Pre-programmed Flash memory Recommended Best practices, X-ray and Post Oven Reflow

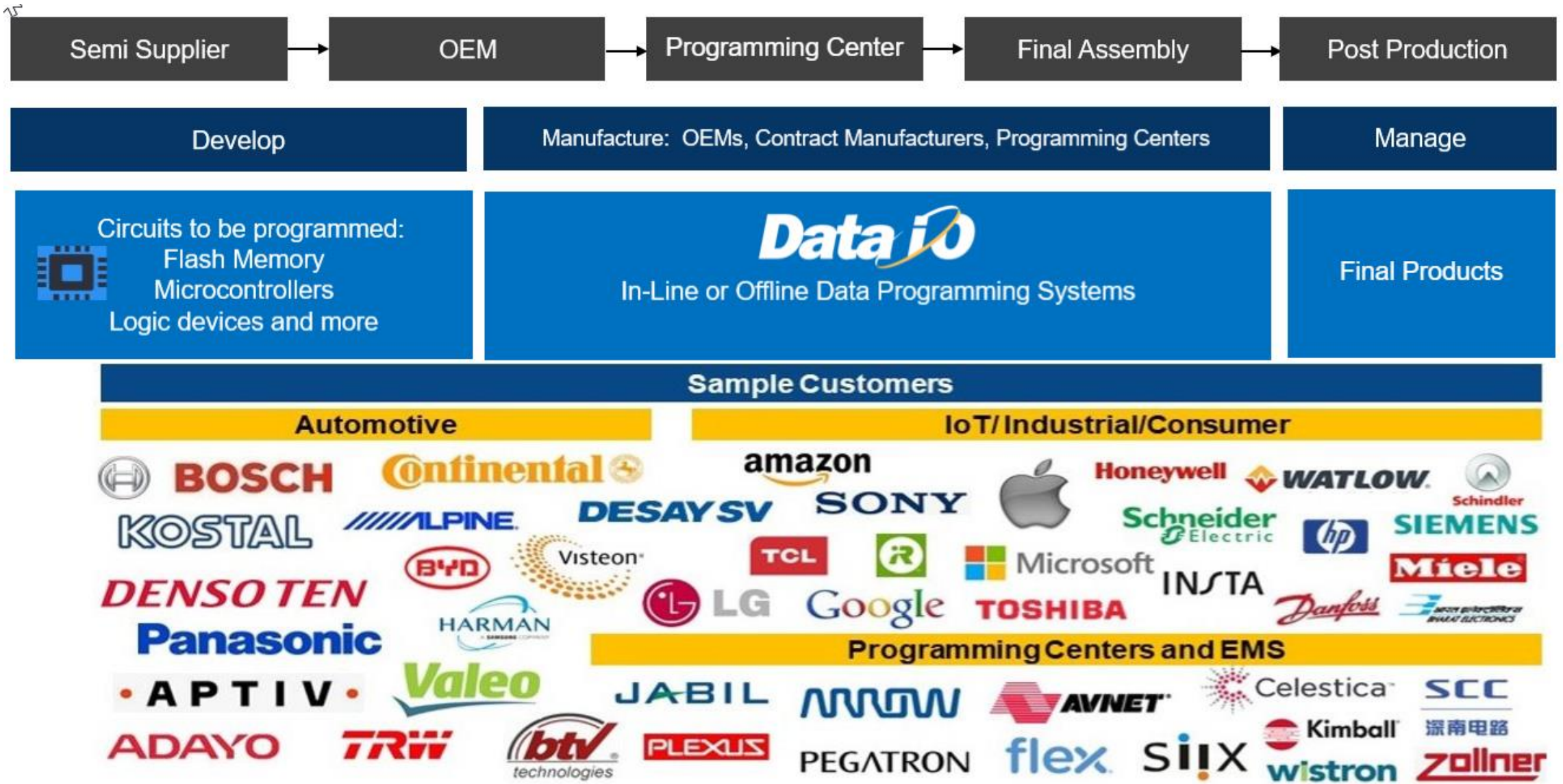
www.dataio.com

Abstract

Advancements in the flash technology to support larger storage in a small package have raised concerns on the reliability of pre-programmed devices during the manufacturing process. High energy radiation exposure can be a source of stress for some preprogrammed Managed-NAND devices if not managed properly. This stress varies depending on the grade of the managed NAND device including Commercial, Industrial and Automotive. Managed-NAND integrates NAND flash memory and an embedded controller chip in a single package to perform error correction (ECC), wear leveling and bad-block management internally to ensure the integrity of the data programmed in the Flash array. NAND performance is relative to the quality and sophistication designed into the embedded controller firmware.

Production bottlenecks and high cost of programming large files at test make preprogramming the preferred method for production managers building product using high-density eMMC NAND flash. While there are several well documented papers to validate that X-Ray inspection can impact data retention in preprogrammed eMMC NAND devices, little is mentioned regarding technology advancements designed to correct eMMC data retention errors including bit-flips. This session is intended to help production managers better understand eMMC NAND and 3D UFS with a focus on the technology safeguards and recommended best practices to ensure data integrity from the time the eMMC or UFS device is preprogrammed to final product. Error correction code (ECC) enabled eMMC devices preserve data integrity and are essentially immune to "reasonable" doses of irradiation.

Who We Are & What We Do



Executive Summary

The rapid growth in NAND automotive flash memory content and **the impact of data retention through X-ray inspection and oven reflow** has become a topic of discussion among automotive electronic suppliers, semiconductor vendors and programming vendors

Data I/O partnered with industry leaders to study the impact of x-ray and oven reflow on Managed NAND devices

- X-ray tests were performed with Managed NAND flash in 15nm and 20nm lithography from multiple semiconductor vendors. Our study found that **processing Managed NAND flash through X-ray inspection is safe when following best practices**, with filtering having the biggest impact

- Oven reflow test was performed using automotive grade 3D TLC UFS devices from multiple semiconductor vendors. Our study found that **pre-programming is safe** and full device performance is maintained with a post reflow data refresh

Data I/O has published a set of **recommended best practices and guidelines** to ensure data retention when processing preprogramming Managed-NAND flash through X-ray and oven reflow

Data I/O and Partners Collaborate

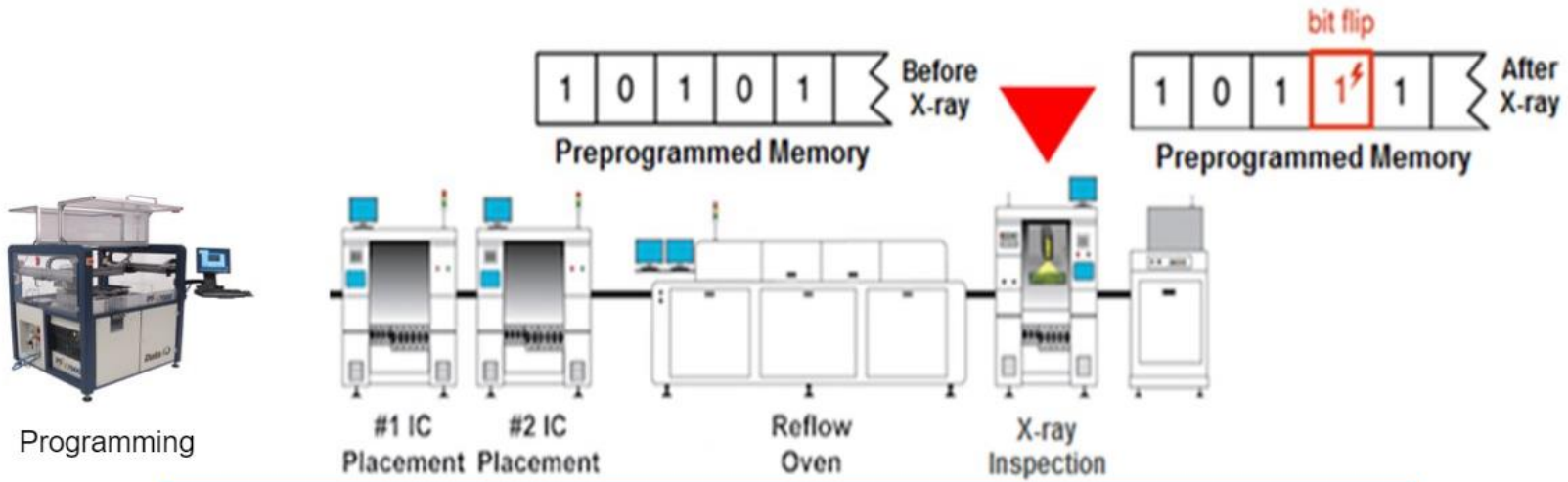
	2016	2018	2019
Industry Concern	2D NAND Through Oven Reflow is not Safe	eMMC Managed NAND Through X-Ray is not Safe	3D NAND, TLC Through Oven Reflow is not Safe
Data I/O Response	Joint Study with leading memory vendor, Micron	Joint study with X-ray Vendor, Nordson DAGE	Joint Study with leading memory vendor, Toshiba
	Published Findings at Flash Memory Summit	Published Findings APEX Tech Presentation	Plans to Publish Findings
	Data I/O Recommended Best Practices	Data I/O Recommended Best Practices	Data I/O Recommended Best Practices

Data I/O is the only programming equipment supplier to conduct joint studies with industry partners to address key issues.

X-Ray Problem Statement

Managed-NAND integrates NAND flash memory and an embedded controller chip in a single package to perform error correction (ECC), wear-leveling and bad-block management internally

- Preprogramming is the preferred method for programming large files, gigabytes (GB) of data
- Low Energy Radiation is a source of stress for pre-programmed managed NAND devices



Data I/O and Nordson agreed to conduct a controlled experiment to see the impact of XRAY on data integrity

Test Purpose

Education

- Understand how an operator sets up an X-ray machine
- Understand the impact of X-ray machine settings on image quality

Criteria

- Sample test using automotive grade Managed-NAND
- Source parts from multiple flash memory suppliers
- Test parts of different process geometry: 15nm and 20nm

Goals

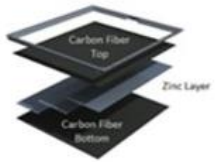
- Find the breaking points, unsafe X-ray setup parameters
- Establish safe X-ray setup parameters that provide a quality image
- Publish a set of recommended best practices

Equipment Used

The following test equipment was used for our X-ray test study:

- Offline X-ray machine, with and without optional filtering tray
- Data Programming and Verification using the Data I/O LumenX desktop programmer
- Two vendors of automotive grade eMMC devices
  - Vendor A at 15nm linewidth
  - Vendor B at 20nm linewidth
- 10 samples of each eMMC test device were preprogrammed with an X/OR data pattern prior to X-ray

X-ray Machine



Filtering Tray

Device Programmer

Semi-vendor A (32GB)
15nm Lithography

Semi-vendor B (8GB)
20nm Lithography

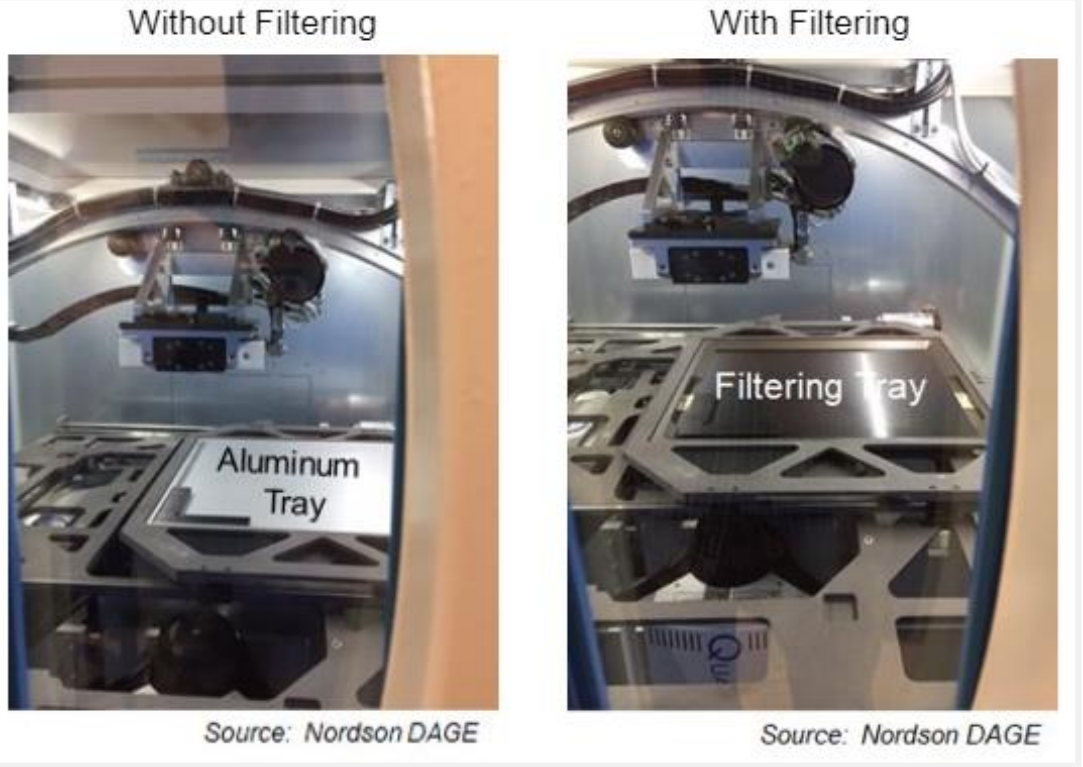
X-ray Test and Data Validation process

1. **Insert preprogrammed test device onto tray**

   Aluminum Tray and Filtering Tray (150 Micron Zinc)
2. **Input X-ray machine settings**
3. **Verify image quality**
4. **Begin X-ray inspection for targeted time**
5. **Remove device from X-ray**
6. **Insert device into Programmer socket**
7. **Run Verify Test to confirm data integrity (Pass/Fail)**
   - *If Fail, stop test and discard device, record findings*
   - *If Pass, reinsert device back into X-ray machine*
   - *Go to Step #4*

QUADRA 7 X-RAY MACHINE

'INTERNAL VIEW'



Source: Nordson DAGE

Source: Nordson DAGE

VENDOR A: TEST PLAN & RESULTS 15NM EMMC, Managed NAND

X-Ray Set-up Parameters		Test 1	Test 2	Test 3	Test 4
	Filtering Tray	No	No	No	Yes
	Tube Voltage	120KV	100KV	80KV	80KV
	Tube Wattage	5W	5W	3W	3W
	Distance to Target	1.5mm	12.4mm	12.4mm	12.4mm
	Exposure Time	10 min	5.5 min	5.0 min	5.0 min
	Image Clarity/Quality	Excellent	Excellent	Excellent	Excellent
	Test Results				
Times through X-ray	1	Fail	Fail	Pass	Pass
	2			Fail	Pass
	3				Pass
	4				Pass
	5				Pass
	6				Pass
	7				Fail

Zinc Filtering (150 micron) had the biggest impact

- *X-ray setup parameters of 80KV, 3W, 12.5mm distance are typical*
- *5 minutes of exposure time is excessive, not typical for inline X-ray*

VENDOR B: TEST PLAN & RESULTS 20 NM EMMC, Managed NAND

X-Ray Set-up Parameters		Test 1	Test 2	Test 3	Test 4	Test 5
	Filtering Tray	Yes	No	Yes	Yes	Yes
	Tube Voltage	80KV	60KV	60KV	80KV	60KV
	Tube Wattage	3W	2W	3W	2W	2W
	Distance to Target	12.4mm	12.4mm	12.4mm	12.4mm	12.4mm
	Exposure Time	5.0 min	5.0 min	5.0 min	5.0 min	5.0 min
	Image Clarity/Quality	Excellent	Excellent	Excellent	Excellent	Excellent
	Test Results					
Times through X-ray	1	Pass	Pass	Pass	Pass	Pass
	2	Fail	Fail	Pass	Pass	Pass
	3			Pass	Pass	Pass
	4			Fail	Fail	Pass
	5					Pass
	6					Fail
	7					

Zinc Filtering (150 micron) had the biggest impact

- *X-ray setup parameters of 60KV, 2W, 12.5mm distance provided a quality image*

X-ray Test Summary

Processing preprogrammed Managed-NAND Flash Memories through X-ray is safe when following recommended best practices

- Zinc Filtering is the single **most important** requirement
  - Low Energy Photons are filtered out. They do not provide good image quality, but impact device reliability
- Automated XRAY processes are better than a manual inspection as less total time is required
- X-ray machine operators should follow recommended best practices

Multiple Silicon Vendors were able to achieve reliable programming with excellent XRAY image quality when following best practices

Automotive Electronics Tier 1 suppliers can confidently move to 100% XRAY inspection while using Data I/O LumenX programmers

Oven Reflow Problem Statement

Memory devices become increasingly susceptible to reflow induced memory loss as process geometries shrink and reflow temperatures increase. Data I/O previously established that programming was safe with MLC devices. Does this change with automotive grade TLC?

- *As vendors move from MLC to TLC devices, will there still be acceptable margin through reflow?*
- *Is there an impact to cell lifetime if devices are pre programmed?*
- *What are the best practices for newest generation of devices?*

Executive Summary

Data I/O and a leading UFS memory vendor have collaborated to study the impact of oven reflow (temperature) on data retention for Automotive Grade 3D UFS, TLC devices.

Experiment shows:

- *Reflow slows down read performance, but **does not** cause reliability failures (bit flip).*
- *More reflows cause more read performance slow down, but do not cause loss of data.*
  - *Up to 3 reflows possible*
  - *Refreshing the device after reflow fixes read performance issues completely*

Conclusion: Preprogramming is safe and full performance is maintained with a post reflow refresh

Preprogramming Test Plan – Automotive 3D UFS
7 Evaluations, 20pcs of 128GB, 50pcs of 256GB (2 Firmware Versions)

Evaluation Process

1. Preprogram (100%), without PSA using specific algorithm for each supplier and device.
2. Reflow at standard profile
3. Read data, check error rate (%)
4. Measure read performance (MB/s)
5. Selective Refresh, measure time
6. Force Refresh, measure time
7. Erase user data
8. Repeat for next reflow cycle

Evaluation-1 (128GB)

-10pcs
-Evaluation of reflow 1x
-Evaluation of reflow 2x

Evaluation-2 (128GB)

-10pcs
-Evaluation of reflow 1x
-Evaluation of reflow 3x

Evaluation-3 (256GB)

-9pcs
-Evaluation of reflow 3x
-Ship to vendor for analysis

Evaluation-4 (256GB)

-20pcs
-Evaluation of reflow 1x
-Evaluation of reflow 2x

Evaluation-5 (256GB)

-21pcs
-Evaluation of reflow 1x
-Evaluation of reflow 3x

Programmers vs. Duplicators
Programmers Meet Automotive Industry Strict Quality Standards

Programmers	Duplicators
IP (Data Files) Stored on a Secure Network	IP (Data Files) Stored on "Master" Devices - Prone to Intellectual Property Theft
Job Changeovers Secured and Managed	Job Changeovers are Prone to Human Error
Supports multivendor UFS Devices - Adjusts critical timing features of unique UFS devices	Generic UFS Interface - May not be suitable for all UFS vendors
UFS Devices Individually Tested	UFS Devices, not Individually Tested
UFS 3.0 Standard Supported - Uses different programming voltages than UFS 2.x	Support for UFS 3.0 may requires HardwareRedesign
Supports Dynamic Data, Serial Numbers	Cannot Serialize IC's
Supports Bare NAND - Hundreds of Bad Block Schemes	Cannot Support Bare NAND - No controller for Back Block Management (BBM)
Supports RPMB - Replay Protected Memory Block Feature	Does Not Support RPMB - Replay Protected Memory Block Feature
Supports Security Provisioning - Asymmetric Keys and Certificates	No Provisioning Support
Supports Full Device Traceability and Reporting	No Unique Device Statistics

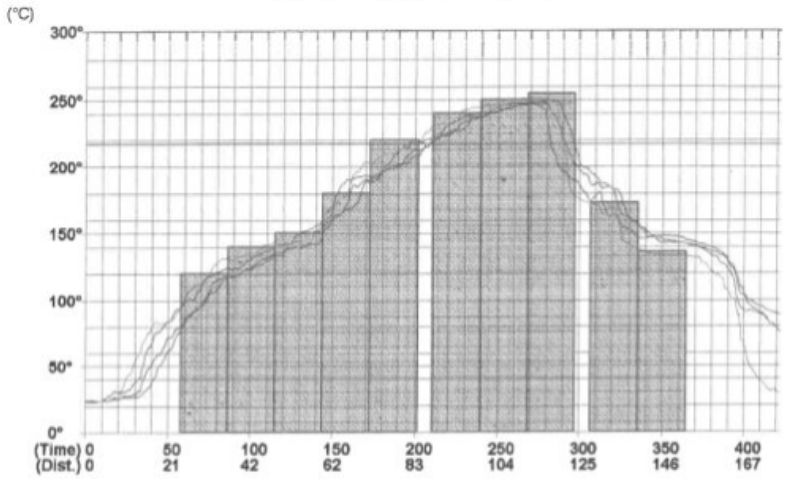
Because of the Process Reliability Concerns with Duplicators, only programming technology was evaluated

2 Oven Reflow Profiles Used - Standard MFG and JEDEC

Data I/O - MFG Reflow Profile

Recommended by EMS Partner, Approved by Semi-Partner

LEADFREE2 5-13-2019

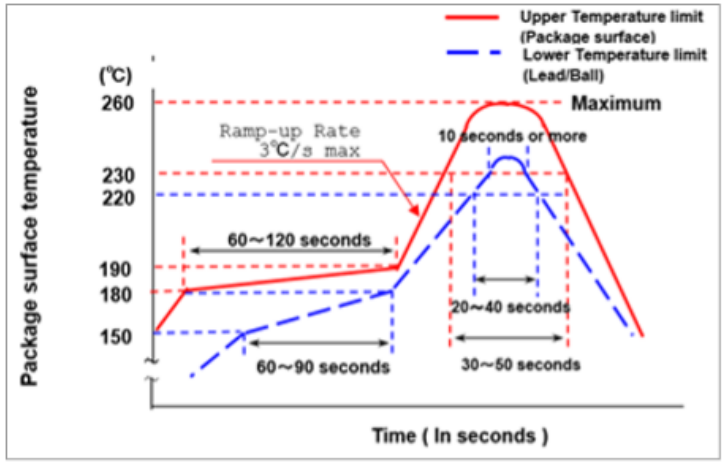


IR Condition	
STANDARD	T_peak=251degC, t_peak=30sec

Legend	TC1	TC2	TC3	TC4
Liquid Time	86	83	92	96
Peak Temperature	247	248	250	251

Semi-Vendor - JEDEC Max Reflow Profile

Used by Semi-Partner



IR Condition	
JEDEC (J-STD-020E)	T_peak=260degC, t_peak=30sec

Profile Name: LEADFREE2 5-13-2019
Process Name: Process Name Here
Recipe name: LEADFRE2
Product Name: DATA/IO
User Name: CHHOU TAING
Conveyor Speed: 25
Number of Samples: 424
Maximum Distance: 176
Liquid Temperature: 217

Data Retention Results

Evaluation 1, 2

128 GB

- 20 devices
- Evaluation after reflow: 10 devices (1x & 2x), 10 devices (1x & 3x)
- No data errors found

Evaluation 3

256 GB

- 9 devices
- Evaluation after reflow: 9 devices (3x)
- Shipped to memory vendor for analysis
- No data errors found

Evaluation 4, 5

256 GB

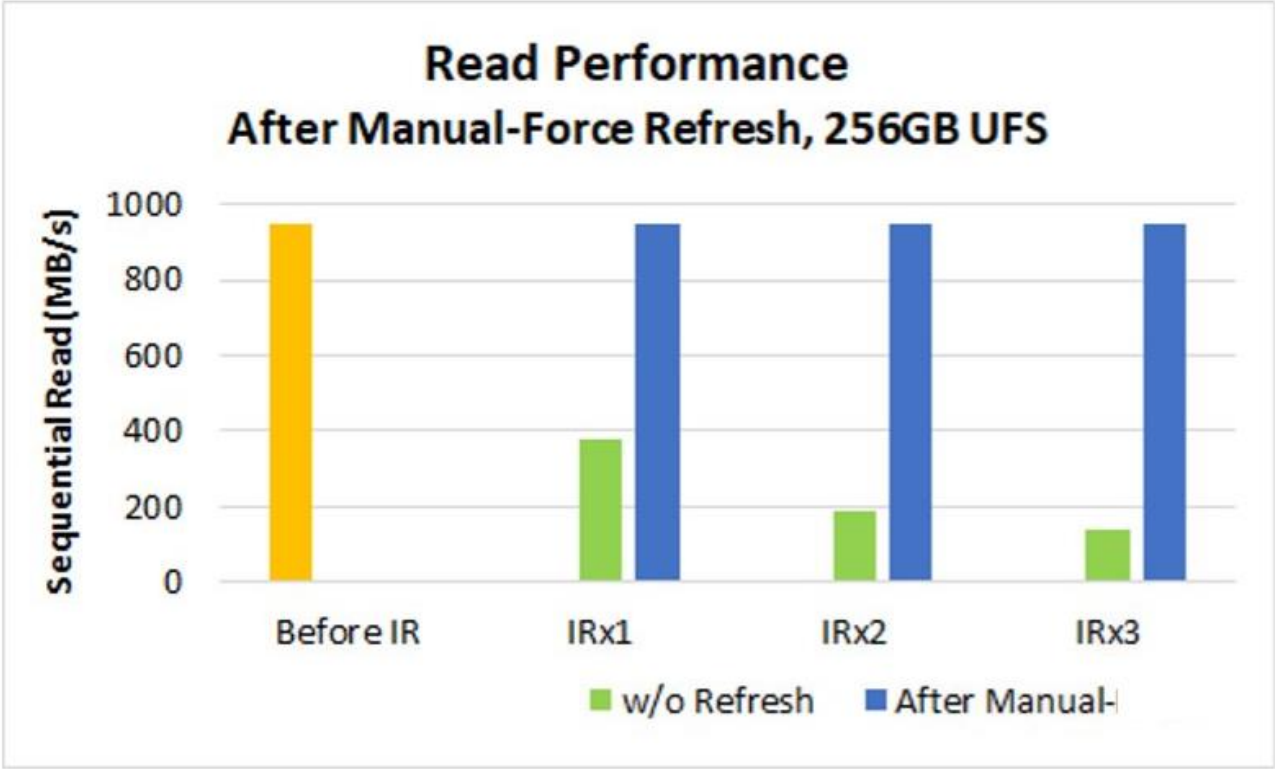
- 40 devices
- Evaluation after reflow: 20 devices (1x & 2x), 20 devices (1x & 3x)
- No data errors found

No data errors were found

Read Performance is Recovered After Manual Refresh

Impact of oven reflow on device read performance

- ✓ Using Manual Refresh, Read performance is **completely** recovered after refresh
- ✓ Data I/O recommends to **use Manual Refresh after reflow**
  - from both "read performance" and "data retention" points of view



Joint Oven Reflow Test Summary

Preprogramming Automotive Grade 3D UFS, TLC Flash Memory on Data I/O LumenX programmers is safe

- Zero data loss, all tests
- No Impact to Long term reliability

Recommended Manual-Force Refresh after oven reflow restores read performance

- Refresh times are near constant for both Standard MFG Reflow temperature at 251degC, and JEDEC Peak Reflow temperature at 260degC

After the study, the memory supplier decided to support 100% preprogramming

Duplicators were not evaluated and are not recommended for Automotive Programming

Thanks!