Advances in Persistent Memories: Markets and Applications

Mark Webb
MKW Ventures Consulting, LLC
mark@mkwventures.com
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 <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

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

1.5TB Persistent Memory+ 8TB HDD
# How to work with 1TB of Data

**OVERSIMPLIFIED!**

<table>
<thead>
<tr>
<th>System Configuration</th>
<th>Data Access Details</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>196GB DRAM+8TB HDD</td>
<td>Data is on HDD</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Load part of it in to Memory</td>
<td>-</td>
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<tr>
<td></td>
<td>Swap out blocks of data as needed until done</td>
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<tr>
<td></td>
<td>Memory access times 30ns</td>
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<tr>
<td></td>
<td>HDD access time mS</td>
<td>-</td>
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<tr>
<td></td>
<td>Hope no power lost during work</td>
<td>-</td>
</tr>
<tr>
<td>196G DRAM+1TB NVMe SSD+ 8TB HDD</td>
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</tr>
<tr>
<td></td>
<td>Load it all to SSD</td>
<td>-</td>
</tr>
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<td>If power lost, you are good</td>
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</table>
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

<table>
<thead>
<tr>
<th>Memory Type</th>
<th>Latency</th>
<th>Density</th>
<th>Cost</th>
<th>HVM ready</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAM</td>
<td>*****</td>
<td>***</td>
<td>***</td>
<td>*****</td>
</tr>
<tr>
<td>NAND</td>
<td>*</td>
<td>*****</td>
<td>*****</td>
<td>*****</td>
</tr>
<tr>
<td>MRAM</td>
<td>*****</td>
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<td>*</td>
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<tr>
<td>3DXP</td>
<td>***</td>
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<tr>
<td>ReRAM</td>
<td>***</td>
<td>****</td>
<td>****</td>
<td>**</td>
</tr>
<tr>
<td>NRAM</td>
<td>***</td>
<td>**</td>
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<td>*</td>
</tr>
<tr>
<td>Other</td>
<td>***</td>
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<td>*</td>
</tr>
</tbody>
</table>

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 <=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”

<table>
<thead>
<tr>
<th>Year</th>
<th>Revenue Middle</th>
<th>Revenue High</th>
<th>Requirements to meet Middle</th>
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<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>
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<tr>
<td>2025</td>
<td>$7.0B</td>
<td>$10B</td>
<td>Multiple new memories allow utilization in mobile, server, PCs</td>
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**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
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