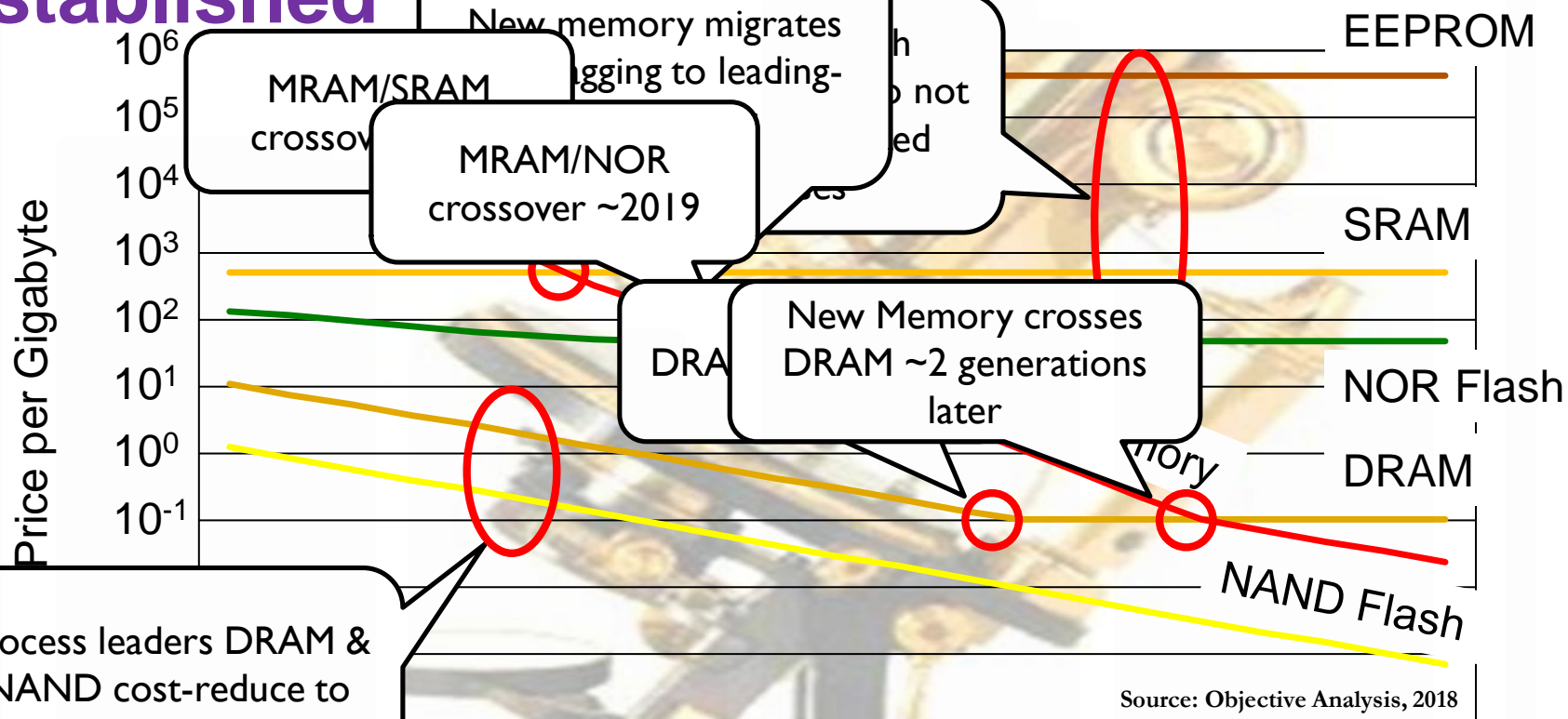
In 2004 NAND GB 1/3 of DRAM's



The Same is True of All Memory Technologies

There can be no price advantage without
comparable scale

New Memory Prices Will Move Past Established



Outline

- ❑ Persistent Memory Types
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Support Requirements

- ❑ Hardware support
 - ❑ Supporting early development
 - ❑ Ongoing requirements
- ❑ Software support
 - ❑ O/S support
 - ❑ Application program support

Hardware: Early Development

- ❑ NVDIMM-N
 - ❑ DRAM with flash backup
- ❑ BIOS changes
- ❑ New signals to DIMM
 - ❑ Indicates power fail

NVDIMM Report

- ❑ Objective Analysis
- ❑ Explains the NVDIMM markets
 - ❑ NVDIMM-N
 - ❑ NVDIMM-P
- ❑ Vendor profiles
- ❑ Support requirements
- ❑ Market forecast

Now Available!

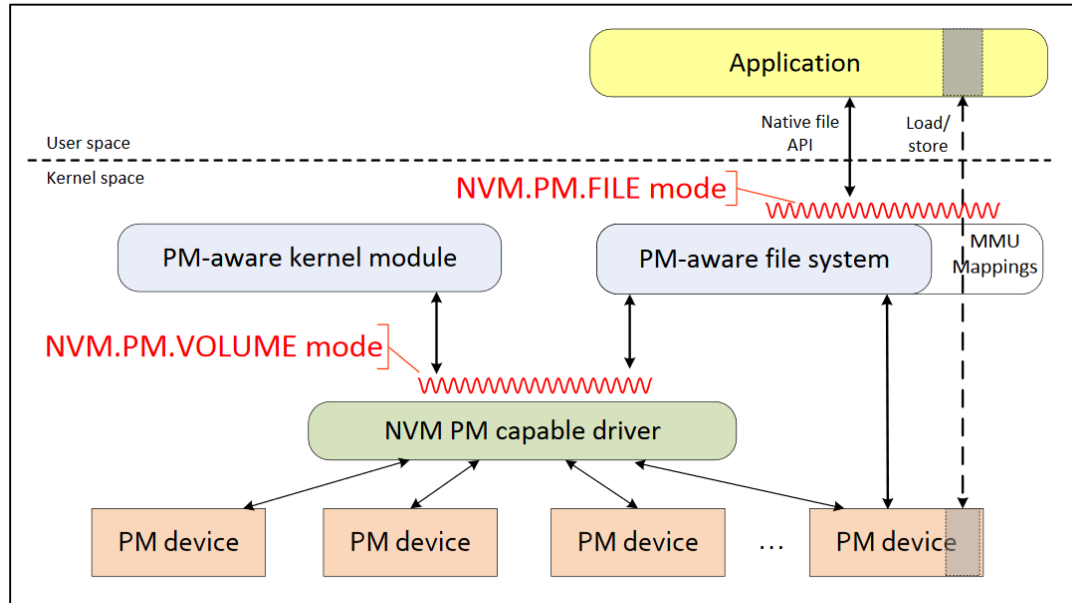
Ongoing Hardware Requirements

- ❑ Nonuniform Memory Architecture: “NUMA”
- ❑ MMU Redesign
- ❑ Faster context switches needed
 - ❑ Use polling for now
- ❑ Updated DDR bus
 - ❑ Support for non-deterministic access times

Software: Operating System Support

❑ SNIA's Persistent Memory Programming Model

❑ <https://www.SNIA.org/PM>



Software: Application Program Support

- ❑ PM is useless if its advantage is untapped
 - ❑ Persistence is unknown my most software
- ❑ This change will take some time

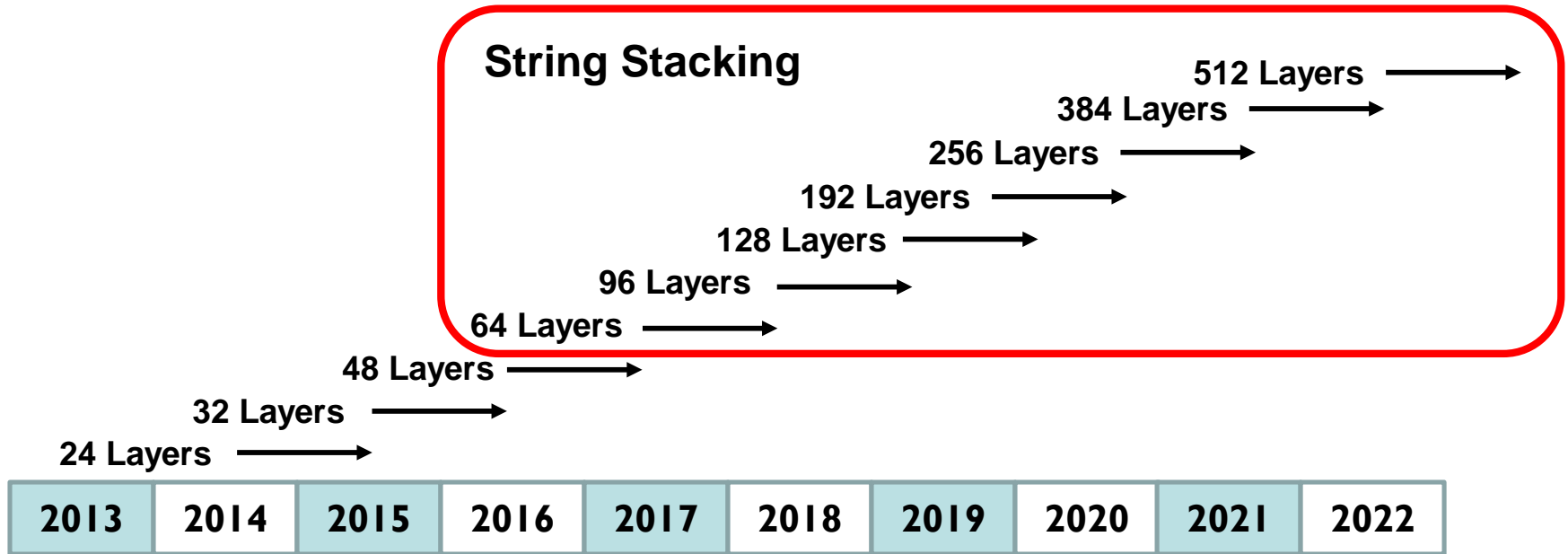
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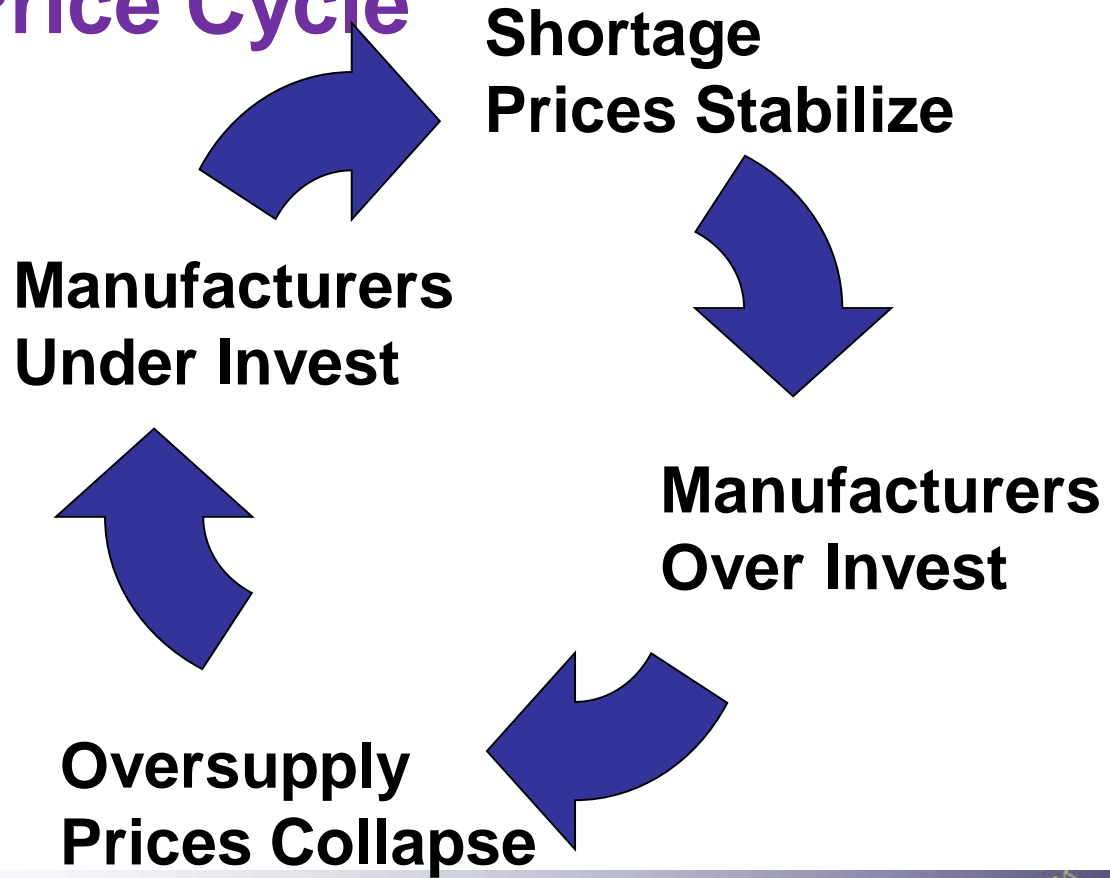
Outlook

- ❑ Nothing works in a vacuum
 - ❑ PM is a part of the greater memory ecosystem
 - ❑ The memory market swings wildly
- ❑ Foundry processes will have a huge impact

3D NAND Layers will Continue to Increase



Commodity Price Cycle



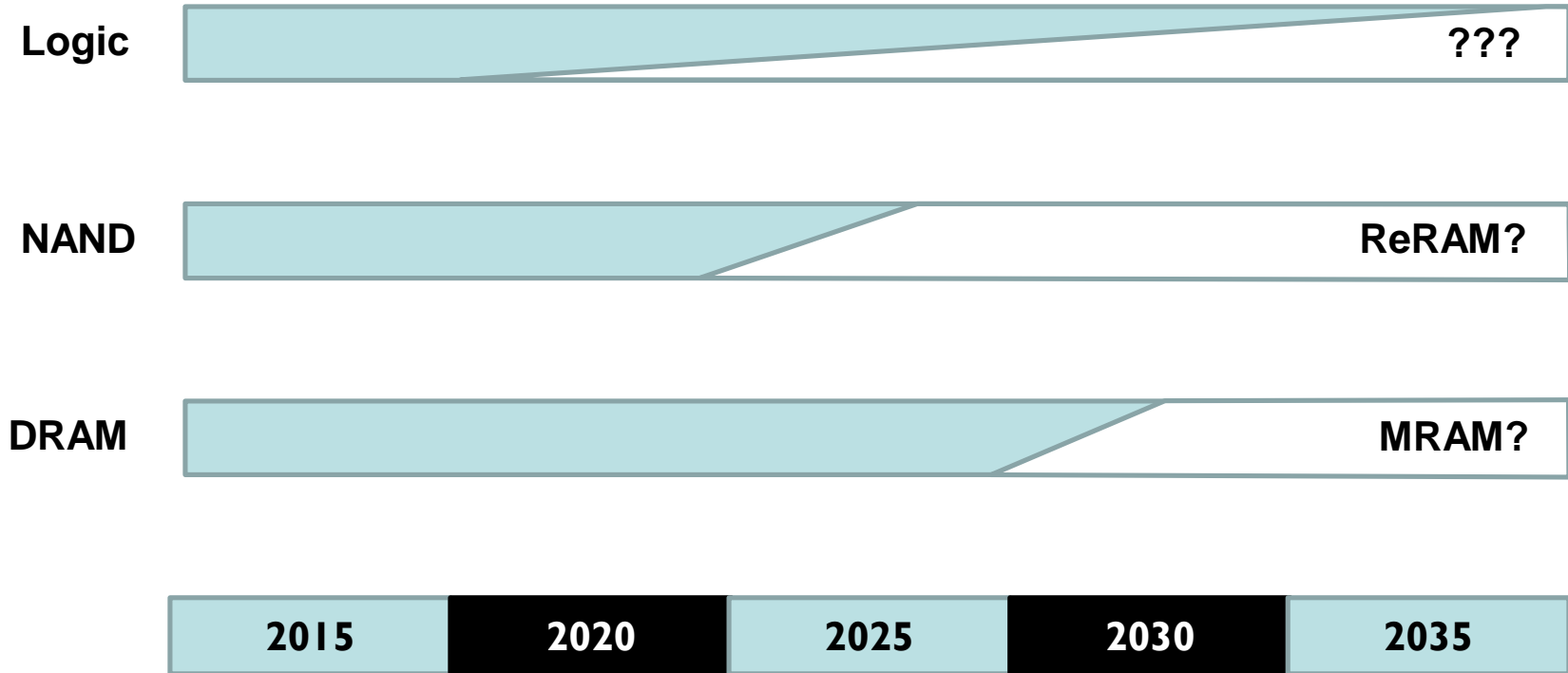
What Drives the Next Cycle?

- ❑ Stable prices to mid-2018
 - ❑ Stable prices drive profits
 - ❑ Will collapse once 3D NAND becomes cost-competitive
 - ❑ China not a factor until downturn
- ❑ 2018 price collapse
 - ❑ Supply-driven overcapacity
 - ❑ Largest-ever price-cost gap

Impact to PM?

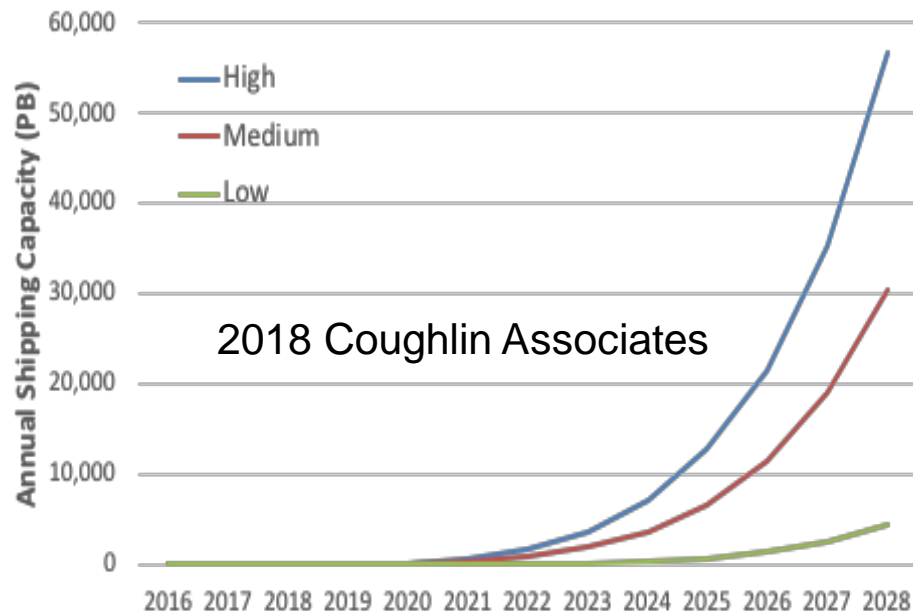
- ❑ Persistent memory competes against established technologies
 - ❑ Example: 3D XPoint must be cheaper than DRAM
- ❑ A DRAM collapse will create an XPoint collapse
 - ❑ Even though XPoint is sole-sourced!

Timeline for Change



Source: Objective Analysis, 2018

High, Low and Baseline PB Emerging Memory Shipments



- Emerging NVM market could exceed \$6B by 2023 (Emerging Memories are Poised to Explode, Coughlin Associates and Objective Analysis, <http://www.tomcoughlin.com/techpapers.htm>)

Questions?

Coughlin Associates

- Technical and Market Analysis
- Consulting
- Reports and Newsletter
 - Emerging Memories Poised to Explode: Emerging Memory Report
 - Digital Storage in Media and Entertainment
 - Digital Storage Technology Newsletter
- Conferences
 - Storage Visions Conference, October 22-23, 2018 at the Hyatt Regency Hotel in Santa Clara, CA
 - Creative Storage Conference, May 2019 in Los Angeles



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at Storage Visions 2018!*

FOCUS ON:

Surviving The Data Apocalypse
Memory/Storage-Centric Computing
High Performance Applications
Storage for High Res Capture And Prod.
Flash, HDDS And Tape Slay Data Challenges
Apocalypse or Opportunity?

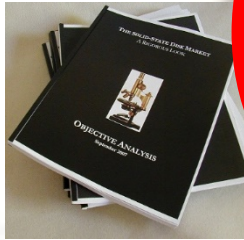
Big Data and Small Pipes
Long Term Storage
Clouds, AI And Data Growth
Challenges and Promise Of
Ubiquitous Data
Emerging Memory Technologies

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OBJECTIVE ANALYSIS

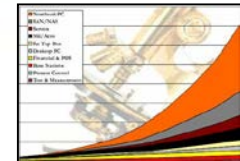
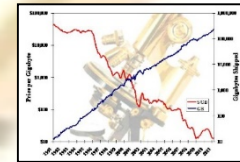
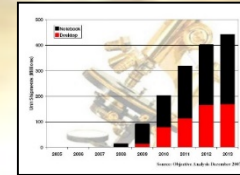


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OBJECTIVE ANALYSIS

Semiconductor Forecast Accuracy

Year	Forecast	Actual
<u>2008</u>	Zero growth at best.	-3%
<u>2009</u>	Growth in the mid teens	-9%
<u>2010</u>	Should approach 30%	32%
<u>2011</u>	Muted revenue growth: 5%	0%
<u>2012</u>	Revenues drop as much as -5%	-2.7%
<u>2013</u>	Revenues increase nearly 10%	4.9%
<u>2014</u>	Revenues up 20%+	9.9%
<u>2015</u>	Revenues up ~10%	-0.2%
<u>2016</u>	Revenues up ~10%	1.1%
<u>2017</u>	Revenues up ~20%	22%
<u>2018</u>	Strong start supports 10+% growth	TBD