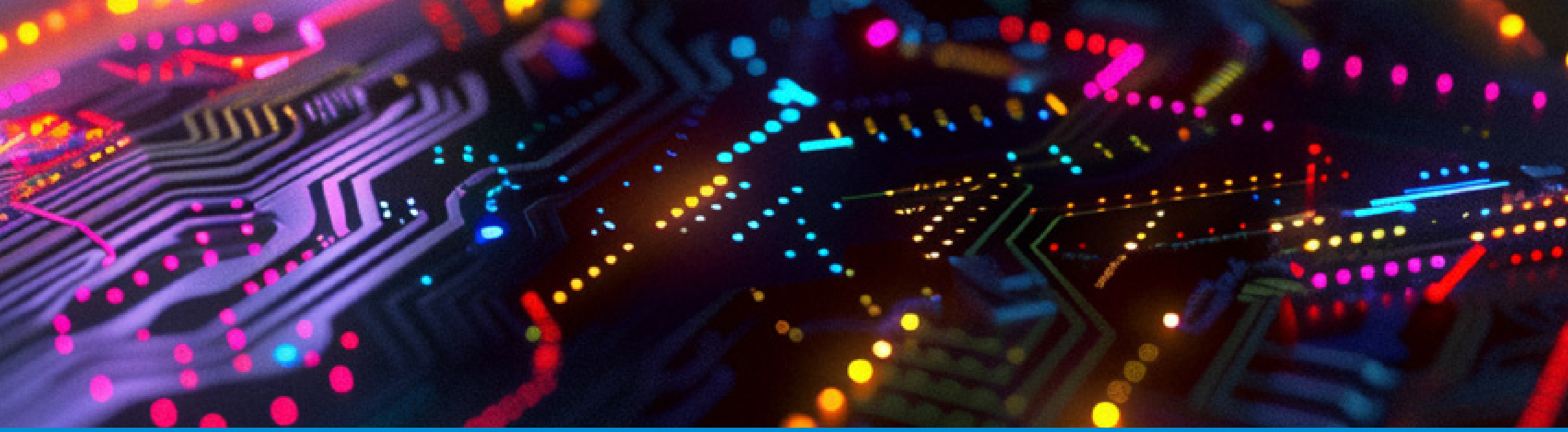

X-ray Inspection of Radiation Sensitive Devices Recommended Best Practices for Preprogramed Managed NAND

By Dave Rohona and Vineeth Bastin

Abstract

Automated X-ray inspection post solder reflow is used to automatically analyze and detect structural defects including solder voids, opens, shorts, insufficient solder and other defects. These defects typically account for 80% to 90% of the total defects on an assembled circuit board.

During X-ray inspection, semiconductor devices are exposed to varying levels of dose radiation. Recent commentary has raised questions regarding ionized radiation impact on preprogrammed memory content, specifically Managed NAND. This is of particular concern as memory lithography scales down and more bits are programmed per cell.

Introduction

This paper is intended to bring out awareness and provide recommended best practices when processing preprogrammed managed NAND through X-ray inspection. As flash memory storage migrates from mobile to automotive, where lives are potentially at risk (such as autonomous driving modes), following X-ray inspection best practices is not an option, it is a must. This paper is for the production manager responsible for setting up X-ray equipment parameters.

Embedded multi-media controller (eMMC) and Universal Flash Storage (UFS) are examples of Managed NAND. Both integrate NAND flash memory and an embedded controller chip in a single package to perform error correction (ECC), wear leveling and bad-block management internally. NAND Error Correction Code (ECC) performance is relative to the quality and sophistication designed into the embedded controller firmware. Managed-NAND ships in commercial, industrial and automotive grades, with automotive grade being the most robust. Both memory technologies are offered in standard BGA packaging.

Managed-NAND stores data by programming memory cells to different charge levels. As NAND lithography's shrink, memory cells carry less charge, which are more sensitive to charge leakage and radiation. This paper studies the radiation impact on 15nm and 20nm automotive grade Managed NAND flash memories.

Methodology

Two Managed NAND vendors were chosen, Vendor A at 15nm and Vendor B at 20nm

- Ten new samples of each device were preprogrammed with an identical X/OR data pattern

The following X-ray machine parameters were input manually

- Tube Voltage: Kilovolts (KV)
- Tube Power: Watts (W)
- Distance to Target: Millimeters (mm)
- Exposure Time: Minutes

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Preprogrammed devices were placed onto the following tray options, inside the X-ray machine

- Aluminum Tray
- Filtering Tray (150 Micron), Zinc

Starting Point

The first test was performed by exposing a preprogrammed Managed NAND device to extreme levels of dose radiation far outside normal X-ray machine setup parameters.

- The objective was to find the breaking point of the Managed NAND device and work backwards to identify the safe X-ray machine setup parameters.

X-ray Test and Data Validation Process

• Insert preprogrammed test device onto selected tray

1. Aluminum Tray or 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. Install device into the desktop 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

Test Materials

The test equipment and materials used in this study are described below.

X-ray Machine

An industry leading offline X-ray inspection system was used which has been used in a wide range of industries including electronics packaging, wafer level manufacturing, automotive, energy and aerospace electronics inspection.

Device Programmer

An industry leading desktop programmer was used for programming software content into managed NAND flash memories. Two programming jobs were created, Job #1 for Vendor A device and Job #2 for Vendor B device. The programmer was used to preprogram the same data file into 10 each Vendor A and Vendor B devices. At post X-ray inspection, each device was inserted into the programmer socket and the data was verified against the master data file.

Filtering Tray

Testing was performed using both an "aluminum tray" and a "filtering tray". Circuit boards needing inspection are placed onto either tray. For our test study, preprogrammed devices were not soldered to a printed circuit board. The device itself was placed directly onto the tray. The filter tray has a zinc layer sandwiched between two carbon fiber sheets.

Test Study, Vendor: A (15nm)

Test 1A: X-ray Setup Parameters

The initial X-ray machine setup parameters (Table 1) were set to extreme levels, far outside what is considered normal for circuit board inspection. The objective was to find the breaking point of the device whereby data retention has been compromised or altered.

- 1 new preprogrammed device was placed onto the "aluminum" tray inside the X-ray machine
- The image quality was confirmed as excellent

Table 1 - X-ray Setup

X-ray Machine Setup Parameters	Test #1 Settings
Filtering Tray	No
Tube Voltage	120KV
Tube Wattage	5W
Distance to Target	1.5mm
Exposure Time	10min.

Summary: Test 1A

After X-ray the device was transferred to the desktop programmer for data verification, comparing the data in the device with the master data file. The device data failed verification after a one ten minute cycle through X-ray (Figure 1).

The failure came as no surprise considering the preprogrammed device was exposed to an estimated 20,000 RADS of dose radiation. The device was marked as bad and sealed.

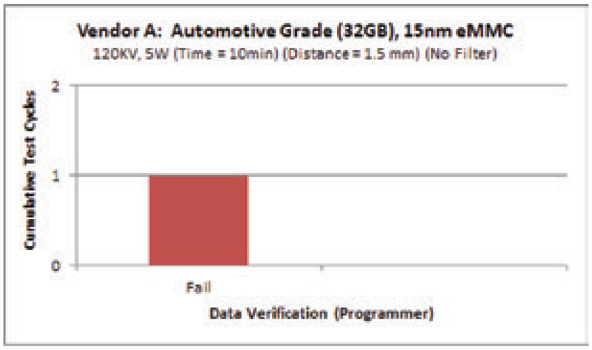

Figure 1: 1st Cycle Data Failure

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Test 2A: X-ray Setup Parameters

We dialed back the Tube Voltage from 120KV to 100KV, adjusted the Target Distance from the beam to the device from

1.5mm to 12.4mm which is considered typical and reduced the exposure time from 10 minutes to 5.5 minutes as noted in Table 2. The Test #2 settings highlighted in red are setup parameters adjustments made from Test #1.

- 1 new preprogrammed device was placed onto the "aluminum" tray inside the X-ray machine
- Image quality was confirmed as excellent

Table 2: X-ray Setup

X-ray Machine Setup Parameters	Test #1 Settings	Test #2 Settings
Filtering Tray	No	No
Tube Voltage	120KV	100KV
Tube Wattage	5W	5W
Distance to Target	1.5mm	12.4mm
Exposure Time	10min.	5.5min.

Summary: Test 2A

After X-ray the device was transferred to the desktop programmer for data verification. The device data failed verification after one 5.5 minute cycle through X-ray (Figure 2). Again, these results came as no surprise as the X-ray setup parameters are still outside what are considered normal operation.

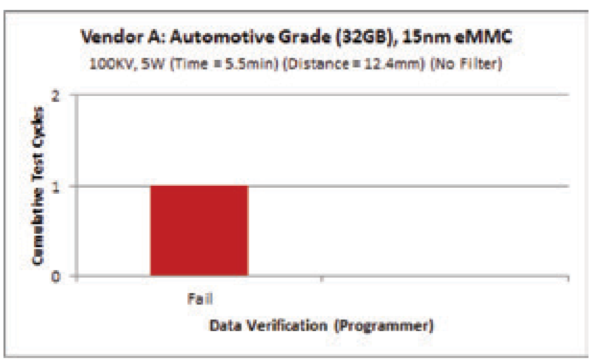

Figure 2: 1st Cycle Data Failure

Test 3A: X-ray Setup Parameters

We continued to dial back the Tube Voltage from 100KV to 80KV, Tube Wattage from 5W to 3W and exposure time from

5.5 minutes to 5 minutes as shown in Table 3. These are considered typical X-ray setup parameters that one might expect to see in automotive applications. The Test #3 settings highlighted in red are setup parameters adjustments made from Test #2.

- 1 new preprogrammed device was placed onto the "aluminum" tray inside the X-ray machine
- Image quality was confirmed as excellent

Table 3: X-ray Setup

X-ray Machine Setup Parameters	Test #1 Settings	Test #2 Settings	Test #3 Settings
Filtering Tray	No	No	No
Tube Voltage	120KV	100KV	80KV
Tube Wattage	5W	5W	3W
Distance to Target	1.5mm	12.4mm	12.4mm
Exposure Time	10min.	5.5min.	5min.

Summary: Test 3A

After X-ray the device was transferred to the desktop programmer for data verification. The device passed data verification after one five minute cycle through X-ray. The same device was processed through X-ray inspection a second time at the same settings. After the second cycle through X-ray, the device failed data verification as shown in Figure 3.

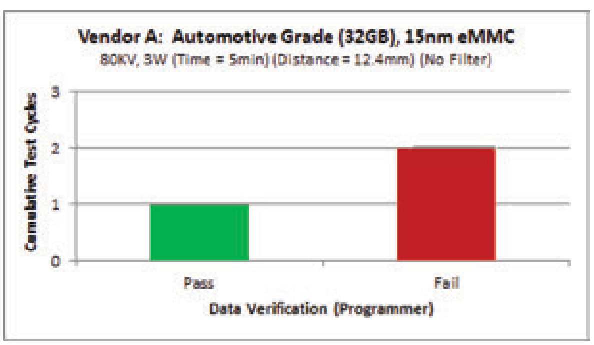

Figure 3: 1st Cycle Data Pass, 2nd Cycle Data Fail

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Test 4A: X-ray Setup Parameters

The aluminum tray was removed from the X-ray machine and replaced with the Zinc "Filtering Tray" as shown in Table 4. All other X-ray setup parameters remain the same as Test #3.

- 1 new preprogrammed device was placed onto the "Filtering Tray" inside the X-ray machine
- Image quality was confirmed as excellent

Table 4: X-ray Setup

X-ray Machine Setup Parameters	Test #1 Settings	Test #2 Settings	Test #3 Settings	Test #4 Settings
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	10min.	5.5min.	5min.	5min.

Summary: Test 4A

The tests show that "Filtering" has the biggest single impact on data retention. The same device passed 6 consecutive times through X-ray inspection as shown in Figure 4. The same device was exposed to 30 minutes of cumulative dose radiation before failure on the seventh cycle through X-ray.

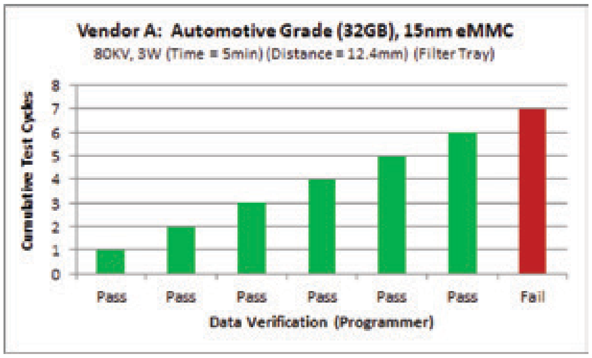

Figure 4: 6 Cycles Data Pass, 7th Cycle Data Fail

Test Study, Vendor: B (20nm)

Test 1B: X-ray Setup Parameters

Considering that 20nm lithography is more robust than 15nm, we chose to begin Vendor B testing using the "Filtering Tray" and the identical settings that we concluded with for Vendor A Test #4 as shown in Table 5.

- 1 new preprogrammed device was placed onto the "Filtering" tray inside the X-ray machine
- Image quality was confirmed as excellent

Table 5: X-ray Setup

X-ray Machine Setup Parameters	Test #1 Settings
Filtering Tray	Yes
Tube Voltage	80KV
Tube Wattage	3W
Distance to Target	12.4mm
Exposure Time	5min.

Summary: Test 1B

The results came as a complete surprise. We expected the Vendor B device to pass at least six cycles through X-ray. However, the device failed data verification after the second X-ray cycle as shown in Figure 5. We repeated test #1 with a new device to rule out any anomalies and got the exact same results.

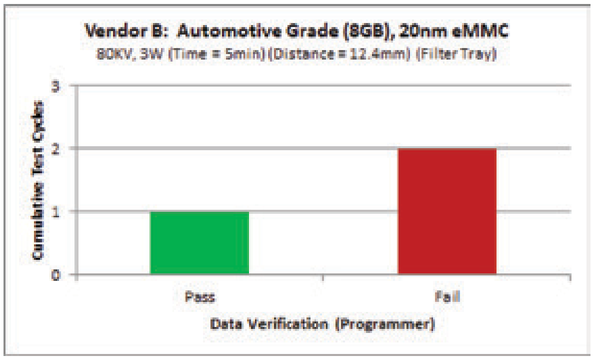

Figure 5: 1st Cycle Data Pass, 2nd Cycle Data Fail

Test 2B: X-ray Setup Parameters

The filtering tray was removed and replaced with the aluminum tray. We dialed back the Tube Voltage from 80KV to 60KV and Tube Wattage from 3 to 2 watts as shown in Table 6.

- 1 new preprogrammed device was placed onto the "aluminum" tray inside the X-ray machine
- Image quality was confirmed as excellent

Table 6: X-ray Setup

X-ray Machine Setup Parameters	Test #1 Settings	Test #2 Settings
Filtering Tray	Yes	No
Tube Voltage	80KV	60KV
Tube Wattage	3W	2W
Distance to Target	12.4mm	12.4mm
Exposure Time	5min.	5min.

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Summary: Test 2B

After one cycle through X-ray the device was transferred to the desktop programmer for data verification. The device passed data verification after one cycle through X-ray. The same device was processed through X-ray a second time at the same settings. The device failed data verification after its second cycle through X-ray as shown in Figure 6.

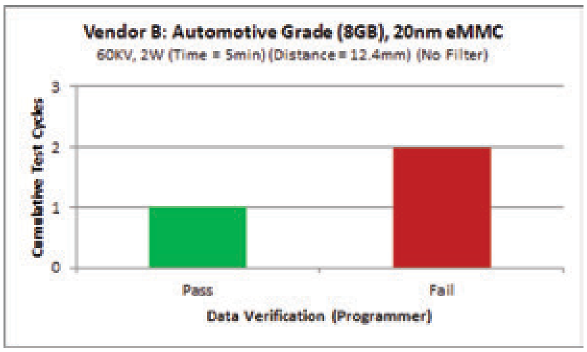

Figure 6: 1st Cycle Data Pass, 2nd Cycle Data Fail

Test 3B: X-ray Setup Parameters

The aluminum tray was removed and replaced with the filtering tray. We increased the Tube Wattage from 2 to 3 watts as shown in Table 7.

- 1 new preprogrammed device was placed onto the "filtering tray" inside the X-ray machine
- Image quality was confirmed as excellent

Table 7: X-ray Setup

X-ray Machine Setup Parameters	Test #1 Settings	Test #2 Settings	Test #3 Settings
Filtering Tray	Yes	No	Yes
Tube Voltage	80KV	60KV	60KV
Tube Wattage	3W	2W	3W
Distance to Target	12.4mm	12.4mm	12.4mm
Exposure Time	5min.	5min.	5min.

Summary: Test 3B

Using the filtering tray and increasing the Tube Wattage from 2 to 3 watts resulted in one device passing data verification after three consecutive cycles through X-ray as shown in Figure 7. The device was exposed to 15 minutes of cumulative dose radiation before failure on the fourth cycle through X-ray.

When comparing these results with Test 1B, we find that dialing back the Tube Voltage from 80KV to 60KV results in two additional passes through X-ray inspection before failure.

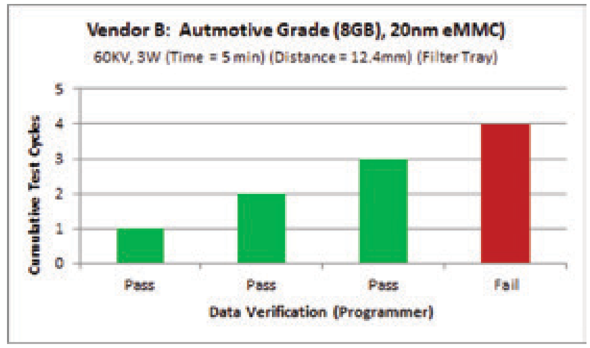

Figure 7: 3 Cycles Data Pass, 4th Cycle Data Fail

Test 4B: X-ray Setup Parameters

We wanted to understand what happens if we increased the Tube Voltage to 80KV and dialed back the Tube Wattage to 2 watts as shown in Table 8.

- 1 new preprogrammed device was placed onto the "filtering tray" inside the X-ray machine
- Image quality was confirmed as excellent

Table 8: X-ray Setup

X-ray Machine Setup Parameters	Test #1 Settings	Test #2 Settings	Test #3 Settings	Test #4 Settings
Filtering Tray	Yes	No	Yes	Yes
Tube Voltage	80KV	60KV	60KV	80KV
Tube Wattage	3W	2W	3W	2W
Distance to Target	12.4mm	12.4mm	12.4mm	12.4mm
Exposure Time	5min.	5min.	5min.	5min.

Summary: Test 4B

We find increasing the Tube Voltage to 80KV and dialing back the Tube Wattage from 3 to 2 Watts yields the same results as Test 3B. The same device passed data verification after three consecutive cycles through X-ray as shown in Figure 8.

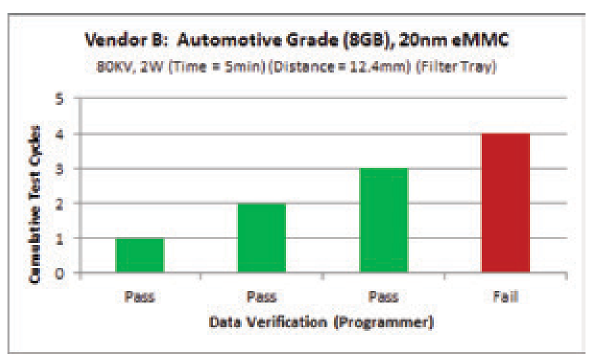

Figure 8: 3 Cycles Data Pass, 4th Cycle Data Fail

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Test 5B: X-ray Setup Parameters

We decided to dial back the Tube Voltage from 80KV to 60KV as shown in Table 9. At these settings it is important to confirm we have a quality image, which we did. Our X-ray machine featured image enhancement capabilities to boost image quality if needed, which was not necessary and was not used.

- 1 new preprogrammed device was placed onto the "filtering tray" inside the X-ray machine
- Image quality was confirmed as excellent

Table 9: X-ray Setup

X-ray Machine Setup Parameters	Test #1 Settings	Test #2 Settings	Test #3 Settings	Test #4 Settings	Test #5 Settings
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	5min.	5min.	5min.	5min.	5min.

Summary: Test 5B

For Vendor B device, using Test #5 settings the same device passed 5 consecutive times through X-ray inspection as shown in Figure 9. The same device was exposed to 25 minutes of cumulative dose radiation before failure on the sixth cycle through X-ray.

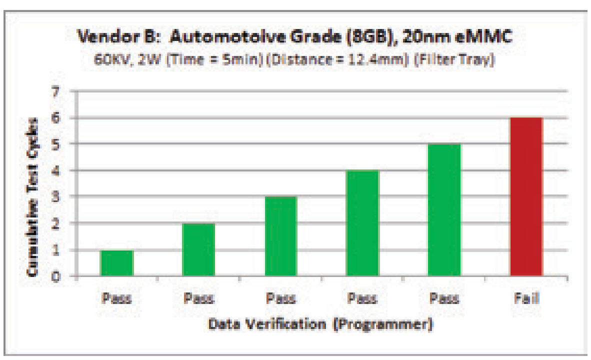

Figure 9: 5 Cycles Data Pass, 6th Cycle Data Fail

Summary/ Conclusions

Processing preprogrammed Managed-NAND Flash Memories through X-ray is safe when following recommended best practices. Zinc Filtering is the single most important requirement. While it is not possible to apply one X-ray machine's setup parameters to all machine vendors and models, our study should help provide some basic guidelines to follow. We have built in safety margins having witnessed up to 5 consecutive pass cycles of cumulative dose radiation exposure at 5 minutes per cycle which is considered extreme.

Recommended X-ray machine setup parameters for preprogrammed Managed-NAND Flash are:

- Tube voltage: 60KV
- Tube power: 2 Watts
- Distance to target: 12.4 millimeters is typical, the further the distance from beam to target is better
- Exposure time: 5 minutes is extreme, the shorter the exposure time, the better
- Filtering (Zinc): 150 Micron is a must

For more information, speak with your Nordson representative or contact your Nordson Test & Inspection regional office

Europe, SEA, Africa
ti-sales-eu@nordson.com

China
ti-sales-cn@nordson.com

Singapore
ti-sales-eu@nordson.com

Korea
ti-sales-korea@nordson.com

Americas
ti-sales-us@nordson.com

Japan
ti-sales-jp@nordson.com

Taiwan
ti-sales-tw@nordson.com

www.nordson.com/TestInspect | +1 760.918.8471

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