Overview of Persistent Memory
FMS 2018 Pre-Conference Seminar

Mark Webb
MKW Ventures Consulting, LLC
Mark’s Presentations at FMS

- Persistent Memory Preconference Class (Monday 8:45AM)
- MRAM Developer Day: MRAM Memory Technology Roadmap and Market (Monday 11:45AM)
- Advances in Persistent Memory (PMEM 101-1, Tuesday 8:30AM)
- Annual Update on Emerging Memory Technologies (NEWM-102B-1, Tues 4:55)
- 3D Xpoint Technology Expert table (Beer/Pizza) (Tuesday 7PM-830PM)
- 3D XPoint: Current Implementations and Future Trends (NEWM-201A-1, Wed 8:30AM)
Contents

• Persistent Memory Definitions
• Applications and what is shipping today
• NVM Technologies for persistent memory
• Persistent 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 <1us 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

CPU
DRAM
SSD
HDD

Memory/Storage with PM

CPU
DRAM
PM
SSD
HDD

Increasing Speed/Cost
Increasing Capacity
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!

<table>
<thead>
<tr>
<th>196GB DRAM+8TB HDD</th>
<th>196G DRAM+1TB NVMe SSD+ 8TB HDD</th>
<th>1.5TB Persistent Memory+ whatever</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data is on HDD</td>
<td>Data is on HDD</td>
<td>Data is on HDD/SSD</td>
</tr>
<tr>
<td>Load part of it in to Memory</td>
<td>Load it all to SSD</td>
<td>Load it all to persistent memory</td>
</tr>
<tr>
<td>Swap out blocks of data as needed until done</td>
<td>Load part of it in to Memory</td>
<td>Complete work on data</td>
</tr>
<tr>
<td>Memory access times 30ns</td>
<td>Swap out blocks of data with SSD until done</td>
<td>Leave it there or store it to SSD/HDD</td>
</tr>
<tr>
<td>HDD access time mS</td>
<td>Perhaps treat SSD as memory</td>
<td>Memory access time is 30-150ns</td>
</tr>
<tr>
<td>Hope no power lost during work</td>
<td>Memory access times 30ns</td>
<td>No SSD/HDD access needed</td>
</tr>
<tr>
<td></td>
<td>SSD access time 10µS</td>
<td>If power lost, you are good</td>
</tr>
<tr>
<td></td>
<td>Hope no power lost during work</td>
<td></td>
</tr>
</tbody>
</table>
Persisting Memory Applications
... It’s Here Today

- Server DIMMS/Main Memory for Compute and Servers
- RAM requirements where max speed is needed and memory cannot be lost due to outage.
- Tremendous ecosystem and standards work supporting this
- Log file, networks, quick start ups and quick restarts.
- 16GB applications growing to 64GB
- 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
  - Costs more than DRAM and does not provide increased capacity.

- **NVDIMM-F** is version with only Flash. “SSD on Memory bus”
  - NAND on DRAM Bus has always shipped in limited volume
  - Much slower than DRAM at higher capacity
NVDIMM-N, NVDIMM-F

NVDIMM-N

NVDIMM-F

Controller

Host DDR4 RAS-CAS Interface

Backup Power Source (e.g. supercaps)
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

<table>
<thead>
<tr>
<th></th>
<th>Latency</th>
<th>Density</th>
<th>Cost</th>
<th>HVM ready</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DRAM</strong></td>
<td>*****</td>
<td>***</td>
<td>***</td>
<td>*****</td>
</tr>
<tr>
<td><strong>NAND</strong></td>
<td>*</td>
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<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td><strong>MRAM</strong></td>
<td>*****</td>
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<tr>
<td><strong>3D XP</strong></td>
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<td>****</td>
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<tr>
<td><strong>ReRAM</strong></td>
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<td>**</td>
</tr>
<tr>
<td><strong>NRAM</strong></td>
<td>***</td>
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<td>**</td>
<td>*</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>***</td>
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<td>*</td>
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</tbody>
</table>

Notes: NOR/SRAM and low density Not in Included (Small), Low density FeRAM not included
The Latency Spectrum and Gaps
~2015

More Like Memory

More Like Storage

The GAP (PM/SCM)

<table>
<thead>
<tr>
<th>CPU/SRAM</th>
<th>DRAM</th>
<th>NAND SLC to TLC</th>
<th>HDD</th>
<th>TAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ns</td>
<td>10ns</td>
<td>100ns</td>
<td>1us</td>
<td>1us</td>
</tr>
<tr>
<td>1us</td>
<td>10us</td>
<td>100us</td>
<td>1ms</td>
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</tr>
<tr>
<td>10ms</td>
<td>100ms</td>
<td>1s</td>
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Increasing Density

Increasing Cost

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The Latency Spectrum and Gaps

Future

<table>
<thead>
<tr>
<th>More Like Memory</th>
<th>More Like Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRAM</td>
<td>NAND+DRAM DIMMS</td>
</tr>
<tr>
<td>NAND+DRAM DIMMS</td>
<td>Fast NAND SSDs</td>
</tr>
<tr>
<td>XP DIMMs / ReRAM</td>
<td>NAND QLC SSD</td>
</tr>
<tr>
<td>1ns</td>
<td>100ns</td>
</tr>
<tr>
<td>10ns</td>
<td>1us</td>
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<tr>
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<td>1ms</td>
</tr>
<tr>
<td>CPU/SRAM</td>
<td>10ms</td>
</tr>
<tr>
<td>DRAM</td>
<td>100ms</td>
</tr>
<tr>
<td>3D XP SSD</td>
<td>1s</td>
</tr>
<tr>
<td>XP DIMMs / ReRAM</td>
<td>TAPE</td>
</tr>
<tr>
<td>1ns</td>
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<tr>
<td>10ns</td>
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<td>1s</td>
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</tr>
</tbody>
</table>

Increasing Density

Increasing Cost

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Coming Persistent Memory/ SCM Technologies

- NVDIMM-N meets the specs but is very expensive and density <=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 (Like Optane)
- Other Memories have potential but are much less Mature/low density
- **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
Big Data vs Fast Data vs Persistent Data (Cost question to ponder)

- Big Data: Data analyzed is getting bigger
- Fast Data: Data Analyzed is needed faster.
- Do I want my memory faster, cheaper or persistent??
  - 200GB of DRAM at $2000
  - 150GB of Fast NVDIMM-N at $2000 (hypothetical)
  - 1000GB of slower PM at $3000 (hypothetical)
  - 1000GB of slower DRAM (volatile) at $2500 (hypothetical)
- The answer will determine which products take off
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”

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

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
  - Includes Optane Persistent Memory which requires DRAM
- Revenue could grow 30% CAGR if technologies deliver to commitment dates
### Where should we attach persistent memory?

<table>
<thead>
<tr>
<th>Physical Interface</th>
<th>CPU BUS: PARALLEL</th>
<th>CPU BUS: SERIAL</th>
<th>SERIAL PERIPHERAL BUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIMM</td>
<td></td>
<td>DIMM\text{other}</td>
<td>PCIe</td>
</tr>
<tr>
<td>Non-standard DDR4, NVDIMM-P</td>
<td></td>
<td>DMI for Power 8, CCIX, OpenCAPI 3.1, Rapid-IO, gen-Z</td>
<td>NVMe, DC express*</td>
</tr>
</tbody>
</table>

**Pros**
- Low latency
- High bandwidth
- Power proportional
- Coherent through memory controller

- High bandwidth
- Significant pin reduction
- Higher memory bandwidth to CPU
- Coherent through memory controller, or in some cases can even present lowest point of coherence

- Standardized
- CPU\text{platform independent}
- Latency low enough for storage
- Easy RDMA integration
- Hot pluggable

**Cons**
- CPU memory controller has to implement specific logical interface
- Not suited for stochastic latency behavior
- Not hot pluggable
- BIOS needs change

- CPU memory controller has to support
- May have higher power consumption

Higher latency (~1us)

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Western Digital