Flash Memory Summit

3D Xpoint Status and Forecast 2017

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Memory Technologies

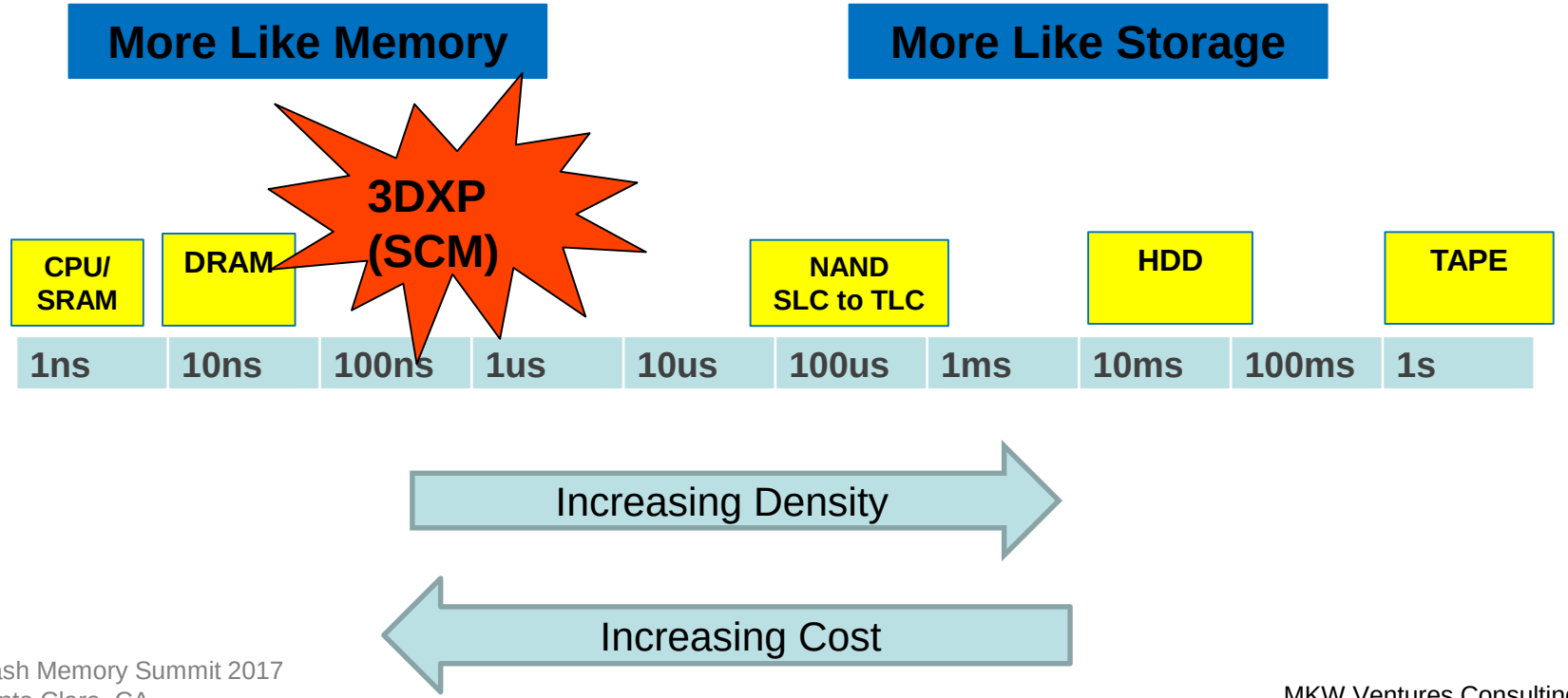
	Latency	Density	Cost	HVM ready
DRAM	*****	***	***	*****
NAND	*	*****	*****	*****
MRAM	*****	*	*	***
3DXP	***	****	****	**1/2
ReRAM	***	****	****	**

3D Xpoint is perfect SCM once it reaches maturity

What we know about 3DXP

- Announced in July 2015
  - 128Gb device… ~205mm^2
  - “1000x faster than NAND, 10x denser than DRAM, 1000x better endurance than NAND”
- After some delay, products emerged in 2017
  - Intel announced Cache SSDs for Client and Enterprise SSDs. 200K units of cache shipped
  - Speeds for actual demonstrations is better than NAND but not at 1000x expectation.
  - “Media speed and the module speed differ”
- DIMMs were delayed to 2018 (fastest application)

The Latency Spectrum and Gaps



Why is 3DXP so great?

- Intel (and Micron) delivered real products with performance
- 128Gb is big deal. High density is needed for SCM
- Crosspoint means it is competitive in cost and scalable ($4F^2$)
- SCM requires backing of architecture. Intel is all in.
- SCM Applications are huge: Fastest SSD, HDD cache, IMDB at lower cost
- No confidence in any of these before 3D Xpoint

Applications

- Optane Cache memory
  - Cache for HDD to provide SSD like speed and HDD like capacity at lower cost than SSD. Caching a HDD in not new.
  - Modules are selling and widely available
  - CES announcements of Notebook implementation have not materialized yet
- Intel P4800x Enterprise SSD is arguably the fastest SSD in the world. Its expensive but worth it for some applications
- DIMMs are potential huge market with performance not limited by PCIe. 2018 shipments

Challenges

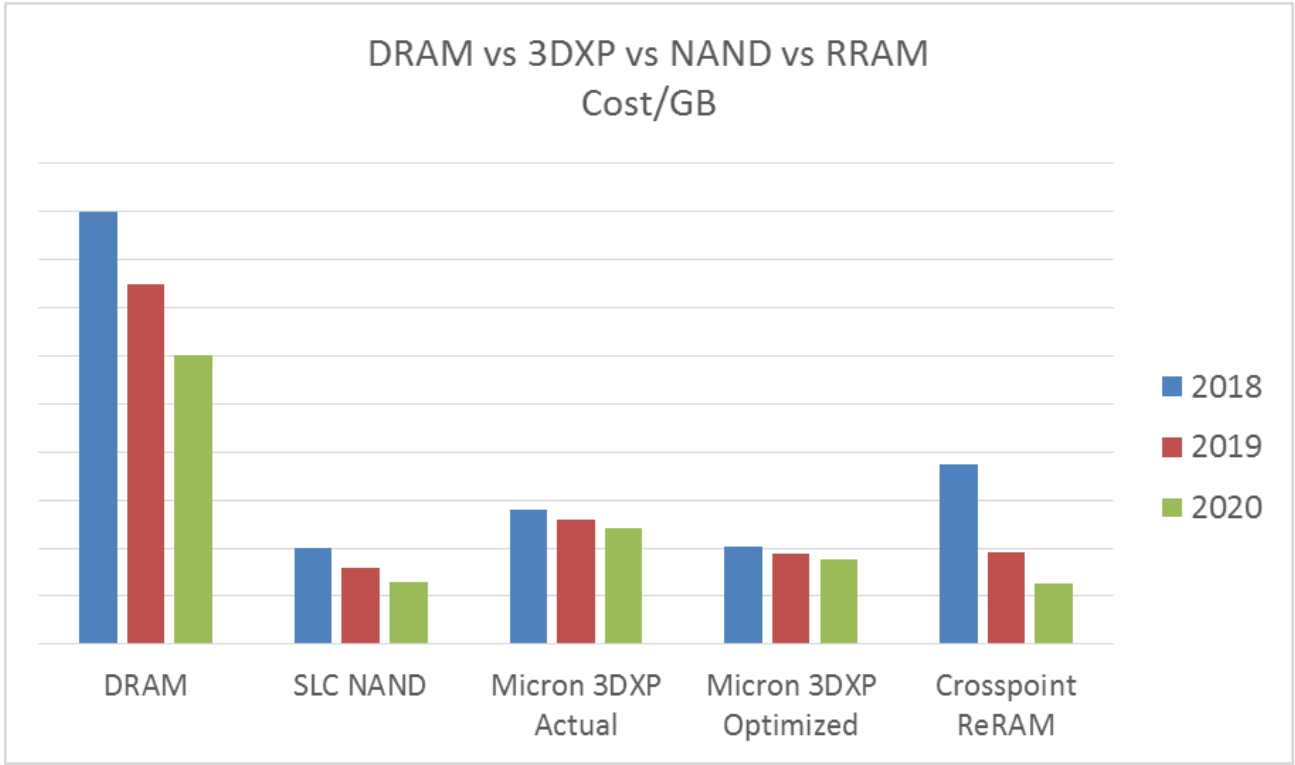
- New markets are ALWAYS slow to grow
  - SCM will grow … more slowly than hoped
- Speed is great, but not 1000x great
- Multiple companies are offering “Fast NAND” (Like Z-NAND).
  - Not random access but simple and inexpensive for Cache and Fast SSD application.
- Not clear that endurance allows DRAM replacement.
- Competitors have PCM memory and perhaps Ovonic selector
- ReRAM continues to make progress with similar cost structure

Teardown Analysis

- Cache product is shipping, 4800x is shipping
- Array efficiency is great at 90%.
- Array size says we have 35-50% overprovisioning.
  - Is it is needed for speed?
  - Is it is needed for ECC bits? redundancy/fails?
  - Is it just extra and the next chip will be 30% lower cost?
- Sometimes when people say it's not PCM, it's PCM
- Based on estimates, the mature cost at would be 2x cost of SLC NAND, <40% cost of DRAM.

Cost for Multi-Gbit Technologies

(From ReRam FMS Session)



Revenue Forecast/Guesstimate

- Sales of 3DXP off to slow start

Revenue Guesstimate

OLD!	2016	2017	2018	2019
3DXP (FMS2016)	<10M	300M	1B	1.5B
SCM Other (FMS2016)	<10M	50M	200M	500M

NEW!	2016	2017	2018	2019
3DXP (FMS2017)	<10M	<200M	500M	1.0B
SCM Other (FMS2017)	<10M	50M	150M	500M

Ask Intel for actual revenue forecasts at earnings Call

Summary

- 3DXP is a great achievement in NVM
- Classic SCM and applications
  - Faster than NAND, Slower than DRAM
  - SSDs and Cache today, DIMMS in 2018
  - Cost will always be between NAND and DRAM
    - Currently 2x the cost of SLC NAND, <40% cost of DRAM
- It will ramp slower than every hopes
  - <$200M in revenue in 2017
- It enables SCM competition in next two years

- BACKUP

500x faster is actually 2x Faster

Hypothetical NAND SSD vs HDD Example

	SATA HDD	NAND SATA SSD	SSD Improvement	Notes
Bit Latency	50ms	100us	500x	Raw speed
Random IOPS	500	50000	100x	Accessing individual bytes
Seq Reads	70 MB/S	500MB/s	7x	Copy/backup
Boot time	30s	15s	2x	load time
Excel Macro	10s	10s	1x	Running in memory. No effect

Lots of details on why… and, yes, DIMMS change this in servers