



Alternative Non-Volatile Memory Adoption Timeline

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Technologies

Many NVM technologies exist today.

- NOR: low density, low growth, incredibly mature, consolidated suppliers
- NAND: why we are here and why this conference grew at amazing rate
 - 3D NAND has removed the “we are at the wall” feeling.
- Phase change memory
 - Very old technology, licensed and researched by nearly every memory company
- MRAM
 - Very old, recent variations provide future promise
- RRAM
 - Recent press from multiple companies and crosspoint options are encouraging
- Other variations or technologies are being researched (Ex: CNT, Polymer) but are far from acceptance. I will completely ignore these until 2020 FMS

- 3D NAND, TLC have us back on track for significant cost and density improvements over time.
- Current product plans are that 3D is only 128Gbit and above.
 - No 2D scaling means limited cost reduction below 128Gbit
- With 3D, expect 25% cost reduction/year through 2020
- NAND is: Very high density, very slow latency, very low cost
 - Side note: Cost is still 5X higher than HDD
- Latency is the issue (3D does not solve this). DRAM to NAND is the “Latency Gap” that Alternative NVM needs to fill (picture)



Latency Graph

The Reason for New NVM

- Need clear graph for presentation



Phase Change Memory

- This technology “dead” because no writes research articles on it.
 - Marks take: “PCM is so mature... it is boring”
- Researched and licensed and run by many companies.
 - Transistor access or crosspoint/OTS (Micron 2011 FMS Paper)
- BUT: 3x higher cost than NAND and 5x slower than DRAM
- BUT: Cheaper than DRAM and faster than NAND
 - This will allow multiple applications in the “Latency Gap”
- With revenues <2% of total NVM market, these are best defined as niches.
 - Not replacing DRAM, Not replacing NAND anytime soon

- MRAM has many advantages and potential applications
 - It is in production with real applications and real revenue
 - High cost, low density makes competition with NAND markets difficult.
- Fast latency and relative maturity in the <256Mbit market makes it applicable for anything close to processor, caching.
 - NVM in DRAM application is perfect MRAM application. Small market today
 - Certain companies could easily define architecture changes to cause tipping point adoption (Apple, Intel, Microsoft, ARM, Qualcomm, etc)
- A 10x reduction in cost and a 10x improvement in density would be required to enter any significant portion of the NAND market
- Fast growth in computing applications from a relatively small base today expected.

RRAM

- The papers that stopped being written on PCM ended up written on RRAM. For good reason...
- Latency and power potential is better than PCM.
- Cost-Density is possible with cross point arrays, stacking on inexpensive logic, and architectural improvements to minimize leakage.
 - Cost within 50% NAND is possible with mature logic technology
 - Best NVM for achieving NAND cost
 - Therefore RRAM has higher confidence of dominating NVM bit shipments.
- Mbit level chips and being designed and tested today.
- Gbit level chips are possible but need to be demonstrated to develop widespread applications by 2017-2018 timeframe

What about those announcements

- Lots of public announcements that fall into new NVM
- HP and press continues to mention “Memristor”
 - It is vague enough to fit many of these technologies
- Intel/Micron announce Xpoint
 - Higher cost than NAND*. Performance slower than DRAM, similar to PCM. Not replacing DRAM or NAND*
 - Stated that this is NOT RRAM (filament) or Phase Change*
 - 128Gbit and Crosspoint architecture is huge accomplishment
 - This will move ALL alternative NVM forward quickly.



Implementation Predictions

- NAND: 3D continues bit growth, slowly. 3D <25% of bits in 2016.
- PCM: multiple storage products in next year.
 - low volume system shipments in 2016. revenue is <2% of NVM business in 2016/17
- MRAM: continued bit growth targeting low latency, near processor applications and cache for storage products (DRAM replacement)
 - Potential tipping point for some DRAM replacement in next 2 years.
 - No applications to mass storage for next 5 years.
- RRAM: Technical demonstration in low density (<256Mbit) region in 2016.
 - Gbit level in 2017 with high confidence cost projection to allow NAND replacement