Mixing Metallurgy: Reliability of SAC Balled Area Array Packages Assembled Using SnPb Solder

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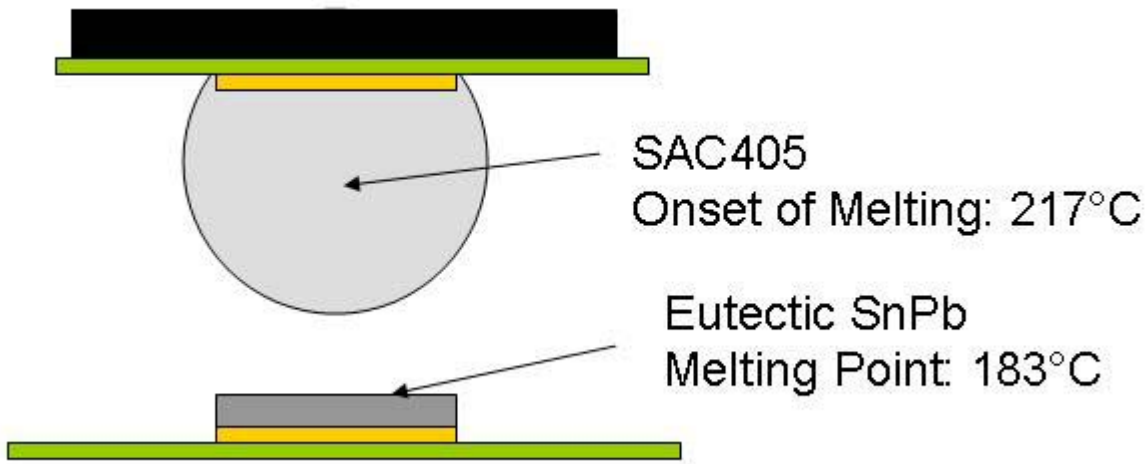
Why Mixed Assembly?

- Some BGA components are not available in SnPb versions
  - Some new components never issued in an SnPb version
  - Some existing components' SnPb versions phased out
- Not all OEMs with RoHS exemptions ready to convert to lead free
- Need to find a way to integrate SAC balled components into SnPb assemblies

Mixing Process

- Before Reflow



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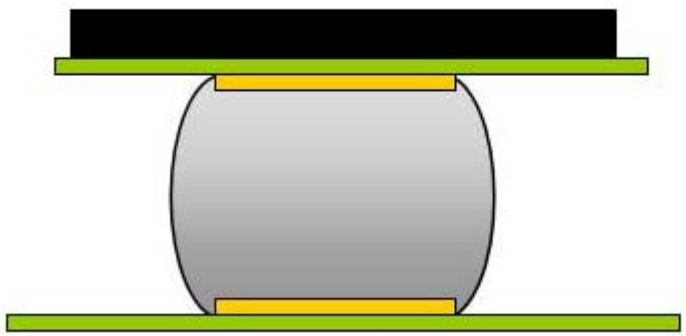
Mixing Process

- During Reflow
  - SnPb paste fully reflows as normal
  - SAC ball begins to dissolve into molten SnPb paste during time above liquidus



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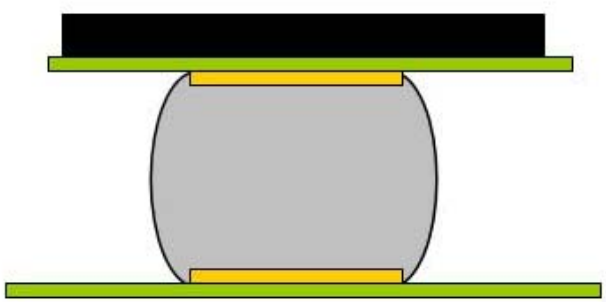
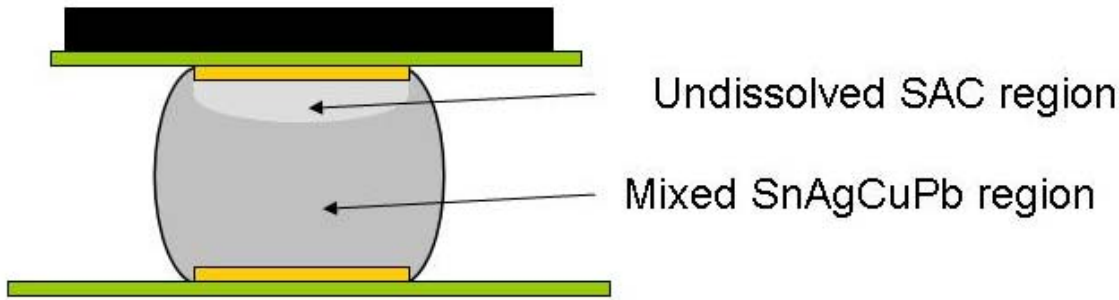
Mixing Process

- After Reflow
  - Depending on conditions, the final joint may mix completely, or may have a fully mixed portion and an undissolved SAC portion



Fully Mixed Joint



Partially Mixed Joint

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Previous Work

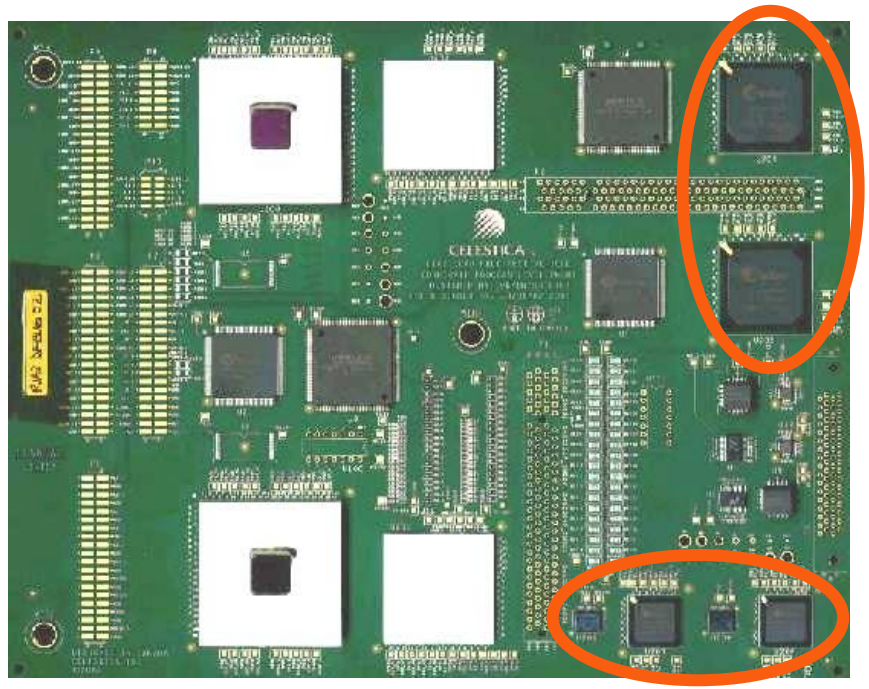
- Previous project on mixed assembly indicated good reliability for components with peak reflow temperatures of 215°C and 220°C
- This target reflow temperature was measured on CBGA component, so smaller components were hotter
- This implies using a hotter than normal profile to achieve these results
- Many tin/lead assemblies cannot be reflowed at hotter temperatures due to restrictions on the temperature of other components

Test Plan

- Phase One
  - Assemble cards using a range of reflow profiles
    - Three peak temperatures
    - Vary time above liquidus
    - BGAs with SAC405 balls or SAC305 balls
    - Perform Time Zero Analysis for degree of mixing
    - Select one profile for each peak temperature for use in Phase Two
- Phase Two
  - Assemble cards using reflow profiles selected in Phase One
    - Perform Time Zero Analysis for degree of mixing and microstructure
    - Perform ATC to determine the reliability of the assemblies

Test Vehicle – Phase One

- “RIA2” Test Vehicle
  - Represents a mid-complexity assembly representative of Telecom or Server application
  - 8” x 10”, 0.093” Thick
  - ImmAg Surface Finish for this project
- Three BGA types populated for this study



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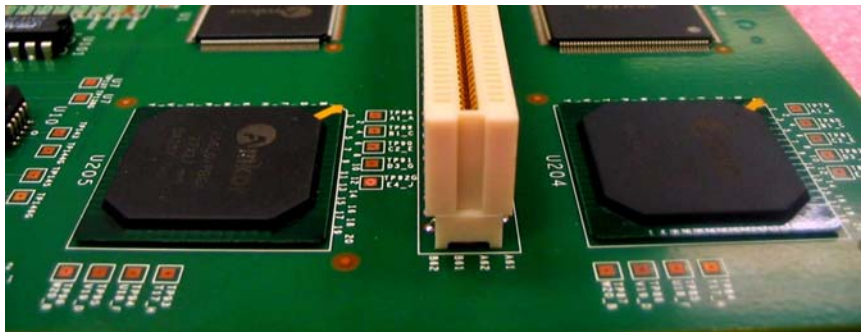
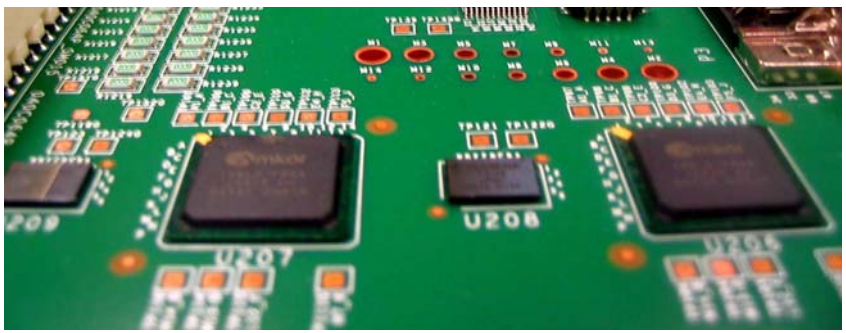
Components – Phase One



- Three Components Selected
  - PBGA256
  - PBGA196
  - CSP46



Component	Pitch	Alloy	Ball Diameter
PBGA256	1.27 mm	SAC 305	0.75 mm
PBGA256	1.27 mm	SAC 405	0.75 mm
PBGA196	1.00 mm	SAC 305	0.60 mm
PBGA196	1.00 mm	SAC 405	0.50 mm
CSP46	0.75 mm	SAC 305	0.30 mm
CSP46	0.75 mm	SAC 405	0.35 mm

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Target Profiles – Phase One

Profile Number	Target Peak Temperature	Target Time above 183°C
1	205°C	100s
2	205°C	120s
3	210°C	60s
4	210°C	80s
5	210°C	120s
6	215°C	70s
7	215°C	100s

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Results – Phase One

Effect of Component Type

		Mixing %						
		205C°		210C°			215C°	
		100s	120s	60s	80s	100s	60s	100s
SAC305	PBGA	30	30	40	60	60	70	90
	µBGA	50	50	50	60	60	70	100
	CSP	100	100	100	100	100	100	100
SAC405	PBGA	40	50	60	60	60	60	90
	µBGA	60	75	70	70	85	80	100
	CSP	100	100	100	100	100	100	100

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Results – Phase One

Effect of Peak Temperature and Time Above Liquidus

		Mixing %						
		205C°		210C°			215C°	
		100s	120s	60s	80s	100s	60s	100s
SAC305	PBGA	30	30	40	60	60	70	90
	µBGA	50	50	50	60	60	70	100
	CSP	100	100	100	100	100	100	100
SAC405	PBGA	40	50	60	60	60	60	90
	µBGA	60	75	70	70	85	80	100
	CSP	100	100	100	100	100	100	100

Results – Phase One

Effect of Ball Alloy

		Mixing %						
		205C°		210C°			215C°	
		100s	120s	60s	80s	100s	60s	100s
SAC305	PBGA	30	30	40	60	60	70	90
	µBGA	50	50	50	60	60	70	100
	CSP	100	100	100	100	100	100	100
SAC405	PBGA	40	50	60	60	60	60	90
	µBGA	60	75	70	70	85	80	100
	CSP	100	100	100	100	100	100	100

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Profiles Selected for Phase Two

- Peak Temperature – 205°C
  Time Above Liquidus – 120 seconds
- Peak Temperature - 210°C
  Time Above Liquidus – 80 seconds
- Peak Temperature - 215°C
  Time Above Liquidus – 100 seconds

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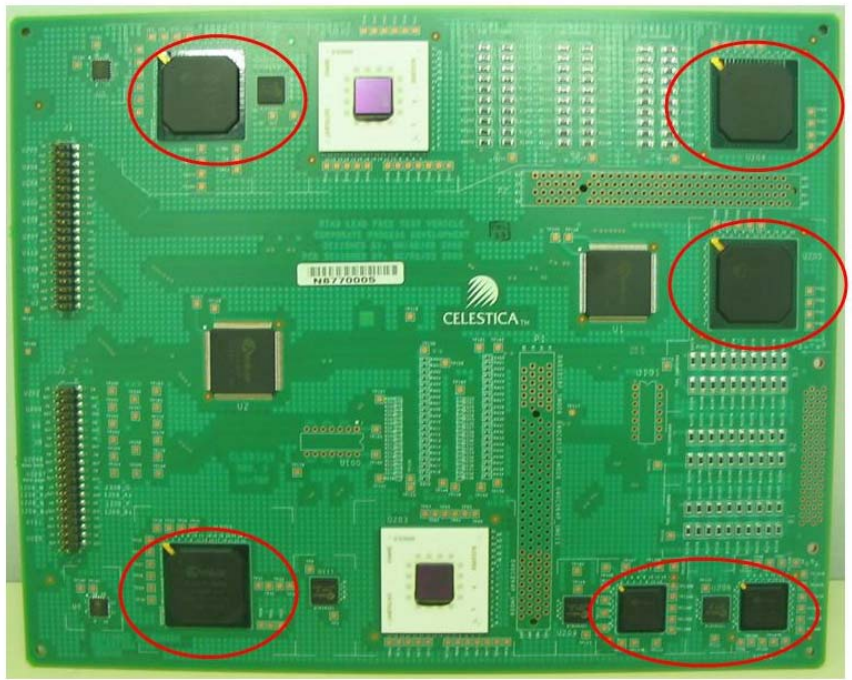
Test Vehicle – Phase Two

- "RIA3" Test Vehicle
  - Evolution of RIA2 design
  - 8" x 10", 0.093" Thick
  - OSP Surface Finish for this Study
- Four BGA Components Populated for this Study



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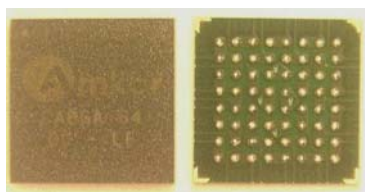
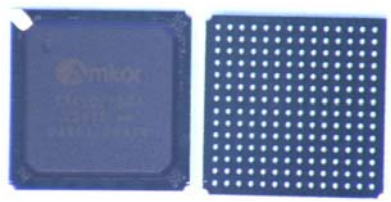
Components – Phase Two

- Four Components Selected
  - PBGA676
  - PBGA256
  - PBGA196
  - CSP64

Component	Pitch	Alloy	Ball Diameter
PBGA676	1.00 mm	SAC 305	0.63 mm
PBGA676	1.00 mm	SAC 405	0.63 mm
PBGA256	1.27 mm	SAC 305	0.75 mm
PBGA256	1.27 mm	SAC 405	0.75 mm
PBGA196	1.00 mm	SAC 305	0.50 mm
PBGA196	1.00 mm	SAC 405	0.50 mm
CSP64	0.75 mm	SAC 305	0.46 mm
CSP64	0.75 mm	SAC 405	0.46 mm





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Results – Phase Two

Degree of Mixing – Effect of Component Type

Cell #	Peak Temp.	Component Alloy	Degree of mixing (%)				
			PBGA676 U201	PBGA 256 U204 1st row	PBGA 256 U204 4th row	PBGA 196 U206	CSP 64 U208
1-1	205°C	SAC305	45-75	70-85	80-90	50-80	80-90
1-2	205°C	SAC405	40-50	60-70	60-80	60	60-70
1-3	210°C	SAC305	30-50	35-40	30	60	65-70
1-4	210°C	SAC405	40-50	40	40-50	50	60
1-5	215°C	SAC305	60-95	100	90-100	100	100
1-6	215°C	SAC405	70-100	100	90-100	100	100

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Results – Phase Two

Degree of Mixing – Effect of Peak Temperature

Cell #	Peak Temp.	Component Alloy	Degree of mixing (%)				
			PBGA676 U201	PBGA 256 U204 1st row	PBGA 256 U204 4th row	PBGA 196 U206	CSP 64 U208
1-1	205°C	SAC305	45-75	70-85	80-90	50-80	80-90
1-2	205°C	SAC405	40-50	60-70	60-80	60	60-70
★ 1-3	210°C	SAC305	30-50	35-40	30	60	65-70
★ 1-4	210°C	SAC405	40-50	40	40-50	50	60
1-5	215°C	SAC305	60-95	100	90-100	100	100
1-6	215°C	SAC405	70-100	100	90-100	100	100

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Results – Phase Two

Degree of Mixing – Effect of Ball Alloy

Cell #	Peak Temp.	Component Alloy	Degree of mixing (%)				
			PBGA676 U201	PBGA 256 U204 1st row	PBGA 256 U204 4th row	PBGA 196 U206	CSP 64 U208
1-1	205°C	SAC305	45-75	70-85	80-90	50-80	80-90
1-2	205°C	SAC405	40-50	60-70	60-80	60	60-70
1-3	210°C	SAC305	30-50	35-40	30	60	65-70
1-4	210°C	SAC405	40-50	40	40-50	50	60
1-5	215°C	SAC305	60-95	100	90-100	100	100
1-6	215°C	SAC405	70-100	100	90-100	100	100

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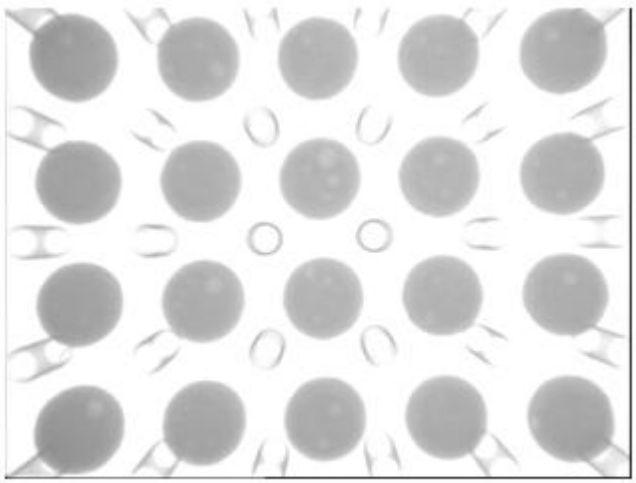
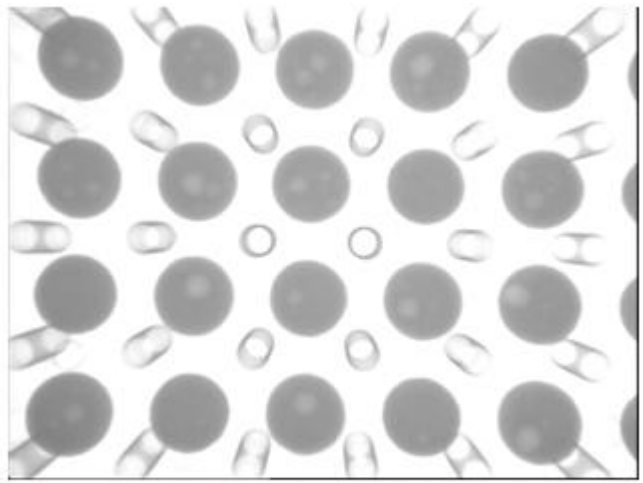
Results – Phase Two

X-Ray Inspection

- No Assembly Defects Found
- Some voiding observed on all samples, although within acceptable levels



1-5, U201, SAC305 ball, 215C



1-6, U201, SAC405 ball, 215C

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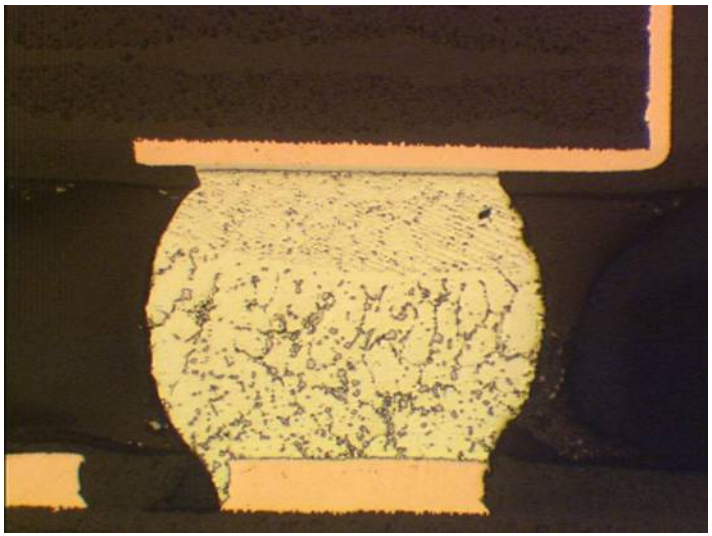
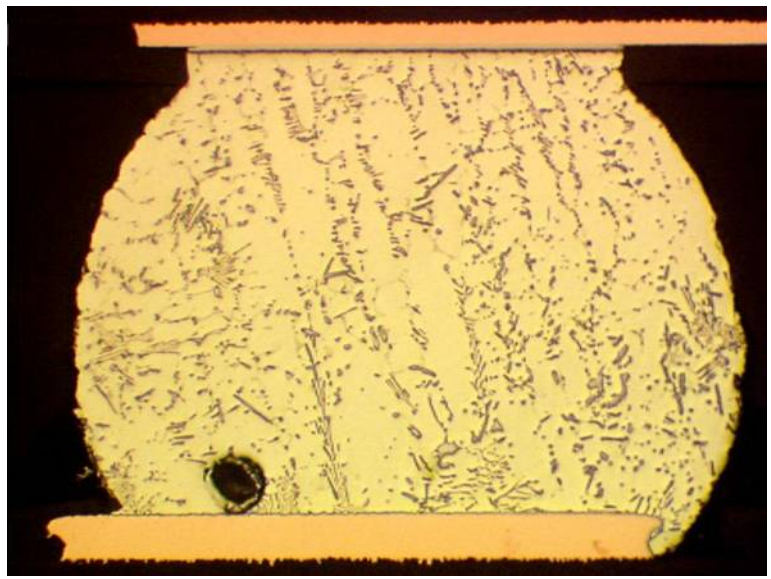
Results – Phase Two

Metallurgy - Overall



CSP64 Joint Formed from SAC405
Ball and SnPb paste at 205°C



PBGA256 Joint Formed from SAC305
Ball and SnPb paste at 215°C

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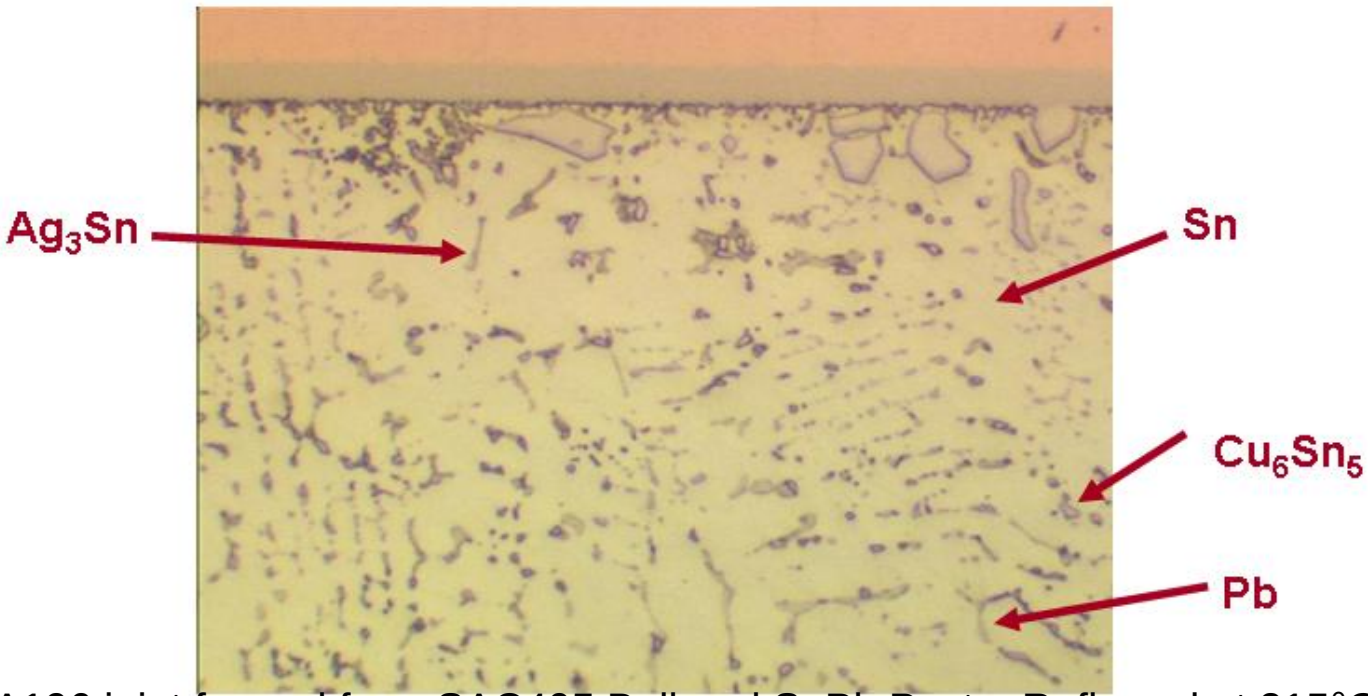
Results – Phase Two

Metallurgy – joint microstructure consists of:

- Primary Sn Dendrites
- Ternary Sn-Pb-Ag_3Sn eutectic
- Quaternary Sn-Pb-Ag_3Sn-Cu_6Sn_5 eutectic



PBGA196 joint formed from SAC405 Ball and SnPb Paste, Reflowed at 215°C

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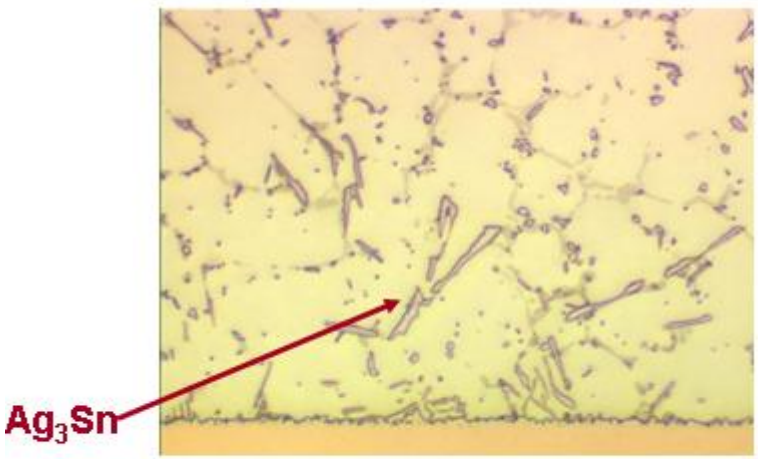
Results – Phase Two

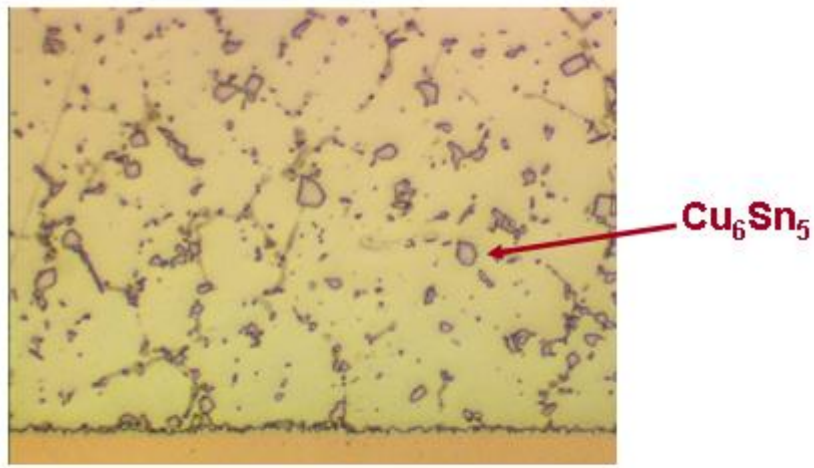
Metallurgy – Microstructure

- Slight variations in microstructure noted in different component types
  - For PBGA256, similar structure to PBGA196, but primary Ag_3Sn and Cu_6Sn_5 were observed
  - SAC 305 – Larger Number of Ag_3Sn Needles
  - SAC 405 – Larger Number of Cu_6Sn_5 Particles

PBGA 256



1-1-17, U204,1st row,SAC305,205C,400x



1-2-6, U204,1st row,SAC405,205C,400x

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Reliability Testing

- Conducted in Accordance with IPC-9701
- 6000 Cycles, 0°C to 100°C
- 100% In-situ Monitoring using Dataloggers
- Failure Criteria: Five consecutive readings showing minimum 20% Resistance Increase over max. resistance recorded during the hot dwell on the first cycle

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Cycles to Failure, PBGA196

SAC305, 205°C

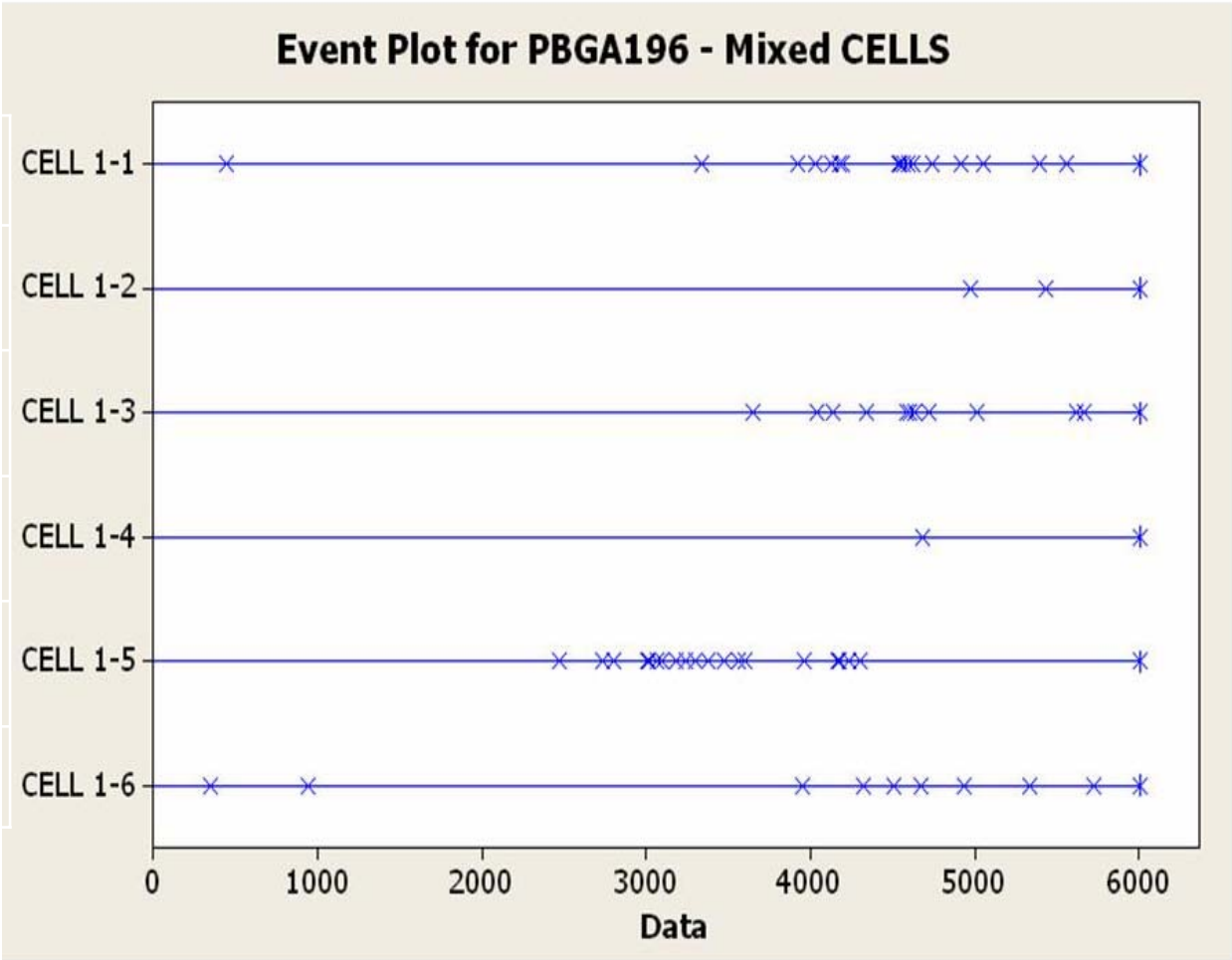
SAC405, 205°C

★ SAC305, 210°C

★ SAC405, 210°C

SAC305, 215°C

SAC405, 215°C



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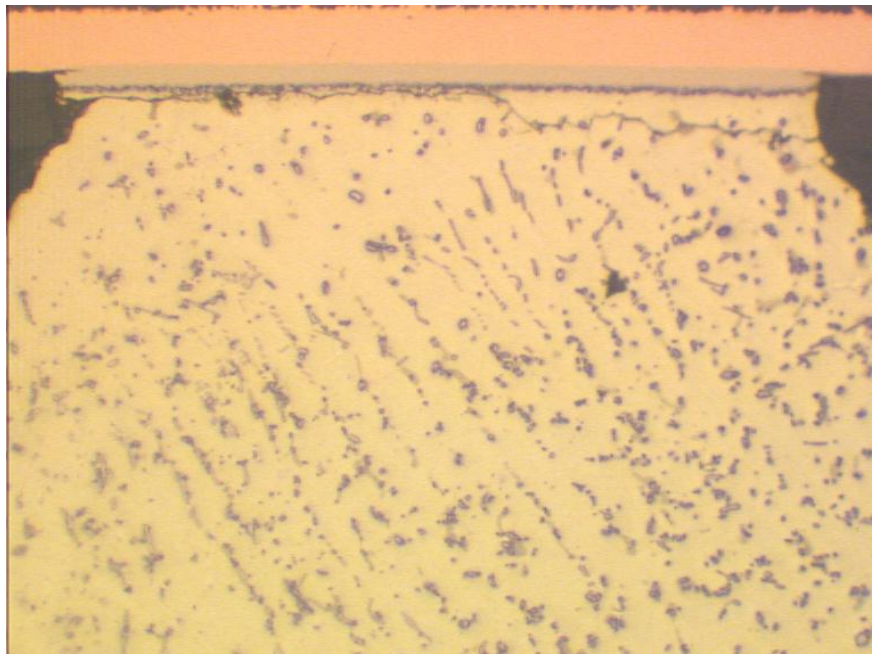
Failure Analysis on Cells 1-5 and 1-6

Cross Section Results

- Joints were fully mixed, though microstructure was not necessarily completely uniform
- Cracks are on component side and propagate through the bulk solder

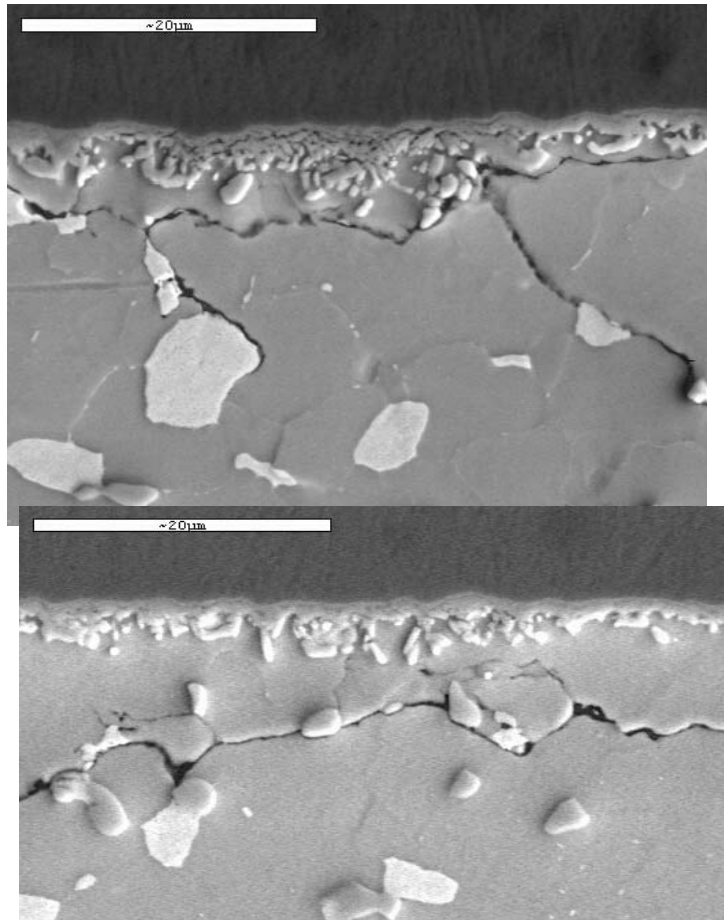


PBGA196 Joint formed from SAC305 Ball and SnPb Paste, 215°C

Failure Analysis on Cells 1-5 and 1-6

Crack Propagation Path

- Cracks propagate between Sn grains and along interfaces between Sn grains and Pb grains
- Pb Precipitates observed along some grain boundaries
- Where Ag_3Sn particles were observed in grain boundaries, cracks propagated around the particles



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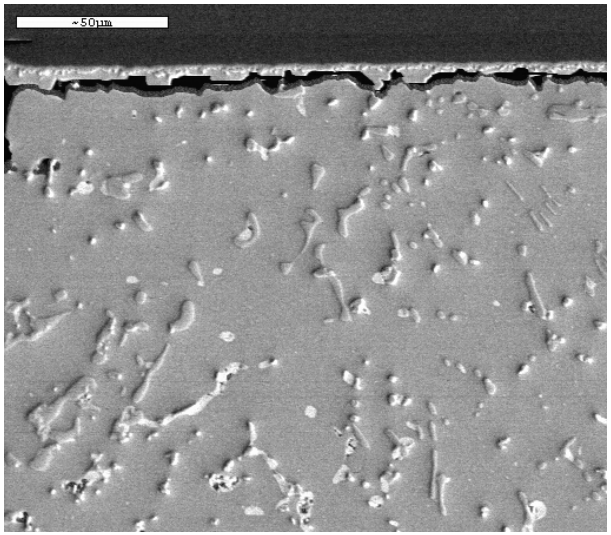
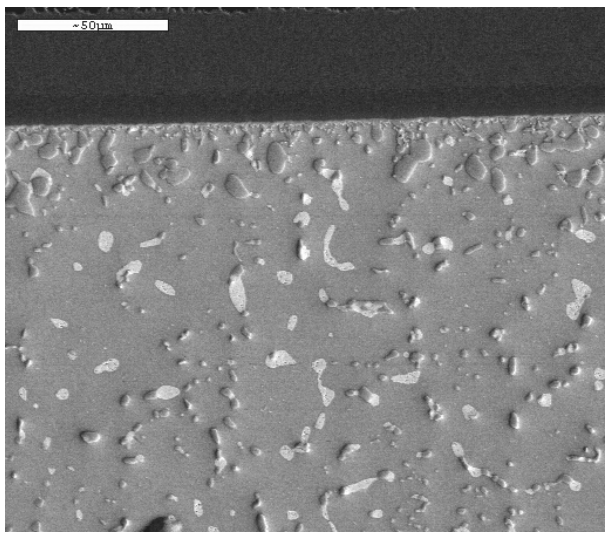
Failure Analysis on Cells 1-5 and 1-6





- Differences in Microstructure were observed between joints formed from components with SAC305 balls (upper image) and SAC405 balls (lower image)
- Mixed joints formed from SAC305 balls have fewer intermetallics and greater spacing between intermetallic particles

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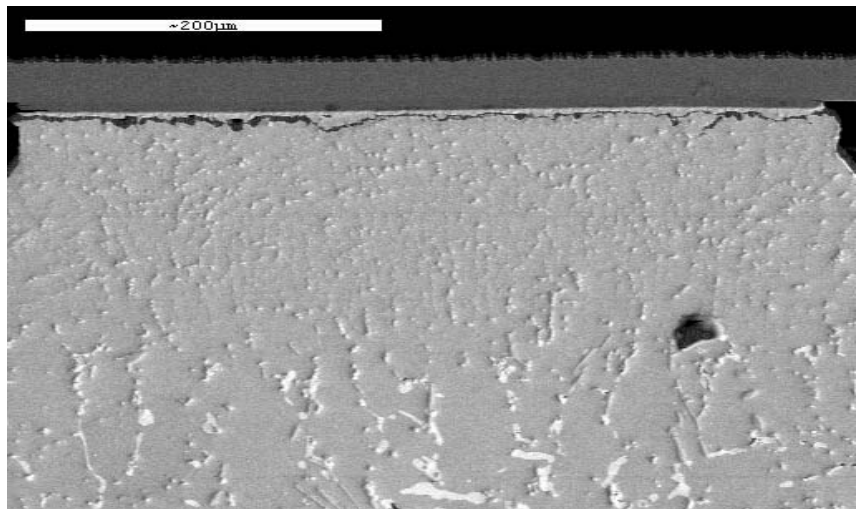
Failure Analysis on Cells 1-1 through 1-4

- Cells 1-1 through 1-4 had joints with less than 100% mixing
- No joints formed from SAC405 balls had full cracks, but joints formed from SAC305 balls did have full cracks



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Intermetallic Thickness Measurements

- Intermetallic Thickness Increases with Increasing Peak Temperature
- May account for decrease in reliability with Peak Temperature

Cell	Board Side Thickness	Component Side Thickness
1-1 (SAC305, 205°C)	1.6 μm	0.9 μm
1-2 (SAC405, 205°C)	1.4 μm	1.0 μm
1-3 (SAC305, 210°C)	1.4 μm	0.9 μm
1-4 (SAC405, 210°C)	1.3 μm	0.8 μm
1-5 (SAC305, 215°C)	2.2 μm	1.2 μm
1-6 (SAC405, 215°C)	2.1 μm	1.2 μm

Conclusions – Assembly

- Fully mixed solder joints could be formed at profiles with a target peak temperature as low as 205°C for the smallest joints studied (CSP46 from Phase 1). No other components were able to form fully mixed joints in all locations with any of the profiles used.
- The amount of mixing depends on peak temperature, time above reflow, solder paste volume and solder joint volume.
- Voiding was observed on all components, but was well within acceptable levels.

Conclusions - Reliability

- Early indications are that the reliability of the components will be acceptable for many applications, although thermal cycling must be continued for final conclusions to be drawn and for comparisons to be made with pure tin/lead or lead free assemblies.
- Degree of mixing does not appear to influence the reliability of the PBGA196
- Mixed joints formed from SAC305 balls appear to perform more poorly in reliability testing than joints formed from SAC405 balls.
- Lower peak temperatures appear to create more reliable joint, possibly due to thinner intermetallic layers

Future Work

- Completion of full 6000 Cycles of ATC
- Analysis of ATC results for remaining component types
- Comparison of reliability of mixed joints to pure tin/lead and pure SAC305 or pure SAC405 joints
- Mechanical testing still needed
  - Shock
  - Vibration
  - Four Point Bending
- Accelerated Thermal Cycling of Mixed Joints in Harsh Environment (-55°C to 125°C)

Acknowledgements

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Thank you