



Flash Memory Summit

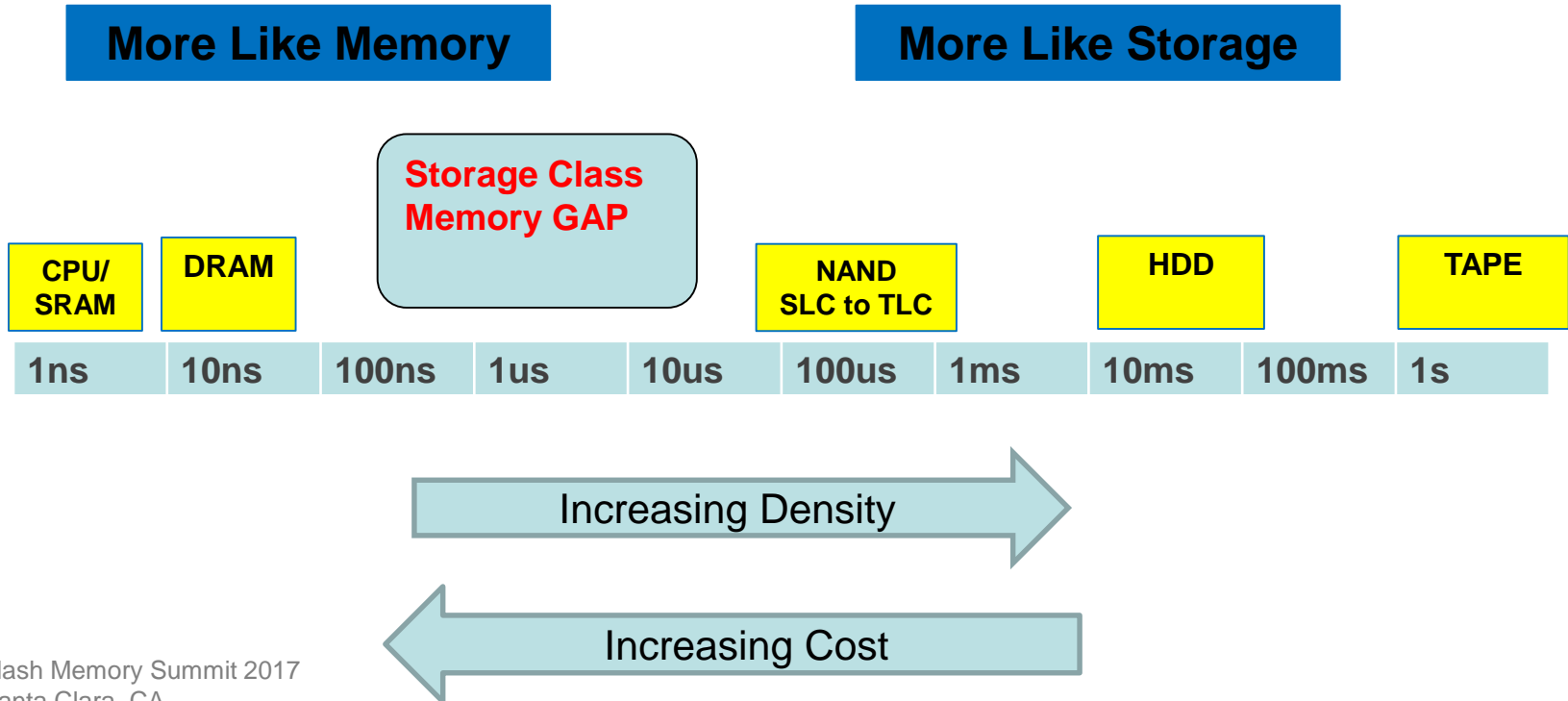
ReRAM Status and Forecast 2017

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The Latency Spectrum and Gaps





Storage Class Memory

- Storage Class Memory (SCM) is promising application for NVM
- Intel/Micron have announced 3D Xpoint as solution
 - Intel support for architecture, software, applications is providing the demand along with the memory
 - Intel is now shipping M.2 SSD cache modules for client
 - Intel is shipping high performance Datacenter SSDs
 - Other NVM options can benefit from this lead
- Potential Market for 3DXpoint/RRAM SCM is >\$1B in 2018. >\$2B in 2020



New NVM Technologies

	Latency	Density	Cost	HVM ready
DRAM	*****	***	***	*****
NAND	*	*****	*****	*****
MRAM	*****	*	*	***
3DXP	***	****	****	** 1/2
ReRAM	***	****	****	**
NRAM*	***	**	**	*

RRAM density, Cost, and latency numbers make it ideal to fill SCM gap



Summary of New NVM

- 3D Xpoint = Phase Change Memory
 - Long history. Use of Ovonic switch (per Techinsights) allows cross point array
 - Latency 2-5x slower than DRAM (Read... maybe more write)
 - Intel shipped >200k cache units so far and announced SSDs
- MRAM
 - Old technology. STT gaining traction and shipping for revenue (foundry)
 - Fastest NVM... close to DRAM. Max density today is 256Mbit.
 - No model on how to match DRAM/NAND densities of cost
- ReRAM (This Talk)
 - Opportunity for highest density and lowest cost
 - Performance is optimal for Storage class memory
 - 2016: Papers/announcements. 2017+: Real applications and products



What We Know About RRAM

- Lots of technology papers on storage and select elements
- Historic Revenue has come from embedded applications in Mbits
 - Unity (Rambus), Adesto, Panasonic, Weebit nano
 - These are interesting for physics but not applicable to SCM
 - Higher density needed
- 2017: Crossbar, Inc ReRAM is available today as embedded memory (1T1R) from Foundry. Standalone memory planned
- 2017: 4DS announced functionality on 1000+ cells, 40nm path, DRAM like speeds
 - Interface switching is different for historical filament based
- WDC continues to highlight ReRAM as the SCM of choice



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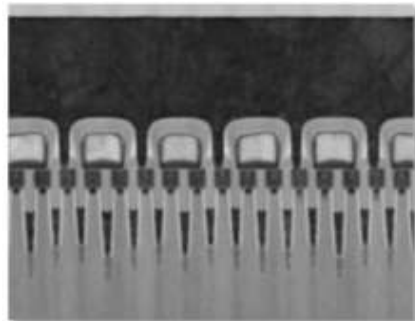
Model/Estimates for ReRAM

- More laterally scalable than NAND
- Crosspoint solutions are low cost ($4F^2$) and allow foundry utilization
- New selector elements allow for high density 1TnR
- Latency is far better than NAND, approaching DRAM
- Cycling past 1M Cycles is achievable
 - No high density SCM is on a path to infinite/DRAM cycling
- All of these are the requirements for SCM
- ReRAM is moving out of research and into real products
 - We now need to focus on roadmap and costs and applications



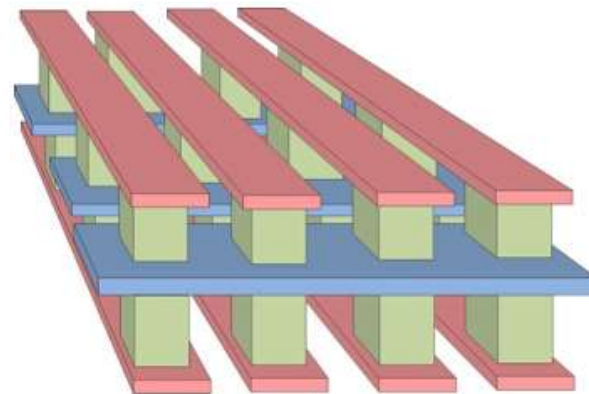
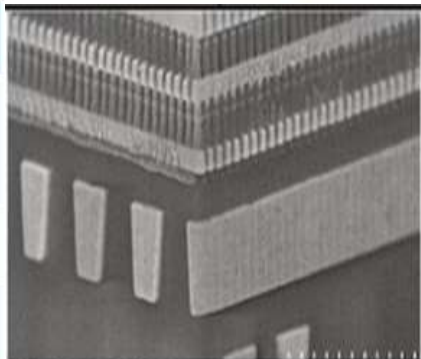
Previous Technologies Reviewed

Device	COST \$/GB
2017 DRAM COST	1X
27nm	1.1x
20nm	0.6x
14nm	0.4x



Advanced 27nm RRAM Cell

Device	COST \$/GB
2017 DRAM COST	1X
24nm	0.6x
14nm	0.3x



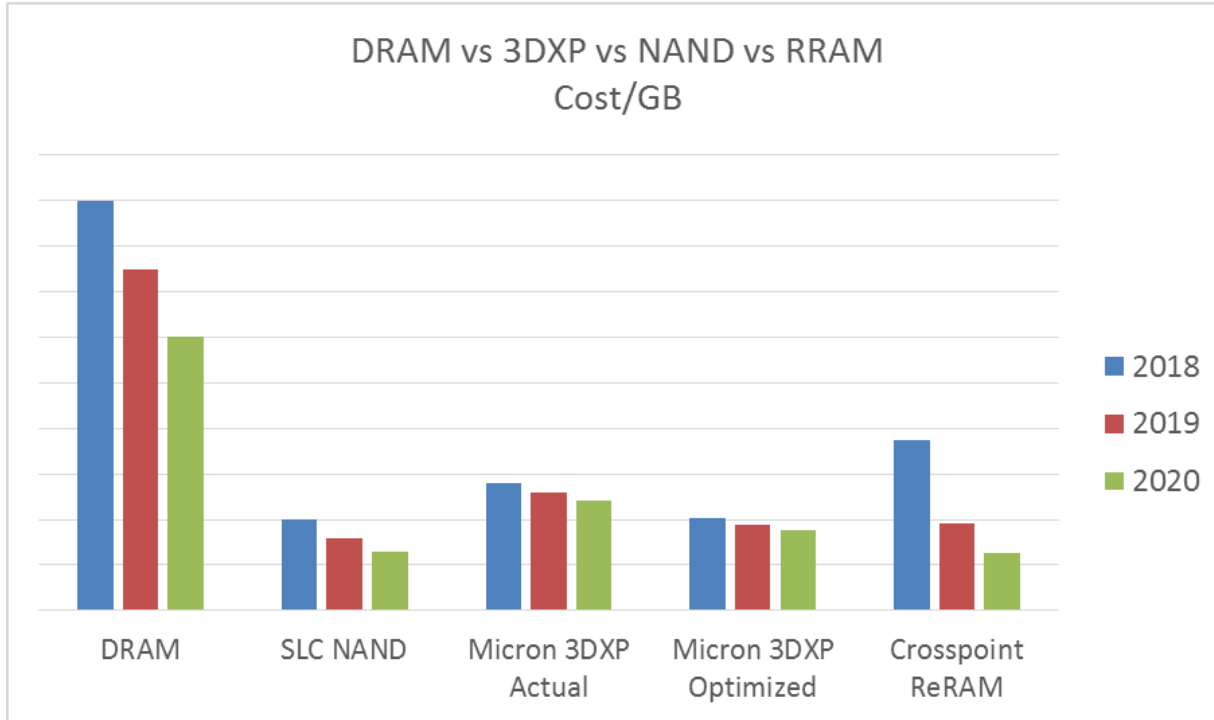
- Multiple ReRAM technologies reviewed
- **Stacked Crosspoint (~4F²) is optimum for next 5 years**
- Allows memory optimized or foundry
- 3D NAND like vertical later



Cost vs Performance

- ReRAM can compete with multiple technologies in SCM space
- SLC NAND for Storage
- DRAM on high speed applications
- 3D Xpoint as most visible SCM today
 - SSDs, Cache memory
 - 3D Xpoint actual and optimized
- Compare to 2L Crosspoint, SLC RRAM array in 100Gbit-400Gbit range. Process from 28nm to 14nm

Cost for Multi-Gbit Technologies





Cost Takeaway

- Multiple technologies are cheaper and more dense than DRAM
- 2 Layer Crosspoint ReRAM scales cost quickly from 28nm to 14nm (and beyond).
 - Modeled to be lower cost than SLC NAND and 3D Xpoint in 2020
 - 5x cost improvement over DRAM enables multiple applications/SCM use
- MLC/more layers/10nm-7nm allows even greater cost benefit
- Vertical cells (Like 3D NAND) lower cost even more but requires stable mature technology and dedicated memory processing



Summary

- SCM is moving from a concept to high revenue market
 - 3D Xpoint will create and grow this market demand
 - ReRAM is a leading candidate to meet SCM requirements
- 2017s ReRam Showed significant progress
 - ReRam availability at foundry today
 - Performance in cycling and speed is meeting goals
 - Geometry scaling to new nodes (28/14nm.... 10/7 possible)
- Model shows a Crosspoint ReRAM technology Cost
 - Better than SLC NAND cost at 14nm
 - Equivalent or better than 3D Xpoint at 20-14nm