Advances in Non-Volatile Storage Technologies

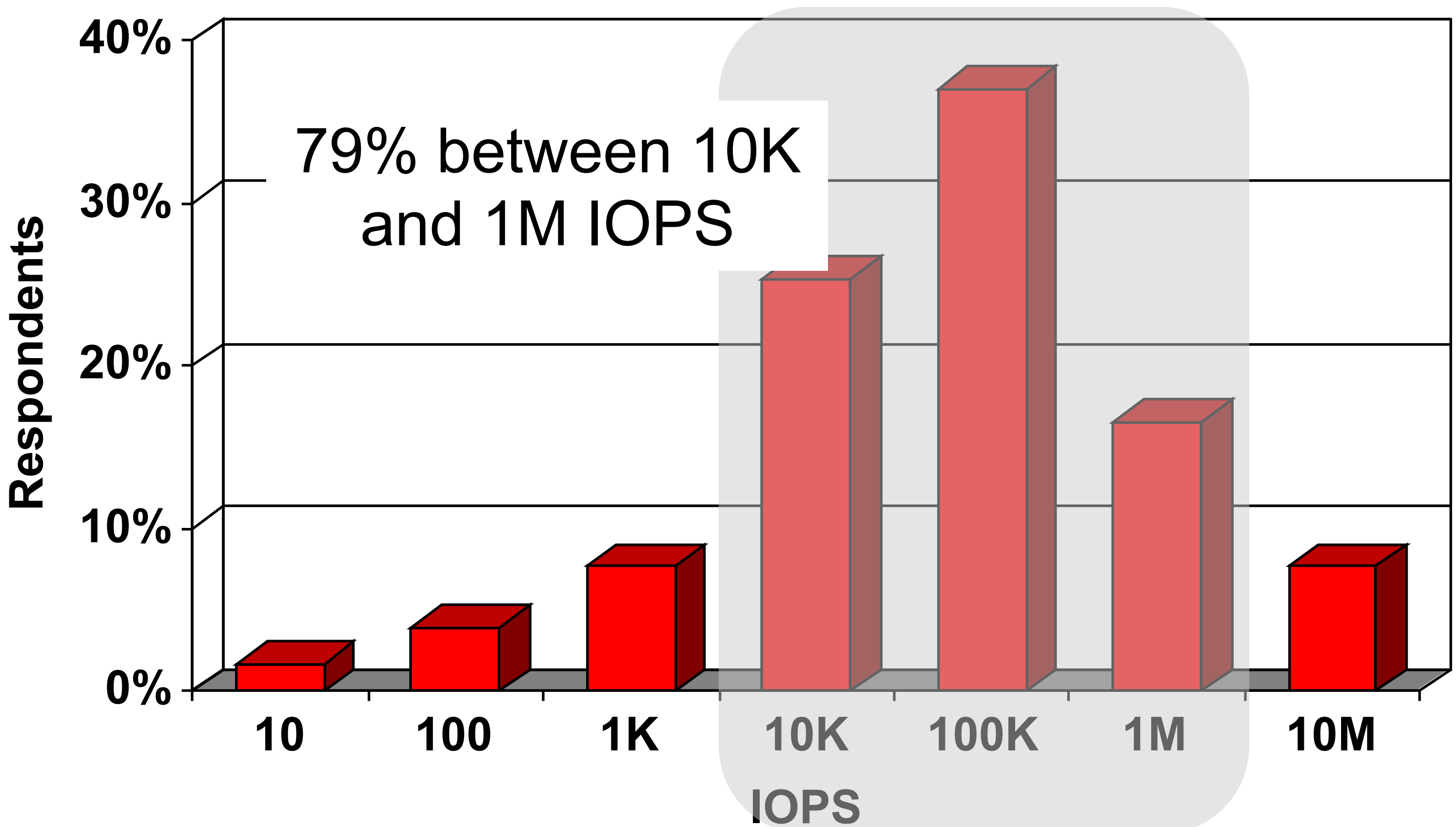
Tom Coughlin
Coughlin Associates
Ed Grochowski, Computer Memory/ Storage Consultant

Outline

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

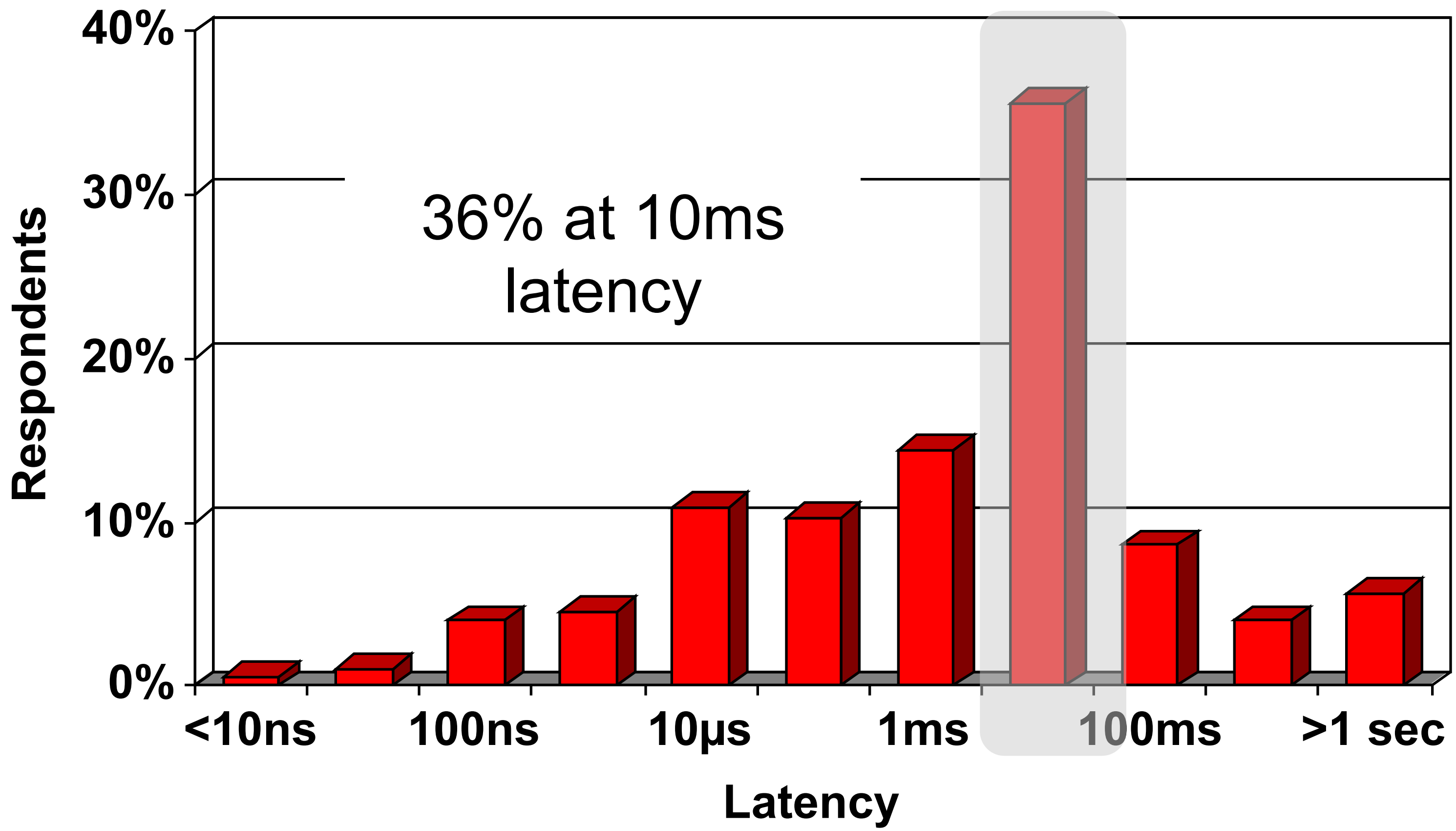
The Shape of Things to Come

IOPS Required



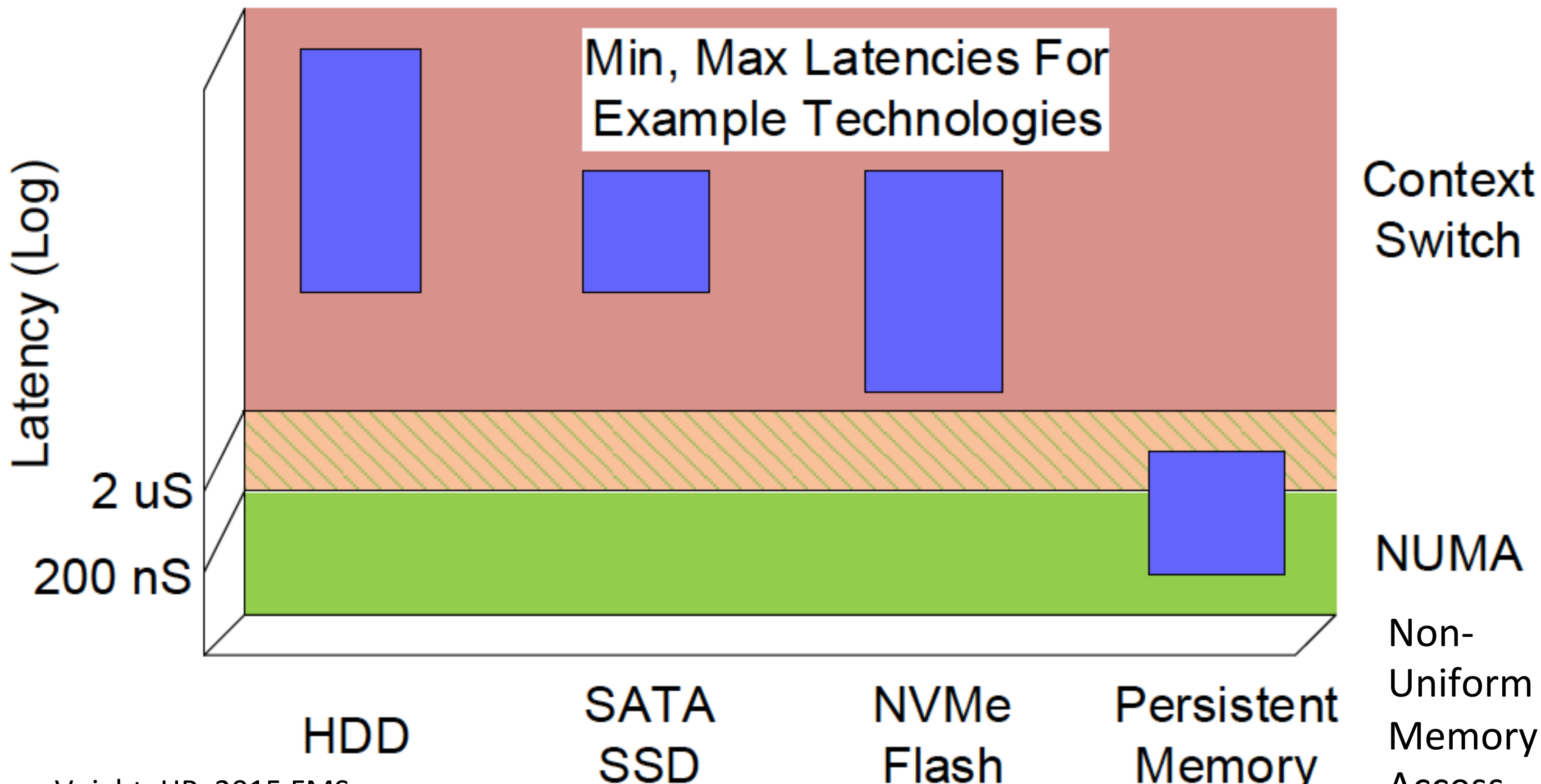
From the 2014 How Many IOPS Do You Really Need Report, Coughlin and Handy, http://www.tomcoughlin.com/techpapers.htm

Maximum Latency Requirement



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

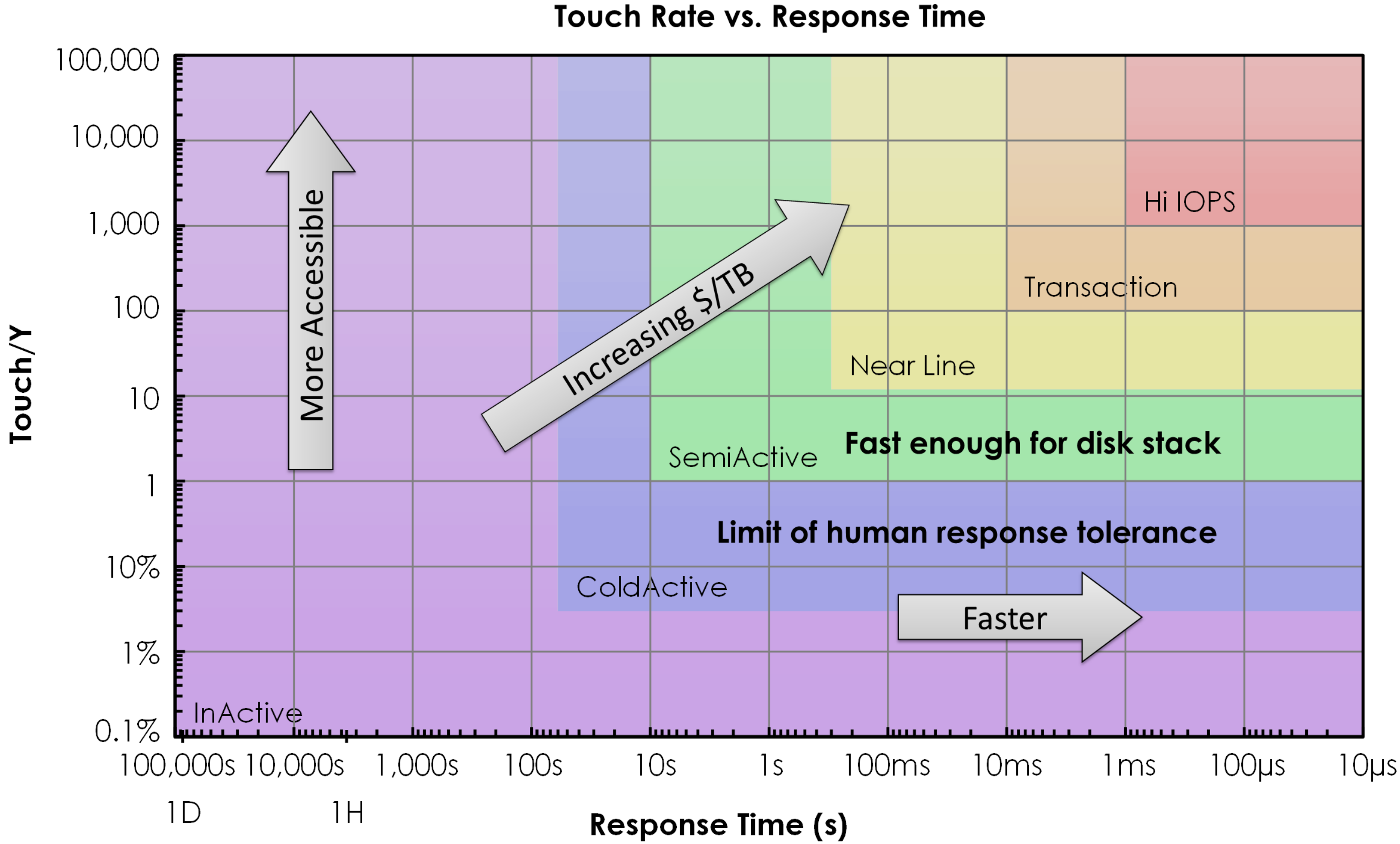
Latencies Separate Computer Memory from Storage



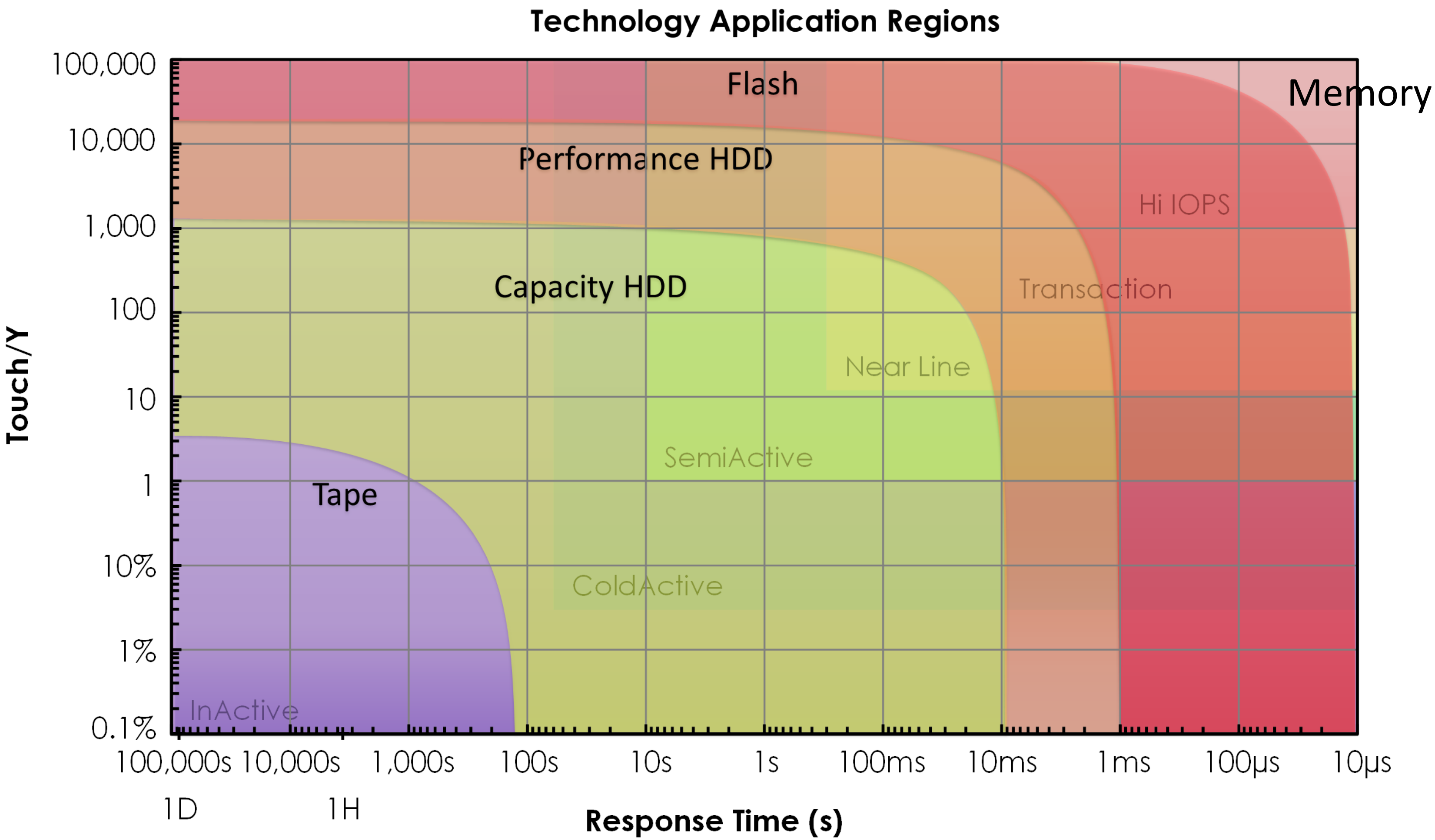
Non-Uniform Memory Access

Doug Voight, HP, 2015 FMS

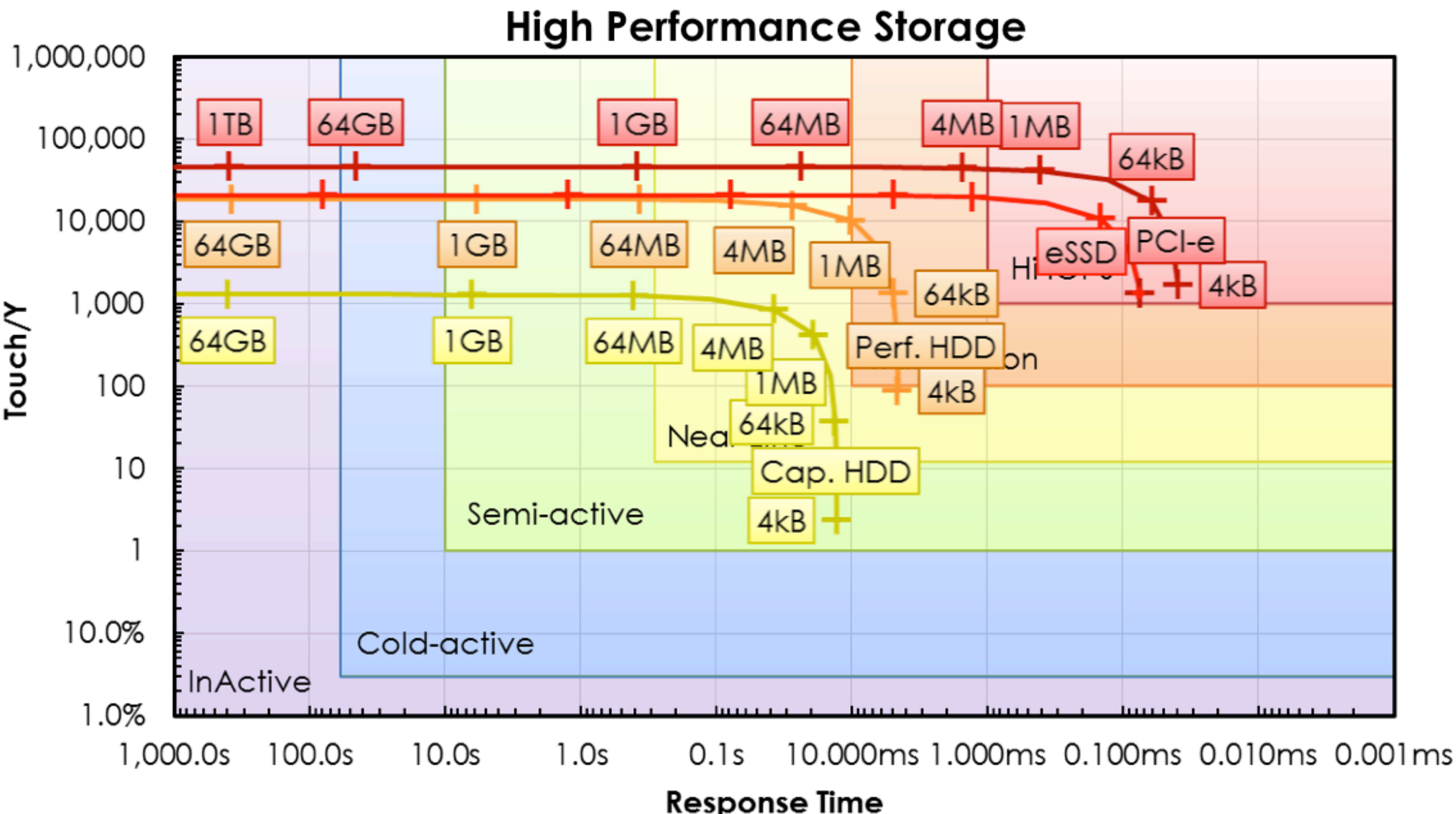
Touch rate versus response time indicating various types of uses



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

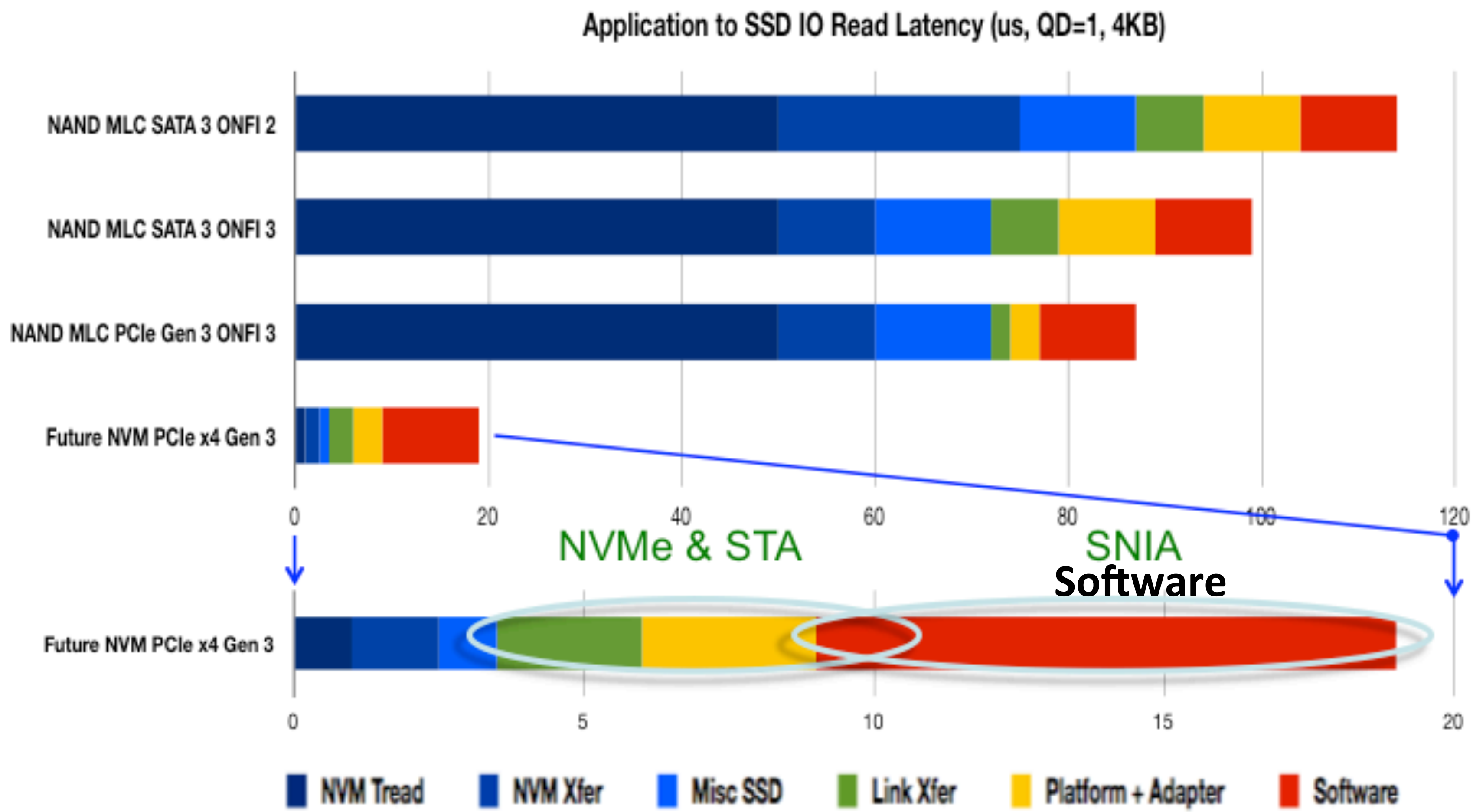


Ent. SSDs, perf. HDDs and capacity HDDs



Storage Latency with Current and Future NV Solid State NV Technologies

(from NVMP talk at SNIA Winter Symposium, 2014)



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

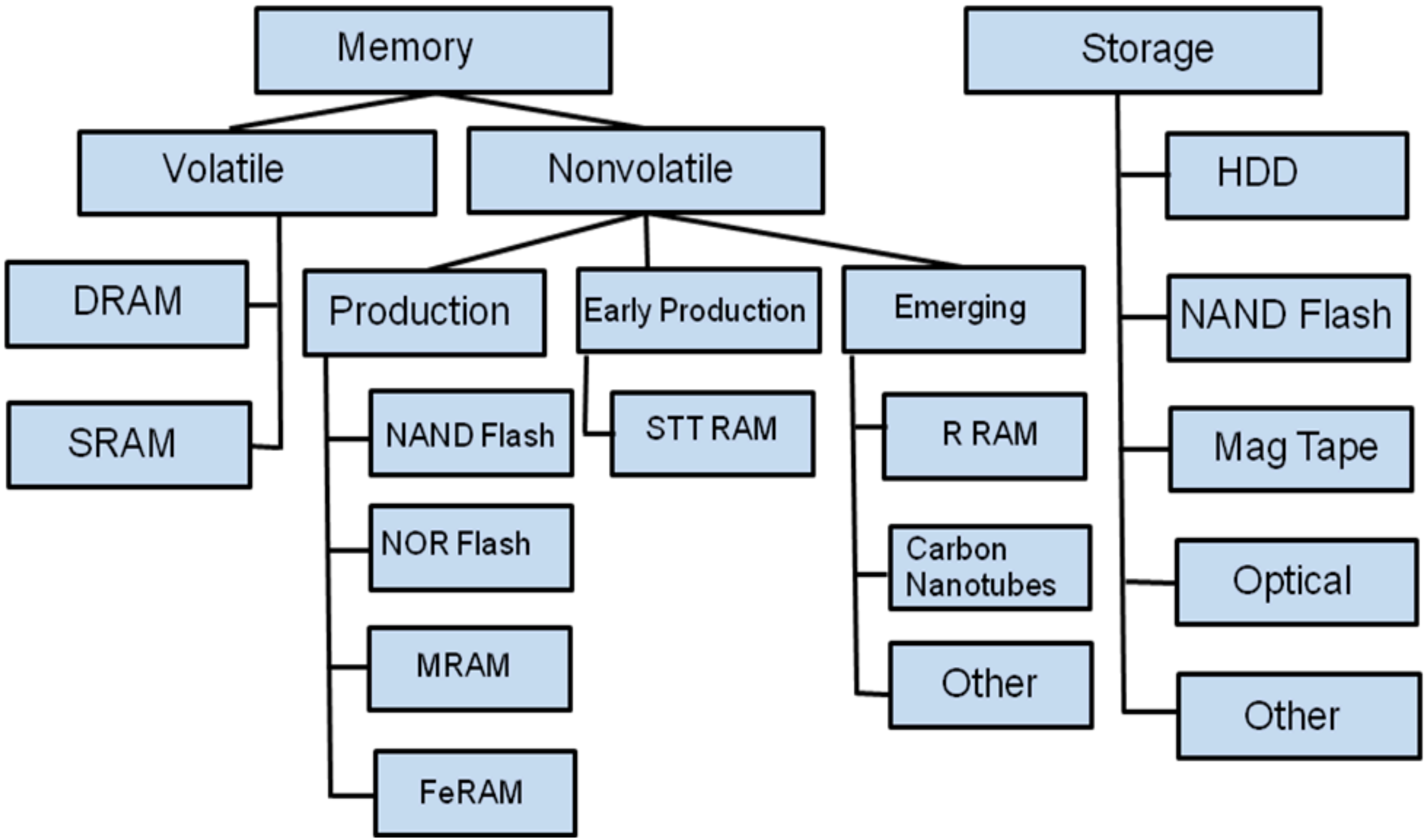
Challenges of Persistent Memory

- 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

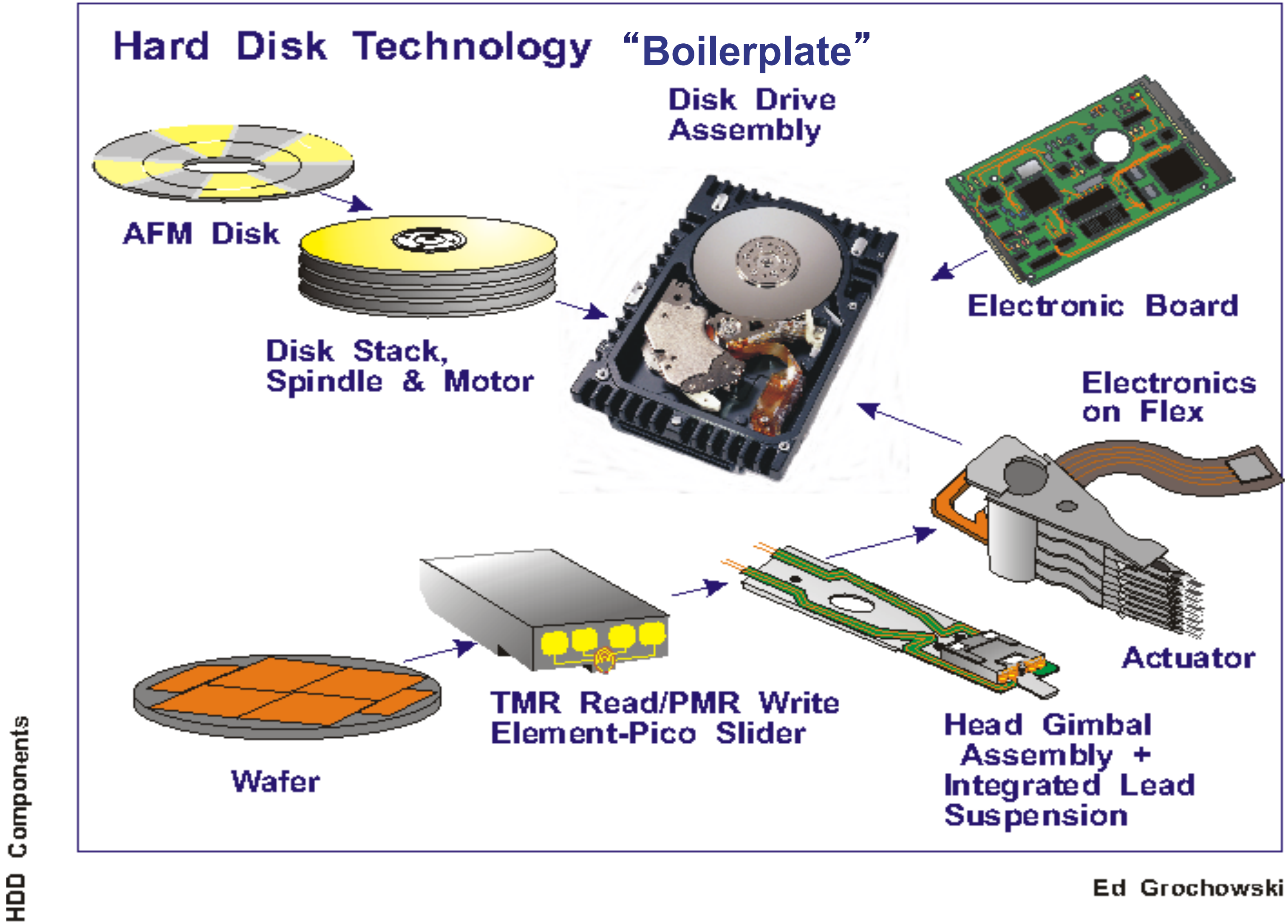
In Search of New Memories

Memory and Storage Today

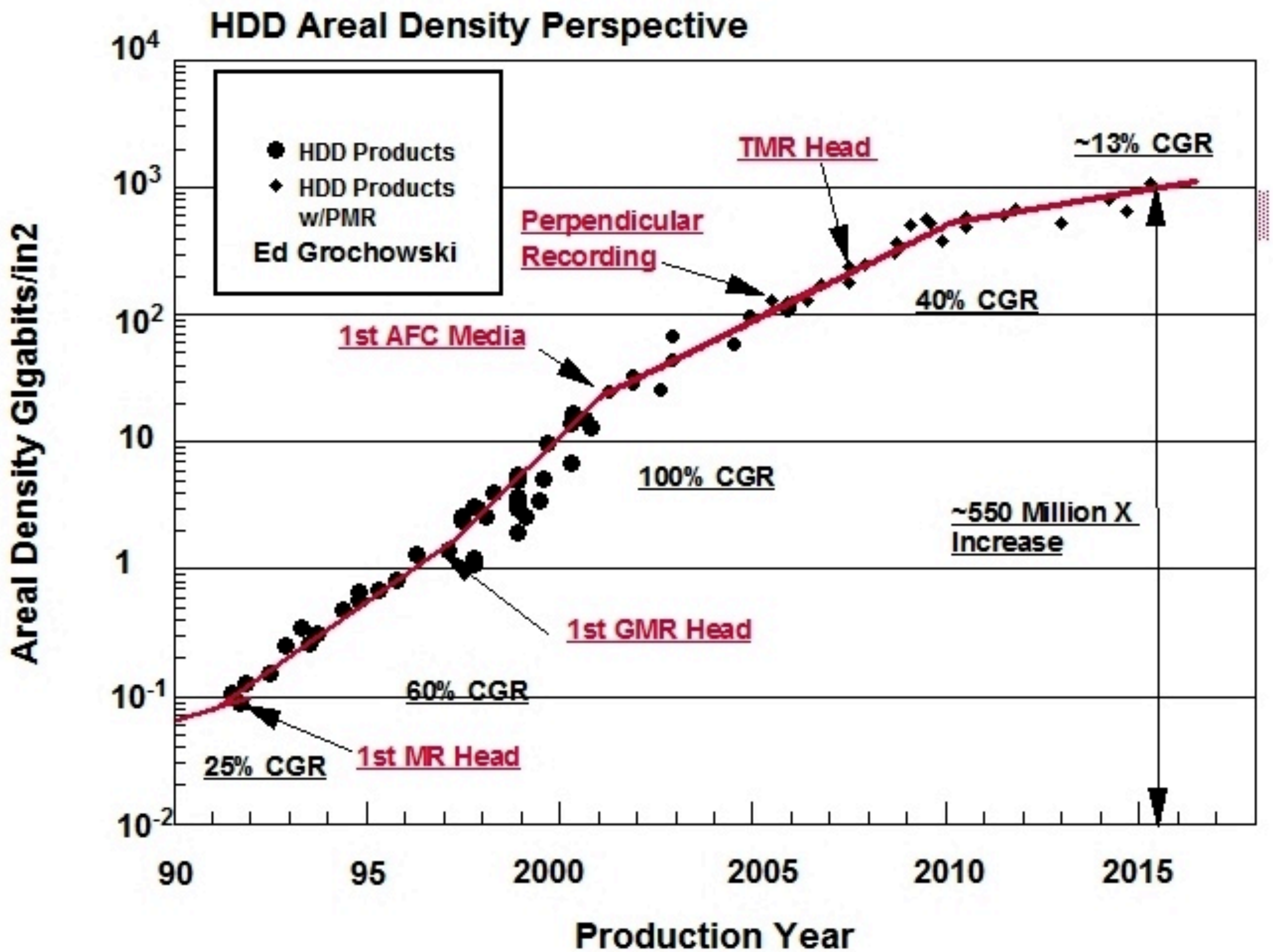
2015 Emerging NVM and Their Manufacture
Report, Coughlin Associates



Hard Disk Drives

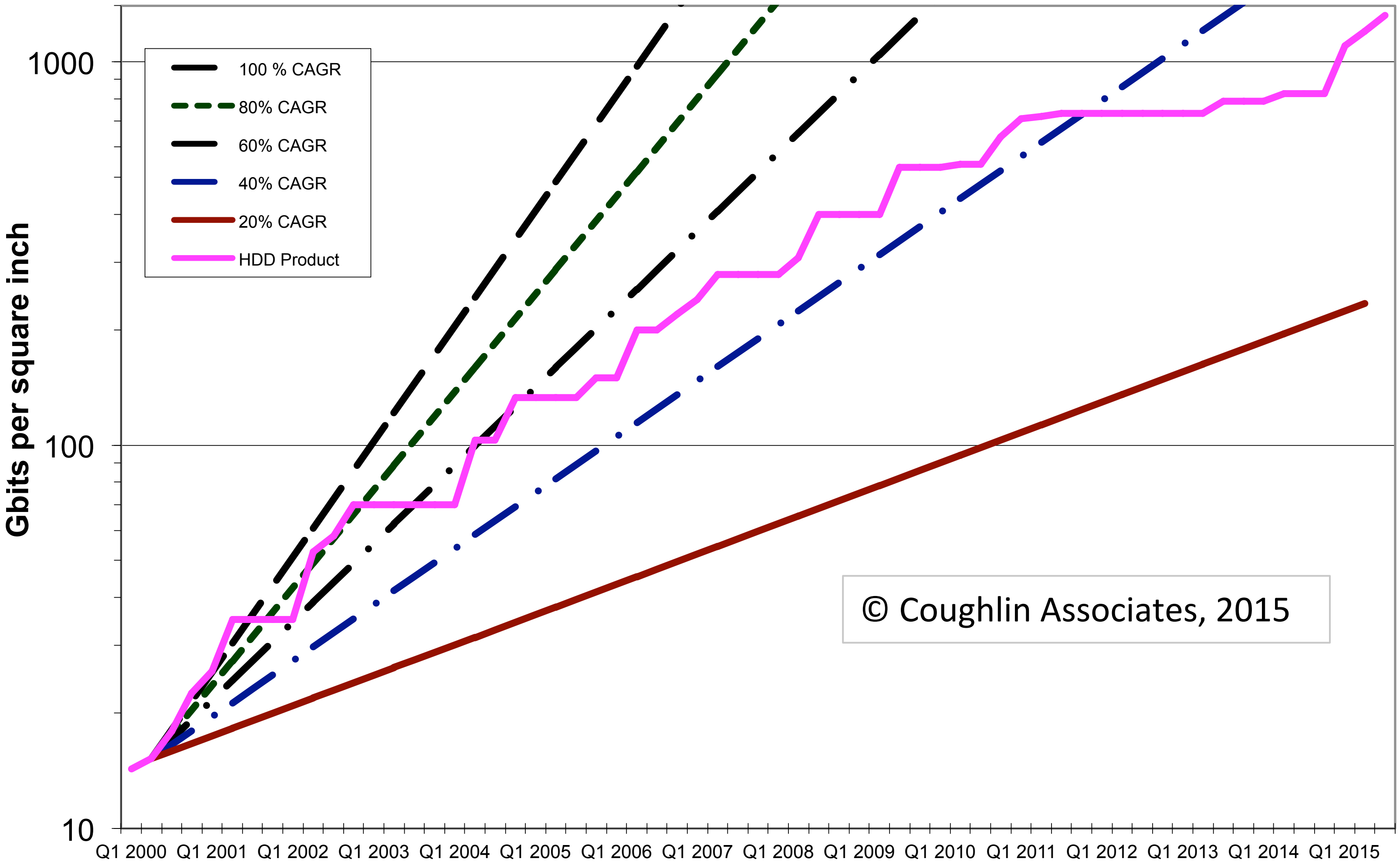


HDD Areal Density Growth



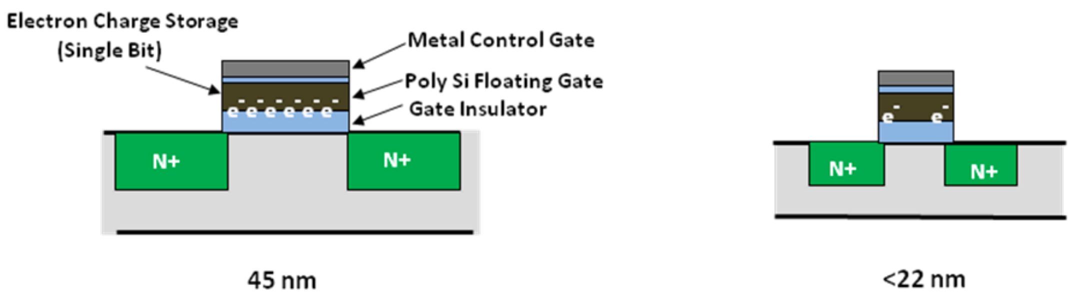
Recent Developments: SMR, HAMR, He-filled HDDs, MAMR with 3D Recording,

Actual Quarterly Announced HDD Product AD Charts

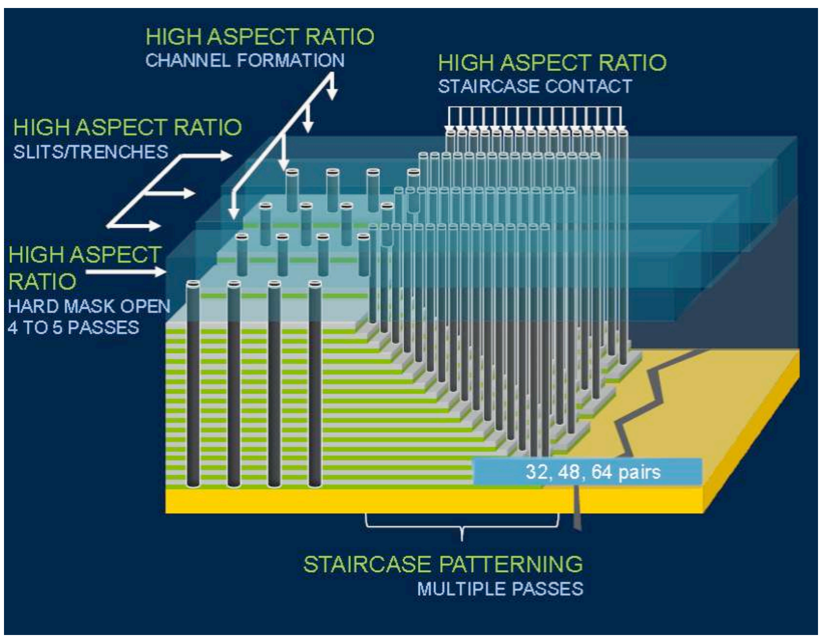


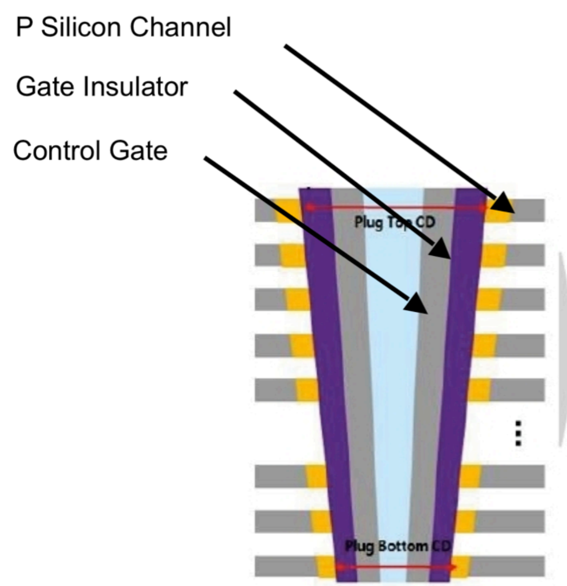
Flash Memory

Flash Scaling

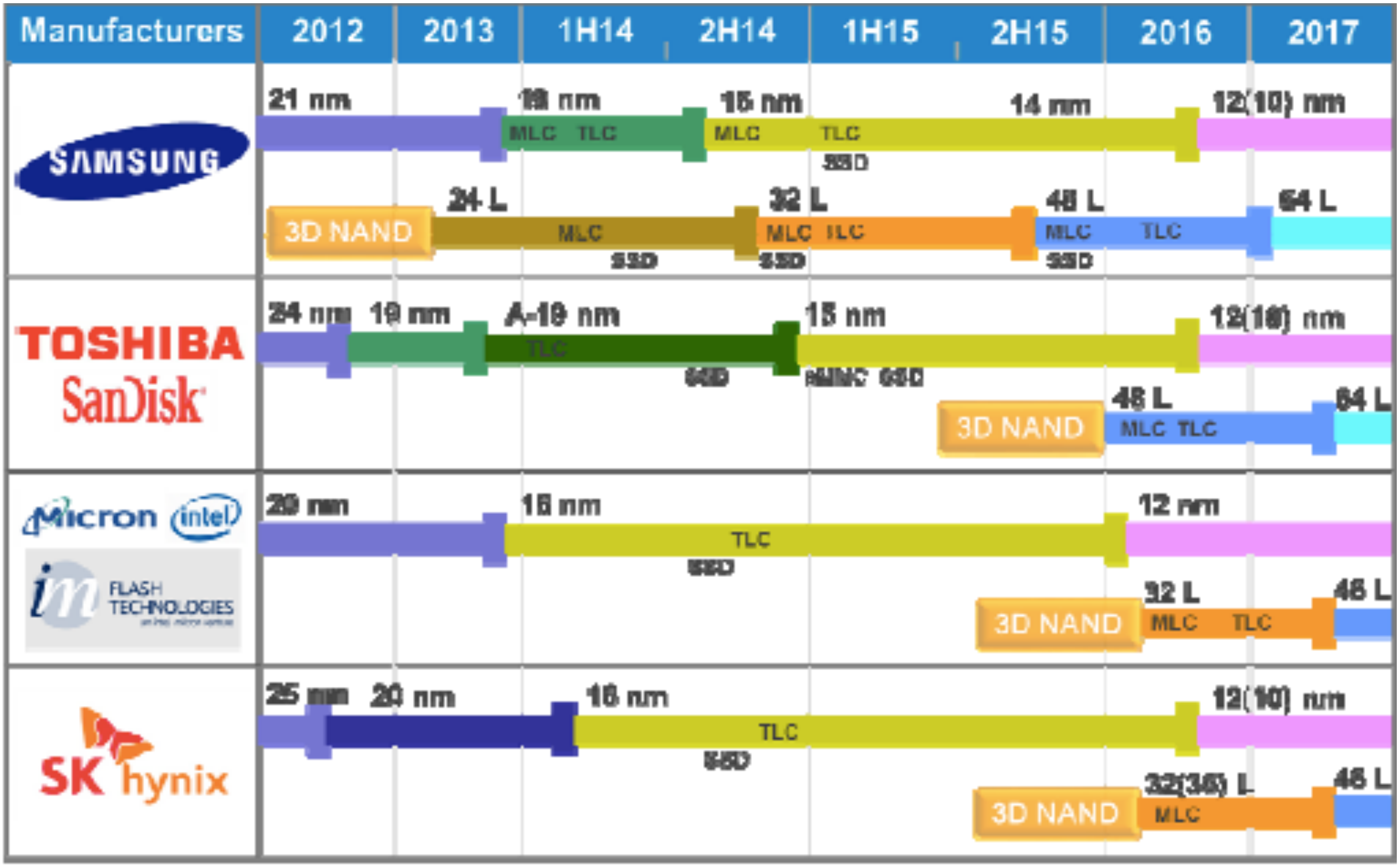


Floating Gate SLC
(2 voltage levels)



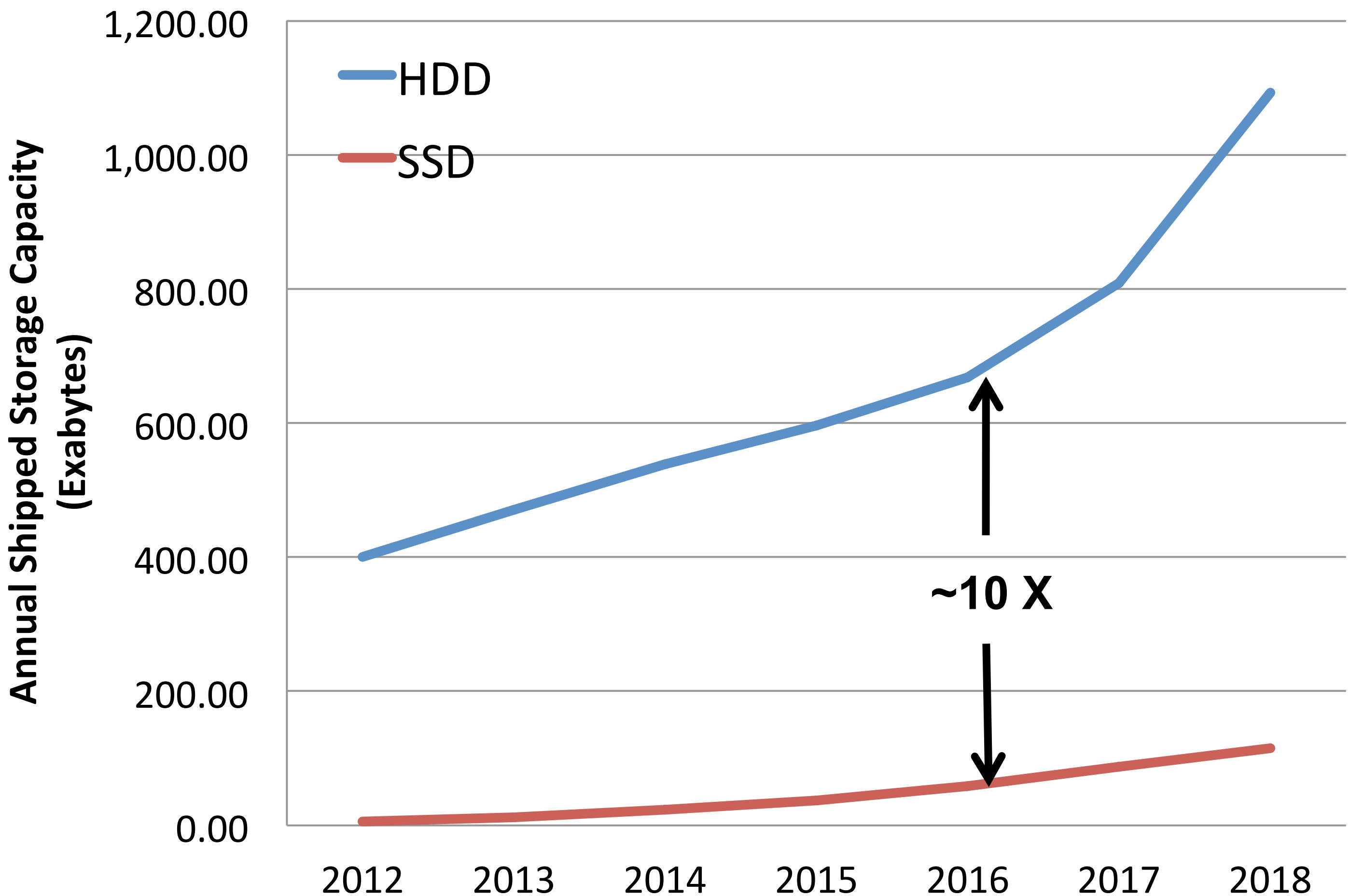


NAND Technology Roadmap



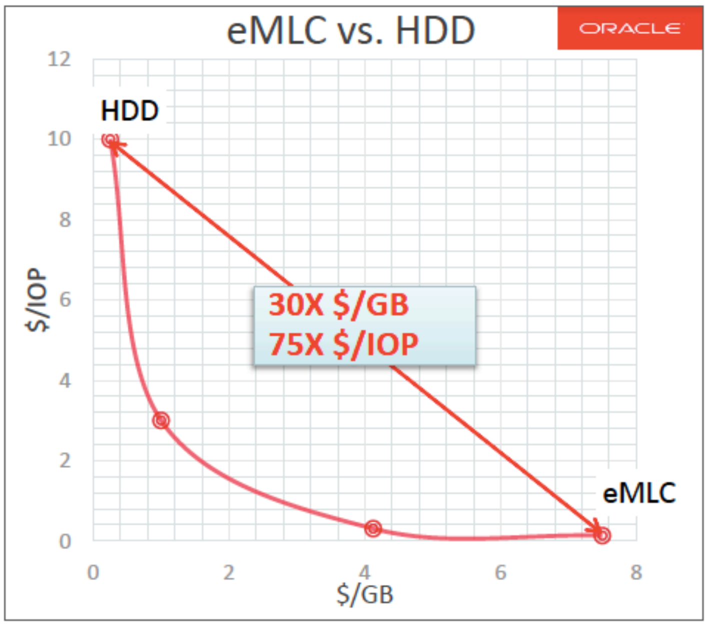
J. Choe FMS 2015

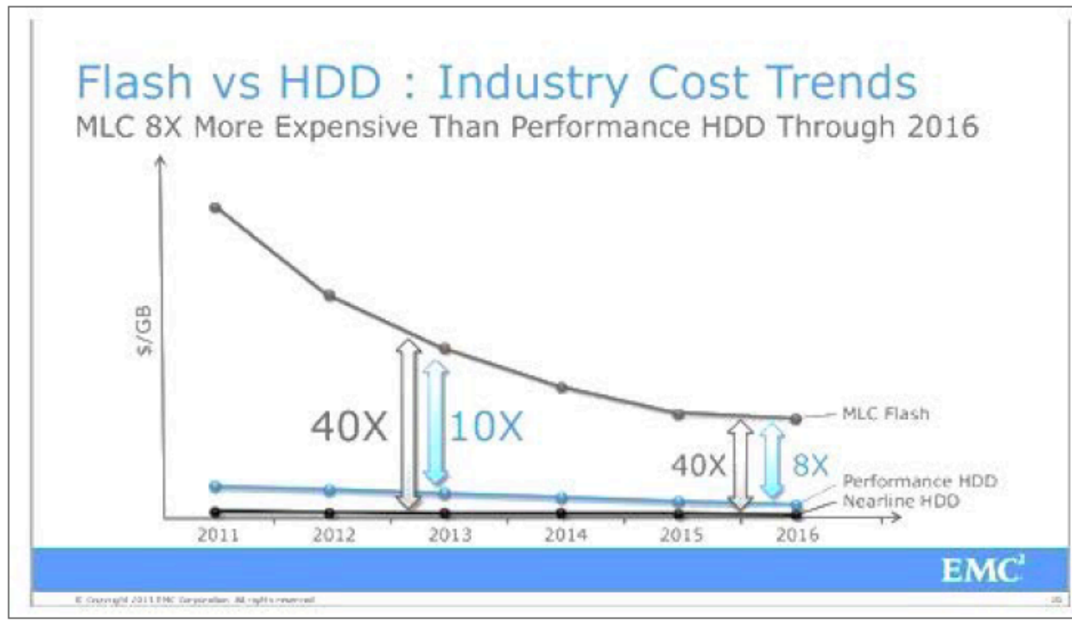
Annual HDD/SSD Storage Shipments



Comparisons of Flash and HDDs

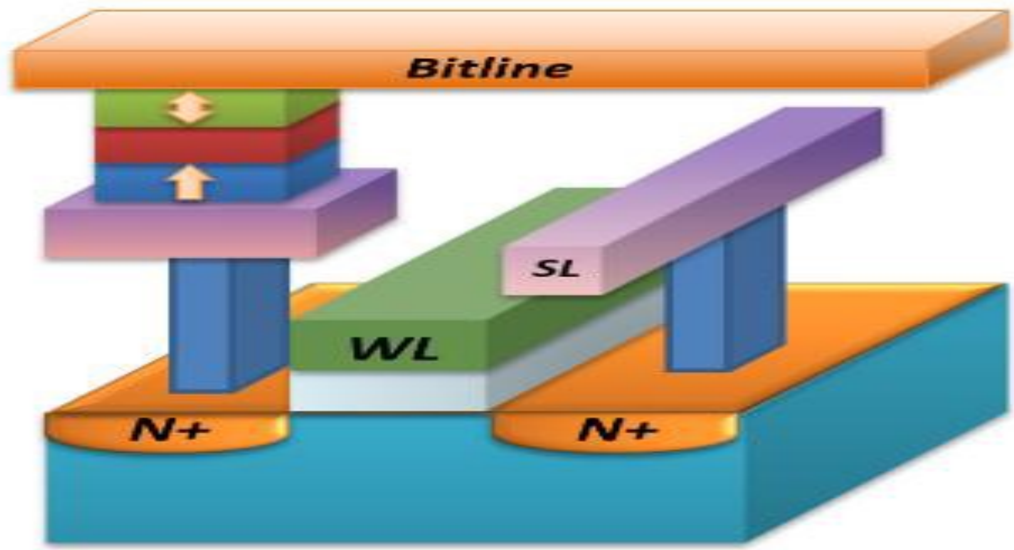
Mike Workman Keynote, 2015 FMS





Emerging Memory Technology

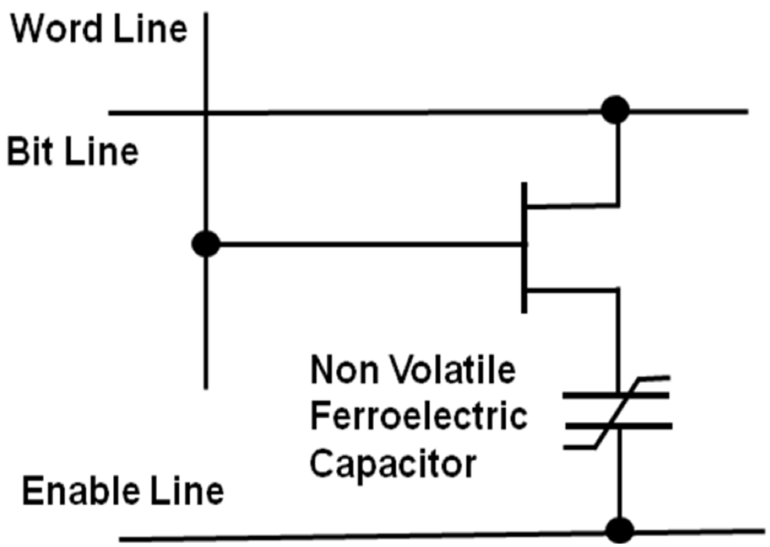
- NVM will save power
- Persistent memory enables memory sharing (RDMA)
- Embedded NVM technology can lead to “logic-in-memory architecture”

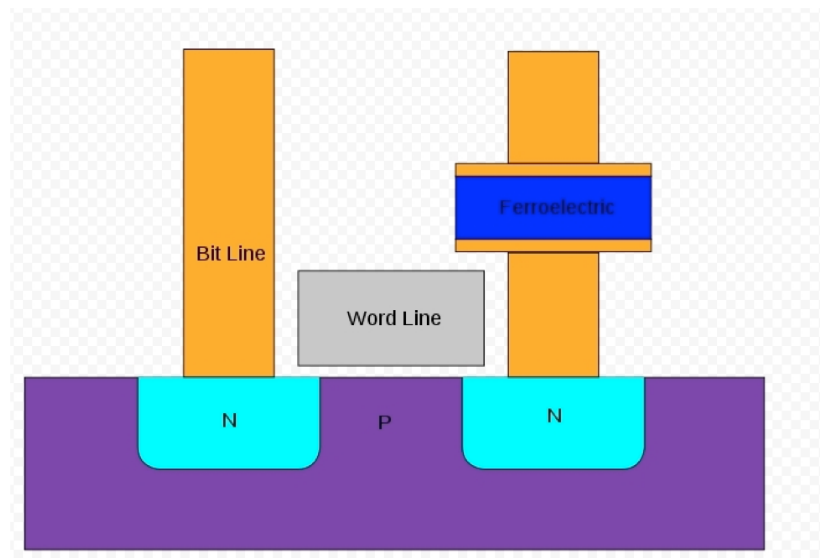


The emerging NVM market could exceed $2 B by 2019

2014 Emerging NVM Report and Their Manufacture, Coughlin Associates

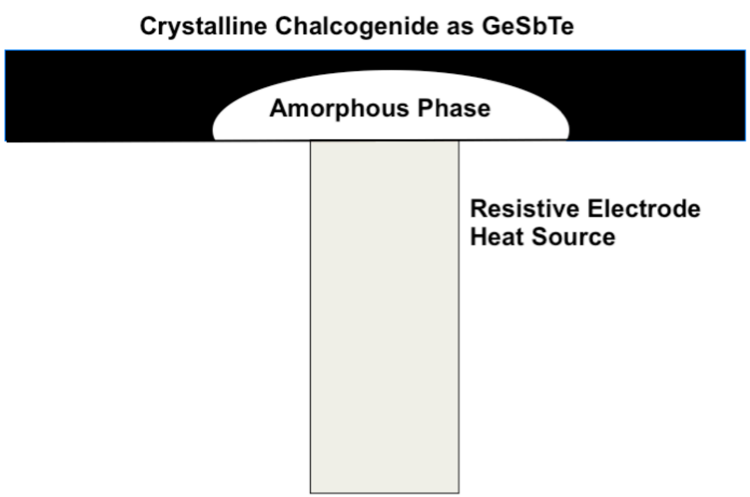
FeRAM

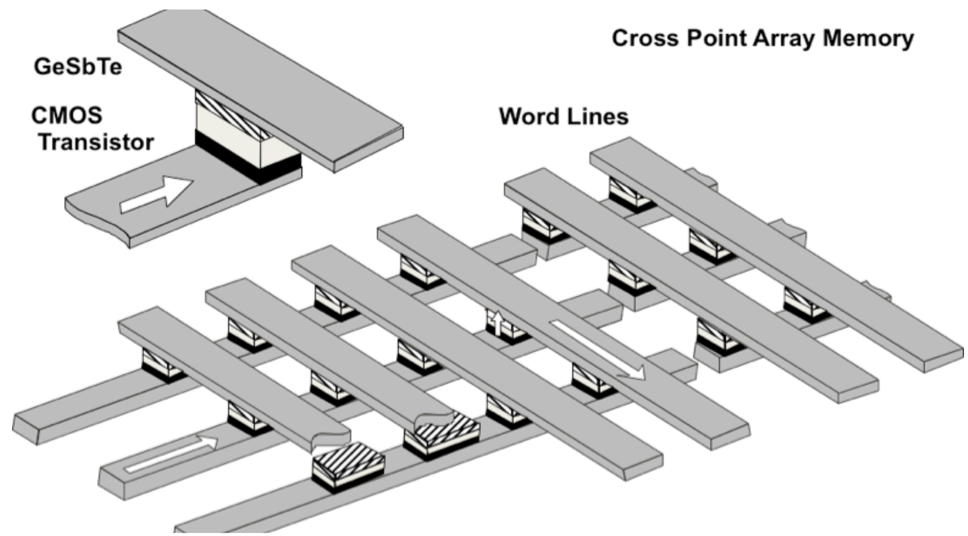




FeRAM products shipping for many years for niche applications, hard to scale density…

Phase Change Memory (PCM)

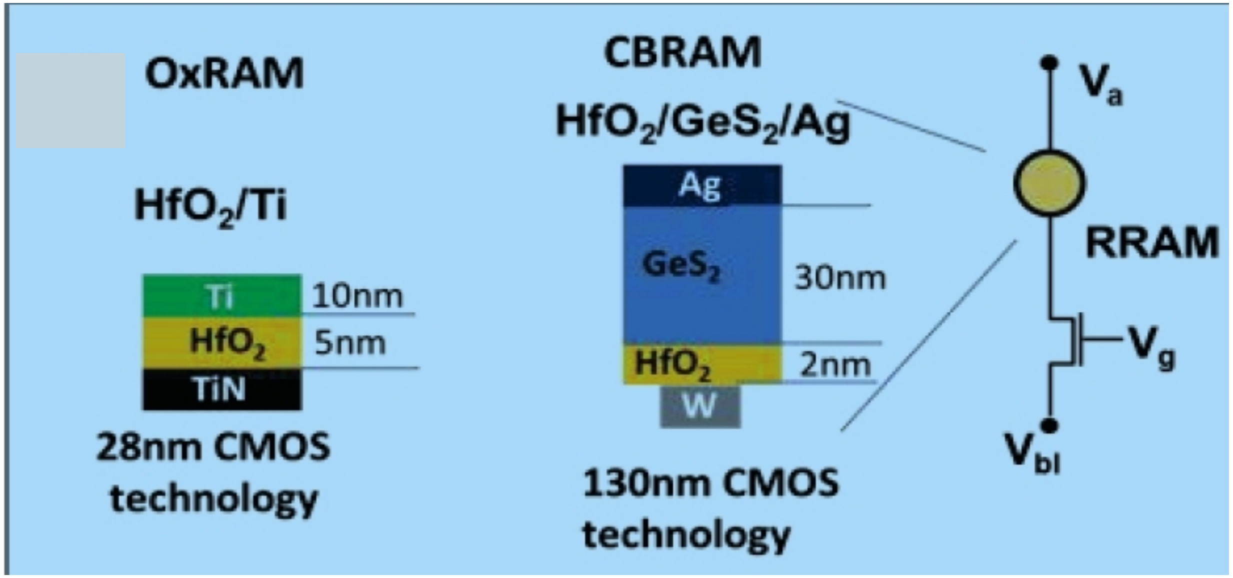


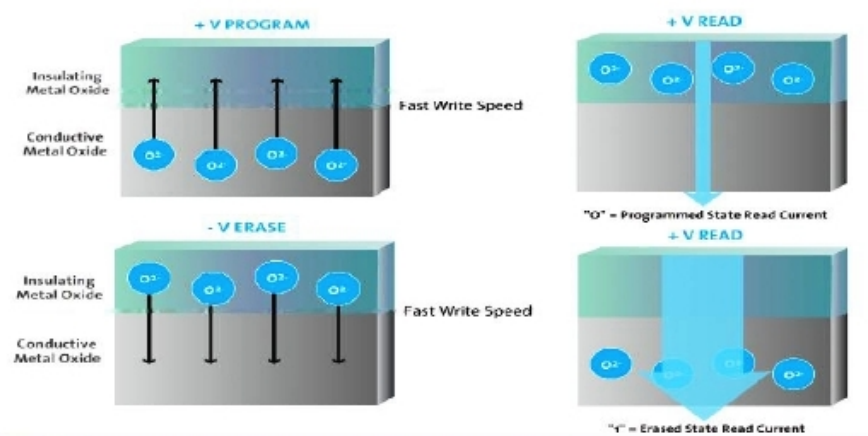


Several industry experts think that Micron/Intel's 3D XPoint Technology is a crossbar phase change memory

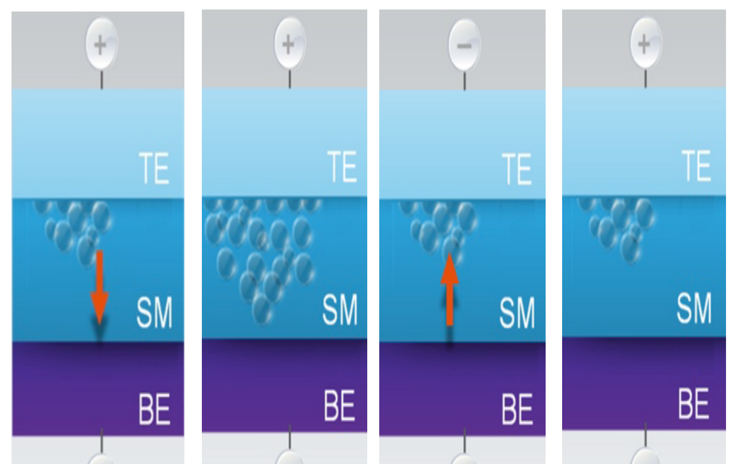
TYPES OF RRAM TECHNOLOGY

Sources/ Crossbar, Tezzaron Semi.





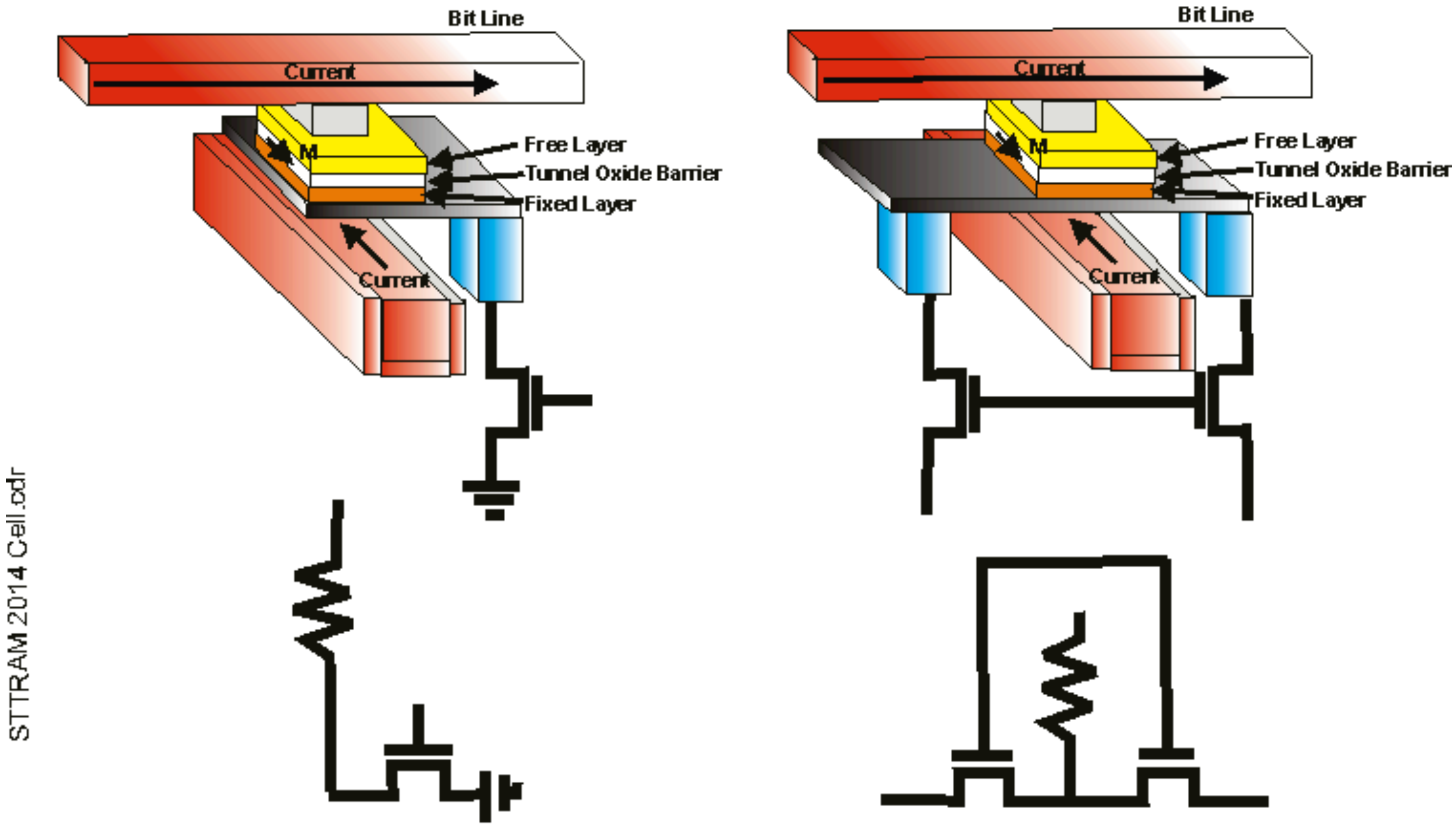
Oxide Conduction Via Oxygen Vacancies



Metal Filament Formation (CBRAM)

STT MRAM Replacing DRAM and SRAM

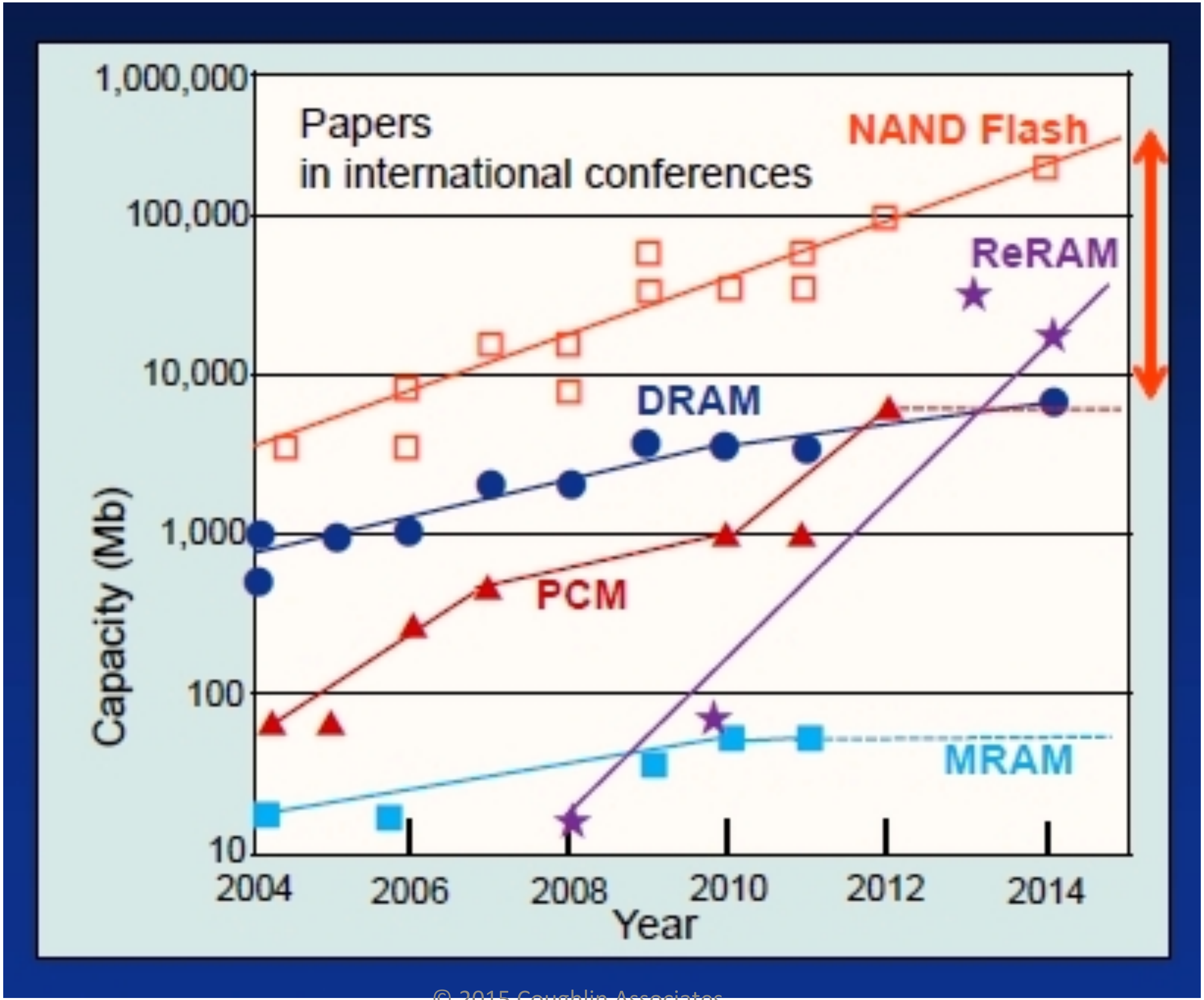
Over 50 M MRAM chips shipped by Everspin



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

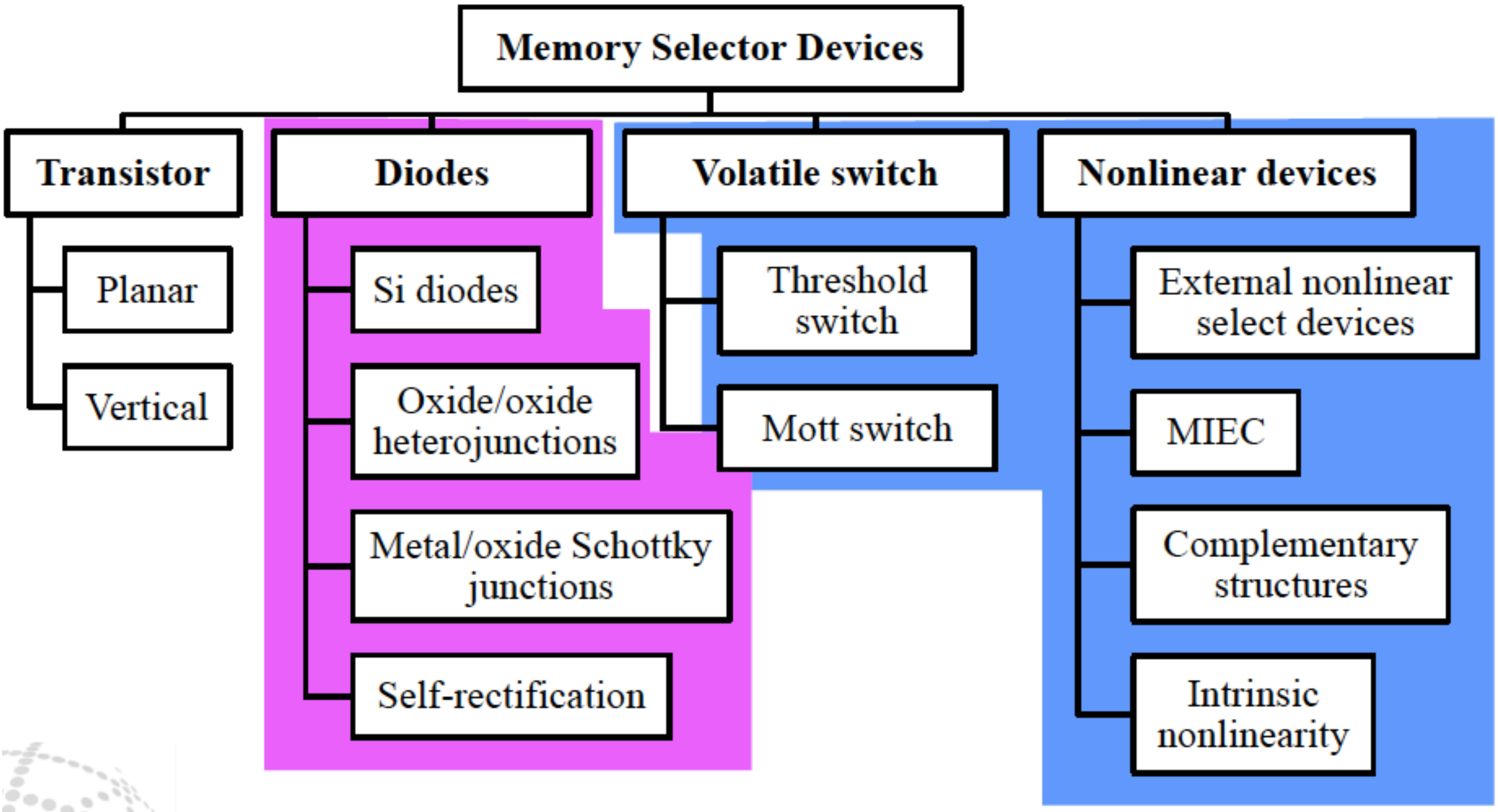
SRAM Replacement
(High Performance Memory)

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



Memory Selector Device Options

An Chen, 2014 AVS TFUG Seminar



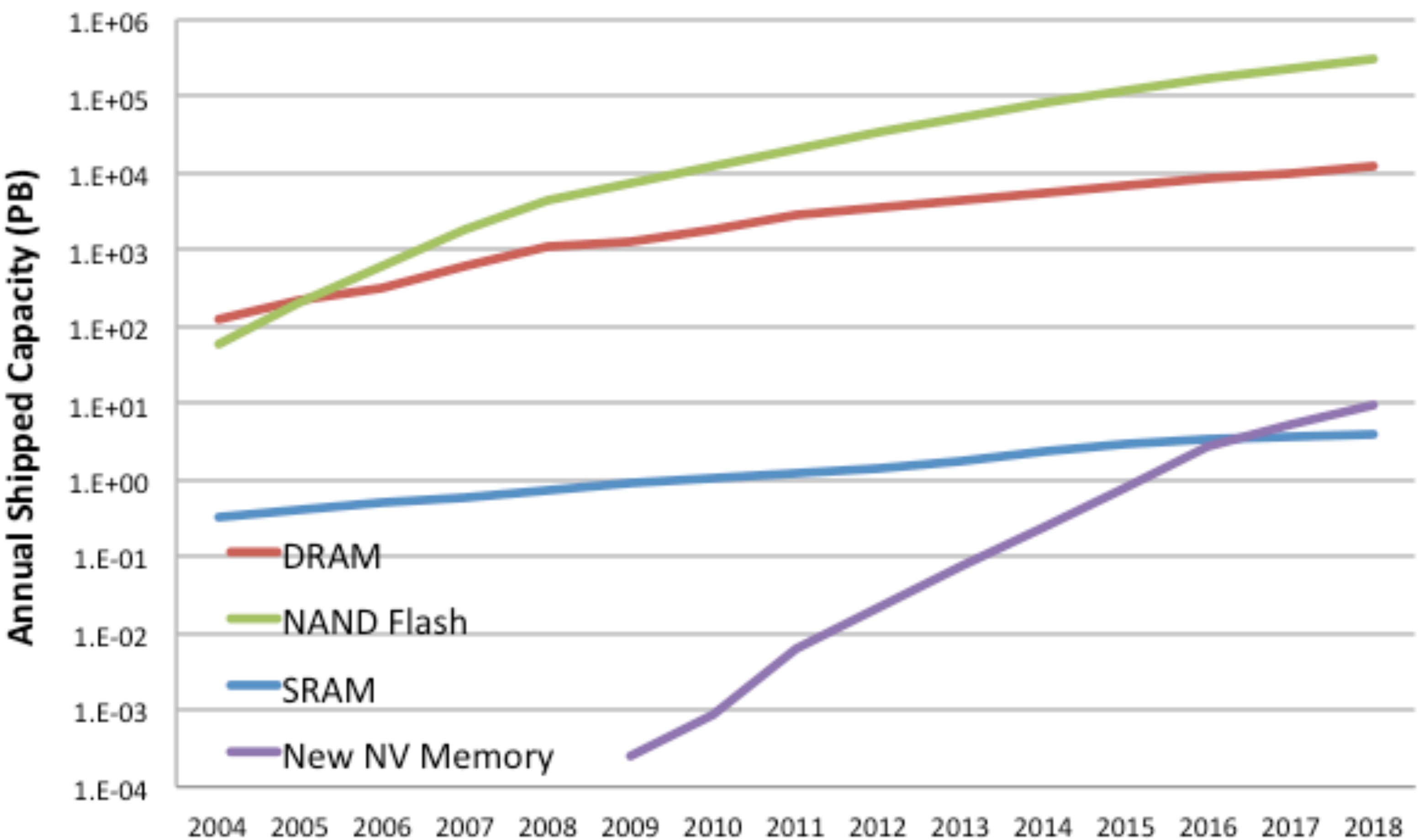
SUMMARY OF STORAGE AND MEMORY TECHNOLOGIES

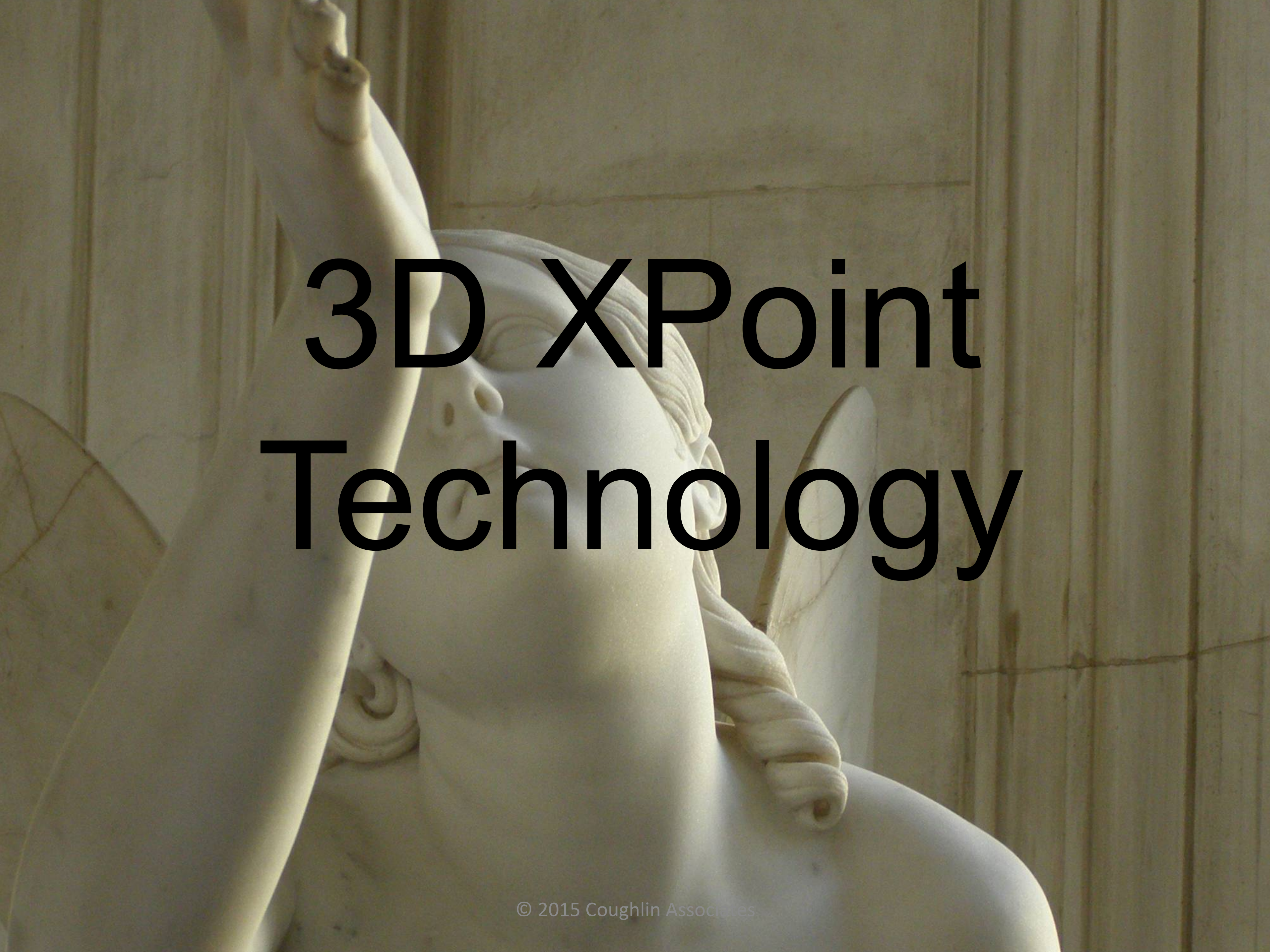
	HDD	Flash (SLC)	Flash MLC)	Fe-RAM	M-RAM	PC-RAM	Re-RAM	STT-RAM	Race Track	CNT
Cell Structure	none	1T/0C	1T/0C	1T/1R	1T/1R	1T/1R	1T/1R-0T/1R (e)	1T/1R	none	1T/1R
Cell Size (F^2)	0.5	4-5	4-5	16-32	16-32	5-8	4-6	4	1 (e)	5(e)
Read Time (ns)	2000	50	50	20-50	3-20	5-20	10-20	3-15	500	50(e)
Write Erase Time (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/in2	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	

Ed Grochowski 4

Annual Memory Capacity Shipments

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

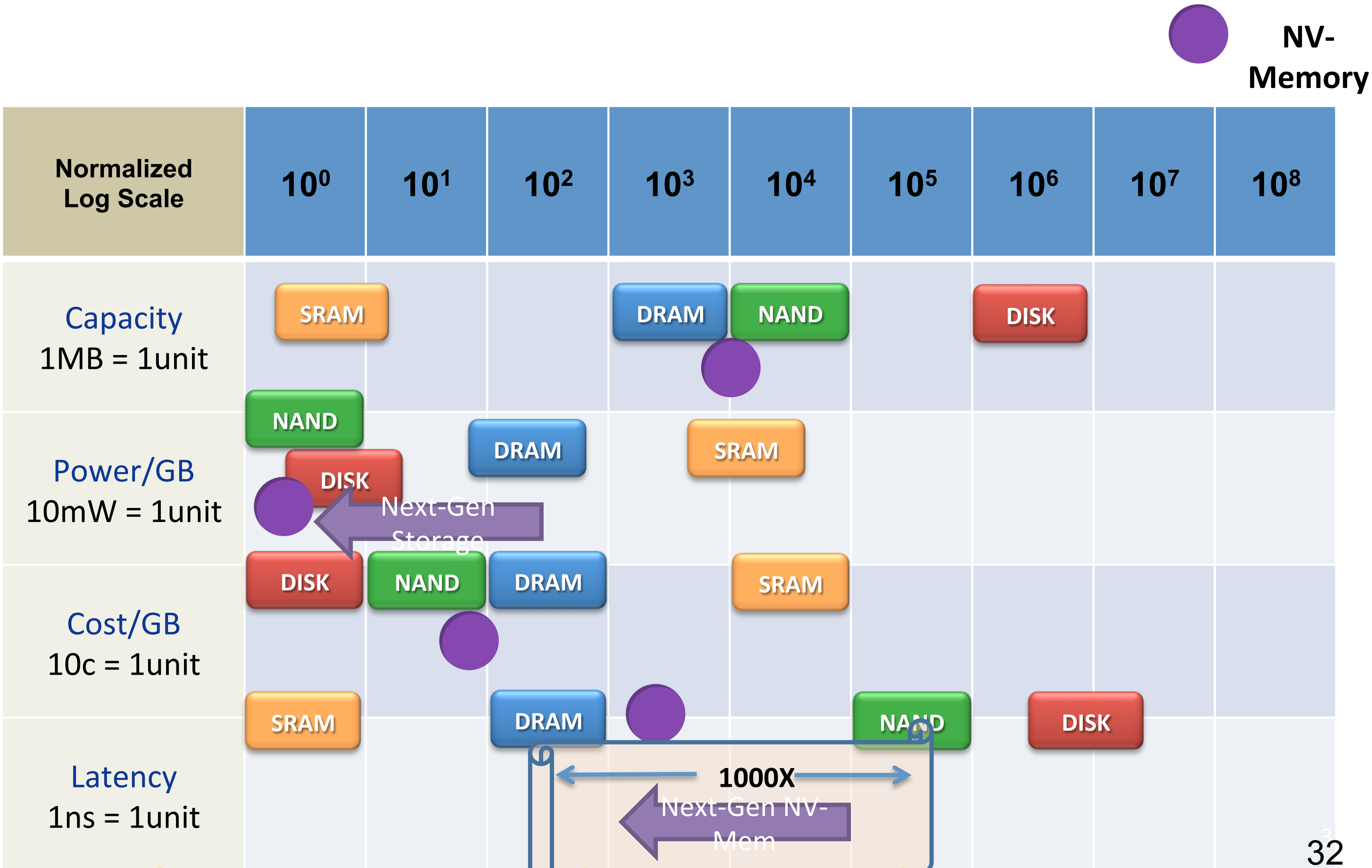




3D XPoint Technology

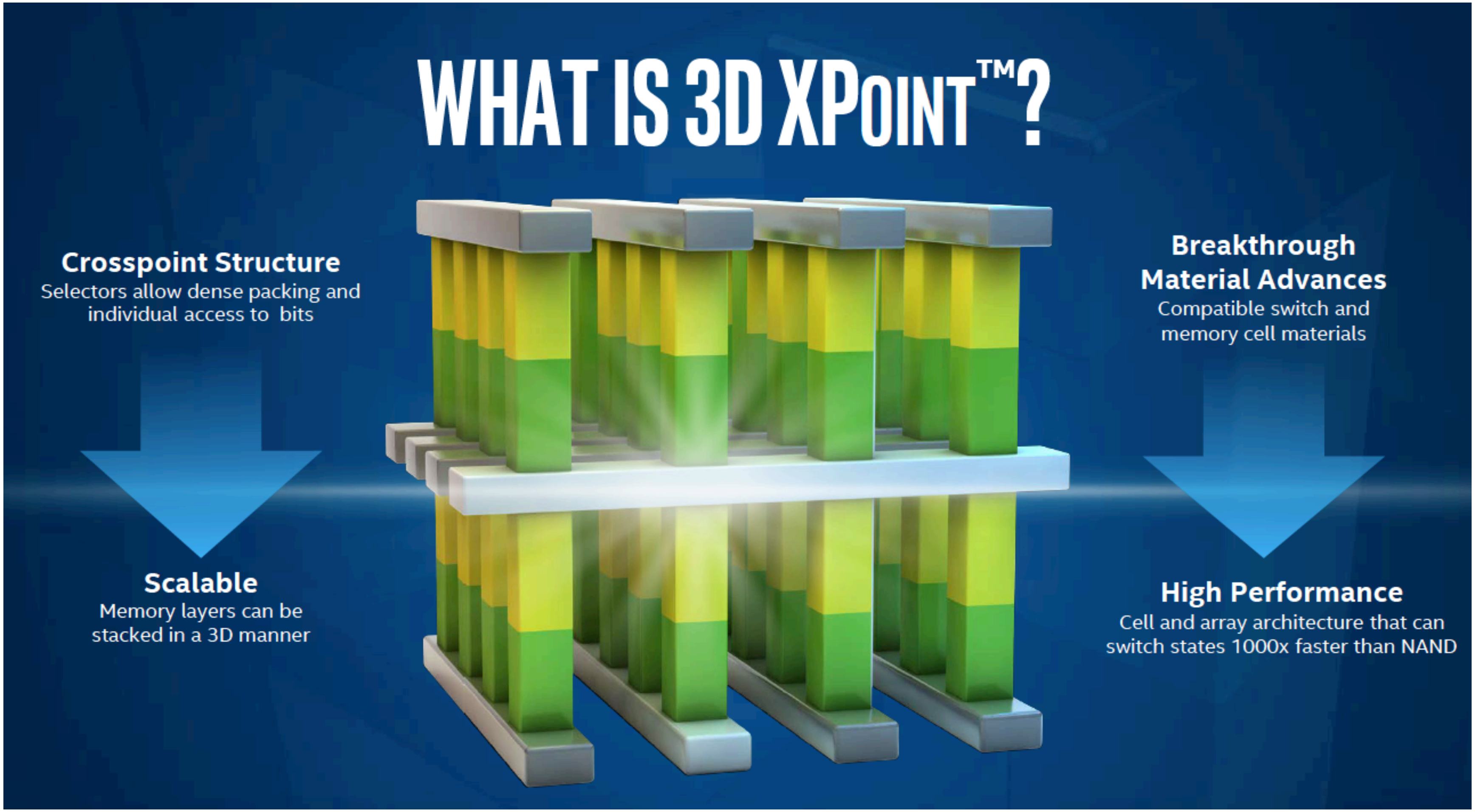
Comparison of Memory Technologies

Slide from 2015 Storage Visions Conference

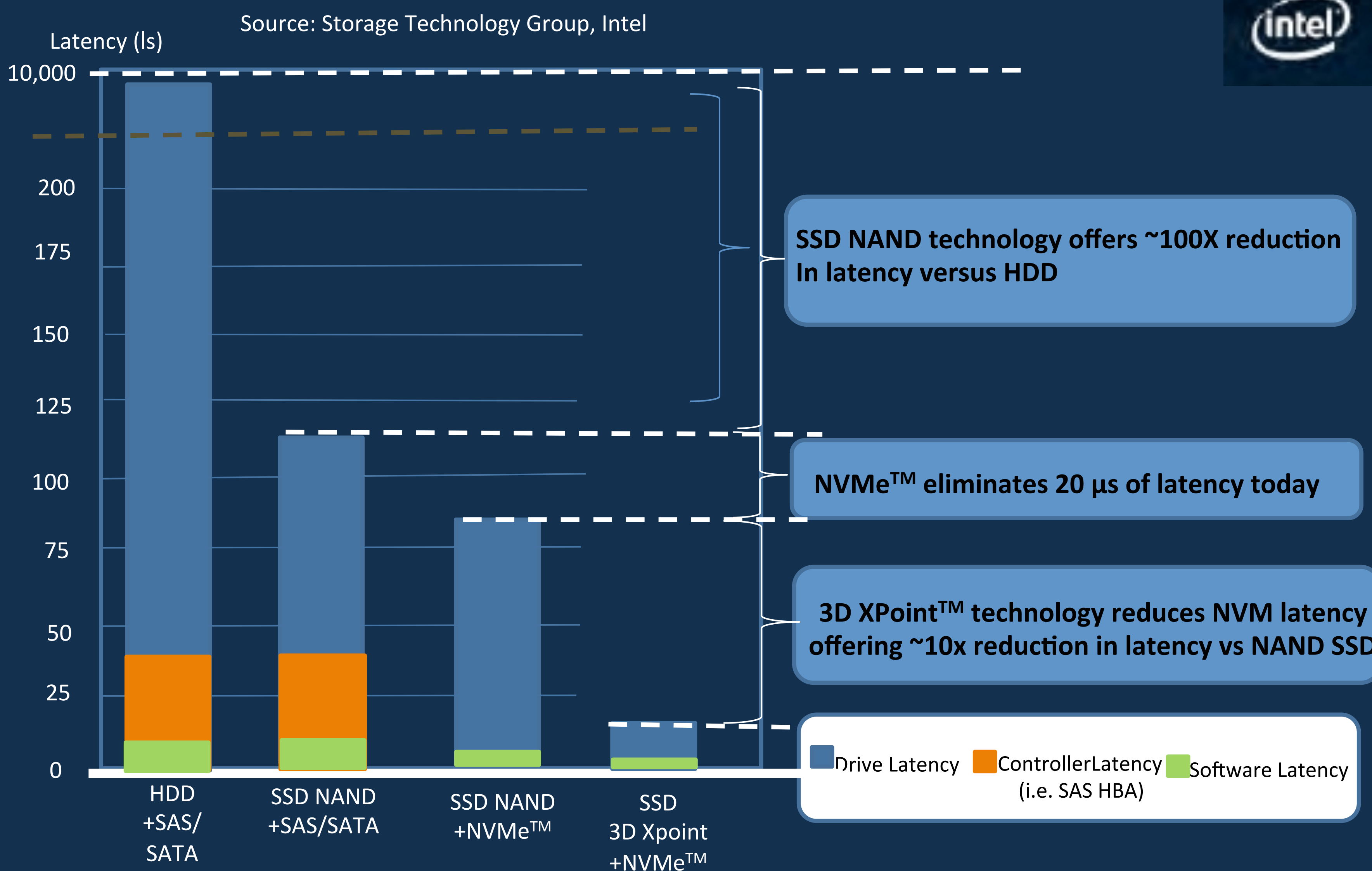


Next Gen Memory must fill the DRAM & Flash latency gap

3D XPoint Memory

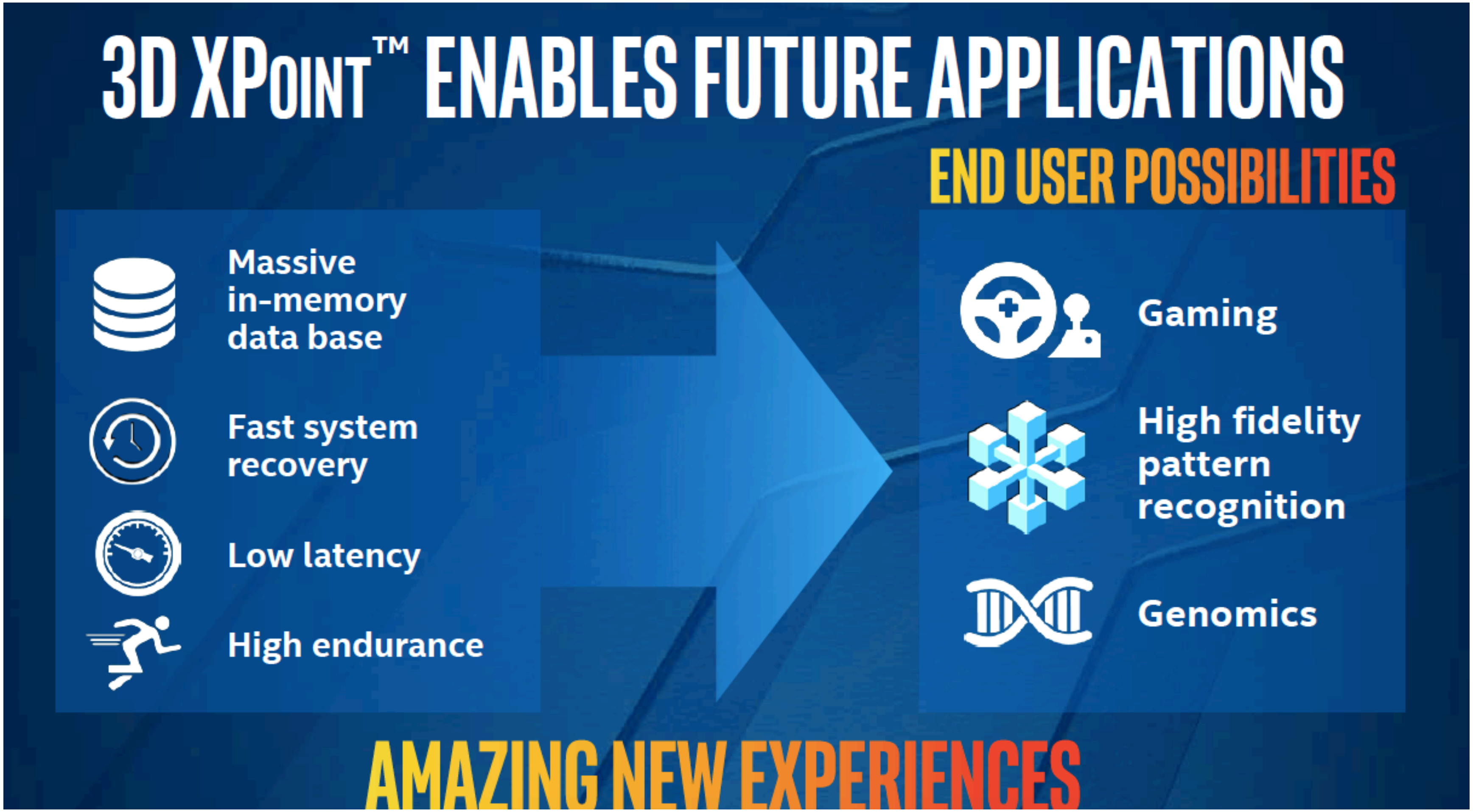


3D XPoint Comparisons to NAND



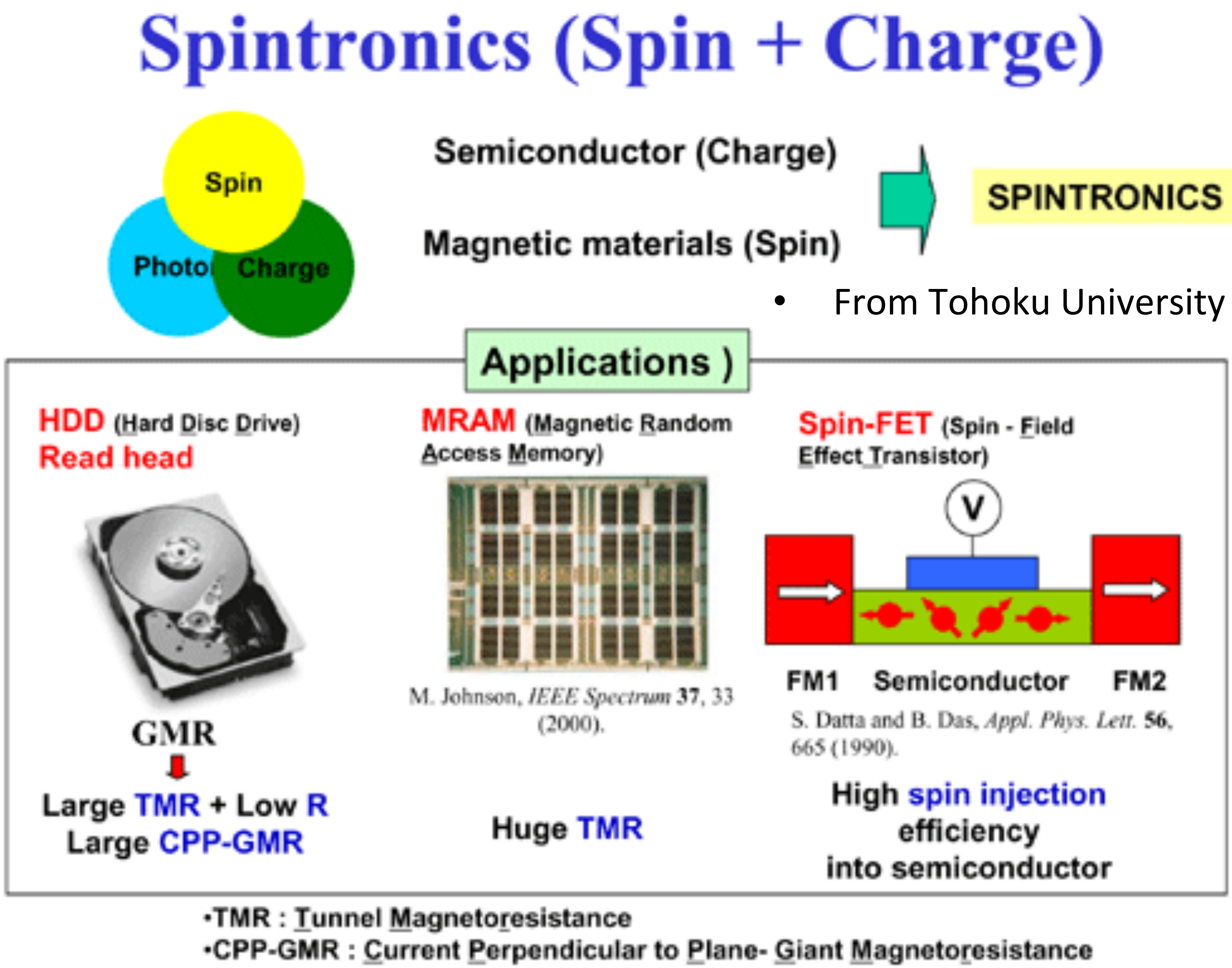
Technology claims are based on comparisons of latency, density and write cycling metrics amongst memory technologies recorded on published specifications of in market memory products against internal Intel specifications

3D Xpoint Memory



The Memory is the Computer

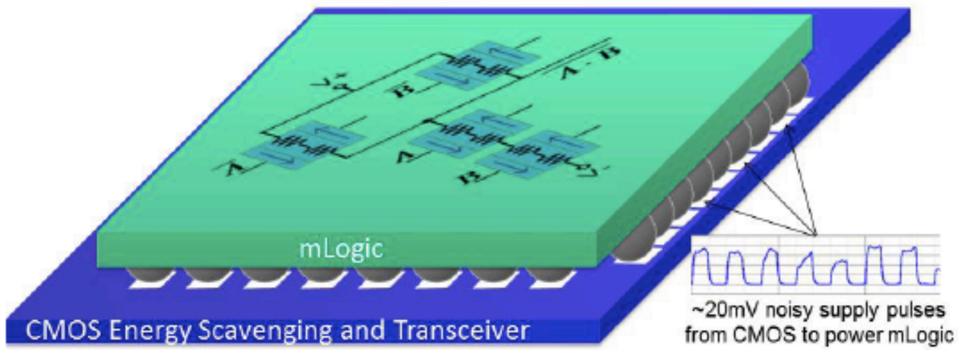
Spintronics



- From Tohoku University in Japan

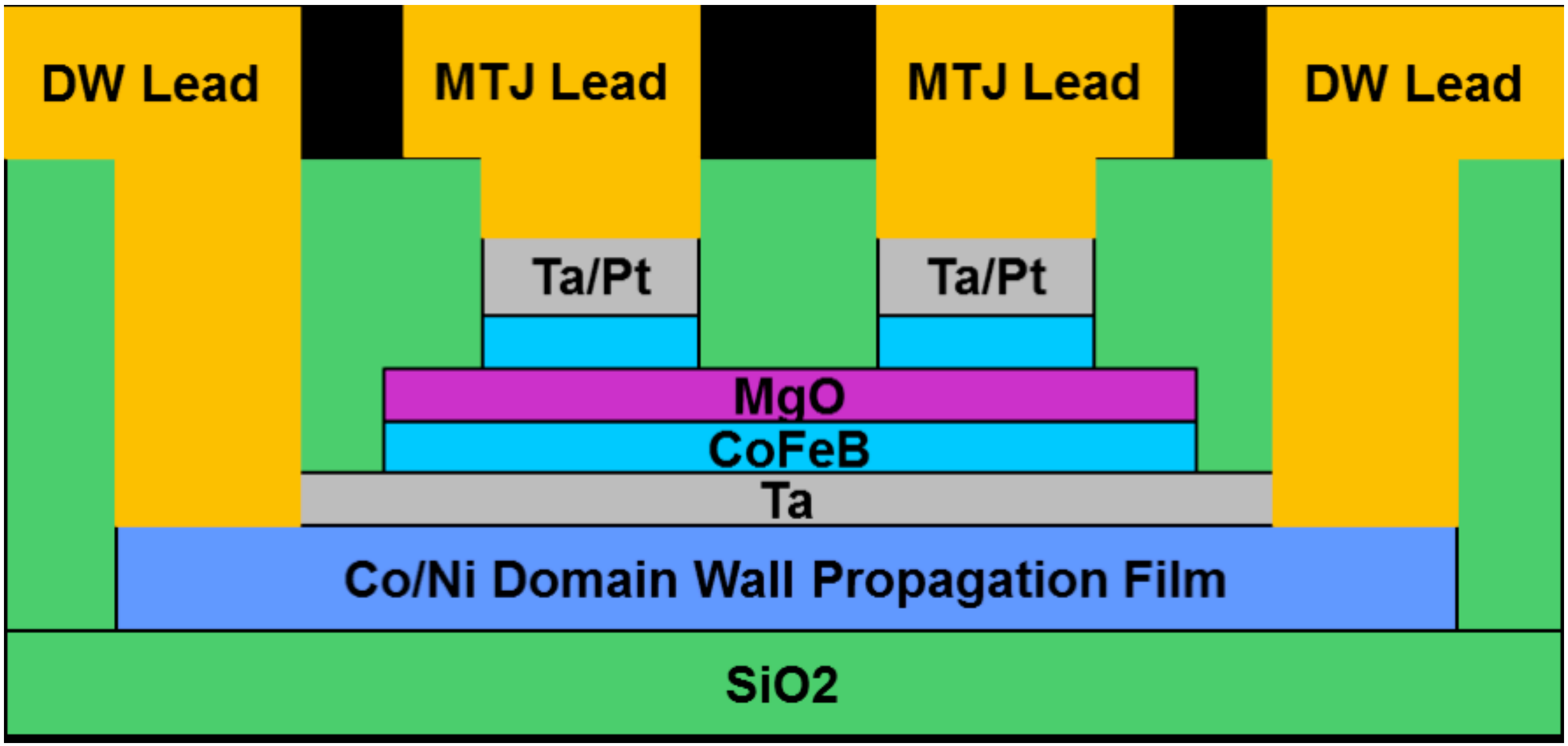
Spin-Based Computing

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

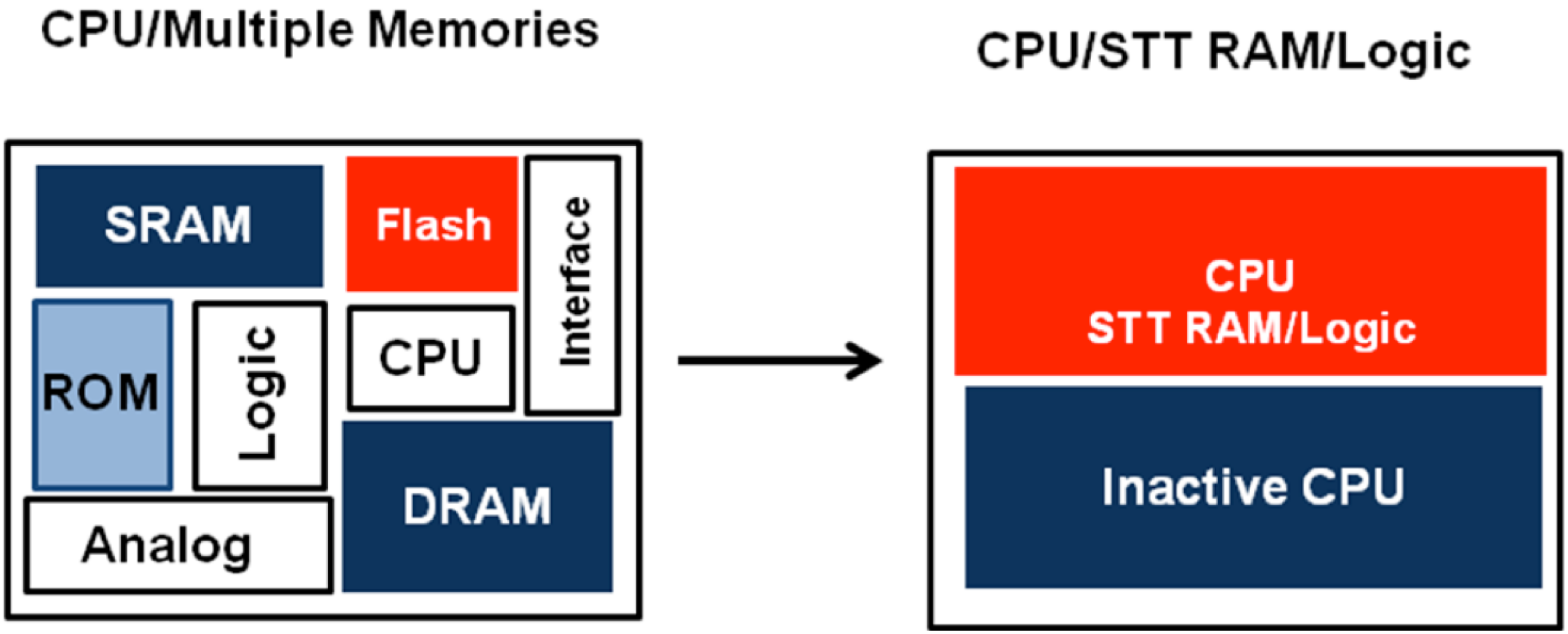


- ***All STT based metallic logic***
- ***Nonvolatile logic states***
- ***Ultra-low pulsed voltage***
- ***Portable & energy-harvesting***
- ***Rad-hard for space applications***
- ***Very low cost manufacturing***
- ***Scalable to 5nm CD***

mCell Spin Logic Unit
(J. Zhu, Carnegie Mellon Univ.)



STT Logic Application (Reducing Dark Silicon)



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


Thanks