



Flash Memory Summit

Advances in Persistent Memories: Markets and Applications

Mark Webb

MKW Ventures Consulting, LLC

mark@mkwventures.com



Flash Memory Summit

Contents

- Persistent Memory Definitions
- Applications and what is shipping today
- Technologies and memory configurations
- Challenges and opportunities
- Revenue projections and forecasts



Different Concepts of Persistent Memory

- It's a universal Non-Volatile Memory Technology (Device Geeks)
 - PCM, ReRAM, MRAM, Memristor, NVRAM
- It's a storage/memory concept (Storage Experts)
 - What if we wrote to address and didn't have to worry about data loss or storage later?
- Its BIG DATA Memory (End users)
 - I want to look at all my TBs of data like hot data



A Persistent Memory Definition

- It's persistent ... ie NVM (duh!). No need to worry about loss
- It's accessed like memory on memory bus
 - “Byte addressable” Could also be used in Block Mode
 - Anything can be virtual memory... but this is less interesting
- Speed...unclear, lets say $<1\mu\text{s}$ latency
 - 2018 PM Summit had some great discussions on this (WDC/Bandic)
 - Raw memory read latency on order of 100ns
- Used for data being worked on and addressed by programs. Not primarily used as Storage



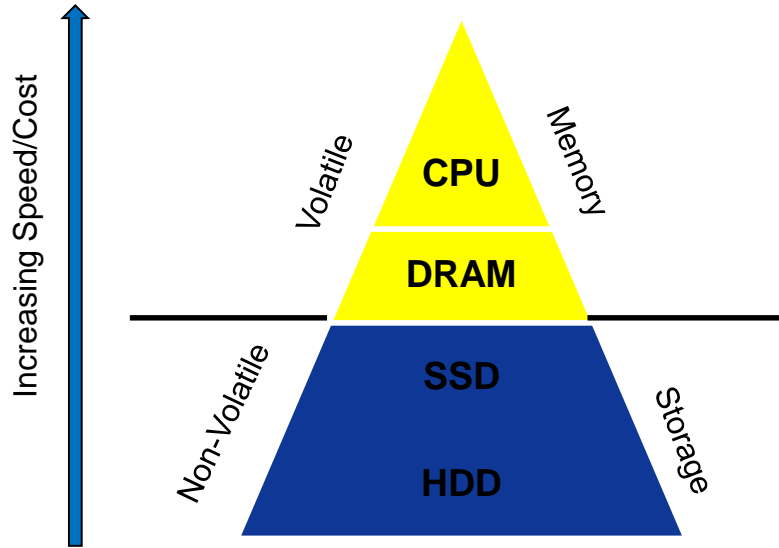
How is PM Accessed

- Like DRAM: DDR4 bus. Parallel memory slots on server/PC board (Today). NVDIMM-N, NVDIMM-P or non-standard DDR4
 - Also PMoF/RDMA
- On New Bus: GenZ, OpenCAPI, Rapid-IO (coming)
- *Through NVMe/Storage bus: This is available today working with different memories but it is not my focus*

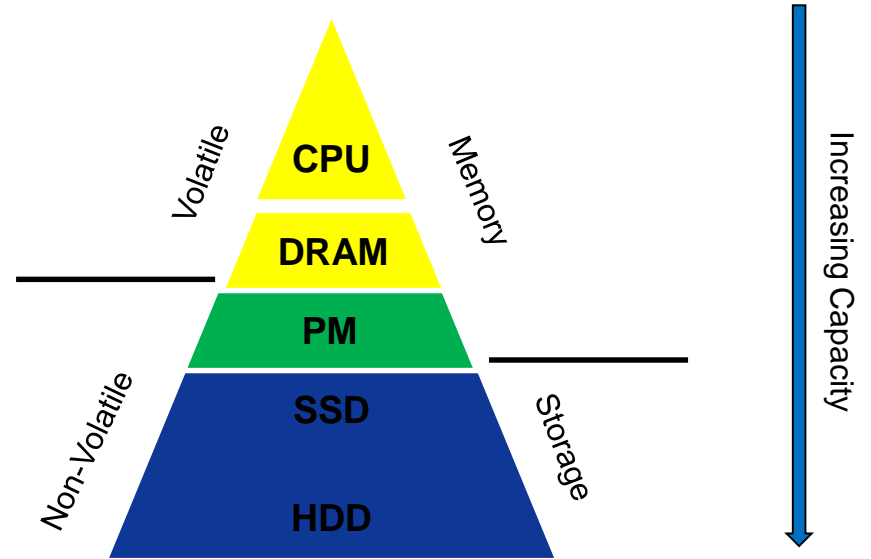


Historical Memory/Storage vs PM

Historical Memory Storage



Memory/Storage with PM

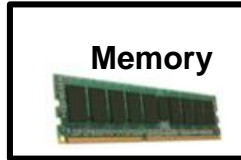




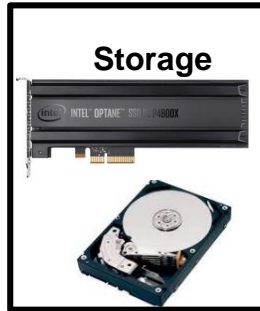
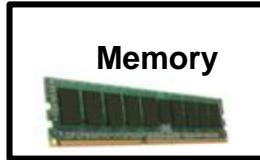
How to work with 1TB of Data

OVERSIMPLIFIED!

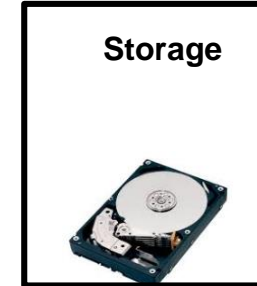
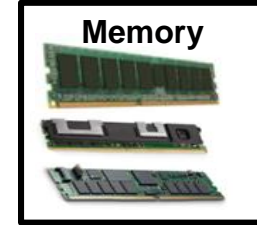
196GB DRAM+8TB HDD



196G DRAM+1TB NVMe SSD+ 8TB HDD



1.5TB Persistent Memory+ 8TB HDD





How to work with 1TB of Data

OVERSIMPLIFIED!

196GB DRAM+8TB HDD

- Data is on HDD
- Load part of it in to Memory
- Swap out blocks of data as needed until done
- Memory access times 30ns
- HDD access time mS
- Hope no power lost during work

196G DRAM+1TB NVMe SSD+ 8TB HDD

- Data is on HDD
- Load it all to SSD
- Load part of it in to Memory
- Swap out blocks of data with SSD until done
- Perhaps treat SSD as memory
- Memory access times 30ns
- SSD access time 10uS
- Hope no power lost during work

1.5TB Persistent Memory+ whatever

- Data is on HDD/SSD
- Load it all to persistent memory
- Complete work on data
- Leave it there or store it to SSD/HDD
- Memory access time is 30-150ns
- No SSD/HDD access needed
- If power lost, you are good



Persistent Memory Applications

... It's Here Today

- Server DIMMS/Main Memory for Storage systems
- RAM requirements where max speed is needed and memory cannot be lost due to outage.
- Log file, journaling, networks, fast restart requirements
- Applications with long processing times, Modeling
- Financial transaction processing
- Multiple Suppliers here at FMS
- Still relatively low volume and penetration (<5% of servers)



What's Shipping Today

- NVDIMM-N is classic version of persistent memory DIMM
 - Addressed just like DRAM in a DIMM
 - Backed to NAND periodically or when power lost
 - Typical NVDIMM is 16G DRAM plus 32G of SLC NAND with control and capacitor/battery
 - Appears as 16GB of DRAM at DRAM speed
 - Downside: Costs more than DRAM and does not provide increased capacity.



High Density Server DIMMs

- Future Apps: Large databases where loading and swapping portions is not efficient.
 - Size of SSD (Terabyte) with memory bus speed (Mark's definition)
 - This is a major revenue Focus
- Anything where faster loading, faster analysis provides monetary return to pay for it
- Examples:
 - Financial database/transaction processing (\$/mS metrics available)
 - VMs that are currently memory limited (10x more VMs/Server)
 - Video/entertainment/Animation (Huge databases, PM Summit)
 - Similar to applications currently using high performance NVMe SSDs



Persistent Memory Applications (MORE)

CE/Mobile Devices (Potential Revenue)

- Smaller density replacing Capacitor/battery backed DRAM, replacing SRAM/DRAM/Flash. CE device optimization
- For cost-speed reasons, these applications often optimize NAND and DRAM and HDD in gaming/CE systems
- Potential to create a memory system that is fast enough and allows less chips, faster overall speed, better reliability.
- For Many apps, lower density is OK enabling more media (memory types) options
 - 16M SRAM+1G DRAM+8G NAND could use MRAM for aspects.
 - 2G DRAM+16G NAND could go to ReRAM/PCM-3D Xpoint



Memory Types/Media

| | Latency | Density | Cost | HVM ready | |
|-------|---------|---------|-------|-----------|-----------------------------|
| DRAM | ***** | *** | *** | ***** | Combined Today |
| NAND | * | ***** | ***** | ***** | |
| MRAM | ***** | * | * | *** | Alone or Combined In future |
| 3DXP | *** | **** | **** | **** | |
| ReRAM | *** | **** | **** | ** | |
| NRAM | *** | ** | ** | * | |
| Other | *** | ** | ** | * | |

Notes: NOR/SRAM and low density Not in Included (Small), Low density FeRAM not included



Coming Persistent Memory/ SCM Technologies

- NVDIMM-N meets the specs but is very expensive and density \leq DRAM
- Optane Persistent Memory (DIMM) will be dominant PM very quickly
 - Better density than DRAM, lower cost
 - But slower speed, cycling limitations mean tradeoffs.
- ZNAND/Fast NAND: slower than DRAM, cycling limitations (good for SSDs)
- MRAM: Much more expensive than DRAM (But close on speed)
- ReRAM: Slower than DRAM, Cycling limitations (much like Optane)
- **DRAM “replacement” isn’t the way to persistent memory market growth !**



Example of Cost Challenges

- 2018 estimated Cost (not price) per Bit (DRAM RDIMM=1x)
 - MRAM: 5x
 - NVDIMM-N: 1.6x
 - ReRam (today): 0.75x
 - 3D Xpoint (today): 0.55x
 - Fast SLC NAND (today): 0.15x
- DRAM+ReRAM/Optane/NAND is lower cost/bit, more capacity at “similar” performance



DRAM/NVM Combinations

- NVDIMM-P Supports multiple memories and hybrid systems
- Coming solutions are some DRAM merged with lots of NVM.
 - Lower cost, near DRAM performance, managed endurance
- 3D-Xpoint persistent memory combines DRAM DIMMs and 3D Xpoint DIMMs with processor/memory controller managing data
 - ~5:1 Xpoint:DRAM ratio, manage data for performance/endurance
- Netlist HybriDIMM/Xitore: DRAM and Fast NAND on DIMM
- Z-NAND and solutions from All NAND and NVDIMM vendors will use similar architecture
 - Cheaper than DRAM, Lots of memory, Managed endurance



Predictions for Market

- All of these options will be provided to end users
 - NVDIMM-N/P, Optane DIMM, Hybrid DIMM, Z-NAND/Fast NAND combined with DRAM, etc
 - Some Proprietary, Some open, with the usual arguments why
- If Persistent memory is important, Certain architectures will become standard and grow faster leading toward “High Revenue”
- If we are having “what’s possible” discussions at end of 2019, Market will be much, much lower than middle revenue 😞....



Persistent Memory

Revenue Growth “Guess-timate”

| Year | Revenue Middle | Revenue High | Requirements to meet <u>Middle</u> |
|------|----------------|--------------|---|
| 2020 | \$2.0B | \$3.0B | Optane, NVDIMM must takeoff ASAP |
| 2022 | \$3.9B | \$7.0B | Persistent memory is in all compute areas. Multiple bus options evaluated |
| 2025 | \$7.0B | \$10B | Multiple new memories allow utilization in mobile, server, PCs |

NOTES:

Revenue “low” is too depressing to show. I’m an optimistic guy

NVDIMM+SCM/NVRAM standalone memory only. Virtual memory on storage bus not included

NVDIMM could be DRAM+NAND, Fast NAND, SCM

Embedded PM is difficult to measure revenue



Mark's Summary

- Persistent memory is here today, but it is just a start
- To grow, we need to be cost effective.
 - DRAM replacement by expensive tech won't work broadly
 - Memory that is too slow won't work broadly
 - Neither DRAM nor NAND are getting replaced.
- DRAM + NAND/SCM will be the PM future (like NVDIMM-P)
 - Includes Optane Persistent Memory which requires DRAM
- Revenue could grow 30% CAGR if technologies deliver to commitment dates



How to work with 1TB of Data

OVERSIMPLIFIED!

196GB DRAM+8TB HDD

- Data is on HDD
- Load part of it in to Memory
- Swap out blocks of data as needed until done
- Memory access times 30ns
- HDD access time mS
- Hope no power lost during work

196G DRAM+1TB NVMe SSD+ 8TB HDD

- Data is on HDD
- Load it all to SSD
- Load part of it in to Memory
- Swap out blocks of data with SSD until done
- Perhaps treat SSD as memory
- Memory access times 30ns
- SSD access time 10uS
- Hope no power lost during work

1.5TB Persistent Memory+ whatever

- Data is on HDD/SSD
- Load it all to persistent memory
- Complete work on data
- Leave it there or store it to SSD/HDD
- Memory access time is 30-150ns
- No SSD/HDD access needed
- If power lost, you are good