NAND Flash Evolution: Capabilities & Characteristics

Flash Benefits
- Lower $/GB Cost
- Higher Capacity
- Higher Unit Volume

Flash Challenges
- Shorter Endurance
- Performance w/less die
- Lower Reliability
- Higher ECC Req.
- Evolving Flash Types

Growing Dependence on Flash Controller to Close Gap

All flash is different and changes every 18 months!
- Endurance, Reliability, Performance, Interface

Program / Erase Cycles

- Previous Generation: 10K
- Current Generation: 3K
- Next Generation: 1K

Error Correction Requirements (bits/KB)

- 5x nm MLC: 4 bits/KB
- 3x nm MLC: 12 bits/KB
- 2x nm MLC: 40 bits/KB
- 3-bit per cell: 60 bits/KB

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Introducing the LSI SandForce SF3700 Flash Controller

- Newly engineered to solve the latest challenges of NAND Flash
- Designed for both Enterprise and Client markets
- Provides native PCIe and SATA interfaces in a single ASIC
- Builds on the award winning technology of current SandForce Flash Controllers
- OEM SSD manufacturers bringing up designs now; mass production expected 1H’14
SF3700 Flash Controller

New modular and flexible design best supports evolving flash types

- Modular/Flexible Architecture Enables:
  - Single ASIC with multiple host interfaces
  - Ability to support new host interface features
  - Support for new Flash modes
  - Continuous innovation through product life

- Benefits
  - Faster time to market
  - Better cost and inventory management
  - Extended product life
  - Richer product portfolio

40nm Process

SATA III, 6Gb/s AHCI

PCIe Gen2 x4 NVMe & AHCI

MAP Management Unit

Garbage Collection

Dual AES-256

Intelligent Wear Leveling

Back-End Controller

GPIO

Programmable NAND Interface

Toggle / ONFI
9 channels
SLC / eMLC / MLC / TLC
2y, 1x, 1y nm

Front-End I/F

Core

Back-End I/F

PHY

DuraWrite™

Read Disturb Management

Intelligent Wear Leveling

SHIELD™

RAISE™

RAISE™

Back-End Controller

GPIO

Programmable NAND Interface

Toggle / ONFI
9 channels
SLC / eMLC / MLC / TLC
2y, 1x, 1y nm

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SF3700 Performance
Random and Sequential

- These SF3700 results assume 100% entropy (worst case)

<table>
<thead>
<tr>
<th>PCIe Performance</th>
<th>SF3700 (256GB) MLC</th>
<th>Samsung XP941 (512GB) MLC*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing Conditions</td>
<td>Early FW FOB 100% Entropy</td>
<td>LSI Spec 8GB Span 100% Entropy</td>
</tr>
<tr>
<td>Rnd Read (IOPS)</td>
<td>150K</td>
<td>82-99K</td>
</tr>
<tr>
<td>Rnd Writes (IOPS)</td>
<td>81K</td>
<td>60-70K</td>
</tr>
<tr>
<td>Seq Reads (MB/s)</td>
<td>1450</td>
<td>986-1134</td>
</tr>
<tr>
<td>Seq Writes (MB/s)</td>
<td>1800</td>
<td>677-935</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SATA Performance</th>
<th>SF3700 (256GB) MLC</th>
<th>Samsung 840 Pro (256GB) MLC*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing Conditions</td>
<td>Early FW FOB 100% Entropy</td>
<td>LSI Spec 8GB Span 100% Entropy</td>
</tr>
<tr>
<td>Rnd Read (IOPS)</td>
<td>90K</td>
<td>91K</td>
</tr>
<tr>
<td>Rnd Writes (IOPS)</td>
<td>46K</td>
<td>70K</td>
</tr>
<tr>
<td>Seq Reads (MB/s)</td>
<td>562</td>
<td>413</td>
</tr>
<tr>
<td>Seq Writes (MB/s)</td>
<td>502</td>
<td>373</td>
</tr>
</tbody>
</table>


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**SF3700 Latency**
Predictable latency is key for datacenters

- **Write latency should hit 100% as quickly as possible**
- **Read latency should stay vertical as long as possible**

- Flash performance trades off Latency vs. IOPS: \( IOPS = \frac{QD}{\text{latency}} \)

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* Performance Model

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DuraWrite™ Data Reduction – SF3700 Improvements

- Enhanced version of field-proven LSI SandForce data reduction technology
  - Higher data reduction capability
  - Improved block picking and garbage collection

- Provides numerous advantages for typical data

- Includes many recursive benefits

Solves NAND Issues

- Shorter Endurance
- Performance with less die
SHIELD™ Error Correction Technology
Advanced Low-density Parity Check (LDPC) for Flash Storage

- The strongest SSD ECC available today
- Applies progressively stronger decoding methods as necessary

SHIELD technology uniquely combines a number of features and correction techniques

Solves NAND Issues
- Lower Reliability
- Higher ECC Req.
- Evolving Flash Types

Don’t be fooled by other LDPC solutions
SHIELD Error Correction Technology
Adaptive Code Rate

- Flash at beginning of life (BOL) is more robust; requires less ECC
- Leverages DuraWrite™ Flash Translation Layer to dynamically change Spare area
- Gives extra spare ECC field to OP and increase performance / endurance
  - Up to 3% more OP (as much as 41% more total OP*)
- As drive reaches end of life (EOL), SHIELD increases ECC to maintain readability and increase endurance beyond NAND spec

**Conventional Error Correction:**
Stores fixed ECC in spare field

**Adaptive ECC (BOL):**
Stores ECC in a portion of spare field and increase OP

**Adaptive ECC (EOL):**
Stores ECC in spare field and uses some of the NAND page

Solves NAND Issues
- Lower Reliability
- Higher ECC Req.
- Evolving Flash Types

Adaptive ECC allows for more free space
@ BOL = Higher Performance / Endurance

*Based on physical OP change = (3 / 7.37)
**RAISE™ Data Protection SF3700 Enhancements**  
*(Redundant Array of Independent Silicon Elements)*

- RAISE protects data from unrecoverable ECC failures  
  - If SHIELD ever failed, RAISE would step in to protect the data

### New Options
- Auto-Reallocation – RAISE Level 2 Option  
  - After a die failure either:  
    1. Another die can be automatically allocated to protect against an additional die failure (reduces OP)  
    2. The affected data can be moved into a RAISE level 1 configuration without using another die
- Fractional RAISE – RAISE Level 1 Option  
  - Protects against failures in lower die-count configurations; uses less than a full die
- Optional 9th Flash channel for an extra die enables RAISE protection when providing full binary user capacity

<table>
<thead>
<tr>
<th>RAISE Levels</th>
<th>Description</th>
<th>Failures Protected</th>
<th>Die Used</th>
<th>Correctable Elements</th>
<th>Probability of data loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Original)</td>
<td>Protects against failures in higher die-count configurations</td>
<td>Single page &amp; block</td>
<td>1</td>
<td>1</td>
<td>Lower</td>
</tr>
<tr>
<td>2 (New)</td>
<td>Protects against full die failures with additional die or high OP</td>
<td>Multiple page &amp; block, &amp; single die</td>
<td>2</td>
<td>2</td>
<td>Lowest</td>
</tr>
</tbody>
</table>
## Key Feature Summary

<table>
<thead>
<tr>
<th>SF3700 Features</th>
<th>User Benefits</th>
<th>Flash Challenge Solved</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DuraWrite Enhancements</td>
<td>• Higher Performance</td>
<td>• Shorter Endurance</td>
</tr>
<tr>
<td></td>
<td>• Longer Endurance</td>
<td>• Performance w/less die</td>
</tr>
<tr>
<td>• SHIELD Error Recovery</td>
<td>• Higher Data Reliability</td>
<td>• Lower Reliability</td>
</tr>
<tr>
<td></td>
<td>• Longer Endurance</td>
<td>• Higher ECC Req.</td>
</tr>
<tr>
<td>• New RAISE Levels and Options</td>
<td>• Higher Data Protection</td>
<td>• Lower Reliability</td>
</tr>
<tr>
<td>• Flexible, modular architecture</td>
<td>• Adaptability to future Flash</td>
<td>• Evolving Flash Types</td>
</tr>
<tr>
<td>• Low, predictable latency</td>
<td>• Consistent performance to meet SLAs</td>
<td>• Performance w/less die</td>
</tr>
</tbody>
</table>

Engineered to solve the challenges of NAND Flash
SF3700 Reference Design SSDs

- Fastest time-to-market with largest selection of flash vendors
- Widest selection of form factors (standard / custom)
- DRAM-Less design enables many other options
- Directly engage with flash, drive, system OEMs & cloud service providers

LSI Enables the Entire Production Flow

- Flash Controllers
- Firmware
- Mfg & Test Tools
- Turnkey Reference Designs
- Doc & Support

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LSI DuraClass™ Technology Optimizes Data Storage

- **Reliability** – RAISE™ and SHIELD™ technology, End-to-End protection
- **Endurance** – DuraWrite™ technology, MLC flash in Enterprise
- **Single-Chip** – DRAM-less, super dense designs
- **Performance** – Low latency with low CPU utilization
- **Extensive Manageability** – Simple IT management
- **Drive Level Security** – Safe Data Storage without Compromises
- **Capacity Density** – More bits in small systems
- **System Efficiency** – Best total performance per watt
- **Flexible Power Management** – Increased battery life
LSI SandForce SF3700 Flash Controller

- Newly engineered to solve the challenges of NAND Flash

- Expanding award-winning DuraClass technology
  - SHIELD advanced LDPC error correction
  - DuraWrite data reduction improvements
  - RAISE data protection enhancements

- Continuing a proven business model
  - Complete turnkey solutions
  - Wide Flash memory support

Accelerating the Growth of SSD Deployments
Live Demonstrations

- LSI will be running live demonstrations of the SF3700 at two events:
  - Supercomputing 2013
    - November 18-21; Denver, Colorado
  - Accelerating Innovation Summit 2013
    - November 19-21; San Jose, California

- LSI partners showing SF3700 demonstrations at AIS include:

- Demonstrations include Toshiba A19nm and Micron 20nm Flash