Head in Pillow X-ray Inspection at Flextronics

Alejandro Castellanos, Adalberto Gutierrez, Gilberto Martin, Matthew Vandiver, Ranga Dematampitiya, Hung Le, Elliott Le, Phuong Chau, Hao Cui, An Qi Zhao, Wei Bing Qian, Fuqing Li, Jacky Yao, Jiyang Zhang, Leonard Brisan, Cristian Gurka, Shane Young, Johann Bruenner, Martin Novak, Nadarajan M Singaram, Zhen (Jane) Feng, Ph. D., David Geiger, Murad Kurwa

FLEXTRONICS International Inc.
Av Lopez Mateos Sur 2915 km 6.5, Guadalajara, Jalisco 45640, Mexico

Abstract

Manufacturing technology faces challenges with new packages/process when confronting the need for high yields. Identifying product defects associated with the manufacturing process is a critical part of electronics manufacturing. In this project, we focus on how to use AXI to identify BGA Head-in-Pillow (HIP), which is challenging for AXI testing. Our goal is to help us understand the capabilities of current AXI machines.

For the study we used two boards exhibiting HIP defects with four types of AXI machines at four sites in Flextronics manufacturing, or vendor laboratory. The AXI machines used have different X-ray technologies: Laminography and Tomosynthesis. We collected three sets of data with AXI 1 machine (Laminography), and AXI 4 machines (Tomosynthesis); one set of data with AXI2 (Tomosynthesis); and 4 sets data for AXI3 (Tomosynthesis). We studied AXI measurement data with the different AXI Algorithm Threshold settings. The data indicated clearly that the Algorithm Threshold settings are very critical for detecting HIP, including open. The defective HIP pins are validated by using 2DX and CT scan.

The test data consist of Defects Escaped %, False call PPM and also Gage R & R. The AXI images for HIP pins, false call pins and defects escaped pins are presented in the paper. The 2DX and CT images are provided for identifying HIP type (shape and size).

Introduction

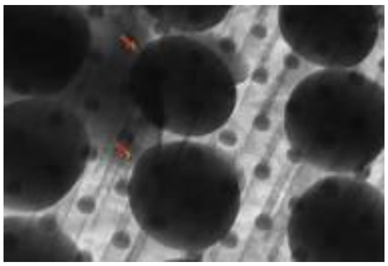
More BGA and area array devices are appearing on PCBAs as product and functional complexity increases. Furthermore, to achieve good signal integrity, more I/Os are packed in smaller areas within the available real estate. It is very important to use AXI and other Non-destructive techniques to identify BGA joint qualities and prevent escape. We did a study for BGA crack several years ago with AXI, Time Domain Reflectometry (TDR), 2DX, and Cross-section/SEM Comparison; however we didn't have good detected results from AXI[1]. During the study, we realized that 2D X-ray with tilting angle detector has the capabilities to identify BGA crack at 5 microns or higher. Recently more AXI machines using both Laminography and Tomosynthesis technologies have better capabilities to detect BGA defects; therefore we would like to develop the optimization Algorithm and Threshold settings to identify HIP on BGA for high volume products.

Based on 2DX images, we have identified two boards containing HIP: #495 with 45 HIPs, and #266 with 2 HIPs. With the HIP defective boards, we have tested them at four sites, with four different AXI machines. AXI1 is a Laminography machine; AXI2, AXI3, and AXI4 are Tomosynthesis machines from different vendors. We worked together with site engineers and vendors' support engineers for this project. We focused on HIP defects escaped %, false call PPM and Gage Repeatability & Reproducibility (Gage R&R) with that BGA.

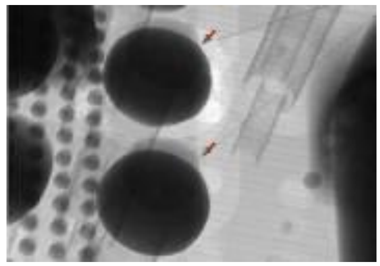
"A picture is worth a thousand words." Indeed, a high - quality microstructure of solder joint provides "sights' and "insights" into the state of solder joint integrity and its anticipated behavior[2]. Similar benefits can be achieved using high quality 2D and 3D offline X-ray inspection images and data. Through this study, we try to understand more about AXI machines capabilities, especially for improving AXI programming optimization used for our best practices. Although machine's testing conditions were not exactly the same, but close, the philosophy for achieving optimization is similar. Look at the measurement data first, finding the difference between good solder joint and defective solder joint; and then balance the defects escaped % and false call numbers to find the right threshold settings. For the high volume products, monitoring AXI programs is an ongoing process based on further fine tuning with feedback from ICT, Functional test and 2D / 3D offline X-Ray inspection.

Experiments and Analysis

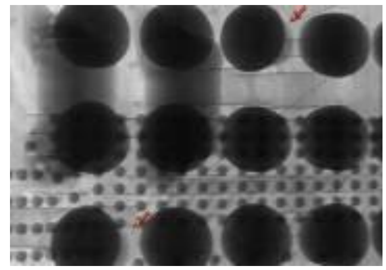
Two boards with HIP defects were from production SMT line of a different site. The BGA has 1017 balls with ball diameter of 21 mils for outer balls and 19 mils for inner balls of the pad. The HIP defective pin (ball) is identified at 2DX machine with tilting angle detector. Tilting (oblique) angle is 55 to 68 degrees; and rotation of the X-ray detector 0 to 360 degrees around the examined joint. This is not trivial, but it is very easily accomplished using the 2DX equipment. The oblique and rotation angles of the X-ray detector are key factors for identifying BGA defects, such as HIP, open, and small crack[1]. There are total 47 HIP pins on the two boards based on 2DX images (resolution 0.1µm). Some 2DX HIP images are shown in Figures 1, where pins with arrow are HIP, except for pin number G32 which is crack (9µm).



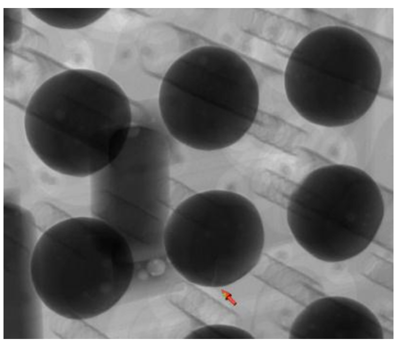
HIP: AA15, AB15



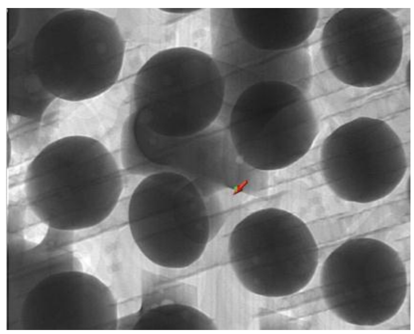
HIP: Z24, AA24



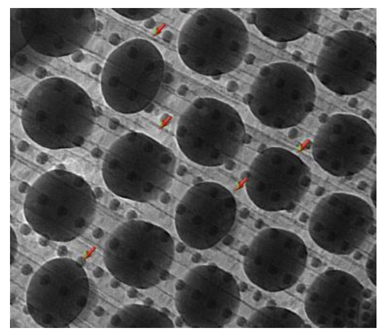
HIP: L13, N11



Crack: G32



HIP: N30



HIP: V17, W17, Z16, Z18, Z19

Figure 1. Samples of 2DX Images of Defective Pins (Board #495)

For this project, the "Defects escaped %" and "False Call PPM" are calculated with the equations listed below:

Defects Escaped % = # of HIP escaped / Total # of HIPs, where Total # of HIPs is 47. (Equation 1)

False Call PPM = (Total # of False call / Total Pins # tested) X10^6, where Total tested pins number is 2034 for two boards. (Equation 2)

The Gage R&R results are calculated with SPC tool Minitab with nine sets of variable data by three operators from each machine. Data of BGA diameter for pad & middle slice, and some main AXI Algorithm (Open outlier, Neighbor Outlier, Solder area pad…) are collected during the studies.

A. AXI 1 (Laminography)

AXI 1 type is the largest number of AXI machines in our worldwide manufacturing sites. From our experience, AXI 1 plays a good role of detecting various solder joint defective types (Solder Bridge, Insufficient, Excess …) based on experience during the last 15 years; it does not detect 100% of BGA HiP defects effectively. At Flextronics, we encourage engineers from different sites to share good knowledge, such as an experience with latest software, and new Algorithm's features. We want to have the best performance by maximizing the machine's capabilities in every site inside of Flextronics.

First, we tested two boards with AXI 1 type at site 1; then used the same program to test the same boards at sites 2 and 3 with a little bit of fine-tuning (editing of Threshold settings). The main thresholds which we focused on are: 1. Open Outlier for Pad slice; 2. Open Outlier for Middle ball slice.

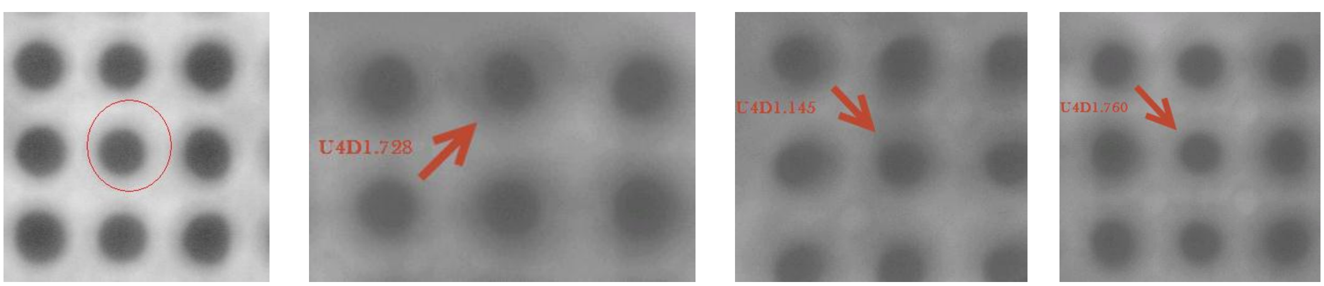
As we know, each AXI machine flags a pin as a defect if the measurement falls outside of the Algorithm Threshold limit. So it is important to know the difference between a good and bad solder joint with various measurements data for each Algorithm. It is easy to have optimization Threshold setting if the measurement difference has a big gap; otherwise it is challenging to make AXI program detecting defects with low false call rate.

The main thresholds of adjustment are: 1. Open Outlier for Pad slice; 2. Open Outlier for Middle ball slice. The Threshold setting is < -3 for “Open Outlier Lower Sensitivity for Pad slice”, and is > 3 for “Open Outlier Sensitivity for Middle ball slice”. These should be good threshold numbers for many products (BGA packages). Table 1 listed the pins which are called defect from site 2 based on their Threshold settings: Open Outlier Sensitivity for slice 1 (MidBall) is **3;** Open Outlier Lower Sensitivity for slice 2 (Pad) is **-3**. The program detected 17 HIP pins from 45 defects (board # 495); and it had 7 pins as false calls, and had escaped 28 HIP defects. The detected HIP pins (labeled in green color), escaped HIP (labeled in red color), and false call pins (labeled in orange color) are listed in Figure 2. There are no significant differences between the good and HIP pins based on the AXI 1 images. This may be the effect of AXI1 HIP detection capabilities.

Table 1. AXI 1 Open Outlier Measurement Data for Pad and Middle Ball slices (Board #495)

BGA U4D1 Pin #	Pin Type	OpenOutlier (MidBall)
T24	HIP	3.11
Z18	HIP	3.17
N30	HIP	3.27
N11	HIP	3.3
P13	HIP	3.3
AH13	HIP	3.31
W14	HIP	3.36
U8	HIP	3.39
T12	HIP	3.48
AK18	HIP	3.73
AG16	HIP	3.93
AH19	HIP	4.34
AL11	HIP	4.62
AA27	HIP	4.71
AJ10	HIP	4.73

BGA U4D1 Pin #	Pin Type	OpenOutlier (Pad)
AD28	False call	-4.06
Z12	False call	-3.77
Z23	False call	-3.37
AB15	HIP	-3.29
AD15	HIP	-3.24
A23	False call	-3.14
L13	HIP	-3.13
AC15	False call	-3.09
G28	False call	-3.05
M15	False call	-3.05



AB15 (escaped) L13 (detected) AD28 (false call) M15(false call)

Figure 2: AXI 1 Images of detected HIP; escaped HIP, and False Call Pins

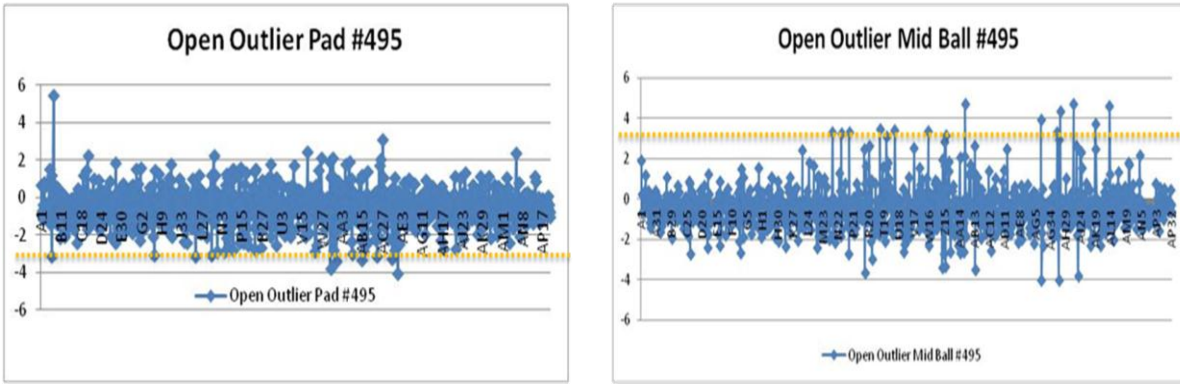


Figure 3: AXI 1 "Open Outlier" measurement data for Middle Ball and Pad slices (Board #495)

Figure 3 shows "Open Outlier" measurement data for Middle Ball and Pad slices of board #495. The measurement data tells us that AXI1 has the capabilities to detect some HIP pins. However, there is no clear measurement data gap between the good and HIP pins with the current version AXI software as it is reflected on AXI 1 images. Therefore, we understand why some HIP pins escaped, and also has difficulty to have zero false call. Table 2 lists the number of Detected HIP, False call, and HIP escaped with different Threshold settings at site 2. With the Default Threshold settings from AXI 1, the program didn't detect any HIP with zero false call. If we tighten the Threshold from < -3 to < -2.5 for pad slice, and from >3 to >2 for middle ball, the detected HIP increased from 18 to 29, however the false call increased from 7 to 17 with the same program. As a recommendation, we suggest the settings for Open outlier < -3 for pad slice, and > 3 for middle ball slice which are the main Algorithms that can detect HIP. The rest of the parameters for Open outlier can be used with default numbers if the test results are fine.

Table 3 listed AXI 1 testing results summary by using equations 1 and 2 from site 1; site 2; and site 3. The site 1 used Default Threshold setting; site 2 and site 3 use the same Threshold settings which are listed in the first two lows of Table 2 for testing two boards. The data tells us that AXI 1 has the capabilities to detect HIP with the right Algorithm Thresholds settings.

Table 2. AXI 1 Detected HIP and False Call Vary with Threshold Settings (Board #495)

Board #	Open Outlier Threshold Settings	Detected	False Call	Escaped
266	Pad < -3 as defect; Mid Ball > 3 as defect	1	5	1
495	Pad < -3 as defect; Mid Ball > 3 as defect	18	7	27
495	Pad < -2.5 as defect; Mid Ball > 2 as defect	29	17	16
266	Pad < -6 as defect; Mid Ball > 6 as defect	0	0	2
495	Pad < -6 as defect; Mid Ball > 6 as defect	0	0	45

Table 3. Testing Summary with of AXI 1

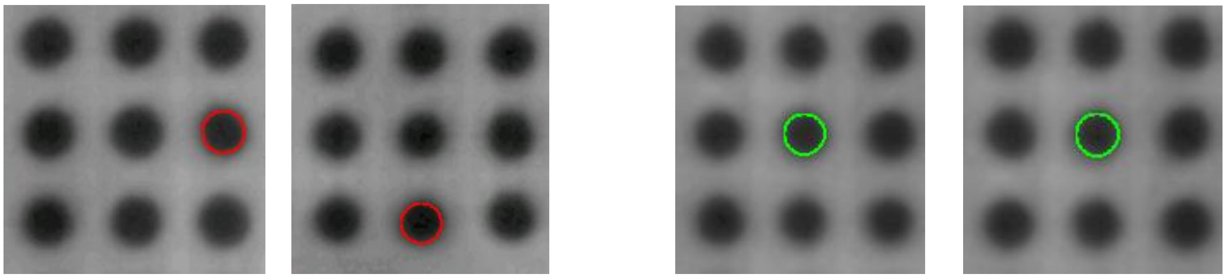
Site	# of Total Escaped Defects	Defects Escaped %	# of Total False Call	False Call PPM
1	46	97.87%	0	0
2	28	59.57%	12	5900
3	24	51.06%	13	6391

B. AXI 2 (Tomosynthesis)

There are a few AXI 2 machines at Flextronics manufacturing. For AXI 2 machine, the Threshold settings for Neighbour outlier is < **-3.5** for pad, and > **4.5** for middle ball. Table 4 listed AXI 2 test results summary from site 1. Two detected HIP pins (labeled as green color), and two escaped HIP (labeled red color), are listed in Figure 4. Similarly, there is not a huge difference on pin images between good and HIP pins. In comparisons to AXI1 versus AXI2, the AXI 2 (Tomosynthesis) seems to have better HIP detection than AXI 1 (Laminography).

Table 4. Testing Summary with AXI 2

Site	# of Total Escaped Defects	Defects Escaped %	# of Total False Call	False Call PPM
1	16	34.04%	3	1475



T24(detected) L13(detected) AA15 (escaped) AB15(escaped)

Figure 4: AXI 2 Images of detected HIP; escaped HIP pins (Board #495)

C. AXI 3 (Tomosynthesis)

AXI 3 machine uses Tomosynthesis technology which is similar to AXI 2 machine. The AXI 3 has faster testing speed than AXI 1, and AXI 2. We used the same HIP boards tested at four sites, and worked with the vendor to have Algorithm and Threshold settings studies. The Algorithm Threshold settings are different when we tested the boards at different site with the latest software at that time. The main Algorithm Thresholds for detecting HIP with AXI 3 are listed in Table 5. Because board #495 and #266 were built at different manufacturing facilities with little different solder shape and volume, so different Algorithm Thresholds were set to detect HIP effectively at site 3 and site 4.

Figure 5 shows detecting HIP pins, escaped pins, and false call pins for board # 495, and all pins for board #266 which is from site 2. The AXI 3 flagged pin as HIP when its pad Neighbor Outlier > 2.2 with multi-pass Algorithm. AXI3 detected 38 HIPs (escaped 7) with 6 false calls for board # 495, and detected 2 HIP (no escaped) with 6 false calls for board # 266. Table 6 listed the test summary from each site with AXI 3 which has better performance than AXI 1 for both HIP detection percentage and false call PPM.

Table 5. Algorithm Thresholds with AXI 3

Site	Algorithm (Neighbor Outlier)	Threshold
1	Minimum and Maximum for Pad	< - 3.2 ; > 4.5
2	Neighbor Outlier - Pad (multi-pass)	> 2.2
3	Neighbor Outlier - Pad	> 2.2 (#495); >3.3(#266)
4	Neighbor Outlier - Pad	> 2.2 (#495); >3.3(#266)

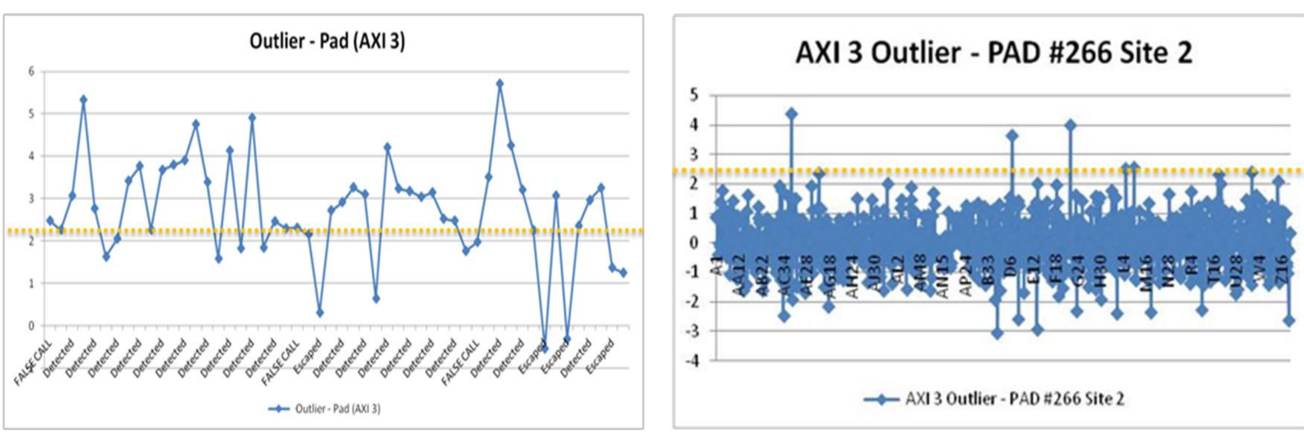
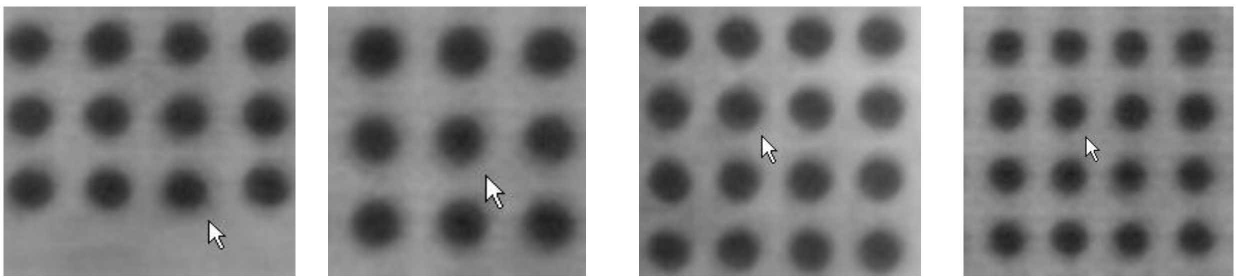


Figure 5. AXI 3 "Open Outlier" Measurement Data for Pad Slices from Site 2 (Board #495 & #266)

Table 6. Test Summary with AXI 3

Site	# of Total Escaped Defects	Defects Escaped %	# of Total False Call	False Call PPM
1	13	27.66%	9	4425
2	7	14.89%	12	5900
3	5	10.64%	7	3441
4	8	17.02%	12	5900

The AXI 3 images for detected HIP, escaped HIP and false calls are shown in Figure 6. There is no very clear difference between good and HIP pins similar to AXI 1, and AXI 2. It is not easy for operators to indentify real defective HIP defects based on these images from the repair station. Therefore we should be very carefully to set Threshold correctly to detect HIP. We prefer to detect some HIP without high rate of false calls on one BGA especially for large volume production line based on current AXI capabilities.



L13(detected) R15(detected) G32 (escaped) T20 (false call)

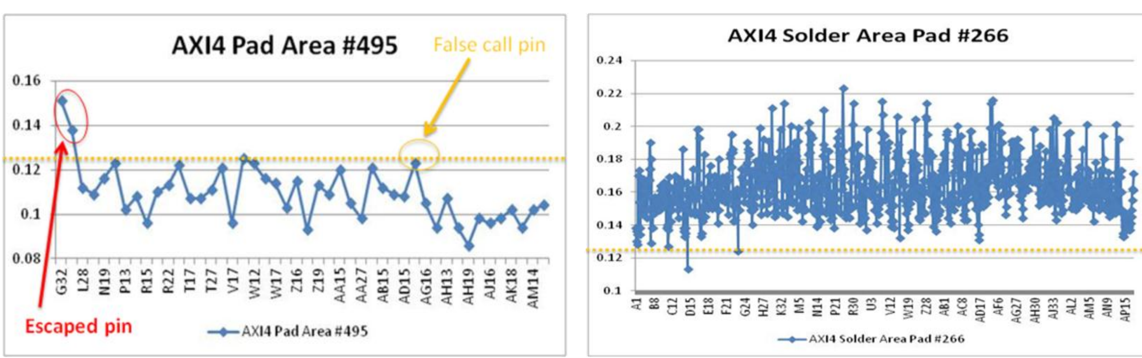
Figure 6: AXI 3 Images of detected HIP; escaped HIP, and False Call Pin (Board #495)

D. AXI 4 (Tomosynthesis)

AXI 4 uses Tomosynthesis technology also. Its resolution can be adjusted per different package or solder joints. We had test data from three sites with little fine tuning for the program. The AXI 4 main Algorithm Thresholds for detecting HIP are listed in Table 7. Similarly, different Algorithm Thresholds for two boards are adjusted to detect HIP effectively.

Table 7. Algorithm Thresholds with AXI 4

Site	Algorithm	Threshold	Note
2	Solder Area Pad	< 83% ; >130%	< 0.129 or < 0.144 mm^2
3	Solder Area Pad	< 70% ; >130%	< 0.125mm^2
4	Solder Area Pad	< 70% ; >130%	< 0.130mm^2 ; < 0.142 mm^2

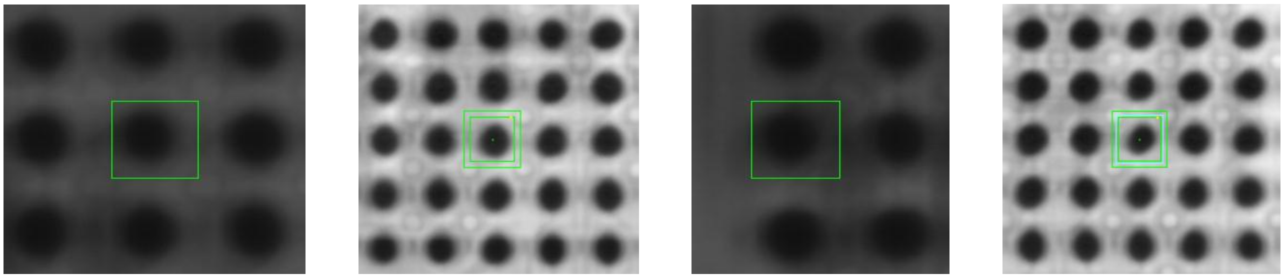


Board #495 with partial pins Board #266 with all pins

Figure 7. AXI 4 "Solder Area" Measurement Data for Pad Slice from Site 3 (Boards #495 & #266)

Figure 7 shows AXI 4 measurement Solder Area at pad level for detected pins, escaped HIP pins, and false call pins for board #495; and all pins for # 266. At Site 3, with the settings listed in Table 7, AXI 4 detected two HIP pins (no escaped) for board

266 without any false call; and detected 43 HIPs (escaped 2 HIP) with one false call for board # 495. The two escaped and one false call images are listed on Figure 8. As other AXI machine, there is still no very clear difference between good and detective HIP pins as shown in Figure 8.



R15 (detected) G32 (escaped) L13 (escaped) AD31 (false call)

Figure 8: AXI 4 Images of detected HIP; escaped HIP, and False Call Pin (Board #495)

Table 8. Test Summary with AXI 4

Site	# of Total Escaped Defects	Defects Escaped %	# of Total False Call	False Call PPM
2	2	4.26%	4	1967
3	2	4.26%	1	492
4	1	2.13%	4	1967

Table 8 listed the test summary from each site with AXI 4 which has better performance than AXI 1 for both detection percentage and false call.

Comparison and Improvement

All four AXI machines have capability to detect BGA HIP defect with different success levels. The AXI performance is based on program Algorithms, its thresholds' setting, and machine testing conditions. We also collected data for Gage R&R from these AXI machines from the different sites. The Gage R&R for BGA ball diameters are less than 30% for all AXI machines. The Gage R&R for middle ball diameters are less than 10% for some AXI machines. However the Gage R&R for Open outlier, Solder area, Neighbor outlier are not what we expected because most of them are at the boundary level: around 30%. This is why AXI testing results are not repeatable. For example, please refer to the AXI 1 test summary shown in Table 9. There are nine test cycle results with board # 266 and #499 at AXI 1 machine in our manufacturing (Table 9). It is easy to see the difference of AXI 1 test results with the same Algorithm Thresholds settings (Pad < -3 as defect; Mid Ball > 2 as defect).

Table 9. Testing Summary with AXI 1

# of Testing	Board #266 has 2 HIP pins					Board #495 has 45 HIP pins			
	AXI 1 Results	Detected HIP	Escaped HIP	False calls		AXI 1 Results	Detected HIP	Escaped HIP	False calls
1	7	1	1	6		28	18	27	10
2	7	1	1	6		32	18	27	14
3	10	1	1	9		29	17	28	12
4	9	2	0	7		29	18	27	11
5	8	1	1	7		31	17	28	14
6	12	1	1	11		30	18	27	12
7	11	2	0	9		31	18	27	13
8	8	1	1	7		30	18	27	12
9	8	1	1	7		28	18	27	10

Current AXI technology still has plenty of room for improvement in detecting HIP due to its hardware and software limitations. So, what can we do in order to optimize the AXI HIP detection capabilities? In Flextronics, we share our best practice from site to site; such as this project, we suggest setting these Algorithm Thresholds settings (Pad < -3 as defect; Middle Ball > 3 as defect) as a start, then look at the measurement data to adjust according to the process. We also share our experience with AXI vendors, and provide feedback to them as well as working together with them for better and improved AXI performance.

Table 10 listed below uses two subtypes for this BGA due to two different types of pad on the board: pad diameter is 19 mils for inner balls, and 21 mils for outer balls on BGA. For AXI 1, we have reduced HIP escaped number from 27 to 15 with the same false calls; for AXI 4, we have reduced false call number from 4 to 1 with the same defects escaped. This best practice shows good results with the two different AXI machines.

Table 10. AXI 1 and AXI 4 Test Summary with 1 and 2 Types Algorithm Threshold Settings

Site	AXI	Type of Algorithm Threshold	# of Total Escaped Defects	Defect escaped %	# of Total False Call	False Call PPM
2	AXI 1	1	27	60.0%	7	6883
2	AXI 1	2	15	33.3%	7	6883
4	AXI 4	1	1	2.2%	4	3933
4	AXI 4	2	1	2.2%	1	983

In order to verify our AXI / 2DX results, we performed 3D CT Board Level X-Ray Inspection (Limited Angle Computer Tomography). This is a novel technique permitting areas of a very large board to be examined using 3D CT without cutting the board. Figures 9-12 show the CT images and results. Figure 9 demonstrates clearly that pin G32 has a 9 micron crack. This potentially critical defect was identified with offline 2D X-Ray (2DX image, Figure 1) and confirmed using large board CT. However none of the AXI machines detect it as defect.

There are varying types of HIP defects with different size and shape as shown in Figures 10 and 11. All current AXI machines have capabilities to detect HIP N30 shown on Figure 10, however not all machines detected HIP pins Z15, AA 15, and AB15 (Figure 11). Laminography AXI 1 machine detects HIP type defects as pin AB15; however it is challenging for AXI 1 to detect HIP type as Z15. Tomosynthesis AXI machines do not easily detect HIP type as AB15.

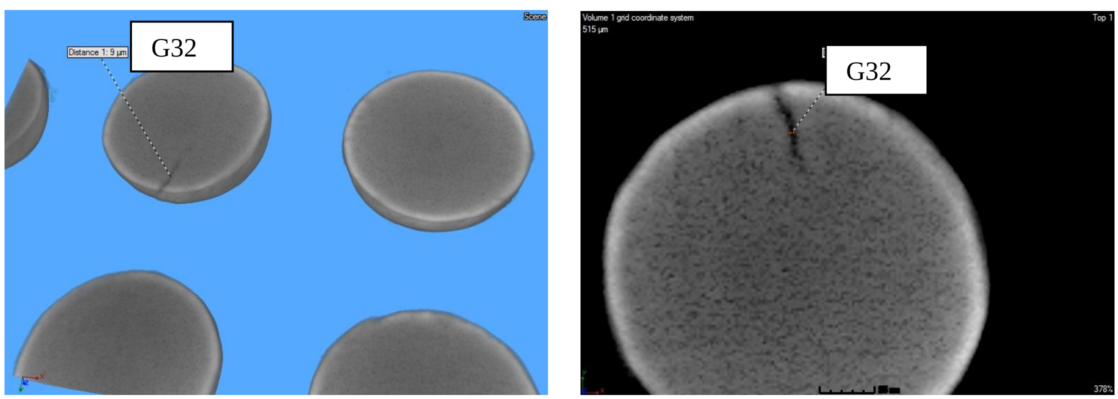


Figure 9. CT Image for BGA Crack with 9 µm

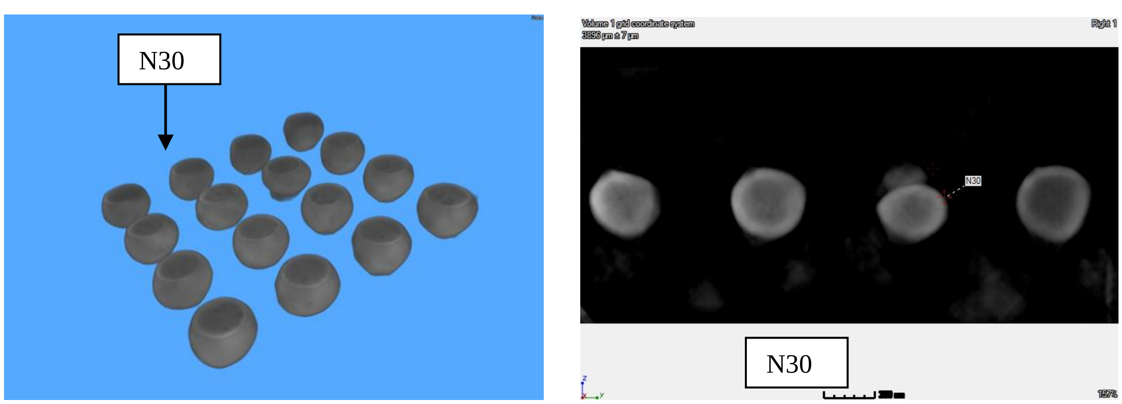


Figure 10. CT Images for HIP N30

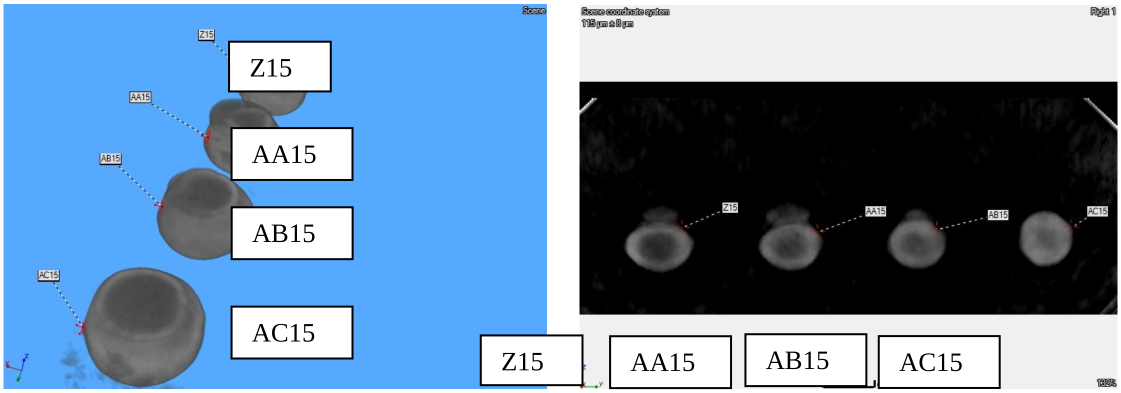


Figure 11. CT Images for HIP (AB15, Z15 and AA15), AC15 is good.

Summary

- Current AXI has capabilities to detect some HIP with right Algorithm threshold settings. The Tomosynthesis technology looks better than Laminography technology for detecting HIP as the Tomosynthesis technology are utilizing digital technology as compared to the analog Laminography technology.
- The Algorithm threshold settings are very critical for detecting HIP. The false call number has to be reasonable for the production line. The AXI program optimization is based on its measurement data analysis.
- There are no clear image differences between good solder joint and HIP with current AXI machine, especially for HIP type defect AA15 shown as in Fugue 11. Therefore we have to have good balance between HIP defect escaped and false call.
- We are looking forward to see AXI machine with more accurate and repeatable measurement data, and better image separation between good solder joint and HIP pins.
- 2DX and Large Board CT are very important techniques used to verify the AXI results and fine tune the algorithms.

Reference

1. Zhen (Jane) Feng, Juan Carlos Gonzalez, Evstatin Krastev, Sea Tang, and Murad Kurwa, “Non-Destructive Techniques for Identifying Crack Defect in BGA Joints: TDR, 2DX, and Cross-section/SEM Comparison”, SMTA Proceeding, August, 2008.
2. Jennie S. Huang, “Can Microstructure Indicate a Good Solder Joint? Part III”, SMT Magazine, October, 2012.
3. Flextronics ATG, “CT versus AXI with HIP”, project is ongoing, Oct., 2012

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APEX EXPO IPC 2013 INFORMATION that INSPIRES INNOVATION

Head in Pillow Inspection at Flextronics

Alejandro Castellanos, Adalberto Gutierrez, Gilberto Martin, Matthew Vandiver, Ranga Dematampitiya, Hung Le, Elliott Le, Phuong Chau, Hao Cui, An Qi Zhao, Wei Bing Qian, Fuqing Li, Jacky Yao, Jiyang Zhang, Leonard Brisan, Cristian Gurka, Shane Young, Johann Bruenner, Martin Novak, Zhen (Jane) Feng, Ph. D., David Geiger, Murad Kurwa

Flextronics International Inc.

February 20th, 2013

Agenda

- Background
- Experiments and Analysis
  - ✓ AXI 1
  - ✓ AXI 2
  - ✓ AXI 3
  - ✓ AXI 4
- Comparison and Improvement
- Summary

Background

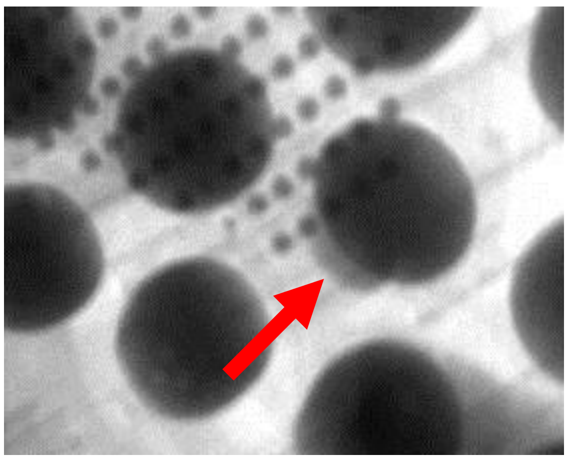
- History of HIP AXI studies at Flextronics
- Question

  What are current AXIs’ capabilities to detect

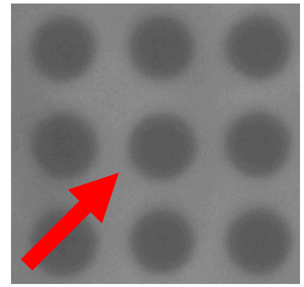
  HIP/open with production boards today?

AXI 1 and 2DX Image comparison in 2008

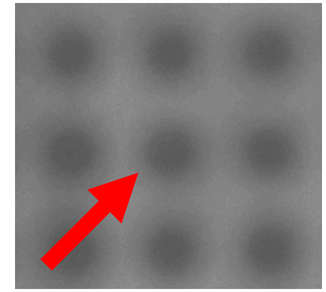
Ball # G24



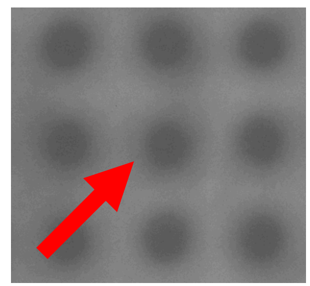
2DX image for G24



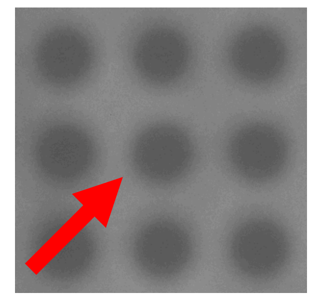
Slice 1



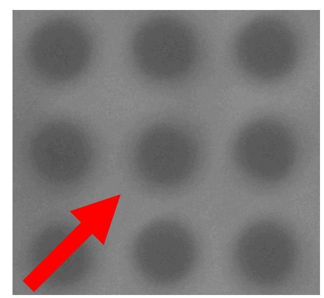
Slice 2



Slice 3



Slice 4



Slice 5

AXI 1 images for G24

There was no difference between good balls and bad ball.

Identifying HIP Detecting Capabilities with X-ray

- Recently more AXI machines have capabilities to detect HIP/open with different success level.
- However, current AXI does not have very clear difference for images between good and defective HIP pins.
- Understand more about AXI machines capabilities,.
- 2DX is a good tool of HIP verification.
- Optimization of threshold setting to detect HIP/open.

Experiments and Analysis

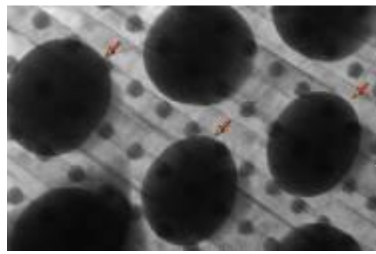
- Two production boards with total 47 defects were selected for the studies. 2DX images were provided for identifying HIP locations.
- We tested these two boards with 4 AXI types machines at 4 sites.
- Board & BGA Description

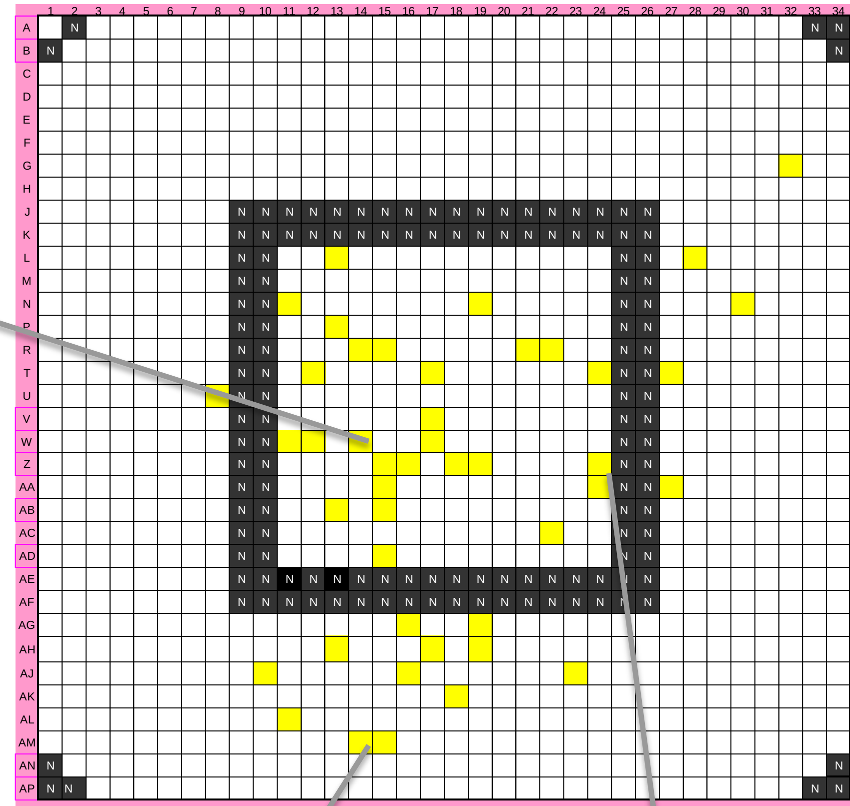
  - 267mm x 210mm, 1.2mm thick

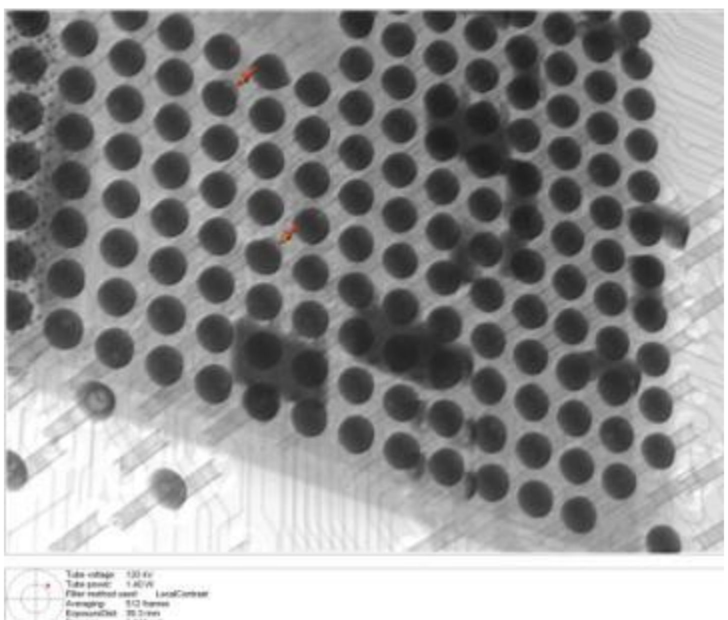
  - BGA (1mm ball pitch, 1017 I/O)

2DX Images of Defective HIP

SN495: 45 defective pins
(W14, Z15, Z16,…)

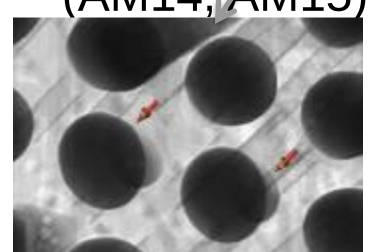


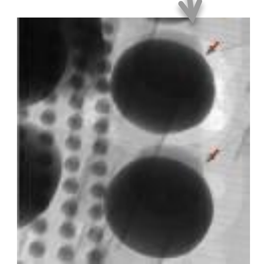




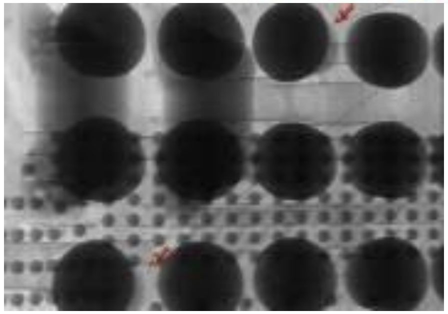
SN266: 2 defective pins (D10, G11)

SN495: 45 defective pins
(AM14, AM15) ; (Z24, AA24)

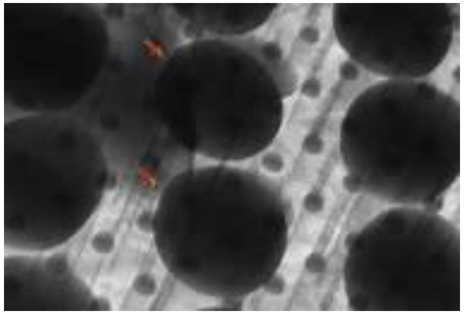




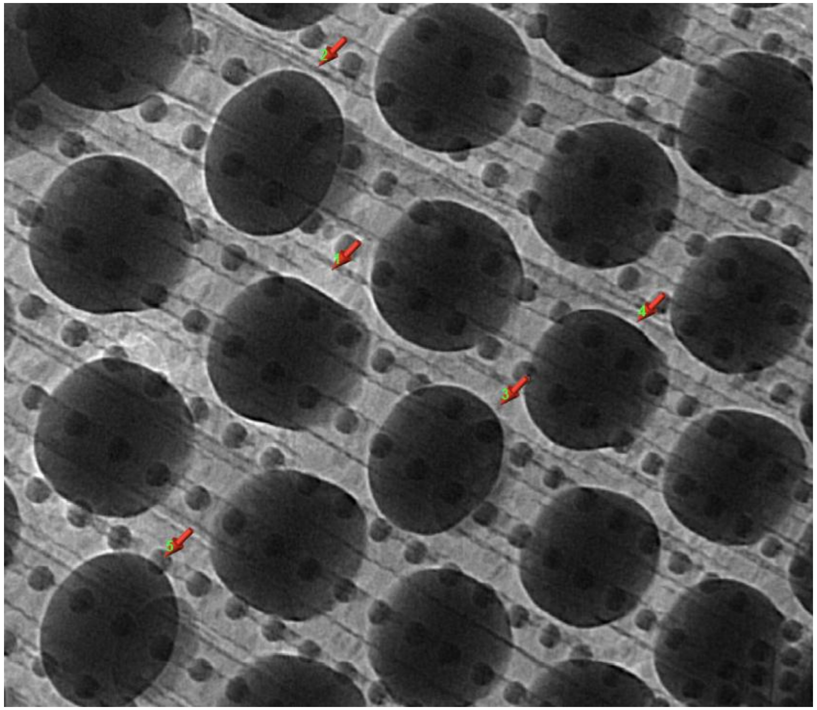
2DX Images of Defective HIP



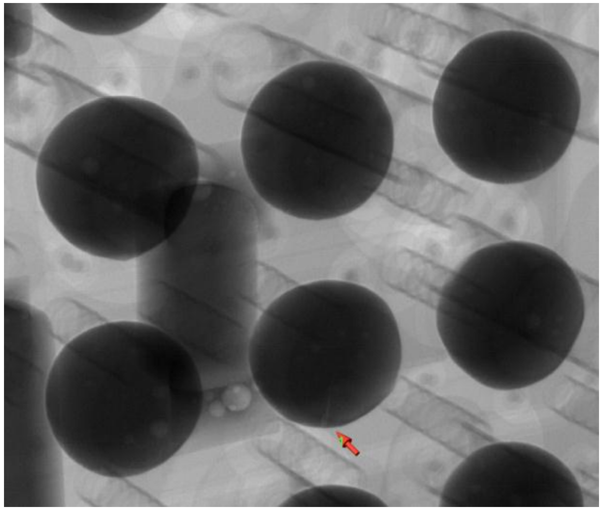
HIP: L13, N11



HIP: AA15, AB15



HIP: V17, W17, Z16, Z18, Z19



Crack: G32

Data Collection

- Defects Escaped %

  = Total # of Defects escaped/Total # of Defects

  where Total # of defects is 47

- False Call PPM

  = (Total # of False call / Total tested #)X10^6

  where Total tested pin is 2034 (1017 X 2 = 2034)

- Gage R&R

  Test nine times with the board by three operators.

  Each operator tests 3 times.

- Collect some detected defects Images and False call Images.

AXI HIP Detection Capabilities: AXI 1 at site 1, 2, and 3

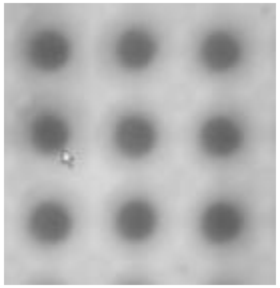
Board #	Open Outlier Threshold Settings	Detected	False Call	Escaped
266	Pad < -3 as defect; Mid Ball > 3 as defect	1	5	1
495	Pad < -3 as defect; Mid Ball > 3 as defect	18	7	27
495	Pad < -2.5 as defect; Mid Ball > 2 as defect	29	17	16
266	Pad < -6 as defect; Mid Ball > 6 as defect	0	0	2
495	Pad < -6 as defect; Mid Ball > 6 as defect	0	0	45

Site	# of Total Escaped Defects	Defects Escaped %	# of Total False Call	False call PPM
1	46	97.87%	0	0
2	28	59.57%	12	5900
3	24	51.06%	13	6391

Site 2 & 3 used Fine Tuning AXI 1 program (adjusted Threshold).

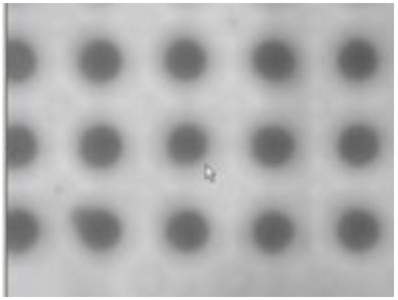
AXI 1 Images at site 1

Detected pin (Board #266)



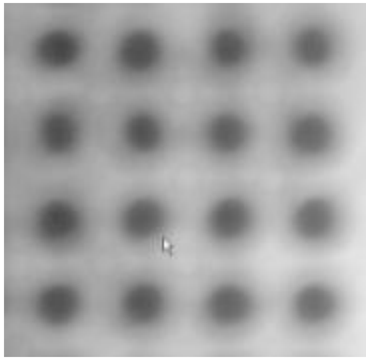
Pin D10

Escaped pin (Board #266)

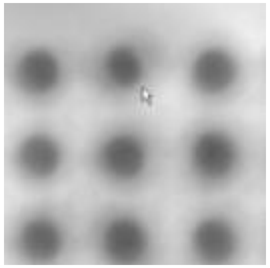


Pin G11

Escaped pin (Board #495)



Pin G32



Pin L13

Pin T24

Fine Tuning for AXI 1 Program at site 2

- Main Algorithm Item & Open Outlier Threshold

Middle Ball > 3 as defect

Family: **BGA2**

Subtype: **BGA1017_35X35_1MM_MOD_CO_U 3**

Basic Additional

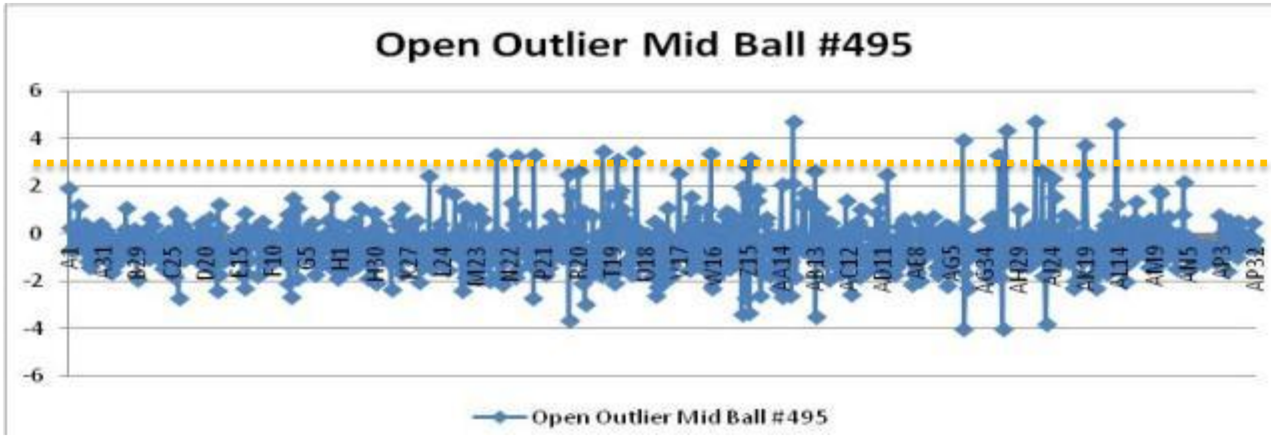
Locator | SPC | **Open** | Short | Insufficient | Misalignment | Voiding

Name	Value	Default	Low Limit	High Limit
Enable Open Outlier for Slice 1	Yes	Yes		
Enable Open Outlier for Slice 2	Yes	Yes		
Enable Open Outlier for Slice 3	Yes	Yes		
Outlier Sensitivity for Slice 1	3.0	10.0	0.0	10.0
Outlier Sensitivity for Slice 2	10.0	10.0	0.0	10.0
Outlier Sensitivity for Slice 3	10.0	10.0	0.0	10.0
Minimum Open Signal Nominal	-1000.0	-1000.0	-1000.0	1000.0
Maximum Open Signal Nominal	1000.0	1000.0	-1000.0	1000.0
Minimum Open Signal Average	-1000.0	-1000.0	-1000.0	1000.0
Maximum Open Signal Average	1000.0	1000.0	-1000.0	1000.0
Minimum Flattening	-1.0	-1.0	-1.0	1.0
Maximum Flattening	1.0	1.0	-1.0	1.0
Outlier Lower Sensitivity for Slice 1	-6.0	-6.0	-10.0	0.0
Outlier Lower Sensitivity for Slice 2	-3.0	-6.0	-10.0	0.0
Outlier Lower Sensitivity for Slice 3	-6.0	-6.0	-10.0	0.0

Pad < -3 as defect

AXI1 Data from Site 2– board #495

AXI1	BGA U4D1 Pin #	Pin Type	OpenOutlier MidBall
889	T24	HIP	3.11
1003	Z18	HIP	3.17
803	N30	HIP	3.27
786	N11	HIP	3.3
818	P13	HIP	3.3
230	AH13	HIP	3.31
969	W14	HIP	3.36
905	U8	HIP	3.39
877	T12	HIP	3.48
303	AK18	HIP	3.73
199	AG16	HIP	3.93
236	AH19	HIP	4.34
330	AL11	HIP	4.62
54	AA27	HIP	4.71
261	AJ10	HIP	4.73



Detected pin & False call

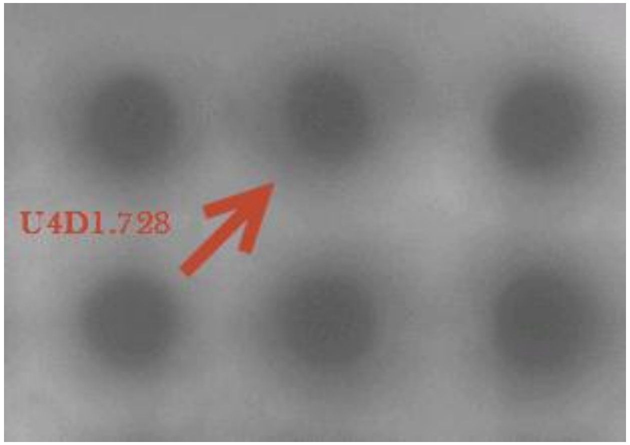
AXI1	BGA U4D1 Pin #	Pin Defect	OpenOutlier Pad
145	AD28	False call	-4.06
997	Z12	False call	-3.77
1008	Z23	False call	-3.37
74	AB15	HIP	-3.29
134	AD15	HIP	-3.24
22	A23	False call	-3.14
728	L13	HIP	-3.13
104	AC15	False call	-3.09
645	G28	False call	-3.05
760	M15	False call	-3.05

Open Outlier Threshold Settings:	Detected	False call	Escaped
Pad < -3 as defect; Mid Ball > 3 as defect	18	7	27
Pad < -2.5 as defect; Mid Ball > 2 as defect	29	17	16

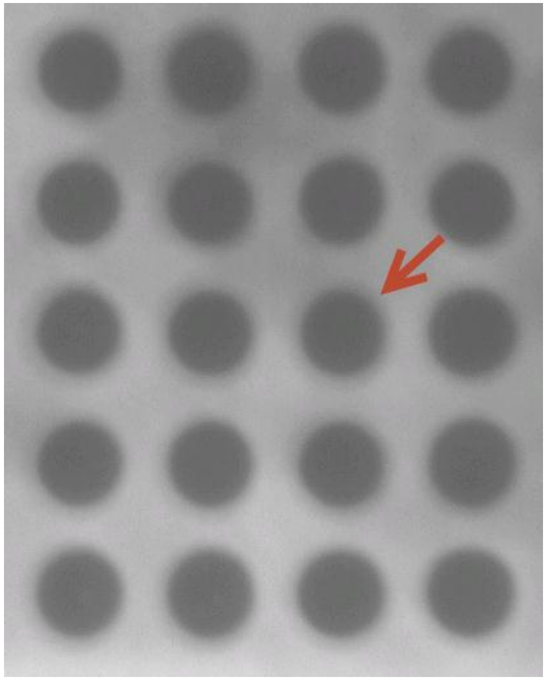
Open Outlier Threshold Settings: Pad < -3 as defect; Mid Ball > 3 as defect

AXI 1 Images at Site 2

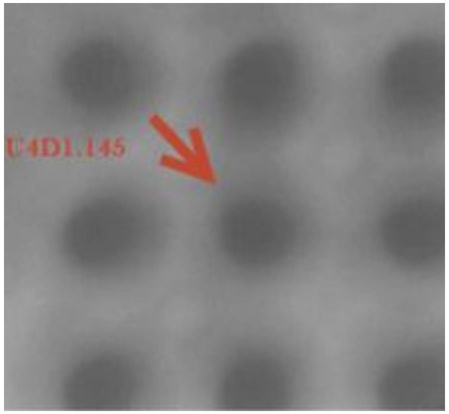
Detected HIP pin L13



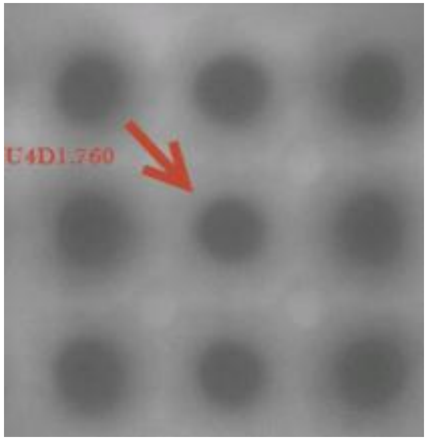
Escaped pin G32



False call pins



AD28

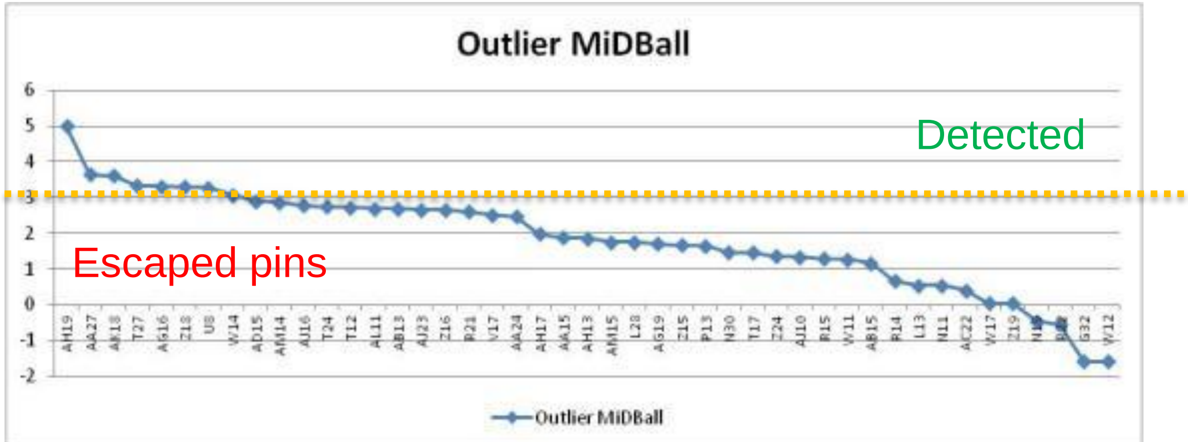


M15

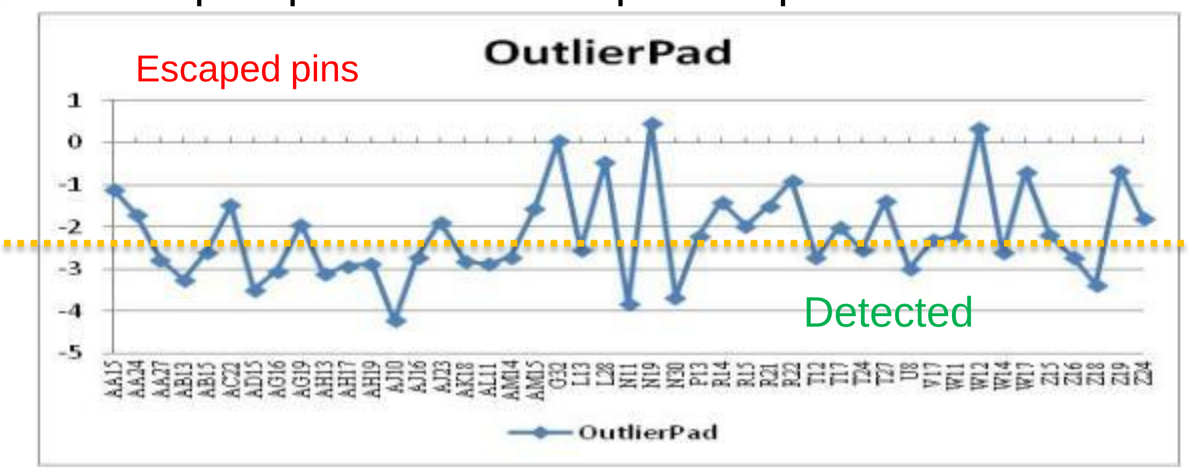
Board # 495

AXI 1 Data at Site 3 (board #495)

BGA Pin	AXI1	HIP (2DX) for #495	Site3-AXI1 TEST STATUS	OutlierPad
AA15	44	HIP	Escaped	-1.1
AA24	53	HIP	Escaped	-1.71
AA27	54	HIP	Detected	-2.78
AB13	72	HIP	Detected	-3.25
AB15	74	HIP	Detected	-2.6
AC22	111	HIP	Escaped	-1.48
AD15	134	HIP	Detected	-3.49
AG16	199	HIP	Detected	-3.04
AG19	202	HIP	Escaped	-1.94
AH13	230	HIP	Detected	-3.12
AH17	234	HIP	Detected	-2.93
AH19	236	HIP	Detected	-2.87
AJ10	261	HIP	Detected	-4.22
AJ16	267	HIP	Detected	-2.71
AJ23	274	HIP	Escaped	-1.87
AK18	303	HIP	Detected	-2.81
AL11	330	HIP	Detected	-2.88
AM14	367	HIP	Detected	-2.71
AM15	368	HIP	Escaped	-1.56
G32	649	HIP	Escaped	0.04
L13	728	HIP	Detected	-2.53
L28	741	HIP	Escaped	-0.45
N11	786	HIP	Detected	-3.83
N19	794	HIP	Escaped	0.48
N30	803	HIP	Detected	-3.66
P13	818	HIP	Escaped	-2.2
R14	849	HIP	Escaped	-1.4
R15	850	HIP	Escaped	-1.97
R21	856	HIP	Escaped	-1.5
R22	857	HIP	Escaped	-0.89
T12	877	HIP	Detected	-2.73
T17	882	HIP	Escaped	-2
T24	889	HIP	Detected	-2.54
T27	890	HIP	Escaped	-1.39
U8	905	HIP	Detected	-2.98
V17	942	HIP	Escaped	-2.31
W11	966	HIP	Escaped	-2.21
W12	967	HIP	Escaped	0.36
W14	969	HIP	Detected	-2.61
W17	972	HIP	Escaped	-0.7
Z15	1000	HIP	Escaped	-2.19
Z16	1001	HIP	Detected	-2.71
Z18	1003	HIP	Detected	-3.38
Z19	1004	HIP	Escaped	-0.66



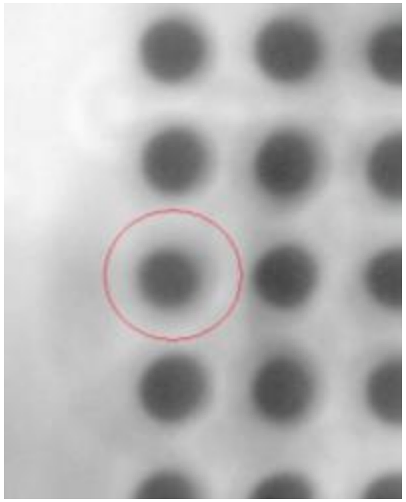
Escaped pin & Detected pin call pin



Open Outlier Threshold Settings	Detected	False call	Escaped
Pad <-2.5for Bd # 495; Mid ball > 3	22	6	23
Pad < -2.8 for Bd # 266; Mid ball > 3	1	7	1

Open Outlier Threshold Settings: Pad < -2.5 (#495); <-2.8 (#266) as defect; Mid Ball > 3 as defect

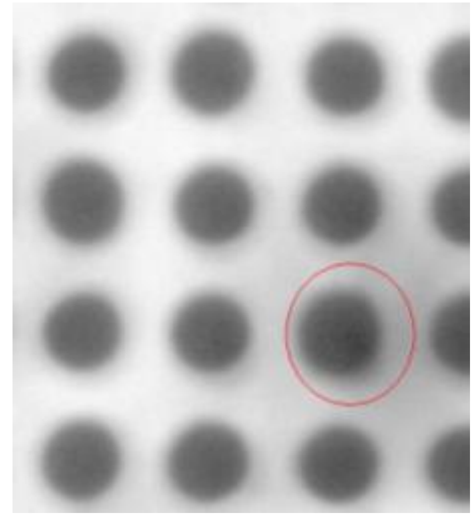
AXI 1 Images at Site 3

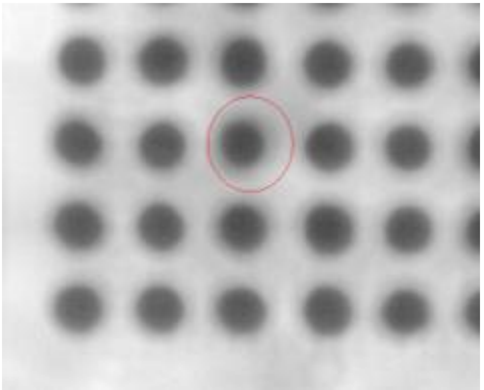


Detected pin

L13

AK18

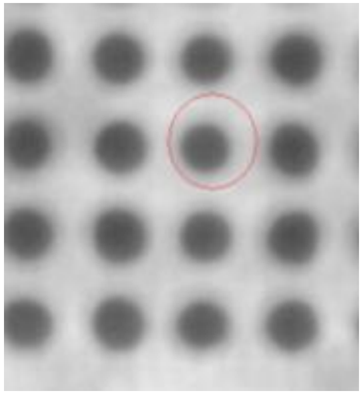




Escaped pin

AB13

AB15



Board # 495

AXI HIP Detection Capabilities: AXI 2

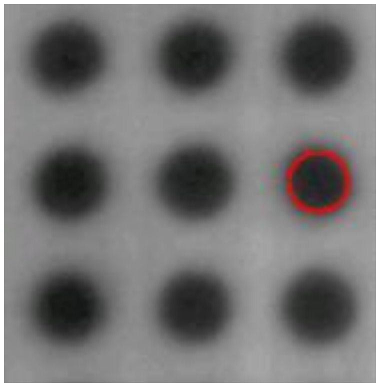
Algorithm Threshold Settings:

Neighbour outlier is < **-3.5** for pad, and > **4.5** for middle ball.

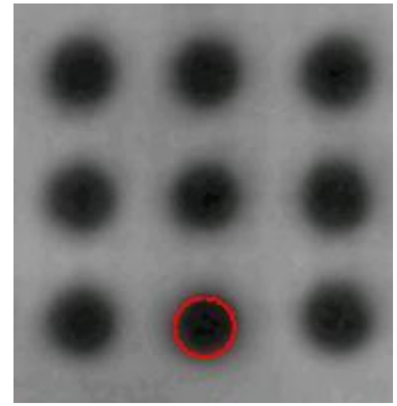
Site	# of Total Escaped Defects	Defects Escaped %	# of Total False Call	False call PPM
1	16	34.04%	3	1475

AXI 2 Images at Site 1

Detected pin

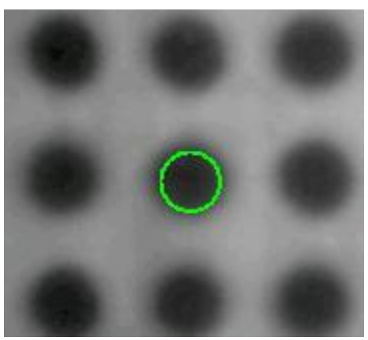


T24

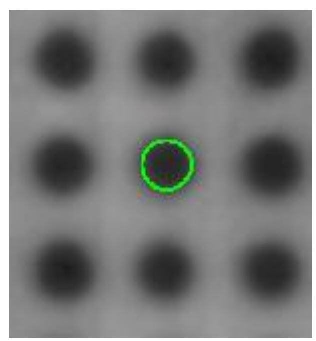


L13

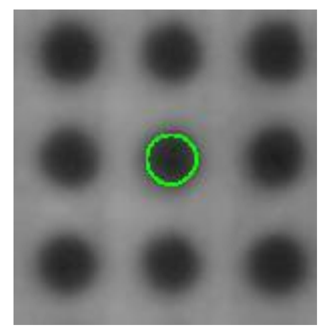
Escaped pins



Pin G32



Pin AA15



Pin AB15

(Board #495)

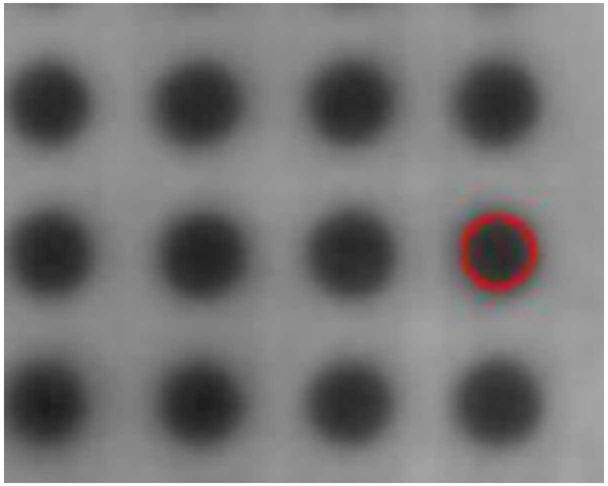
AXI HIP Detection Capabilities: AXI 3 at Site 1, 2, 3, 4

Site	Algorithm (Neighbor Outlier)	Threshold
1	Minimum and Maximum for Pad	< - 3.2 ; > 4.5
2	Neighbor Outlier - Pad (multi-pass)	> 2.2
3	Neighbor Outlier - Pad	> 2.2 (#495); >3.3(#266)
4	Neighbor Outlier - Pad	> 2.2 (#495); >3.3(#266)

Site	# of Total Escaped Defects	Defects Escaped %	# of Total False Call	False call PPM
1	13	27.66%	9	4425
2	7	14.89%	12	5900
3	5	10.64%	7	3441
4	8	17.02%	12	5900

AXI 3 use s/w 3.2 (**multi-pass**) tests the boards at site 2, and use 4.0 version at site 1. The difference is next neighbor # from 1 (site 1, 3, 4) to 4 as pass (site 2).

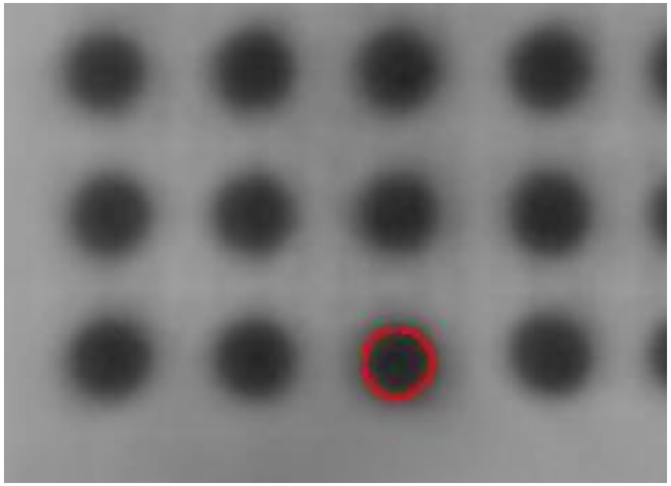
AXI 3 Images at Site 1



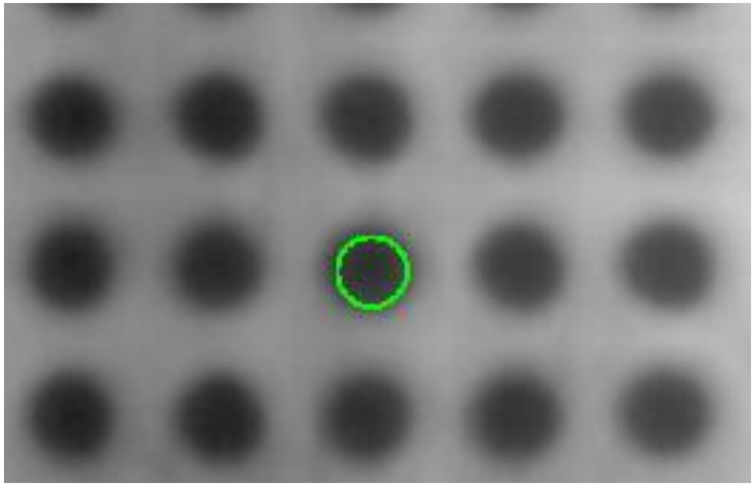
Detected pins

T24

L13

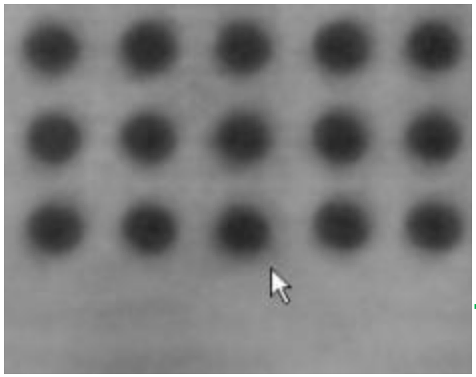


Escaped pin G32



(Board # 495)

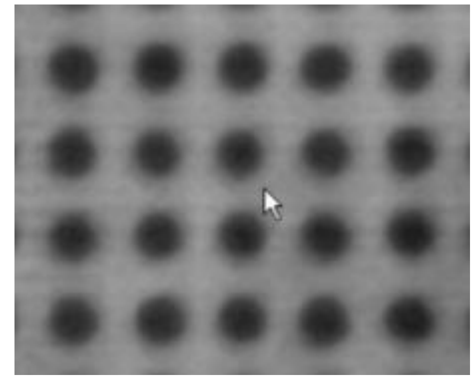
AXI 3 Images at Site 2

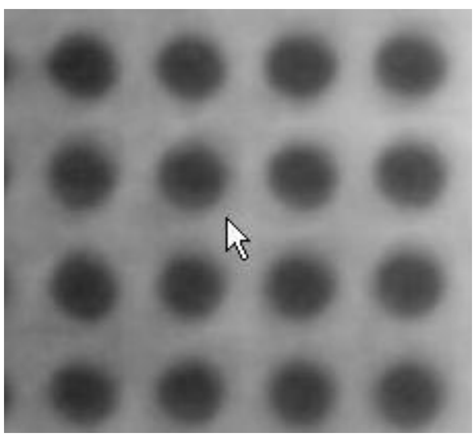


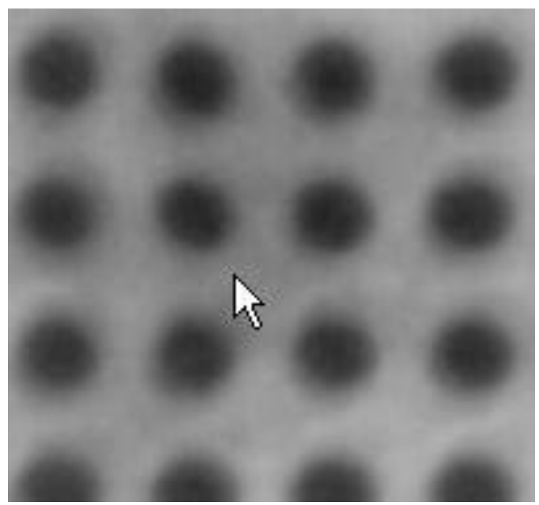
Detected pin

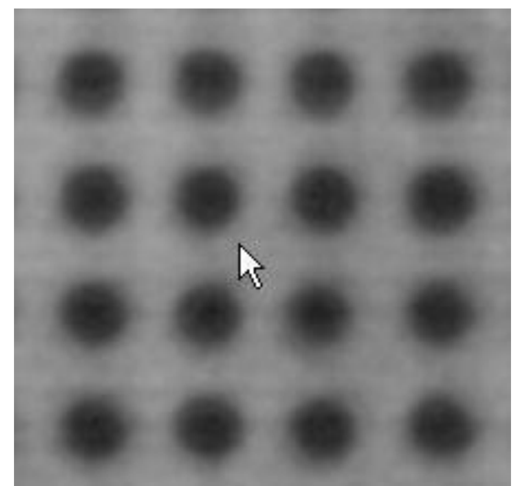
728 = L13

850 = R15









Escaped pin 649 = G32

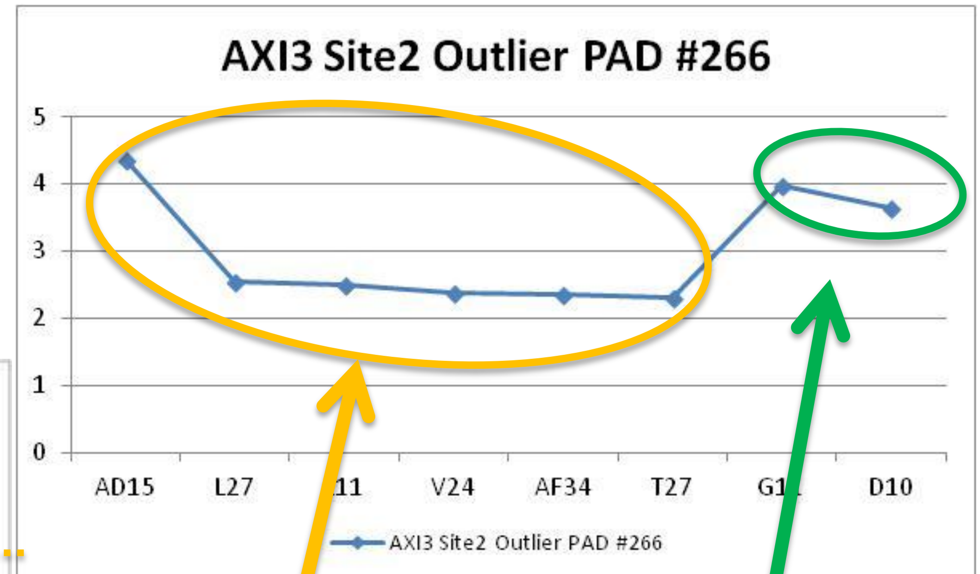
False call pin 705 = K4, 885 = T20

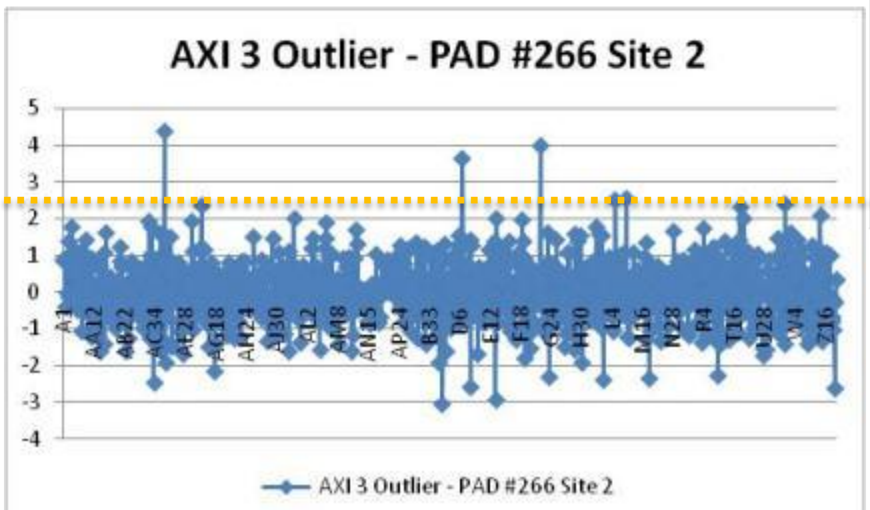
(Board # 495)

AXI 3 Data at Site 2 (Board #266)

BGA U4D1 Pin #	AXI3 Site2 Outlier PAD #266	AXI3 Pin #	Detect results	HIP Pin
AD15	4.37	134	FALSE	
L27	2.55	740	FALSE	
L11	2.5	726	FALSE	
V24	2.38	949	FALSE	
AF34	2.35	183	FALSE	
T27	2.3	890	FALSE	
G11	3.98	628	Detected	HIP
D10	3.64	525	Detected	HIP

HIP Outlier Pad Threshold >2.2





False call pins

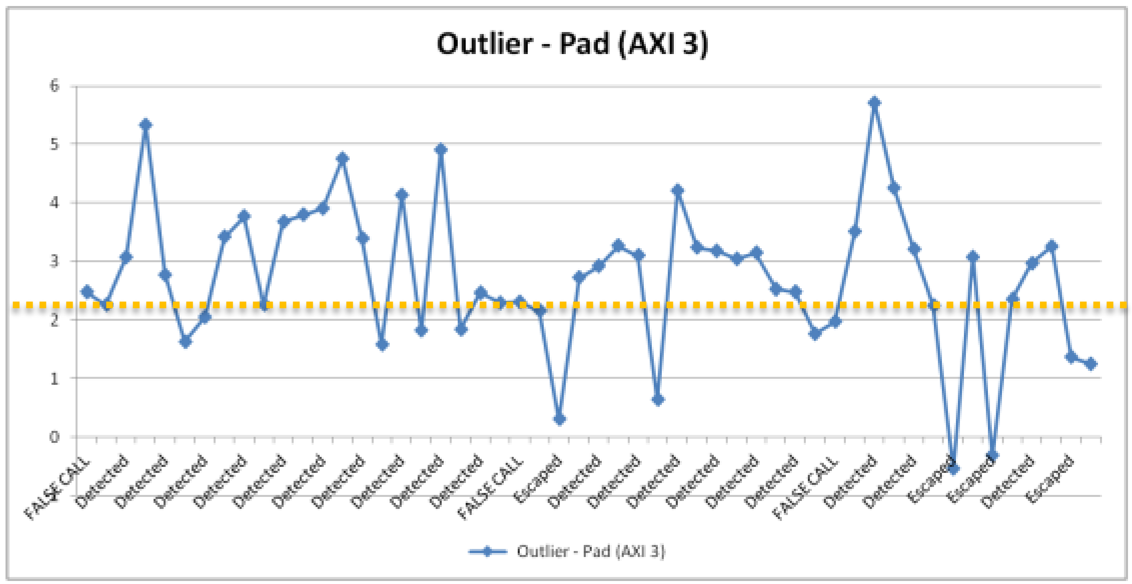
Detected pins

All pins listed here are defective, and false call pins.

AXI 3 Data at Site 2 (Board #495)

BGA U4D1 Pin #	HIP (2DX) for SN495	# from AXI 3	Test Result	Outlier-Pad (AXI3)
A1		1	FALSE CALL	2.48
AA15	HIP	44	Detected	2.26
AA24	HIP	53	Detected	3.07
AA27	HIP	54	Detected	5.33
AB13	HIP	72	Detected	2.77
AB15	HIP	74	Escaped	1.63
AC22	HIP	111	Detected	2.05
AD15	HIP	134	Detected	3.41
AG16	HIP	199	Detected	3.76
AG19	HIP	202	Detected	2.26
AH13	HIP	230	Detected	3.68
AH17	HIP	234	Detected	3.79
AH19	HIP	236	Detected	3.9
AJ10	HIP	261	Detected	4.75
AJ16	HIP	267	Detected	3.38
AJ23	HIP	274	Detected	1.58
AK18	HIP	303	Detected	4.13
AK19		304	FALSE CALL	1.82
AL11	HIP	330	Detected	4.91
AL28		347	FALSE CALL	1.84
AM14	HIP	367	Detected	2.46
AM15	HIP	368	Detected	2.3
C9		490	FALSE CALL	2.31
C31		512	FALSE CALL	2.15
G32	HIP	649	Escaped	0.3
K4		705	FALSE CALL	2.71
L13	HIP	728	Detected	2.91
L28	HIP	741	Detected	3.26
N11	HIP	786	Detected	3.09
N19	HIP	794	Escaped	0.64
N30	HIP	803	Detected	4.21
P13	HIP	818	Detected	3.23
R14	HIP	849	Detected	3.18
R15	HIP	850	Detected	3.04
R21	HIP	856	Detected	3.14
R22	HIP	857	Detected	2.52
T12	HIP	877	Detected	2.47
T17	HIP	882	Detected	1.76
T20		885	FALSE CALL	1.97
T24	HIP	889	Detected	3.51
T27	HIP	890	Detected	5.71
U8	HIP	905	Detected	4.25
V17	HIP	942	Detected	3.21
W11	HIP	966	Detected	2.25
W12	HIP	967	Escaped	-0.54
W14	HIP	969	Detected	3.07
W17	HIP	972	Escaped	-0.32
Z15	HIP	1000	Detected	2.35
Z16	HIP	1001	Detected	2.96
Z18	HIP	1003	Detected	3.25
Z19	HIP	1004	Escaped	1.36
Z24	HIP	1009	Escaped	1.25

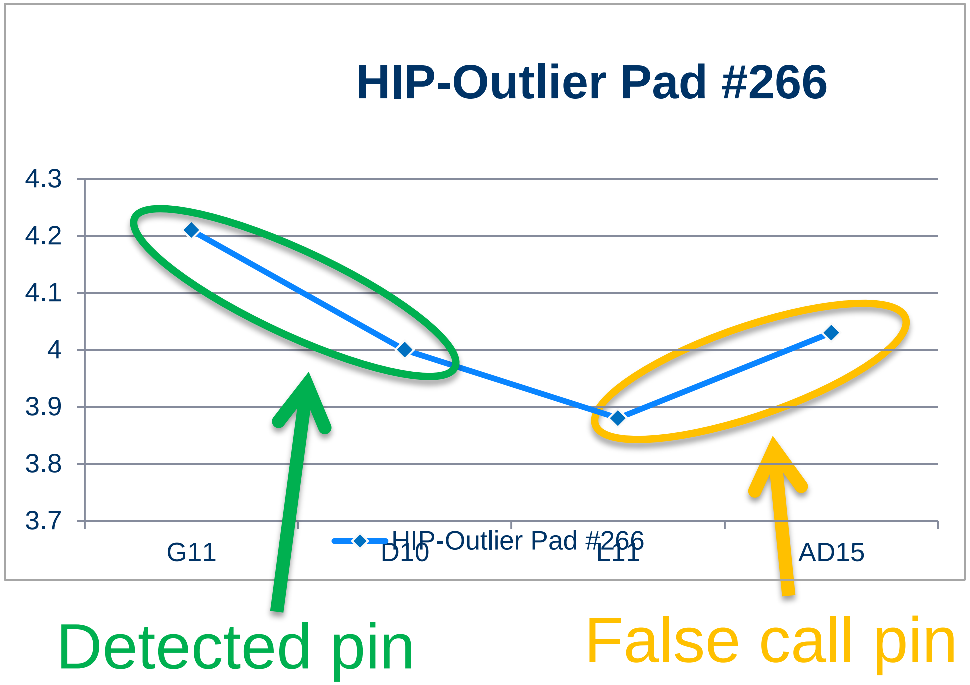
Escaped pin & Detected pin & False call pin



HIP Outlier Pad Threshold >2.2, it is defect.

AXI 3 Data at Site 3 (Board #266)

Pin from AXI3	Sample ID	HIP-Outlier Pad #266	Site3-AXI3 TEST STATUS	Pin Defect
628	G11	4.21	Detected	HIP
525	D10	4	Detected	HIP
726	L11	3.88	FALSE	
134	AD15	4.03	FALSE	

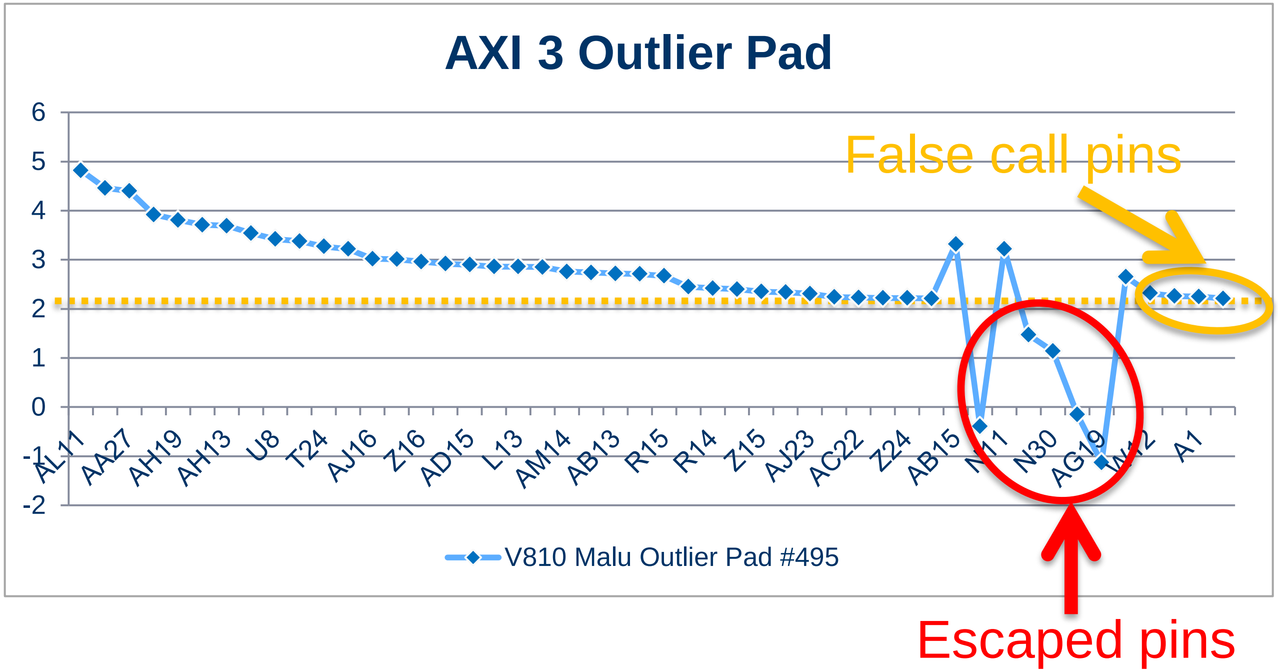


HIP Outlier Pad Threshold:
>2.2 for board #495, >3.3 for board # 266.

All pins listed here are defective, and false call pins.

AXI 3 Data at Site 3 (board #495)

Sample ID	Pin from AXI3	AXI3 Site3 Outlier Pad #495	Site3-AXI3 TEST STATUS
330	AL11	5.94	Detected
890	T27	5.59	Detected
54	AA27	4.82	Detected
261	AJ10	4.46	Detected
236	AH19	4.4	Detected
303	AK18	3.92	Detected
230	AH13	3.81	Detected
234	AH17	3.71	Detected
905	U8	3.69	Detected
1003	Z18	3.54	Detected
889	T24	3.42	Detected
199	AG16	3.38	Detected
267	AJ16	3.27	Detected
969	W14	3.22	Detected
1001	Z16	3.02	Detected
818	P13	3.01	Detected
134	AD15	2.96	Detected
942	V17	2.92	Detected
728	L13	2.9	Detected
53	AA24	2.86	Detected
367	AM14	2.86	Detected
877	T12	2.85	Detected
72	AB13	2.76	Detected
856	R21	2.74	Detected
850	R15	2.72	Detected
741	L28	2.71	Detected
849	R14	2.67	Detected
882	T17	2.45	Detected
1000	Z15	2.42	Detected
368	AM15	2.4	Detected
274	AJ23	2.35	Detected
857	R22	2.34	Detected
111	AC22	2.31	Detected
972	W17	2.24	Detected
1009	Z24	2.23	Detected
44	AA15	2.22	Detected
74	AB15	2.22	Detected
966	W11	2.21	Detected
786	N11	3.32	Detected
794	N19	-0.39	Escaped
803	N30	3.22	Detected
1004	Z19	1.47	Escaped
202	AG19	1.14	Escaped
649	G32	-0.15	Escaped
967	W12	-1.13	Escaped
1008	Z23	2.65	FALSE
1	A1	2.32	FALSE
276	AJ25	2.26	FALSE
510	C29	2.25	FALSE
490	C9	2.21	FALSE

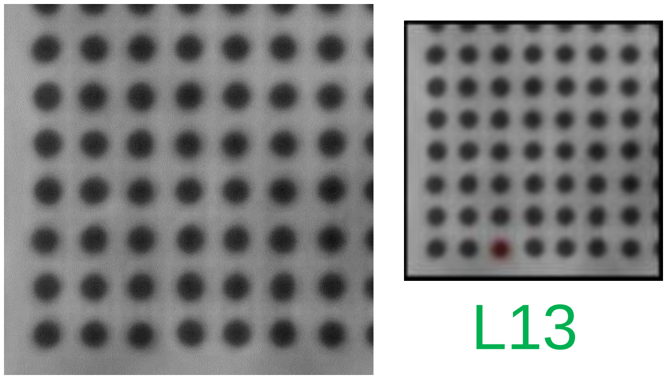


Escaped pin & Detected pin & False call pin

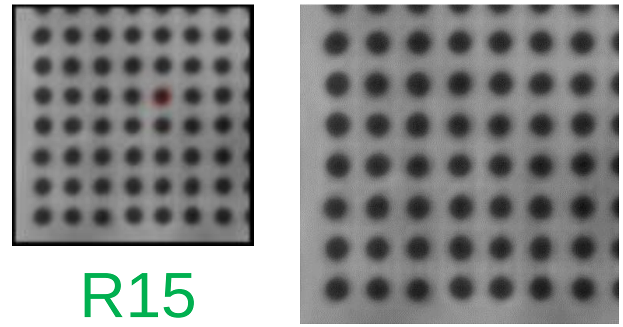
HIP Outlier Pad Threshold:
>2.2 for board #495, >3.3 for board # 266.

AXI 3 Images at Site 3

Detected pin

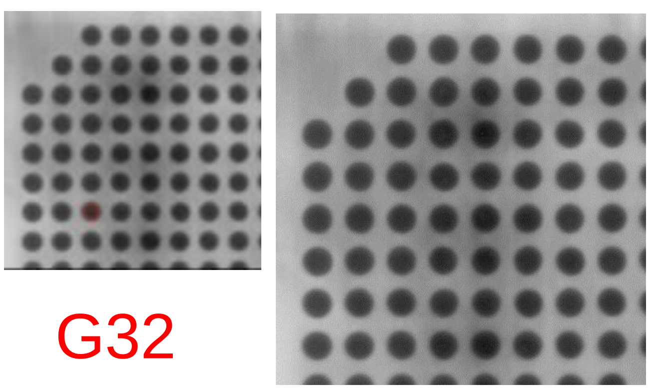


L13



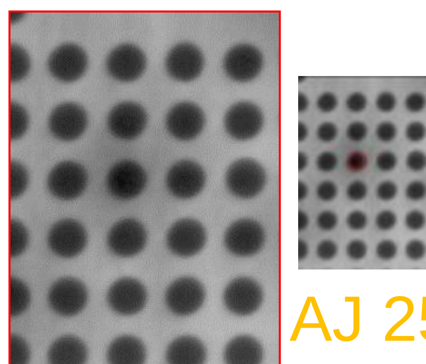
R15

Escaped pin

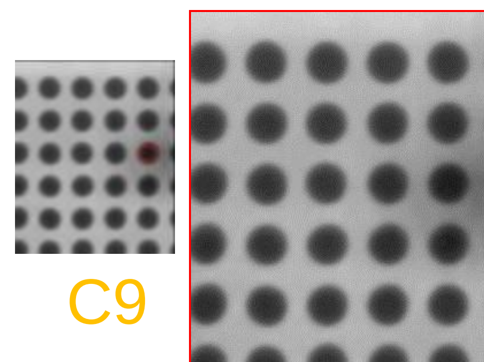


G32

False call pin



AJ 25



C9

AXI HIP Detection Capabilities: AXI 4 at site 2, 3, 4

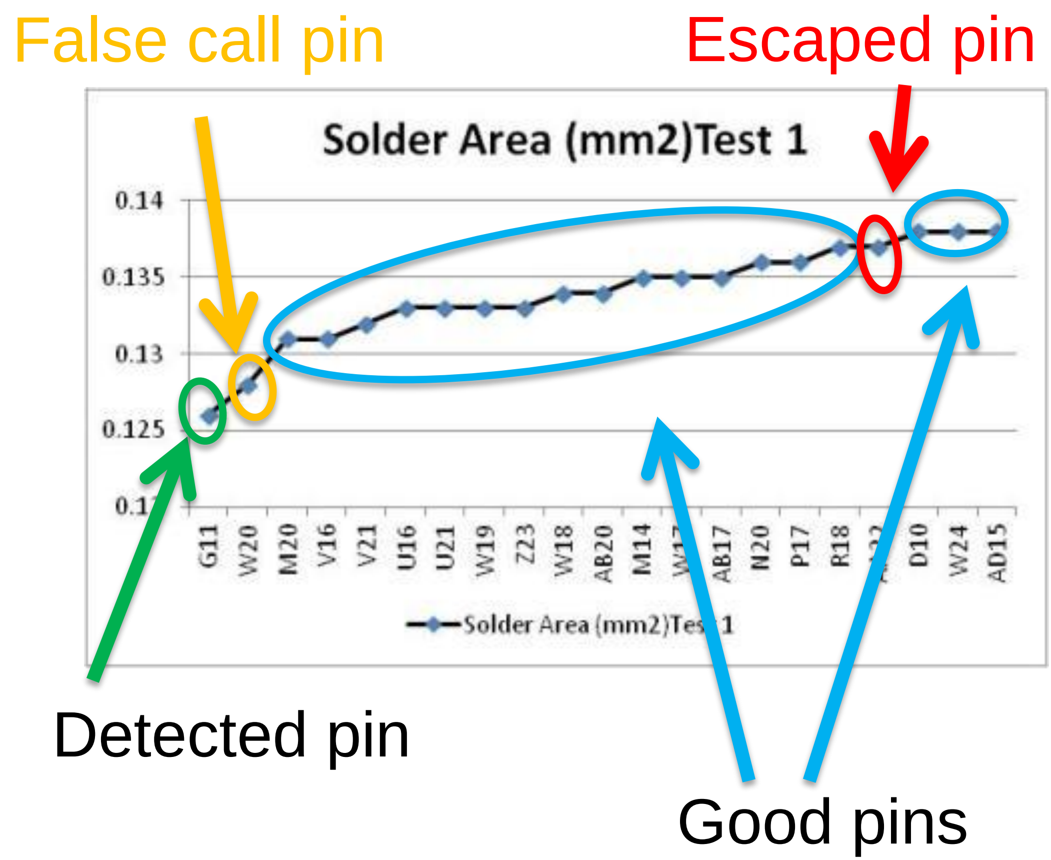
Site	Algorithm	Threshold	Note
2	Solder Area Pad	< 83% ; >130%	< 0.129 or < 0.144 mm^2
3	Solder Area Pad	< 70% ; >130%	< 0.125mm^2; < 0.144 mm^2
4	Solder Area Pad	< 70% ; >130%	< 0.125mm^2 ; < 0.142 mm^2

Site	# of Total Escaped Defects	Defects Escaped %	# of Total False Call	False Call PPM
2	2	4.26%	4	1967
3	2	4.26%	1	492
4	1	2.13%	4	1967

S/W version V3001

AXI 4 Data at Site 2 (board #266)

Pin # from AXI4	Solder area Pad (mm2)	HIP Detected Status
G11	0.126	Detected
W20	0.128	False call
M20	0.131	
V16	0.131	
V21	0.132	
U16	0.133	
U21	0.133	
W19	0.133	
Z23	0.133	
W18	0.134	
AB20	0.134	
M14	0.135	
W17	0.135	
AB17	0.135	
N20	0.136	
P17	0.136	
R18	0.137	
AA22	0.137	
D10	0.138	Escaped
W24	0.138	
AD15	0.138	



Solder Area Threshold < 0.129mm^2

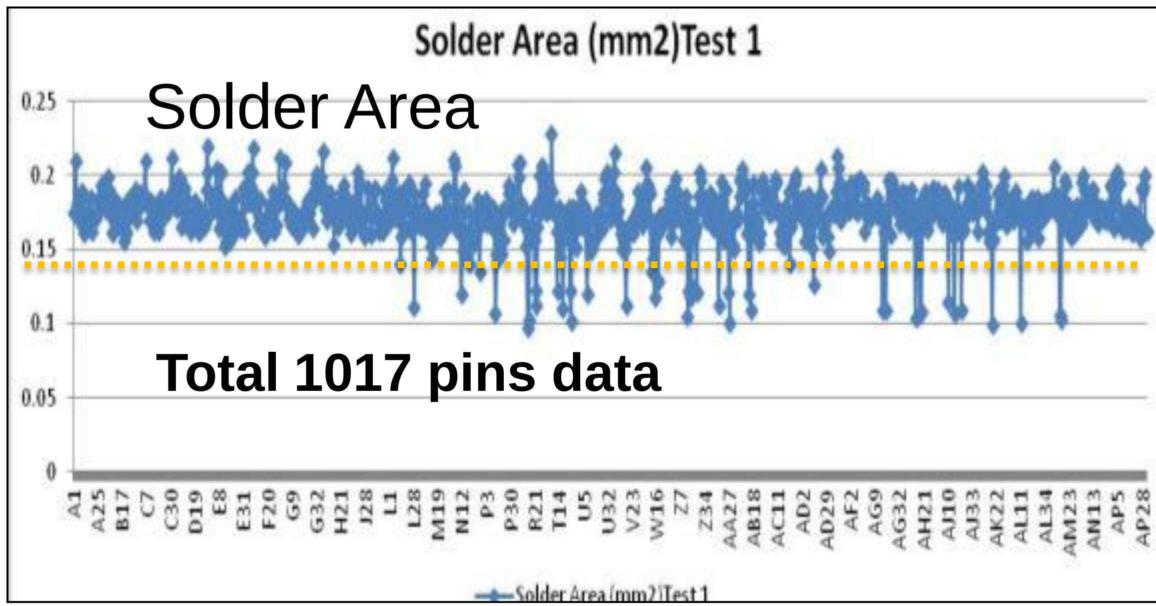
XI 4 Data at Site 2 (board #495)

Pin # AXI4	Solder area Pad (mm2)	AXI4 Site2 Test Statu
G32	0.195	Escaped
W12	0.143	Detected
L13	0.14	Detected
N19	0.14	Detected
AC22	0.14	Detected
W11	0.135	Detected
N30	0.134	Detected
W17	0.128	Detected
AD15	0.126	Detected
Z19	0.125	Detected
R22	0.122	Detected
T12	0.121	Detected
T24	0.121	Detected
Z16	0.121	Detected
Z24	0.12	Detected
AA24	0.12	Detected
N11	0.119	Detected
U8	0.119	Detected
AB13	0.119	Detected
W14	0.117	Detected
Z18	0.117	Detected
AJ10	0.114	Detected
R21	0.112	Detected
V17	0.112	Detected
AA15	0.112	Detected
L28	0.111	Detected
T17	0.11	Detected
AB15	0.109	Detected
AG19	0.109	Detected
AJ23	0.109	Detected
AG16	0.108	Detected
AH19	0.107	Detected
P13	0.106	Detected
AJ16	0.106	Detected
AH17	0.105	Detected
AM14	0.105	Detected
Z15	0.104	Detected
AH13	0.103	Detected
R15	0.102	Detected
AM15	0.102	Detected
T27	0.101	Detected
AA27	0.1	Detected
AL11	0.1	Detected
AK18	0.099	Detected

Escaped pin
&
Detected pin

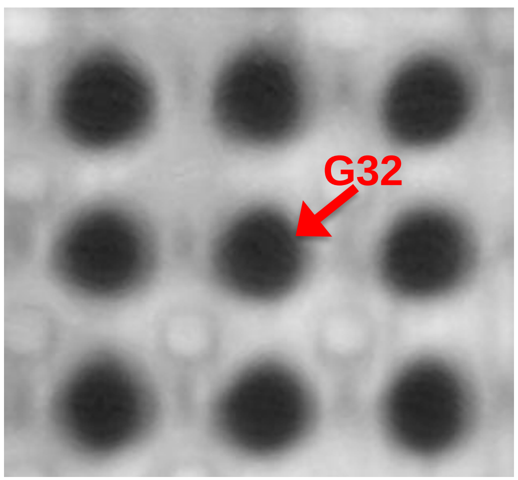
False call pin

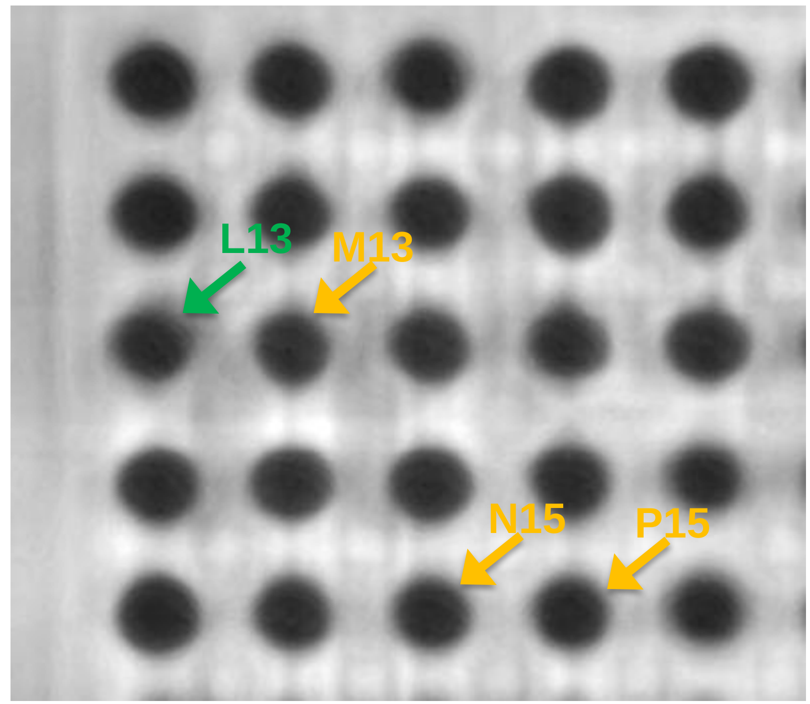
Pin #	HIP Detected pin (put "Y")	HIP False called pin (put "F")	Solder Area (mm2)
M13		F	0.143
N15		F	0.143
P15		F	0.142



Solder Area Threshold <0.144mm^2

AXI 4 Image at Site 2



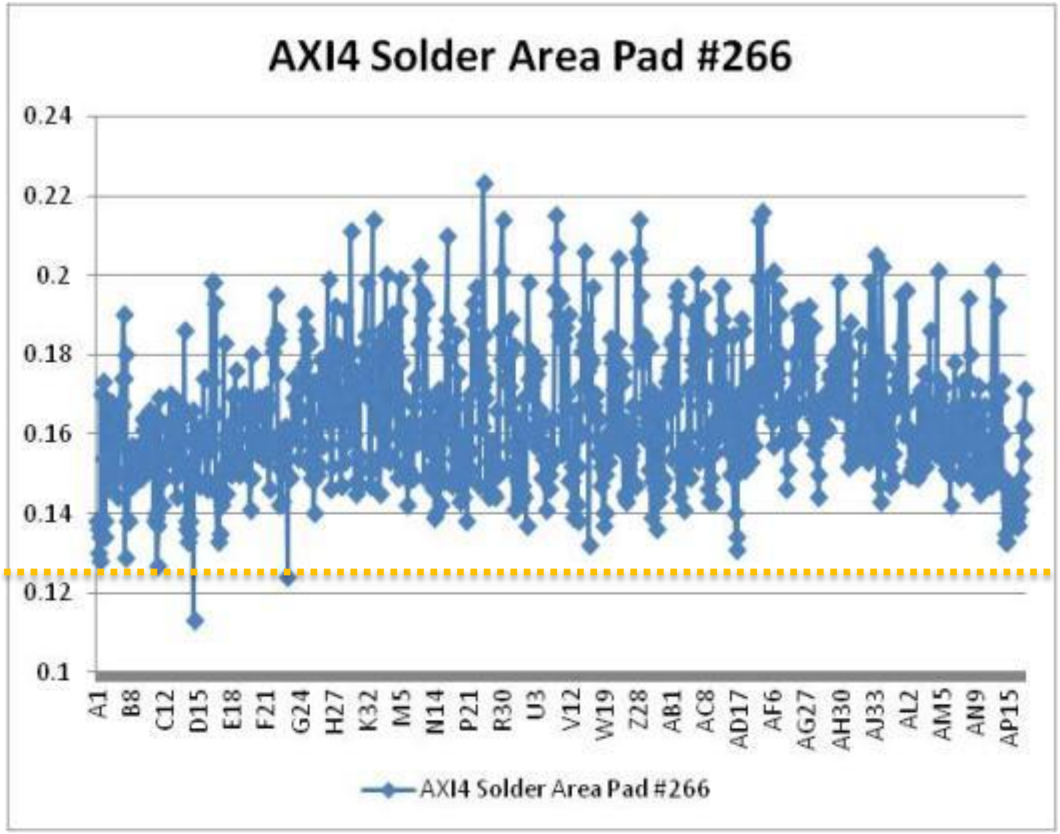


Escaped, Detected, False call pins

(board #495)

AXI 4 Data at Site 3 (board #266)

Sample ID	AXI4 Solder Area Pad #266	AXI4 Site3 Test results	Pin Defect
D10	0.113	Detected	HIP
G11	0.124	Detected	HIP
C4	0.127		
A6	0.128		
B2	0.129		
A4	0.13		
AD14	0.131		
W1	0.132		
D4	0.133		
E2	0.133		
AP10	0.133		
AP12	0.133		



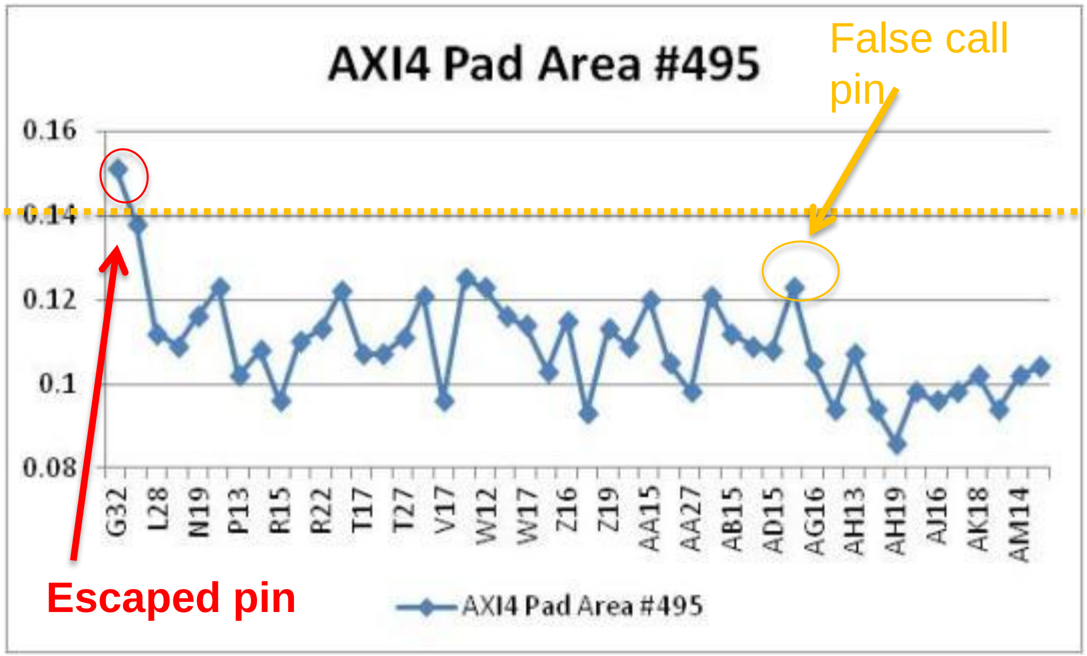
Solder Area pad ≤0.125mm^2

No False call pin; no escaped pin

AXI 4 Data at Site 3 (board #495)

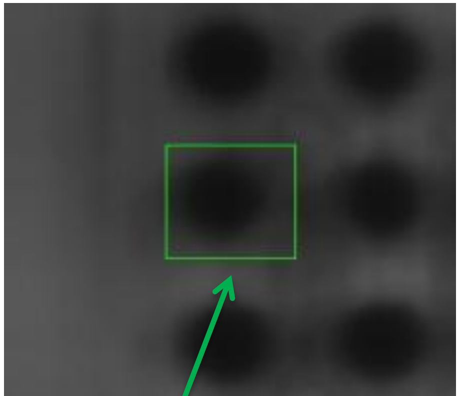
Sample ID	AXI4 Pad Area #495	Site3-AXUI4 TEST STATUS	Pin
G32	0.151	escaped	HIP
L13	0.138	Detected	HIP
L28	0.112	Detected	HIP
N11	0.109	Detected	HIP
N19	0.116	Detected	HIP
N30	0.123	Detected	HIP
P13	0.102	Detected	HIP
R14	0.108	Detected	HIP
R15	0.096	Detected	HIP
R21	0.11	Detected	HIP
R22	0.113	Detected	HIP
T12	0.122	Detected	HIP
T17	0.107	Detected	HIP
T24	0.107	Detected	HIP
T27	0.111	Detected	HIP
U8	0.121	Detected	HIP
V17	0.096	Detected	HIP
W11	0.125	Detected	HIP
W12	0.123	Detected	HIP
W14	0.116	Detected	HIP
W17	0.114	Detected	HIP
Z15	0.103	Detected	HIP
Z16	0.115	Detected	HIP
Z18	0.093	Detected	HIP
Z19	0.113	Detected	HIP
Z24	0.109	Detected	HIP
AA15	0.12	Detected	HIP
AA24	0.105	Detected	HIP
AA27	0.098	Detected	HIP
AB13	0.121	Detected	HIP
AB15	0.112	Detected	HIP
AC22	0.109	Detected	HIP
AD15	0.108	Detected	HIP
AD31	0.123	False call	
AG16	0.105	Detected	HIP
AG19	0.094	Detected	HIP
AH13	0.107	Detected	HIP
AH17	0.094	Detected	HIP
AH19	0.086	Detected	HIP
AJ10	0.098	Detected	HIP
AJ16	0.096	Detected	HIP
AJ23	0.098	Detected	HIP
AK18	0.102	Detected	HIP
AL11	0.094	Detected	HIP
AM14	0.102	Detected	HIP
AM15	0.104	Detected	HIP

Escaped pin
&
Detected pin

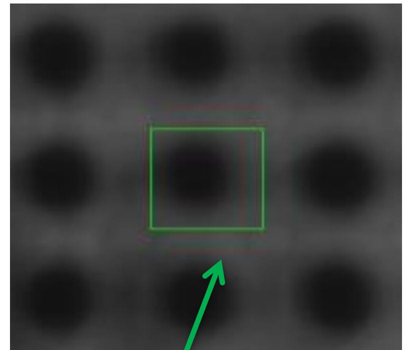


Solder Area Threshold <0.142 mm^2

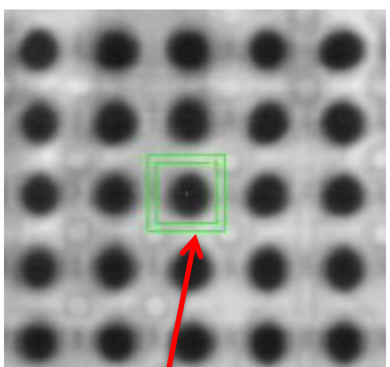
AXI 4 Image at Site 3



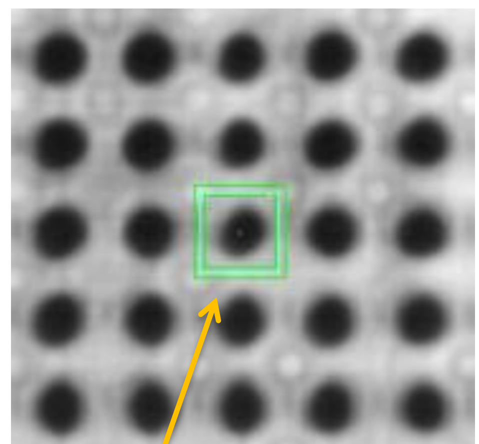
Detected pin L13



Detected pin R15



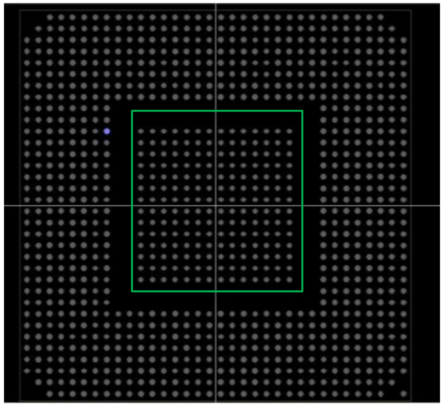
Escaped pin G32



False call pin AD31

Comparison and Improvement

Comparison with 1 and 2 Types Algorithm Threshold Settings

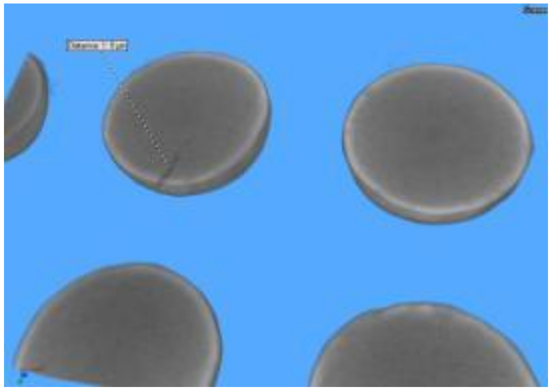


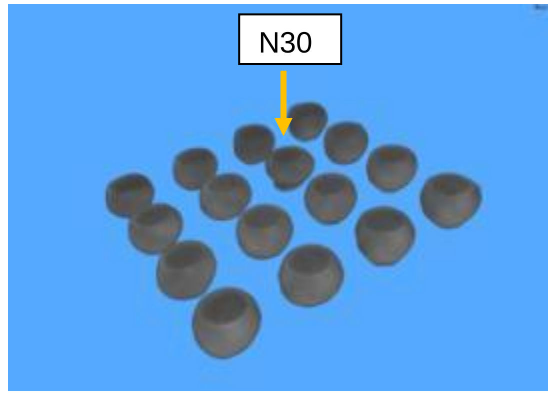
Ball Location	Diameter (pad)
Outer	21mil
Inner	19mil

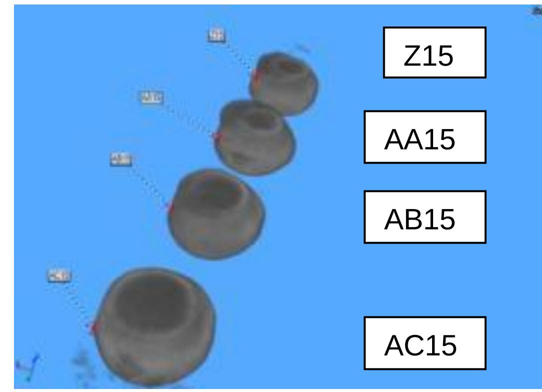
Site	AXI	Type of Algorithm Threshold	# of Total Escaped Defects	Defect escaped %	# of Total False Call	False Call PPM
2	AXI 1	1	27	60.0%	7	6883
2	AXI 1	2	15	33.3%	7	6883
4	AXI 4	1	1	2.2%	4	3933
4	AXI 4	2	1	2.2%	1	983

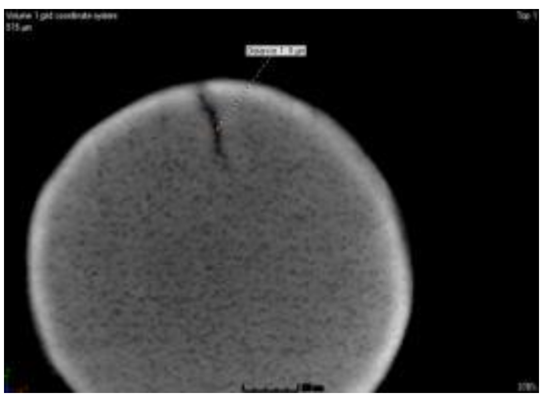
- AXI test results are better with 2 types threshold settings.

CT Images – XD7600 NT

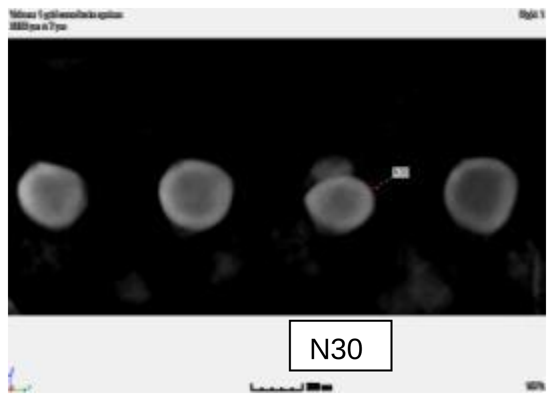




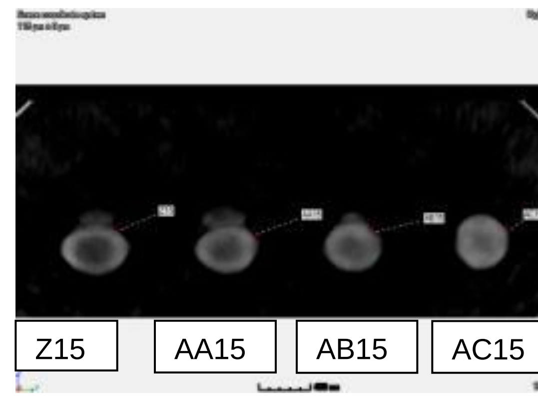




CT Image for BGA Crack with 9 µm



HIP N30



HIP (AB15, Z15 and AA15), AC15 is good.

XD7600 NT Diamond: < 0.1 um(100nm) Feature Recognition Tube

Achievement

- We generated Best Practice file for AXI HIP detection, and shared it in Flextronics WW site manufacturing.
- Sites have good achievement with the suggestion threshold and method.
- Example: GDL test data for field retuned boards

AXI Machine	# of total Escaped	Defects Escaped %	# of total False call	False call PPM
AXI 1	3	37.50%	3	6061
AXI 3	3	37.50%	3	6061
AXI 4	1	12.50%	0	0

AXI1 Correlation between Defect Escaped % and False Call PPM

Threshold Settings (Pad slice; MID ball slice)	# of total Escaped Defects	Defects escaped %	# of total False call	False call PPM
<-6; >6	45	100.00%	0	0
<-5; >5	45	100.00%	0	0
<-4; >4	41	91.11%	1	983
<-3.5; >3.5	39	86.67%	2	1967
<-3; >3	27	60.00%	7	6883
<-2.5, > 2.5	18	40.00%	15	14749

- The correlation tells us AXI1 can detect HIP, however it is difficulty to reduce false call PPM. Usually we do not suggest to have AXI program with false call PPM above 3000, especially for large volume products.
- AXI machines do not have clear difference for its images between good solder joint and HIP joint for about 80% times.

The results are based on data from the site 2 studies.

Summary

- All four AXI machines have capability to detect BGA HIP defect with different success levels.
- The Algorithm threshold settings are very critical for detecting HIP. The AXI program optimization is based on its measurement data analysis.
- There are no clear image differences between good solder joint and HIP with current AXI machine. Therefore we have to have good balance between HIP defect escaped and false call.
- We are looking forward to see AXI machine with more accurate and repeatable measurement data, and better image separation between good solder joint and HIP pins.
- 2DX and Large Board CT are very important techniques used to verify the AXI results and fine tune the algorithms.

Acknowledgements

- Flextronics GDL, Austin, Milpitas, Malu, Doumen, and Timisoara Engineering and Production teams.
- AXI 3, AXI 4 and 2DX support engineering teams.

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Thank you!

Alejandro Castellanos   Alejandro.Castellanos@flextronics.com
Office phone: +52 33 3770 4200 x 4735

Zhen (Jane) Feng   Jane.Feng@flextronics.com
Office phone: +1 (408) 576 7683