AOI Capabilities Study with 03015 Component

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Abstract

Automated Optical Inspection (AOI) is advantageous in that it enables defects to be detected early in the manufacturing process, reducing the Cost of Repair as the AOI systems identify the specific components that are failing removing the need for any additional test troubleshooting[1-3]. Because of this, more Electronic Contract Manufacturing Services (EMS) companies are implementing AOI into their SMT lines to minimize repair costs and maintain good process and product quality, especially for new component types. This project focuses on the testing of component package 03015 which is challenging for AOI.

Highly-automated and effective test methods are becoming a more and more important topic in our industry today. Advances in modern manufacturing technologies have been making factories smarter, safer, and also more environmentally sustainable. Finding and implementing smart machines which provide real time information is critical to success. Currently we have been successful in using 2D/3D AOI for production; however not for the upcoming 03015 components. Therefore, we are working with AOI vendors to ensure successful testing of this component type, with a special emphasis on optimizing algorithm threshold settings to detect defects.

We have been working with five AOI vendors with 5 test vehicles (PCBAs). Each PCBA board has 246 components with three different pitch sizes (100µm, 150µm, 200µm). The results of Attribute GR&R, Defect escapes, and False Call PPM (parts per million) will be presented.

Based on the data which we received up to now, every set of data (5 sets – still waiting for results of AOI system 3) is from the algorithms of 2D AOI although some machines have the3D AOI capability. These machines have shown different levels of performance. AOI system 5's results have an excellent acceptable level for Attribute GR&R; both AOI system 5 and AOI system 6 have only several percentage points of a Defect Escape rate. However, this study is just in its infancy; more improvement and testing will be performed. We will continue to provide new test results from all suppliers.

Keywords:2D/3D AOI, Attribute GR&R, Defect escaped %, False call PPM (parts per million), Algorithm Threshold, Optimization.

Introduction

The printed circuit board assembly industry has long embraced the "Smaller, Lighter, Faster" mantra for electronic devices, especially in recently years[4-5]. With the increasing use of smaller components, more consideration is required to study and implement changes: not only for SMT processes, but also for testing. There have been some studies conducted for SPI (Solder Paste Inspection) with 03015 components[6-7], however, there are very few recommended practices for AOI. That was our goal to have this project with several AOI vendors in this year.

The 03015 [0.3mm x 0.15mm] device is a microchip component. For reference, please note that a human hair is approximately 0.1mm.To ensure a successful implementation of the 03015 components, besides for these three critical areas: (1) placement equipment, (2) assembly materials, and (3) process control, the capabilities of machines used to test these component types is another critical consideration. Now 3D SPI is more commonly used in the SMT process: 3D AOI is quickly increasing.

During the initial stage of our study, we first tested these 5 boards with 03015 components on our 2D AOI machine in our Milpitas manufacturing site. Next, we provided the boards to the R&D labs of five AOI vendors who all have 3D AOI machines. Working with various R&D engineers, it was obviously to see this was a challenging task for their current AOI systems, especially for 3D AOI systems due to component reflection.

Our testing data and results showed that for some the various 2D AOI machines have different capabilities in detecting defective types for 03015: misalignment, tombstoning, and shorts. The defect escaped % decreased with false call PPM increasing, therefore, optimized programming should be based on testing data analysis.

Experiments

In total we asked for five AOI vendors (R&D engineers) work with this project, and we received 4 sets of testing data – AOI System 3 data is to be provided later. The test procedure is the same for all machines with 5 boards.

1. Test Vehicle

Five boards with 03015 components were tested on the AOI machines. Figure 1 is our test vehicle which has three areas A, B, and C for different pitch size. The pitch areas are indicated as different color arrows: red color A - 100µm, yellow color B - 150µm, blue color C - 200µm.

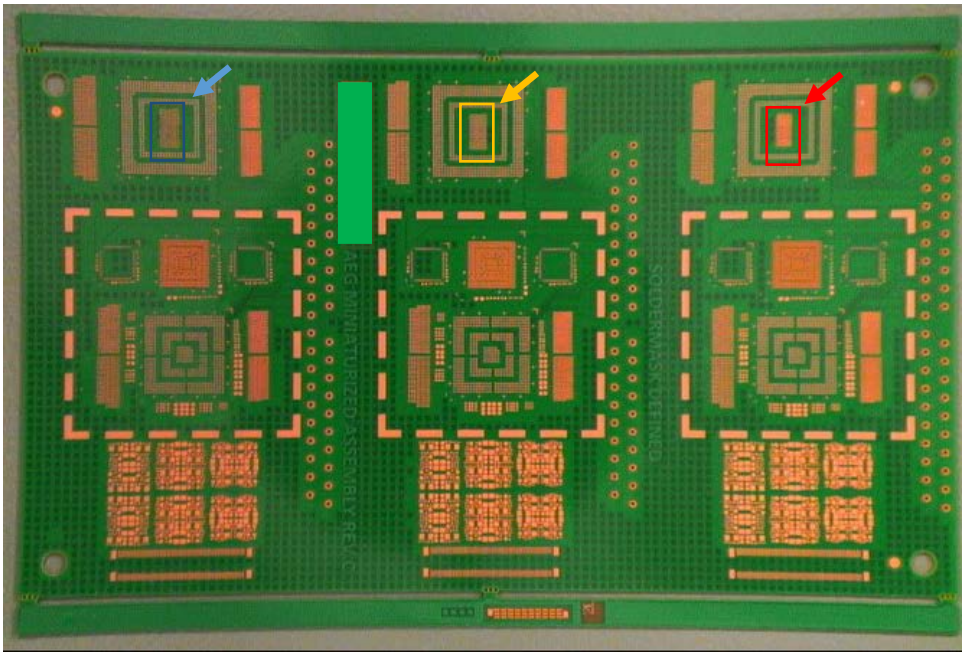


Figure 1 – Company Miniaturized Test Vehicle

The 03015 component was a production resistor: 292µm, 143µm, and 100µm corresponding to its length, width, and height, respectively, as shown in Figure 2 where area A is without fab Mask. There are a total of 87, 81, and 78 components in the area A, B, and C respectively. The pad size (length, width) is 150µm X 150µm on the PCB fab. Figure 3 shows pictures for area A (right column), area B (center column), and area C (left column); After Print (top row), After Placement (center row), and After Reflow (bottom row). There are different colors for optical pictures due to 03015 components reflection which increased AOI testing difficulty.

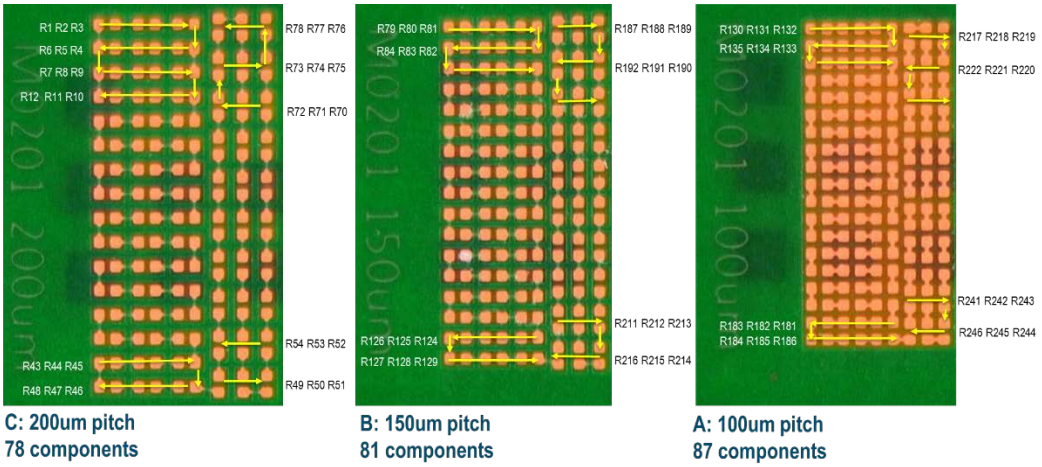
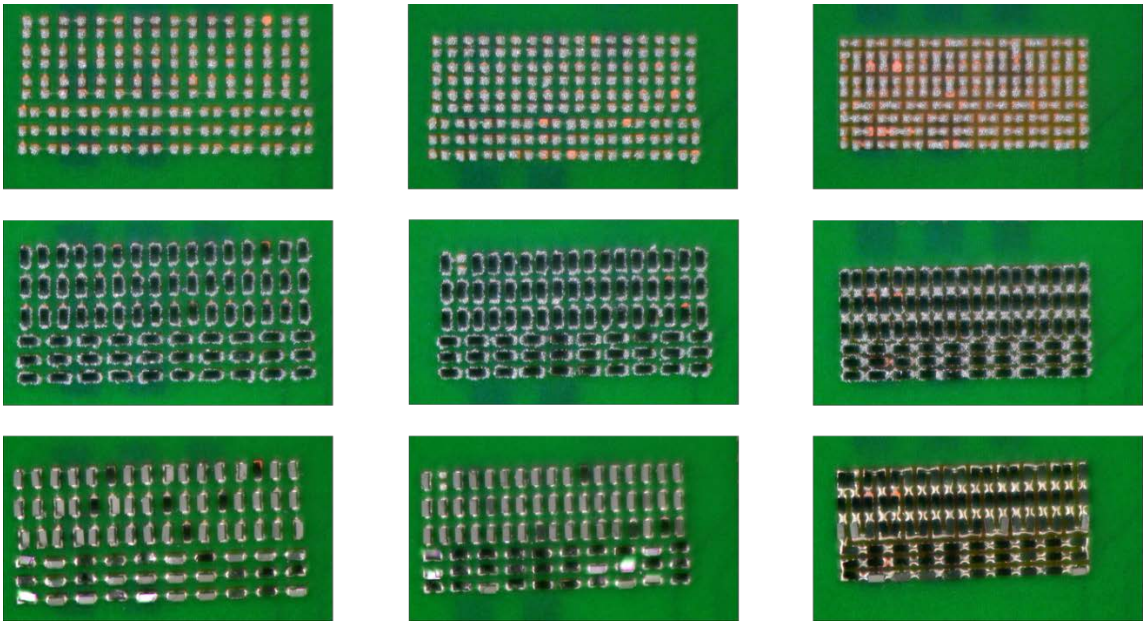


Figure 2 – Three Areas of 03015 Components



C: 200 µm Pitch **B: 150 µm Pitch** **A: 100µm Pitch**

Figure 3 – Optical Picture: After Print (top), After Placement (center), and After Reflow (bottom)

2. Attribute GR&R

We used 78 components with pitch 200µm on board #4 for the Attribute GR&R study; the board was tested a total of 9 times: with three operators each testing the test vehicle three times. Then we used production statistical software for getting Attribute GR&R. The Attribute GR&R data results (Within Appraisers, and Appraiser versus Standard) of AOI 1, AOI 2, AOI 4, AOI 5 and AOI 6 are shown as in Figure 4: 4a - AOI 1, 4b – AOI 2, 4d – AOI 4, 4e – AOI 5 and 4f – AOI 6.

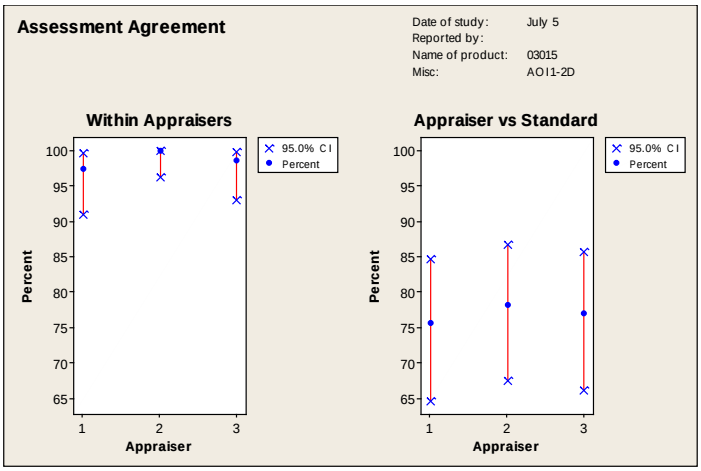


Figure 4a – AOI 1 GR&R

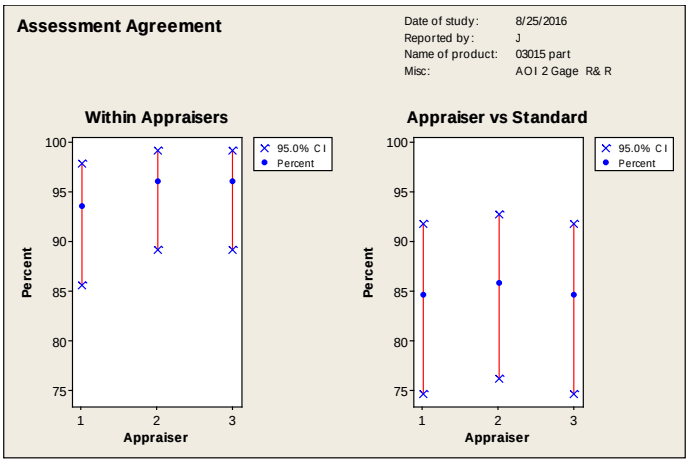


Figure 4b – AOI 2 GR&R

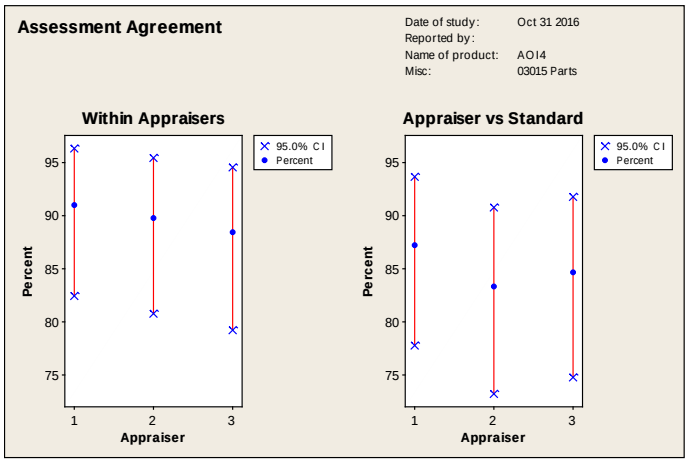


Figure 4d – AOI 4 GR&R

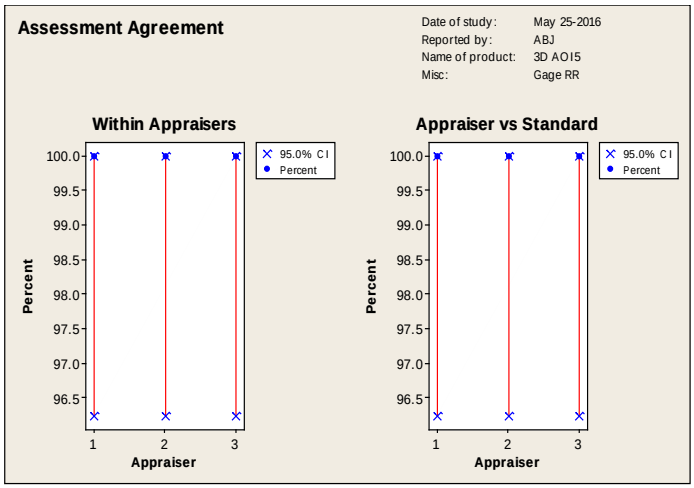


Figure 4e– AOI 5 GR&R

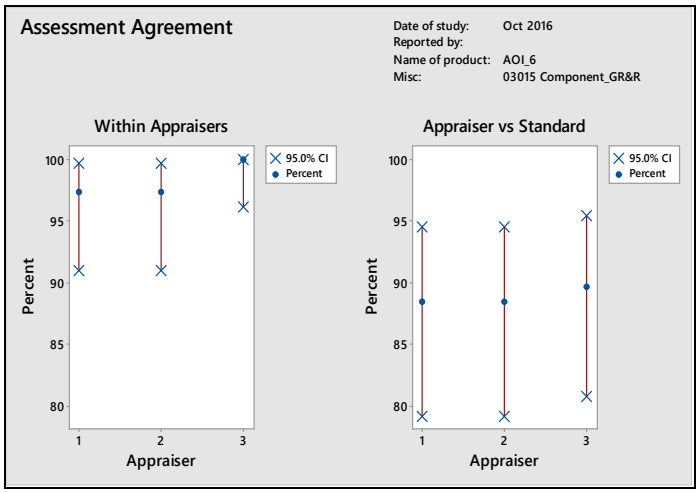


Figure 4f– AOI 6 GR&R

Table 1 – Attribute GR&R Results for AOI 1, AOI2, AOI 4, AOI 5 and AOI 6

Machine	Appraiser Agreement %			Agreement for Each Appraiser vs. Standard (%)		
	Appraiser1	Appraiser2	Appraiser 3	Appraiser1 vs.STD	Appraiser2 vs.STD	Appraiser3 vs. STD
AOI 1	97	100	99	76	78	77
AOI 2	94	96	96	85	86	85
AOI 4	91	90	88	87	83	85
AOI 5	100	100	100	100	100	100
AOI 6	99	99	100	95	95	95

Table 1 lists the Attribute GR&R results of AOI system 1, AOI system 2, AOI system 4, AOI system 5 and AOI system 6 for the Appraisers agreement %, and Agreement for each Appraiser versus Standard %. The Standard results are based on the pictures from AOI machines and the Microscope review; the results are also based on the AOI engineers' discussion/agreement. It is obvious that all these five AOI machines have very good or excellent Attribute Gage R&R for Appraisers agreement %. For the Agreement for Each Appraiser versus Standard %: AOI system 1's result is ok; both AOI system 2 & AOI system 4 have good results. AOI system 6 has very good results. AOI system 5 has excellent results.

3. AOI Testing Results

A total of1230 components on the five boards were tested for this project on different AOI machines, where AOI 1 is 2D AOI, the rest have 3D AOI capabilities – however, 3D was not used in this stage of the study. The main two items (Defects Escaped %, and False Call PPM) were used to evaluate each AOI machine's test capabilities. The defective component location is confirmed by engineers of the company and the AOI Suppliers based on the AOI images, optical pictures, and optical metrology equipment. Figure 5 is the picture from the optical metrology equipment. It is clear to see that components R1, R6, and R7 are misaligned as defects; the components R3, R9, R15, R72, R75, and R78 are confirmed as defects per the AOI image, optical image, and the engineers review.

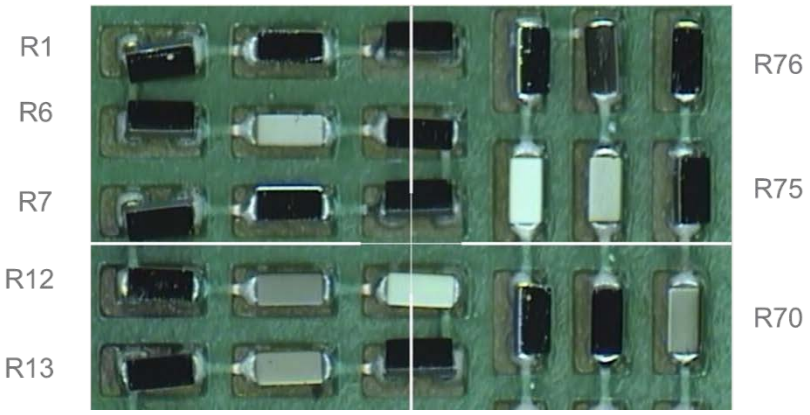
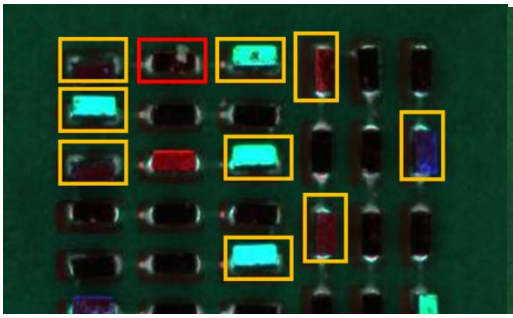
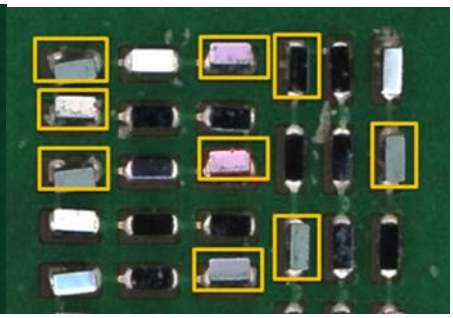


Figure 5– Optical Metrology Equipment Picture for components with Pitch 200µm

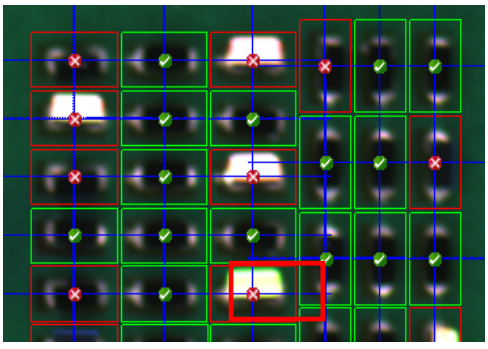
Figure 6 list pictures of four AOI machines for the same 24 components on the same board, where pad pitch is 200µm. For these 24 components locations, 9 are defects. Both of AOI system 1 &AOI system 4 have 1 false call with a red ink rectangle, AOI system 6 has 3 false calls; however, it has 100% agreement with the standard list for AOI system 2, and AOI system 5. A yellow rectangle indicates the component as a defective location. It is noted that all AOI machines (AOI system 2, AOI system 4, AOI system 5 and AOI system 6 are 3D AOI machines) used their 2D algorithm to test these 5 boards since the height of 03015 components could not be measured because a mirror surface material of the component created noise at the machines.

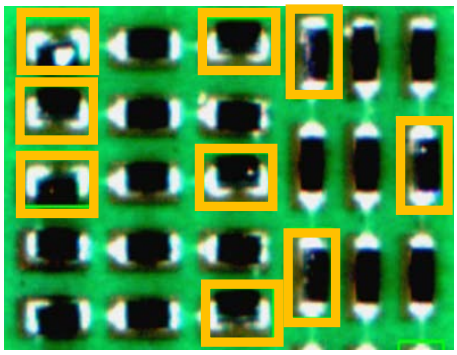


AOI 1: 1 False call

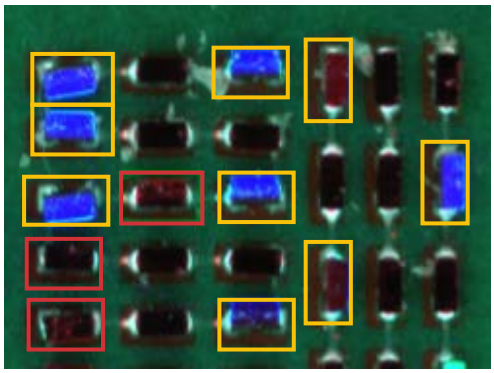


AOI 2: 100% Agreement





AOI 4: 1 False call



AOI 5: 100% Agreement

AOI 6: 3 False call

Figure 6– Picture of AOI System 1, AOI System 2, AOI System 4, AOI System 5 and AOI System 6

The AOI Algorithm Threshold for AOI system 1, AOI system 2, AOI system 4, AOI system 5 and AOI system 6 are listed in Table 2. All these algorithms are 2D AOI functional algorithms. AOI 1 machine was adjusted from the setting of 19 µm/pixel to 10.5 µm/pixel for improved resolution of the camera by the AOI system 1 support engineer at our site. AOI system 2 is the 3D AOI machine with 6 µm resolution with camera type as 12Mpix. However, AOI system2 used its 2D Algorithm (PadMatch) for testing 03015. The threshold settings are: Similarity: 55, Rotation: 4degree, Xshift 35um, Yshift: 35um. AOI system 4 used its LW (Length and Width) Tracking to test the 03015 component, the LW Tracking is 2D Algorithm, and its Threshold Settings for this project are: XY ± 35 µm, and for Theta ± 10 µm.AOI System 5's main Algorithms are: Classification Match 180, Rotation 5 degrees, Xshift35 µm, Yshift 35 µm. The main Algorithm for AOI System 6 are: Horizontal Threshold: 100 µm; Vertical Threshold: 50 µm; Skew Threshold: 40 µm.

Table 2 – AOI Main Algorithm Threshold for AOI System 1, AOI System 2, AOI System 4, AOI System 5 and AOI System 6

Machine	Algorithm	Threshold
AOI 1	Pad Green Rectangular search region	Horizontal offset: 30µm, Vertical offset: 45µm, Skew: 10 degrees
AOI 2	Pad Match (Similarity, Rotation, Xshift, Yshift	Similarity 55, Rotation 4 degrees, Xshift35 µm, Yshift 35 µm
AOI 4	Length/Width Tracking	XY: ± 35 µm, Theta: ± 10 µm
AOI 5	X, Y, Rotation, Solder fillet	Classification Match 180, Rotation 5 degrees, Xshift35 µm, Yshift 35 µm
AOI 6	Measurement of body offset from centroid	Horizontal Threshold: 100 µm; Vertical Threshold: 50 µm; Skew Threshold: 40 µm

Table 3 – AOI Testing Results for AOI System 1, AOI System 2, AOI System 4, AOI System 5 and AOI System 6

Machine	Defects Detection %	Defect Escaped %	False Call #	False Call PPM
AOI 1	92.91%	7.09%	13	17981
AOI 2	64.78%	35.22%	22	17886
AOI 4	53.67%	46.33%	51	41463
AOI 5	97.91%	2.09%	37	30081
AOI 6	98.74%	1.26%	45	36285

AOI test results are listed in Table 3. Both AOI system 5 and AOI system 6 have the very good defects detection %. It is noted that all the machine false call PPM are higher than our expectation which we wish is < 5000 for false call PPM (parts

per million). AOI system 1 data is for four of the five boards, and does not include pad pitch 100μm for three boards due to its limit capability. The data of AOI system 2, AOI system 4, AOI system 5 and AOI system 6 are from all five boards with all 03015 components. AOI system 4 may have significant improvement with a new camera to be installed shortly. AOI system 2, AOI system 5 and AOI system6 also have improvement steps in progress. AOI system 3 will provide its testing results after making some progress.

Conclusions

Current AOI machines have different levels to test 03015 components; however, all AOI machines involved for this project used 2D AOI function;3D algorithms were not usable due to component reflection.

Attribute Gage R&R results are acceptable for these five machines, AOI System 5 had excellent results.

Based on the data which we have now, AOI System 5 has the best performance for Defect Escape %; however, no machine had False Call PPM (parts per million) < 5000.

This study is just the beginning. More boards (with no reflection) are needed to test with the AOI machines, especially when using 3D Algorithms.

More improvements to the machines are coming from several of the AOI System R&D teams.

References

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[5] David Geiger, "Process for Package 03015", IPC APEX 2017

[6] Robert Alexander Gray, "Development of a Robust 03015 Process", IPC APEX 2015

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AOI Capabilities Study with Component 03015

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Flex International

February 15th, 2017

Agenda

- Introduction/Motivation
- Experiments
  1. Test Vehicle PCBA
  2. Machines' Attribute Gage R&R
  3. AOI Test Results
- Conclusions

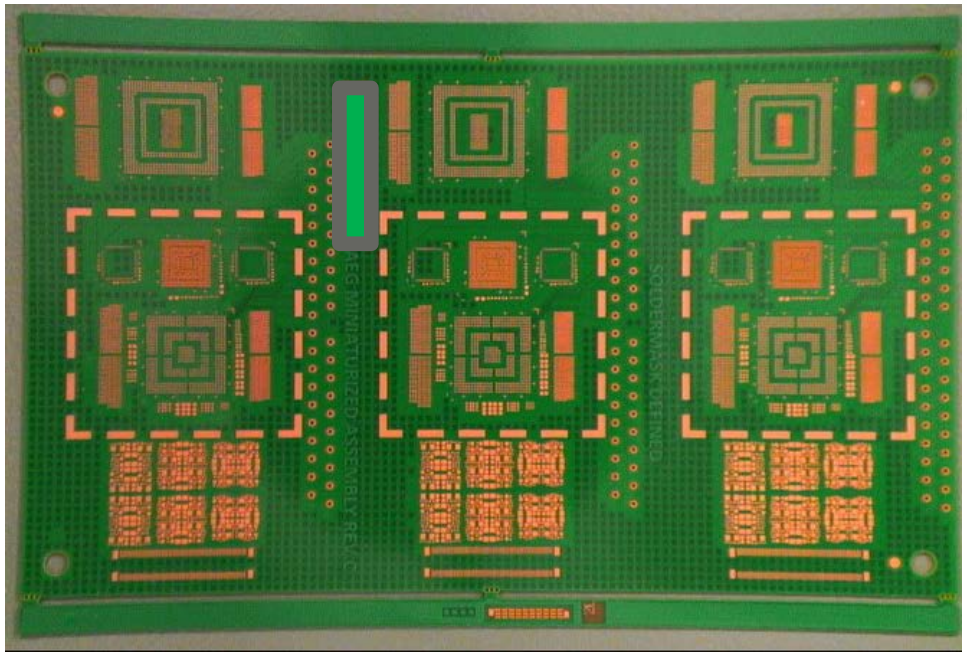
Introduction/Motivation

- Automated Optical Inspection (AOI) is advantageous for maintaining good process & product quality and increasing First Pass Yields especially when it involves the introduction of new package types.
- It is a challenge for AOI to test 03015 package
- Capabilities study with 2D AOI, and 3D AOI:

  AOI 1, AOI 2, AOI 4, AOI 5, and AOI 6

Experiments

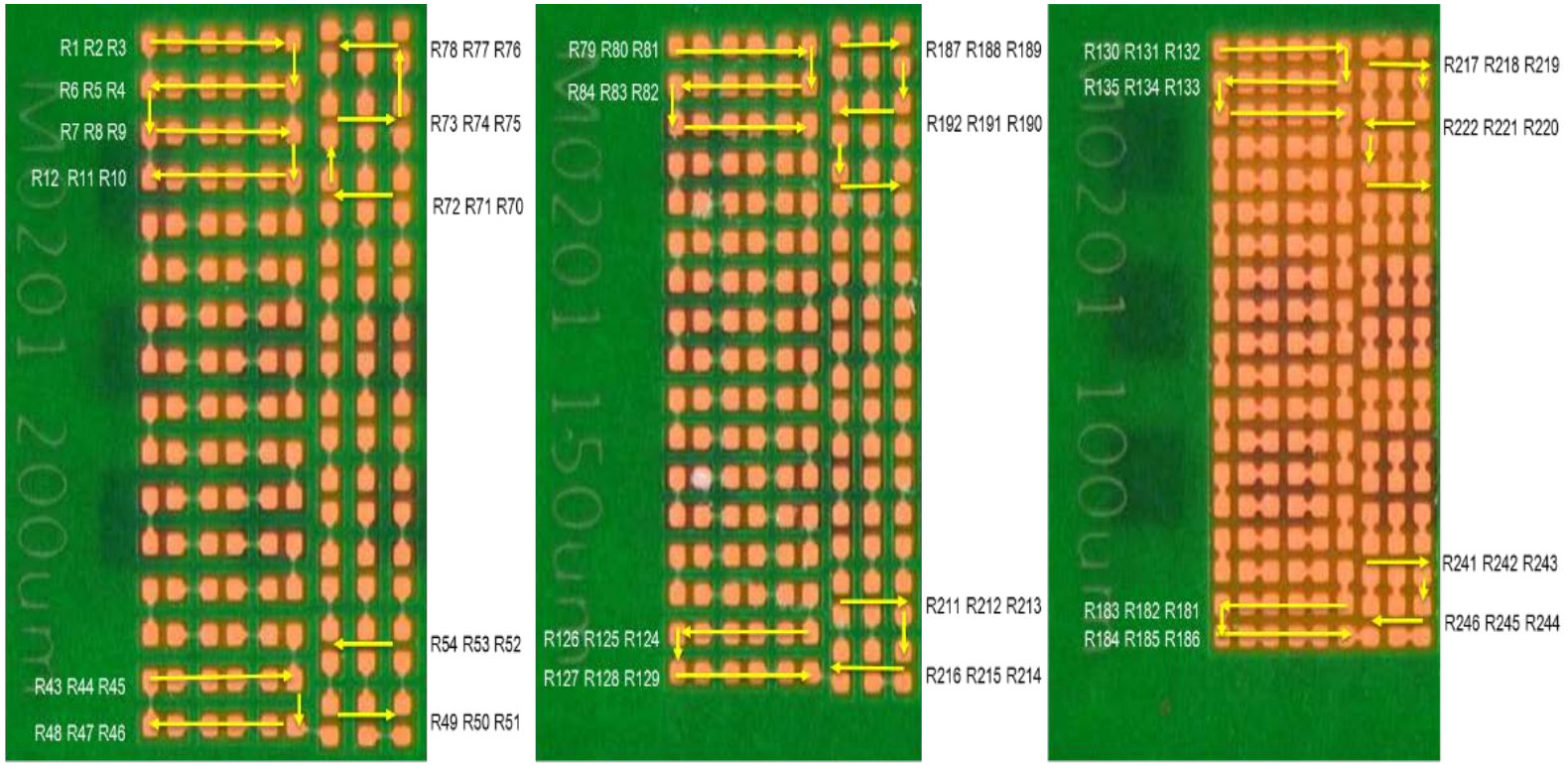
1. Test Vehicle
2. Machines' Attribute Gage R&R
3. AOI Testing Results



Company Miniaturized Test Vehicle

03015 Package (Production Resistor): 292µmX143µmX100µm

1. Test Vehicle (3 Areas: A, B, C)



- Pad size (L X W)

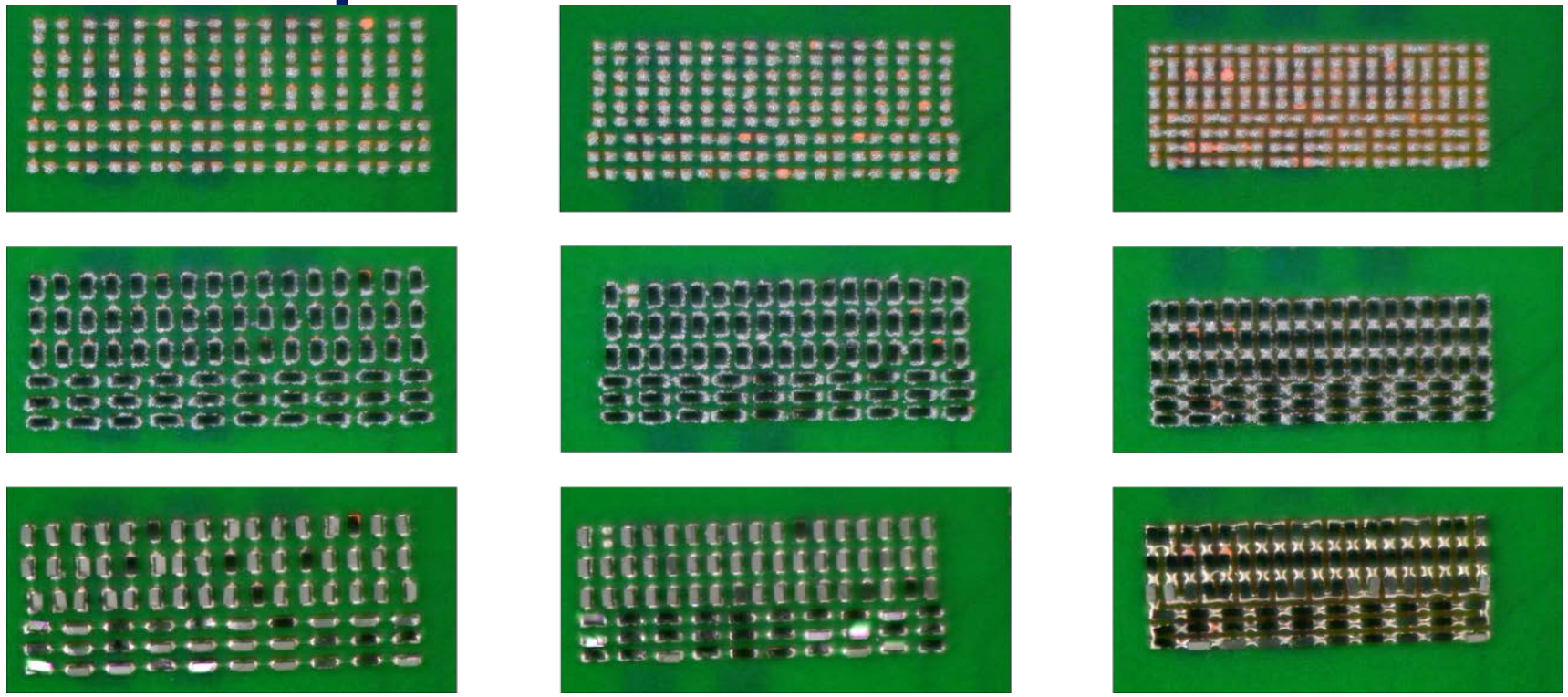
  150µm X 150µm

C: 200µm Spacing
78 components

B: 150µm Spacing
81 components

A: 100µm Spacing
87 components

Optical Pictures



After Print

After Placement

After Reflow

C: 200 µm spacing

B: 150 µm spacing

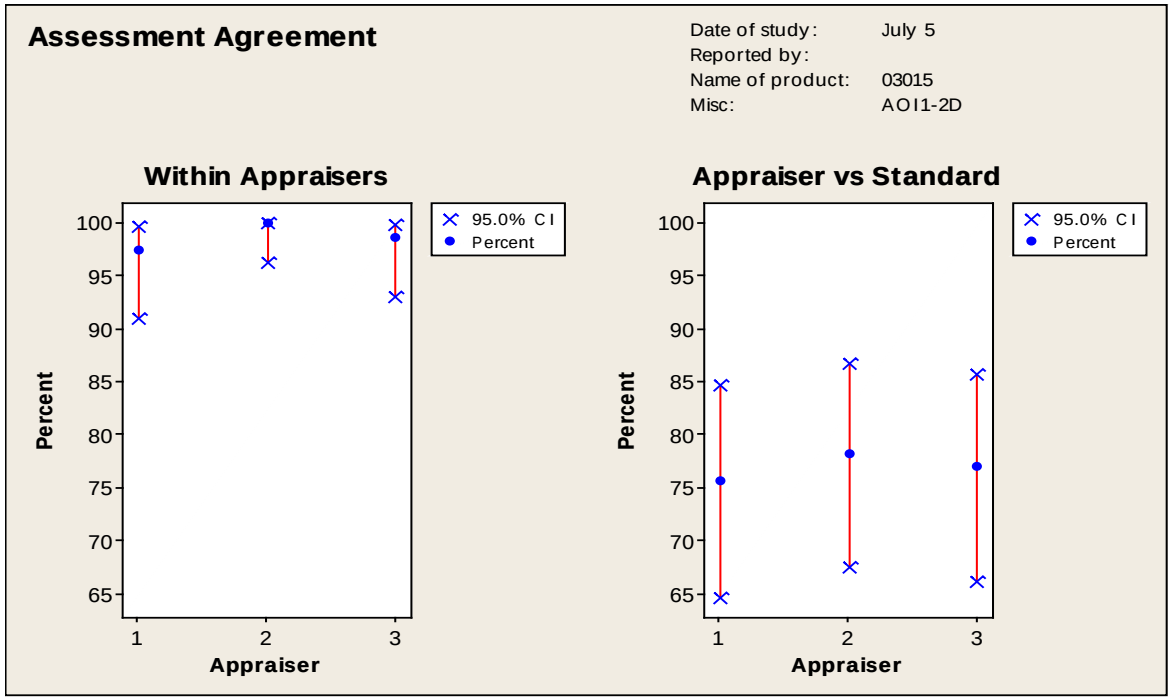
A: 100µm spacing

Different colors of optical pictures: result of reflection

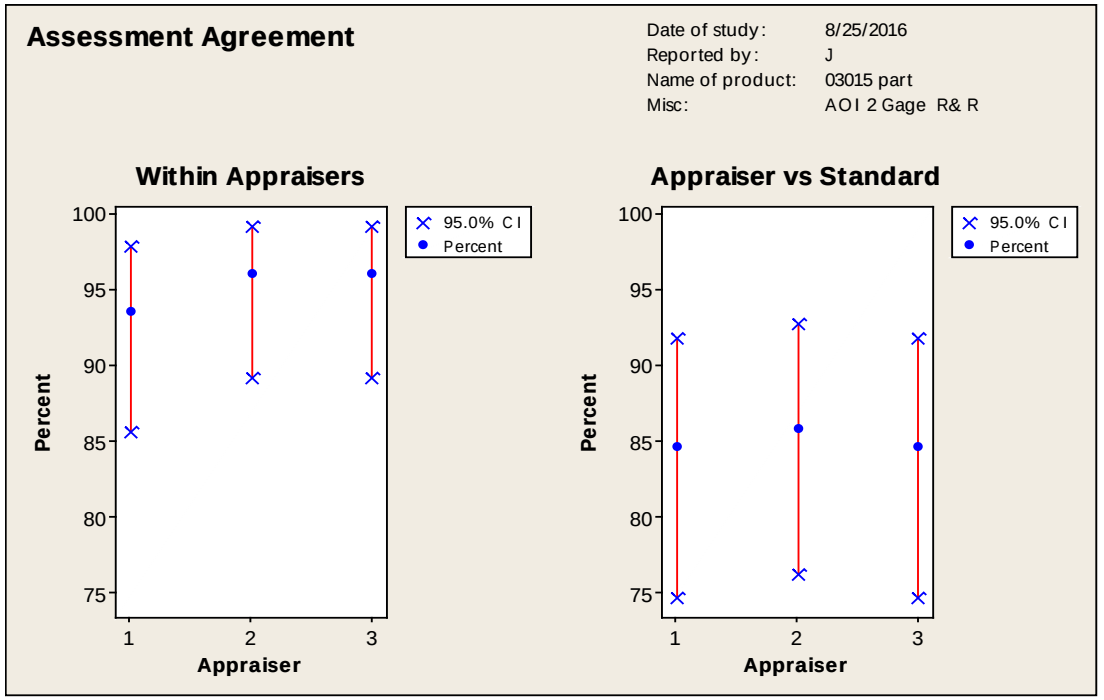
2. Machines' Attribute Gage R&R

- 78 components (spacing 200μm) as data for Attribute Gage R&R
- Nine times tested: three operators, tested three times per operator

AOI 1

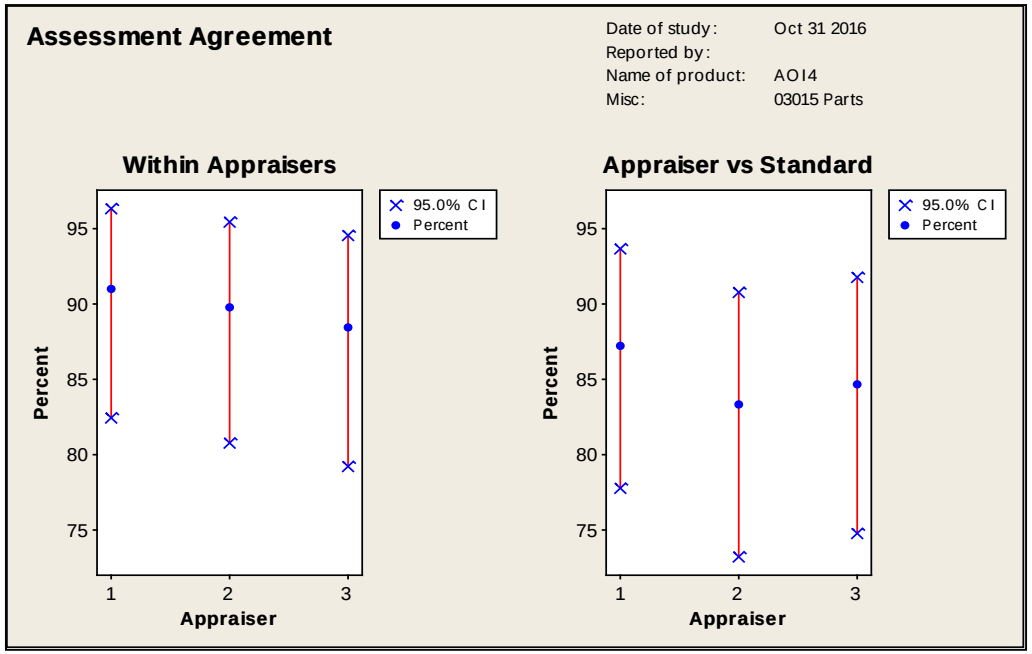


AOI 2



Attribute Gage R&R

- Using Production Statistical Software to analyze the data

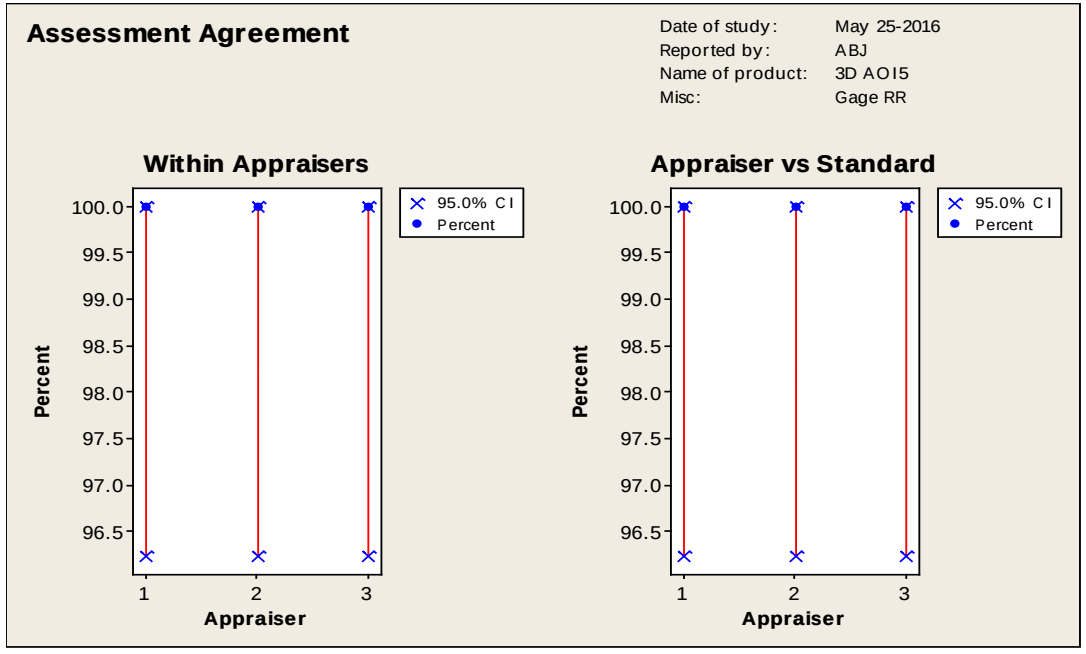


AOI 4

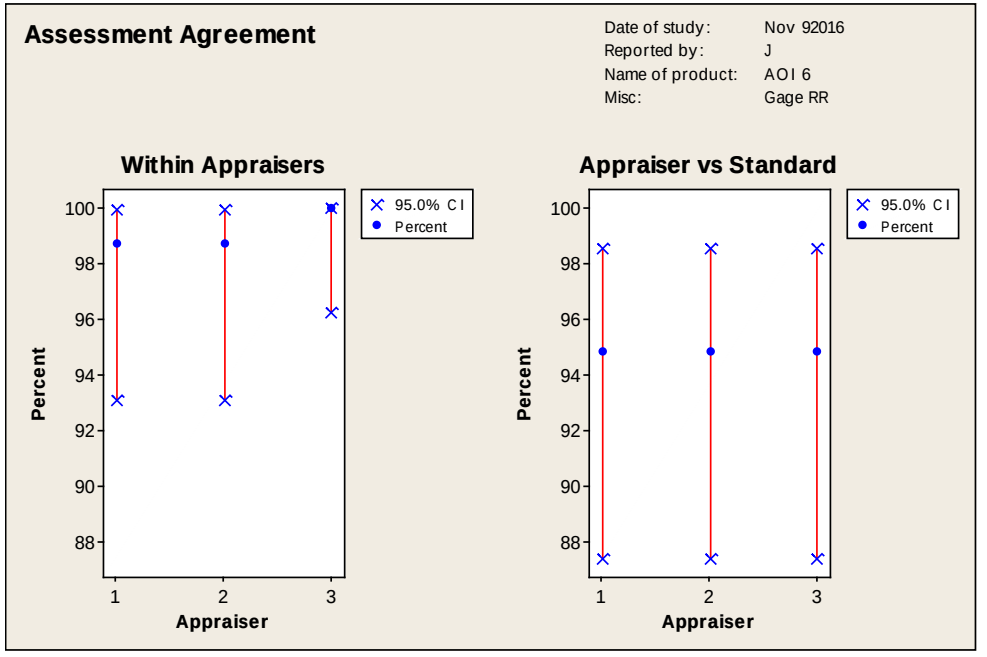
Attribute Gage R&R

- Using Production Statistical Software to analyze the data

AOI 5



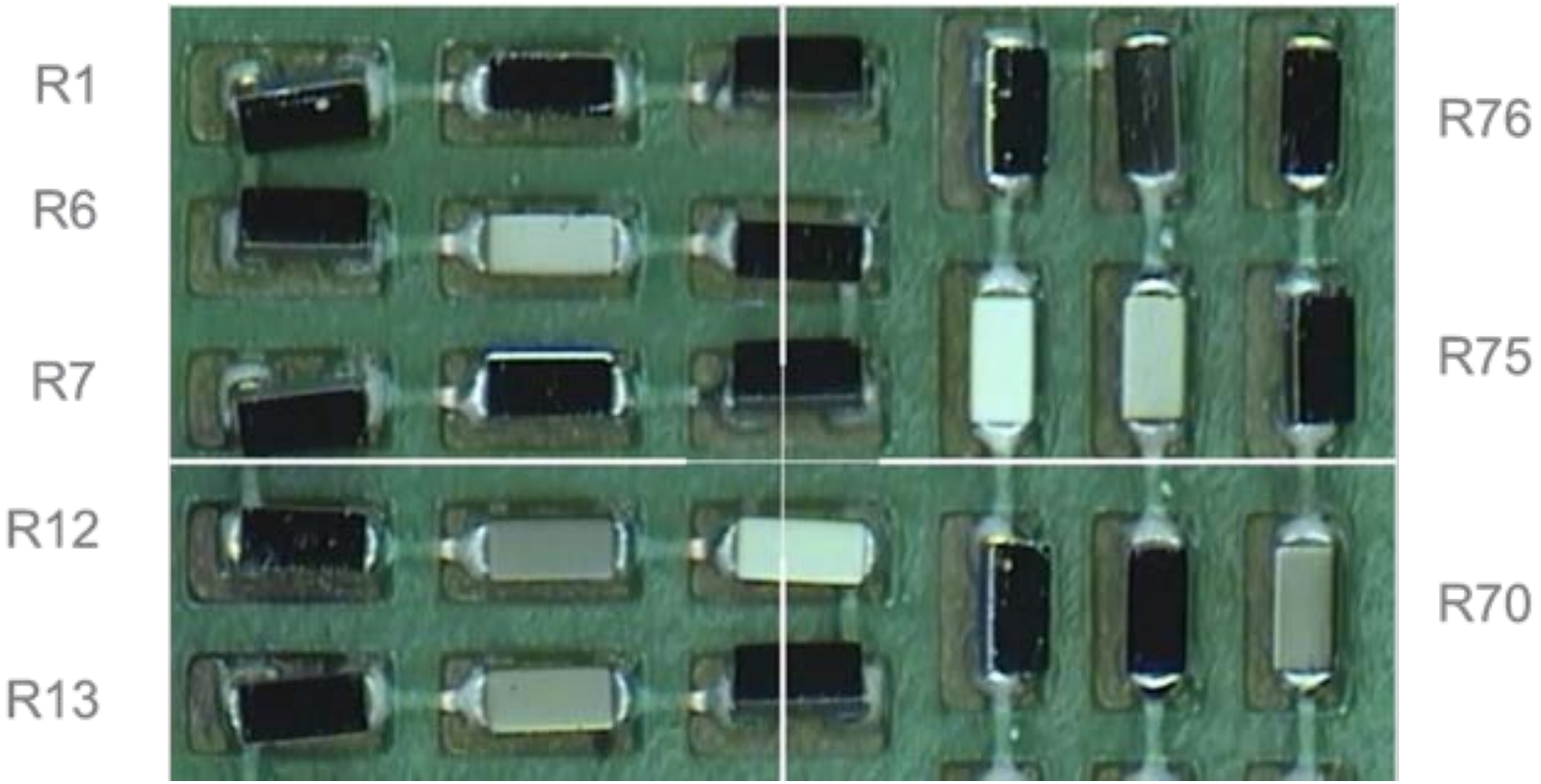
AOI 6



Attribute Gage R&R Results

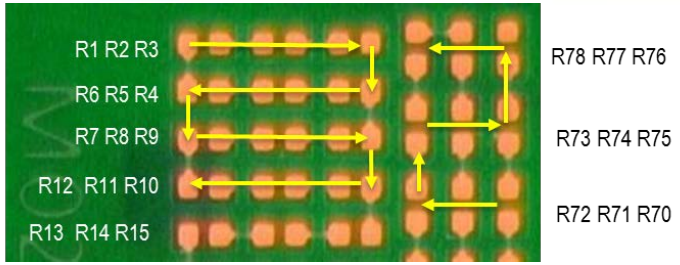
Machine	Appraiser Agreement %			Agreement for Each Appraiser vs Standard (%)		
	Appraiser1	Appraiser2	Appraiser3	Appraiser1 vs STD	Appraiser2 vs STD	Appraiser3 vs STD
AOI 1	97	100	99	76	78	77
AOI 2	94	96	96	85	86	85
AOI 4	91	90	88	87	83	85
AOI 5	100	100	100	100	100	100
AOI 6	99	99	100	95	95	95

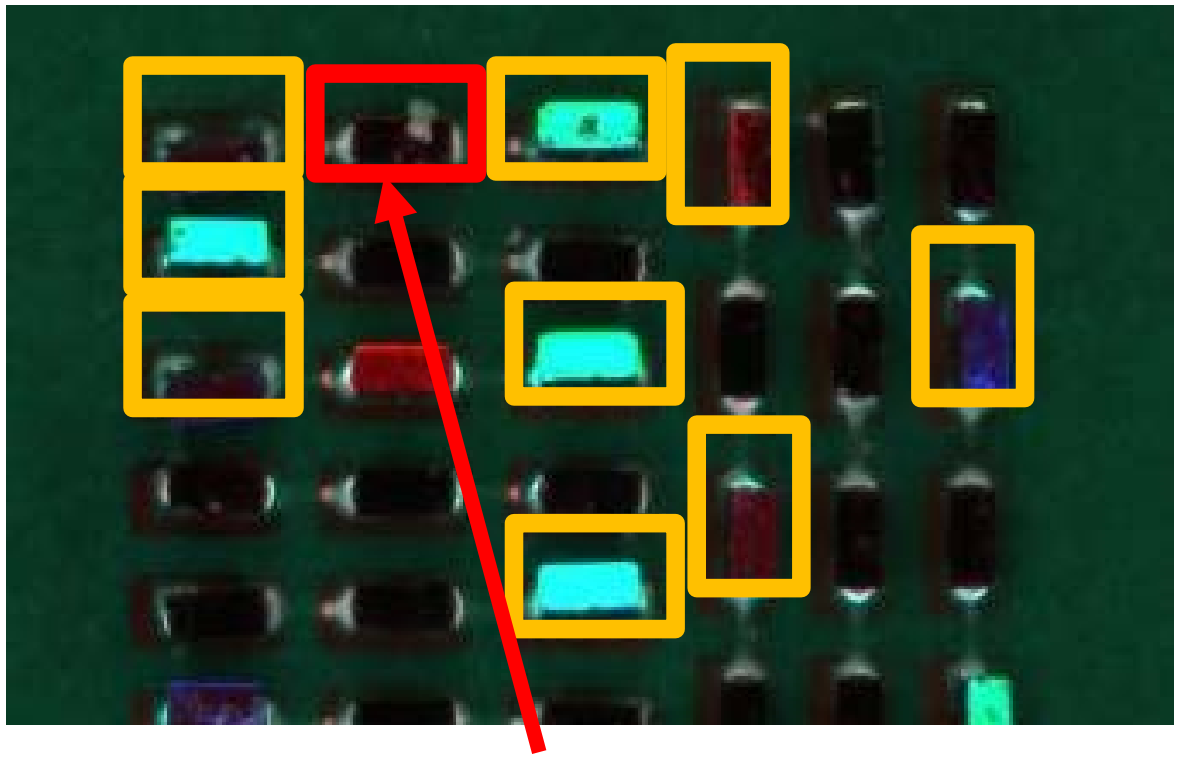
3. Picture from the Optical Metrology Equipment



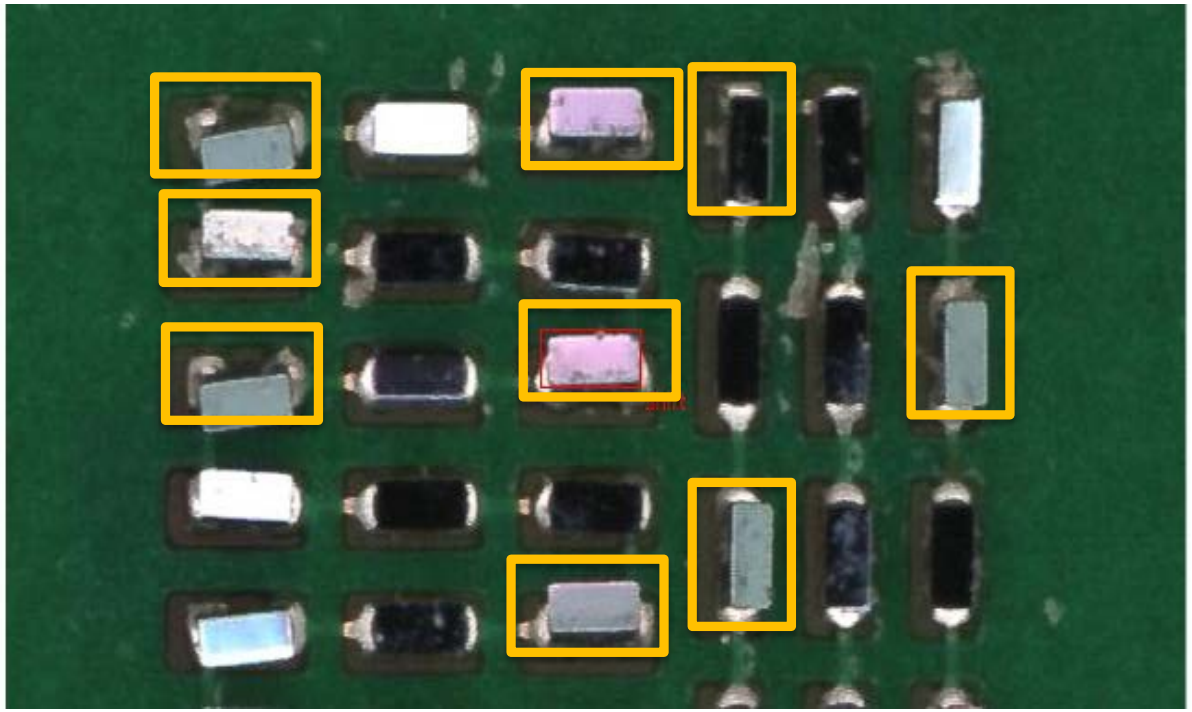
AOI Picture (AOI 1, AOI 2)

Board # 4



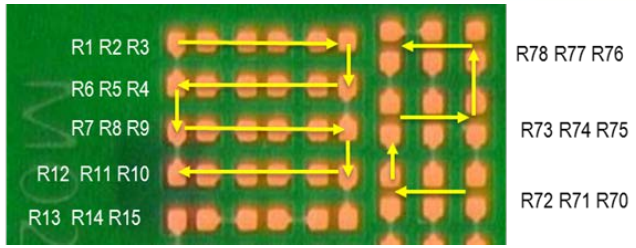


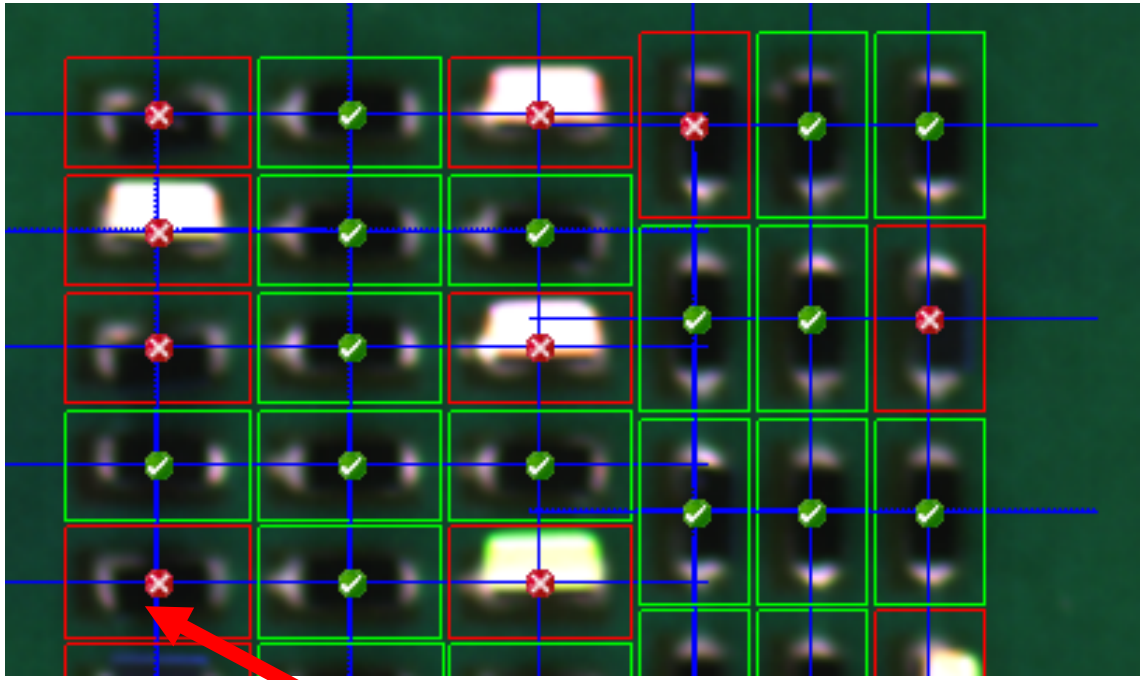
AOI 1: 1 false call



AOI 2: 100% agreement

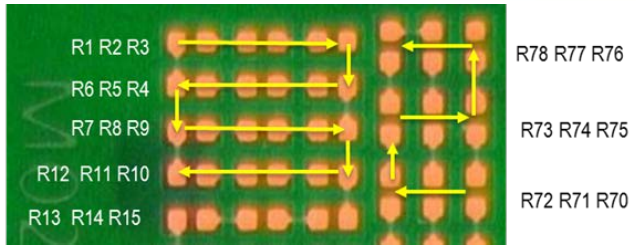
AOI Picture (AOI 4)

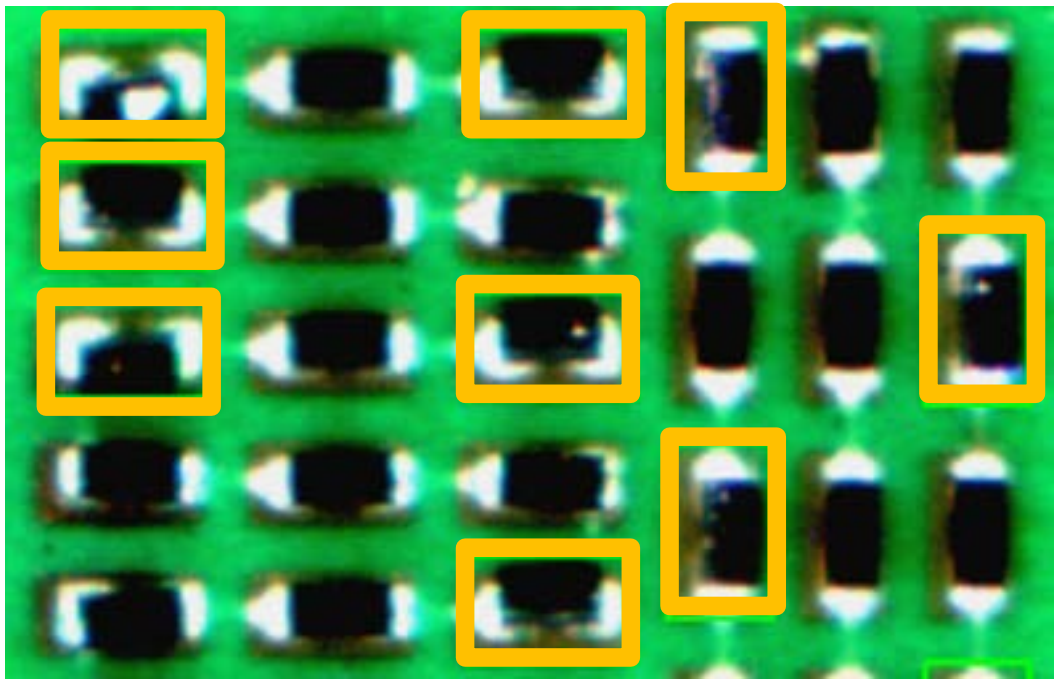




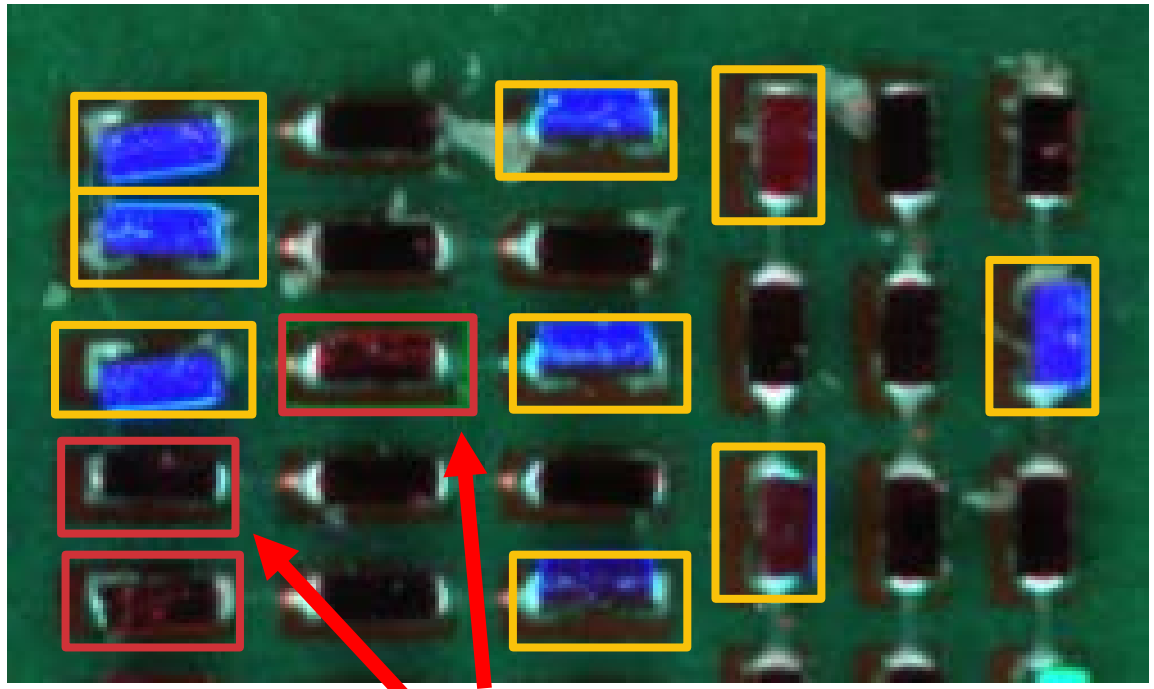
AOI 4: 1 false call

AOI Picture (AOI 5, AOI 6)





AOI 5: 100% agreement.



AOI 6: 3 false call

AOI Algorithm Threshold

Machine	Algorithm	Threshold
AOI 1	Pad Green Rectangular search region	Horizontal offset: 30µm, Vertical offset: 45µm, Skew: 10 degrees
AOI 2	Pad Match (Similarity, Rotation, Xshift, Yshift)	Similarity 55, Rotation 4 degrees, Xshift35 µm, Yshift 35 µm
AOI 4	Length/Width Tracking	XY: ± 35 µm, Theta: ± 10 µm
AOI 5	X, Y, Rotation, Solder fillet	Classification Match 180, Rotation 5 degrees, Xshift35 µm, Yshift 35 µm
AOI 6	Measurement of body offset from centroid	Horizontal Threshold: 100 µm; Vertical Threshold: 50 µm; Skew Threshold: 40 µm

- **All Algorithms are 2D AOI Functional Algorithms due to component reflection**

AOI Testing Results - 1

Machine	Defects Detection %	Defect Escaped %	False Call #	False Call PPM
AOI 1*	92.91%	7.09%	13	17981
AOI 2	64.78%	35.22%	22	17886
AOI 4	53.67%	46.33%	51	41463
AOI 5	97.91%	2.09%	37	30081
AOI 6	98.74%	1.26%	45	36285

- All data are obtained with 2D AOI Algorithms.
- AOI 1* data is for 4 boards only, not including pad pitch 100μm for 3 boards.
- The data of AOI 2, AOI 4, AOI 5 and AOI 6 from all 5 boards with all parts.

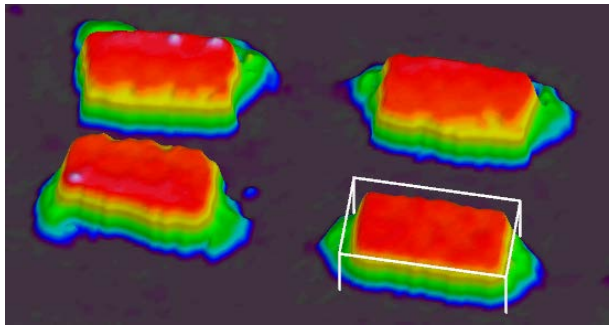
AOI Testing Results -2

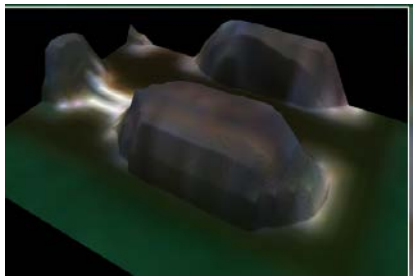
Machine	Defects Detection %	Defect Escaped %	False Call #	False Call PPM
AOI 2	70.00%	30.00%	36	73137
AOI 4	93.33%	6.67%	16	32520
AOI 5	73.33%	26.67%	39	79268

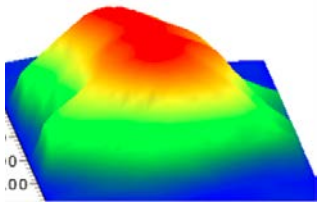
- The results are from the 03015 package without reflection on two new boards.
- Testing data are from AOI 2, AOI 4, and AOI 5 only.
- All testing are using 3D AOI function Algorithms for z- height.

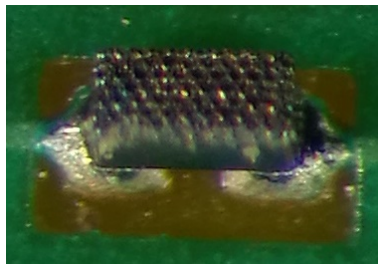
AOI Testing Results with 3D AOI Images - 1

200 µm spacing

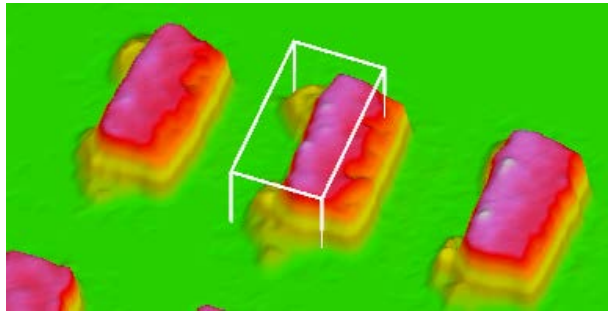




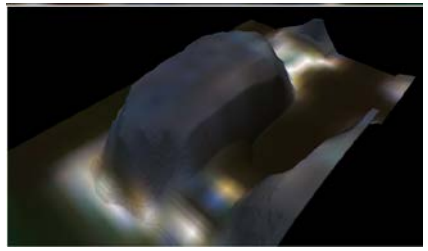




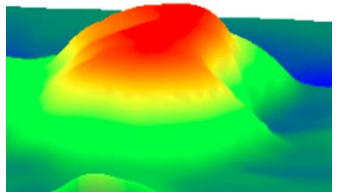
Board #1, R5



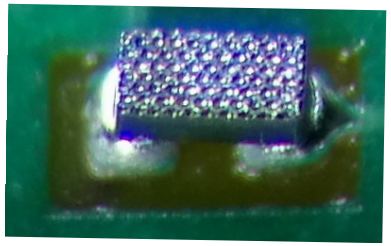
AOI 2



AOI 4



AOI 5

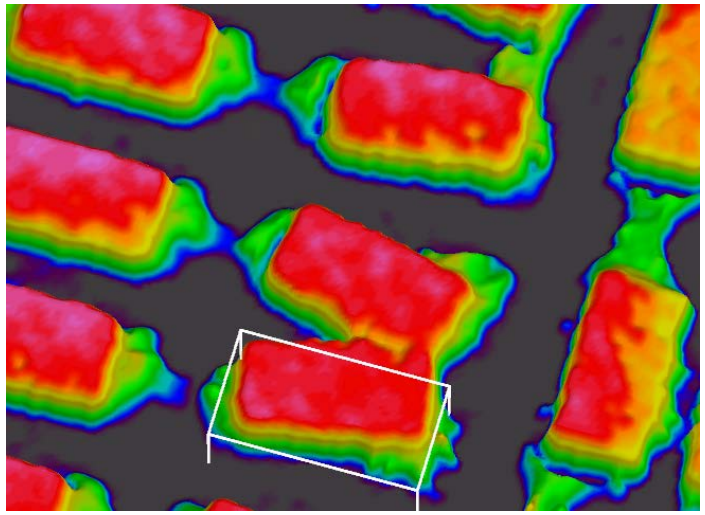


Board #1, R77

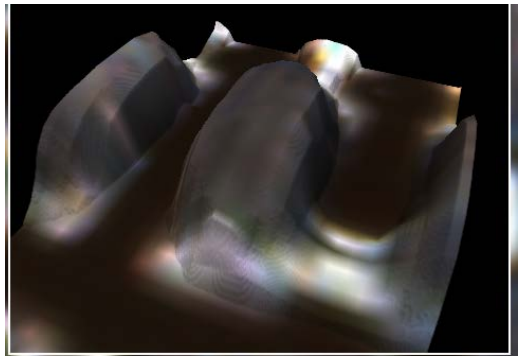
- **3D AOI images are only provided from AOI 2, AOI 4, and AOI 5 only.**

AOI Testing Results with 3D AOI Images -- 2

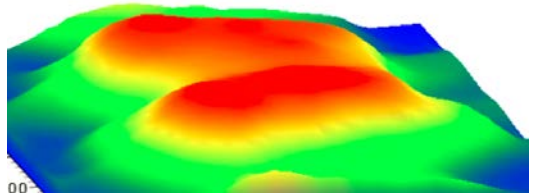
100 µm spacing



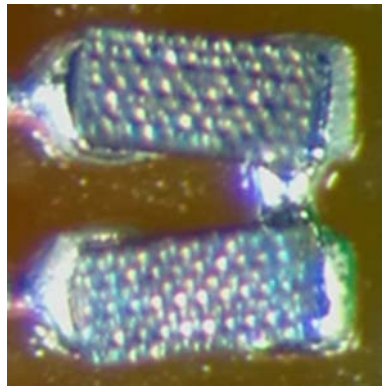
AOI 2



AOI 4



AOI 5



Board #2
R145

- AOI 2 has good 3D Images for 100 µm spacing pins
- On the 100um spacing section the components are almost all touching each other and there is only very narrow gap between the components, this brings difficulty in the 3D inspection as not enough reference plan could be calculated.

Conclusions

- Current AOI machines have different capability levels to test 03015 components; however, all AOI machines involved for this project used 2D AOI function Algorithm due to component reflection.
- Attribute Gage R&R results are acceptable for these four machine, AOI 5 had excellent results.
- AOI 5 and AOI 6 have very good performance for Defect Escaped %; however, no machine met our expectations: False Call < 5000 PPM (parts per million) when using 2D AOI Algorithm.
- This study is just the beginning with 3D AOI. A bigger variety of boards are needed to test with the AOI machines, especially for 100 µm spacing by using 3D Algorithms.

Thank You!

- Company Advanced Engineering Group lab, and Milpitas Test team; AOI vendors (AOI 1, AOI 2, AOI 3, AOI 4, AOI 5 and AOI 6).
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- Barbara Koczera, Ben Lichtwardt, Zi-yang Seow, Yew Sze Pei, Daniel Hung, Steve Marks, Allen Phan, Marvin Larin, Satoshi Otake, Alejandro Mariscal-Magana, Ed Moll et al.

Thank You for Your Attending

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