Reliability of Ball Grid Arrays Converted from Pb-free to Tin-Lead by Robotic Hot Solder Dip (RHSD). Multiple Reball Trial and Test Results

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Abstract
Pb-free Ball Grid Arrays (BGA) present unacceptable reliability risks for defense and space programs, but what are the options when SnPb devices are no longer available? BGA manufacturers express concern over the additional reflow cycles necessary for the reballing process. In addition, traditional re-balling processes for SnPb components requiring rework do not accomplish the complete flush of the existing alloy necessary prior to attaching new spheres. However, there is evidence that BGAs, as a rule, are very robust. Furthermore, an imminent industry specification, IEC/TS 62647-4, Process Management for Avionics – Aerospace and Defense Electronic Systems Containing Lead-Free Solder – Part 4: Ball grid array (BGA) Re-balling, provides guidance necessary to successfully convert Pb-free spheres to SnPb without thermal or mechanical damage.

An examination of one BGA part type, reballed up to ten times, provides a view of IEC/TS 62647-4 type guidance and testing as well as the impact of multiple reballing attempts on the BGA. Barring another available specification for reballing, this specification was used for structure in this study.

Introduction
Individual company attitudes and approaches to BGA reballing are spread across a wide spectrum. On one side of the spectrum, BGA reballing is considered unsafe, never to be attempted. On the other, BGAs are reballed regularly and multiple times without controls. Often the chosen approach is based on experience (or lack of experience) with BGA reballing in general or the results obtained reballing a specific component. Regardless of initial attitude, for one reason or another – conversion of Pb free BGAs being a common driver – it appears many companies are compelled to reball BGAs. If that is the case, it would be helpful to have guidance on reballing procedure and test methodology for quality assurance. When released, the industry specification, IEC/TS 62647-4 will help provide that.

The facility processing the BGAs for this paper deballs and reballs a wide variety of BGAs. Some are indeed very sensitive and some appear impervious to the stresses of reballing. For this paper they chose a BGA with a common structure and routine reballing process and exposed it to multiple reball cycles. Throughout the cycles, those BGAs were put through the standard tests of the IEC/TS 62647-4 (Draft). The results are described herein.

Test component
This was a 54 Ball TFBGA (Thin and Fine Pitch Ball Grid Array). The structure is BT Substrate with mold encapsulated die and bonds. The original balls were SAC 305, 0.018 inch (0.45MM) width at receipt. Replacement balls are Sn63Pb37. Component pads are nickel over copper. Figures 1 and 2 show the top and bottom side of the part prior to reballing.

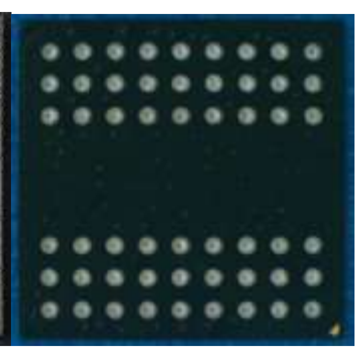


Figure 1–Top Side of Reball Vehicle **Figure 2- Bottom Side of Reball Vehicle**

Procedures
There are several accepted methods for deballing/reballing components. The methods used for this 54 Ball TFBGA are Robotic Hot Solder Dip (RHSD) for deballing and oven reflow for reballing. In general, prior to processing BGAs it is important to review the manufacturer’s data sheet and customer restrictions to avoid damaging the component. For example, compare recommended flux and component reflow profile to ensure they are compatible. Also, verify that the process output (ball size) will meet manufacture’s or end user’s specification. Finally, observe mechanical, thermal and liquid restrictions

such as caps, vents, cavities, and easily damaged surfaces. Apply protective mask where needed. This component and the component datasheet was examined and no special precautions were required.

The 54 Ball TFBGA was handled as a Moisture Sensitivity Level (MSL) 3 rated device and was baked before and after the process for 16 hours at 125°C per IPC/JEDEC J-STD-033. Please note that water immersion SAM testing was conducted before and after the reball/deball process. Visual inspections were conducted per JEDEC JESD22-B101. Testing will be covered in detail after procedures.

Initially three sets of four parts were processed, with an additional control group left unprocessed. Once the results from the post process tests of the three reballed groups were reviewed, seven more sets of four were run through the BGA deballing and reballing process. The first group of four (Serial Numbers 1-4) were deballed and reballed one time. The second set was deballed and reballed two times and etc. A total of 40, 54 Ball TFBGA were processed. The last group was deballed and reballed 10 times. Since the initial intention was to deball and reball only three times the fourth set was the control group. As a note, there were 20 additional parts left un-serialized and unprocessed and available if needed for baseline comparison. The deball and reball serial number groups restarted at serial number 15 through 19 for the groups reballed and deballed four times and greater.

Deballing

The most common reason for reballing is to change the sphere and attaching alloy to or from Pb free. This 54 Ball TFBGA component is going from Pb free to Sn63Pb37.

Traditional methods of removing Pb-free spheres are often poorly controlled: solder wicking braid, vacuum desoldering, and solder pot immersion. Complete alloy removal at the pad level is not consistently accomplished. That residue from the original alloy combined with the new alloy will result in the same inconsistent results and joint weakness as using a Pb-free sphere placed onto a board pad with a SnPb solder paste deposit. In addition, the high temperature and pressure from hand-held tools can damage pads, mask, and substrate as shown in Figure 3

Figure 3 – Damage from Hand-Held Tools.

IEC/TS 62647-4 (Draft) states "Deball equipment shall be capable of completely replacing the existing solder balls and ball attach finish with SnPb."

It has been established through extensive testing that Robotic Hot Solder Dip (RHSD) with a dynamic solder wave in an inert gas environment accomplishes complete Pb-free alloy removal. A robotic system used for this process should be capable of maintaining solder temperature within 3°C of set point. A robotic system with this control was used for this study.

A robotic system is important because it allows for precise immersion depth, time, and temperature control. For example, Figure 4, 5, and 6 show how a BGA is handled in a robotic system at several steps of the deballing process. The figures depict a larger BGA for demonstration purpose. Please note how only the ball surface is exposed the processing fluids.

Each 54 Ball TFBGA component in this study was presented to the robotic handling system from JEDEC trays. During the deballing process, the component body did not reach reflow temperature (183°C). The process flow was as follows: component pickup with a vacuum nozzle, balls fluxed with water soluble flux for one second, excess flux blown off for two seconds, component pre-heated for flux desiccation, and activation in 150°C convection flow for four seconds, 54 Ball TFBGA ball surface passed through edge of 215°C nitrogen blanketed, solder wave for three seconds, component washed in 60°C ultra-filtered water for six seconds, and returned to tray.

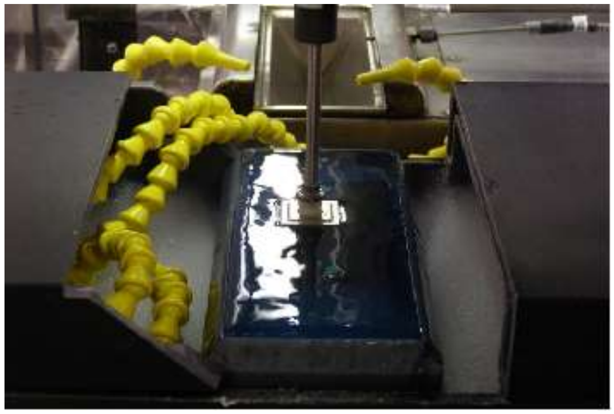


Figure 4 – Flux Application

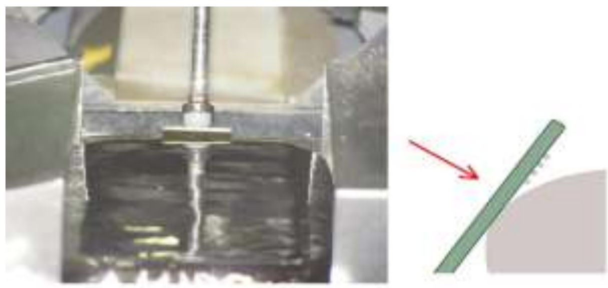


Figure 5 – Solder Ball Removal at the Edge of Wave

Figure 6 – Water Wash - Flux Removal

Post RHSD, component finish and base material are inspected prior to transfer to next step. The object of the deballing process is to remove the original ball and original ball attach alloy while leaving a small meniscus of the new surface alloy on the pad. The appearance of the deballed pads will appear as shown in Figure 7.

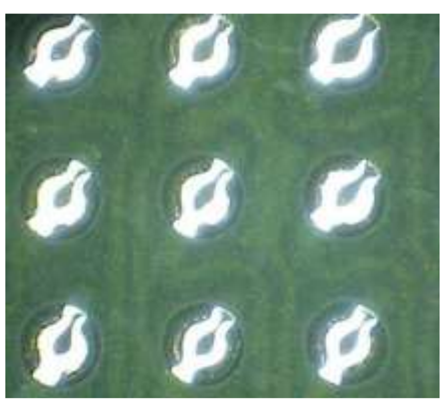


Figure 7 – Pad Surfaces Post Robotic Solder Dip

Reballing
The method chosen to reball these components had to be capable of maintaining ball position on top of pads with the menisci shown in Figure 7. In this case, the component body is held in an individual base (mobile platform) and a laser etched stencil is secured to mobile platform. Spheres are corralled perfectly to pad centers though the reflow process. Process speed can be easily increased by the ability to scale the platform as desired to reball multiple units simultaneously. There is no need for solder paste due to existing deposit.

Each component type is thermally profiled to ensure the ramps, dwells, and peaks comply with IPC/JEDEC J-STD-020 or manufacturer / customer guidance and restrictions. This was accomplished for the 54 Ball TFBGA with a set up component.

The process flow used for reballing follows: component body is inserted into mobile platform (Figure 8), pads are fluxed, a laser etched stencil is placed on platform locating pins (Figure 9), solder spheres are applied, mobile platform stencil and balls are placed onto conveyor oven belt and run through a convection oven reflow. Components are removed from tooling and placed in handling trays. Components are washed with deionized water in a batch cleaner and oven dried.

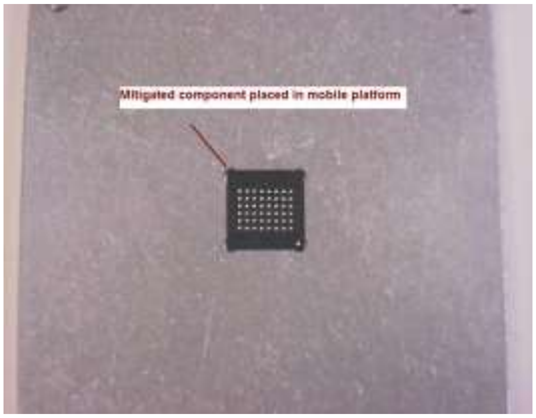


Figure 8 – Component in Mobile Platform

Figure 9 – Laser Etched Stencil in Place to Align Solder Spheres to Component Pads

Once the components exit oven dry, they are visually inspected. Figure 10 shows the original ball appearance of the 54 Ball TFBGA on top and the reballed appearance on the bottom. The difference in luster between the SAC 305 appearance (top) and Sn63Pb37 balls (bottom) is typical. In addition, a ball on the lower end of the size tolerance of the component data sheet was used for no particular reason beyond an earlier customer preference which we decided not to alter for this study.

Figure 10 – Unprocessed (top) and Processed (bottom) Components

Testing
IEC/TS 62647-4 (Draft) Qualification guidelines were used for testing, though quantities were adjusted for this study. See Figure 11. Barring another available specification for reballing, this specification was used for structure in this examination.

	Test Method	Sample Size
Pre Application	Test Method 100 (Visual Ins.)	100%
	Test Method 300 (AM)	100%
Post Application	Test Method 100 (Visual Ins.)	100%
	Test Method 300 (AM)	100%
	Test Method 500 or 501(Ionic Cleanliness)	10 pcs
	Test Method 600 (Solderability)	3 pcs
	Test Method 1000 (DPA)	3 pcs
	Test Method 1100 (X-Ray Inspection)	3 pcs
	Test Method 1200 (XRF)	3 pcs
	Test Method 1300 (Ball Shear)	3 pcs

Figure 11 - IEC/TS 62647-4 (Draft) Qualification Test Guidelines

IEC/TS 62647-4 (Draft) is similar to other customer supplied guidelines and the GEIA-STD-0006 document in that it provides qualification and production lot testing. The qualification lot is typically a standard size (e.g. 50 in the case of qualification in this draft specification) and is meant to be accomplished before production lots are released. The production lot testing is applied to a sample size extracted from the production lot.

This list of tests is perhaps longer than most customer lists that the processing facility handles, but it captures the impact on the component mechanical structure of the deballing and reballing process. Most customer supplied specifications for reballing stop short of DPA and will contain ether X-ray or Scanning Acoustic Microscopy (SAM) for internal structure. Where many specifications diverge (for lead frame components as well as BGAs) is in electrical and other stress testing. For example, in the IEC/TS 62647-4 (Draft) there is a set of optional tests which include Thermo-Moire testing, temperature cycling, and temperature and humidity bias plus electrical testing. In an ideal world, there might be extensive testing done on all reballed parts. However, time and cost considerations have to be weighed against reballing risk. For a third party, electrical testing of BGAs often involves a significant tooling development fee and long delay.

The focus here was on mechanical impact, and the tests conducted are listed in Figure 11 (with reduced quantities).

External Visual per JEDEC Standard JESD22-B101
There are detailed check lists in JESD22-B101 for filling out if necessary. Basically, the guidance is: “The component shall be viewed by the eyes, unaided or with low magnification (3X to 7X). Uncertain visual observations may be verified by using a higher magnification (up to 30X).” The inspector is evaluating the below items:

- Foreign material.
- Evidence of flux residue.
- Evidence of any nonconformance with the detail drawing or applicable purchasing information.

- Absence of any required feature.
- Missing solder balls, - broken or damaged solder balls. Balls with pits, voids, indentations, gouges, and/or depressions that exceed 20% of the ball diameter.
- Warping, other substrate / mask delamination or damage.

All of the samples in all of the deballed/reballed groups in this study passed visual inspection per Method 100, JEDEC JESD22-B101 without issue. Typical measurements of ball size are shown in Figure 12.

S/N	# Times Re-balled	Ball Height	Ball Width
N/A	0	0.0145"	0.0185"
4	1	0.0132"	0.0167"
8	2	0.0128"	0.0173"
12	3	0.0128"	0.0173"
39	8	0.0126"	0.0176"
49	10	0.0128"	0.0176"

Figure 12 Ball Size Measurement Samples

Scanning Acoustic Microscopy (SAM)

SAM analysis was conducted before and after processing per IPC/JEDEC J-STD-035. This was die, substrate, and through scan transmission analysis to detect delamination and cracking inside of package.

Pre-process view is in Figure 13. Areas of concern are shown up as yellow or red.

Figure 13- Pre process view, Top of Die, C-mode image

Post-process SAM shown below in Figure 14 is after 10X Reball. Areas of concern will show up as yellow or red.

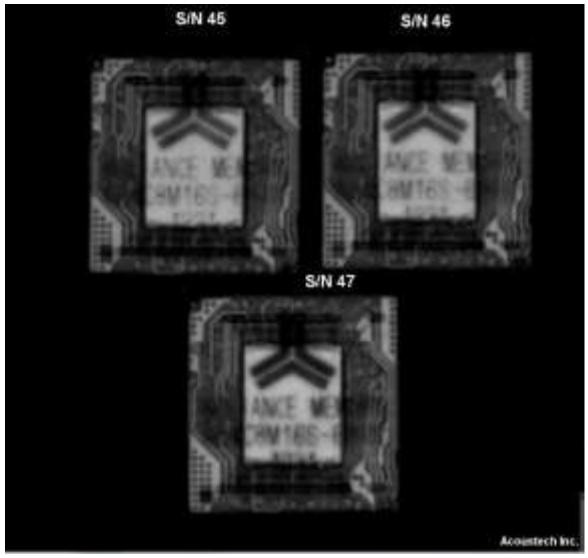


Figure 14- Post process view, Top of Die, C-mode image

SAM testing is very sensitive to delamination in plastic parts. Some would say too sensitive as the depth of delamination can be difficult to determine and SAM can be over sensitive to other component features. However, it is a good starting place for many parts when evaluating structure and how sensitive the component is to heat (evaluating components pre and post a thermal process). Experience indicates that most BGAs, if handled properly, are very resistant to delamination. There were no areas of concern noted in the pre or post-process SAM analysis of these parts.

Ionic Cleanliness Per IPC IPC-TM-650-2.3.25 Resistivity of Solvent Extract (ROSE).
Ion Chromatography can also be used in this test. Chromatography handles a broader spectrum of contamination. Processing facility experience with ROSE testing has determined that the ROSE tester is very sensitive to the fluxes used in these processes. Past comparative tests between ROSE and Ion Chromatograph provided confidence the parts would fail if not clean of these fluxes.

All samples tested clean. Results of several samples shown in Figure 15

Form# F059-A

IONIC CLEANLINESS TEST

Test Date 3/19/2015

Customer Name: Eng. Evaluationn BGA's

Production Log 54908-01

Part No. 913-AS4C8M16S-6BIN

Device Surface Area 1.48

Square size (UOM) cm²

Limit per square 1.50

Comment:

Device No.	Device Lot Code	Result	µg/sq
S/N 4	NOT SPECIFIED	PASS	0.03
S/N 8	NOT SPECIFIED	PASS	0.91
S/N 12	NOT SPECIFIED	PASS	0.95

Figure 15 Ionic Cleanliness Results on Three Samples.

Solderability Per IPC/EIA J-STD-002, Test S, Surface Mount Simulation Test.
For this test, a ceramic substrate is printed with solder paste using the 54 Ball TFBGA aperture array. The stencil thickness is designated in IPC/EIA J-STD-002. The component is placed on top of this pattern of paste deposits so that the balls are mated with the paste. The assembly is run though a convection reflow oven using J-STD-002 parameters. After reflow, the component is carefully removed from the substrate and inspected using 10X microscope magnification. All leads must exhibit a continuous solder coating free from defects for a minimum of 95% of the critical area of any individual lead.

All reballed components satisfactorily met this solderability criteria.

Destructive Physical Analysis (DPA), MIL-STD-883, Method 5009.

For the purposes of this study, inspection elements were selected to examine and display reballing process impact at the BGA pad level.

In the early days of BGA manufacturing, BGAs were not known to be as robust as most are considered today. Strides in substrate composition, die attach, wire bonding, and overall plating have contributed greatly to this improved perception. Historically, one important concern is the area around the BGA pad: more specifically at the substrate to pad connection and in the pad itself. That is, during deballing and reballing cycles, pads might separate from the substrate or the pad might dissolve by exposure to molten alloys. Worse yet, those failures may not occur immediately but be imminent and destined to fail post-assembly in later operation. That can still happen, but those events are much more the exception than the rule. Pads separating from the substrate is a very rare event. In addition, many of the modern component pads have a nickel barrier over the original copper pad. It is not always easy to gather that information from a manufacturer's data sheet, but if you have one available, XRF spectrum analysis can indicate if there is nickel on the pad. The operators in this study have reballed well over 250 different part types. The vast majority of the pads have a nickel barrier over the copper pad. An unprotected copper pad will be more susceptible to dissolution when in contact with the molten alloys used in most reballing effort.

The pads of the 54 Ball TFBGA contained this nickel barrier.

The following analysis and pictures focus on the intermetallic and nickel layers throughout the reballing steps. Figure 16 shows, as cross sectioned, one of the devices reballed 10 times.

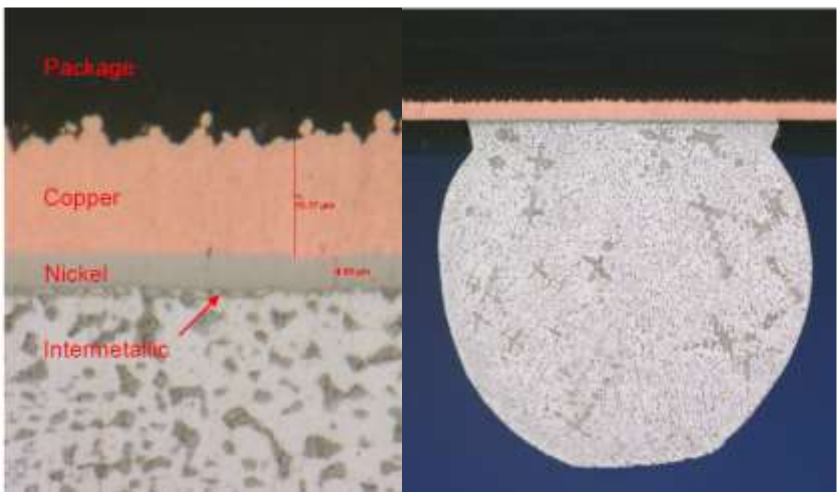


Figure 16 - Cross Section SN 47, Reballed 10 X

Table 1 lists thickness and shear test results from representative samples of each group of reballed components. That is, the unprocessed control component (shown as 0 reball in left column) up to and including components reballed 10 times.

Table 1 Statistics 1 µm = 39.37 microinch

Reball #	SN		Nickel µm		Intermetallic µm			Shear test grams			Copper µm		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
0	13	5.78	6.27	6.85		1.166		537.42	579.73	620.38			
4	16 & 17	5.14	5.55	5.85	0.273	0.41	0.554	478.42	505.43	515.43	12.18	13.45	13.95
5	21 & 22	4.14	4.43	4.73	0.198	0.38	0.629	492.64	512.97	537.09	13.18	13.68	14.54
6	26 & 27	6.27	6.61	6.86	0.223	0.44	0.6.4	483.58	510.03	539.8	14.31	14.77	15.31
7	31 & 32	5.14	5.62	5.91	0.24	0.48	0.752	507.11	510.34	515.31	13.06	14.31	15.25
8	36 & 37	4.14	4.43	4.73	0.347	0.44	0.521	503.93	514.56	533.11	13.18	13.68	14.54
9	41 & 42	2.6	2.98	3.37	0.347	0.48	0.653	490.46	502.85	512.2	13	13.93	15.01

10	**46 & 47**	**3.96**	**4.34**	**4.79**	**0.298**	**0.49**	**0.984**	**492.09**	**502.22**	**515**	**13.54**	**14.63**	**15.55**

Though the overall trend was toward thinning, the nickel barrier held up well to multiple deballing/reballing processes. The intermetallic layer dropped immediately after the first reball processes, then stabilized for all the later reball processes. Figure 17 is a sample of one of the close up views of the intermetallic. The shear test results will be covered later.

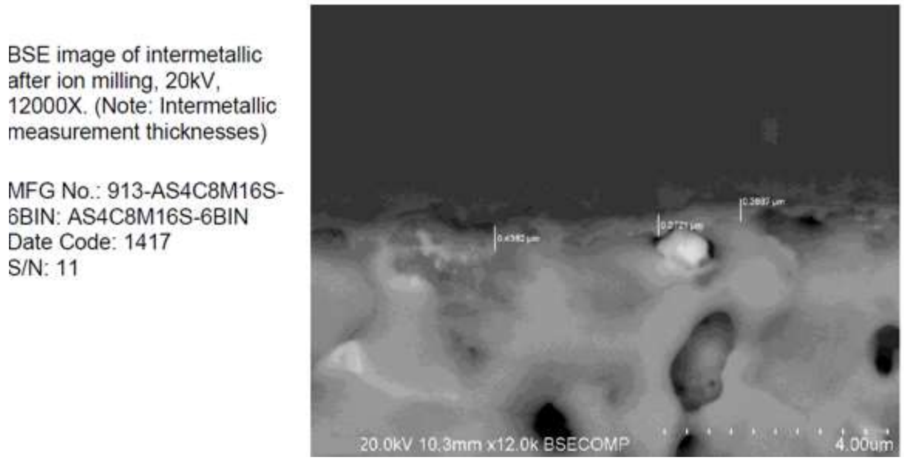


Figure 17 – Close up Image of Intermetallic.

X-Ray Inspection

The X-ray inspection in the IEC/TS 62647-4 (Draft) is for solder voids using criteria (void tables) in IPC-7095. We combined that analysis with the X-ray of the parts during DPA for the purposes of this paper. No anomalies, such as warping, wire bond breaks, or die separation were noted in the structure. The BGA balls were void free. Please see Figure 18.

Figure 18 – Side and Bottom X-Ray View of SN 9

X-Ray Fluorescence (XRF) for Composition per JEDEC JESD213.

All parts were examined after solder dip and reballing for correct alloy composition. Unless there is a problem with the solder supplied for the bath or the replacement solder balls, the new surface finish and the placed balls should measure Sn63Pb37 which is what the results in each group of reballed parts reflected.

Ball Shear Test to JEDEC JESD22-B117

For shear testing, the test method states that piece parts shall meet JEDEC JESD22-B117. The purpose of this test is to assess the ability of solder balls to withstand mechanical shear forces. The test method applies to solder ball shear force testing prior to end-use attachment (assembly). Solder balls are sheared individually; force and failure mode data are collected and analyzed. In IEC/TS 62647-4 (Draft) the failure mode must be Mode 1 failure to pass. That is, the exact shear force data is secondary to the mode of failure. This is a common requirement.

Failure mode 1 is: solder ball fracture at or above the surface of the solder mask within the bulk solder material. The other main failure modes are: pad separation from the component, the solder ball lifting from the pad, and the ball breaking at the intermetallic layer. All of those failure modes other than Mode 1, indicate a weakness either in the structure of the component or the connection of the solder ball to the pad. Figure 19 is representative of the results obtained with the components in this study. As noted earlier, the initial solder ball from the unprocessed control component was a little larger than the balls the reballed parts. That accounts for much of the distinction in force required to shear. Across all of the reball groups, shear mode failure remained Mode 1and shear force was consistent as would be expected with the same failure mode.

Figure 19 – Example of Sheared Balls

Summary/Conclusions

In general, reballing can eliminate the reliability risks of Pb-free/SnPb solder joint mixtures without introducing significant new risks. The refreshed component can be successfully mounted on SnPb compatible assemblies with long-term high-reliability.

However, even with continuing industry experience indicating the above to be true, each new customer, part, or project requires its own evaluation. We have demonstrated here how industry adoption of a procedure like IEC/TS 62647-4 will help provide a safe and effective reballing solution with an appropriate verification protocol.

IEC/TS 62647-4 (Draft) is not yet released. There is continuing discussion over various techniques. However, whatever the final form, the document will provide practical advice that will apply across all methods chosen. For example, “To avoid reliability problems, the BGA de-balling/re-balling process needs to be qualified and carefully controlled to prevent the possibility of piece part failure after re-balling.” That can apply to all new parts, processes, and vendors. Additionally, even though this study shows that some parts can withstand as many as ten reball cycles and appear unharmed, the document suggests, “Piece parts within the production lot shall not be reworked more than TWICE.” That is a reasonable starting place when considering the reballing process.

The multiple reballing processes in this paper demonstrate the benefits of following a standard for process and testing. The particular robustness shown by this 54 Ball TFBGA is not yet considered common, but the part was not chosen for the study because of any identified unique durability. It was chosen because it was readily available and had an established, straight forward process. It would not be surprising to find many parts that are easily capable of withstanding deballing/reballing – including the two rework steps mentioned above – and then go on to provide long term, reliable service in the field.

Reliability of Ball Grid Arrays Converted from Pb-free to Tin-Lead by Robotic Hot Solder Dip (RHSD). Multiple Reball Trial and Test Results

Charley Dennehy

Corfin Industries LLC

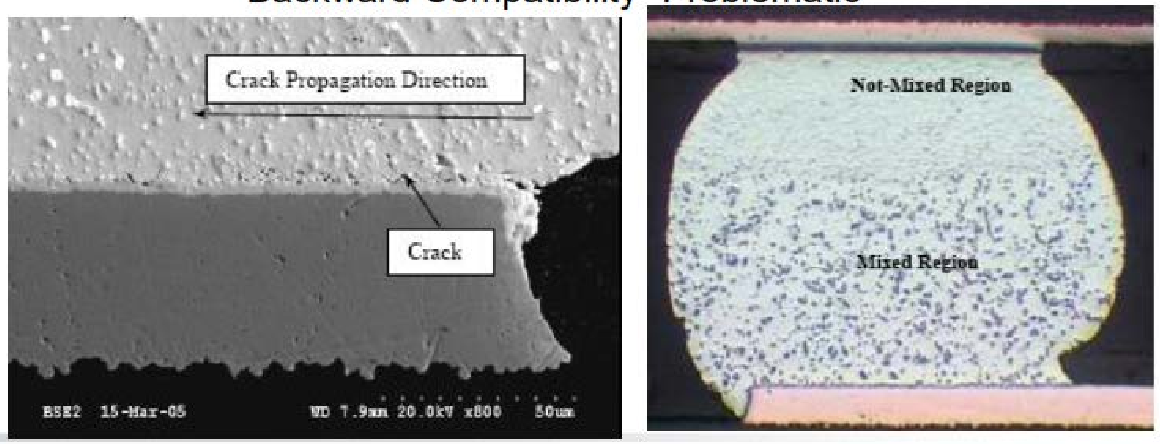
Why Reball Pb-Free Ball Grid Arrays?

- Pb-free Ball Grid Arrays present an unacceptable reliability risk for defense and space programs.
- SnPb options are diminishing.

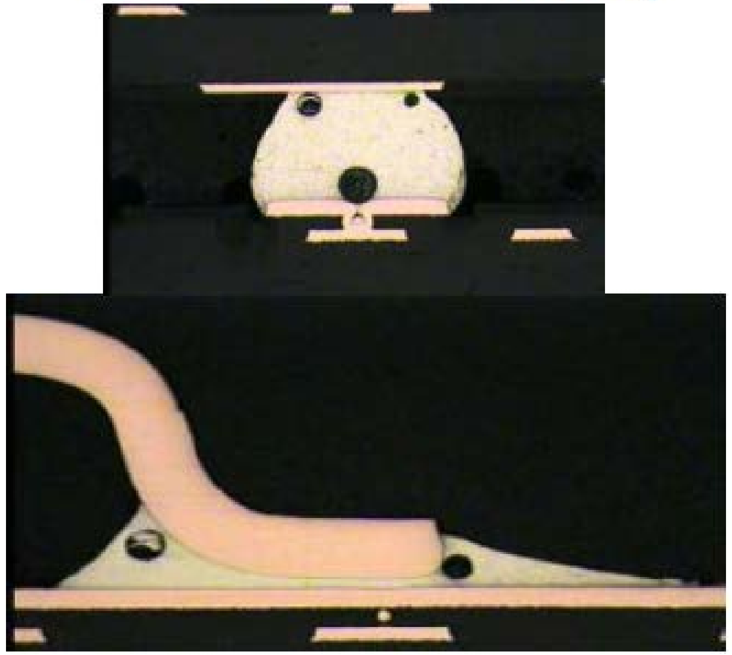
- Pb-free components require higher reflow temperature, exposing PCBs and other components designed for SnPb reflow to potential thermal damage.
- Mismatched metallurgy results in significantly weaker solder joints.

Mixed Assembly results in weakened solder joints

“Backward Compatibility” Problematic



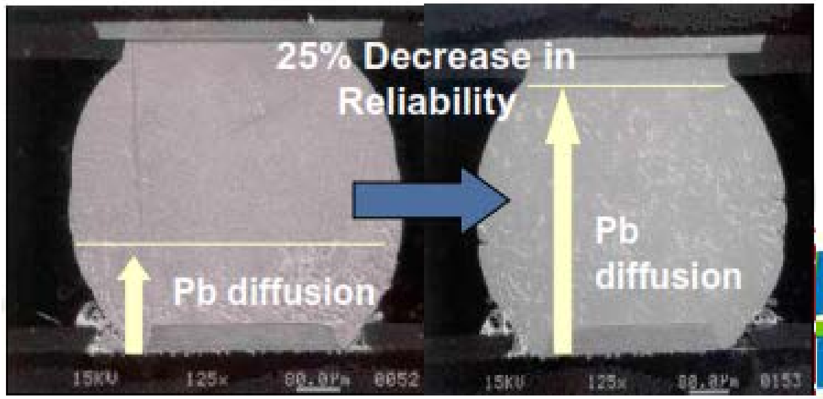
Increased solder voiding



Mixed Technology

Sn/Pb paste/SAC ball 205°C peak reflow

Sn/Pb paste/SAC ball 214°C peak reflow



"Photos courtesy of The Aerospace Corporation”

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Despite the Need to Reball, there are potential Issues

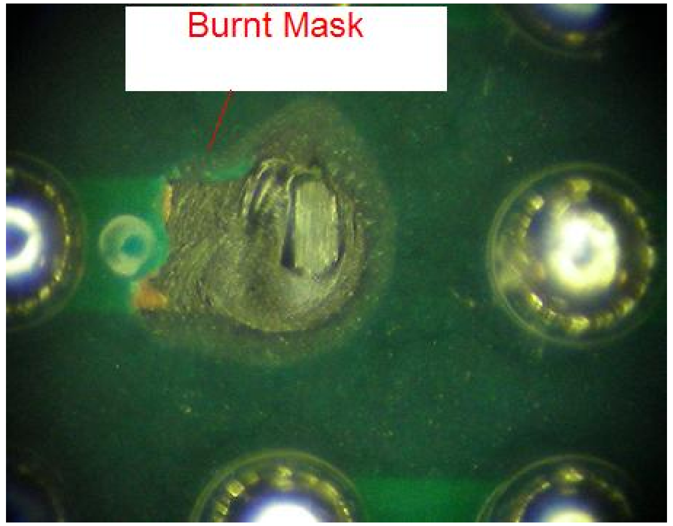
- BGA manufacturers express concern over the additional reflow cycles necessary for the reballing process.
  - Deball
  - Reball
  - Rework

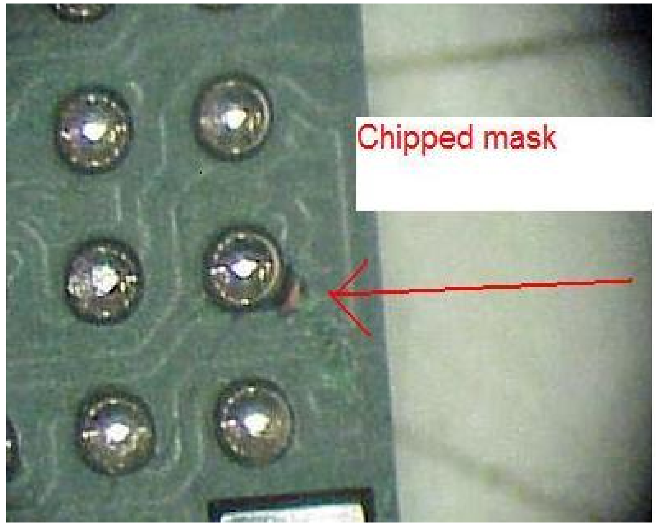
- Is the concern justified?
- Depends on the approach.

Some Existing Reballing Techniques for BGAs

- Reballing of BGAs has long been performed to replace damaged balls, but in low volume and without the requirement to completely remove original alloy.
- Traditional methods of removing Pb-free spheres are often poorly controlled: solder wicking braid, vacuum desoldering, and solder pot immersion.
- Complete alloy removal at the pad level is not accomplished. The residue of the original alloy will result in the same joint weakness as using a Pb-free sphere placed onto SnPb pad on the board.

Classic Hand Wicked or Vacuum Desoldered Pads





- Incomplete removal of existing Pb-free solder results in alloy combinations and unreliable interfaces with new SnPb alloy.
- High-temperature and Pressure from Hand-Held tools damages pads, mask, and substrate.

A Controlled Process can Minimize Issues

- What process can achieve full replacement of the Pb-free alloy, replacement with SnPb, and not introduce risk of reduced reliability?
- Are there post process evaluation tools to validate process output?
- Does an industry standard exist for this process?

Reballing Standard Draft

By INTERNATIONAL ELECTROTECHNICAL COMMISSION

IEC

IEC/TS 62647-4

Technical Specification

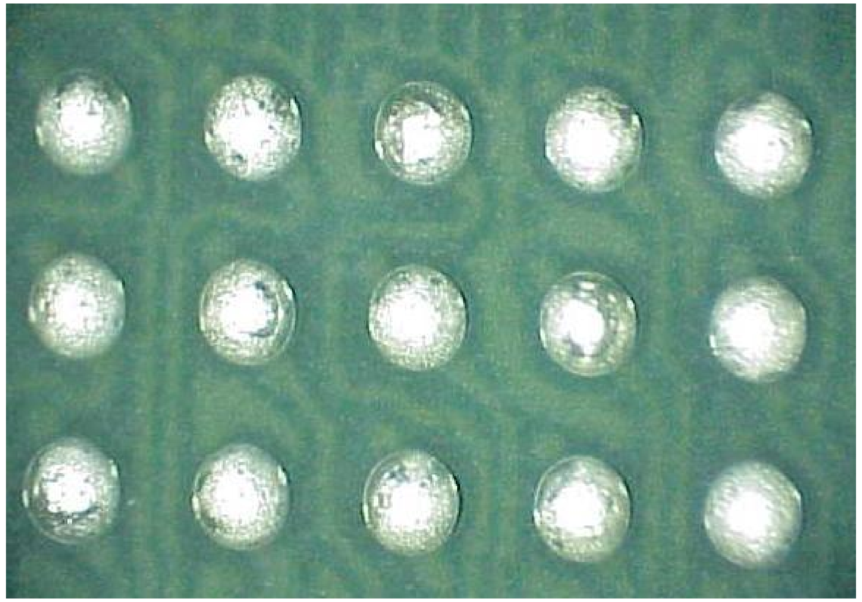
Process management for avionics – Aerospace and defence electronic systems containing lead-free solder – Part 4: Ball grid array (BGA) re-balling

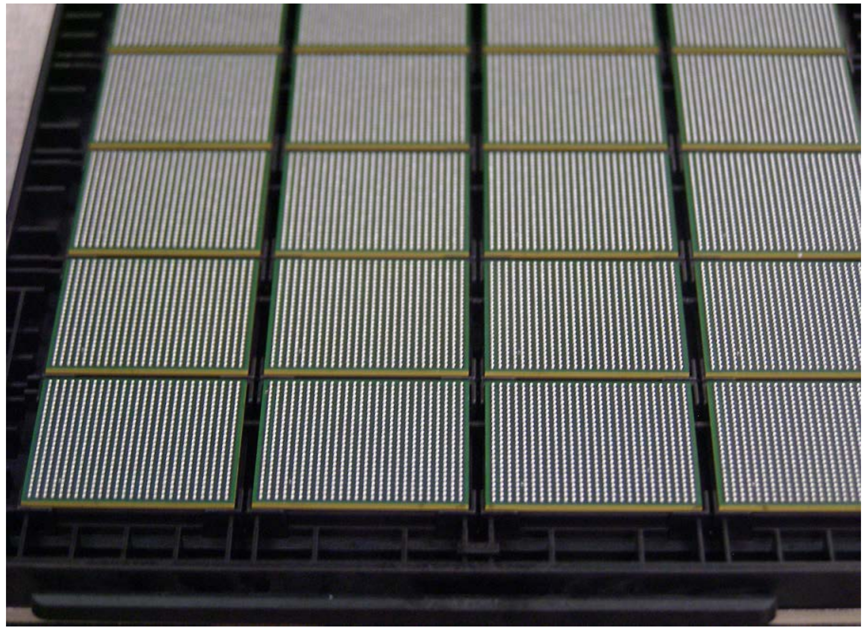
Assure Complete Removal of Existing Pb-Free Sphere

- IEC/TS 62647-4 (Draft) states "Deball equipment shall be capable of completely replacing the existing solder balls and ball attach finish with SnPb."

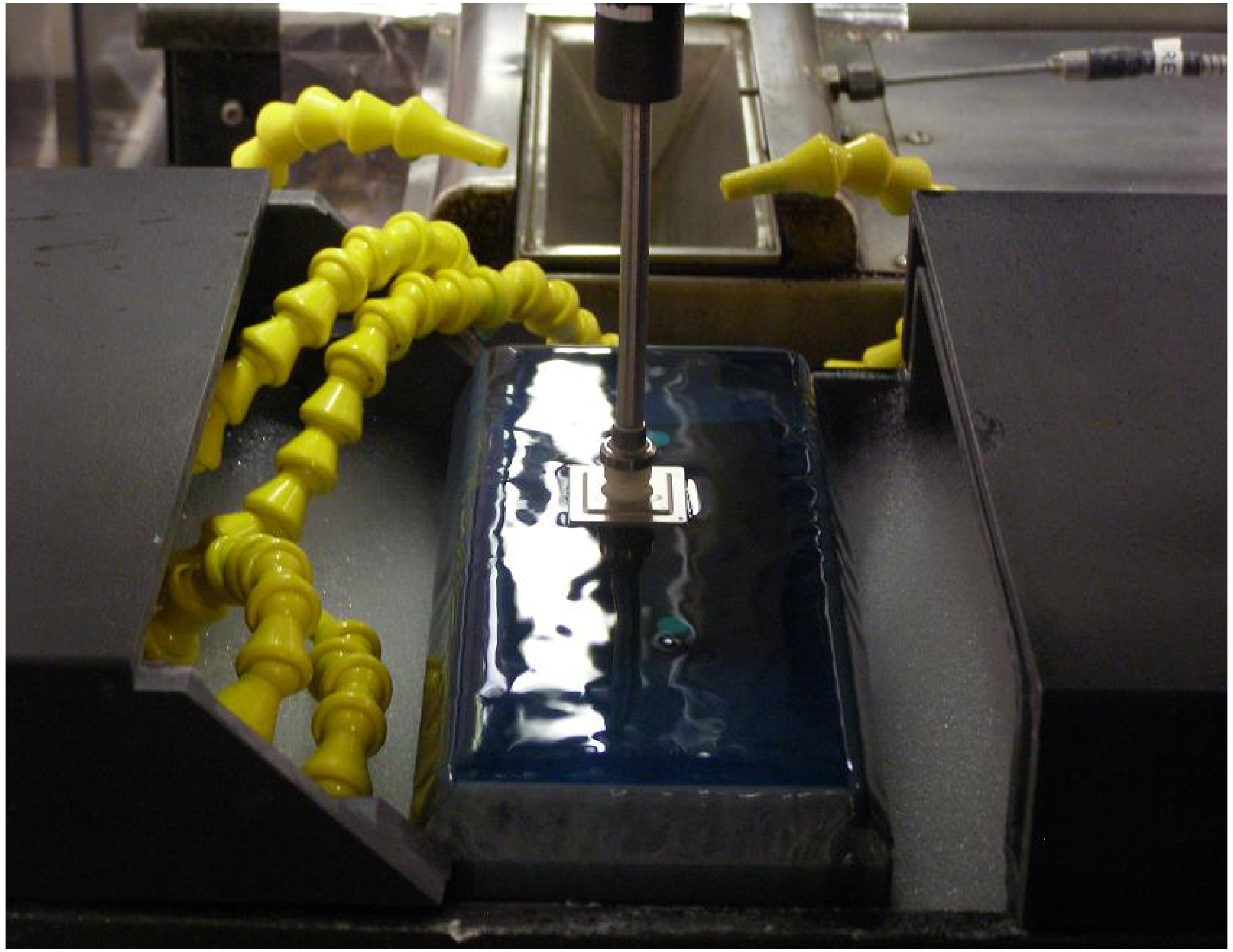
- Robotic Hot Solder Dip (RHSD) with a dynamic solder wave and an inert gas environment accomplishes complete Pb-free alloy removal. The system should be capable of maintaining solder temperature within 3 degrees C of set point.

Pb-Free Solder Sphere Removal

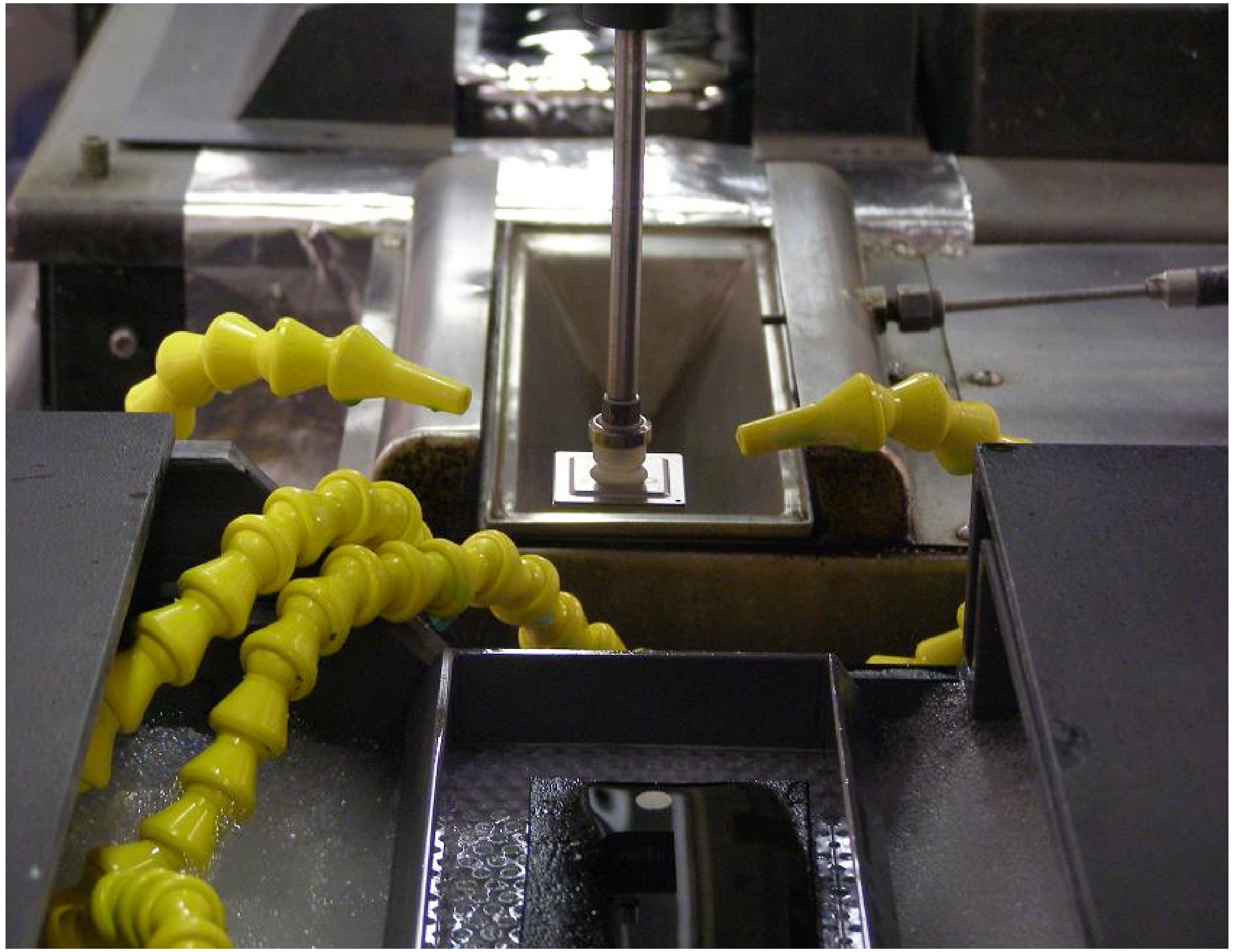




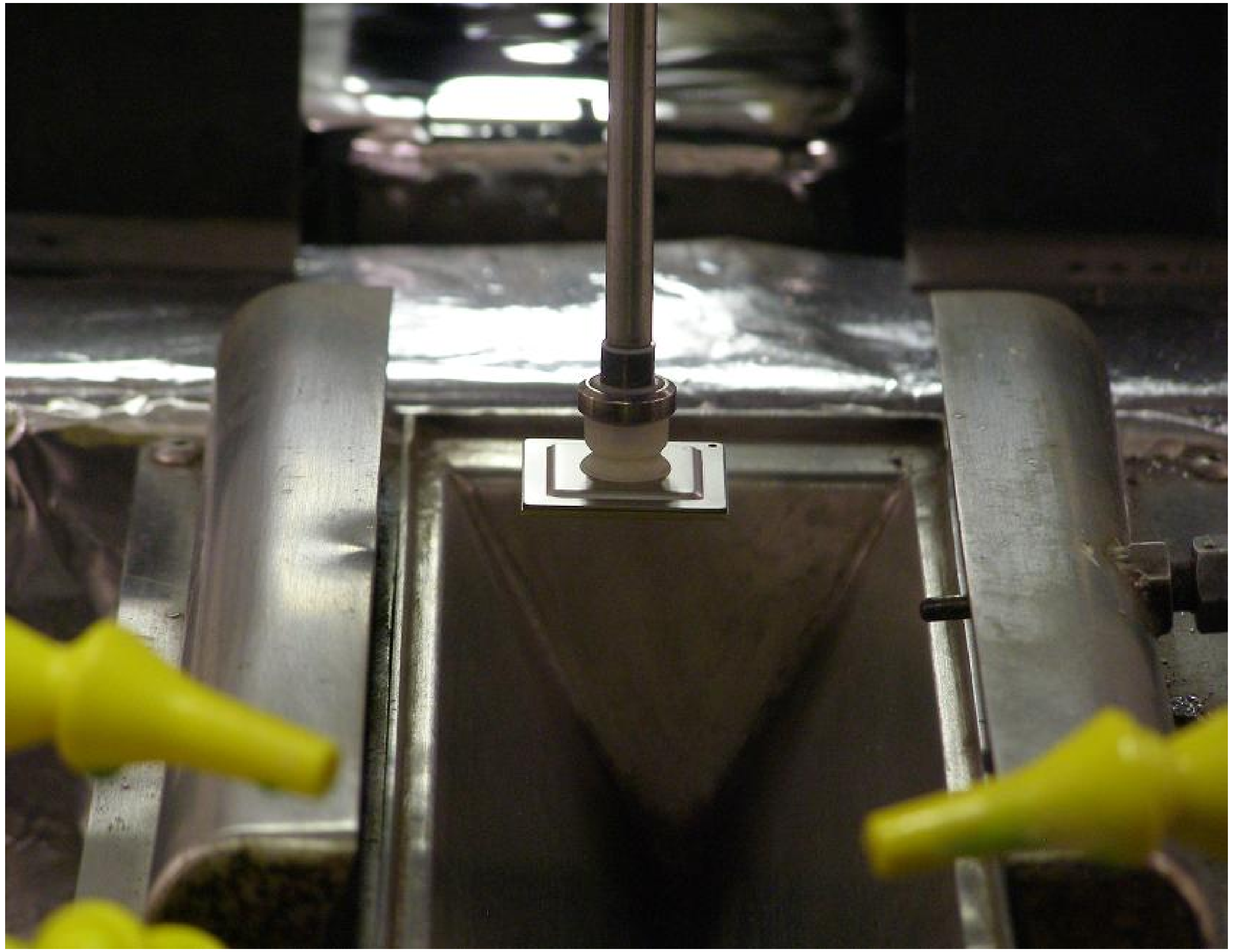
Flux is Applied Prior to Preheat



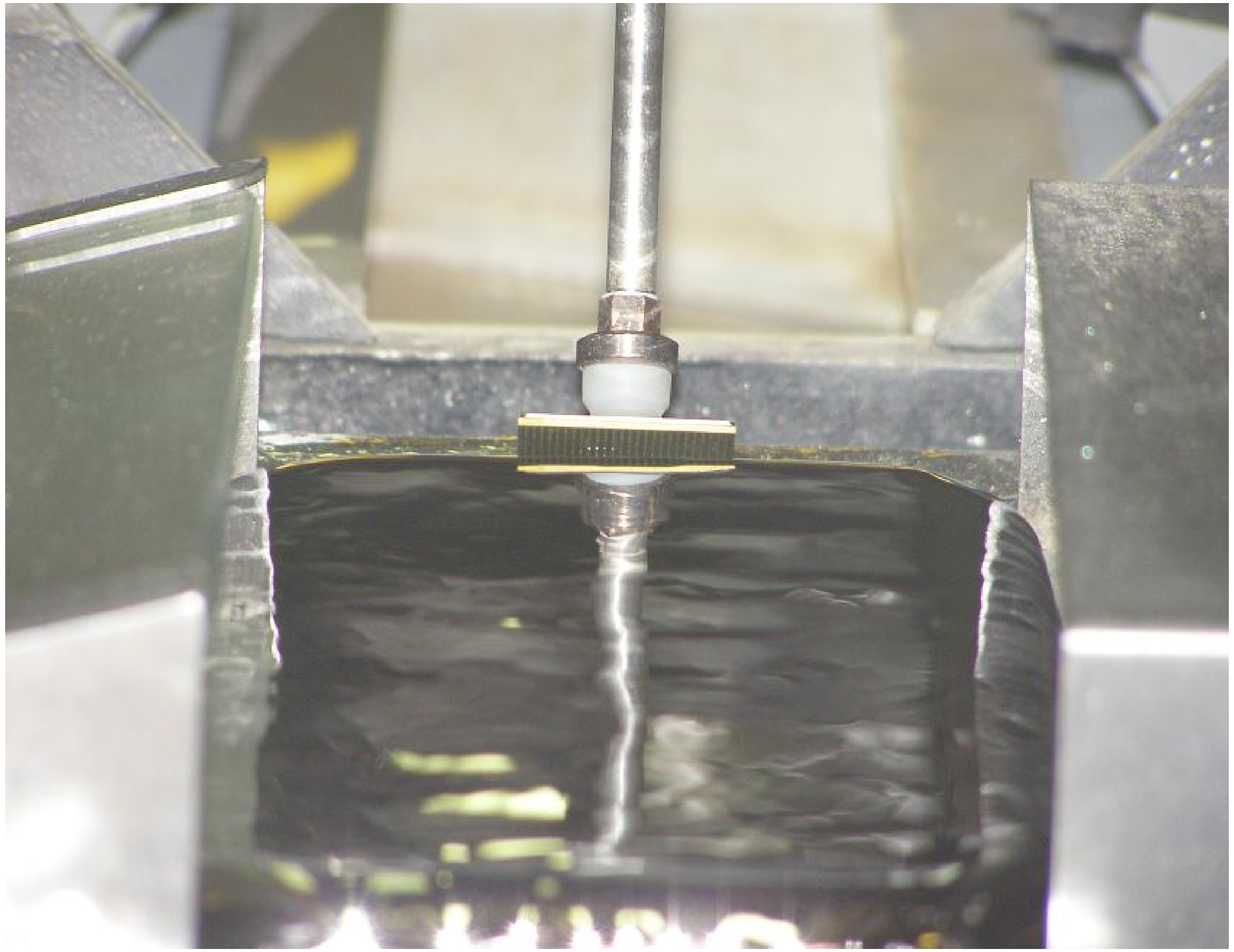
Excess Flux Removal

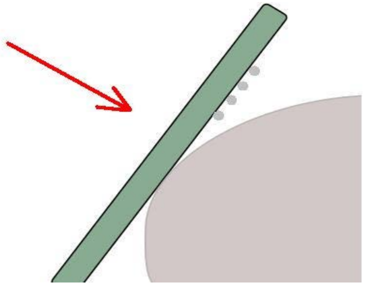


Flux Dehydration and Activation by Forced Hot Air



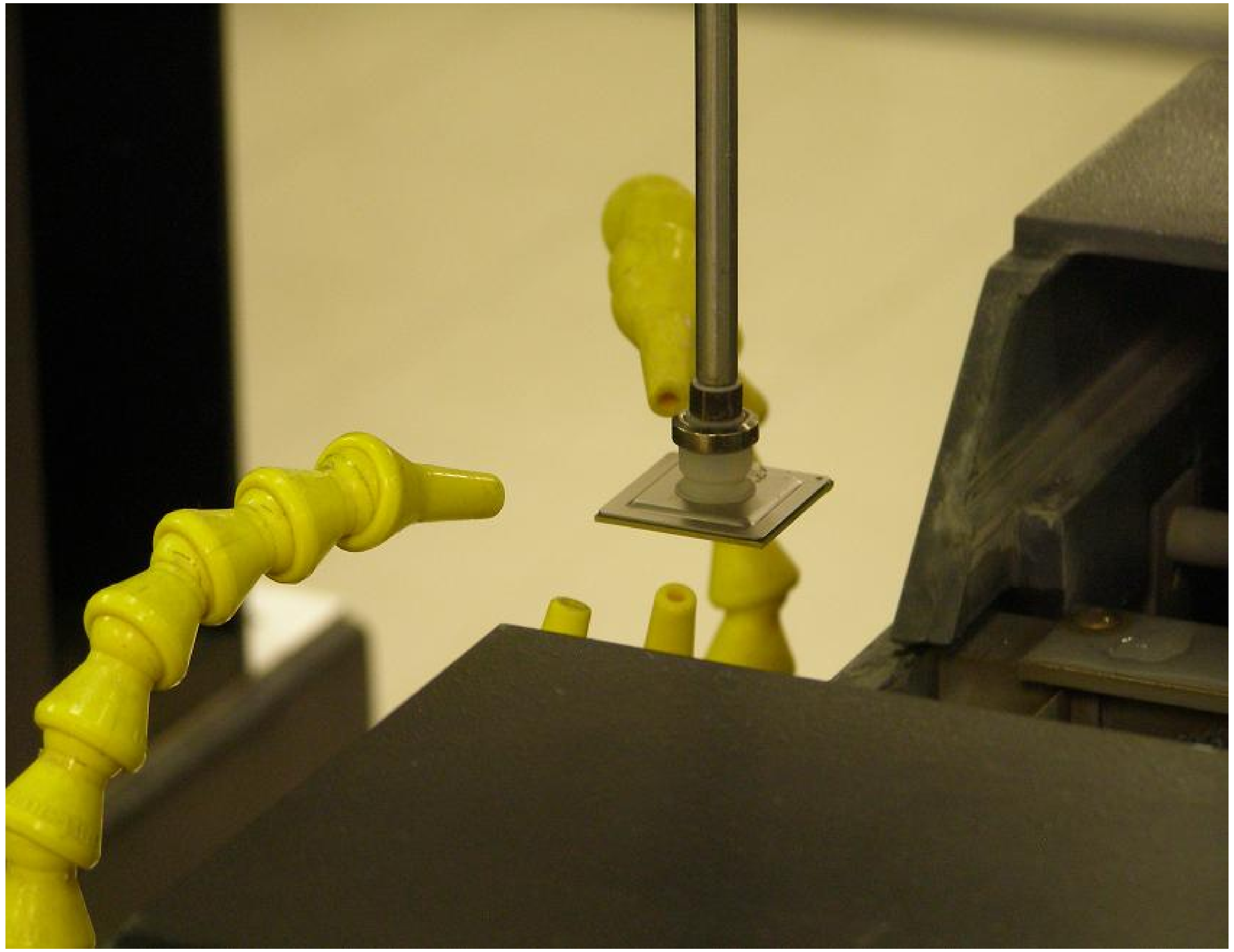
SnPb Flush (205 C) of Existing Pb-Free Alloy in an Inert Environment



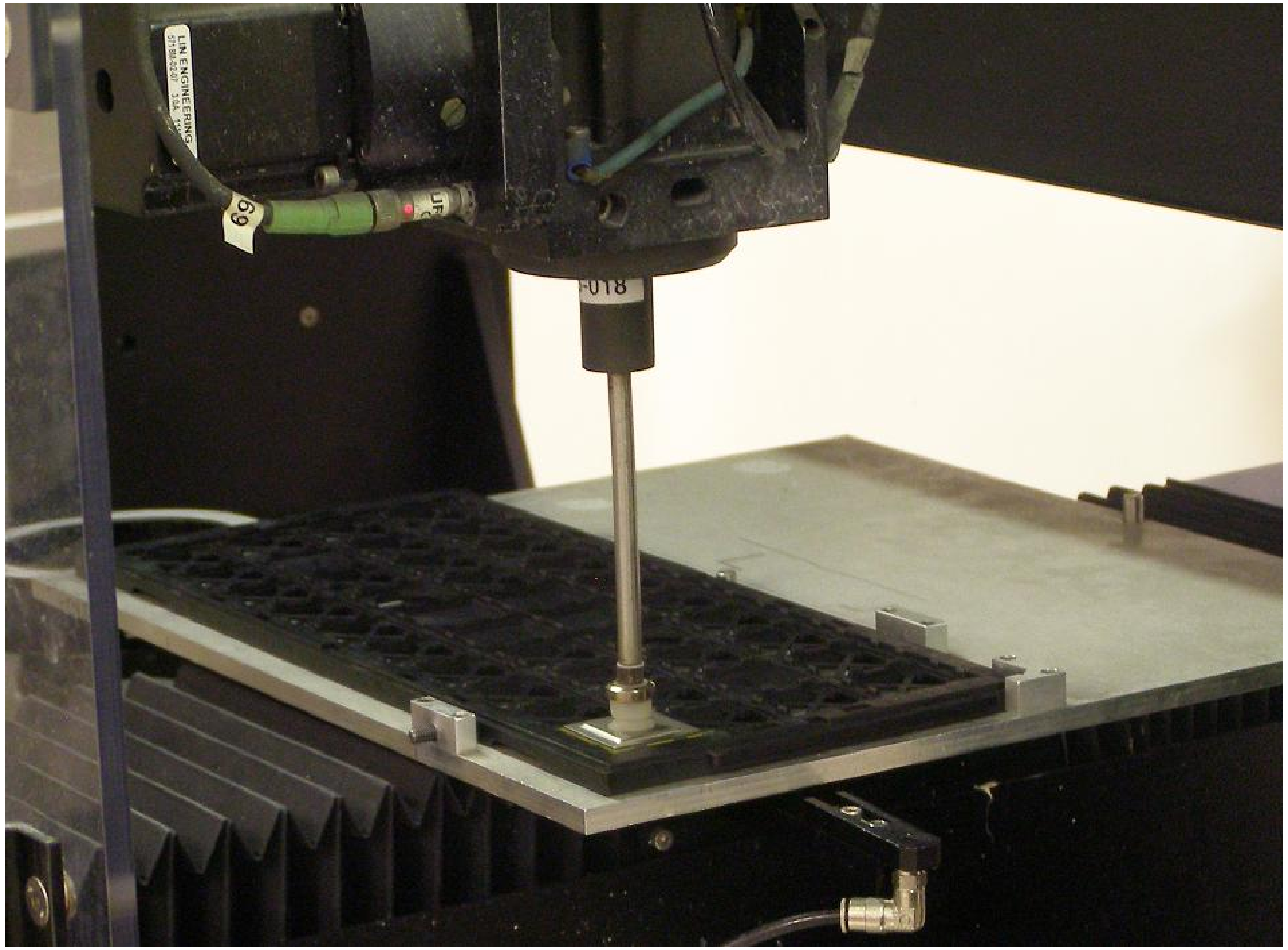


Prompt Inline Cleaning for Flux Removal

Post-Wash Dry



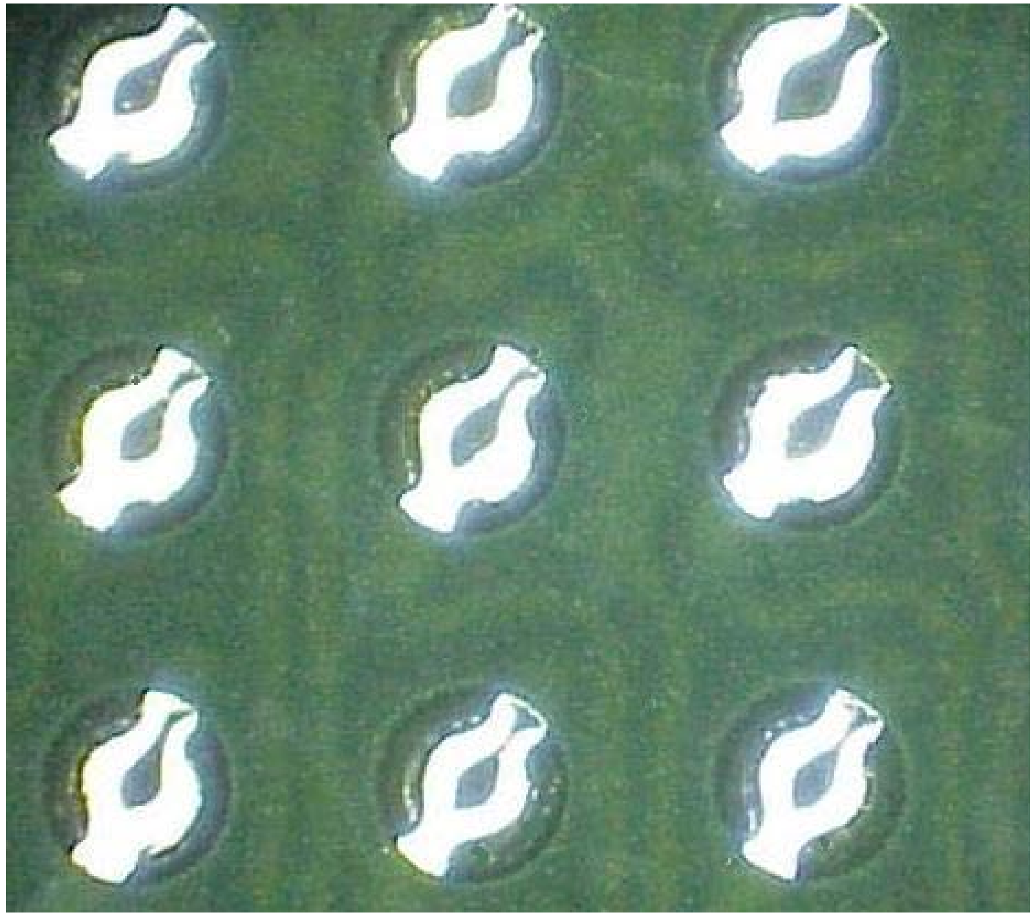
Return to Tray



Robotic System

- Controlled Immersion depth, temperature, dwell, rate of movement over wave.
- Dynamic wave, nitrogen blanket, variable angles of approach to edge of wave.
- Provides smooth and consistent SnPb pad height.

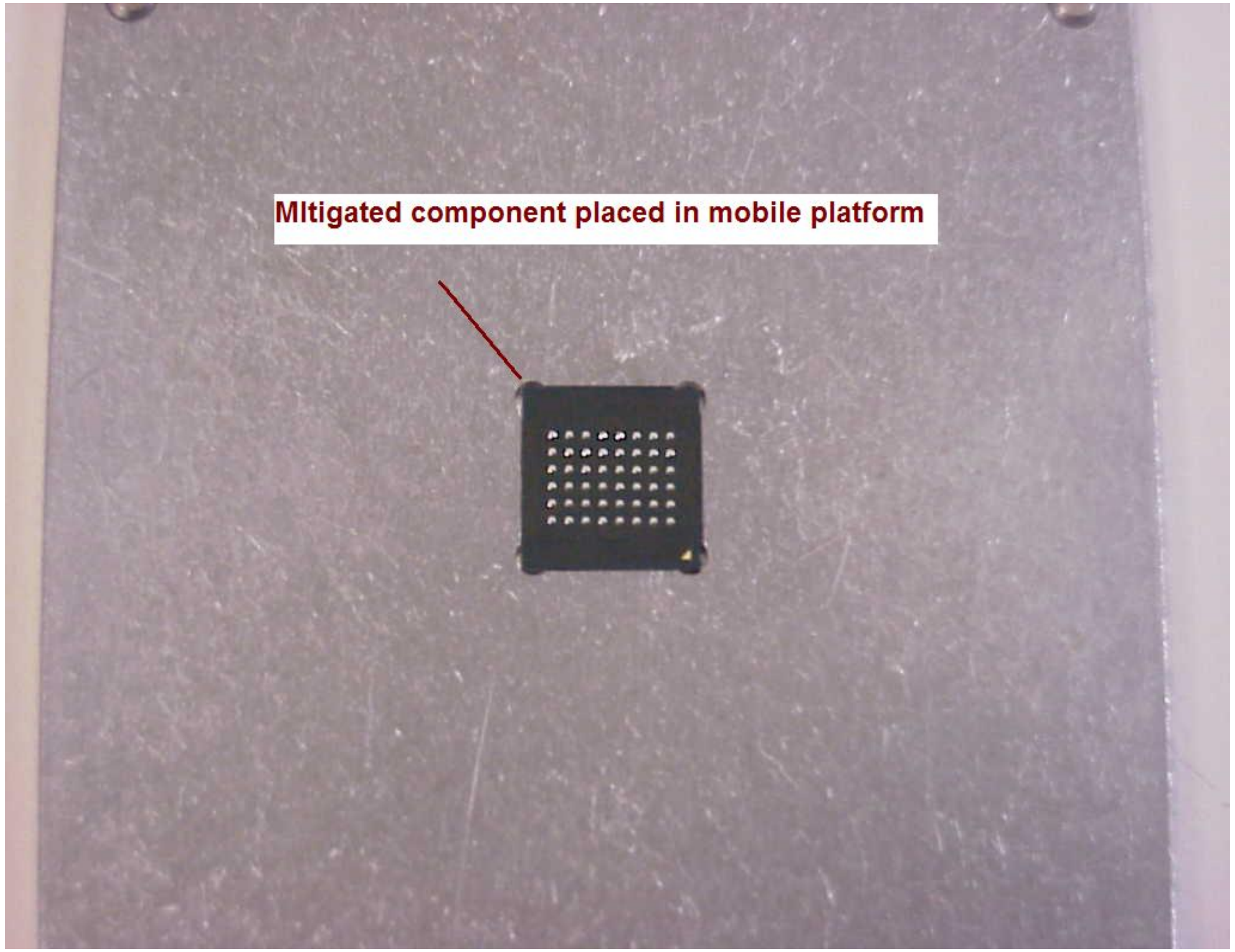
Post Robotic Hot Solder Dip (RHSD) Process Appearance



Part Specific Process Controls

- Compare recommended flux and component reflow profile to ensure they are compatible.
- Verify process output (ball size) will meet manufacturer's or end user's specification.
- Observe mechanical, thermal and liquid restrictions such as caps, vents, cavities and easily damaged surfaces. Mask as required.
- Bake MSL rated devices when required by J-STD-033 for proper moisture removal.
- Testing of BGA mechanical and electrical characteristics pre and post process as required by company protocol or industry standard (pending.)

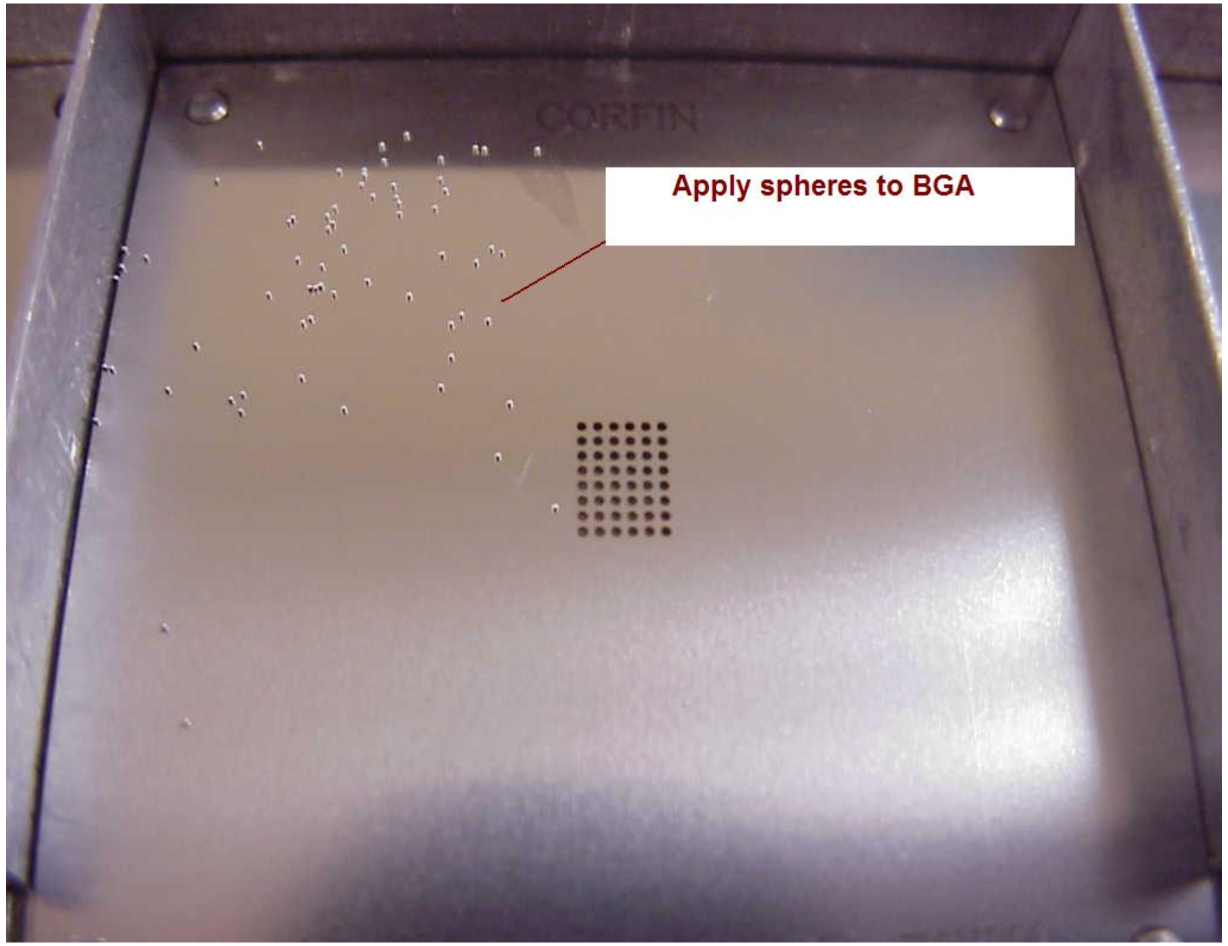
Steps of Reballing



Stencil Application

Laser etched stencil secured to mobile platform. Spheres corralled perfectly to pad centers though the reflow process. Process speed can be easily increased by the ability to scale platform as desired to reball multiple units simultaneously. There is no need for solder paste due to existing deposit.

Ball / Sphere Placement



Programmable Convection Oven Reflow and Post Process Cleaning

IEC/TS 62647-4 (Draft). Post Process Testing.

Establishes milestones for following 10X reballing tests.

- Visual
- Acoustic Microscopy
- Solderability
- Destructive Physical Analysis
- X-ray Fluorescence for composition
- X-ray for voids
- Ball Shear
- Ionic Cleanliness (No clean flux will not pass)

Qualification Test Steps (DRAFT)

Small sample lot size: 50

	Test Method	Sample Size
Pre Application	Test Method 100 (Visual Ins.)	100%
	Test Method 300 (AM)	100%
Post Application	Test Method 100 (Visual Ins.)	100%
	Test Method 300 (AM)	100%
	Test Method 500 or 501(Ionic Cleanliness)	10 pcs
	Test Method 600 (Solderability)	3 pcs
	Test Method 1000 (DPA)	3 pcs
	Test Method 1100 (X-Ray Inspection)	3 pcs
	Test Method 1200 (XRF)	3 pcs
	Test Method 1300 (Ball Shear)	3 pcs

Optional Qualification Test Steps

(DRAFT)

Test Method		Sample Size
Pre Application	Test Method 1400 (Thermo-Moiré)	TBD
Post Application	Test Method 800 (Temperature Cycling + Electrical)	22 pcs
	Test Method 900 (THB + Electrical)	22 pcs
	Test Method 1400 (Thermo-Moiré)	TBD

Production Lot Test Steps (DRAFT)

Test Method		Sample Size
Pre Application	Test Method 100 (Visual Ins.)	45 or 100% if lot size less than 45
	Test Method 300 (AM)	10
Post Application	Test Method 100 (Visual Ins.)	100%
	Test Method 300 (AM)	10
	Test Method 600 (Solderability)	3
	Test Method 1000 (DPA)	3
	Test Method 1200 (XRF Analysis.)	3
	Test Method 1300 Ball Shear	3

Process Monitoring Option (DRAFT)

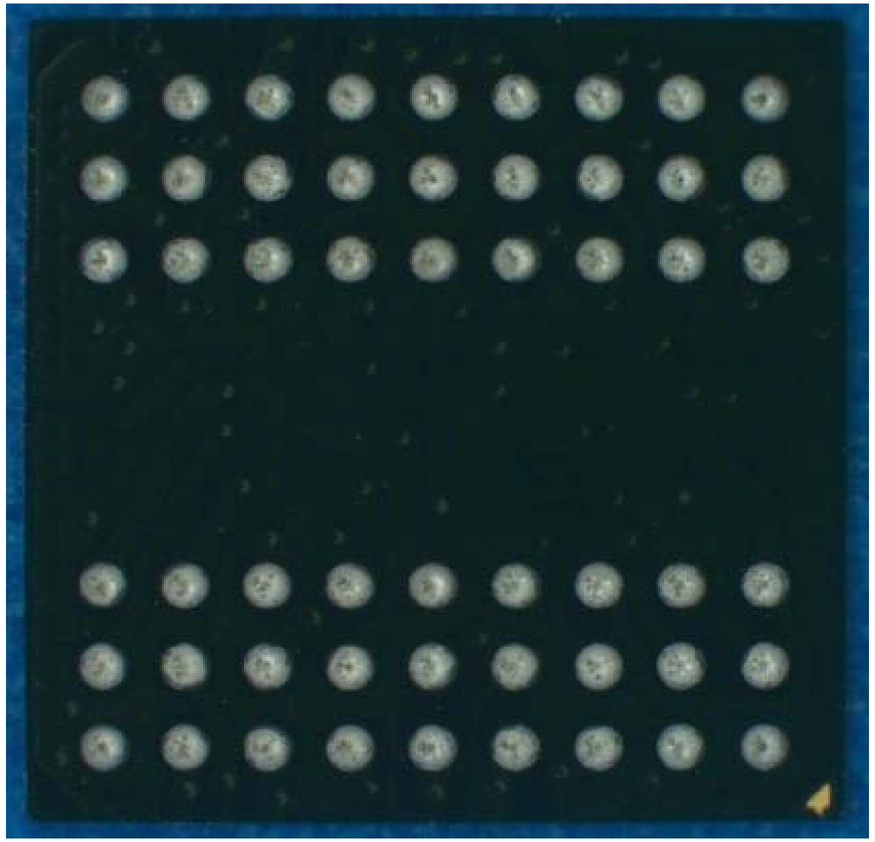
The following Production Lot tests may be replaced by Process Monitors based on agreement between the customer and reballing supplier.

Test	Frequency	Sample Size
Test Method 300 (AM) "After Re-balling Only"	Once per month	10
Test Method 500 or 501 (Ionic Cleanliness)	Once per shift	10
Test Method 600 (Solderability)	Once a week	3
Test Method 1000 (DPA)	Once a month	2
Test Method 1100 (X-Ray)	Once a month	10
Test Method 1300 (Ball Shear)	Once a week	3

Test to Determine Rework Effect on Reliability on Commonly Run Component

- Samples reballed up to ten times.
- Each group segregated by number of cycles.
- SNs 1-4 reballed once, 5-8 reballed twice, 9-12 reballed three times. 13-14 unprocessed, etcetera.
- Tests were run on all ten reballed sets against unprocessed control samples.

Test Vehicle



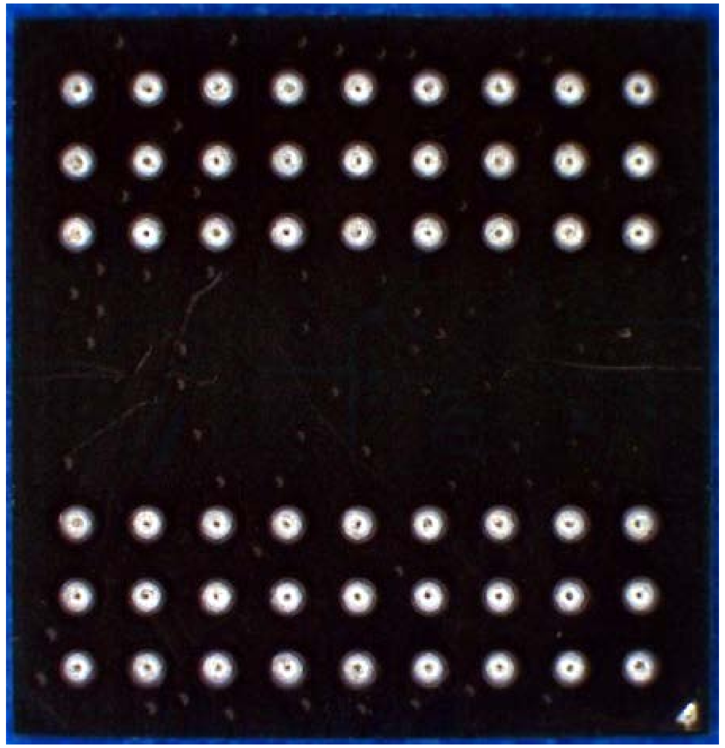
54 Ball TFBGA (Thin and Fine Pitch Ball Grid Array). BT Substrate with mold encapsulated die and bonds. Original balls SAC 305, 0.018 inch (0.45MM) width at receipt. Replacement balls Sn63Pb37. Pads are nickel over copper. Parts reballed. Tests conducted follow.

External Visual per JESD22-B101

- Foreign material.
- Evidence of flux residue.
- Evidence of any nonconformance with the detail drawing or applicable purchasing information, or absence of any required feature.
- Missing solder balls, - Broken or damaged solder balls. Balls with pits, voids, indentations, gouges, and/or depressions that exceed 20% of the ball diameter.
- Warping, other substrate / mask delamination or damage.
- All samples in each group passed visual inspection per Method 100 without issue.

S/N	# Times Re-balled	Ball Height	Ball Width
N/A	0	0.0145"	0.0185"
4	1	0.0132"	0.0167"
8	2	0.0128"	0.0173"
12	3	0.0128"	0.0173"
39	8	0.0126"	0.0176"
49	10	0.0128"	0.0176"

Visual



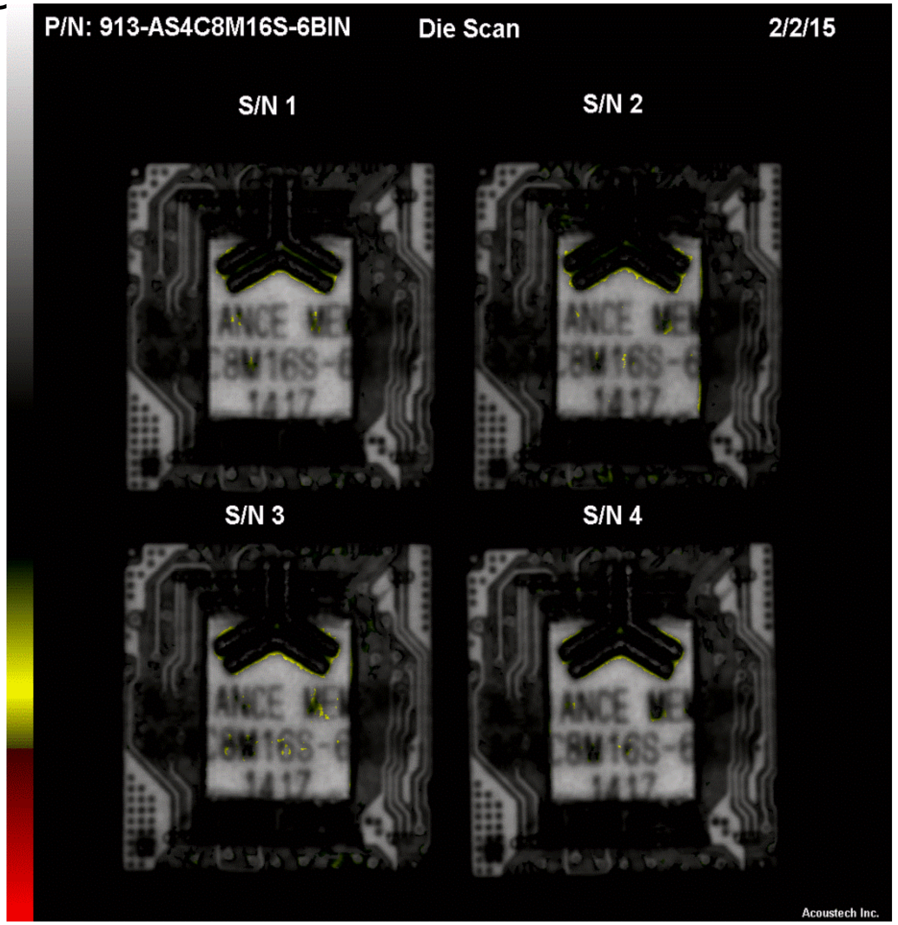
After multiple reballs cycles, ball luster is unchanged

After ten reballs, surface focal point. Component surface unaffected .

Unprocessed and Reballed Visual Comparison

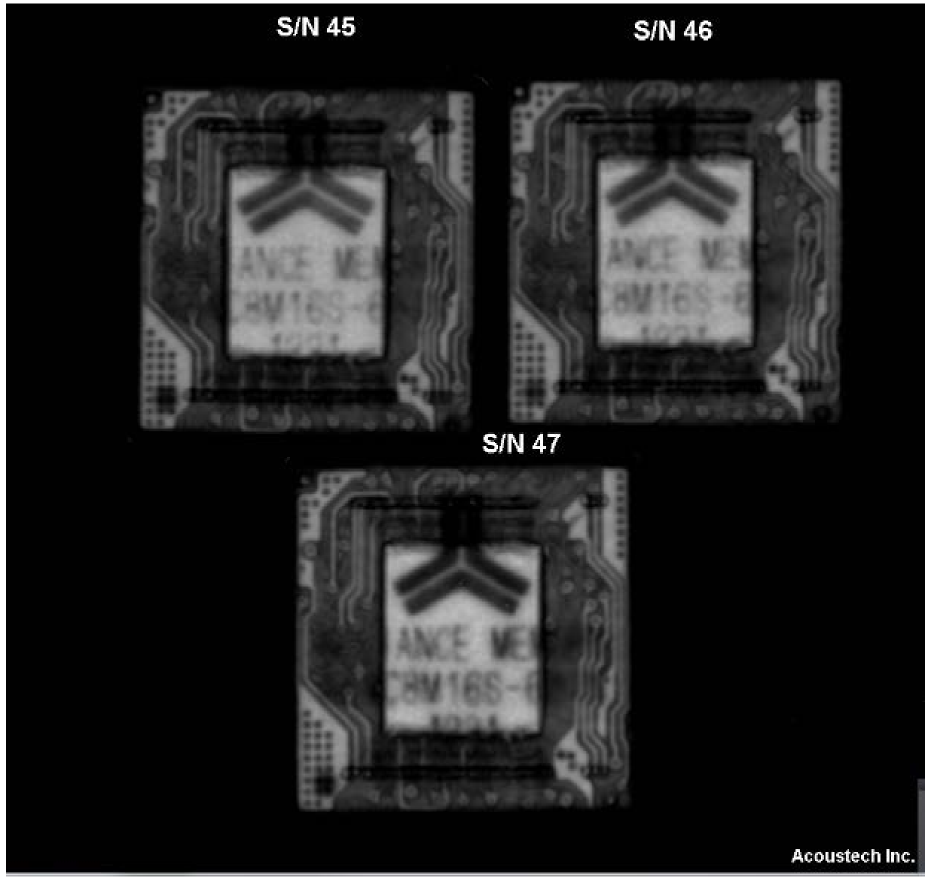
Method 200, Scanning Acoustic Microscopy (SAM)

- Analysis conducted before and after processing per J-STD-035: Die, Substrate and Through Scan transmission analysis to detect delamination and cracking inside package
- Pre process view.
- Top of Die, C-mode image
- Areas of concern will show up as yellow or red



Post-process SAM after 10X Reball.

- Post process view
- Top of Die C-mode image
- No areas of concern



Cleanliness

- <u>Ionic Cleanliness</u> Per IPC IPC-TM-650-2.3.25 Resistivity of Solvent Extract (ROSE).
- Hands-free process steps reduce opportunity for contamination. All reballed parts remained clean.

Form# F059-A **IONIC CLEANLINESS TEST**

Test Date *3/19/2015*

Customer Name: *Eng. Evaluationn* *BGA's*

Production Log *54908-01*

Part No. *913-AS4C8M16S-6BIN*

Device Surface Area *1.48*

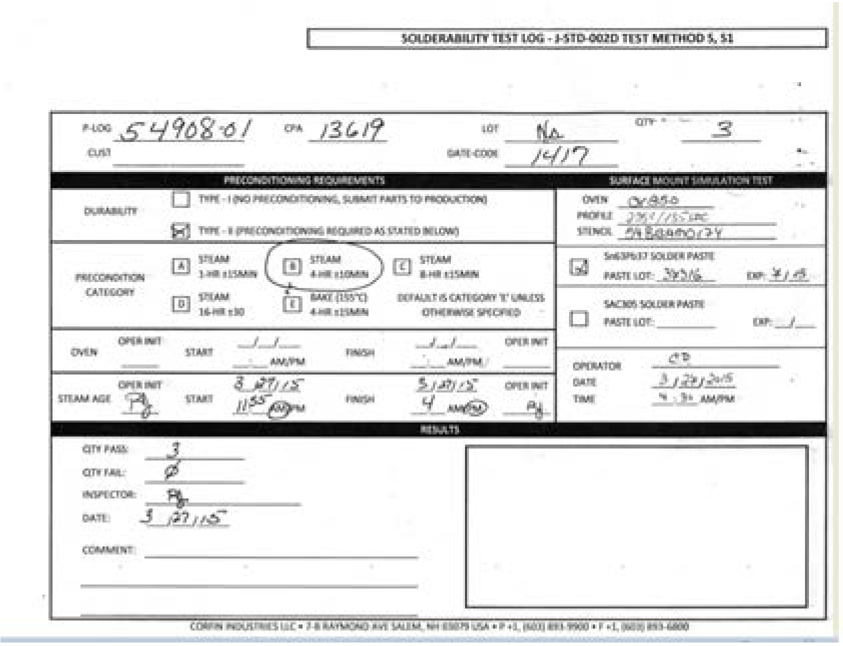
Square size (UOM) *cm²*

Limit per square *1.50*

Comment:

Device No.	Device Lot Code	Result	µg/sq
S/N 4	NOT SPECIFIED	PASS	0.03
S/N 8	NOT SPECIFIED	PASS	0.91
S/N 12	NOT SPECIFIED	PASS	0.95

Method 600 Solderability Per J-STD-002 Test S



SOLDERABILITY TEST LOG - J-STD-002D TEST METHOD S, S1

P-LOG 54908-01 CPA 13619 LOT NA QTY 3
CUST DATE-CODE 1417

PRECONDITIONING REQUIREMENTS

DURABILITY
☐ TYPE - I (NO PRECONDITIONING, SUBMIT PARTS TO PRODUCTION)
☒ TYPE - II (PRECONDITIONING REQUIRED AS STATED BELOW)

PRECONDITION CATEGORY
A STEAM 1-HR ±15MIN
B STEAM 4-HR ±10MIN
C STEAM 8-HR ±15MIN
D STEAM 16-HR ±30
E BAKE (155°C) 4-HR ±15MIN
DEFAULT IS CATEGORY 'E' UNLESS OTHERWISE SPECIFIED

OVEN — OPER INIT — START _/_/_ _ AM/PM — FINISH _/_/_ _ AM/PM — OPER INIT

STEAM AGE — OPER INIT Pg — START 3 27/15 1155 AM/PM — FINISH 3/27/15 4 AM/PM — OPER INIT Pg

SURFACE MOUNT SIMULATION TEST

OVEN OV850
PROFILE 235°/155 LPC
STENCIL 54B8AM0174

☒ Sn63Pb37 SOLDER PASTE
PASTE LOT: 39516 EXP: 3/15

☐ SAC305 SOLDER PASTE
PASTE LOT: EXP: _/_

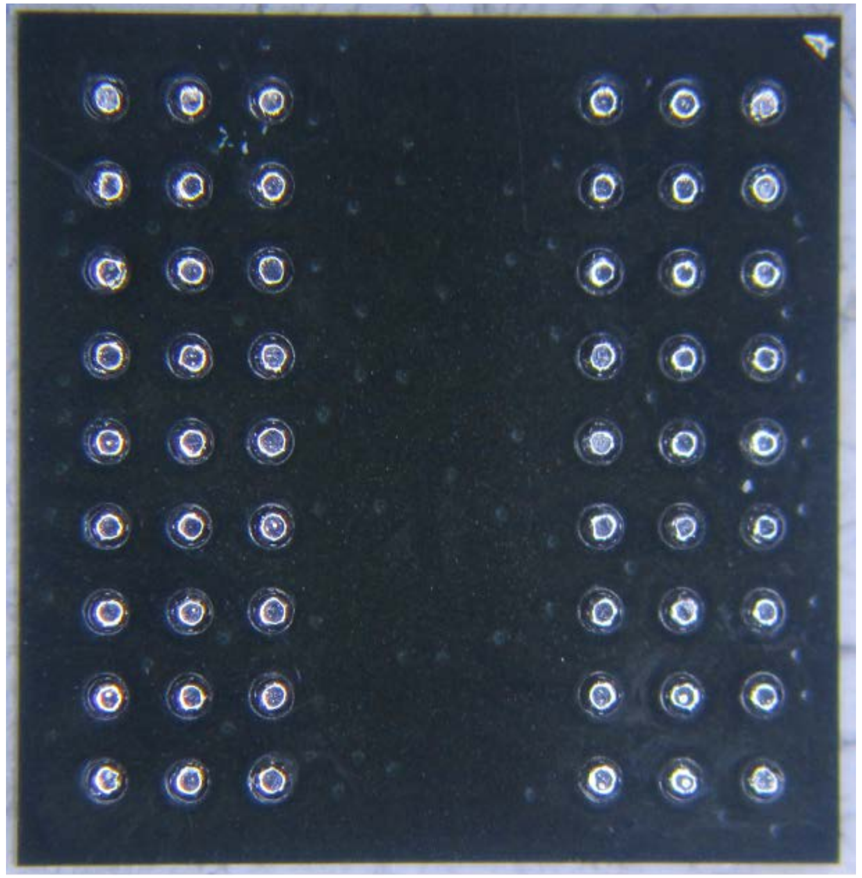
OPERATOR CD
DATE 3/27/2015
TIME 4:30 AM/PM

RESULTS

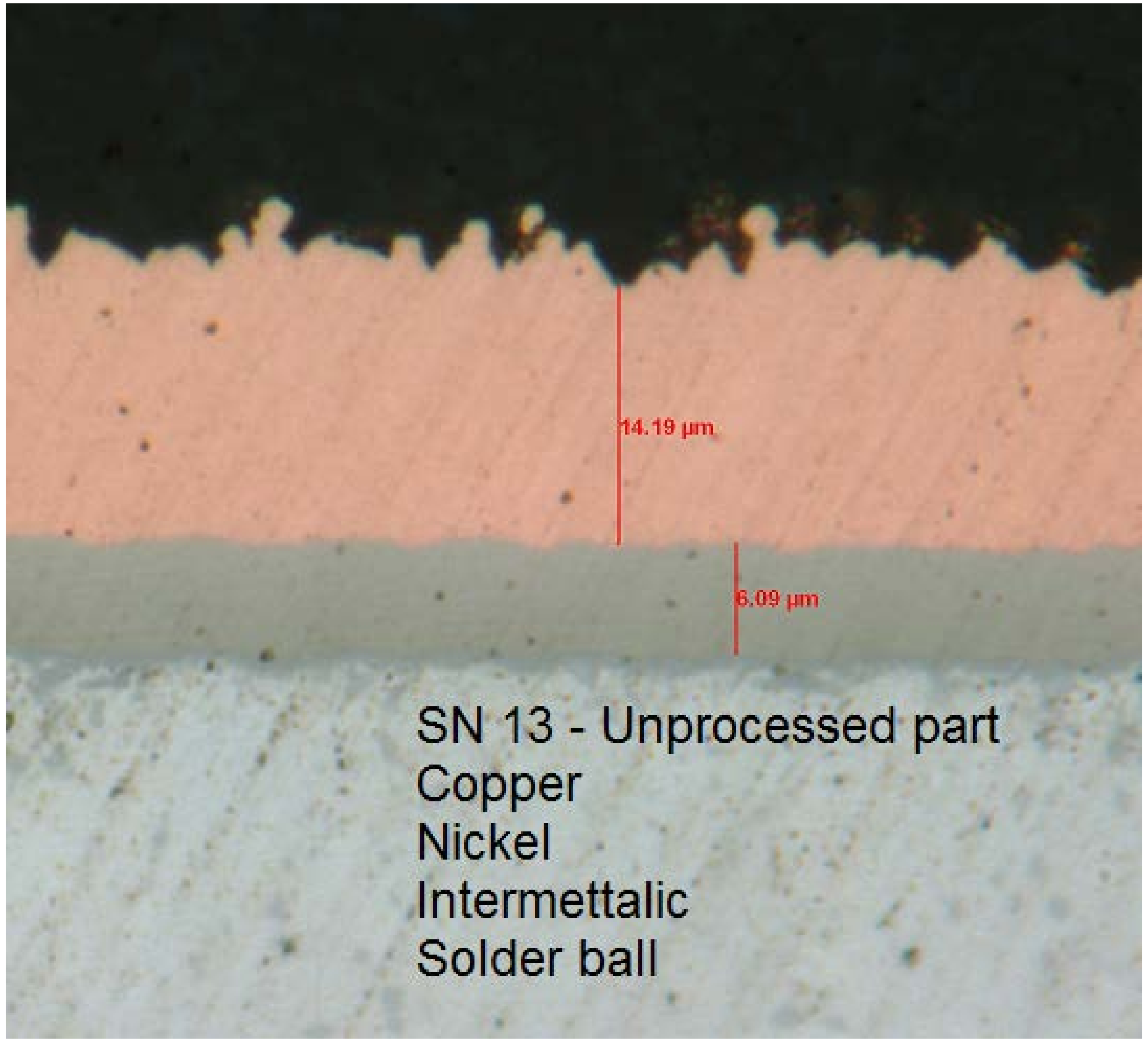
QTY PASS: 3
QTY FAIL: Ø
INSPECTOR: Pg
DATE: 3/27/15
COMMENT:

CORFIN INDUSTRIES LLC • 7-8 RAYMOND AVE SALEM, NH 03079 USA • P +1, (603) 893-9900 • F +1, (603) 893-6800

All test samples passed.



DPA, MIL-STD-883, Method 5009.
Elements selected to examine Reballing process at BGA pads



Cross section of baseline part

Nickel and Copper layers (pad thickness) Unaffected

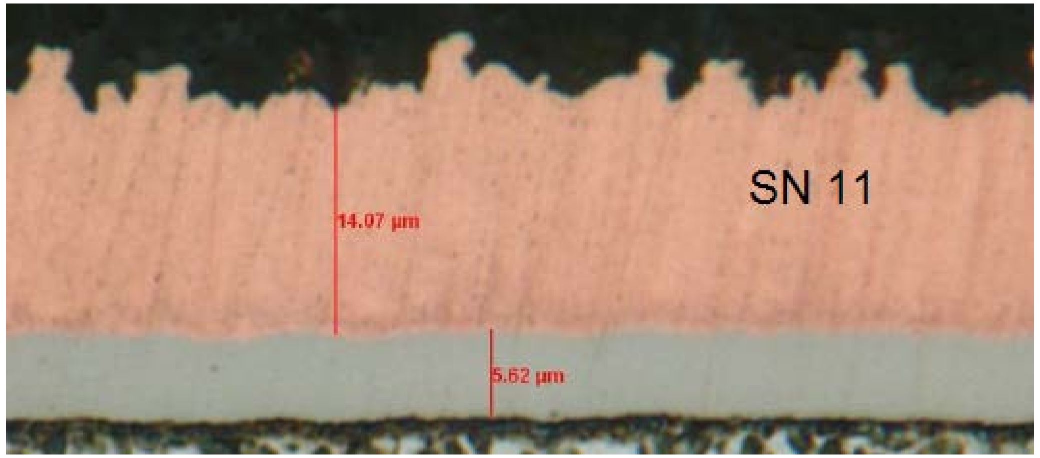
SN 3 Reballed 1 X

Nickel Layer Measurement (µm)	Min.	Max.	Mean
SN 3	6.35	6.86	6.66

SN 7 Reballed 2 X

Nicker Layer Measurement (µm)	Min.	Max.	Mean
SN 7	6.32	7.34	6.86

Cross section on part reballed 3X.



SN 11 Reballed 3 X

*Nickel Layer Measurement (µm)	Min.	Max.	Mean
SN 11	5.93	6.99	6.55

*Note: Nickel measurements were taken using SEM microscopy.

Statistics

1 µm = 39.37 microinch

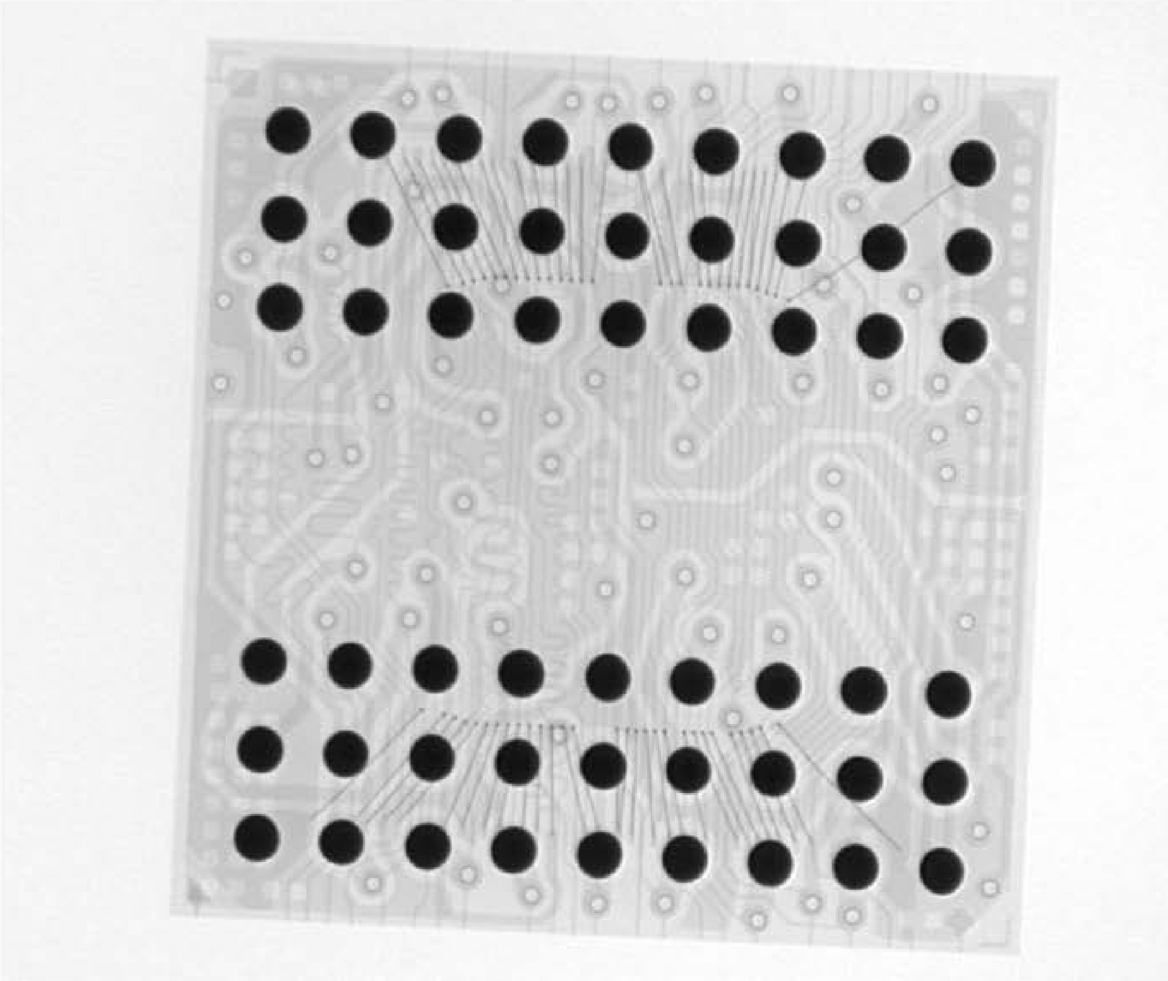
Reball #	SN		Nickel µm			Intermetallic µm			Shear test grams			Copper µm	
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
0	13	5.78	6.27	6.85		1.166		537.42	579.73	620.38			
4	16 & 17	5.14	5.55	5.85	0.273	0.41	0.554	478.42	505.43	515.43	12.18	13.45	13.95
5	21 & 22	4.14	4.43	4.73	0.198	0.38	0.629	492.64	512.97	537.09	13.18	13.68	14.54
6	26 & 27	6.27	6.61	6.86	0.223	0.44	0.6.4	483.58	510.03	539.8	14.31	14.77	15.31
7	31 & 32	5.14	5.62	5.91	0.24	0.48	0.752	507.11	510.34	515.31	13.06	14.31	15.25
8	36 & 37	4.14	4.43	4.73	0.347	0.44	0.521	503.93	514.56	533.11	13.18	13.68	14.54
9	41 & 42	2.6	2.98	3.37	0.347	0.48	0.653	490.46	502.85	512.2	13	13.93	15.01
10	46 & 47	3.96	4.34	4.79	0.298	0.49	0.984	492.09	502.22	515	13.54	14.63	15.55

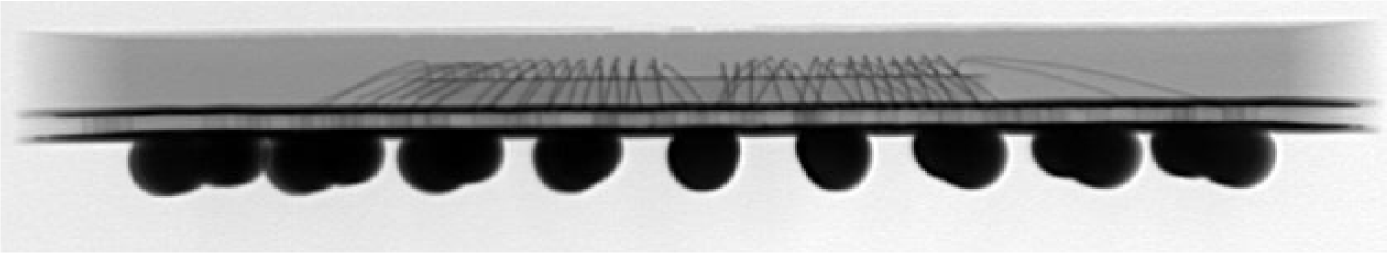
Radiograph Shows No Anomalies

Figure R-1

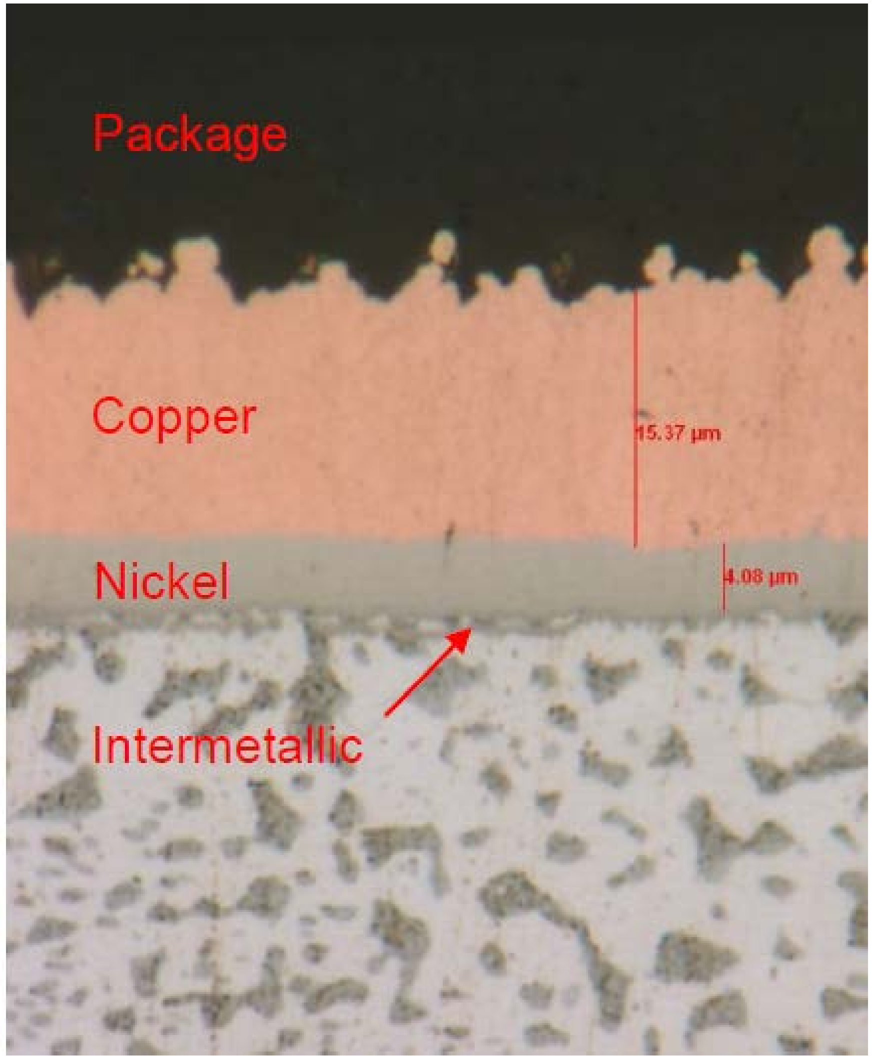
Radiograph of overall device, Y-axis.

MFG No.: 913-AS4C8M16S-6BIN: AS4C8M16S-6BIN
Date Code: 1417
S/N:9





Cross Section SN 47, Reballed 10 X

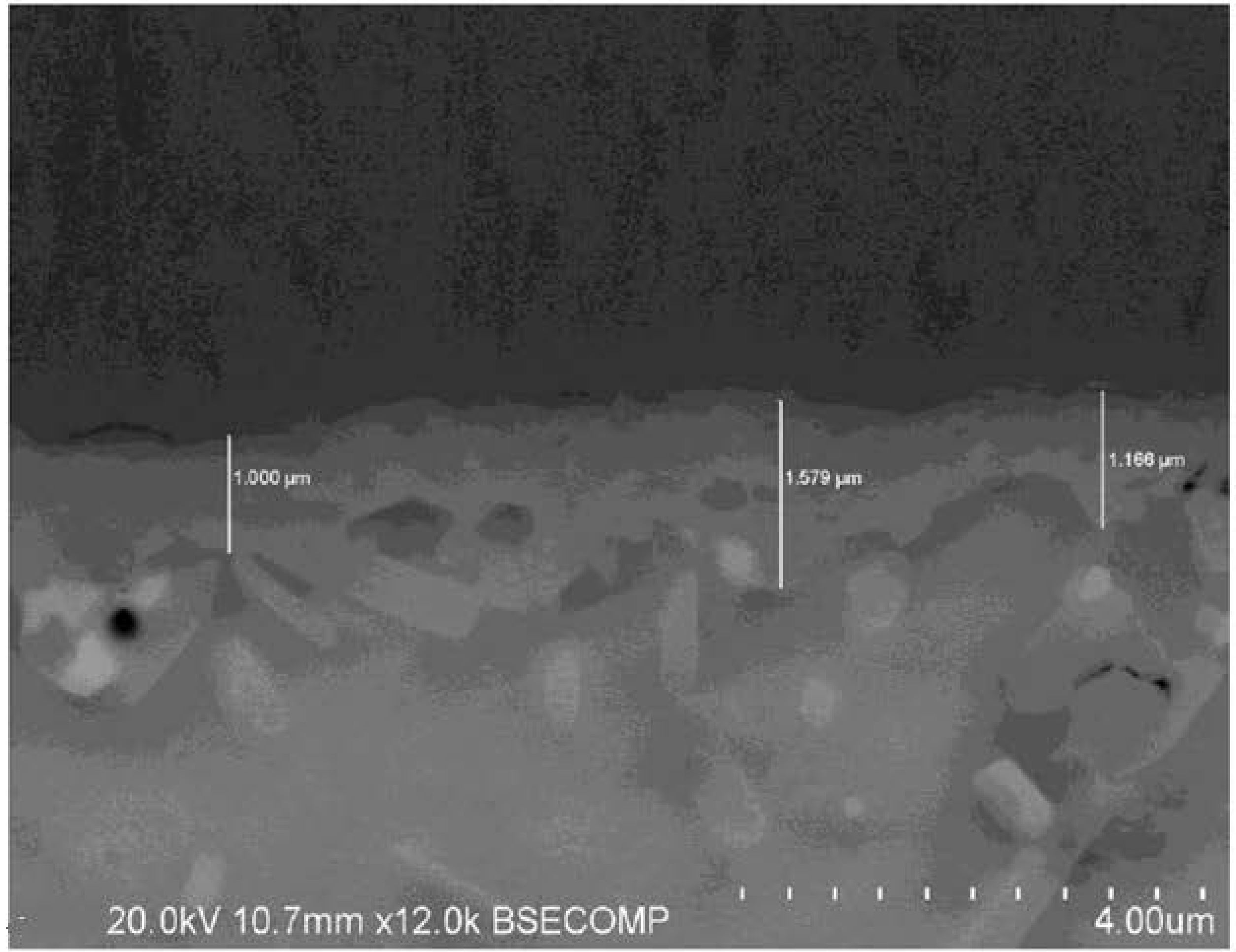


Intermetallic of Unprocessed SAC305 Part

Figure CS-9

BSE image of intermetallic after ion milling, 20kV, 12000X. (Note: Intermetallic thickness measurements)

MFG No.: 913-AS4C8M16S-6BIN: AS4C8M16S-6BIN
Date Code: 1417
S/N: 13



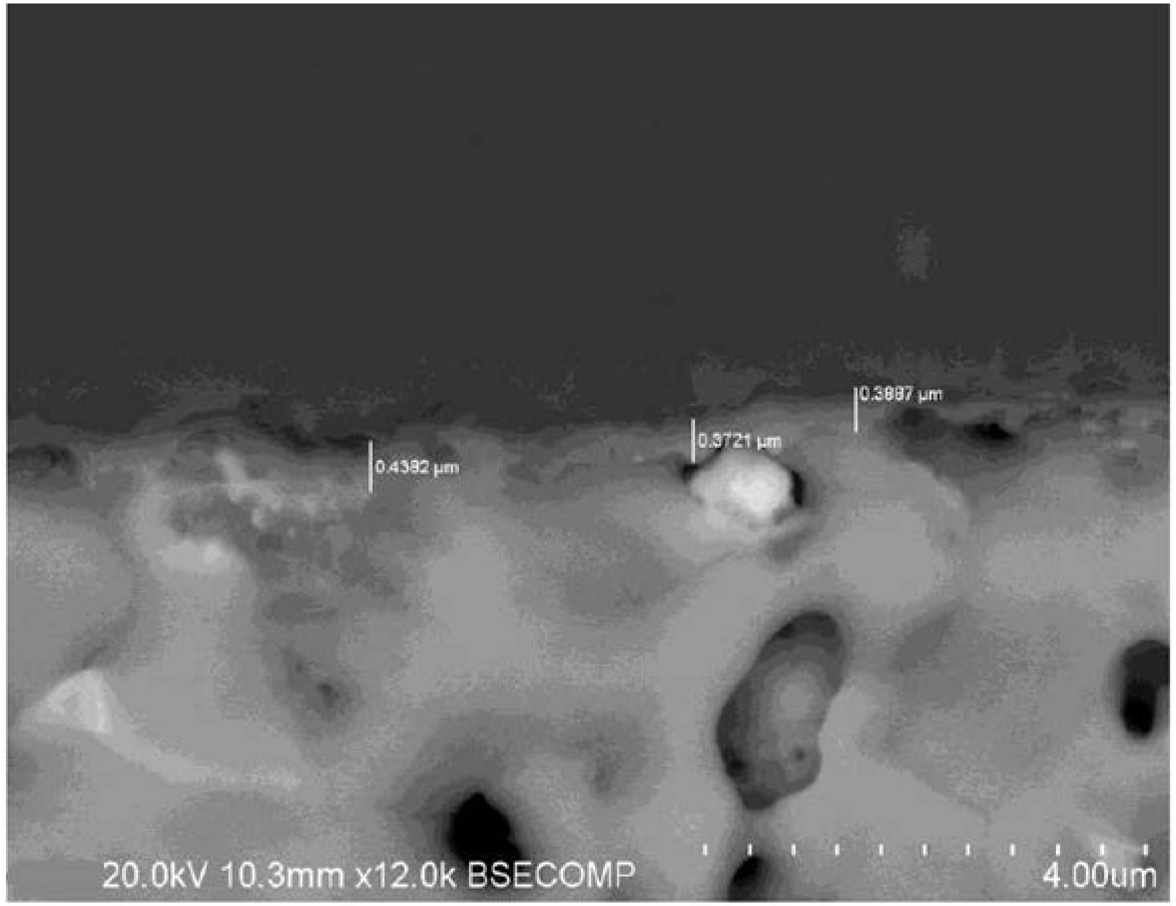
Intermetallic of 3X Reballed Sn63Pb37 part

Typically thinner but consistent layer. Intermetallic consistent throughout three reball cycles.

Figure CS-9

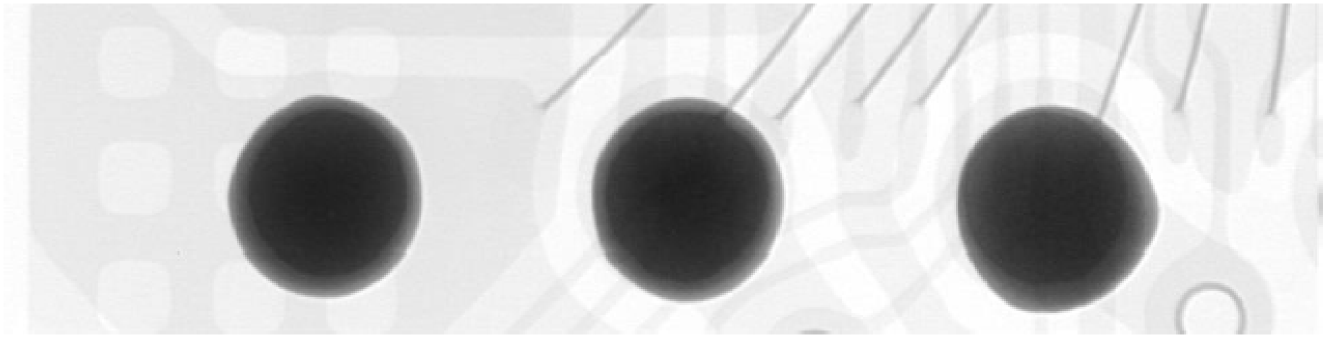
BSE image of intermetallic after ion milling, 20kV, 12000X. (Note: Intermetallic measurement thicknesses)

MFG No.: 913-AS4C8M16S-6BIN: AS4C8M16S-6BIN
Date Code: 1417
S/N: 11



X-Ray Inspection (for voids) per IPC-7095

- Representative picture of all three sets of reballed samples. No Voids Detected.



X-Ray Fluorescence for Composition per JESD213

Form #F051 Rev A/2

Data File: SPACE TEST
Comments: AS4C8M16S

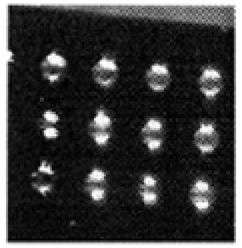
XRAY

Product: 3 / *SnPb/Cu
Application: 3 / *SnPb/Cu

Calibration: Standard free

n=	1	Sn 1 =	66.8 %	Pb 1 =	33.2 %
n=	2	Sn 1 =	65.3 %	Pb 1 =	34.7 %
n=	3	Sn 1 =	65.5 %	Pb 1 =	34.5 %
n=	4	Sn 1 =	67.8 %	Pb 1 =	32.2 %
n=	5	Sn 1 =	64.8 %	Pb 1 =	35.2 %
n=	6	Sn 1 =	65.6 %	Pb 1 =	34.4 %

Operator: CSD SPACE TEST AS4C8M16S
Date: 3/19/2015 Time: 3:23:47 PM

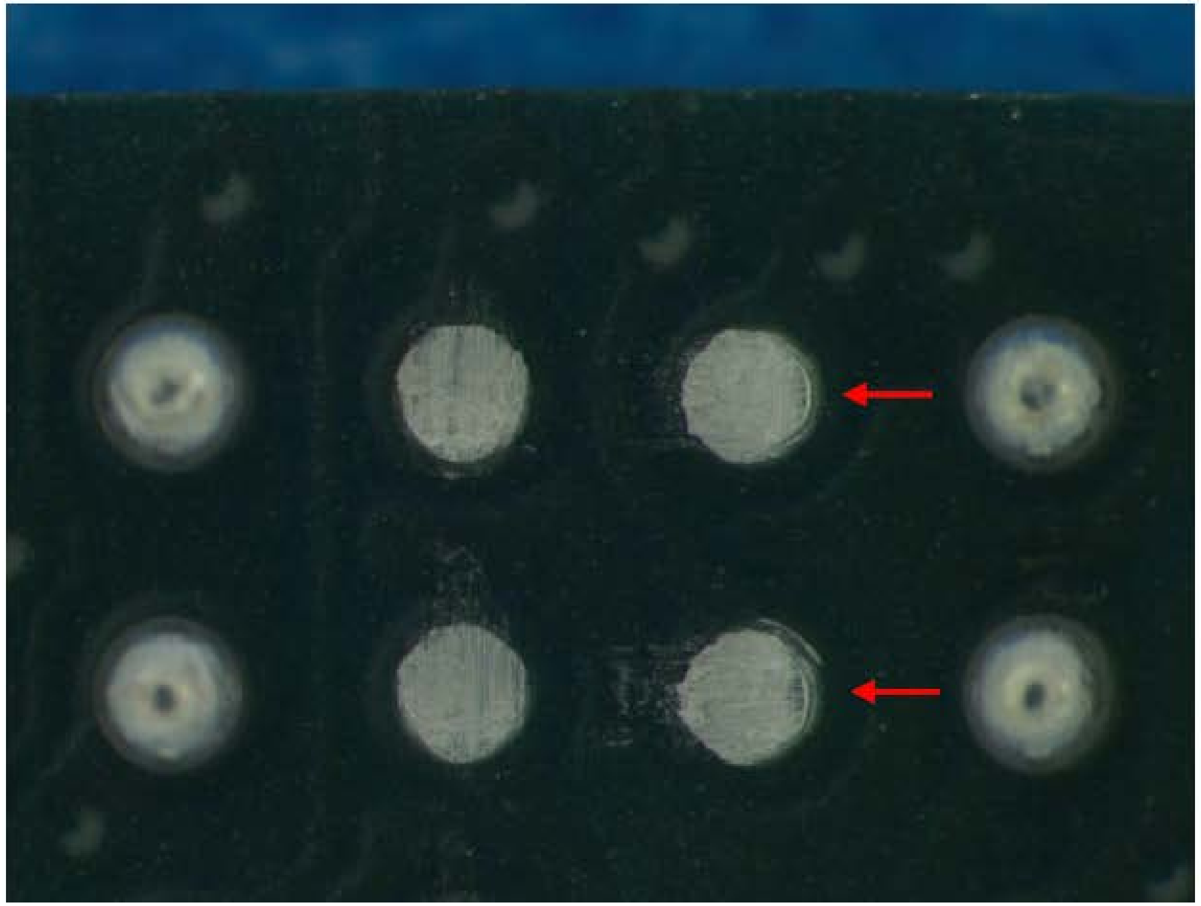


Ball Shear Test to JESD22-B117

Figure BS-4

Optical image of representative ball shears (ductile), 32X.

MFG No.: 913-AS4C8M16S-6BIN: AS4C8M16S-6BIN
Date Code: 1417
S/N: 10



All Shear Test Results Ductile (Required Result)

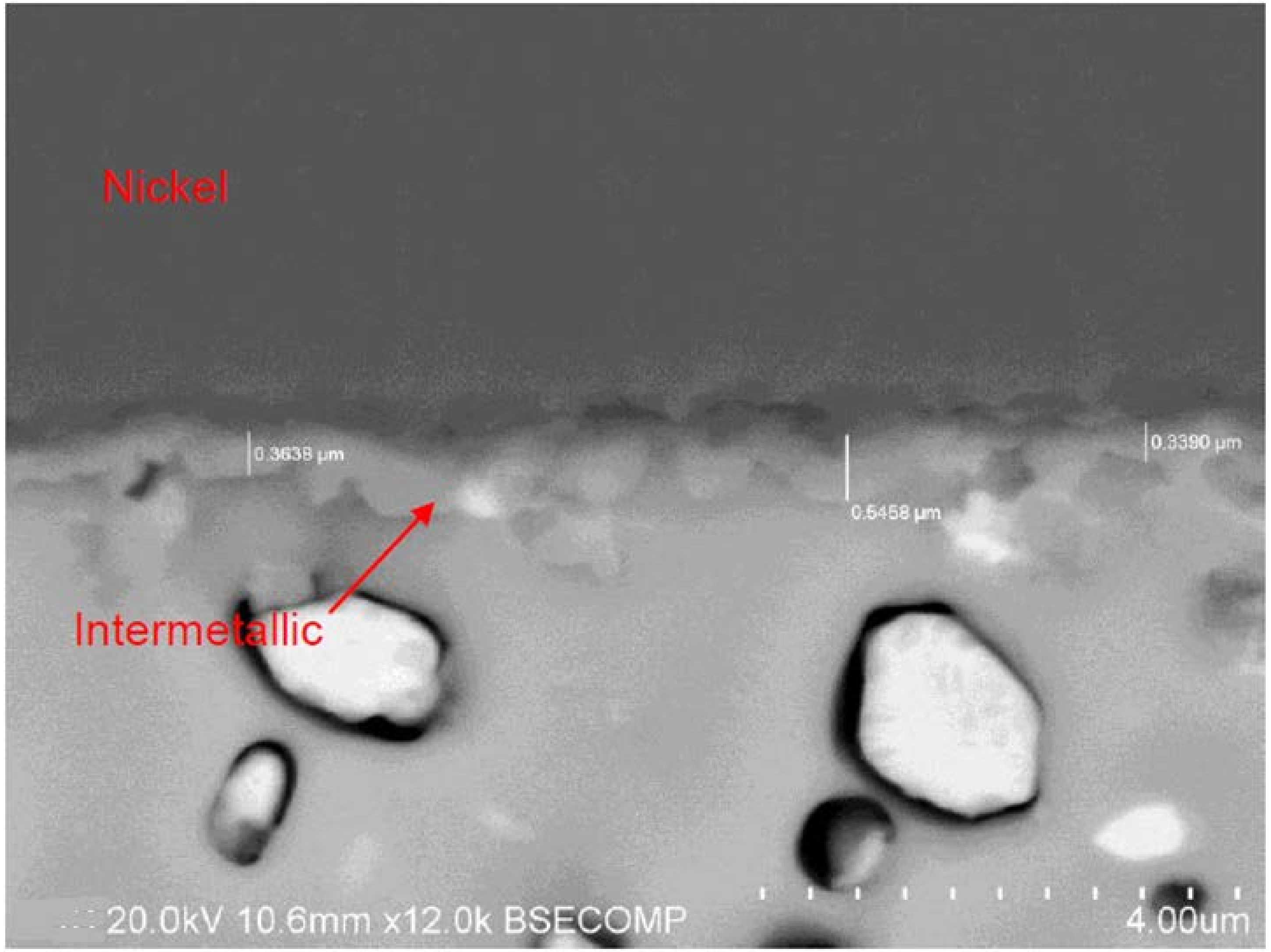
Summary

- Reballing can eliminate the reliability risks of Pb-free solder joints without introducing new risks.
- The refreshed component can be successfully mounted on SnPb compatible assemblies with assured long-term high-reliability.
- Industry adoption of a procedure like IEC/TS 62647-4 will provide a safe and effective reballing solution with appropriate verification protocol.
- BGAs may be reballed as many as ten times through a controlled reballing process and remain viable.

Appendix

- Extra slides of cross sections

A Closer View



Similar Thickness Intermetallic Measurement of Successfully Tested Parts During TMTI

(Transformational Manufacturing Technology Initiative)