The Future of SSD Architectures

Eyal Bek – SSD Product Marketing
Avi Klein – Memory Technology
SanDisk
Source: analysts average PC SSD attach rate: 2010

<table>
<thead>
<tr>
<th>HDD</th>
<th>SSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 TB</td>
<td>128GB</td>
</tr>
</tbody>
</table>

- Instant On
- Lightweight
- Slim
- Longer battery life
- Rugged
Cutting SSD Cost Is Needed to Drive Growth

SSD ASP vs. PC ASP

<table>
<thead>
<tr>
<th>Year</th>
<th>Mainstream SSD</th>
<th>PRO ASP</th>
</tr>
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<tbody>
<tr>
<td>2008</td>
<td>$436</td>
<td>$1,029</td>
</tr>
<tr>
<td>2009</td>
<td>$233</td>
<td>$857</td>
</tr>
<tr>
<td>2010</td>
<td>$216</td>
<td>$783</td>
</tr>
<tr>
<td>2011</td>
<td>$157</td>
<td>$727</td>
</tr>
<tr>
<td>2012</td>
<td>$131</td>
<td>$670</td>
</tr>
<tr>
<td>2013</td>
<td>$110</td>
<td>$627</td>
</tr>
<tr>
<td>2014</td>
<td>$100</td>
<td>$606</td>
</tr>
<tr>
<td>2015</td>
<td>$96</td>
<td>$602</td>
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</table>

Storage share in the BOM is capped

28% 20%
Use Case 1 – Super Fast Side Loading

AJA System Test

- Read Throughput
- Write Throughput

New Devices Require SATA 6Gb/s Performance

<table>
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<tr>
<th>Device</th>
<th>Read Throughput</th>
<th>Write Throughput</th>
</tr>
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<tbody>
<tr>
<td>Pegasus 6 (Thunderbolt)</td>
<td>400 MBps</td>
<td>600 MBps</td>
</tr>
<tr>
<td>MacBook Pro Internal (SATA SSD)</td>
<td>300 MBps</td>
<td>400 MBps</td>
</tr>
<tr>
<td>External FireWire External USB 2.0 800</td>
<td>20 MBps</td>
<td>40 MBps</td>
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(*) copy time in seconds for HD movie

Source: http://www.pcmag.com/article2/0,2817,2388114,00.asp
Use Case 2 – Read or Write Intensive

Application launch (higher is better)

- SSD
- HDD

Boot (higher is better)

Extract Zip folder (higher is better)

- SSD
- HDD

Copy file (higher is better)

Source: Sandisk internal testing
Use Case 3 – Multi Tasking

1. Outlook
2. Windows Media Player,
3. Internet Browser (Download)

Sequential Stream #1:

1 2 3 4 5 6 7 8

Sequential Stream #2:

1 2 3 4 5 6 7

Random Data:

x y

Driver Mixes All Writes

1 2 3 1 2 x 4 5 3 y 6 4 5 6 7 8 7
Use case 4 –
Instant On without Losing Battery Life

What’s Wrong with Existing Sleep?

- Empties battery as memory remains powered
- Not safe – loss of last saved work in case of power outage

New Deep Sleep Enabled by SSD’s

- Data in memory is saved in hiberfil.sys
- Computer can shutdown completely achieving much longer standby time
- Safe – data is saved
In-depth Analysis of Real Computing Usage Workload: Copy File Example

Address According to Operation - Reads & Writes

Let’s Zoom-In….

Source: SanDisk internal testing
Sequential Operations Become Random

Source: SanDisk internal testing
SSD Architecture Evolution

2007
• SLC, 6xnm
• 1ch.
• 32GB
• SATA 1.5Gbs

2009
• MLC, 4xnm
• 4ch/ 10ch.
• 256GB
• SATA 3.0Gbs

2011
• MLC, 2xnm
• 8ch.
• 512GB
• SATA 6.0Gbs

2013

How Do We Keep Scaling and Provide Performance and Reliability of SSD?
## Features Tailored for Usage Scenario

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<th>Architecture Features  (examples)</th>
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<td>Multiple power off/on Access to first I/O</td>
<td>Quick mount Optimize single thread read</td>
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From Our FMS 2010…

- What Changed?

Bridging the Gap
(As shown in FMS 2010)
NAND BASICS
MLC
Best cost per bit
NAND Technology

3 Leveled Cost Reduction:

- **NAND Process**
  - 24nm in Mass Production
  - Migrating to 19nm in H2/2011
  - Expected to Continue Scaling

- **3-bits-per-cell**
  - Mature 4th Generation 3-bits-per-cell Technology

- **High Capacity Die**
  - 24nm 2-bit-per-cell – 64Gb
  - 19nm 3-bit-per-cell – 128Gb
  - Less Die Stacking for a Given Capacity
Reliability

MLC
Best cost per bit
Enhancing NAND Technology Reliability

Goal:
Maintain *Endurance* Target while Scaling – Overcome Natural Drift

Based on SanDisk Internal Evaluation

1) Increase VT Window
2) Dynamic Read
3) Air Gap
4) Proprietary Process, Cell & Programming Scheme Optimization
5) Data Randomization / Scrambling
6) nCache™
7) Hybrid FG Cell Design
8) StrongECC™ + DSP

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Flash Memory Summit 2011
Santa Clara, CA
Enhancing NAND Technology – Sequential Performance

Goal:
Maintain **Performance** while Scaling – Overcome Natural Drift

- Larger Page Size
- All Bit Line Architecture (ABL)
- Parallelism:
  - Multi-Plane in a Die
  - Multi Die in a Product
- Bus performance (e.g. Toggle Mode)
- StrongECC™+ DSP

Enable Higher Performance Level

Source: Klein/Oren FMS 2010
Enhancing NAND Technology – Random Performance

Goal: Maintain Random Performance while Scaling – Overcome Natural Drift

Based on SanDisk Internal Evaluation

Random Performance (e.g. IOPS)

Natural Drift of t-Prog capability
Negative Impact of increase in page size
Enhancing NAND Technology – Random Performance

**Goal:** Maintain *Random Performance* while Scaling – Overcome Natural Drift

- 1) Cache Technology and Optimization per usage
- 2) Page Based Mapping
- 3) Proprietary WL/BL RC reduction
- 4) StrongECC™ + DSP Optimized for Random Performance

Random Performance (e.g. IOPS)
Enhancing NAND Technology – Power

Goal: Maintain *Power / Energy* Target while Scaling

Based on SanDisk Internal Evaluation
Enhancing NAND Technology – Power

Goal: Maintain *Power / Energy* Target while Scaling

1) Proprietary ICC Optimization
2) ABL (All Bit Line) Design Enables Lower Energy per bit
3) Dynamic Power Conscious Parallelism
4) Proprietary Low Power StrongECC™ + DSP
5) Proprietary Low Leakage CMOS
6) AirGap Reduces Capacitance
MLC
Best cost per bit
Flash Memory Summit 2011
Santa Clara, CA
Summary

NAND + System solutions enable continuation of NAND scaling while maintaining reliability, performance & power requirements.
SSD enables a multitude of opportunities in mobile computing
It is up to us to bring the SSD technology to mainstream
This is achievable by:
• Continuous process shrink
• Tailoring solutions to use cases

System design based on real life usage data for enhanced real life user experience
Thank You