The Bleak Future of NAND Flash Memory

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Flash’s Future: Bright

Reliability

Performance

Cost Per Capacity
Flash’s Future: Bright Bleak

Reliability

Performance

Cost Per Capacity
Flash’s Future: Bright Bleak

Reliability

- Decreasing Write Budget
- Increasing Density

Cost Per Capacity

Performance

- Expected Performance Gap
- Low Density Flash
- Disk Drives

Write Latency (µs)

Cost Per Capacity: Decreasing

Density: Increasing
Flash’s Future: Bright or Bleak

Reliability

Cost Per Capacity

Will the price decline be enough?

Performance

Write Latency (µs)

What performance & scaling trends can we expect from our SSDs?

Expected Performance Gap

Low Density Flash

Disk Drives

High Density Flash
Predicting Future Flash-Based SSDs

Fixed SSD Architecture

Flash Chip Trends

Model’s Equations

SSD Trends
The Constant-Die-Count SSD (SSD-CDC)

- Represents High-End (FusionIO, Virident, OCZ)

- Baseline
  - 96 dies
  - 320 GB
  - 34nm, MLC

- Assumptions
  - Constant die count
  - Unlimited PCIe Link
  - Channel Speed: 400MB/s
The Metrics

- Capacity
- Latency
- Throughput
Increasing Density: Multi-bit Cells

SLC
Single-Level Cell
(1 bit)

MLC
Multi-Level Cell
(2 bits)

TLC
Triple-Level Cell
(3 bits)

Floating Gate
(modifies $V_{TH}$)
Increasing Density: Moore’s Law

Feature Size (nm)

Year

ITRS Technology Trend Target

25nm-34nm

6.5nm

2009 2014 2019 2024

Time
The Metrics

• Capacity: 43x

• Latency

• Throughput
Collecting Flash Latency Trends

- In-house flash testing rig
  - XUP Virtex-II
  - Daughter board
  - 10ns resolution

- Chip Collection
  - 45 chips
  - 6 companies
  - 25nm-72nm
  - SLC, MLC, TLC
Empirical Data

Chip Write Latency (ms) vs Feature Size (nm)

- TLC-3
- MLC-2
- SLC-1
Scaling Trends in Empirical Data

- SLC-1
- MLC-2
- TLC-3

Chip Write Latency (ms) vs. Feature Size (nm)
Write Latency of SSD-CDC

- TLC-3
- MLC-2
- SLC-1

2.6x increase in write latency with increasing SSD capacity.
The Metrics

- Capacity: 43x
- Latency: 2.6x
- Throughput
Reduced Bandwidth

SSD-CDC Write Bandwidth (MB/s)

- SLC-1
- MLC-2
- TLC-3

Increased Page Size
MLC: 4kB, TLC 8kB

0.7x
IOPs – 512B Random Accesses

SSD-CDC Write kIOPs

- SLC-1
- MLC-2
- TLC-3

Fastest HDD: 0.2 kIOPs
Our Slowest SSD: 32.0 kIOPs

SSD Capacity (GB)
The Metrics

- Capacity: 43x
- Latency: 2.6x
- Throughput: 0.7x, 0.4x
Conclusion

- **Chip Scaling: A Mixed Bag**
  - Improved: Density and Cost
  - In Decline: Performance and Reliability

- **SSDs: Not always a perfect replacement for disks**
  - Do Get: High Capacity & High IOPs
  - Don’t Get: Low Cost & Low Latency
Questions?

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