Markets for 3D-Xpoint 2019
Applications, Performance, Volume and Revenue

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Memory Technologies Compared

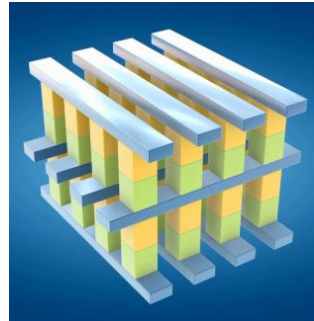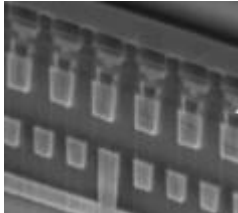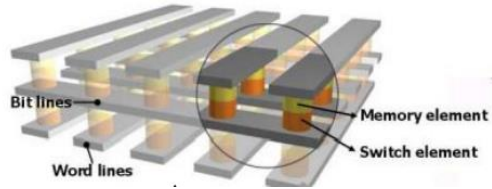|	Latency	Density	Cost	HVM ready
DRAM	*****	***	***	*****
NAND	*	*****	*****	*****
MRAM	*****	*	*	***
3DXP	***	****	****	****
ReRAM	***	****	****	**
Other	***	**	**	*

What is 3D Xpoint

- Micron/Intel Technology announced in July 2015
  - Disclaimer: Intel doesn't have 3D Xpoint anymore. It is "Intel®Optane^{TM} Memory Media"
- Thanks to great analysis last 2 years, we know
  - PCM technology , 20nm lithography
  - Cross point array, Selector in stack
  - We have cross sections and details
  - 10+ years in the making, multiple publications by Intel, Micron, Numonyx, IP providers, etc

Simple Architecture Overview

Current and Emerging Memory Technology Landscape
Atwood FMS 2011
Note: 8 Years ago.
Papers in 2001, 2005, 2009

Source: Intel

Speculated details on Technology based on:
- Memory and SSD modules sold
- EE-Times/Techinsights
- The register/Ron Neale/Chris Mellor Feb 1 2016
- ISS 2016 (Jan 12)
- Dave Eggleston FMS2015
- Plus multiple FMS presentations from Techinsights

Technology Update 2019

- Products
  - Fastest SSD, with best SSD endurance, selling millions of units
  - DIMMs are quite delayed with multiple launches but <u>are selling today</u>.
  - More Optane/3D Xpoint bits sold than all other emerging memories combined in 2019
- Technology
  - Technology shipping today is based on Gen 1
  - Endurance increased significantly over past 2 years
  - Intel/Micron Plan Gen 2 for release in 2020. <u>Estimate</u> is 4 stacks, similar lithography, SLC, 35% lower bit cost. Nominally 256Gbit
  - Expect Gen 2 measurable volume in late 2020

Intel-Micron 3d Xpoint Differences

- Intel has both need and capability to lead on Xpoint
  - Intel needs to push new compute technologies and differentiation
  - Intel can optimize processors/architecture to take advantage of memory/storage capability and limitations
  - Even with this advantage, it has been a slow ramp of DIMMs
- Micron has the technology but will not ramp Gen 1
  - Micron has different goals for memory based on DRAM revenue
  - No measurable revenue today.
  - Plan is to wait for Gen 2, Sample, develop their own markets.
- The end of manufacturing/development partnership means that marketing, IP, and manufacturing rights need to be finalized

3D Xpoint Applications Today

- Fastest NVMe SSDs available on benchmarks [probably]
- Optane™ Memory for PCs
  - It's a cache for HDDs and speeds storage. Millions units sold
  - Intel announced QLC NAND/Optane combination in one M.2
    - Cost effective performance vs TLC SSDs
- Intel Optane DC Persistent Memory (DIMMS)
  - Finally shipping. Supported on most Cascade lake SKUs
  - Memory Mode: Large main memory, cached in DRAM, not persistent
  - App direct mode: True Persistent Memory!!
  - Also can act like SSD on DRAM bus … block modes, file modes, etc

3D Xpoint Technology Numbers

- A model for what 3D Xpoint…
  - 128Gbit Chip with >10% overprovisioning on the chip itself
    - DIMMS are overprovisions by about 25% and have DRAM onboard
  - Read Latency (Chip): ~125ns, Write Latency: "higher"
    - DIMM is spec'd 350ns read, estimated at 650ns+ Write
  - Chip Endurance: ~200K+ cycles spec with management techniques
    - DIMMS do not have endurance limitations in actual use
  - Great persistent memory, but not replacing NAND or DRAM

Optane Persistent Memory (DIMM)

- Model: Optane persistent memory won't replace DRAM, It supplements it.
- Server configurations with Optane DIMMS have above average DRAM capacity installed as well. Intel recommends Xpoint:DRAM ratio of ~5:1
- Memory controller manages endurance and performance by moving data between Xpoint and DRAM.
- If >90% of reads and writes are to DRAM, occasional R/W to slower Xpoint is not impactful
- CPU/memory controller is optimized to work with this configuration
- DRAM+NVM Solution is the OPTIMAL persistent memory solution

3D Xpoint Competition

- Other presentations cover all NVM and detailed comparisons.
- Competing PCM technologies: All companies have worked on PCM, Many showed information at recent conferences.
  - We expect Crosspoint PCM announcements from multiple companies
- MRAM: Great for speed but cannot compete on cost or density
- ReRAM: Crosspoint ReRAM technologies are most direct comparison to 3D Xpoint.
  - Cell Size, Cost, Speed, Cycling, applications are potentially similar
  - Solutions have been announced, production volume is next step
- Fast NAND: Fast NAND+DRAM solutions from NAND/NVDIMM companies will compete in both DIMM and SSD formats.

3D Xpoint Capacity/Manufacturing

- 3D Xpoint is manufactured only in IMFT facility in Lehi, Utah
    - Was a JV with Intel, Micron has executed its option to take 100% ownership around October 2019
    - Micron is <u>required</u> to provide capacity to Intel for another year and <u>may</u> provide capacity long after.
- Intel has moved 3D Xpoint (Intel Optane Memory Media) development to Rio Rancho, NM facility. 2nd Gen+ development will continue there.
- Without additional tools, We estimate IMFT can support Intel volume and Micron initial shipments. Factory could ramp 2-3x from these levels if needed

	Output Q4 2019	Output Q4 2020
Gen 1	45M GB/Month	45M GB/Month
Gen 2	5M GB/Month	25M GB/Month

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Cost and Price for 3D Xpoint DIMMS

- Key 3D Xpoint feature is lower cost than DRAM. This enables MORE total memory

Estimate as to DIMM cost and price

	Cost (Aug 2019)	Cost (Aug 2020)	Price
Xpoint Gen 1	0.8x DRAM	0.5x DRAM	1x/.5x DRAM (List/ASP)

- 3D Xpoint Gen 2: 35% lower cost than Gen 1, Cost crossover Q4 2020

Cost is with Factory running at forecast utilization numbers

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3D Xpoint Revenue

NEW!	2018	2019	2020	2022	2024
3DXP (Non-DIMM)	<$650M	550M	$650M	$750M	$800M
3DXP (DIMM)	<$100M	350M	$700M	$1.9B	$2.8B
3DXP (Total)	<$750M	900M	$1.35B	$2.65B	$3.6B

This is for Micron and Intel. Micron is minimal impact until 2022+. Significant Micron ramp would be upside
Non-DIMM Data based on projections for Optane SSDs and memory sales
DIMM data based on assumptions for Cascade lake share, server DIMM attach rate, average Optane density
DRAM prices has potentially large effect on demand for Optane DIMMS

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Summary

- 3D Xpoint has been a slow ramp BUT it has surpassed all other new memories in shipments

- Due to limitations and speed it is not replacing DRAM and due to cost it will not directly replace NAND

- Optane Persistent Memory is a CPU managed combination of DRAM DIMMs and Xpoint DIMMS
  - DIMMS are shipping today, large scale persistent memory is here

- 3D Xpoint revenue projection was lowered due to SSD pricing and DIMM delays. Still on track for multi-Billion dollar Market

Backup

The Latency Spectrum and Gaps ~2015

More Like Memory

More Like Storage

The GAP (PM/SCM)

| CPU/ SRAM | DRAM | | NAND SLC to TLC | HDD | TAPE |

| 1ns | 10ns | 100ns | 1us | 10us | 100us | 1ms | 10ms | 100ms | 1s |

Increasing Density

Increasing Cost

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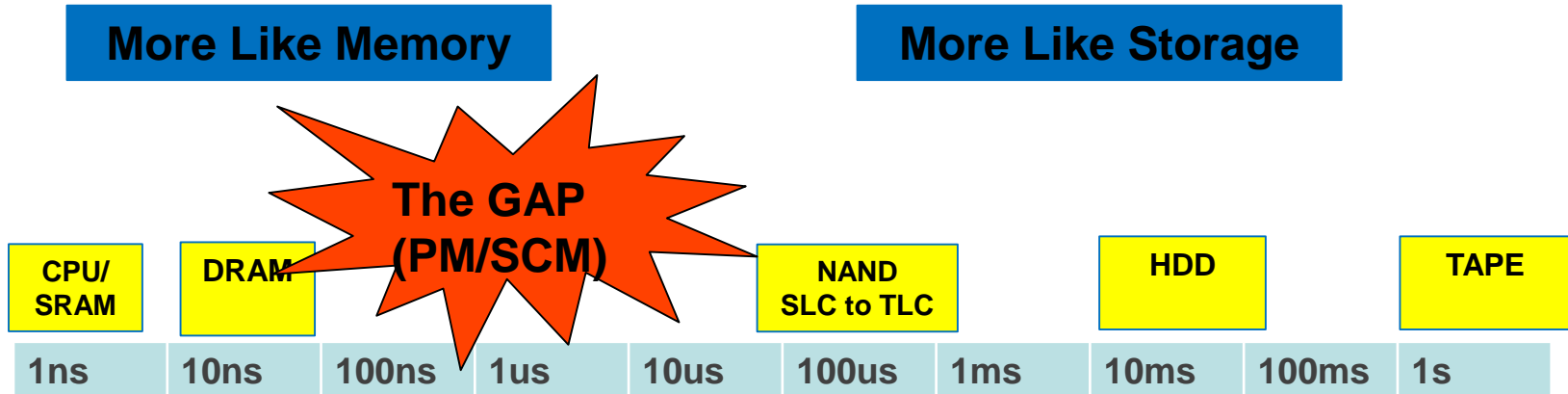
The Latency Spectrum and Gaps
Future

More Like Memory

More Like Storage

| | | MRAM | NAND+DRAM DIMMS | Fast NAND SSDs | NAND QLC SSD | | | |
| CPU/ SRAM | DRAM | | XP DIMMs /ReRAM | 3D XP SSD | NAND MLC to TLC | | HDD | | TAPE |

| 1ns | 10ns | 100ns | 1us | 10us | 100us | 1ms | 10ms | 100ms | 1s |

Increasing Density →

← **Increasing Cost**

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