Effects of SAC Alloy Copper Dissolution Rates on PTH Processes: Cost and performance justify use of certain alternatives to SAC305/405

Craig Hamilton, Polina Snugovsky (Celestica) & Matthew Kelly (IBM)

Based on technical paper

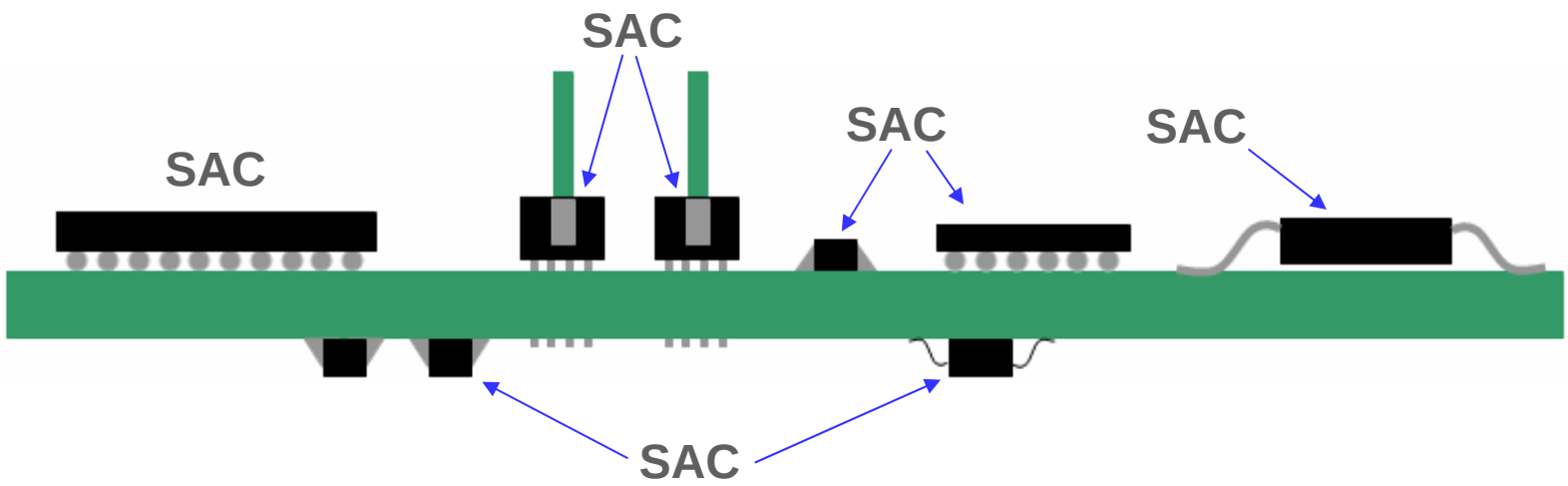
“Have high CU dissolution rates of SAC305/405 alloys forced a change in the lead-free alloy used during PTH processes?”

- **Presented at International Conference on Soldering and Reliability, April 18th, 2007**

- **Presented at SMTAi, PanPacific Microelectronics Symposium, January 31st, 2007**

Historical Pb-free Alloy Selection

- The majority of the electronics manufacturing industry is using SAC305 or 405 alloy to assemble and rework their Pb-free PCBs
  - For both SMT and PTH processes
- This choice dates back to 1999
  - Based on research into the metallurgy of a number of Pb-free alloy compositions
  - Considerations: Low melting temp, close to eutectic point, good properties
- Large focus on SMT reliability to validate SAC alloys
- Less focus on PTH solder joint reliability due to their construction

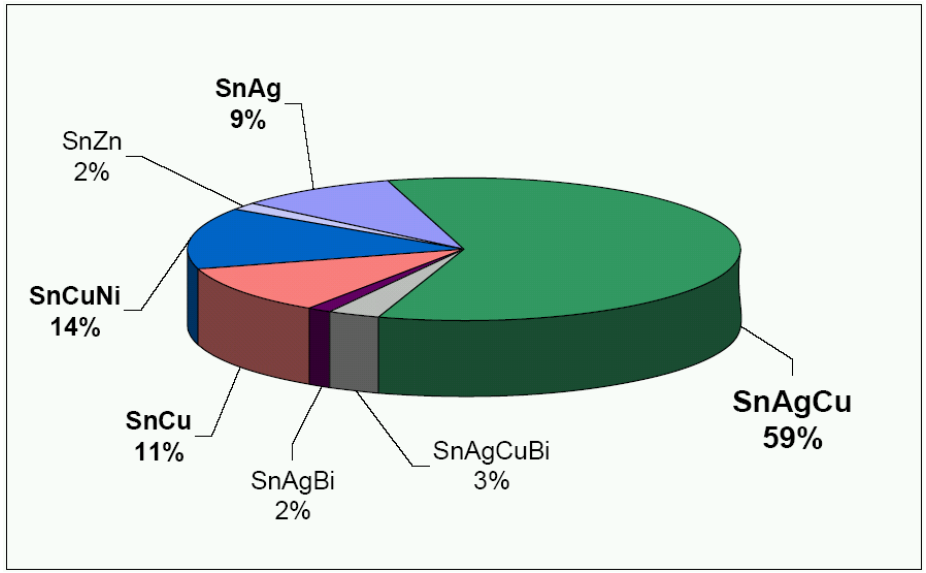


Is a Change in Alloy Required?

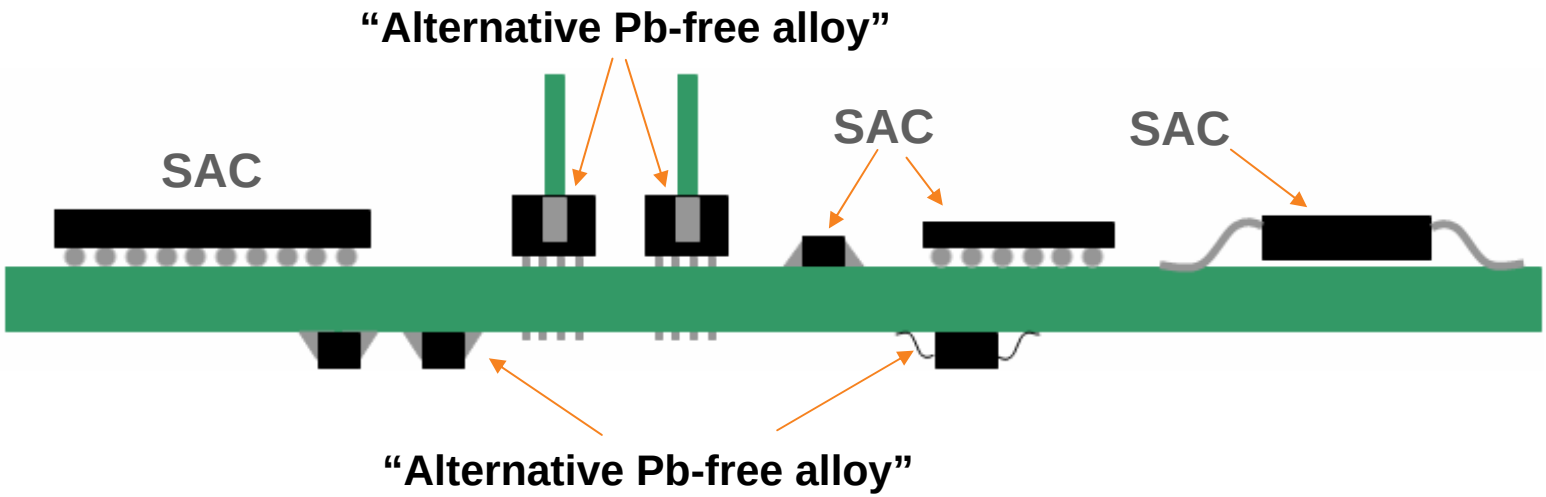
Yes, due to:

- High Cu dissolution rates of SAC305/405
- Higher cost of Sn-Ag-Cu alloys
- Prompting a change away from using these alloys during:
  1. PTH rework process
  2. PTH primary attach process

Trends in wave solder alloys



Source: 2007 European Lead-Free Soldering Network Report



Presentation Agenda

- Background development of SAC305/405 alloys
  - Summary of key findings to date
  - Cu dissolution rates
  - PTH process window
- Study of “Alternative Pb-free alloys”
  - Design of experiment
  - Cu dissolution rates
  - PTH process window
- Preliminary reliability analysis of a Sn-Cu-Ni alloy vs. SAC405
- Discuss the “impact to manufacturing” if an alloy change is made within the:
  - PTH rework process (solder fountain)
  - PTH primary attach process (wave)

Process Development Flow

Define the Problem

- What is Cu dissolution?
- Where does it occur?
- Why is it a problem?

Quantify the Impact

- What factors impact the rates of Cu dissolution?
- What are the Cu dissolution rates of SAC305/405 alloys?
- How does high Cu dissolution rates impact the PTH processes?

Identify & Verify Solutions

- What solutions can control or mitigate Cu dissolution?
- What solutions are viable options?
- Prioritize solutions

Implementation

- What impact will the solution/s have on manufacturing?
- Implement the preferred solution

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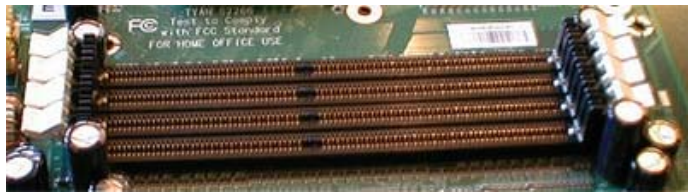
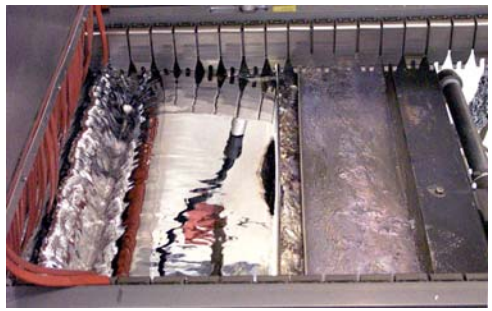
What is Cu Dissolution?

Mechanics of Cu Dissolution:

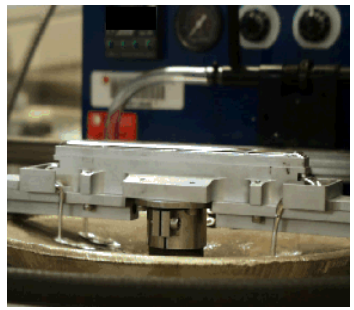
1. Occurs when molten solder alloy comes into contact with copper (Cu) plating
   - Therefore, the primary processes effected are:
     - Primary attach – wave solder
     - PTH rework – solder fountain



PTH Connectors

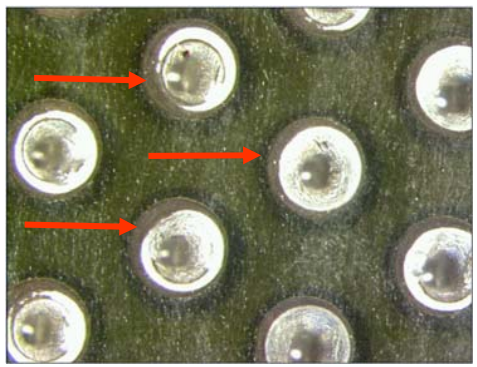


Primary Attach

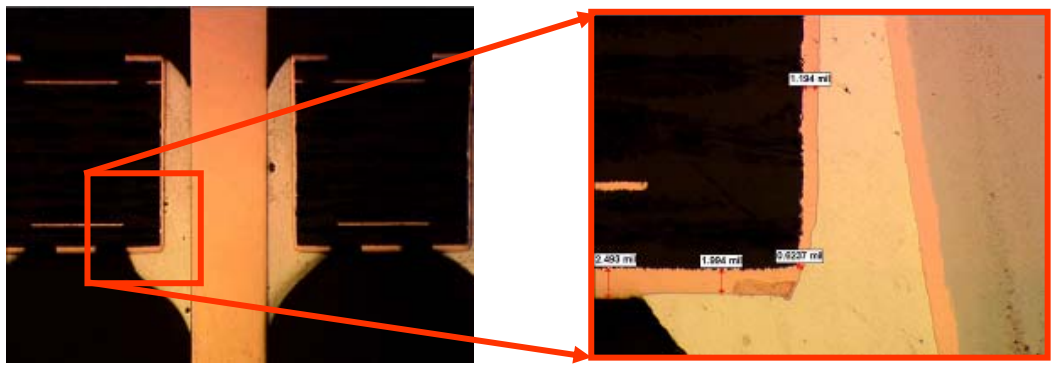


PTH Rework

2. Portions of the Cu plating will dissolve into the molten alloy over time.



Annular Ring



Barrel Knee and Wall

Where does it occur?

Primary vs. Rework:

- Largest impact occurs during the PTH rework process
- The reasons for this are:
  - Higher contact times at solder fountain
  - Higher flow rates at solder fountain
- Therefore, a lot of the development work to date has been focused on the PTH rework process

3 - 10 seconds

Courtesy of Speedline

Primary Attach – Wave Solder

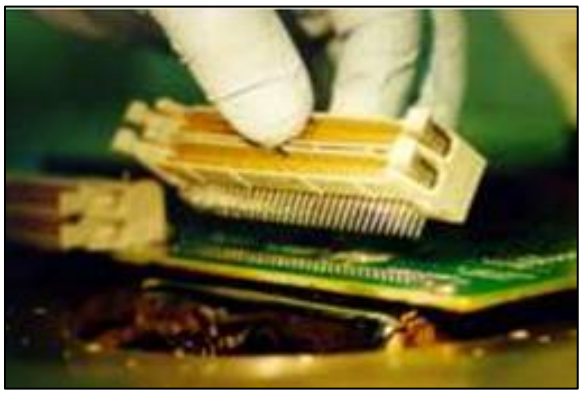
15 - 120+ seconds

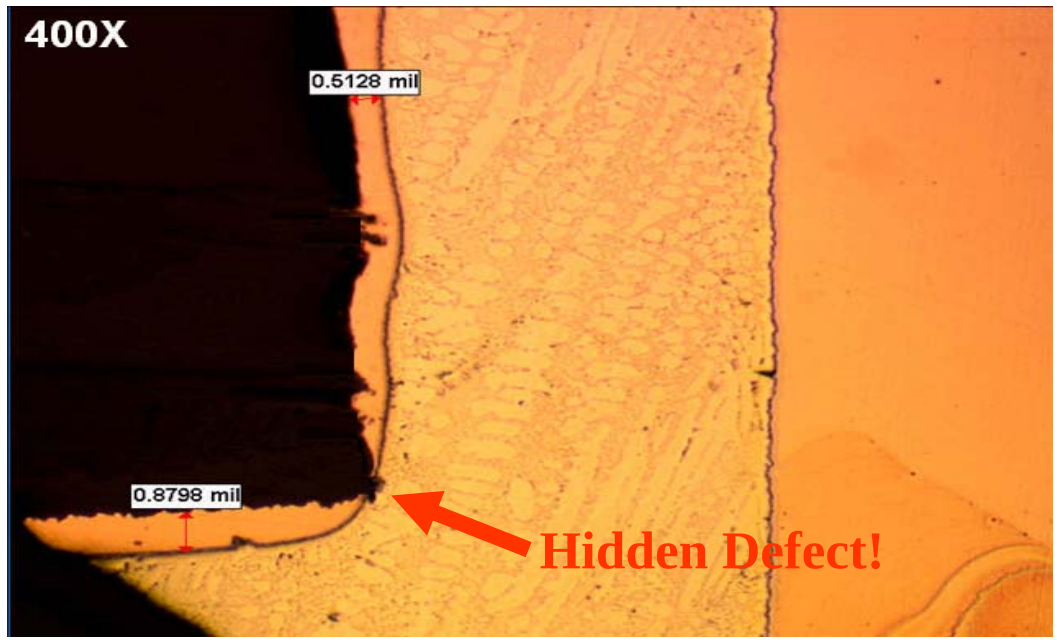
Courtesy of Air-Vac

PTH Rework – Solder Fountain

Why is it a problem?

- Potentially no 1X/2X PTH rework process window available with SAC305/405 alloys
- Various portions of the Cu plating will dissolve during the rework
  - The knee will dissolve at the fastest rate
  - 100% Cu dissolution can occur at the knee - “HIDDEN DEFECT”
- Potential quality, reliability concern
- No current industry IPC specifications for remaining Cu plating post rework





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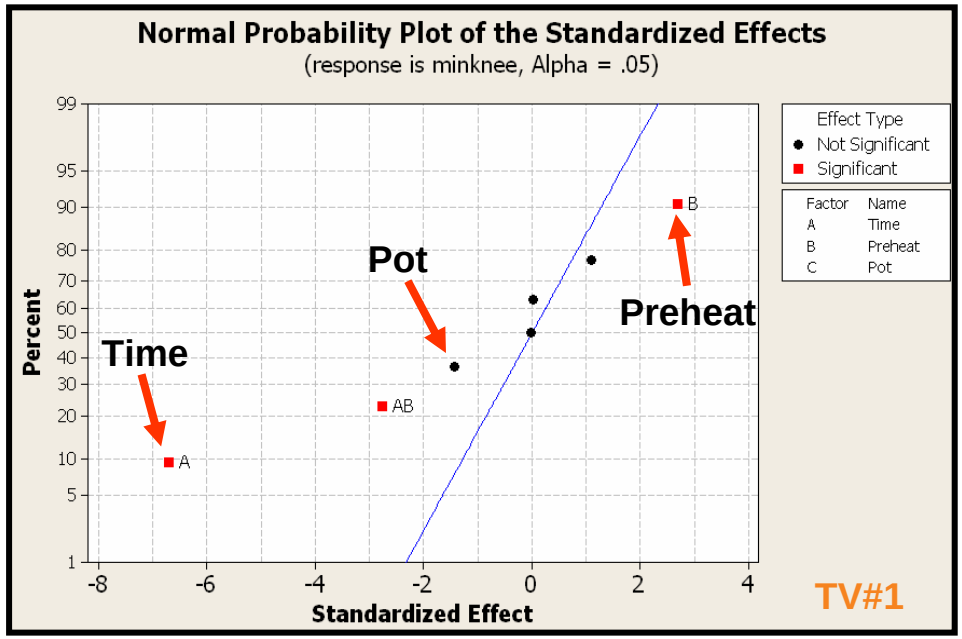
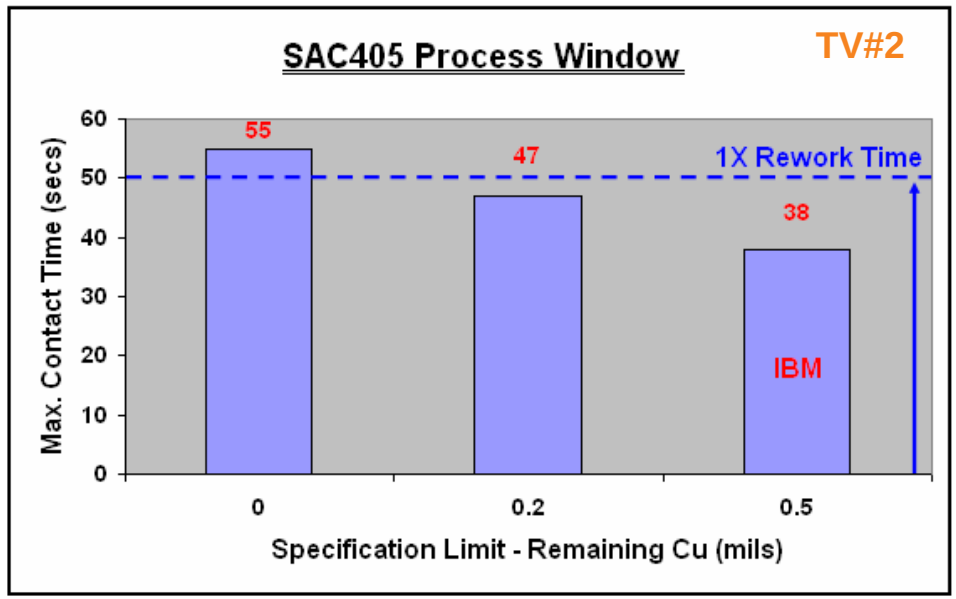
SAC405 Development Summary

Significant factors influencing Cu dissolution :

1. Contact Time
2. Preheat Temperature
3. Flow Rate
4. Alloy Composition

- SAC405 Cu dissolution rates calculated and correlated to a PTH rework process window
  - 1X PTH rework process window is narrow
  - 2X PTH rework not possible
- Alternative solution is required





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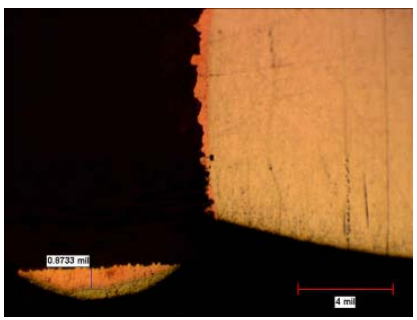

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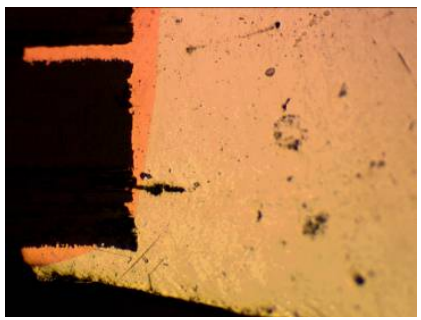

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Project Objectives

1. **Determine Cu dissolution rates**

- Study and compare the Cu dissolution rates of four “Alternative Pb-free Alloys” vs. SAC305 & 405 vs. Sn-Pb

2. **Establish the PTH rework process windows**

- Calculate the PTH rework process window of each alloy using their respective Cu dissolution rates

3. **Select and implement an alternative Pb-free alloy**

- Pick an alloy which delivers a 2X rework process
- Implement alloy into the PTH rework process suitable for high-volume manufacturing

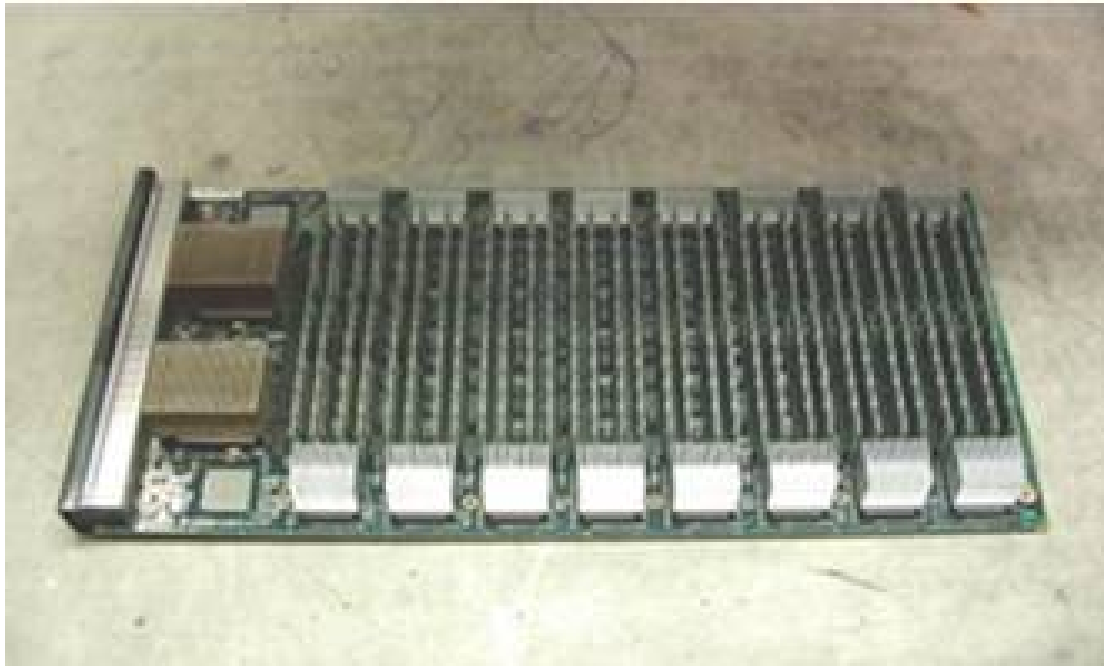
Alternative Pb-free Alloys

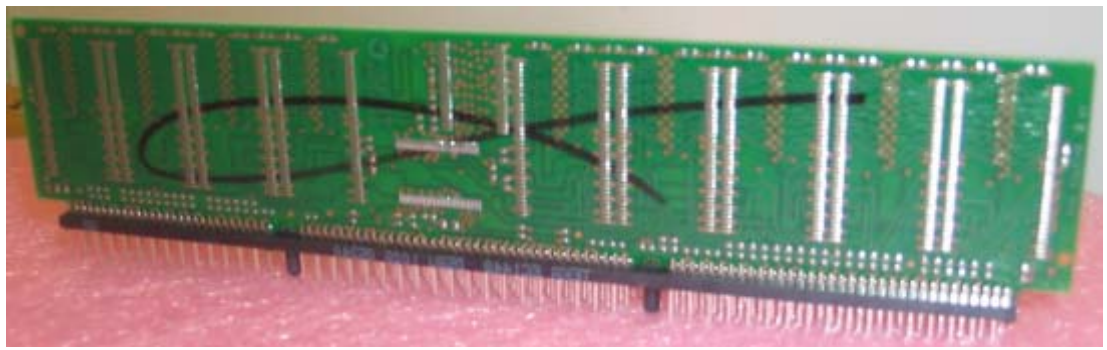
ALLOYS		MELTING RANGE
99.1Sn-0.7Cu-0.05Ni-(<0.01)Ge[1]	(Sn-Cu + Ni)	227°C
98.6Sn-0.3Ag-0.7Cu-Bi-X-Y[2]	(Sn-Ag-Cu + Bi)	217° to 228°C
96.0Sn-2.5Ag-0.8Cu-0.5Sb	(Sn-Ag-Cu + Sb)	217° to 219°C
99.1Sn-0.7Cu-X-Y	(Sn-Cu + X)	227°C
1. U.S. Patent # 6180055	2. Patent # PCT/GB2005/004609	

- 2 x Sn-Ag-Cu based alloys + controlled levels of additives
- 2 x Sn-Cu based alloys + controlled levels of additives
- Typical additives are: Nickel (Ni), Bismuth (Bi), Antimony (Sb), Germanium (Ge)
- **Additives help to:**
  - Control the final grain structure
  - Improve final joint appearance
  - Reduce Cu dissolution
- **Other potential effects include:**
  - Improved wetting
  - Improved flow characteristics
  - Improved barrel fill

Test Vehicle

- IBM Server Product
- 0.096” thick
- 8.9” x 19.4”
- 24 layers with 0.5oz and 1oz Cu
- 12S12P construction
- OSP surface finish
- FR4 High Tg laminate
- 32 in-line DIMM connectors (200 I/O)





Design of Experiment

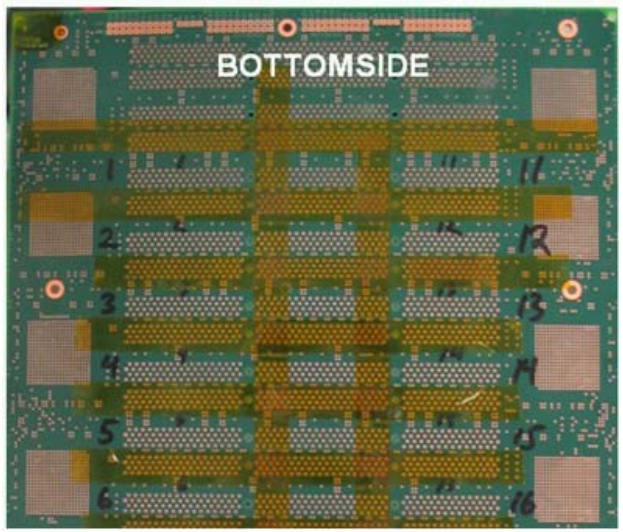
		Contact Time Replicates (secs)					
Exp. #	ALLOY	1	2	3	4	5	6
1-1	Sn-Pb	30	30	30	30	30	30
		50	50	50	50	50	50
1-2	SAC405	30	30	30	30	30	30
		50	50	50	50	50	50
1-3	SAC305	30	30	30	30	30	30
		50	50	50	50	50	50
1-4	Sn-Cu + Ni (1)	30	30	30	30	30	30
		50	50	50	50	50	50
2-1	Sn-Ag-Cu + Bi	30	30	30	30	30	30
		50	50	50	50	50	50
2-2	Sn-Ag-Cu + Sb	30	30	30	30	30	30
		50	50	50	50	50	50
2-3	Sn-Cu + X/Y	30	30	30	30	30	30
		50	50	50	50	50	50
2-4	Sn-Cu + Ni (2)	30	30	30	30	30	30
		50	50	50	50	50	50
DOE RUNS		16	16	16	16	16	16
TOTAL DOE RUNS		96					

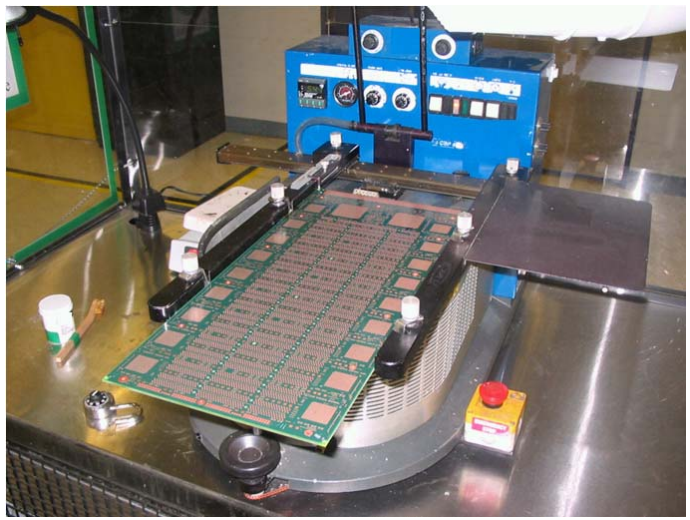
Constants:

- Equipment, Flow Well, Flux Type, Preheat Temp/Type, Flow Rate, Superheat = Melting Temp – Pot Temp = 50°C

Experimental Procedure

- Bare board used
- Actual “DIMM” locations used as the “samples”
- Solder fountain was used to represent real-life manufacturing scenario
  - One sized flow well was used for each run; constant flow rate
- Each sample was fluxed, preheated and exposed to a continuous solder flow based on the DOE
- Contamination controlled; tin rinse performed

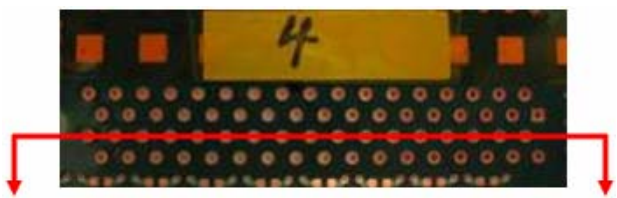


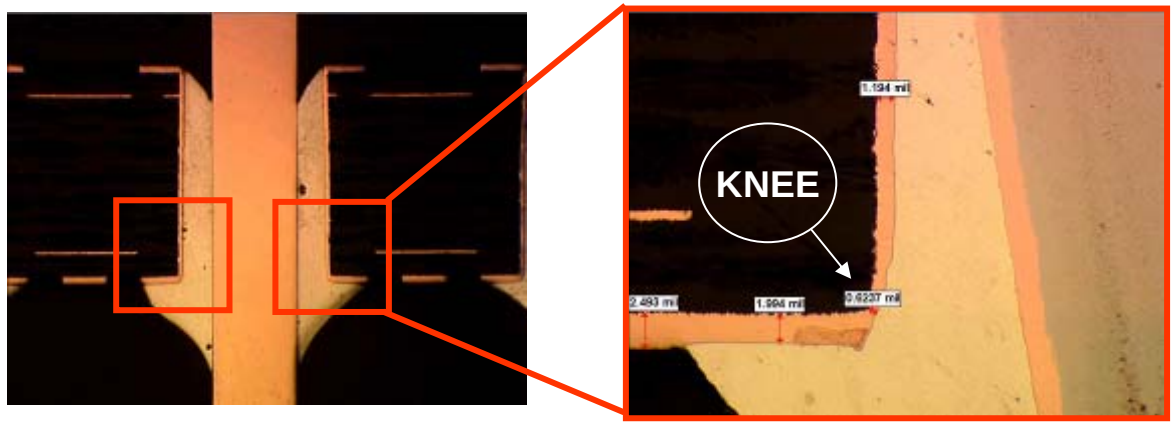


Response and Pass/Fail Criteria

Response (Output):

- Cu plating thickness at the knee
  - Reason: knee has been determined to be the most susceptible location to Cu dissolution
- Each sample x-sectioned and measurements were taken
- Every knee of each barrel per sample was measured
- Baseline Cu thickness measurements were taken





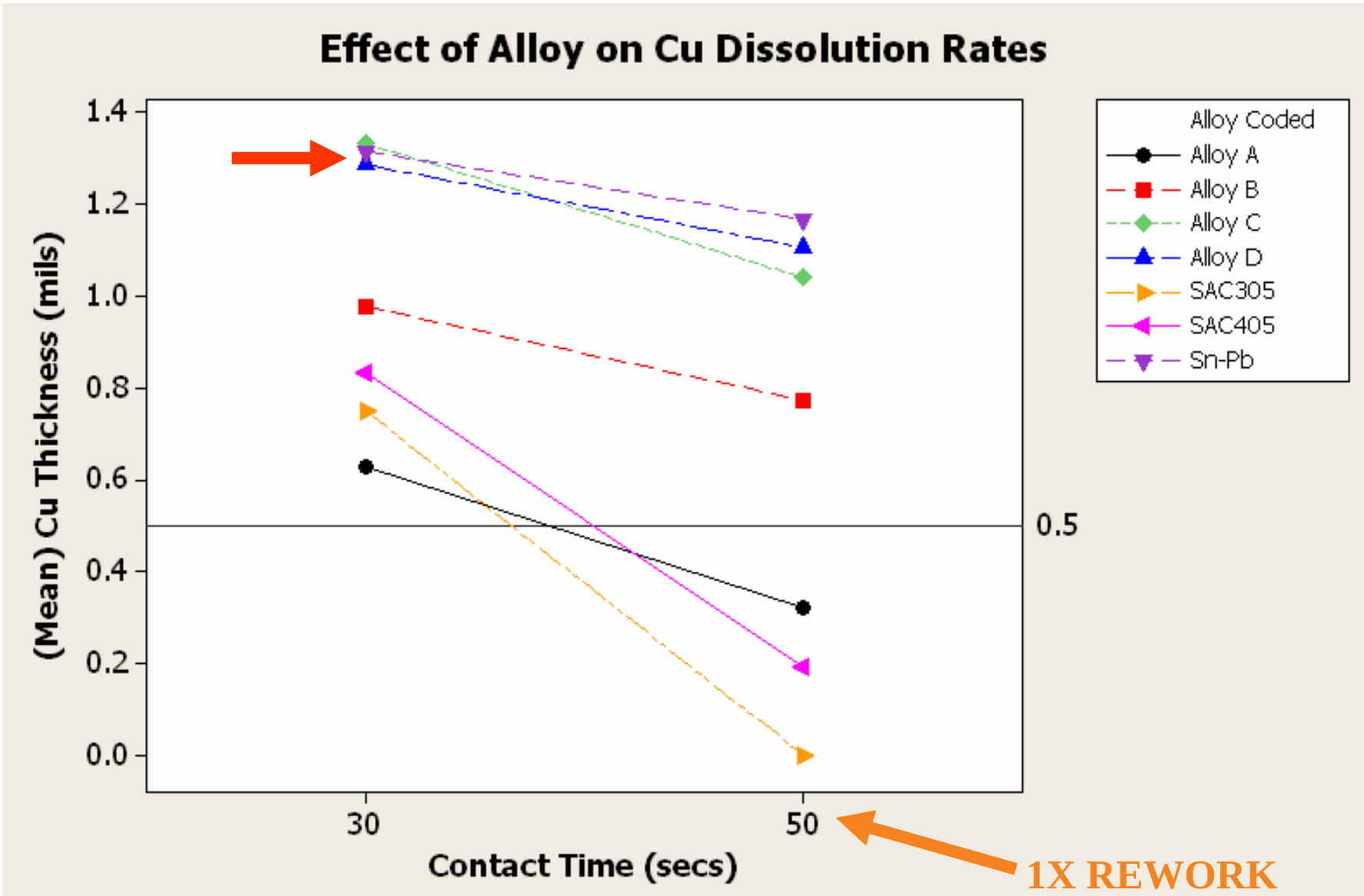
Pass/Fail Criteria:

- 0.5 mils of remaining copper used – IBM Pb-free specification

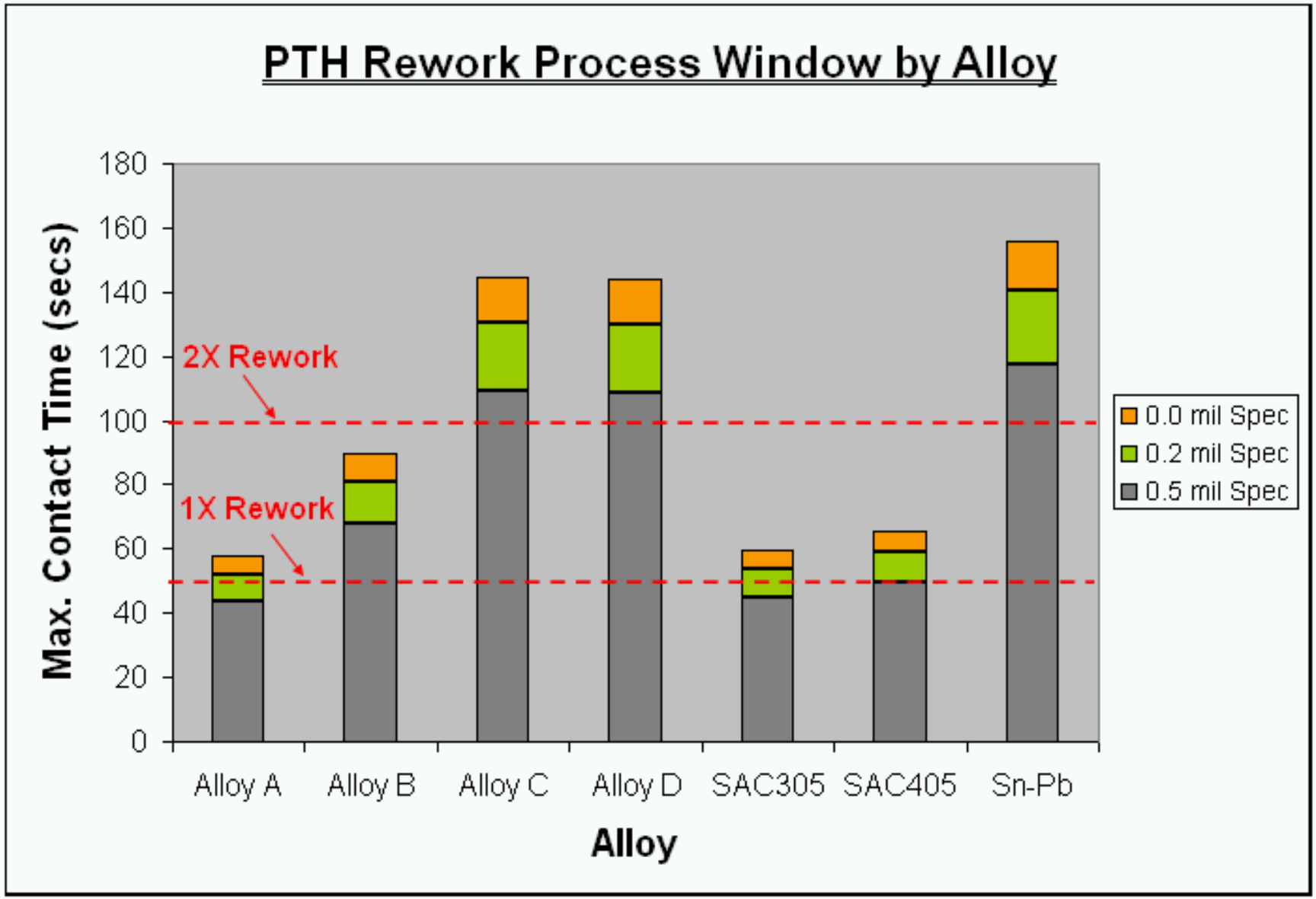
Statistical Results

And process window

Statistical Results



Process Window



Early Reliability Example

Sn-Cu + Ni

Early Reliability Studies

Example: Sn-Cu + Ni vs. SAC405 Study

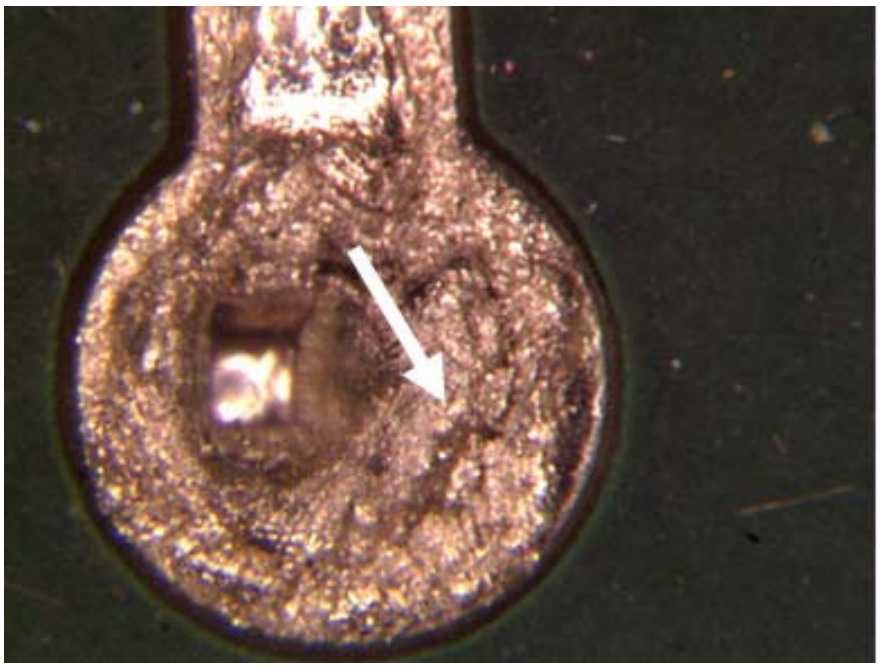
- Earlier reliability work performed on another test vehicle
- Sample of (OSP) boards were wave soldered (in air) using both alloys
- Each board was subjected to ATC, 0-100°C, 6000 cycles
- Waved components were not in-situ monitored
- Time zero and post 6,000 cycle joint analysis performed

Wave Components/PTH Connectors
Glue and Wave Chip Resistors
1206
603
Glue and Wave Leaded Components
SOT23 and SOIC16 leaded components
Through-Hole Components
PDIP14
PCI
Amplimite68

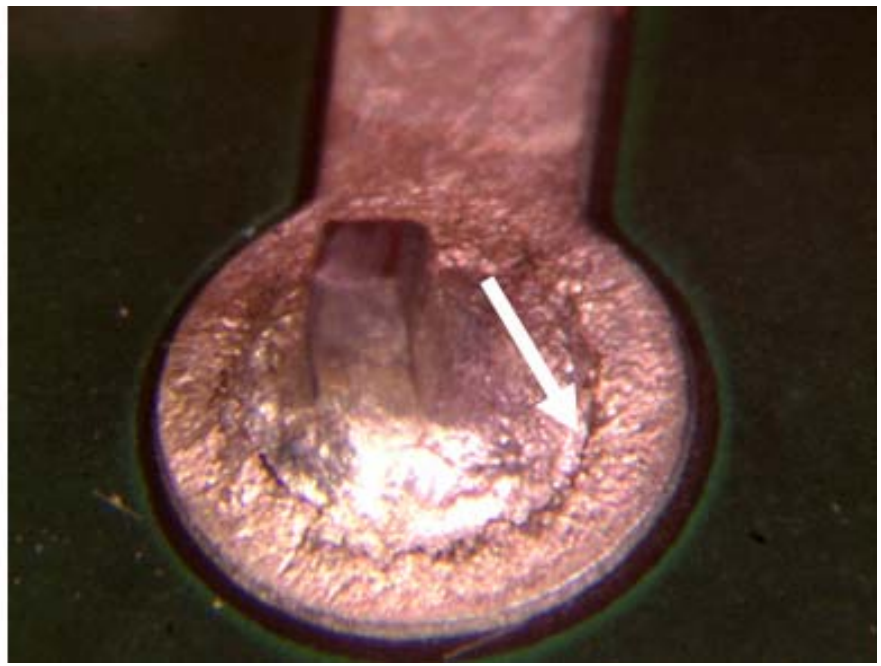
Reliability: 6000 cycles

Summary:

- For both Sn-Cu + Ni and SAC405 alloys, there were no failures due to completely open joints found after 6000 cycles
- Cracks on surface visible, did not result in an open joint



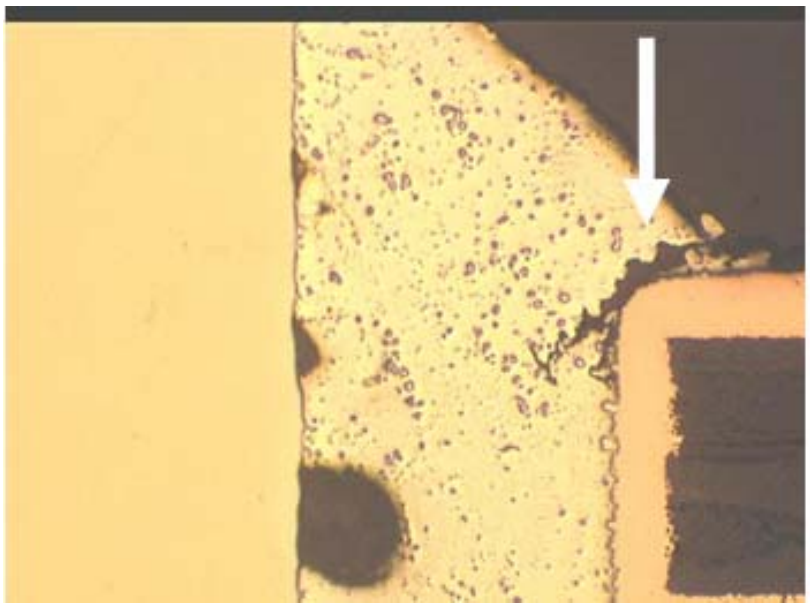
SAC405



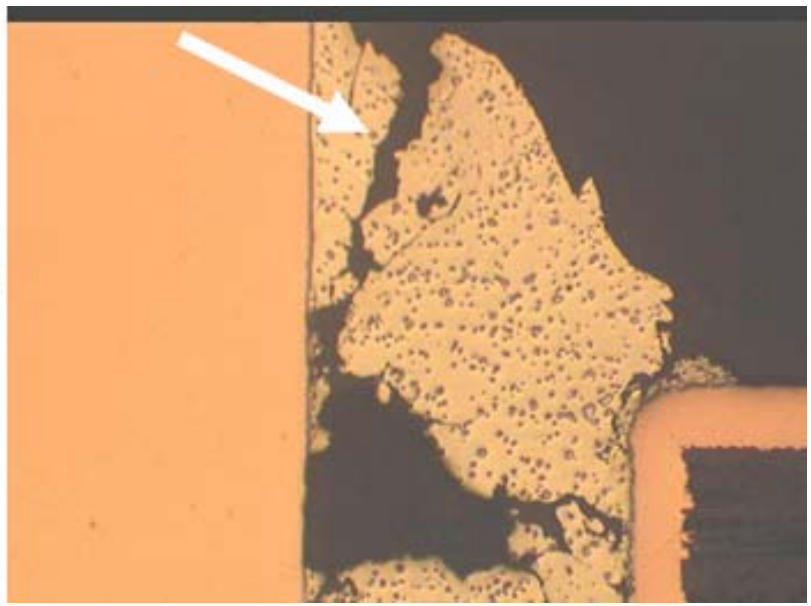
Sn-Cu + Ni

Reliability: 6000 cycles (PTH)

- Stress relaxation corner cracks and cracks along the pins formed in both SAC405 and Sn-Cu + Ni connectors
- Evidence that the Sn-Cu + Ni alloy is more prone to crack formation under thermal fatigue
- Did not result in an open joint!



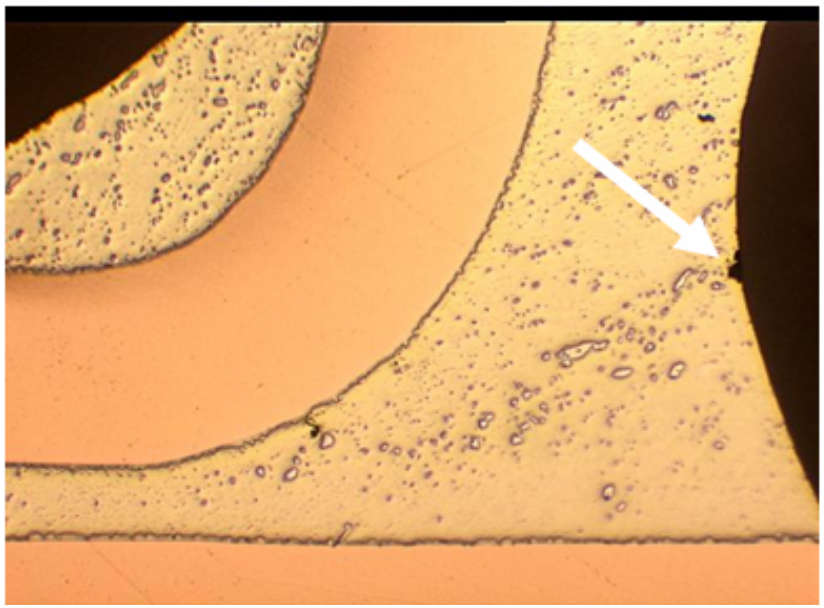
SAC405



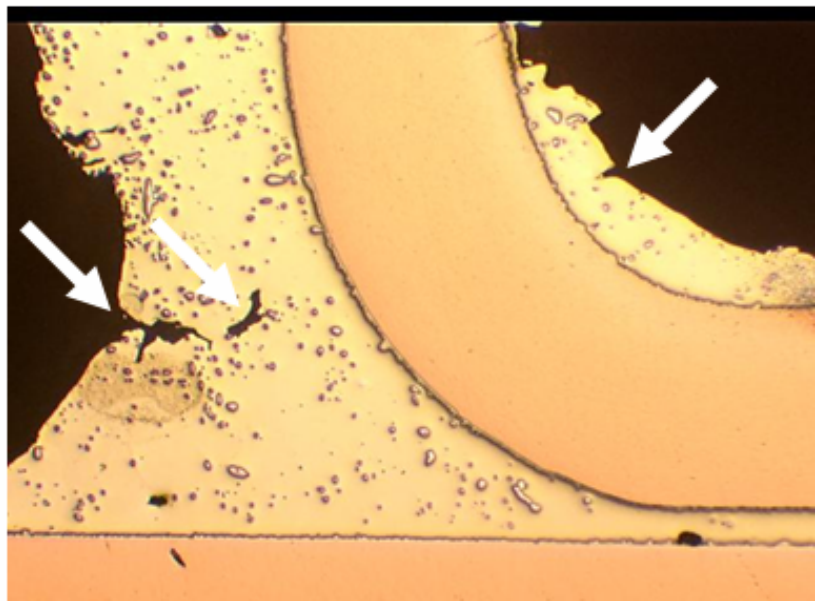
Sn-Cu + Ni

Reliability: 6000 cycles (Leaded)

- SOIC components did not fail after 6000 cycles
- Minor deformations and crack nucleation were visible at the heel and toe areas
- The damage is more significant in the Sn-Cu + Ni joints
- Did not result in an open joint!



SAC405



Sn-Cu + Ni

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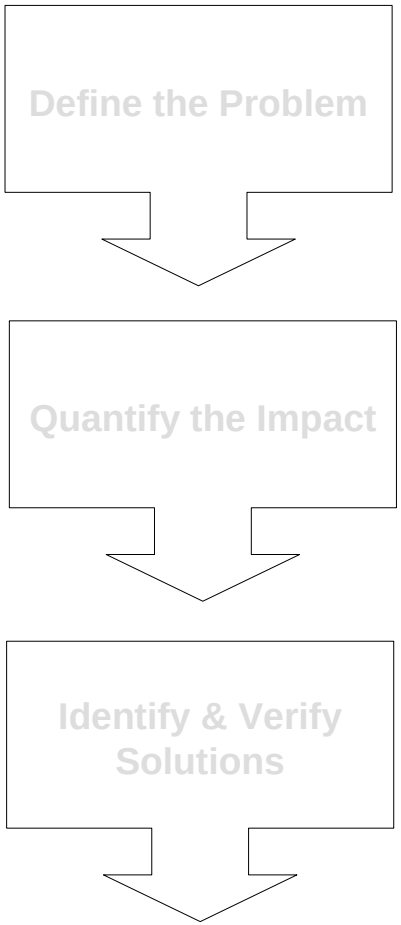

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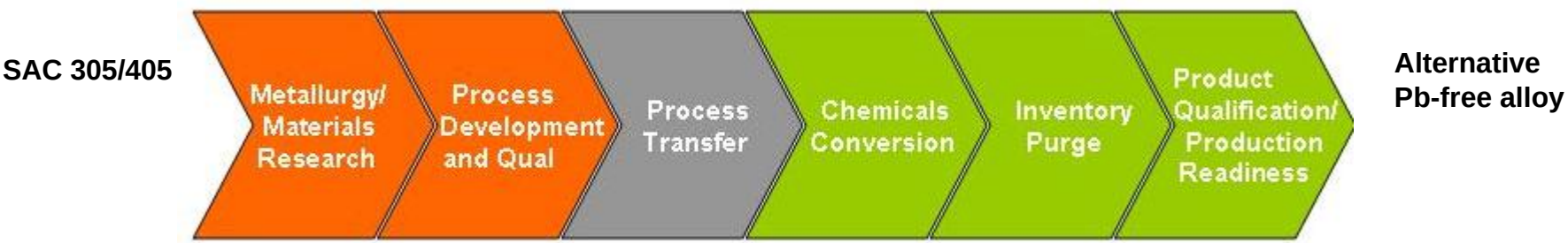
Is a Change in Alloy Required?

Have high Cu dissolution rates of SAC305/405 alloys forced a change in the lead-free alloy used during PTH processes?

- Based on the technical development results obtained to date
  - PTH Rework Process YES
  - PTH Primary Attach Process POTENTIALLY
- There are numerous manufacturing and business impacts which need to be considered before making an alloy change in either process



Impact to Manufacturing

	PTH Process	WAVE	REWORK
			
Alloy Selection	Option 1	SAC305 or 405	SAC305 or 405
	Option 2	SAC305 or 405	"Alternative Alloy"
	Option 3	"Alternative Alloy"	"Alternative Alloy"

- Making a change in the alloy used within the PTH processes will have an impact to:
  - Quality and reliability
  - Supply chain and cost
  - Manufacturing process
- Each of these impacts will need to be addressed before making a change

Impact to Manufacturing

Option 1: SAC Wave / SAC Rework

Pros	Cons
Process and reliability data available.	High Cu dissolution rates
Investments already made in qualifications.	Tight 1X PTH rework process window
Capital investments made in tools, equipment and process.	No 2X PTH rework process window
Investments already made in procurement and supply channels.	Higher dross accumulation rate
Already in production.	Higher alloy cost
Manufacturing yield data available.	Pb-free machine upgrade required
	Increased reliability risks

Impact to Manufacturing

Option 2: SAC Wave / “Alt. Alloy” Rework

Pros	Cons
Lower Cu dissolution rates.	Pot contamination increases. - Process controls required
2X PTH rework process capable.	Effects of mixing alloy not completely understood
Reduction in alloy cost	Multiple alloys used within the PTH processes - Process controls required - Risk of mixing
Reduction in dross accumulation	Higher alloy cost at wave.
Potential improvements in fluidity & hole fill	Pb-free machine upgrade required at wave

Impact to Manufacturing

Option 3: “Alt. Alloy” Wave / “Alt. Alloy” Rework

Pros	Cons
Cu dissolution benefits	Limited reliability data - ATC and mechanical testing required
Reduce pot contamination	Limited yield data
Reduction in alloy cost at wave and rework (up to 50%)	Many machines are currently loaded with SAC305/405 alloy - Switching costs
Reduction in dross accumulation at wave and rework	Many Pb-free products have been qualified using SAC305/405 alloy - Re-qualification of products
No Pb-free machine upgrade required at wave and rework	Supply chain and distribution links
	CM / OEM alignments required - Demand / implementation

Conclusions

- Alloy change is required within the solder fountain process
  - To deliver a 2X rework process
- Alloy change is recommended within the wave process
- Benefits of changing wave alloy:
  - Cost savings
  - Process simplification - homogeneous alloy
  - Reduce contamination risk
  - Process improvements anticipated
- Further work is required before changing wave alloy:
  - Reliability (thermal and mechanical)
  - Yield analysis
  - Implementation assessments

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