iNEMI

International Electronics Manufacturing Initiative

The Pb-Free BGAs in SnPb Assembly Process Project (*The Backward Assembly Process*)

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IPC/APEX 2008
April 1, 2008

Advancing manufacturing technology

Acknowledgement

Agilent Technologies

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OUTLINE

- Project Scope/Motivation
- Overview of Project Objectives
- Experimental design
- Results
- Summary

PROJECT MOTIVATION

- **The coming into effect of the European Union (EU) directive on Reduction of Hazardous Substances (*RoHS*)**
  - **Created supply chain constraints on SnPb components availability especially for the RoHS exempted sector of the industry**
  - **Has created the need for soldering Pb-free SnAgCu BGA solder ball terminations in a Sn-Pb soldering process without yield loss or reliability impact**

BACKGROUND INFORMATION

- **Reflow process challenges when assembling SAC BGA under the** temperature constraints of a conventional **SnPb assembly process:**
  - **Peak Temperature has to be within the SnPb assembly process (range: 205 through 215C – solder joint temperature)**
  - **Time above liquidus has to be in the range 45-90 seconds**
  - **Mix of different component sizes (pitch) in a typical assembly**
    - **This may result in Ball Collapse issues**
  - **Non-mixing of the SAC solder balls and SnPb solder paste alloys at the typical SnPb reflow processing conditions (Non-uniform microstructure) may lead to lower solder joint reliability**

Overview of the Project Phases

- **Phase 1:**

  To assess the process parameters for assembling Pb-free SnAgCu BGAs under the temperature constraints of a conventional tin-lead (SnPb) assembly process

  - **(A quick overview of *The Backward Assembly Process Challenges*)**

    1) **Studied several Peak reflow temperatures, 205, 210, 215, 220 and 225C**
    2) **Stencil, 6mil thick and with 10% reduction in stencil-to-pad opening**

- **Phase 2:**
  - **To Characterize microstructural homogeneity of lead-free BGAs in a SnPb process**
- **Phase 3:**
  - **To examine the solder joint reliability of Pb-free Sn-Ag-Cu Ball Grid Array (BGA) Components in Sn-Pb Assembly Process via accelerated thermal cycling test**
    - **ATC Profile: -40 to 125^{o}C (# of target cycles: 3500) testing**

Overview of the Project Phases

Phase 1:

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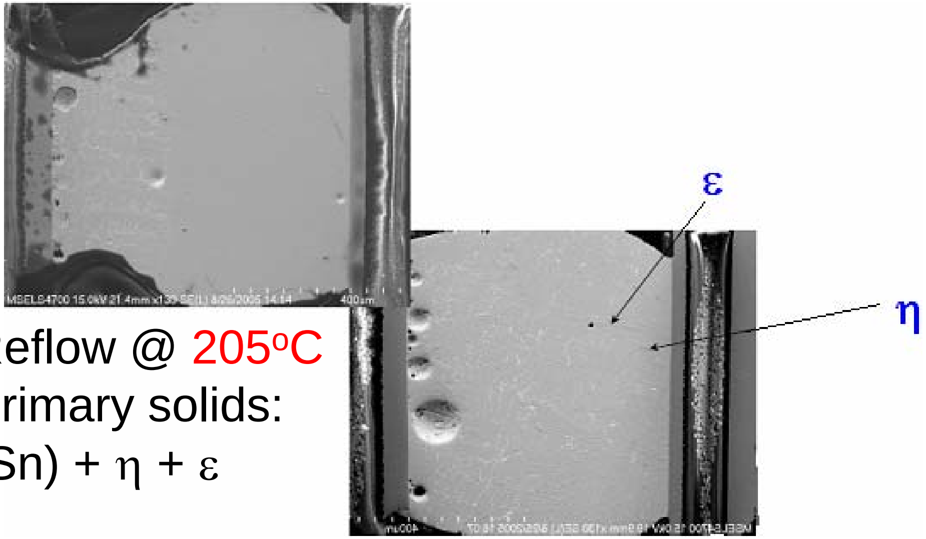
Impact of Peak temperature

Mixed Alloy Solder Joints for a PBGA313 package



Reflow @ 205^{o}C
Primary solids:
(Sn) + η + ε

Reflow @ 225^{o}C
Primary solid: η

<u>Observation</u>

•At the typical SnPb assembly process peak temperatures, we observe non-mixed solder joints which may lead to reduced solder joint reliability

Overview of the Project Phases

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    - (A quick overview of *The Backward Assembly Process Challenges*)
      1) Studied several Peak reflow temperatures, 205, 210, 215, 220 and 225C
      2) Stencil, 6mil thick and with 10% reduction in stencil-to-pad opening

- **Phase 2:**
  - **To Characterize microstructural homogeneity of lead-free BGAs in a SnPb process with the following considerations:**
      1) **Package size/ball volume, Four different Package sizes**
      2) **Reflow Temperature, 210 and 215C**
      3) **Time Above Liquidus, 60 ,90, and 120 seconds**
      4) **Solder paste volume, 10% reduction and 100%**

Overview of Phase II Assembly Matrix

Eight different assembly process flow were generated with FIVE different processing conditions of TALs and Peak Temperatures
Four different packages sizes, 45, 23, 19 and 8 mm^2

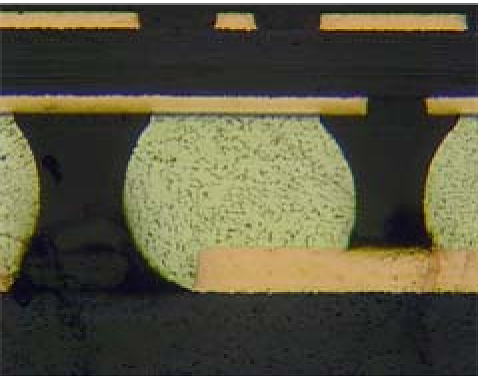
A total of fifteen boards were assembled for initial inspection and another set of Ninety Eight boards were assembled for Mechanical and ATC testing

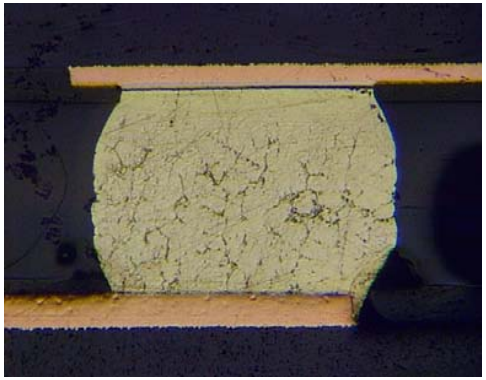
Assembly Process Flow	Reflow Profile Number	BGA Ball Alloy	Solder Paste Alloy	Peak Temp. (^{o}C)	Time Above Liquidus (sec)	Stencil Aperture Opening (%)
1 (Baseline)	1	SnPb	SnPb	210	60	90
2	1	SnAgCu	SnPb	210	60	90
3	2	SnAgCu	SnPb	210	90	90
4	3	SnAgCu	SnPb	210	120	90
5	1	SnAgCu	SnPb	210	60	100
6	2	SnAgCu	SnPb	210	90	100
7 (Baseline)	4	SnAgCu	SnAgCu	235	60	90
8	5	SnAgCu	SnPb	215	60	90

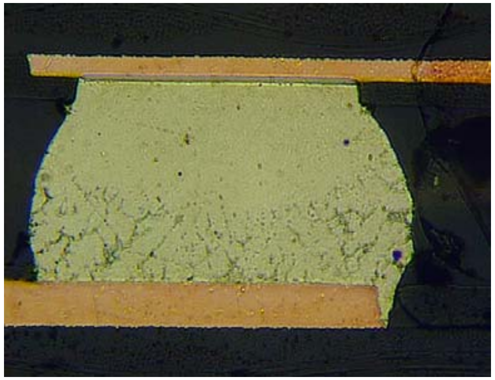
Overview of the Project Phases

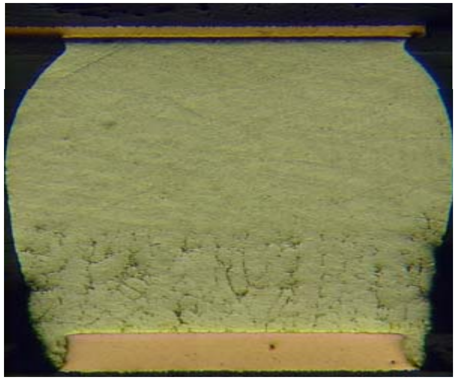
Effect of Package Size on the Solder Joint Microstructural Homogeneity @ Tpeak =210C & TAL = 60 secs

Increasing Package Size →


0.5mm
CTBGA132


0.8mm
CABGA288


1.0mm
PBGA324

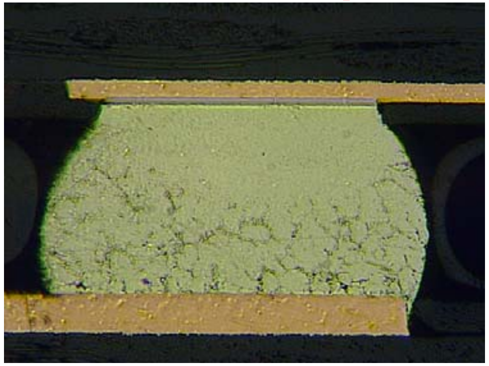

1.27mm
SBGA600

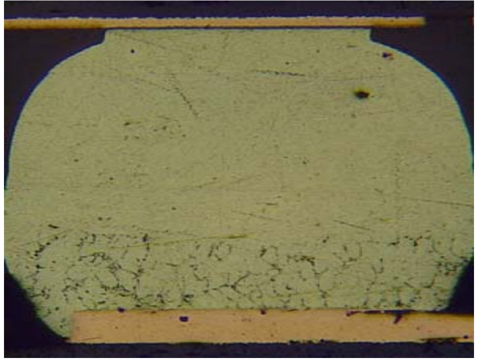
The degree of mixing decreases with increasing package (or solder ball volume) size

Overview of the Project Phases

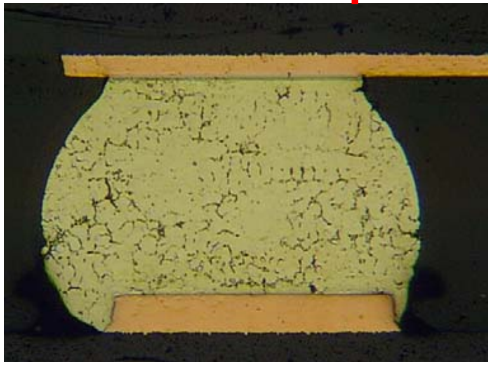
Effect of Peak Temperature on Degree of Mixing

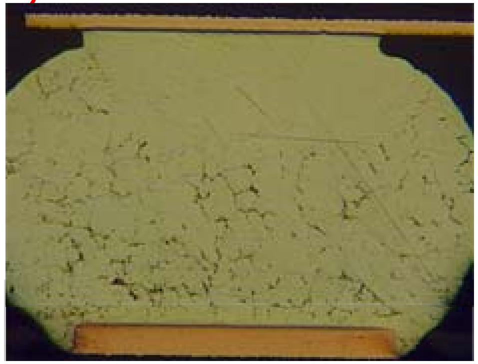
Tpeak = 210C, TAL = 60sec





Tpeak = 215C, TAL = 60sec





1.0mm
PBGA324

1.27mm
SBGA600

Increasing the peak temperature by 5^{o}C with TAL = 60 sec, leads to an increased degree of mixing for both PBGA324 and SBGA600

Overview of the Phase 2 Results

- The *larger the package/ball volume*, the lower the degree of mixing observed
  - CTBGA132 (0.5mm Pitch) showed a 100% mixing at 210^{o}C and 60sec time above liquidus

- *Doubling the time above liquidus* (from 60sec to 120sec), increased the degree of mixing (~30% increase in mixing was observed)

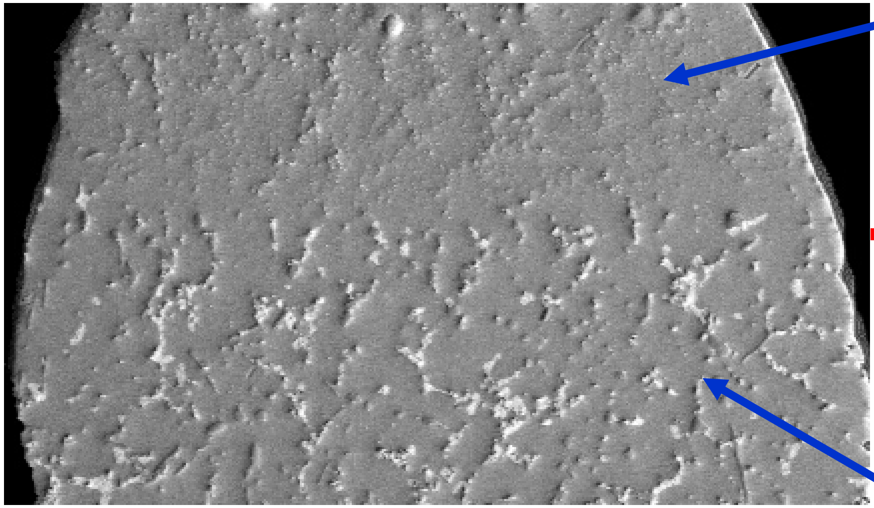
- For the small packages (reduced SAC solder ball volume), *increased paste volume* corresponds to increased degree of mixing
  - However, for the largest (SBGA600) package no significant change in mixing was observed

- *Increasing the peak temperature* from 210^{o}C to 215^{o}C led to a significant increase in the degree of mixing (almost doubled) the extent of mixing

Overview of the Phase 2 Results

Microstructural Morphology of a Mixed alloy Solder Joint reflowed at Low Peak Temperature

Package Side



Board Side

(Sn) + η + ε: starts to melt @ 217 ºC

non-melted SAC at low peak reflow

non melted SAC & partially melted (Sn) + (Pb) + ε

(Sn) + (Pb) + ε: starts to melt @ 177ºC

What is the impact of the segregated phases on the solder joint??

Overview of the Project Phases

- Phase 1:
  - To assess the process parameters for assembling Pb-free SnAgCu BGAs under the temperature constraints of a conventional tin-lead (SnPb) assembly process.
    1) Studied several Peak reflow temperatures, 205, 210, 215, 220 and 225C
- Phase 2:
  - To Characterize microstructural homogeneity of lead-free BGAs in a SnPb process with the following considerations:
    1) Package size/ball volume
    2) Reflow Temperature
    3) Time Above Liquidus
    4) Solder paste volume

How does each of the factors above affect the solder joint reliability (SJR) assembled in a backward reflow process?

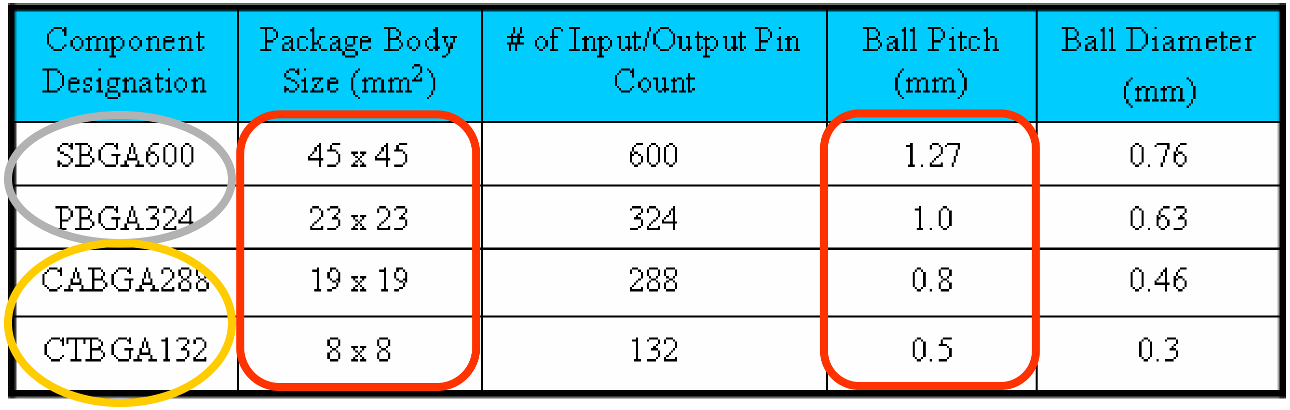
- **Phase 3:**
  - **To examine the solder joint reliability of Pb-free Sn-Ag-Cu Ball Grid Array (BGA) Components in Sn-Pb Assembly Process via accelerated thermal cycling test.**
    - **ATC Profile: -40 to 125°C (for 3500 cycles) testing**

EXPERIMENTAL

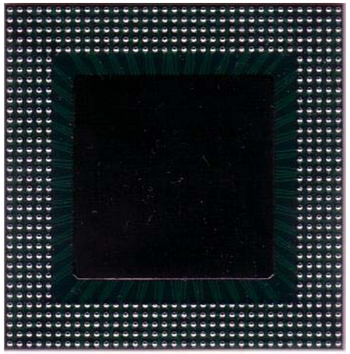
DESIGN

Overview of Components Characteristics

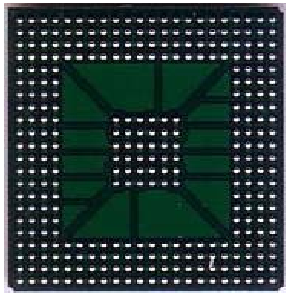
Four different package sizes (Pitch) were selected:



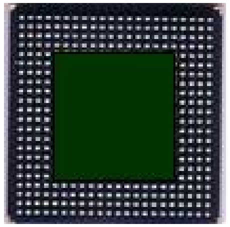
Component Designation	Package Body Size (mm^2)	# of Input/Output Pin Count	Ball Pitch (mm)	Ball Diameter (mm)
SBGA600	45 x 45	600	1.27	0.76
PBGA324	23 x 23	324	1.0	0.63
CABGA288	19 x 19	288	0.8	0.46
CTBGA132	8 x 8	132	0.5	0.3



SBGA600



PBGA324



CABGA288

CTBGA132

Note:

- **Pb-free BGA ball alloy: SAC405**
- **SnPb components of each type were used for baseline run**

Phase 3 Assembly test matrix for accelerated thermal cycle (ATC) test

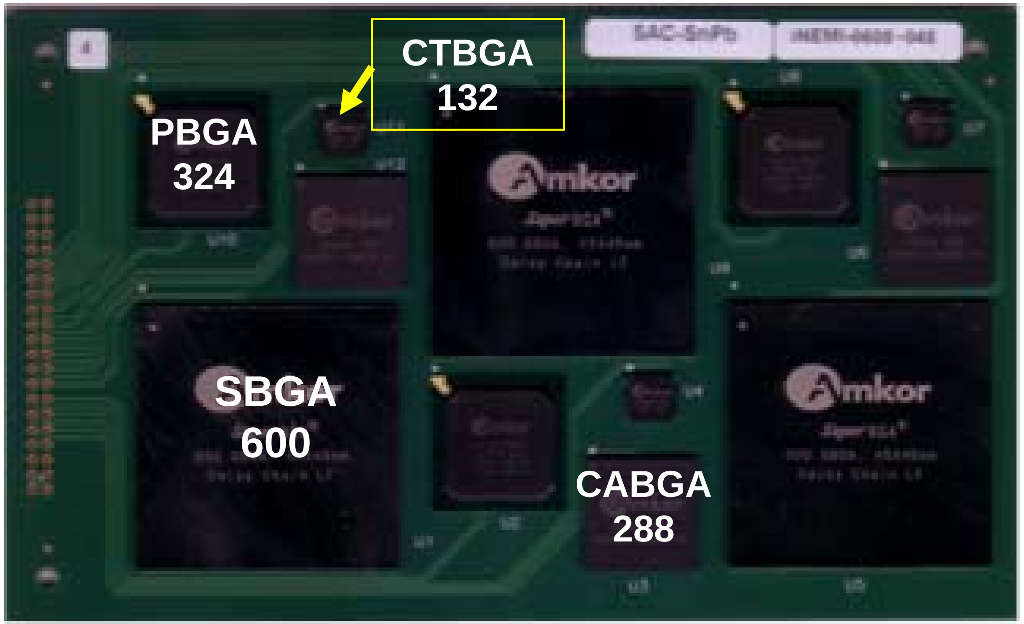
Eight different assembly process flow were generated with FIVE different processing conditions of TALs and Peak Temperatures

Assembly Process Flow	BGA Ball Alloy	Solder Paste Alloy	Peak Temp. (°C)	Time Above Liquidus (TAL) (seconds)	Stencil Aperture Opening (%)	Number of Boards for ATC Testing (Range: -40°C to 125°C)	
						ENIG	OSP
1(Control)	Sn-Pb	Sn-Pb	210	60	90	**3**	**6**
2	**Sn-Ag-Cu**	**Sn-Pb**	210	60	90	**0**	**6**
5	**Sn-Ag-Cu**	**Sn-Pb**	210	60	100	**3**	**6**
3	**Sn-Ag-Cu**	**Sn-Pb**	210	90	90	**0**	**6**
6	**Sn-Ag-Cu**	**Sn-Pb**	210	90	100	**0**	**6**
4	**Sn-Ag-Cu**	**Sn-Pb**	210	120	90	**3**	**6**
7(Control)	Sn-Ag-Cu	Sn-Ag-Cu	235	60	90	**0**	**6**
8	**Sn-Ag-Cu**	**Sn-Pb**	215	60	90	**0**	**3**
						9	**45**

Populated Test Vehicle

- **PCB Dimensions:**
  - **–6.800” x 4.075” x 0.093”**
- **Finish**
  - **–Electroless Nickel Immersion Gold (ENiG)**
  - **–Copper OSP**
- **Number of Layers**
  - **–8 Internal board Layers**

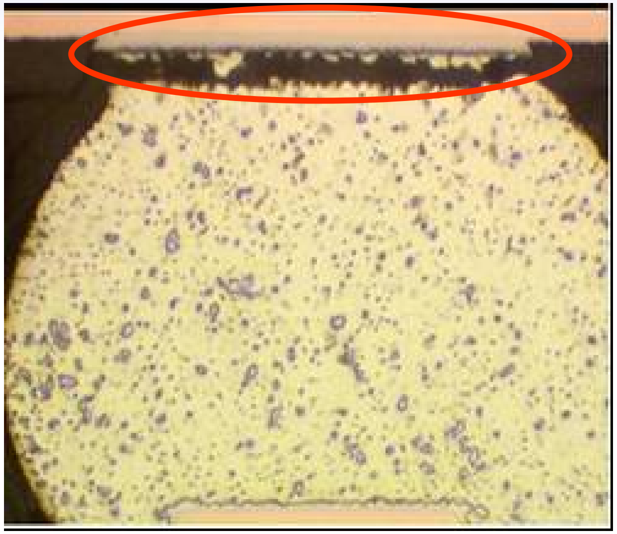
  - **–Tg = 170^{o}C**
  - **–Td = 340^{o}C**



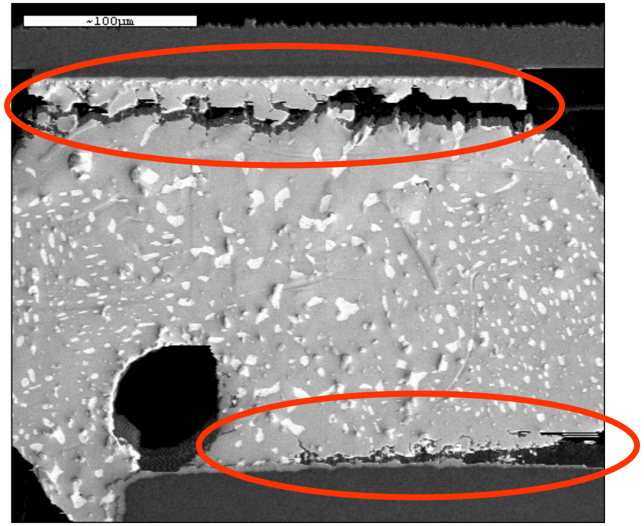
Test vehicle populated with three of each of the four types of components used

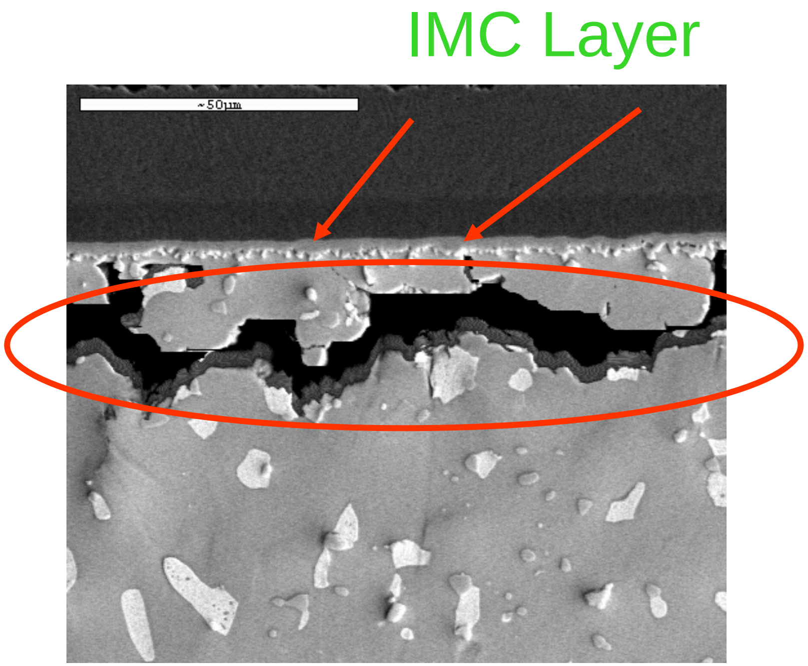
Solder Joint Reliability (SJR) Results

Solder Joint Observed failure Modes



Optical & SEM images showing the most commonly observed failure mode for the CTBGA132 package

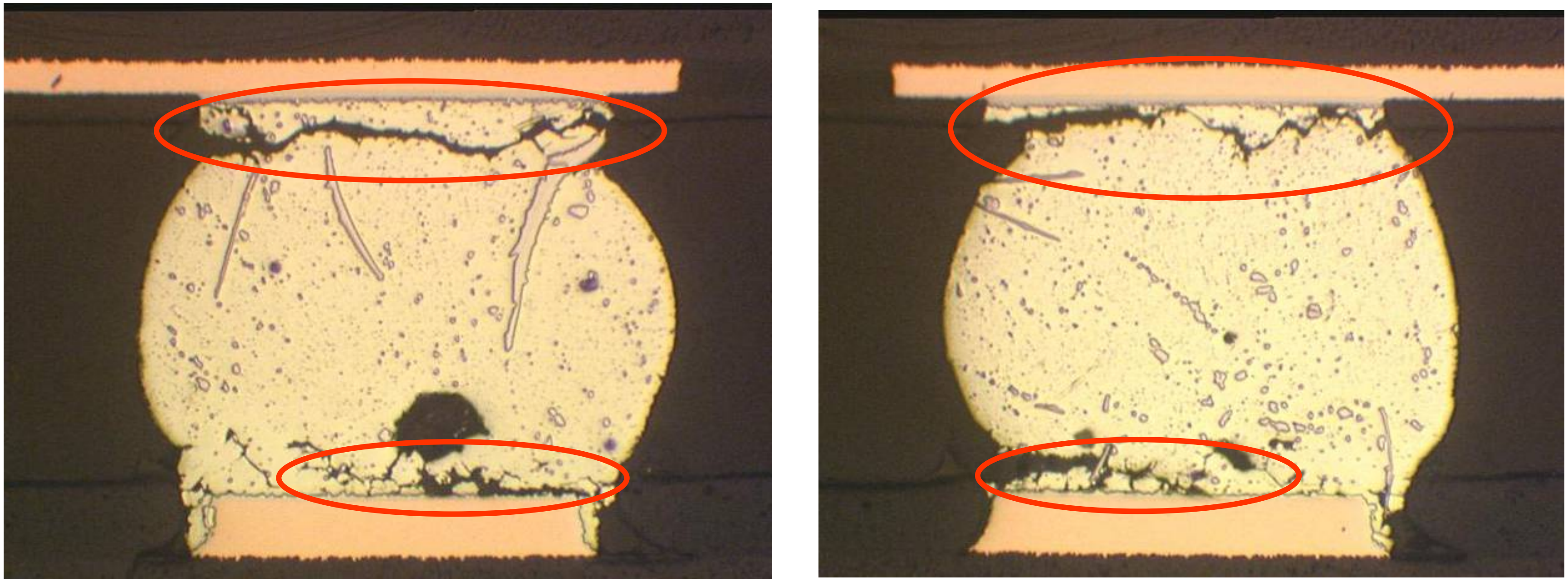




The solder joints are completely open on the package side while the crack is only partial on the package side

Solder Joint Observed failure Modes

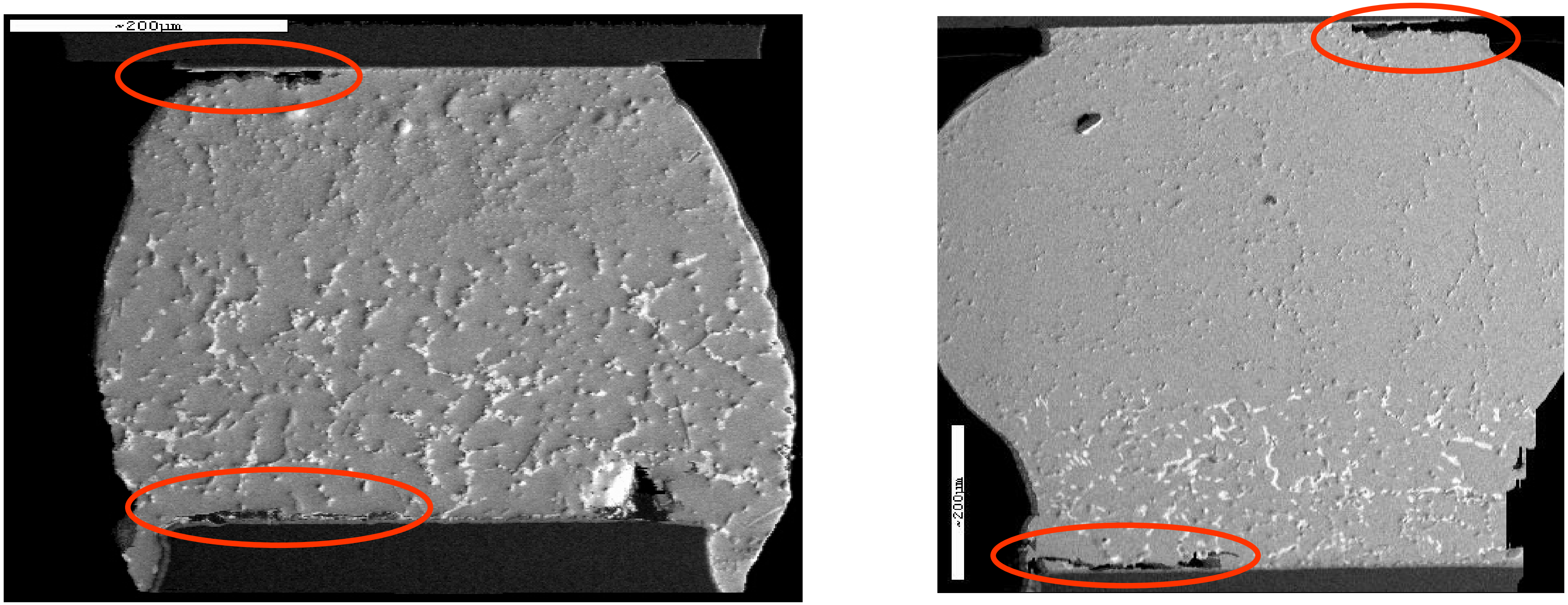
Optical images showing the most commonly observed failure mode for the CABGA288 package



The solder joints are completely open on the package side while the crack is only partial on the package side

Solder Joint Observed failure Modes

SEM images showing the most commonly observed joint fractures on the PBGA324 and SBGA6000 packages



These fractures could not be confirmed by electrical testing during thermal cycling

Electrical Testing Results at the End of ATC Test

A summary of Number of Failed Packages at the end of 3559 Cycles

Decreasing Package Size

	Number of Failed Packages After 3559 ATC testing Cycles										
PCB Finish	OSP	ENIG	OSP	OSP	OSP	ENIG	OSP	ENIG	OSP	OSP	OSP
Assembly Process Flow	1A	1B	2	3	4A	4B	5A	5B	6	7	8
SBGA600	**1/18**	9/9	**0/18**	**0/18**	**0/18**	**0/9**	**0/18**	**0/9**	**0/18**	**4/18**	**0/18**
PBGA324	**0/18**	9/9	**0/18**	**0/18**	**0/18**	**0/9**	**0/18**	**0/9**	**0/18**	**17/18**	**0/18**
CABGA288	18/18	9/9	18/18	18/18	18/18	9/9	18/18	9/9	18/18	18/18	**0**
CTBGA132	18/18	9/9	18/18	18/18	18/18	9/9	18/18	9/9	9/9	18/18	**0**

NOTABLE OBSERVATIONS:

1) **All the standard and mixed alloy CTBGA132 and CABGA288 packages failed at the end of the ATC testing**

2) **All mixed alloy, SBGA600 and PBGA324 packages survived at the end of ATC testing**

SUMMARY OF OBSERVATIONS

- The CTBGA132 and the CABGA288 packages showed a significant number of failures across all of the assembly test conditions, while no failures were recorded for the PBGA324 and SBGA600 packages for the mixed alloy assemblies
- The following conclusions are drawn from this work:
  - For the smallest, CTBGA132 package, all three TAL conditions had full solder alloys mixing
    - The solder joint reliability of the fully mixed test assemblies for all TALs (= 60, 90, and 120 seconds) exceeds that of Sn-Pb and is at least equal to that of pure SAC
  - For the larger, CABGA288 package, increasing the TAL does not provide complete solder alloy mixing
    - The solder joint reliability of all TALs tested (TAL = 60, 90, and 120 seconds) is less than that of both pure Sn-Pb and pure SAC
    - The longest TAL condition displayed a better solder joint reliability among the three TAL conditions

SUMMARY OF OBSERVATIONS

- **For the two largest packages, PBGA324 and SBGA600, despite lack of complete solder alloy mixing, the solder joint reliability was better than that of either “pure” Sn-Pb or “pure” SAC solder joints**

- **Full Sn-Pb and SAC solder alloys mixing is not a sufficient condition to guarantee good reliability**
  - **For *small packages* with *low fatigue life requirements*, *full solder alloys mixing* and *homogeneous microstructure* is required**
    - **while for large packages with long fatigue/extended life requirement, full solder alloy mixing is not necessary for acceptable solder joint reliability**

- **In general, the OSP-copper had better performance than the ENIG surface finish. However, the failure locations were almost exclusively at the package side of the solder joint and within the bulk solder**
  - **At this time no microstructural correlation has been identified linking surface finish and improved or reduced reliability**

Thank You

Questions