A Comprehensive Approach to Flash-SSD Quality Management for Enterprise Storage

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Outline

- Flash-SSD E2E Quality Management Approach & Concept
- Flash Quality
- Firmware Quality
- SSD Qualification Process
- SSD Quality Process
- Summary
3D NAND driven scaling enabling aggressive $/GB reduction thru 2020
3D TLC endurance gains enabling significant Enterprise & Hyperscale SSD market growth
Enterprise storage customers require robust Storage System Quality performance driving continuous focus on Flash-SSD E2E quality

Source – Gartner, March 2016
Quality Shift Left

It’s vital to detect quality problems as quickly as possible:

- loss of customer satisfaction and loyalty
- delayed product shipments
- recall of defective product
- higher costs in warranty claims

Comprehensive approach towards the management of Flash-SSD supplier quality for enterprise storage applications <= ‘Shift Left’ Quality driver
SSD Quality Equation

1. Flash Quality
   1) Flash component reliability
   2) Flash Management
   3) Reliability Monitoring
   4) Fab quality, wafer/die sort, trims
   5) Stacked package quality

2. Firmware Quality
   1) FW qualification/quality management
   2) Error detection & recovery
   3) Key features – Wear Leveling, WA
   4) 1st time data capture

3. SSD Qualification Process
   1) SSD Qualification methodology
   2) Characterization & reliability modeling
   3) EMI/thermal modeling & simulation
   4) Power Hold-up architecture

4. SSD Quality Process
   1) Quality Organization & major imperatives
   2) Manufacturing test
   3) Manufacturing quality process
   4) Corrosion prevention/mitigation
   5) Quality Scorecard

Quality summit as key vehicle to drive quality improvements across core SSD suppliers – adopt systematic benchmark/methodologies

Flash Memory Summit 2016

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1. Flash Quality

- Flash Design
- Fab Quality
- Wafer Test
- Package & Assembly
- Package Test
- Manufacturing SPQL Quality
- Field Quality
Flash Management Key Directions

2D NAND
- Pre-Read Tuning
- Table based (PE cycles)
- ECC
  - BCH Centric
- Vt Offset retries
- RAID/Higher Level Code
- Block Retirement

3D NAND
- Pre-Read Tuning
- Table based (PE cycles)
- ECC
  - LDPC Centric
- Soft Decode methods
- Dynamic Trims
- Vt Offset retries
- Calibrated Reads
- RAID/Higher Level Code
- Plane/Die Protection
- Block/Page Retirement
Flash Component Qualification & Endurance RDT Approaches

**Flash Component Centric**

- Qual methodology and goals based on JESD47 standard
- One-size fits all methodology
- NAND component qualification/quality centric

**SSD Use-case based**

- Tailor Flash Qualification test conditions & goals to meet intended SSD usage requirements
- Align NAND component qualification to emulate SSD operating conditions
- FW policies emulated at NAND level

**Endurance RDT**

- Flash accelerated Cycling thru EOL – monitor cycling endurance by verifying if process/trims intrinsically meet datasheet. Accelerate defect related failure modes via high voltage stressing
- Endurance RDT – validate flash media’s endurance capability thru EOL. Functional fails, NAND Block fails, UBER data errors
*‘Supplier of Gap’ & ‘Best of Breed’ supplier are based on scoring from each parameter category (not one supplier)*
2. Firmware Quality

FW Qualification

Design Coding
- Run unit tests - verify each function
- Run code under the software simulator environment to verify the behavior of each module
- Monitor security code quality

EVT
- Engineering Verification Test
  - Verify drive functions and behavior with FPGA/ actual drive
  - Conduct Performance testing

EVT Review
- Determine if ready to proceed to DVT phase
- Review EVT results for firmware quality, SoC, PCBA and mechanical

DVT
- System tests are conducted by supplier QA team
  - Compatibility testing with OEM system
  - Performance testing as the drive level and the system level
  - RDT - Reliability testing with various Power, Temperature

DVT Review
- Determine if product can be shipped to OEM
  - Review DVT results
  - Judge if it can proceed PQT phase

Early verification System Test – confirm compatibilities & stability

* EVT - Engineering Validation Test: Build several units that function as expected, meeting all functional requirements
* DVT - Design Validation Test: Build lots of units that function as expected, meeting all functional requirement
Data Integrity: Error Detection and Recovery

Data is protected thru several levels of checks and corrections

- **Data in NAND** is protected by
  - NAND BCH-ECC
  - Read Level Correction
  - Corrective Read
  - RAID across NAND
  - FW background data integrity scans

- **Data between Host and NAND** is protected by Data-path Protection, Parity and Power-loss protection
  - Internal Controller Data-paths & Memories
  - External DRAM/buffers
### SSD Qualification Methodology

<table>
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<tr>
<th>Phase</th>
<th>Purpose</th>
<th>Typical Confirmation Items</th>
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</table>
| EVT   | * Confirm basic functionality for key items | * Mechanical (shock & Vib/Temperature distribution)  
* Electricity (Power/Signal Integrity)  
* NAND Control function/ Parameter tuning  
* Firmware Function test  
* SoC Phy verification  
* Performance test |
| DVT   | * Confirm drive readiness by prototype  
* Risk assessment for transition to the mass production | * Verification assurance test (Power/ Transport Jitter/ Weight/ Dimension)  
* Environment (Temperature/ Humidity/ Shock & Vib/ Packaging/ESD/EMI)  
* RDT - Reliability test  
* Firmware Function test  
* Compatibility test  
* Performance test  
* Safety/EMI standard certification  
* Component parts  
* PCBA evaluation  
* Manufacturing Process Test  
* Productivity confirmation |
| PQT   | * Product readiness and Productivity confirmation | * Equipment/Jig  
* In-Process Quality/Yield  
Repair system set up and validation |

**Abbreviations:**  
PQT – Production Qualification Test,  
RDT – Reliability Demonstration Test,  
ORT - Ongoing Reliability Test
SSD Qualification E2E Ownership

1. Flash Characterization and Verification, Flash Management Development

2. ASIC Validation
   Electrical Integration
   Thermal & Mechanical Validation

3. FW unit testing
   FW Qualification and Regression
   Customer System Testing

4. SSD Reliability Modeling
   Product Assurance
   SSD Quality & Reliability

5. Mass Production Readiness
   Factory Validation
   Factory Quality Monitoring Process

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SSD Reliability Model

1. Early Life Fails – Flash particle driven defects, Firmware quality
2. Constant Failure rate – Random defect driven
3. Need to focus on Mid Life/End of Life Reliability failure modes – Flash reliability, Components, Sub-tier quality focus
SSD Qualification Process

- S1: SSD Qualification methodology/requirement
- S2: SSD Characterization & Reliability modeling
- S3: EMI/Thermal modeling & Validation
- S4: Power hold-up architecture

Legend:
- Supplier of Gap
- Best of Breed
4. SSD Quality Process

SSD Manufacturing Test Flow

IQC → PCBA assembly → Automated Optical inspection → Automated x-ray inspection → In Circuit Test

Functional Test 2 → Burn In → Functional Test 1 → Pre Test → Visual Inspection

Final Test → Final Inspection & customer lable → Shipping

ORT: Ongoing Reliability Test

Out of Box Audit
Industry Consistency in how to handle EOL

1) PFA (Predictive Failure Alert) based on rated PE cycles & Data Retention target
2) Continue use of drive upon PFA (read & write). Read only mode – determine when to stop use of drive based on spare block %, block retirement based on OP. Need graceful transition into read only mode
3) Combination of 1) & 2)
SSD Quality Process

Q1: Major Quality Imperatives  Q2: Mfg Test Overview  Q3: Innovation Item  Q4: Mfg Quality Process  Q5: Corrosion prevention  Q6: SSD Quality scorecard

Supplier of Gap  Best of Breed
Summary

- Enterprise Storage growth driven by 3D NAND density, reliability improvements, and $/GB reduction in 2016-2020. Enterprise customers continue to require strong Storage System Quality performance enabled by robust Flash-SSD E2E quality

- A comprehensive approach towards the management of Flash-SSD supplier quality for enterprise storage applications is presented

- Systematic approach focusing on 4 areas critical to Flash-SSD quality – 1) Flash Quality, 2) SSD Qualification methodology, 3) Firmware Quality and 4) SSD Quality. We further apply detailed breakdown and benchmark, thus driving industry best practices and ‘Shift Left’ quality imperatives.