The Evolving NAND Flash Business Model for SSD

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Solid State Storage - Vision

- **Solid State Storage in future Enterprise Compute**
  - Anything performance sensitive goes solid state storage
  - Anything capacity sensitive stays with high capacity HDD
  - Integrating SSD/HDD at system level is key

- **Solid State Storage in future Client Compute**
  - Anything mobile goes solid state storage
  - Anything small capacity goes solid state storage
  - HDD through local or network attached for capacity
SSD – Value Prop & Enabling Price Points

- SSDs deliver a value proposition around:
  - $/IOPS, IOPS/W, $/IOPS/W/in³, Latency
  - Performance, Power & Thermal Scaling,
  - Advanced low power modes
  - Form Factor and Robustness
  - **Not $/GB but enabling price points matter!**

- CY09: SLC Enterprise SSD: less than $20/G => Storage Systems
- CY10: MLC Enterprise SSD: less than $5/GB => Servers
- CY11: MLC Enterprise SSD: less than $5/GB => Storage Systems
- CY12: MLC Client SSD: less than $1/GB => Client Compute Systems
SSD Units – Market Outlook

Client SSD drives ~90% of units

Source: Gartner, August 2010
SSD Revenue – Market Outlook

Source: Gartner, August 2010

Enterprise SSD drives ~50% of revenue
SSD – Future Controller Architectures

New host interfaces:
eNVMHCI, UFS, ...

New Host Data/Local buffer:
STRAM, PCRAM, etc…

Intelligent & Ultra high
Performance NVM-TL

NVM Channel:
Powerful LDPC & DSP

NVM Physical I/F:
NVM Soft-Interface

Non-volatile Memory:
Tiered NAND, Resistive
& Magnetic RAM or PCM

Diagram of SSD controller architecture:
- Host Controller Interface
  (SATA, SAS, PCIe, USB, UFS …)
- Host Data/Local Buffer
  (SRAM/DRAM -> NV Cache)
- NVM Abstraction Layer (Logical to Physical)
  (Wear Leveling, Bad Block Management, Garbage Collection)
- NVM Physical Layer
  (NVM Channel & Error Correction)
- NVM Physical Interface
  (Legacy, Toggle, ONFI, HL-NAND)

NVM (Legacy, Toggle, ONFI, HL-NAND)
SSD – Future FF & I/F Trends

• Size matters – SSD integration trending to new form factors
  – SSD evolution is driving to higher levels of integration
  – Applications driving smaller form factors and new TDP envelopes
  – Expect to see SSD in a package being broadly deployed in tablets, et. al.

• Local storage connectivity trends:
  – PCIe suitable physical layer interface for local storage connectivity
  – PCIe allows for storage connectivity via eNVMHCI, USB, AHCI, …
  – PCIe ideal to fully exploit IOPS and latency SSD have to offer

• Network storage connectivity trends:
  – Ethernet suitable physical layer interface for network storage connectivity
  – Ethernet allows for storage connectivity via file and block protocols, …
  – Ethernet ideal for high performance Solid State Storage Appliances
SSD – Future Media Trends

• Host Data/Local Buffer
  - Typically uses DRAM/SRAM today – issues with power loss when caching
  - Eliminating external DRAM highly desirable – smaller footprint, less power
  - On-Chip SRAM transitioning to NV-RAM -> eliminate super-cap when caching
  - Optimized data path embracing new NVM is key for max performance/endurance

• SSD main memory
  - Typically uses SLC and/or MLC NAND - cost/endurance/reliability trade-offs
  - Special trims enable Compute NAND for SSD leveraging consumer NAND
  - Dynamic multi-bit architectures and tiered NAND in the future
  - New NAND component and SSD system architectures extend NAND in SSD
  - Leverage new non-volatile memories as NV Cache or SSD main memory tier
  - Non-volatile memory candidates Resistive RAM, Magnetic RAM or Phase Change
Reliability – Need adaptive ECC

• SSD require highest reliability amongst NAND apps
  – Smaller lithography and increased MLC enabled NAND cost reductions, a side effect is a higher raw bit error rate
  – BCH based technologies reaching their technology scaling limits requiring increasing NAND spare area for ECC usage (>10%)
  – SSD processors are expected to support up to 80b/1kB ECC in order to enable reliable 20-nm class MLC SSD for Compute Apps
  – Adaptive Error Correction technology is required to enable scaling to application reliability needs from Client SSD to Enterprise SSD

Conventional Error Correction:
Stores ECC in spare field

Adaptive Error Correction:
Stores ECC in spare field and uses some of the NAND page
Reliability – Cluster Failure Mitigation

- Scaling causes increasing probability of infant mortality, word-line, bit-line and other cluster failures in addition to retention failures
- NAND DPPM rates may exceed several thousand DPPM requiring compensation/mitigation to meet acceptable SSD AFR specs
- Some of the failures may be captured through NAND component and SSD level testing at the expense of increased test cost/time
- Compensating cluster failures in addition to ECC is required to achieve highest reliability for SSDs used in Compute Apps

“RAID on Silicon” will evolve from a nice to have to a must have!
Soft-Interface Evolution for NAND

NAND flash physics sensitive to e.g. location, temp, time and disturb must be compensated!

1. Read Compensation
   - Soft Information during Read will be required to maximize endurance life for e.g. Enterprise SSD

2. Write Compensation
   - Soft Information used to adjust NAND writes will be required to adjust for physical cell location

3. Disturb Compensation
   - Multi-dimensional scrambling is required to avoid disturb effects in NAND flash during writes
NAND Channel & Soft-Interface

- NAND Channel leveraging Enhanced LDPC
  - Hard and soft LDPC decoding
  - DSP to cancel flash inter-cell interference
  - Mutual equalization between DSP and LDPC.
  - Decoding enhancement based on flash cell modulation.
  - Self-adaptive ECC scheme bashed on flash status.
  - Error recovery for ECC failure or flash block/die failure.

Need advanced NAND flash channel and NAND soft-interface to enable 1xnm MLC NAND in SSD
Evolving NAND business model

- Increased complexity managing RAW NAND
- Proprietary soft-interfaces for NAND emerging
- NAND with ECC introduced, ClearNAND et. al.
  - Provides reliability at component level
  - Easier system integration and migration
- Question: What functionality is best served where?
  - Technical and business considerations impact decisions
- New NAND industry standards are needed to address diverging Consumer and Compute NAND needs

Need a soft-interface NAND standard for optimal deployment of future NAND in SSD
Executive Summary

• NAND Flash based SSD will scale beyond what you think
  – New Data Recovery Techniques, NAND channel, NAND soft-interface
  – New tiered NAND device & SSD system architectures will emerge

• New NVM technologies will emerge in SSD
  – Initial target for new NVM as NV cache eliminating SRAM/DRAM
  – Gradual introduction of new NVM with NAND in tiered architectures

• Fundamental needs that must be addressed remain same:
  – Reliability, Endurance, Performance, Power & Lowest Cost
  – Existing controller technology can be leveraged and evolved to some extent
  – New revolutionary approaches to Solid State Storage will be required

SSD controller and media advancements required to enable next gen SSD

Enabling price points continue to drive SSD to emerge from the bottom (floor cost) and from the top (performance).