

Advances in Non-Volatile Storage Technologies

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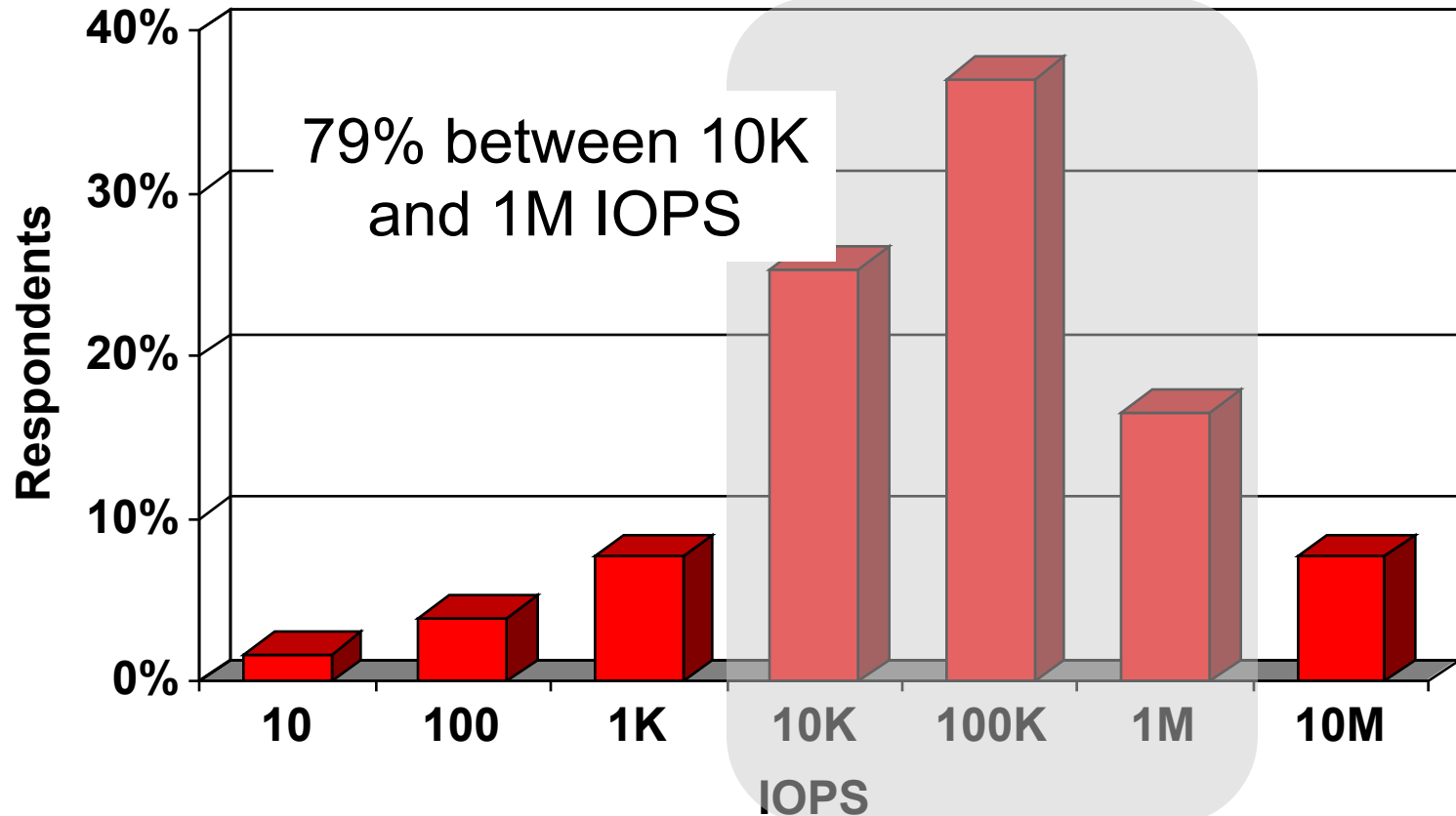
Outline

- The Shape of Things to Come
- In Search of New Memories
- Intel/Micron's 3D XPoint Technology
- The Memory is the Computer
- Conclusions



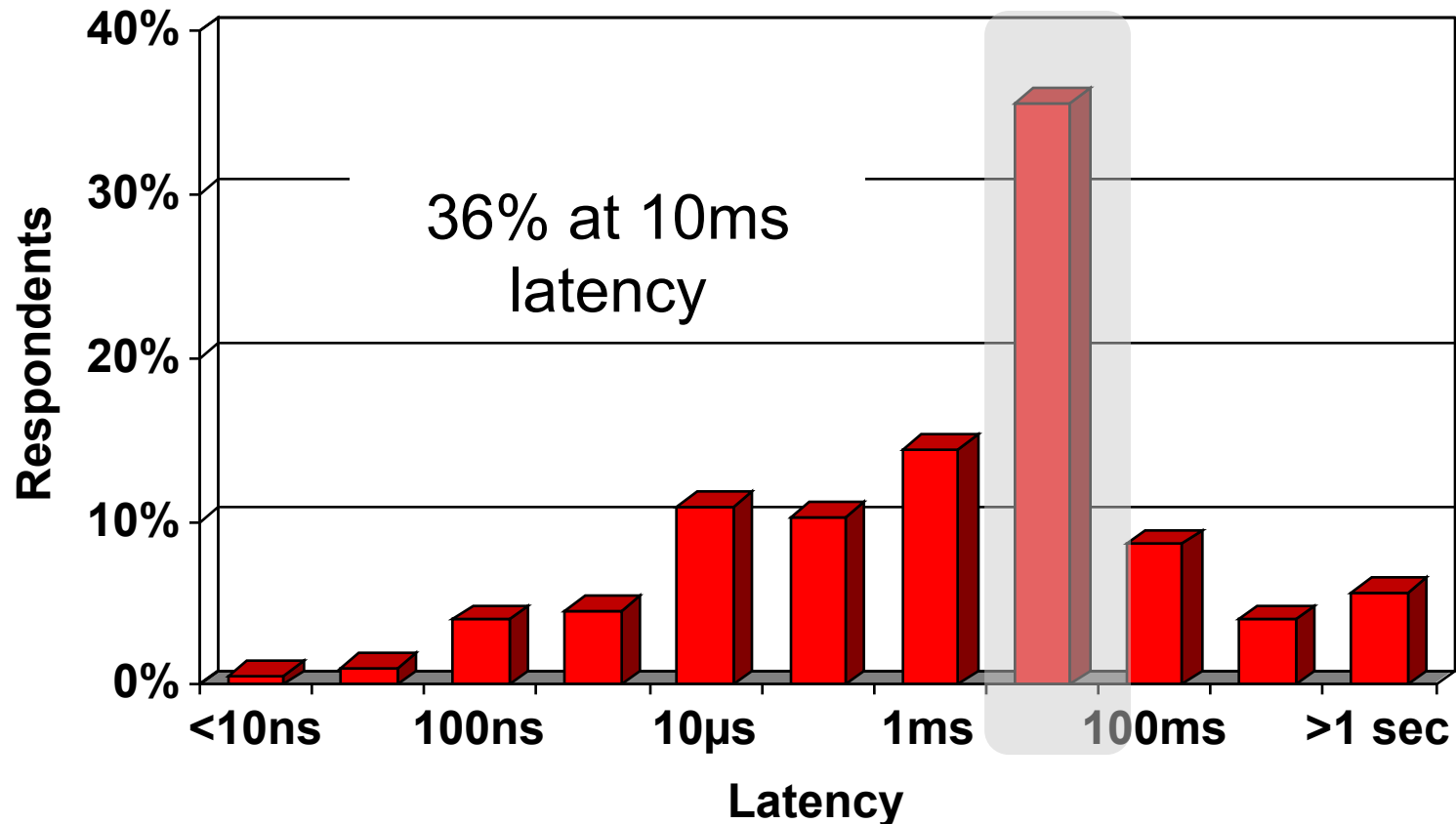
The Shape of Things to Come

IOPS Required



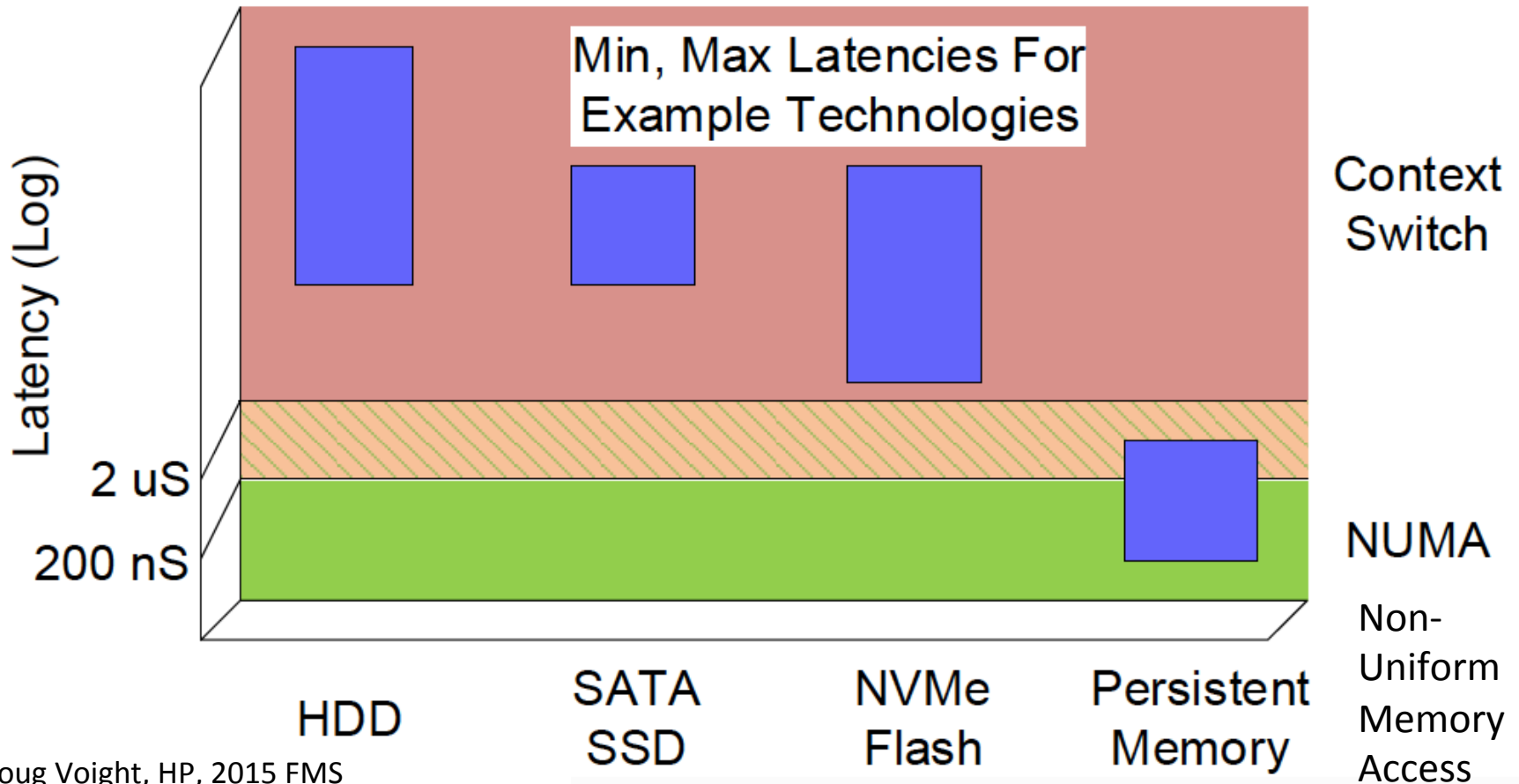
From the 2014 How Many IOPS Do You Really Need Report,
Coughlin and Handy, <http://www.tomcoughlin.com/techpapers.htm>

Maximum Latency Requirement



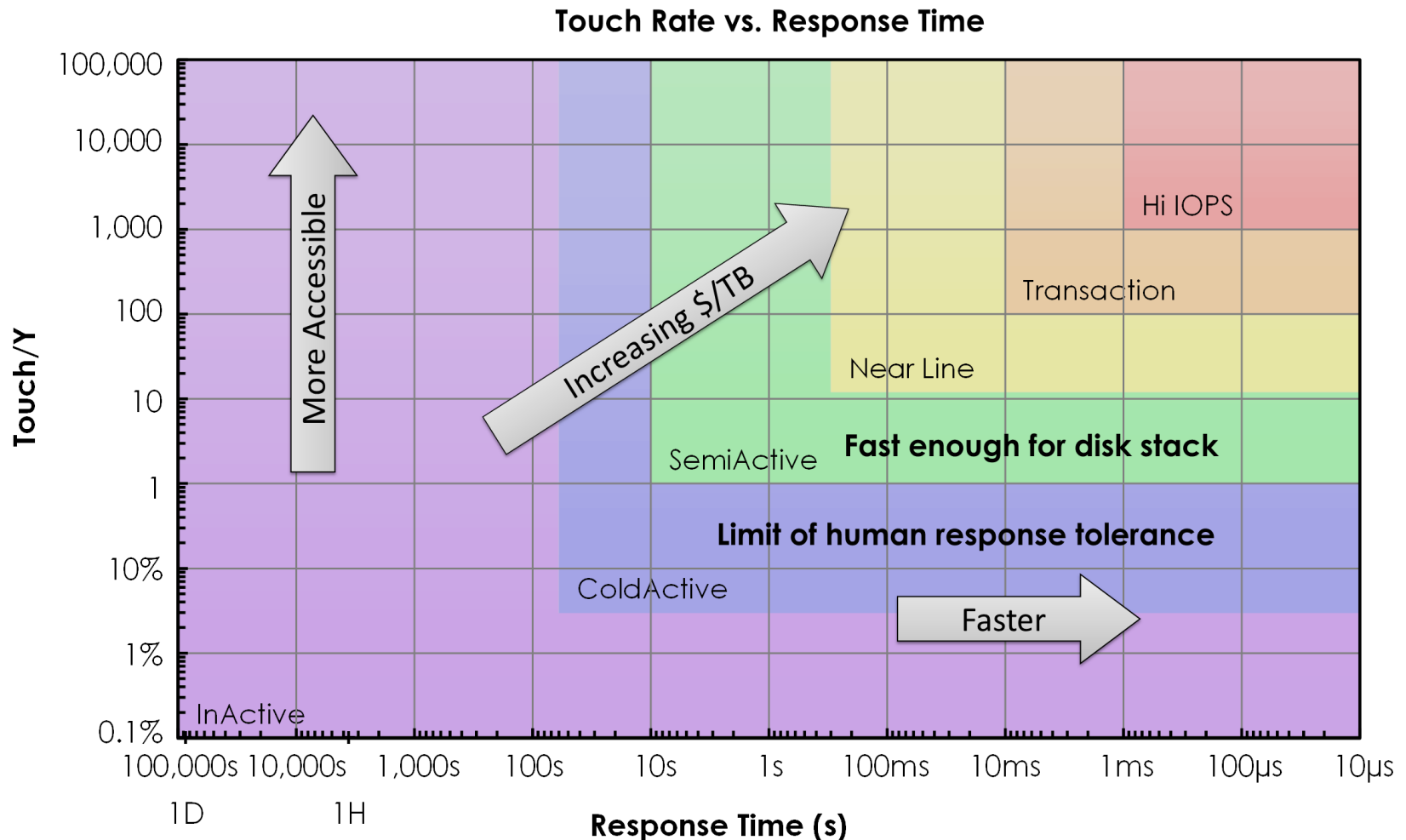
From the 2014 How Many IOPS Do You Really Need Report,
Coughlin and Handy, <http://www.tomcoughlin.com/techpapers.htm>

Latencies Separate Computer Memory from Storage

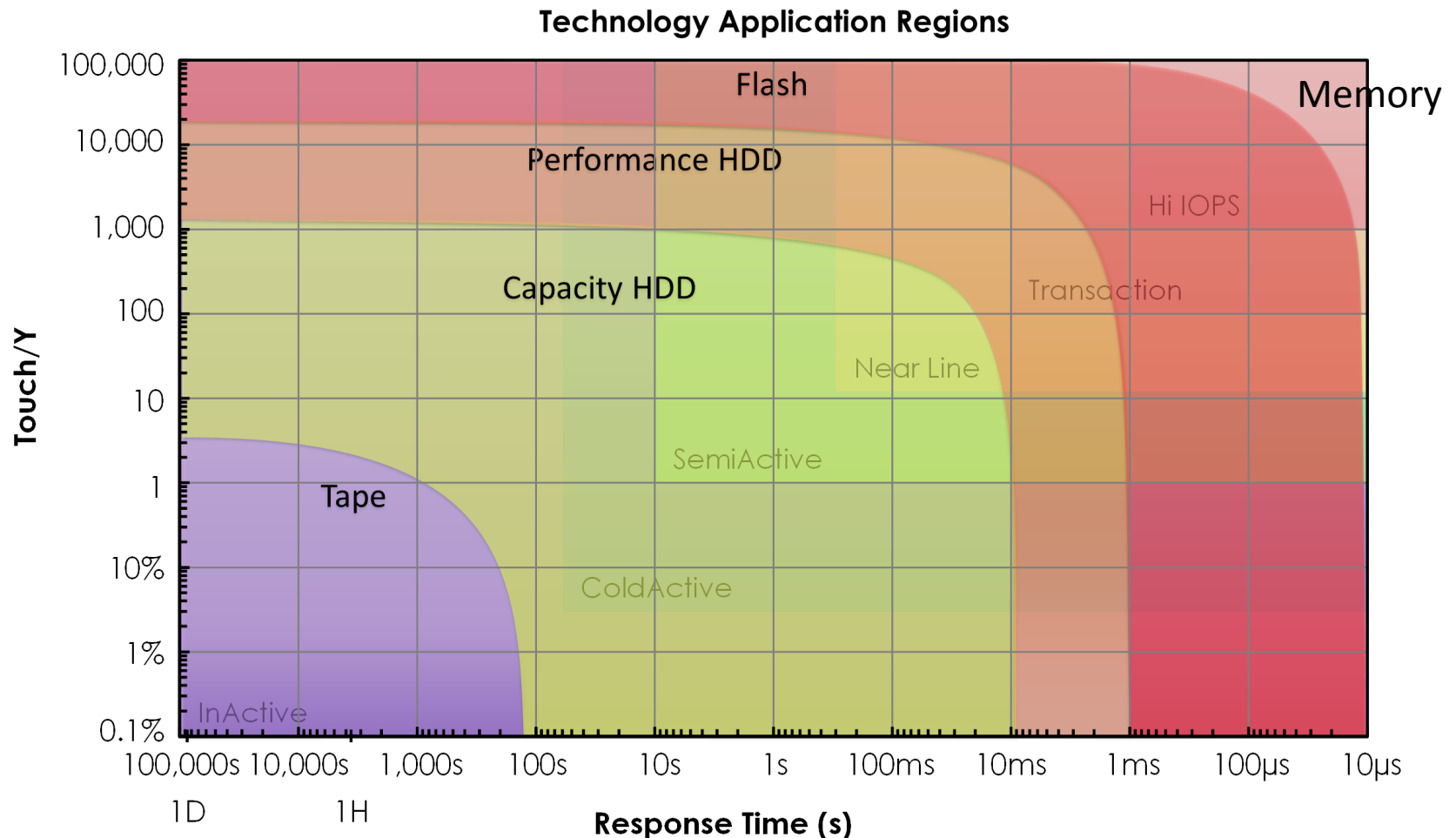


Doug Voight, HP, 2015 FMS

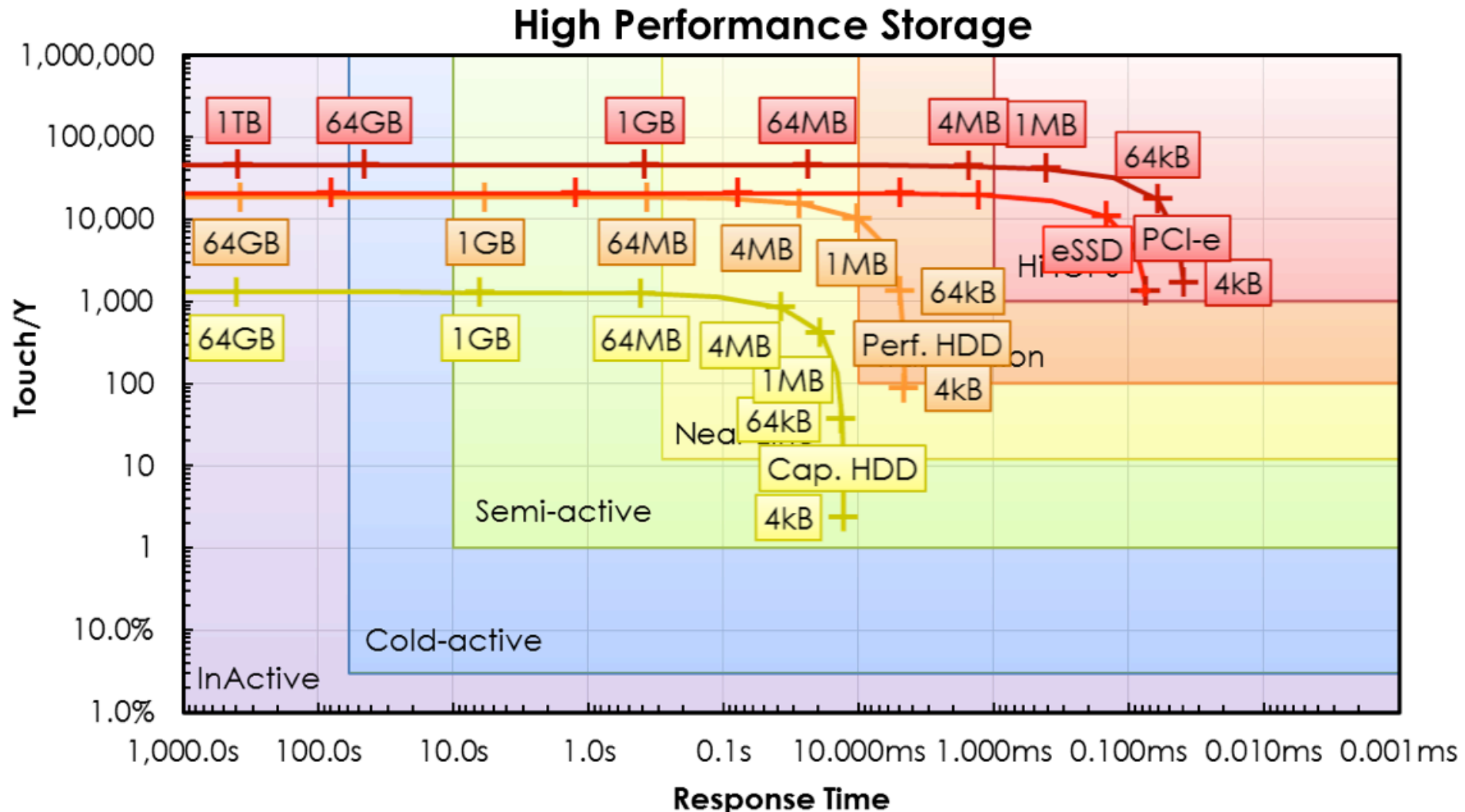
Touch rate versus response time indicating various types of uses



Digital storage technologies regions overlaid on the Touch Rate/Response Time chart



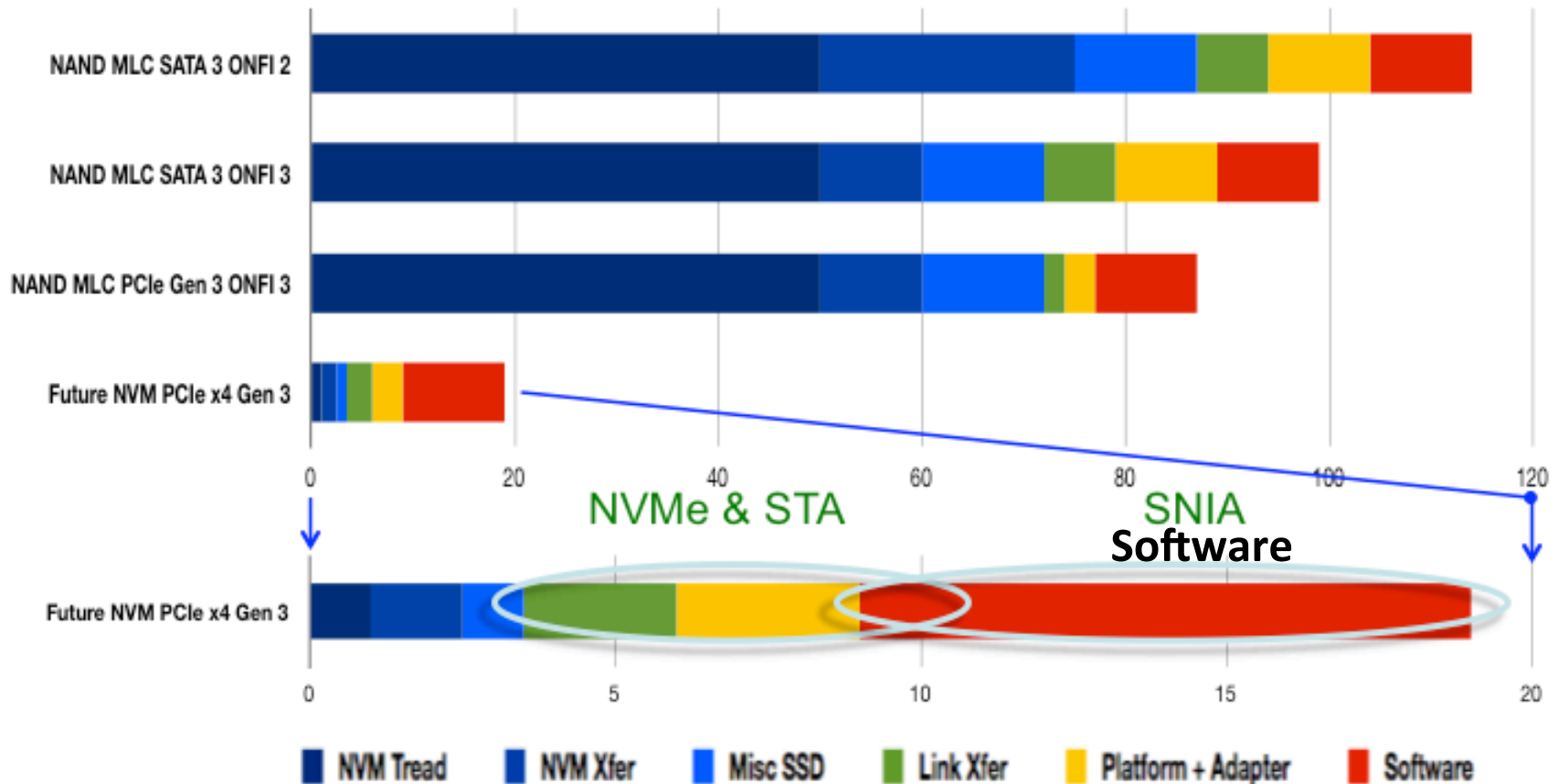
Ent. SSDs, perf. HDDs and capacity HDDs



Storage Latency with Current and Future NV Solid State NV Technologies

(from NVMP talk at SNIA Winter Symposium, 2014)

Application to SSD IO Read Latency (us, QD=1, 4KB)



Implications of Persistent Memory

- NV memory retains its data even when power off—thus instant recovery of state before power down is now possible
- NV memory with the right SW changes can provide much better latencies than current systems and SW
- Non-volatile memory will save power since refreshes not needed
- Persistent memory creates new opportunities to share that memory between different computers or computer chips using Remote Direct Memory Access (RDMA)
- Embedded NVM technology can lead to “logic-in-memory architecture” for future SoC—this can lead to new distributed computer architectures

Challenges of Persistent Memory

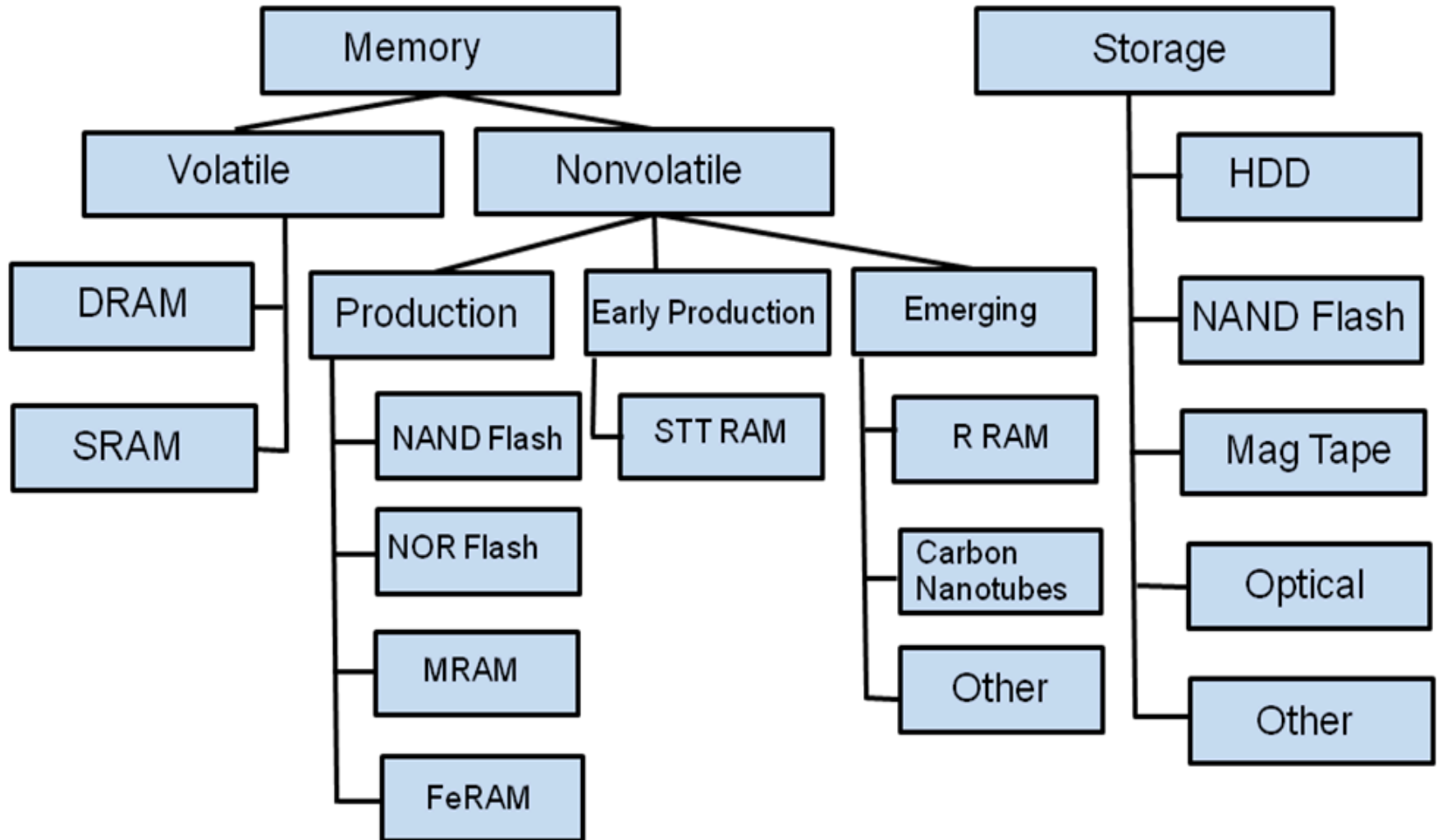
- If the memory isn't cleared by rebooting a system, then reboots to recover functionality with corrupted data won't work
- There will need to be a special reboot and clear function that erases and recovers data in memory
- Or, and this may be an even better solution, we need to built devices and software that are self-monitoring and self correcting so we don't need to reboot in order to retain functionality



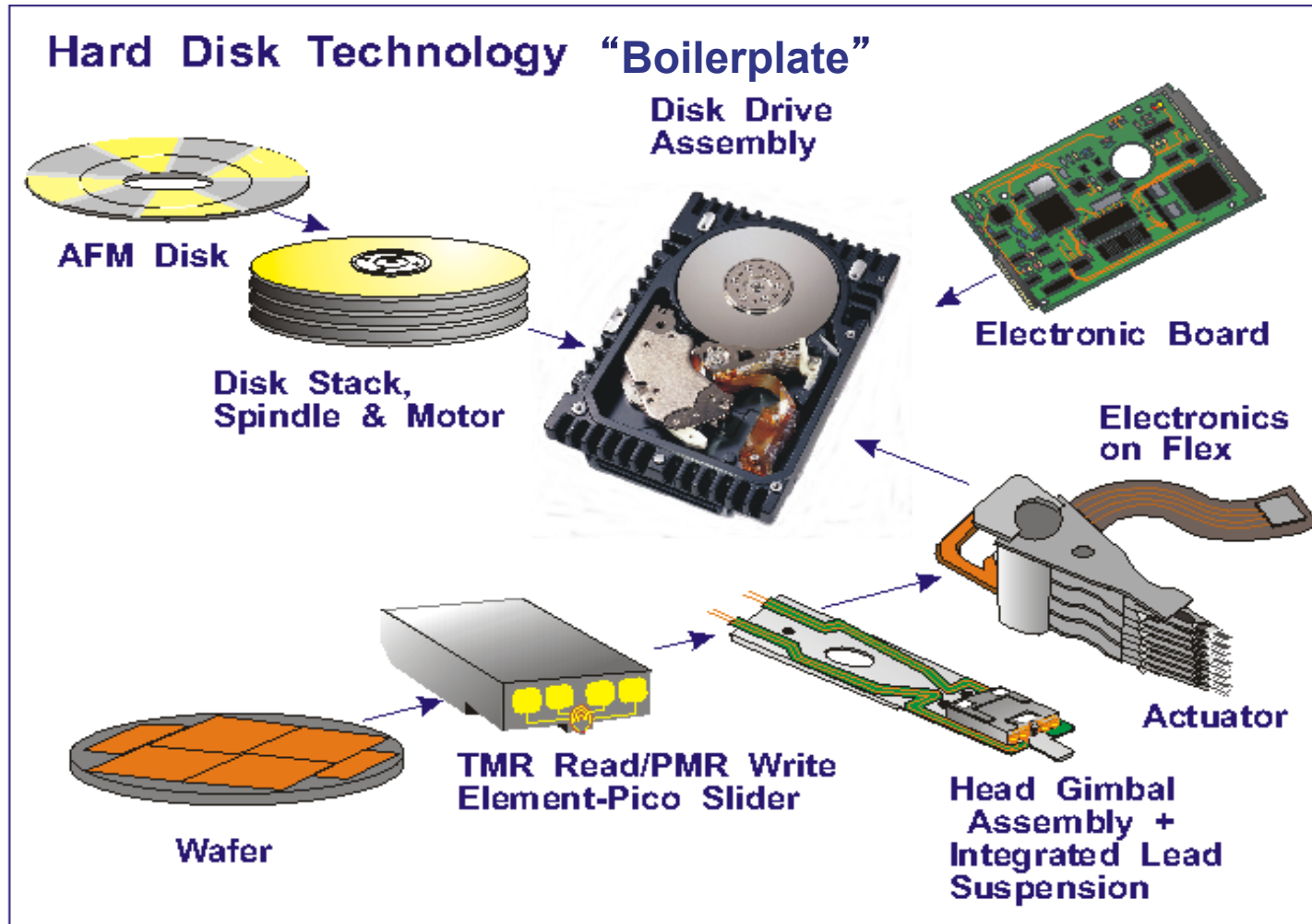
In Search of New Memories

Memory and Storage Today

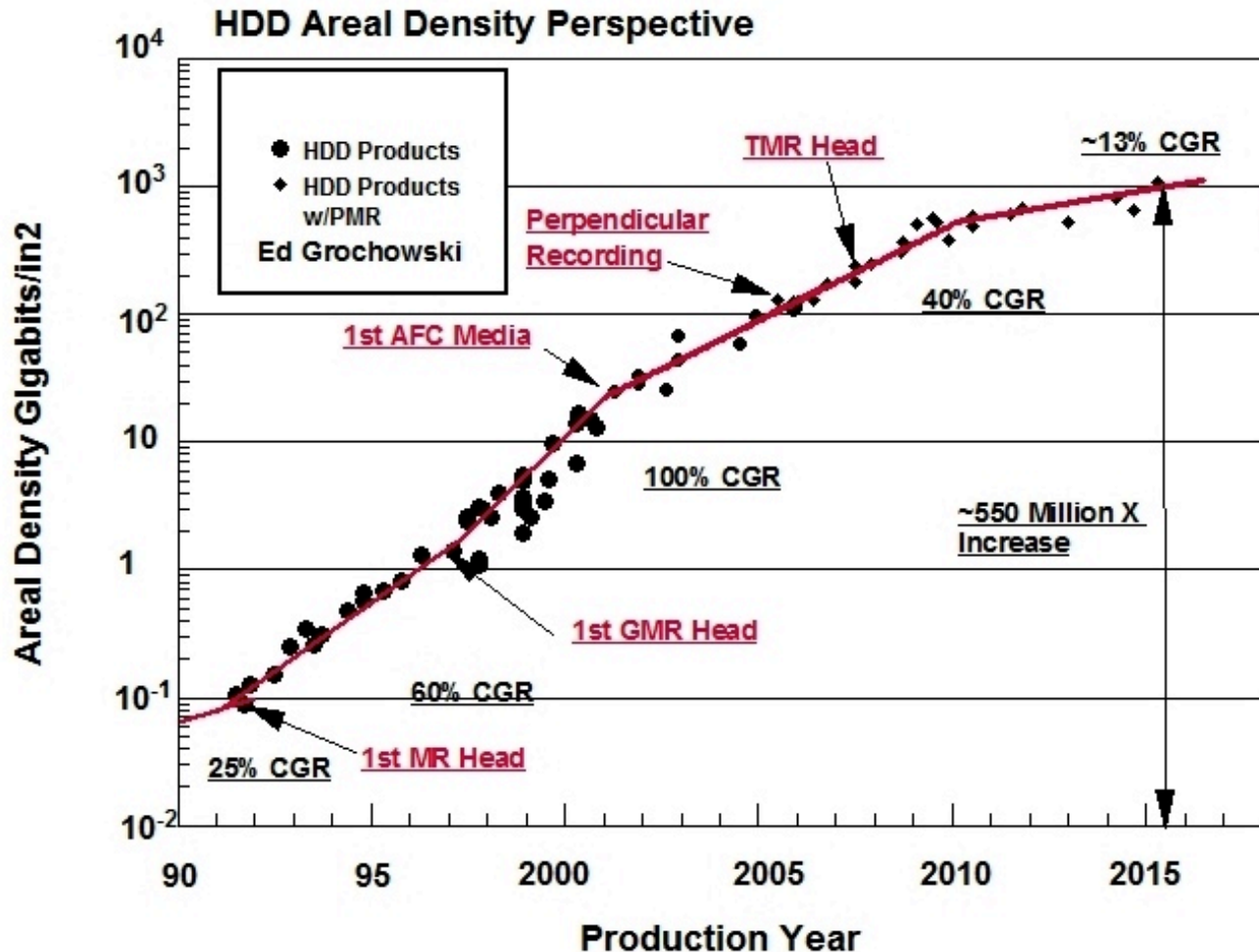
2015 Emerging NVM and Their Manufacture
Report, Coughlin Associates



Hard Disk Drives

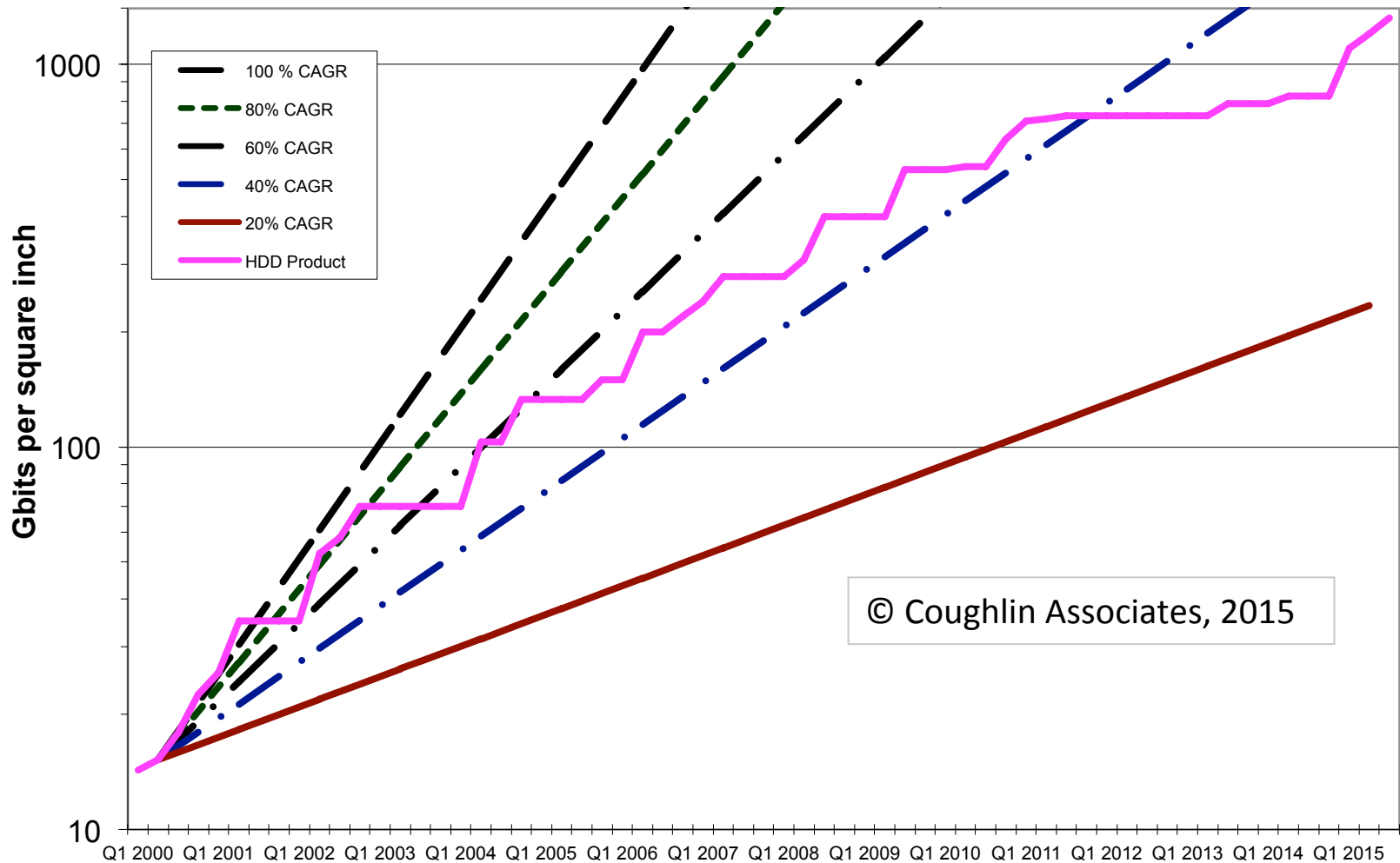


HDD Areal Density Growth



Recent Developments: SMR, HAMR, He-filled HDDs, MAMR with 3D Recording,

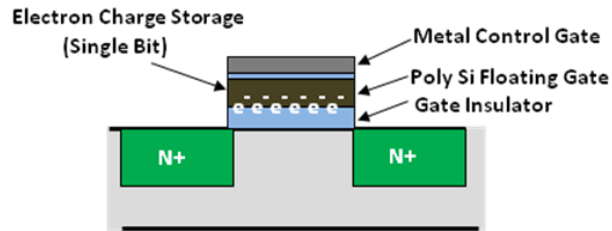
Actual Quarterly Announced HDD Product AD Charts



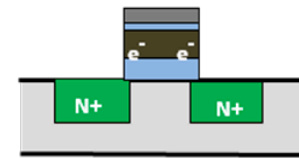
© Coughlin Associates, 2015

Flash Memory

Flash Scaling

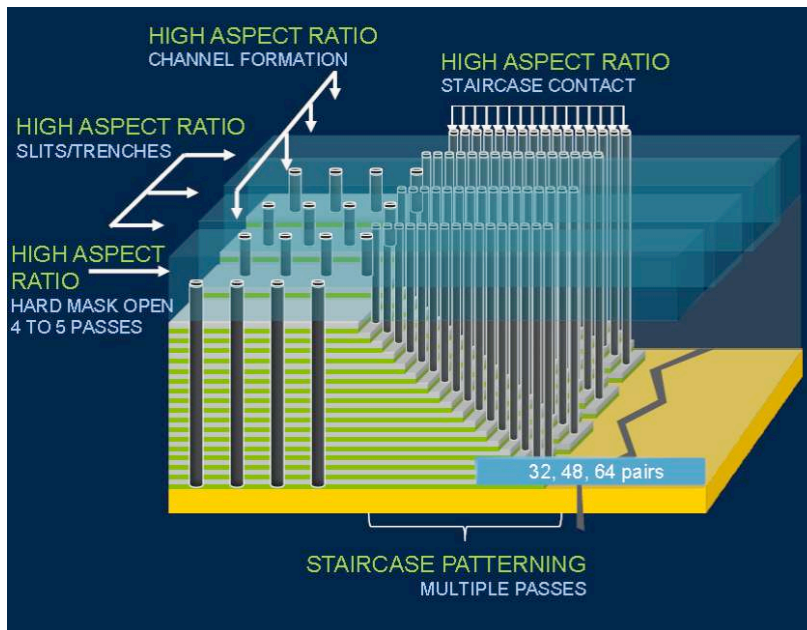


45 nm



<22 nm

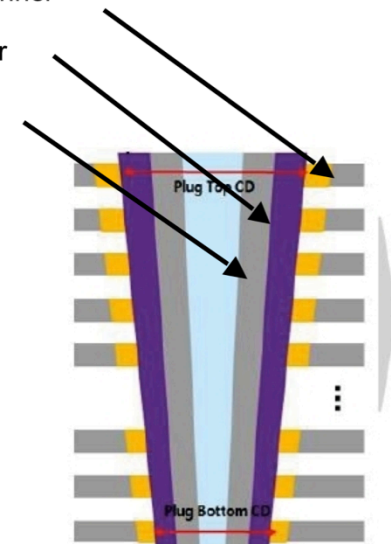
Floating Gate SLC
(2 voltage levels)



P Silicon Channel

Gate Insulator

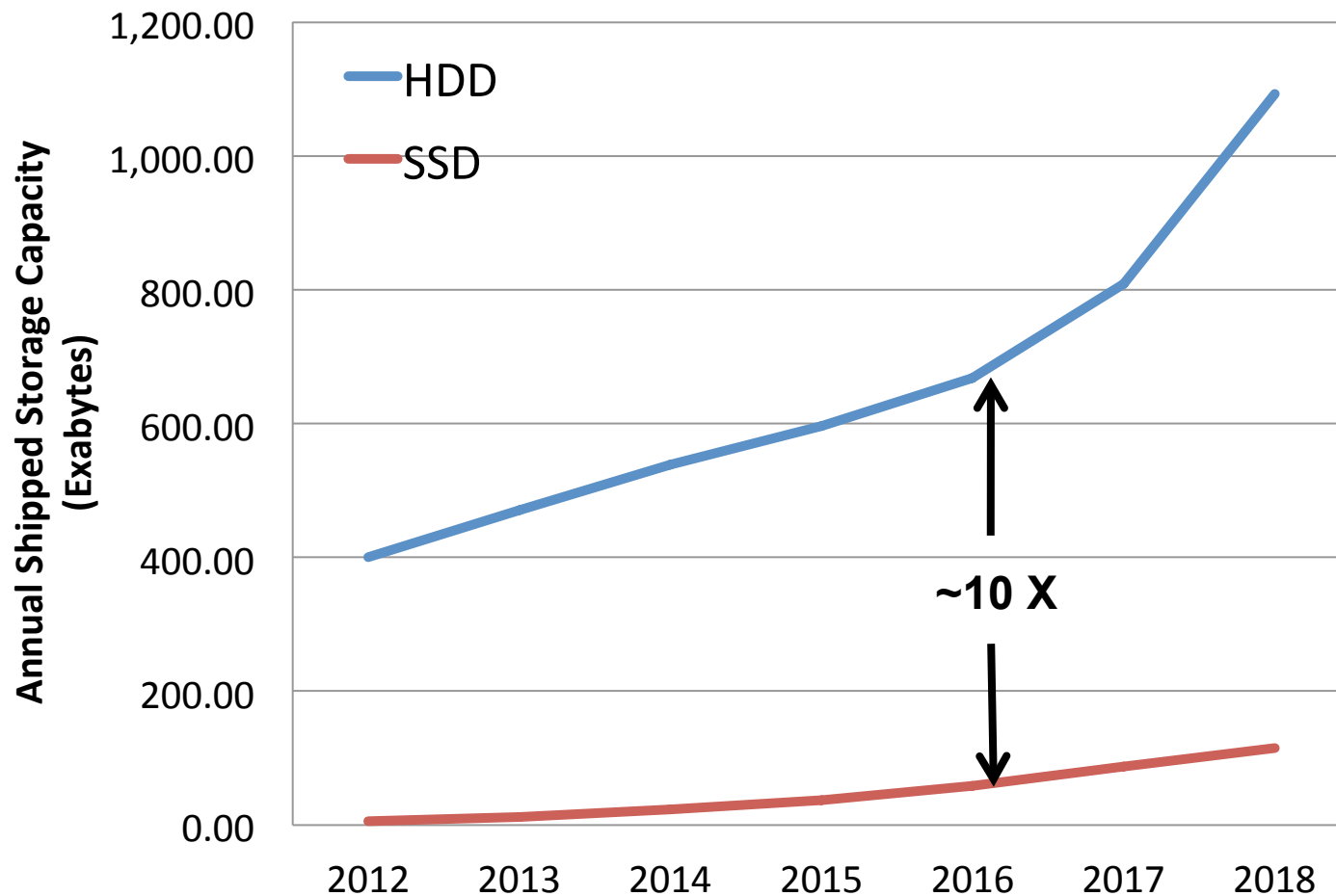
Control Gate



Manufacturers	2012	2013	1H14	2H14	1H15	2H15	2016	2017
SAMSUNG	21 nm MLC SSD	19 nm MLC TLC	18 nm MLC	15 nm MLC TLC	14 nm MLC TLC	12(10) nm		
TOSHIBA SanDisk	24 nm	19 nm	A-19 nm TLC	15 nm MLC MLC 64B	12(10) nm			
Micron intel	20 nm	16 nm	TLC	12 nm				
SK hynix	25 nm	20 nm	18 nm	TLC	12(10) nm			

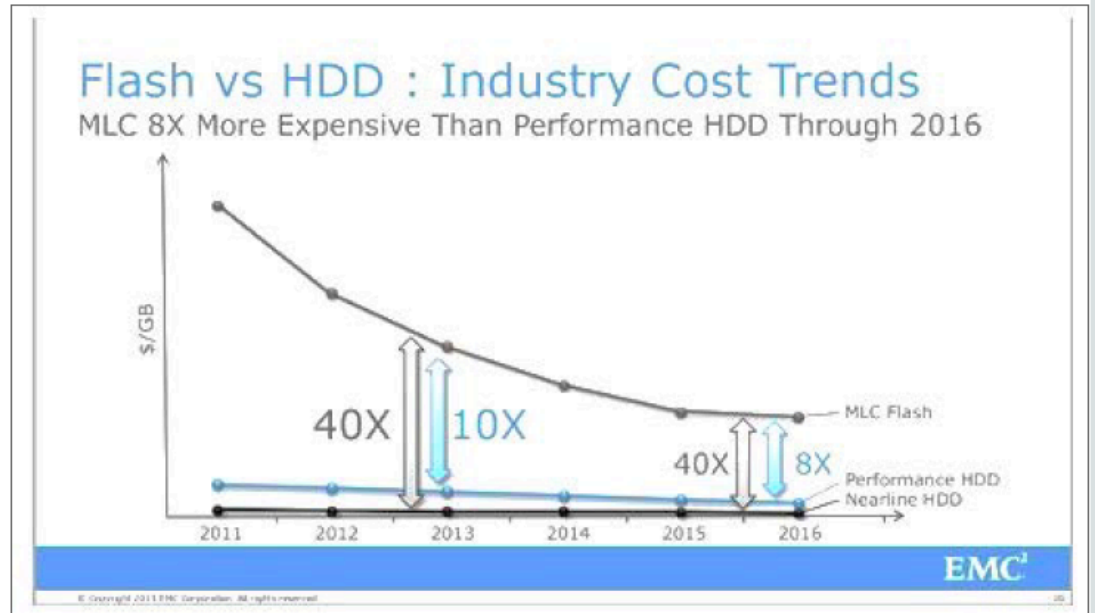
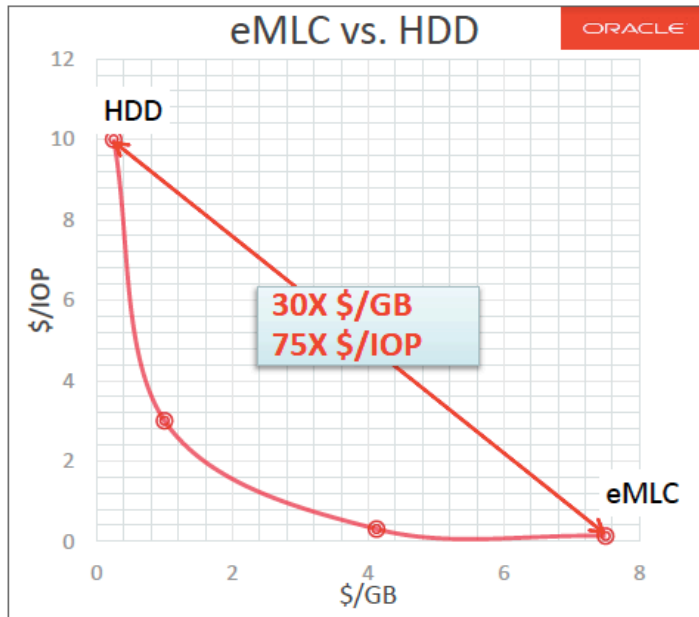
© 2015 Coughlin Associates

Annual HDD/SSD Storage Shipments



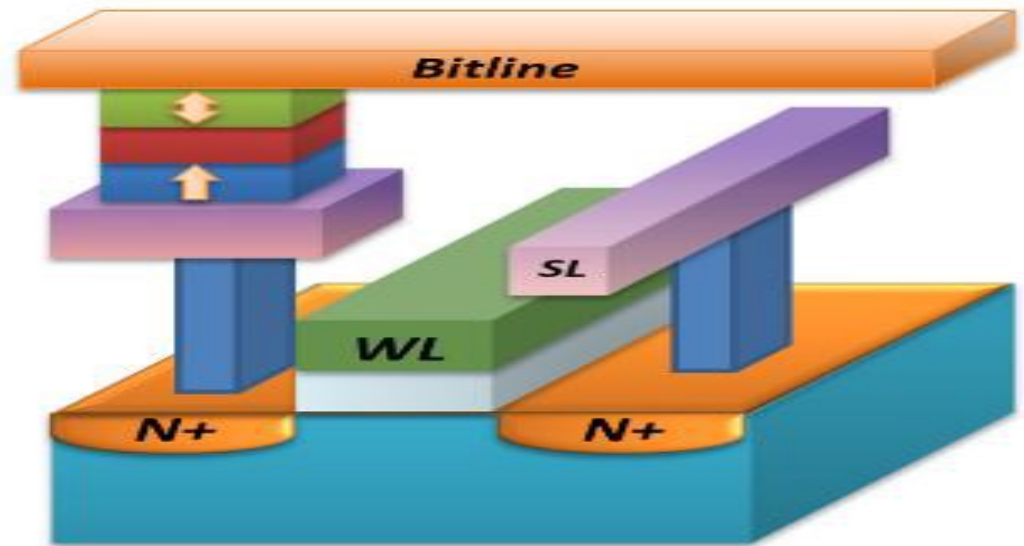
Comparisons of Flash and HDDs

Mike Workman Keynote, 2015 FMS



Emerging Memory Technology

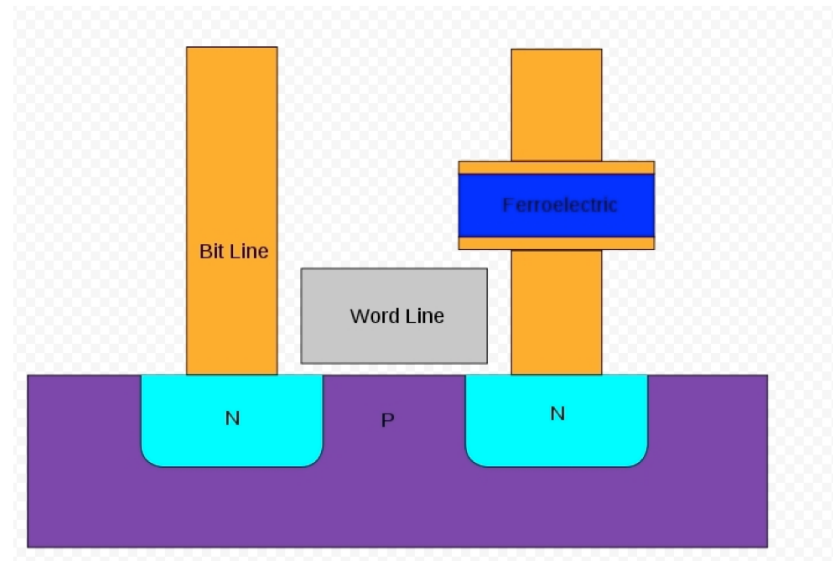
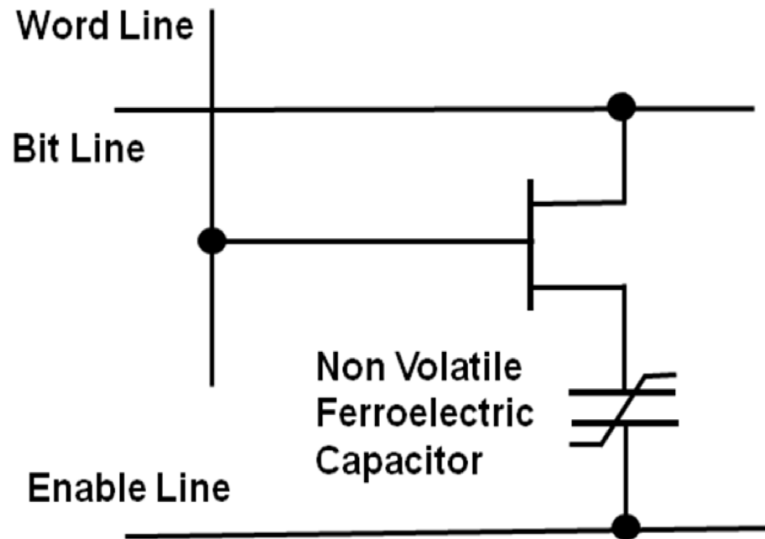
- NVM will save power
- Persistent memory enables memory sharing (RDMA)
- Embedded NVM technology can lead to “logic-in-memory architecture”



The emerging NVM market could exceed \$2 B by 2019

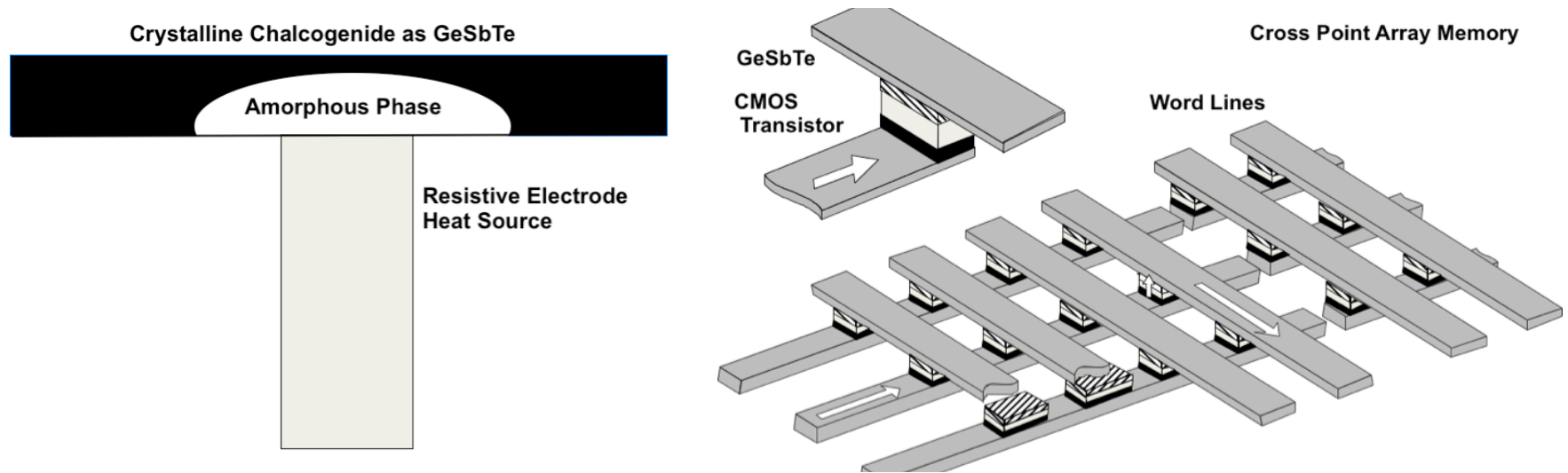
2014 Emerging NVM Report and Their Manufacture, Coughlin Associates

FeRAM



FeRAM products shipping for many years for niche applications, hard to scale density...

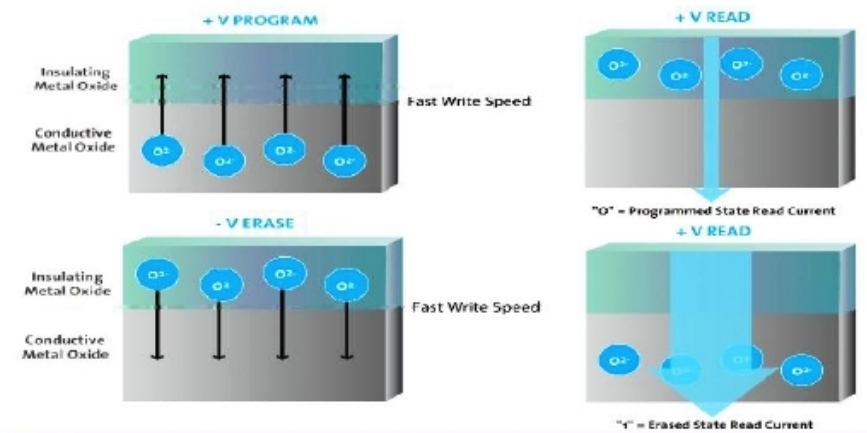
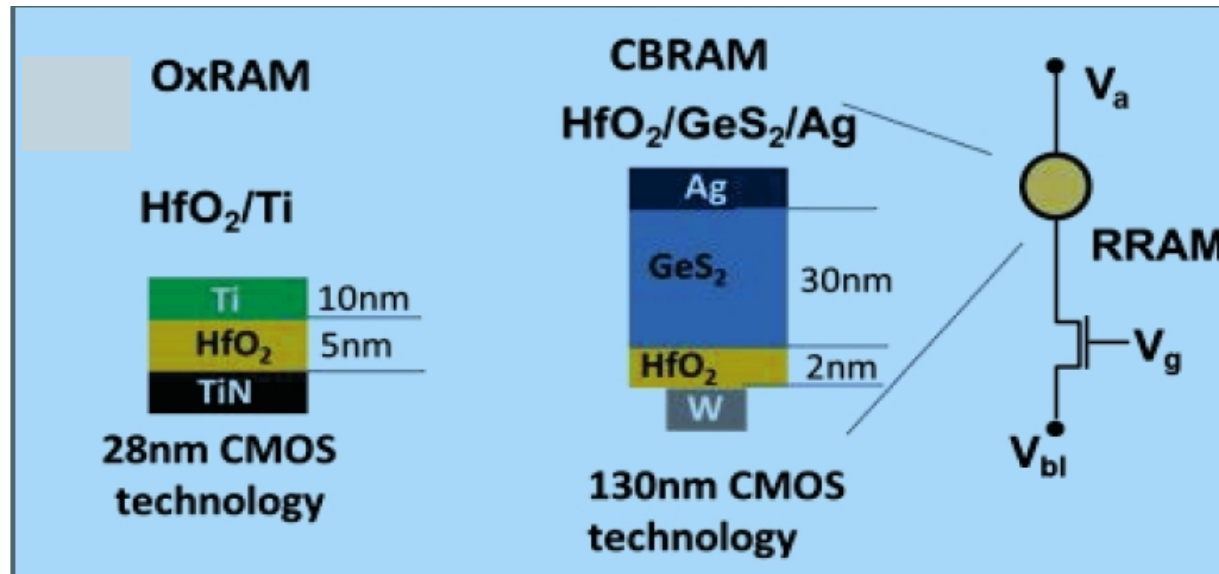
Phase Change Memory (PCM)



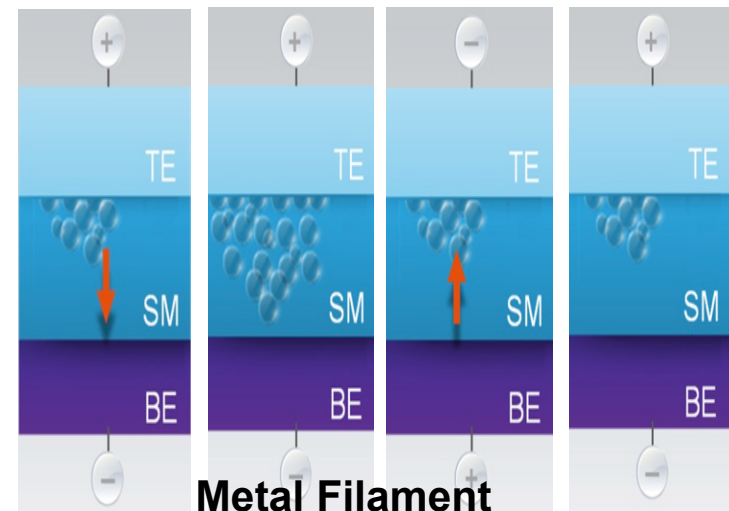
Several industry experts think that Micron/Intel's 3D XPoint Technology is a crossbar phase change memory

TYPES OF RRAM TECHNOLOGY

Sources/ Crossbar, Tezzaron Semi.



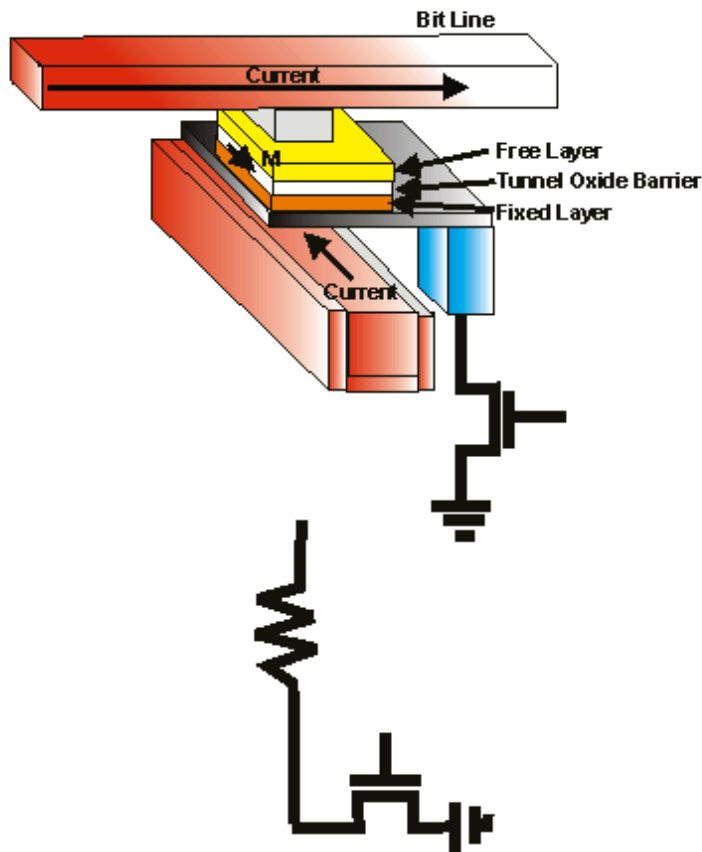
**Oxide Conduction
Via Oxygen Vacancies**



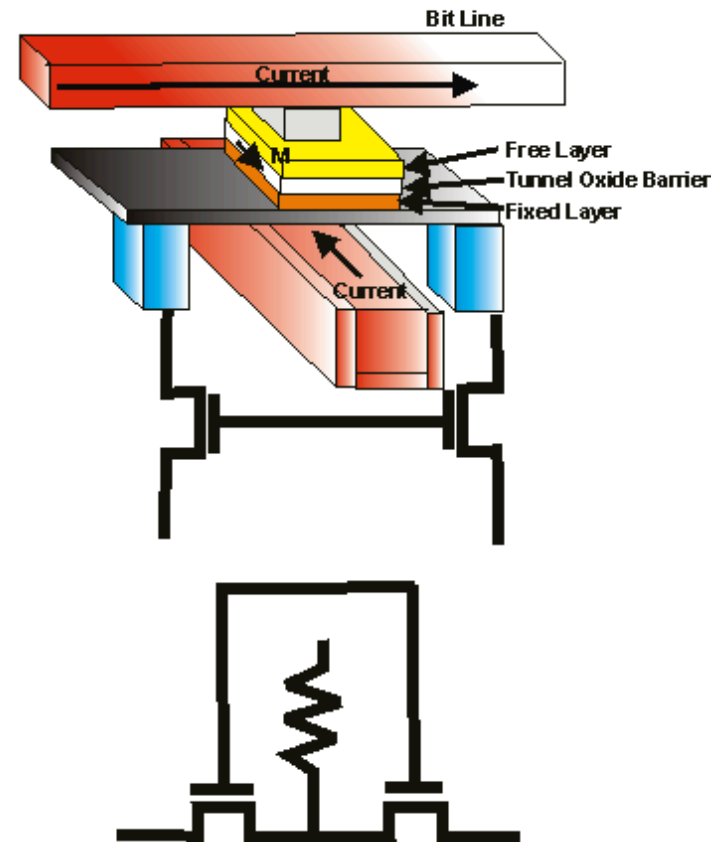
**Metal Filament
Formation (CBRAM)**

STT MRAM Replacing DRAM and SRAM

Over 50 M MRAM chips shipped by Everspin



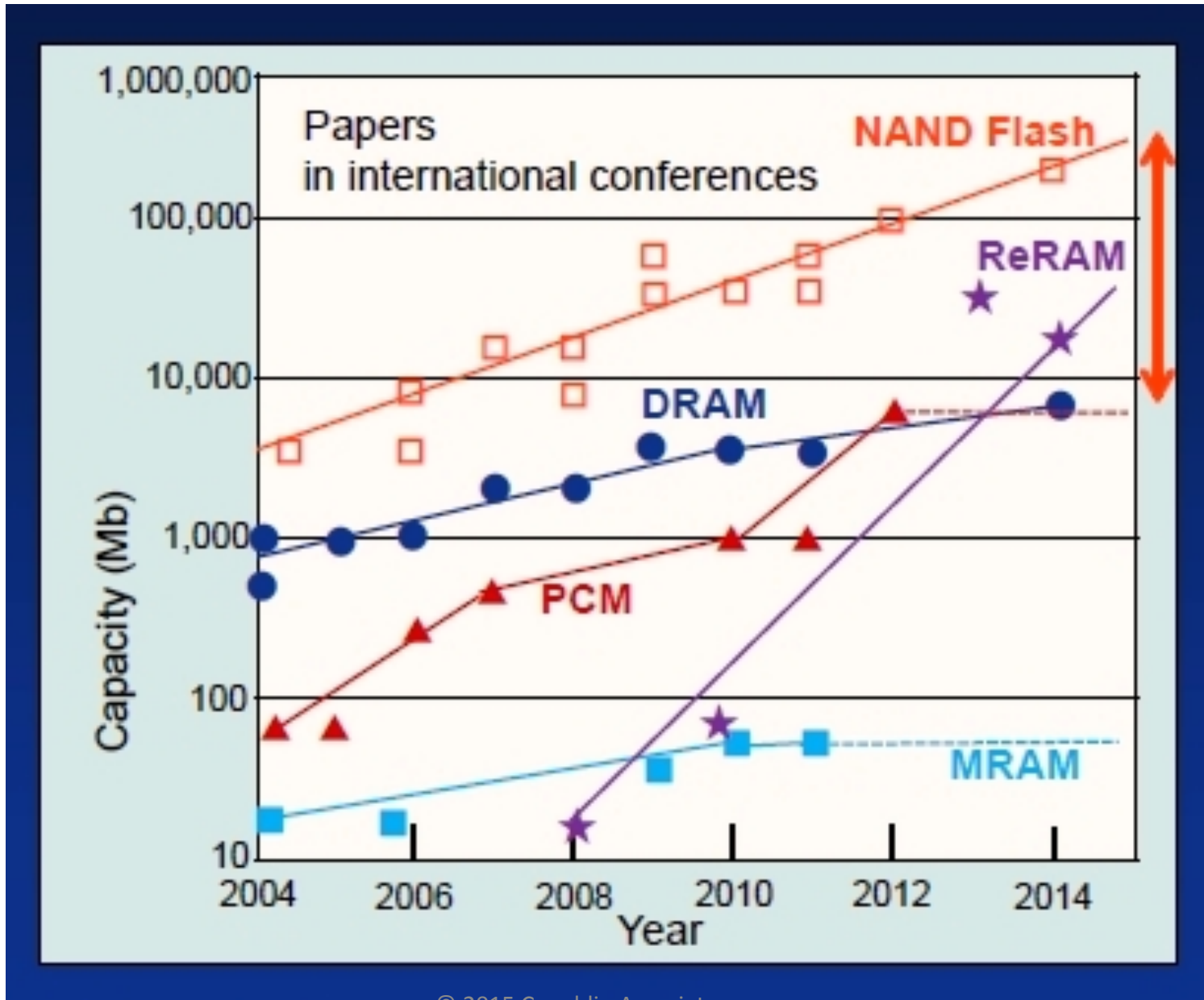
**MRAM (DRAM Replacement)
Memory/Storage Cell
(Potential SRAM Replacement)**



**SRAM Replacement
(High Performance Memory)**

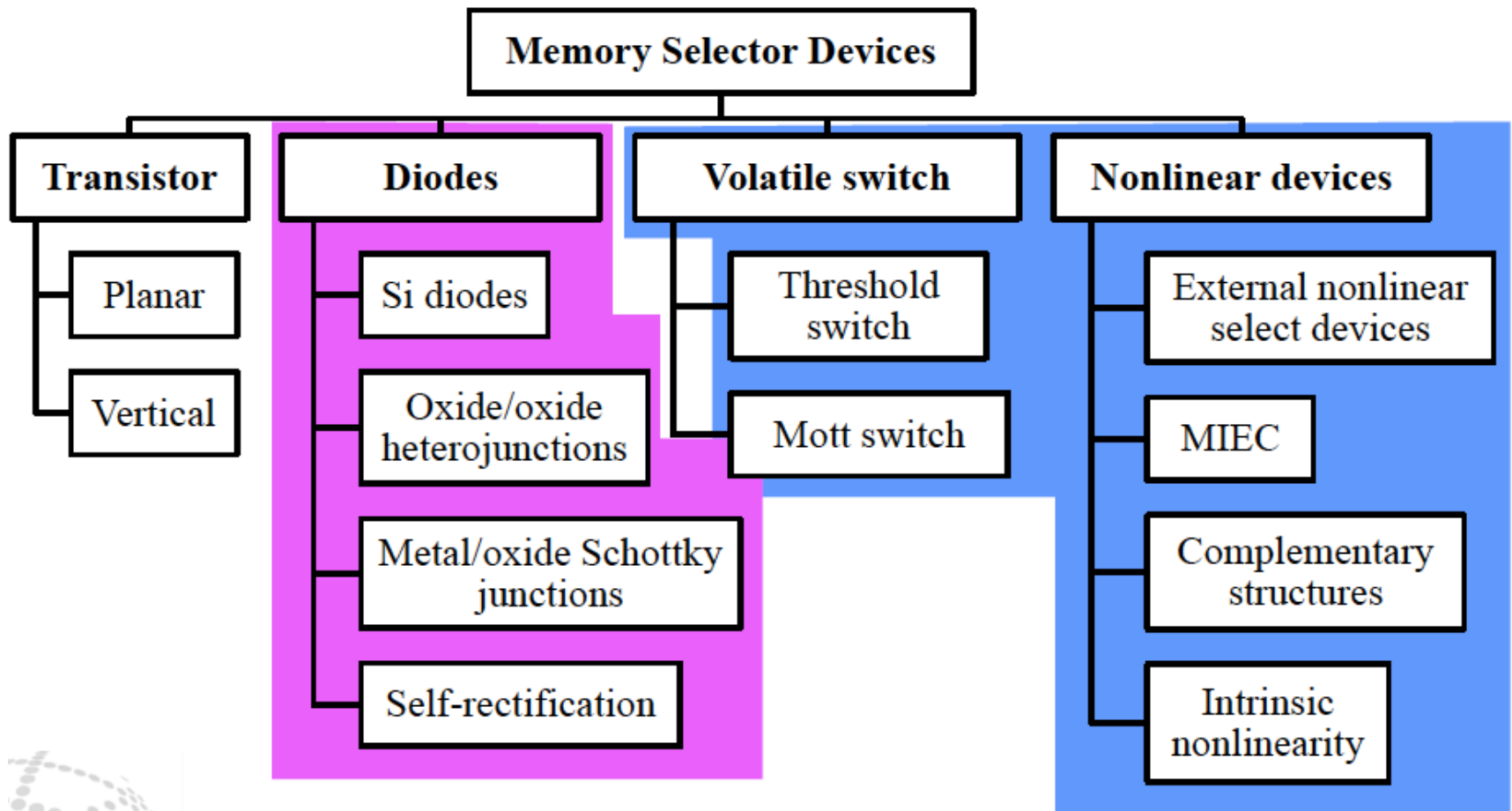
STTMRAM 2014 Cell.pdr

NVM Progress (Amigo Tsutsui, Sony at the 2015 FMS)



Memory Selector Device Options

An Chen, 2014 AVS TFUG Seminar

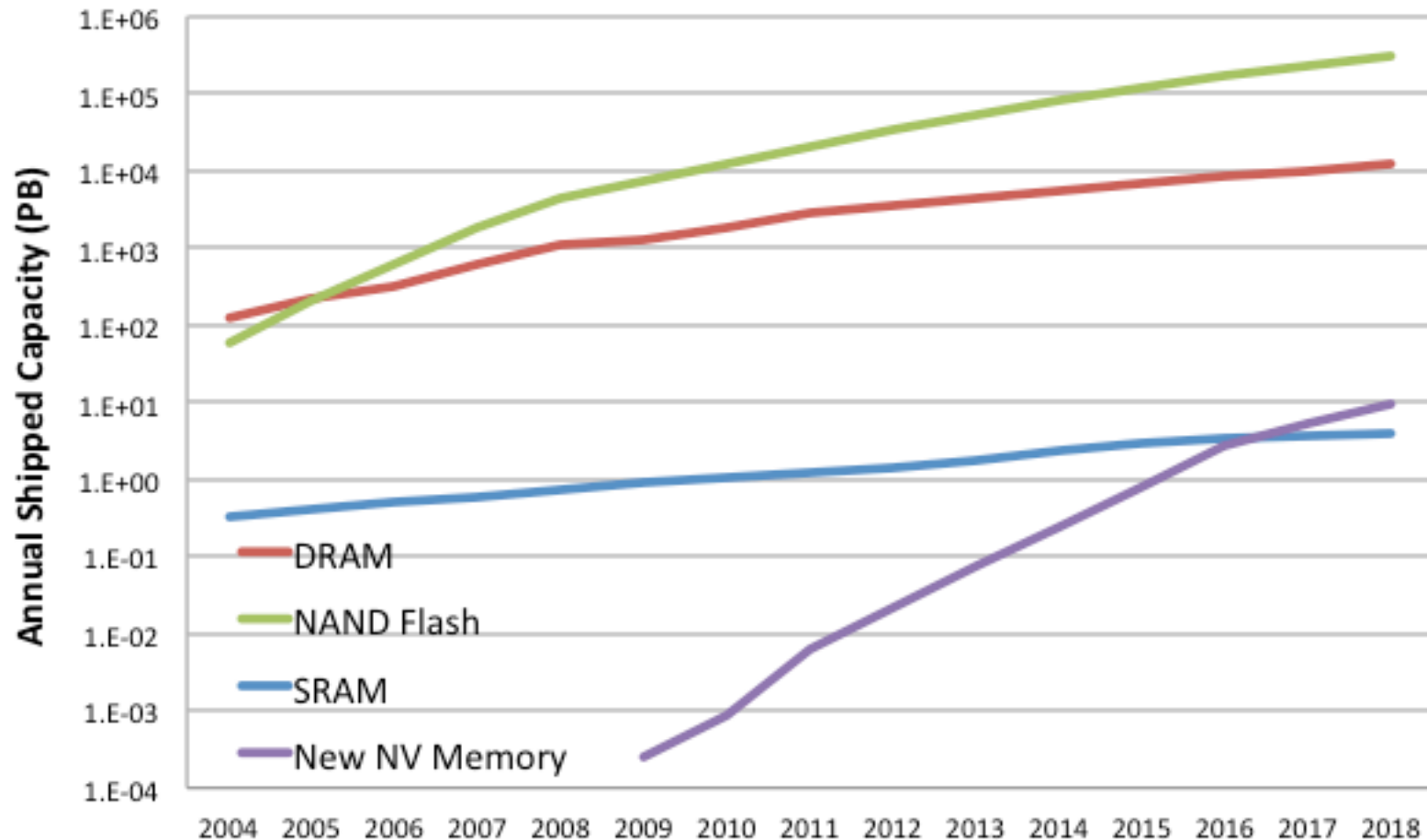


SUMMARY OF STORAGE AND MEMORY TECHNOLOGIES

	HDD	Flash (SLC)	Flash MLC)	Fe-RAM	M-RAM	PC-RAM	Re-RAM	STT-RAM	Race Track	CNT
Cell Structure	none	1T/0C	1T/0C	1T/1R	1T/1R	1T/1R	1T/1R-0T/1R (e)	1T/1R	none	1T/1R
Cell Size (F ²)	0.5	4-5	4-5	16-32	16-32	5-8	4-6	4	1 (e)	5(e)
Read Time (ns)	2000	50	50	20-50	3-20	5-20	10-20	3-15	500	50(e)
Write Erase Time (ns)	500-1000	1 ms-0.1 ms	1 ms-0.1 ms	50	10-20	>30	20	3-15	250	50(e)
Endurance	10 ¹⁶	10 ⁵	10 ³	10 ¹²	10 ¹⁵	10 ¹²	10 ⁵	10 ¹⁵	10 ¹⁵ (e)	10 ¹⁵
Write Power	Med	High	Med	Low	High	High	Low	Low	Low (e)	Low (e)
Max.Areal Density Gbits/in ²	750-1000	150	550	0.1	10	200(e)	>200	>400 (e)	1000 (e)	>200 (e)
Voltage Required	3-5V	3.3 V	1.8 V	2-3V	3V	1.5-3V	1.2V	1.5V	3-5V (e)	3-5V (e)
	Existing Products					In Development			Laboratory	

Annual Memory Capacity Shipments

(2014 Emerging NVM Report and Their Manufacture, Coughlin Associates)

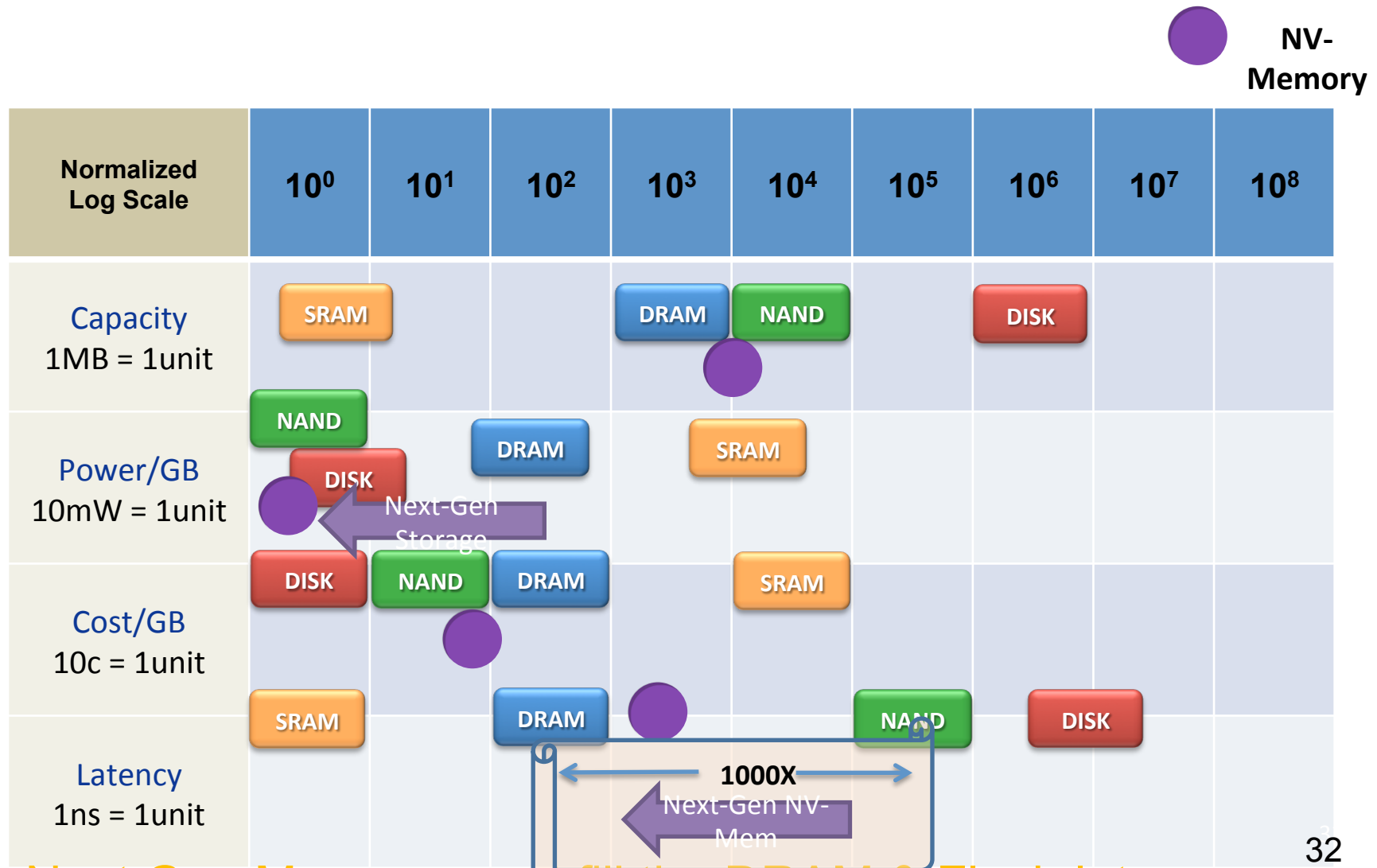




3D XPoint Technology

Comparison of Memory Technologies

Slide from 2015 Storage Visions Conference



Next Gen Memory must fill the DRAM & Flash latency gap

3D XPoint Memory

WHAT IS 3D XPOINT™?

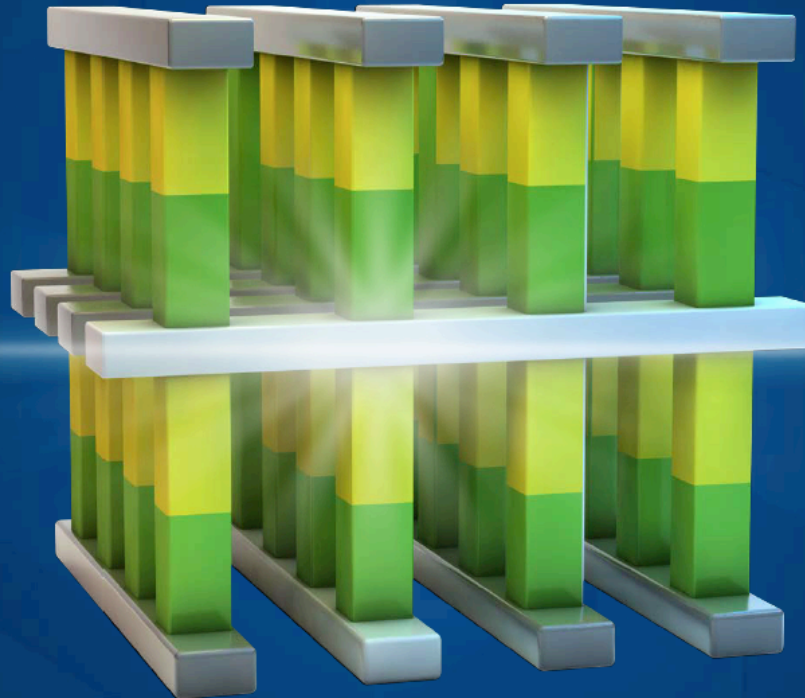
Crosspoint Structure

Selectors allow dense packing and individual access to bits



Scalable

Memory layers can be stacked in a 3D manner



Breakthrough Material Advances

Compatible switch and memory cell materials



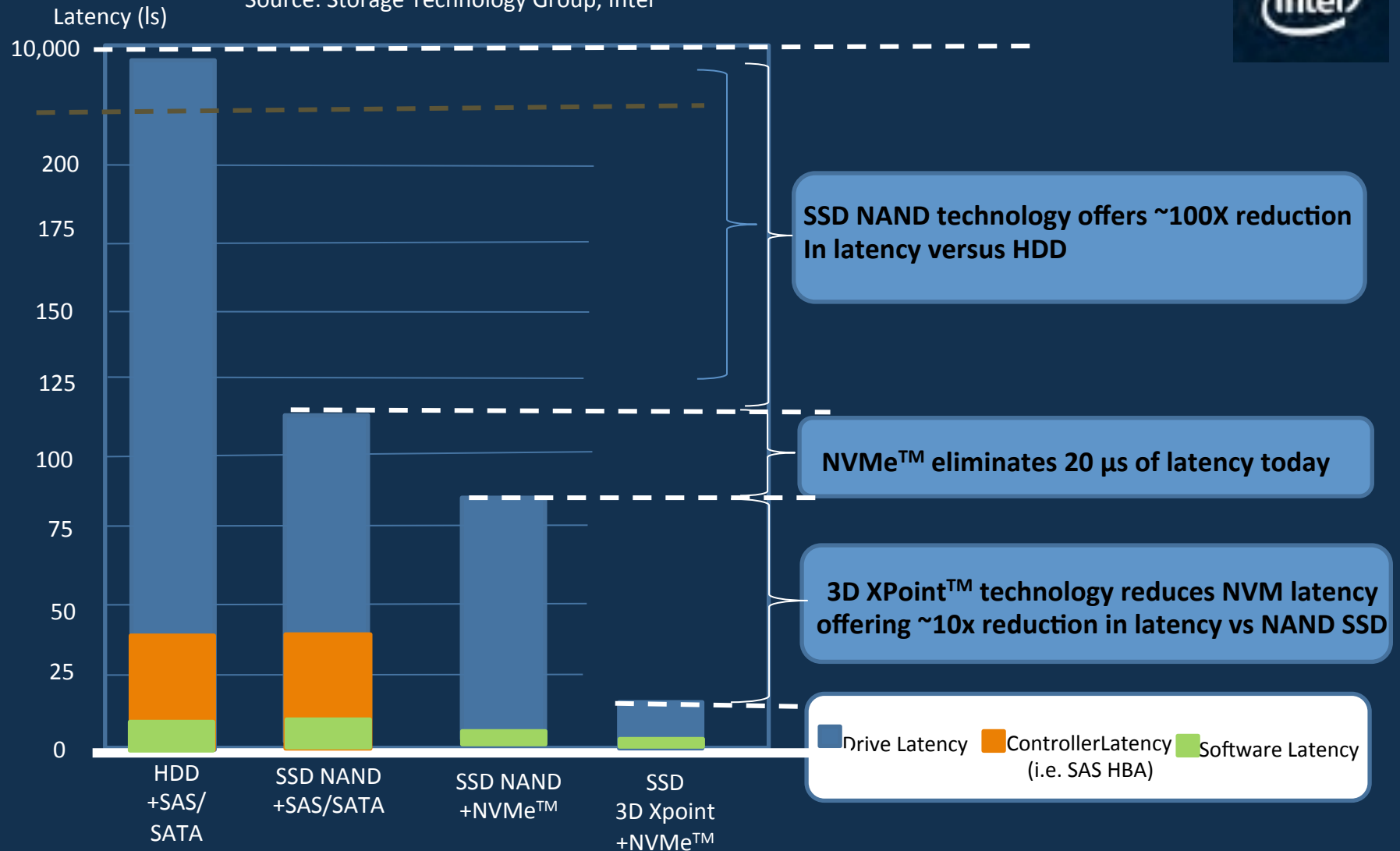
High Performance

Cell and array architecture that can switch states 1000x faster than NAND

3D XPoint Comparisons to NAND



Source: Storage Technology Group, Intel



Technology claims are based on comparisons of latency, density and write cycling metrics amongst memory technologies recorded on published specifications of in market memory products against internal Intel specifications

3D Xpoint Memory

3D XPOINT™ ENABLES FUTURE APPLICATIONS

END USER POSSIBILITIES



Massive
in-memory
data base



Fast system
recovery



Low latency



High endurance



Gaming



High fidelity
pattern
recognition



Genomics

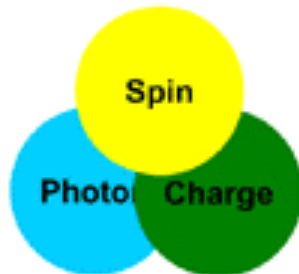
AMAZING NEW EXPERIENCES



The Memory is the Computer

Spintronics

Spintronics (Spin + Charge)



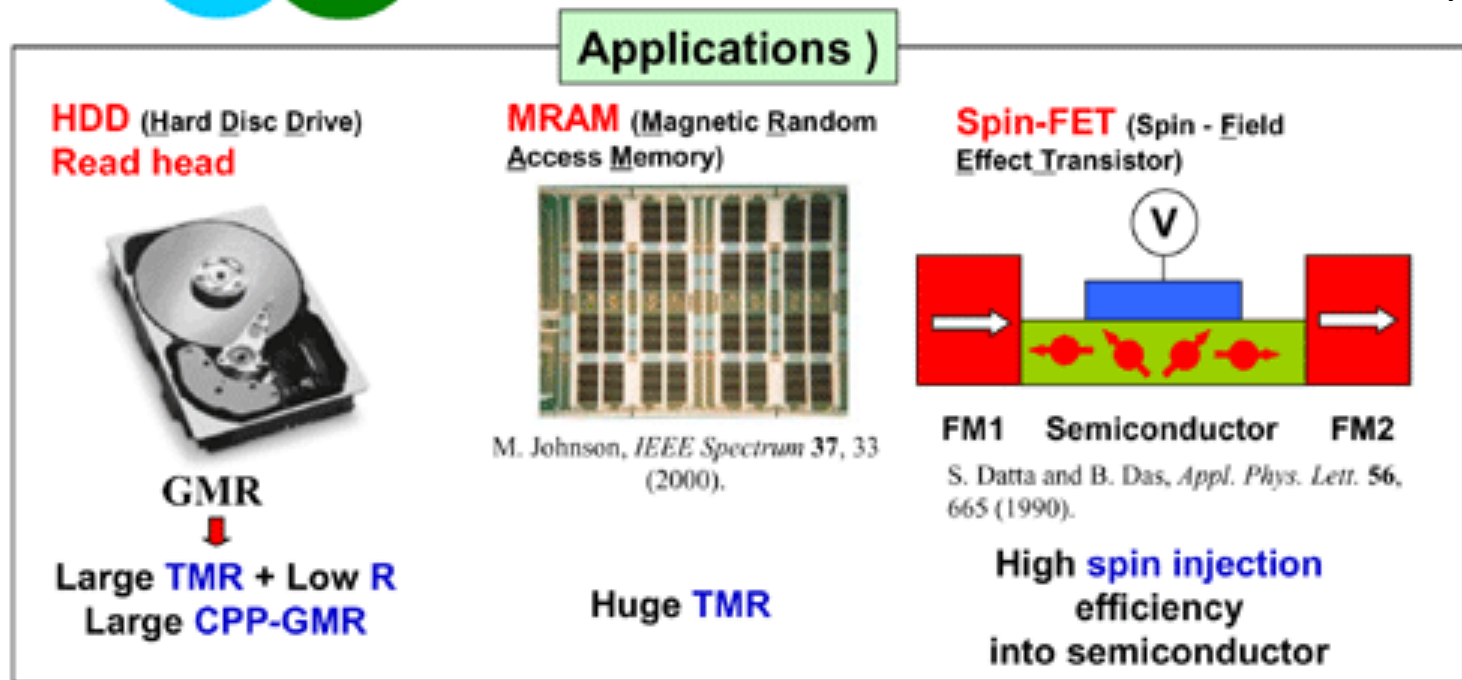
Semiconductor (Charge)

Magnetic materials (Spin)



SPINTRONICS

- From Tohoku University in Japan

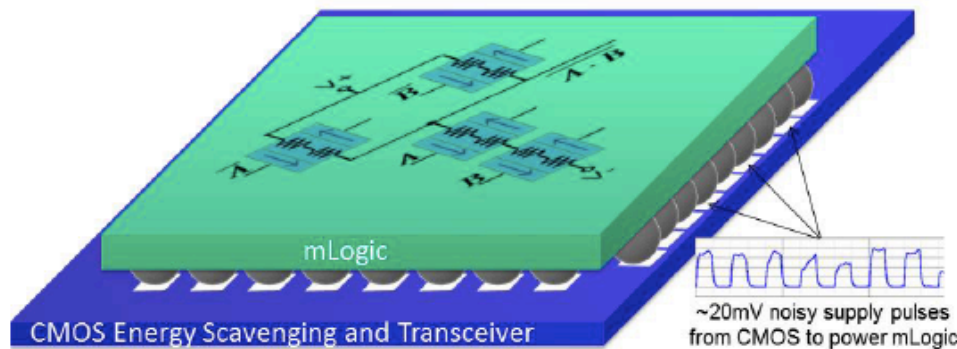


•TMR : Tunnel Magnetoresistance

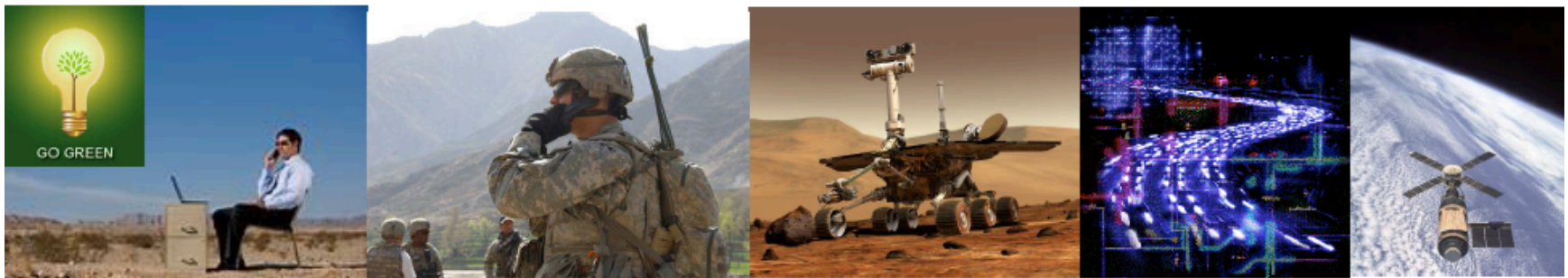
•CPP-GMR : Current Perpendicular to Plane- Giant Magnetoresistance

Spin-Based Computing

mLogic: All Spin Logic Device and Circuits for Future Electronics, Jimmy Zhu, et. Al, March 2015

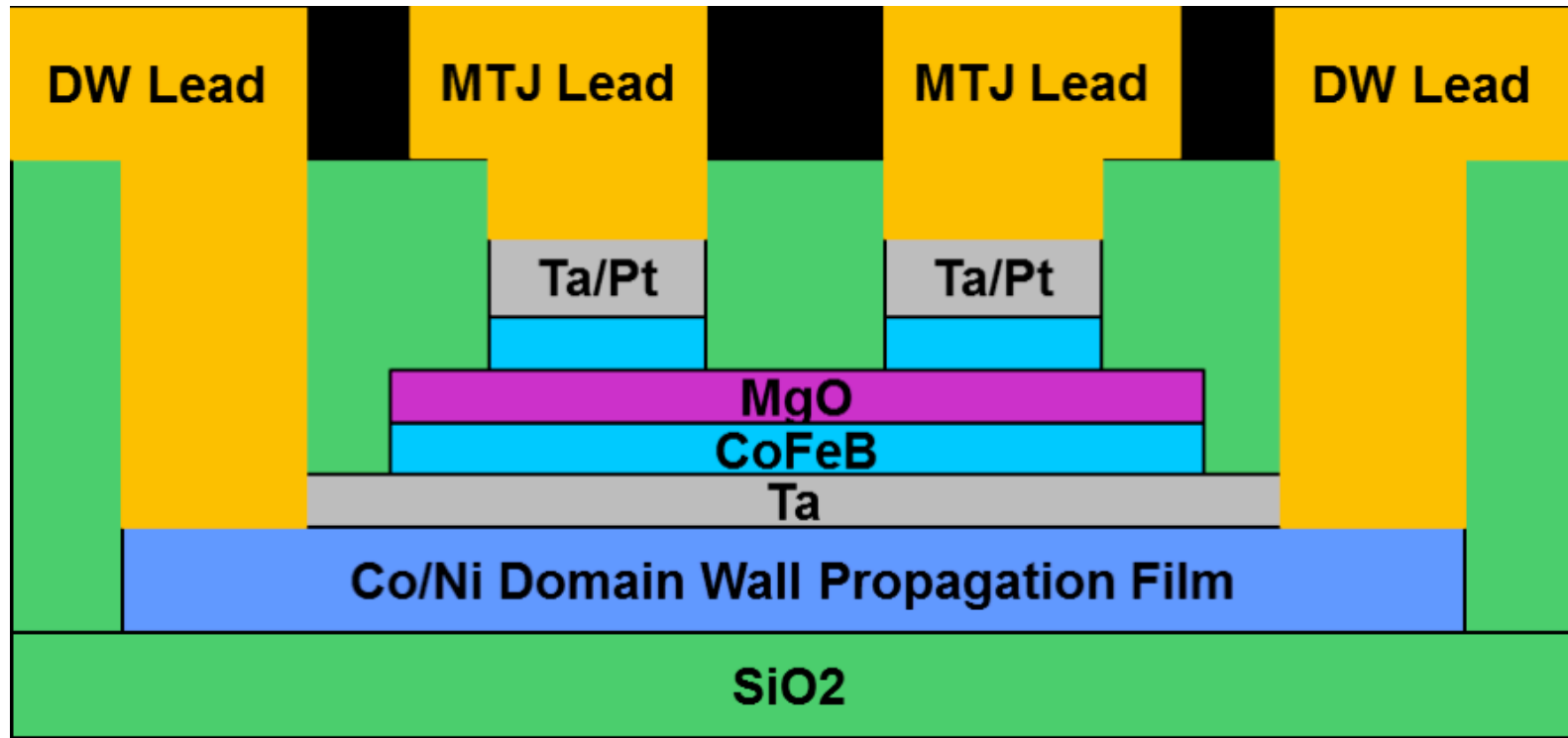


- ***All STT based metallic logic***
- ***Nonvolatile logic states***
- ***Ultra-low pulsed voltage***
- ***Portable & energy-harvesting***
- ***Rad-hard for space applications***
- ***Very low cost manufacturing***
- ***Scalable to 5nm CD***



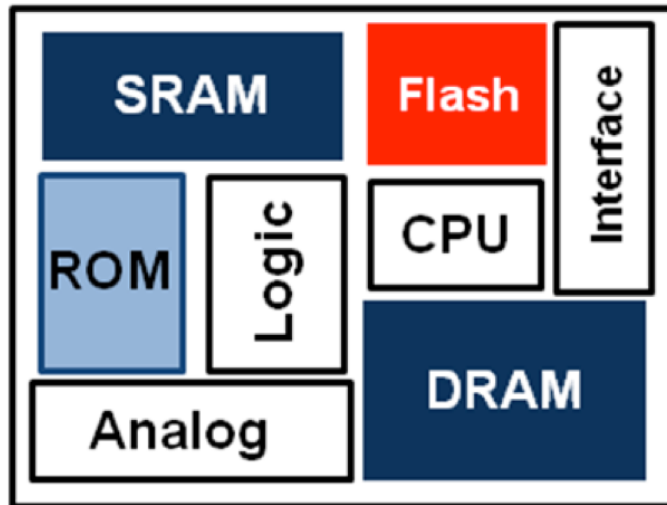
mCell Spin Logic Unit

(J. Zhu, Carnegie Mellon Univ.)

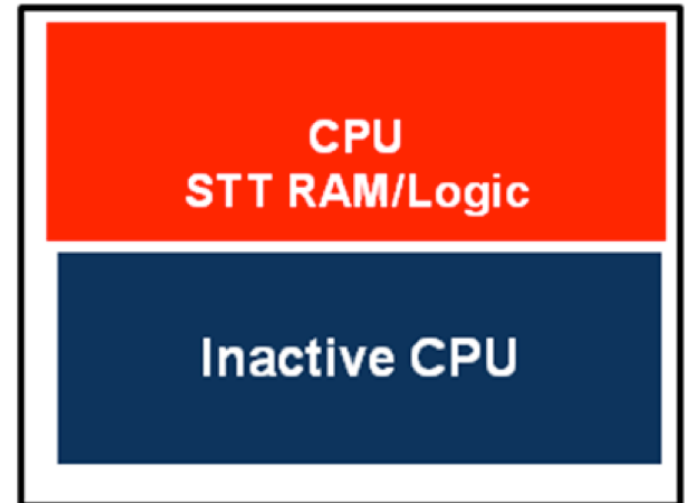


STT Logic Application (Reducing Dark Silicon)

CPU/Multiple Memories



CPU/STT RAM/Logic



What if Spin Transfer Replaced Charge Transfer (Current)?

- Spin transfer would not generate the heat that electrical currents generate
- This allow building powerful devices in small spaces
- Spin could be used for both processing and memory/storage

Conclusions

- Faster memory/storage is needed for modern applications
- The storage/memory landscape has more options than ever—e.g. 3D XPoint
- Non-volatile memories will replace volatile memories
- NVM and processors want to come together
- Spin-based electronics are one example of a technology that could put memory and processing in one device

References

- 2014 How Many IOPS Do You Really Need Report, Coughlin and Handy, Coughlin Associates
- 2014 and 2015 Emerging NVM Report and Their Manufacture, Coughlin Associates
- 2015 Storage Visions Conference Presentations
- Touch Rate: A metric for analyzing storage system performance, Steven Heltzer and Tom Coughlin, 2015
- Information on all these documents are available at: <http://www.tomcoughlin.com/techpapers.htm>

A photograph of a beach scene. In the foreground, a long, dark shadow of a person is cast across the wet sand, extending from the bottom left towards the center. The sand is a light brown color with some ripples. In the middle ground, the ocean waves are breaking, creating white foam. The water is a deep blue color. In the background, there are dark rocks scattered along the shoreline. The sky is a clear, light blue color.

Thanks