Annual Update on Emerging Memories 2020

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Topics

- Why New Memories
- Historical and Recent Technologies compared
- Memory Product Lifecycle
- PCM/Optane/3D Xpoint, MRAM, ReRAM, FE RAM
- Emerged Technologies

Memory Technologies Reviewed

whats new?

	Latency	Density	Cost	HVM ready
DRAM	*****	***	***	*****
NAND	*	*****	*****	*****
MRAM	*****	*	*	****
3DXP	***	****	****	*****
ReRAM	***	***	***	**
NRAM	***	***	***	*
FE RAM	***	**	***	*
Other	***	**	**	*

Why New Memories? NAND Scaling

- NAND flash has line of sight to 256L+ and QLC.
- This takes us to 2025 timeframe with a ~75% bit cost reduction
- We can do a >1Tbit Chip today, 2TB in a package
  - Sweet spot is 256-512Gb so density is not issue
- String stacking, CMOS under array allows a lot of circuit options
- NAND is not done anytime soon. And no one is even close on costs
- NAND is still 4-5x more expensive than HDD but improving over time
- NAND is the high density, low cost solution for all compute

Why New Memory: DRAM Scaling

- DRAM scaling has slowed down but is still steady
- Companies implementing EUV/ Pitch multiplication to get to 10nm
- New architectures could work… if needed. No major change yet
- DDR5 on track to lead bus speed improvements
- DRAM has line of sight through 2026 for scaling
- 10% cost reduction and ~25% density improvement each year
- DRAM is still the go to for Fast, Volatile, Random access memory

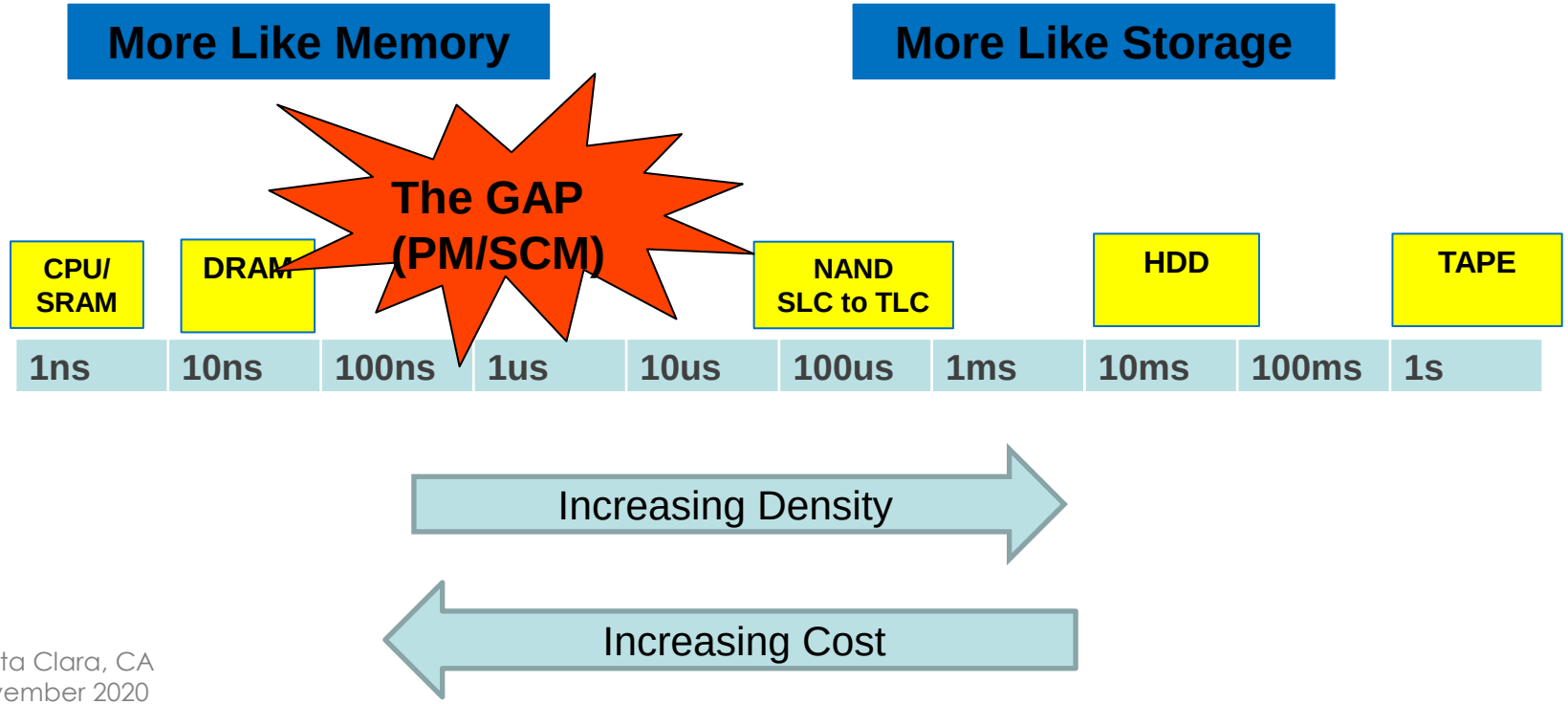
Why New Memory:
Not Meeting Needs

- DRAM and NAND are not meeting needs
- NAND is slow, block oriented, wears out
  - But nothing can approach it for price
- DRAM is volatile, density is growing slowly, it is less than ideal
  - But at least its RAM
  - It doesn't wear out
- We want a Fast NVM and we want a higher density RAM than DRAM

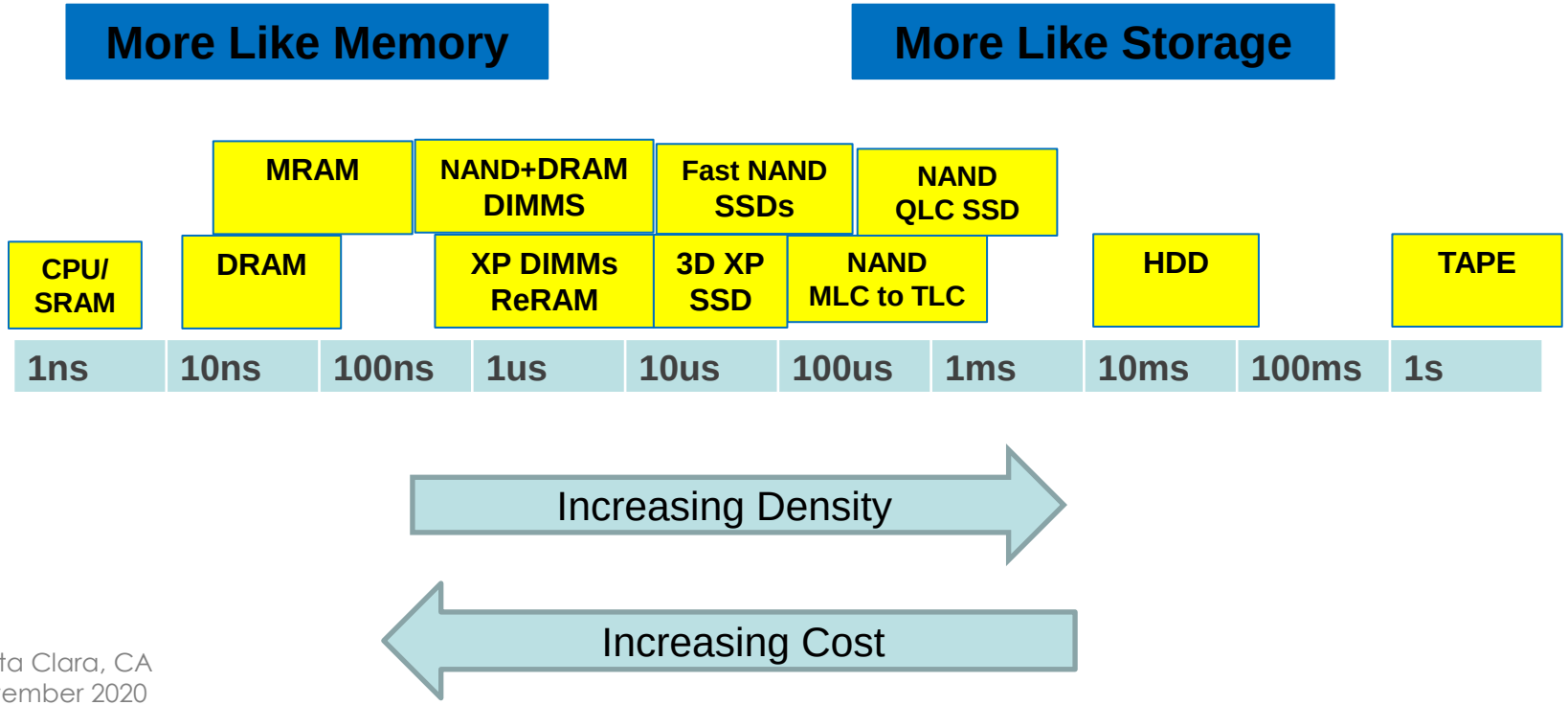
What is Needed in New Technology

- Ideal Universal Memory
  - Fast as DRAM, Non-Volatile, Infinite cycles, Cheaper than NAND
  - This is not coming from anyone soon
  - Nothing is replacing DRAM or NAND in next 10 years
- Reality of what will happen
  - Combination of tradeoffs will need to be made
  - Add in some new technologies to fill gaps

The Latency Spectrum and Gaps ~2015



The Latency Spectrum and Gaps Future



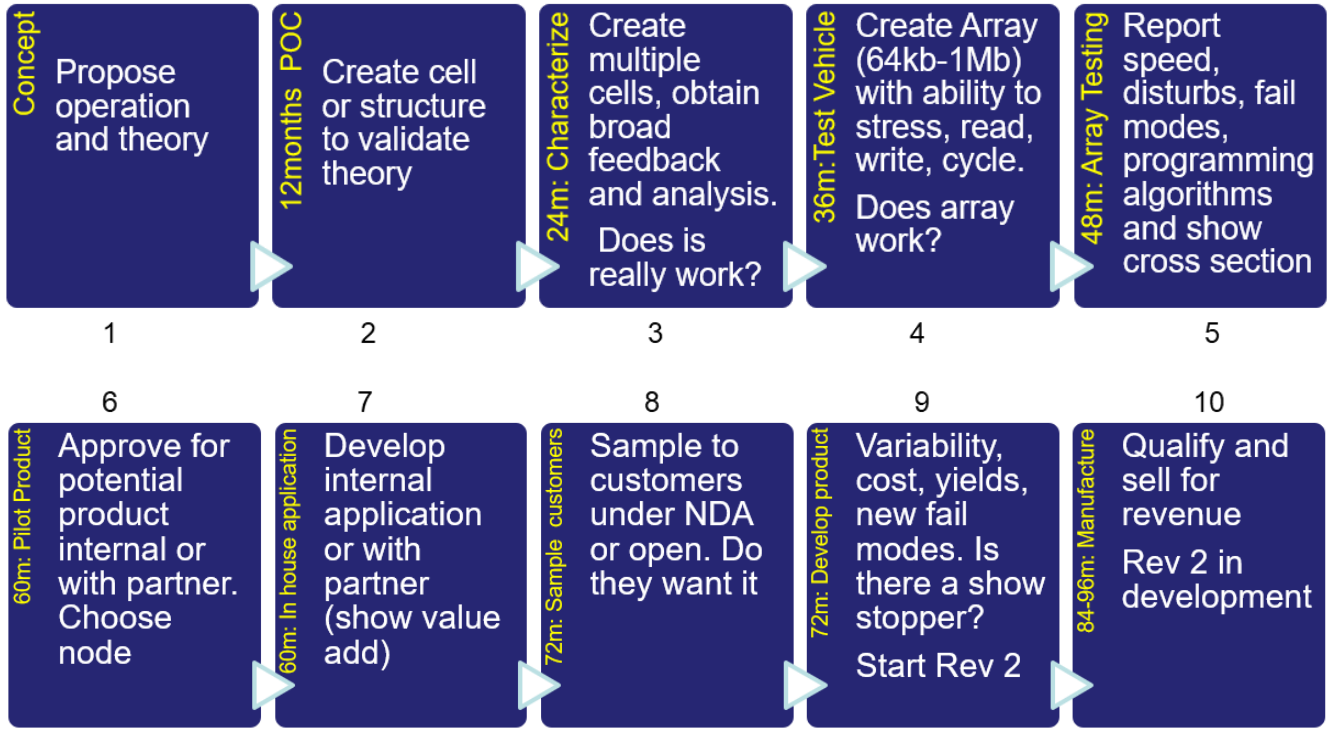
What Do We Have Available Today?

- We now have a volume 3D Xpoint memory ramping with 100s of Millions in revenue in multiple markets
  - More revenue than all previous “new NVM” COMBINED
  - 1B GB will be shipped in 2021
- We have low density ReRAM/FE RAM technologies available for embedded
- We have MRAM being used in actual discrete products and applications
- MRAM is being implemented in foundry designs by all major players
- We have new memories being proposed, But things have changed since 2019
  - **Focus and money will move to growth of “emerged” technologies and away from finding new technologies**

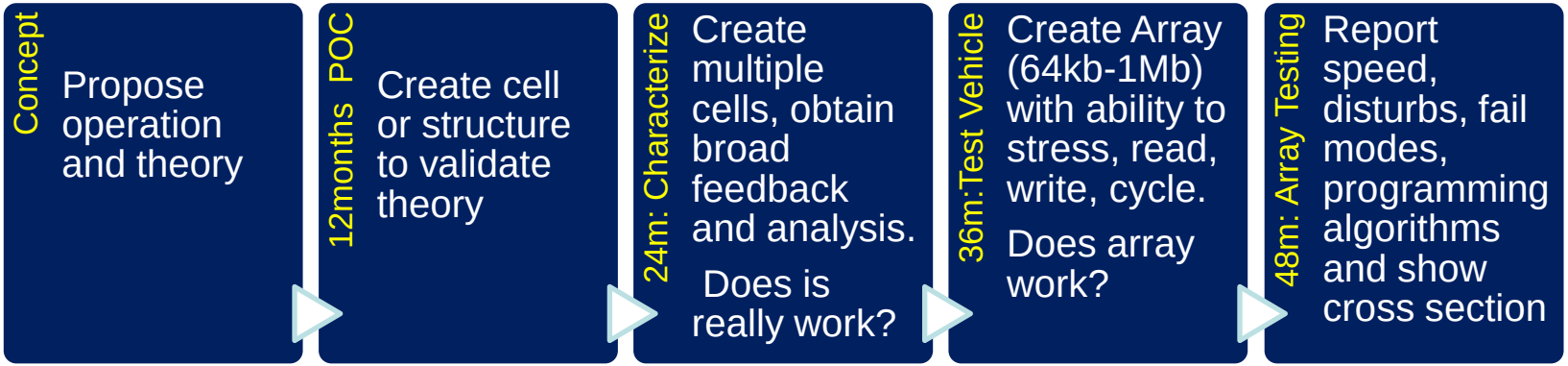
NEW MEMORY PRODUCT LIFECYCLE

- The question is:
  - What technologies are available?
  - Where are they in the development lifecycle. How far from reality are they?
- The Memory Product Lifecycle separates what is real vs what is a hope for some day in future

Memory Product Lifecycle



Product Lifecycle for Memory
Part 1: Technical Proof/Open Communication



End Result: a working technology fully demonstrated and checked out

- Documented Summary: “ A Novel xRAM technology built in 90nm Lithography “
- Doesn’t need to be on leading edge lithography, but should be capable
- With pictures/TEMs/SEMs (4-5 years after concept)

Product Lifecycle for Memory Part 2: "We are going to build a product"

- 7-8 Years from concept assuming no restarts or resource limitations from concept to revenue
- Usually performed in a stealth mode. Presentations disappear (3DXP example)
- Next announcement is samples or early production (MRAM/Xpoint)

So Where Are Our Emerging Technologies?

- Recent EE Times Article: "Emerging Memories May Never Go Beyond Niche Applications"
  - Let's have the tough discussion based on Memory Product Lifecycle.
- We want to talk about non-niche technologies
  - Niche = <1% of memory market long term
- The Memory product lifecycle clearly shows possibility of "Stealth products"
  - So Apple, Samsung, WDC, Micron could be working on items with no knowledge by analysts like me
  - HOWEVER typically only after small array data published
  - 3D Xpoint Example

Technologies in Research Stages (1-5)

These are at least 5 years from production, probably 10 years

- High density 100+Gbit ReRAM (Stage 4)
  - Many flavors and options, but no advantage over PCM and lack of products in last 2 years is troubling
  - We are finding issues as fast as we are solving them
- FeRAM (high density) (Stage 3-4)
  - Great potential to integrate into memory Process
  - Our top potential for “Stealth development” with memory companies
- Nanotube RAM (Stage 3)
  - Changes if we see array characterization or demonstrations
- DNA/Molecular/Other (Stage 2) : Need to leave research study

Technologies in Product Stages (6-10)

- Discrete MRAM, up to 1Gbit (Stage 10)
  - Available today from multiple companies
- Embedded MRAM (Stage 8)
  - Sampling in product development from multiple companies
- ReRAM embedded low density ~1Mb (Stage 10)
  - Available today
- FERAM embedded in Low Density (<1Mb) (Available today)
- ReRAM embedded medium density 8Mb (Stage 6-7)
  - In partnership development with multiple companies/Foundries

Technologies in Product Stages (6-10)

Major Developments In ReRAM/MRAM

- ReRAM: Low density ReRAM characterization and opportunities for embedded presented at IEDM by multiple companies
- MRAM: New MRAM products from Everspin and others available
- MRAM: Characterization from Intel, Samsung,TSMC, GF presented
- MRAM: Improved transistor design and reliability improvement presented from IP companies
- MRAM: Cell scaling of ~30% in last two years
- MRAM Revenue >$100M for discrete in 2022

Technologies in Product Stages (6-10)
3D XPoint

- PCM/3D Xpoint/Optane 128Gbit+ (Stage 10)
  - Available in multiple high volume products from Intel
  - SSDs, Persistent memory available today
  - Micron developing products
- 2nd Generation Ramping now
- Revenue estimate >$1B in 2020, $3.6B in 2024
- ~1B Gbytes to be shipped in 2021
- Faster than NAND, Slower than DRAM. Lower cost than DRAM, More Expensive than NAND
- 90% of the revenue of all Emerging memories today

3D Xpoint Revenue

Aug 2019	2020	2022	2024
3DXP (Non-DIMM)	$650M	$750M	$800M
3DXP (DIMM)	$700M	$1.9B	$2.8B
3DXP (Total)	$1.35B	$2.65B	$3.6B

**NOV 2020 NEW!*	2020	2022	2024
3DXP (Non-DIMM)	$500M	$750M	$800M
3DXP (DIMM/NEW BUS)	$600M	$1.0B	$2.8B
3DXP (Total)	$1.10B	$1.75B	$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/Cooper lake share, server DIMM attach rate, average Optane density
Intel may report out Revenue numbers in preparation for Hynix Sales of NAND unit.

Summary of "EMERGED" Technologies for Datacenter

- If you need 1Mb-1Gb of fast NVM at cell size in 30-50F^2 (.03-.05u^2 Cell) for embedded or discrete
  - MRAM is ready to implement and develop products around
- If you want lower density memory for implementation (<1Mb)
  - ReRAM (and even some FERAM) is available
- If you want high density, 128Gb+ NVM with faster speed than NAND
  - Optane/3D Xpoint is available in multiple flavors and applications
- These should be the focus and investment for Datacenters

Summary

- Memory Product Lifecycle tells us what is now vs someday
- MRAM
  - Cache for SSD/HDD/Storage, NVDIMM without need for power, SRAM/eDRAM replacement for L4 Cache, NOR replacement
  - >100M in revenue in 2022 for discrete products
- PCM/3D Xpoint/Optane:
  - Fast SSD, Persistent Memory (high density), Large main memory
  - >1B in Annual revenue
- Other (Stage 1-5) Technologies are too far away to impact datacenter now

Thank You

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