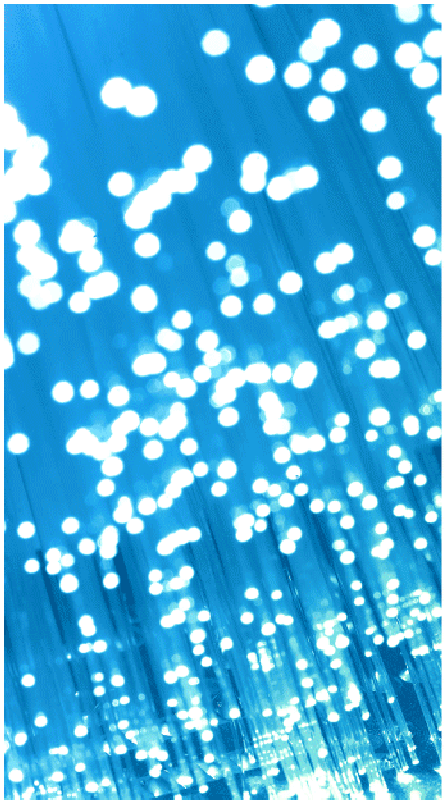
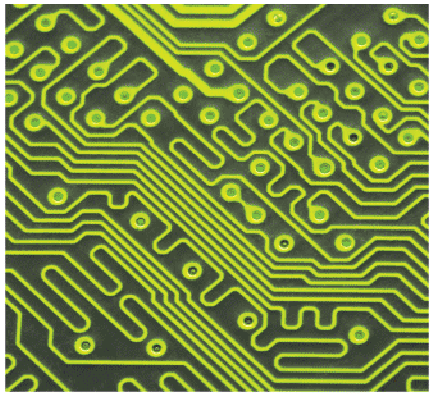
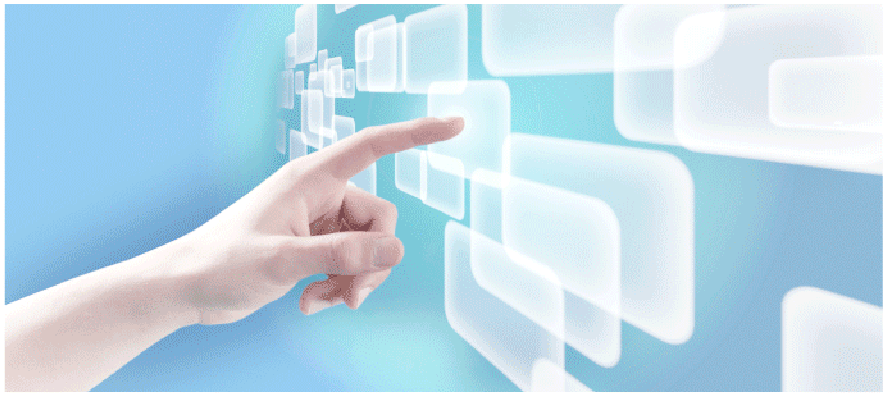
Silicon Valley SMTA conference

FLEXTRONICS


Lead-Free Soldering Materials in Manufacturing

Jennifer Nguyen

Date (11/13/12)

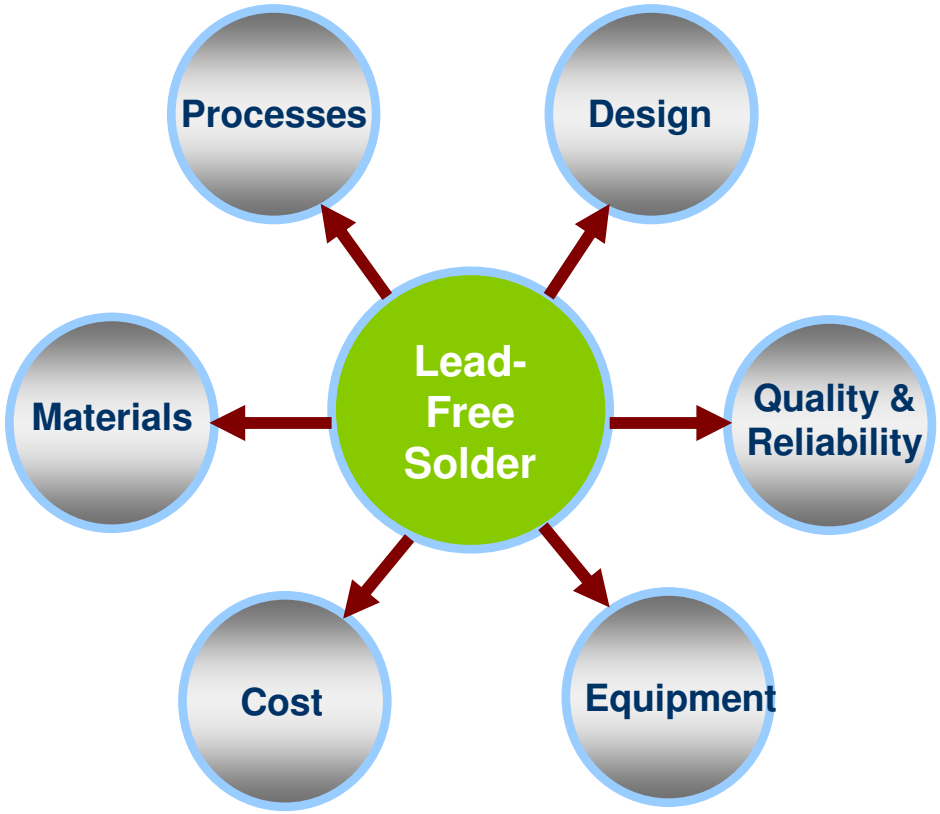
AEG - WW Assembly & Test Technology

Outlines

- Introduction
- Lead-Free Solder Alloys in Reflow Process (SMT components)
  - Common Alloys
  - Alternative Alloys
  - Drivers for Alternative alloys
  - Issues and Challenges
  - Conclusions
- Lead-Free Solder Alloys in Wave Soldering Process (PTH components)
  - Common Alloys
  - Alternative Alloys
  - Drivers
  - Issues and Challenges
  - Conclusions

Which Lead Free Solder Alloys?

- Tin/silver/copper alloy composition (Sn -(3-4%)/Ag/-(0.5-0.7%)/Cu) is commonly used in manufacturing processes.
- Increased interest and use in alternative alloys (tin-copper based alloy or tin-silver-copper with low silver content) due to technical and commercial reasons.



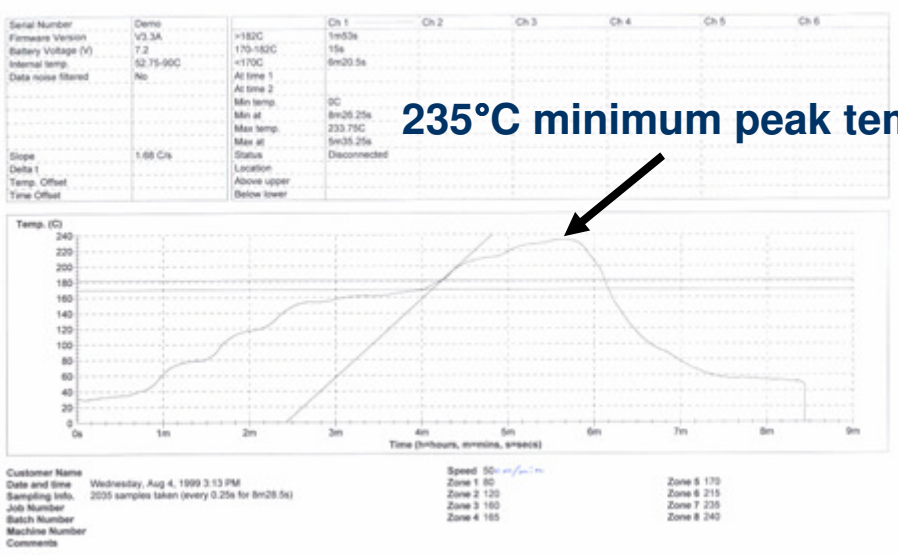
System Approach and Methodology

Lead-Free Solder Alloys in Reflow Process

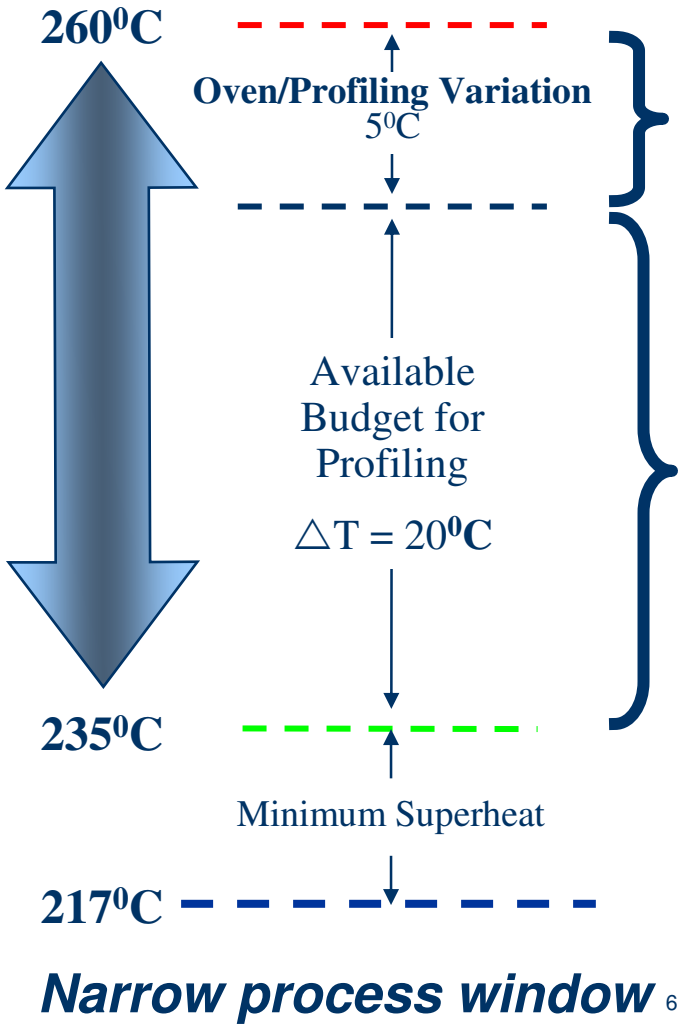
Lead-Free Solder Paste

- SnAgCu is the most common Lead-Free Alloy used in Reflow Process.
- The percentage of Ag is from the range of 3.0-4.0.
- Industry Recommended Alloys
  - INEMI: Sn/3.9Ag/0.6Cu
  - IPC/JEITA: Sn/3.0Ag/0.5Cu
  - EU: Sn/3.8Ag/0.7Cu
- Industry effort is on-going to 'standardize' the composition
  - Simplify supply logistics and qualification efforts
  - Reduce cost
- Today, Sn3.0Ag0.5Cu is the most common solder paste alloy.
- The use of alternative low cost, low/no silver for lead-free solder paste is on the rise.

Reflow Process

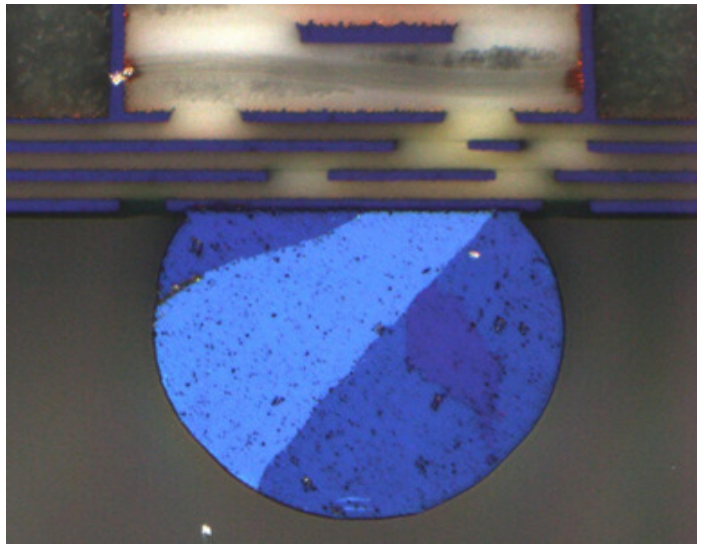


- Process optimization is critical



Narrow process window

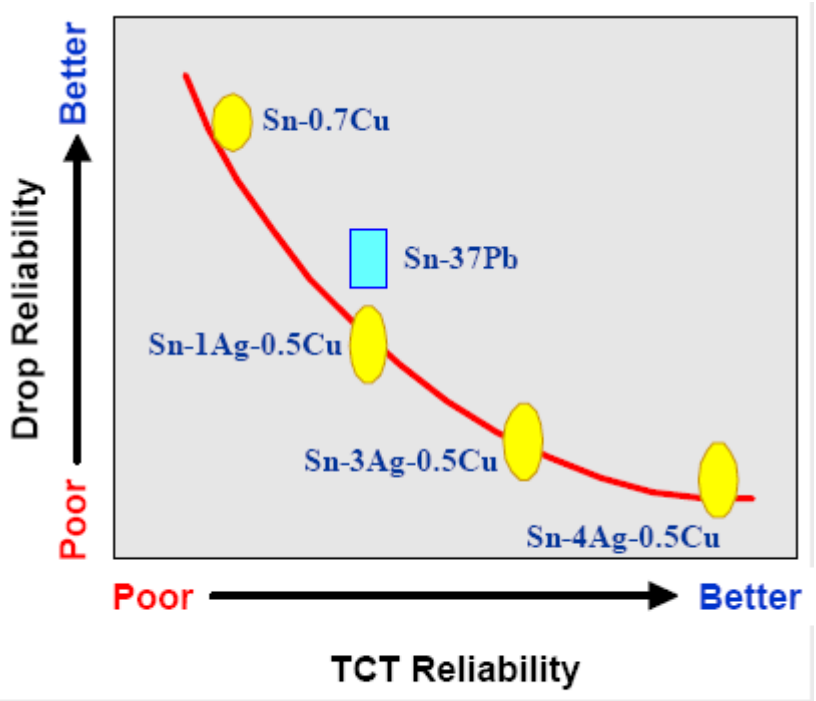
Lead-free Alloys for Area Array Spheres



Top Image: Cross Polarization of a SAC305 Solder Ball showing Grain Pockets

- Composition: SnAgCu (SAC305 is commonly used)
- Alternative lead-free BGA/CSP sphere alloys such as Sn1Ag0.5Cu (low silver %) are on the rise…
- Use environment is an important consideration for reliability
  - Drop or thermal cycling

BGA/CSP Balls



Effect of Ag Weight Content on
TCT and Drop Reliability of Solder Joints
(Courtesy of Hitachi Metals)

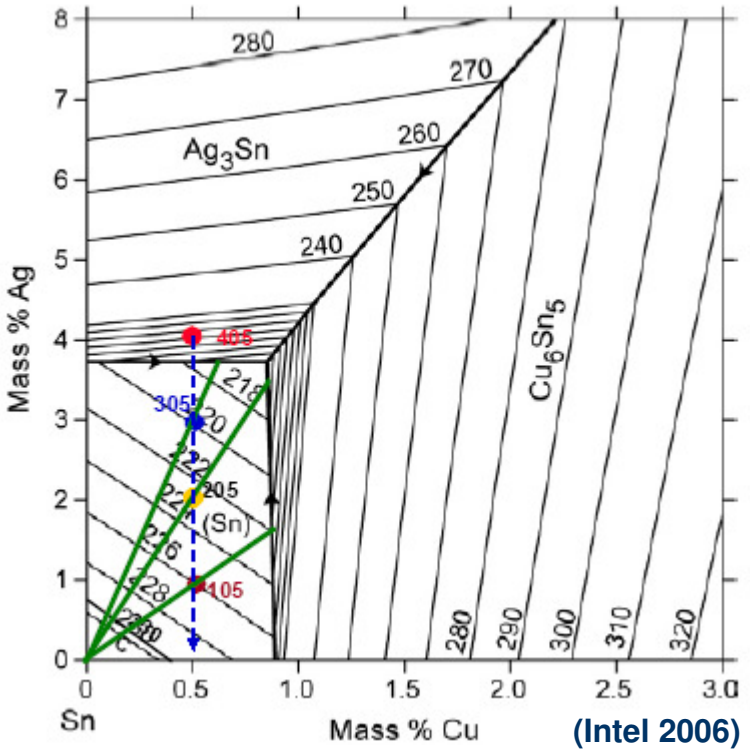


Table 1: Elastic modulus measured by ultrasonic stress wave propagation technique for SnPb and various SAC alloys

Alloy	SAC405	305	105	SnPb
E [GPa]	53.3	51.0	47.0	40.2

Lowering Ag content for high compliance is identified as a viable bulk optimization approach…The current data analysis along with other property/performance data suggests that an optimum Ag content is around 1 wt.% (Intel 2006)

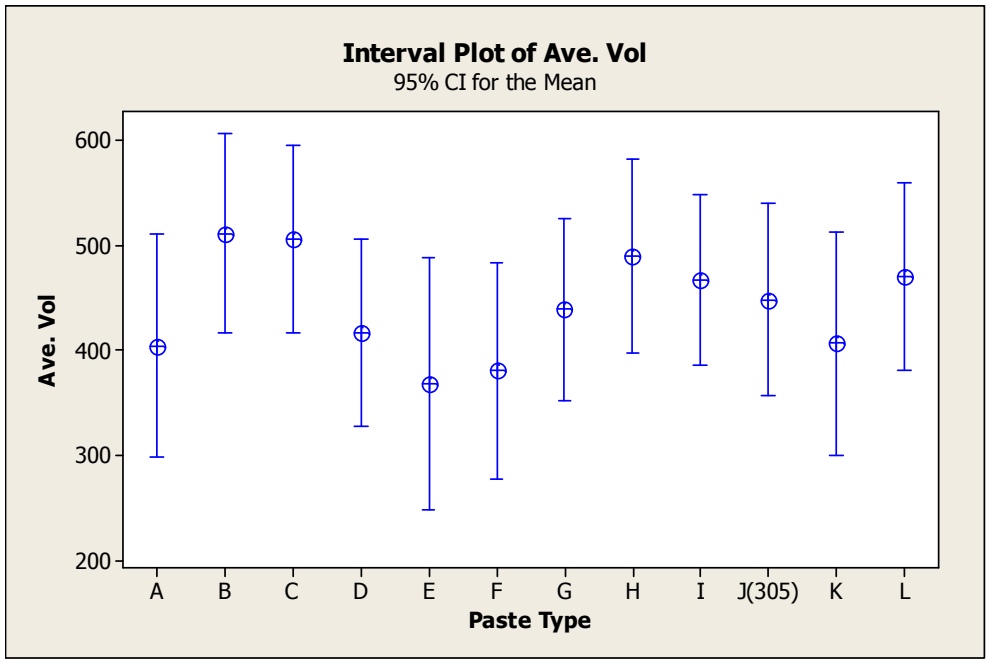
Drivers for Alternative Alloys

- Many alternative alloys used in SMT process have been introduced to address drop/shock performance issues.
- Cost

Alternative LF Solder Pastes_ Opportunities and Challenges

- Many alternative LF solder pastes have good printing and wetting performance.
- Many materials have excessive solder balls and more voiding as compared to SAC305 solder pastes. Very few materials can have the same performance as SAC305 solder pastes.
- The flux chemistry in the solder paste plays an important role in the material performance.
- Alternative lead-free alloys have higher (about 10ºC higher) melting temperature than SAC 305 alloy. A hotter LF reflow profile may be needed.

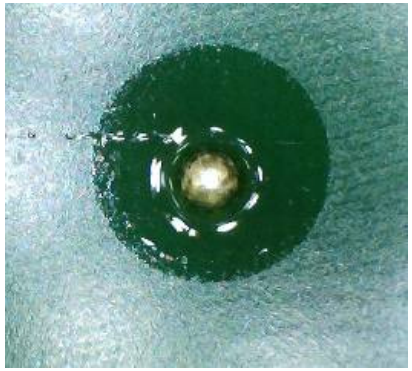
Alternative Lead Free Solder Pastes_ Printing



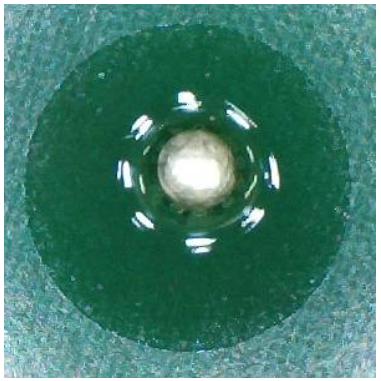
- The flux chemistry in the solder paste and supplier play an important role in the material printing performance as compared to the alloy compositions.

Alternative Lead Free Solder Pastes_ Solder Balls

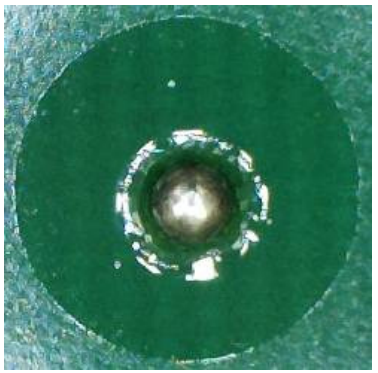
- Some alternative LF pastes have excessive solder balls as compared to SAC305 solder pastes.
- Paste supplier and flux chemistry are critical.



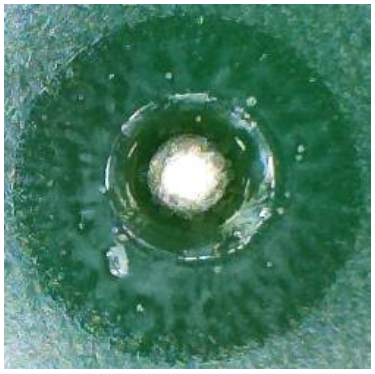
SAC305



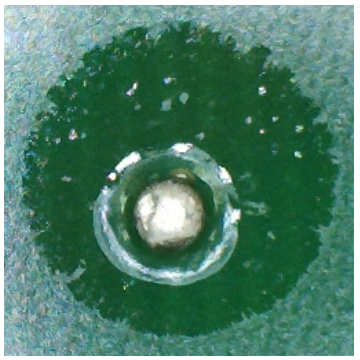
SAC0307



Sn100C_A



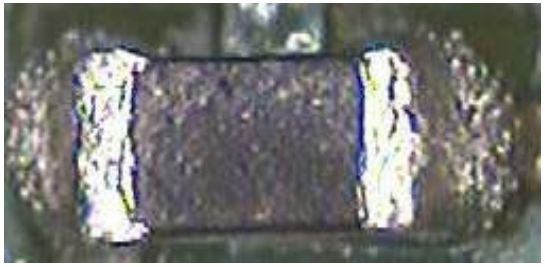
SAC0307+



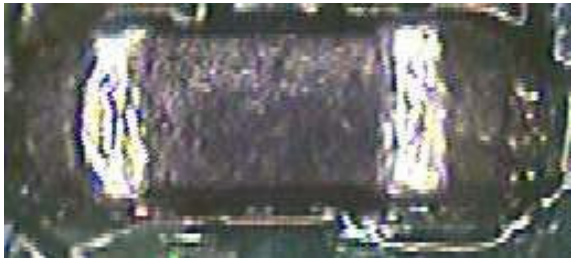
Sn100C_B

Alternative LF Solder Pastes_ Solder Balls (Cont'd)

SAC305



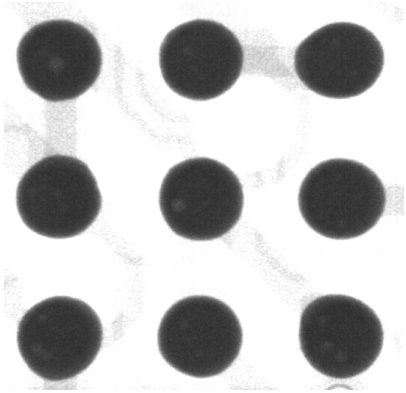
SAC0307



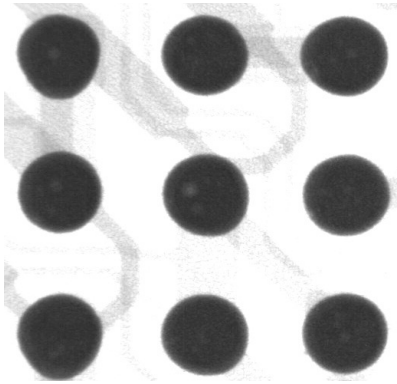
Sn100C

- Alternative alloy solder pastes may have graping and solder ball issues.

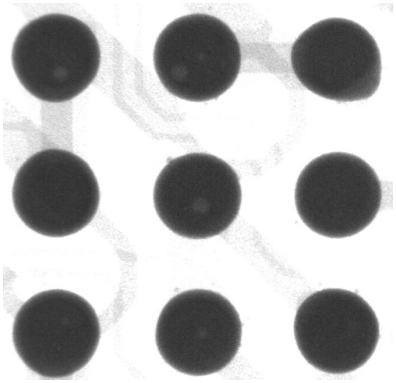
Alternative LF Solder Pastes_ Voiding



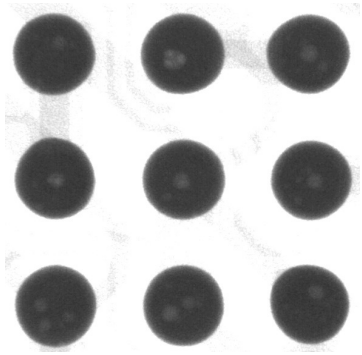
SAC305_ Control



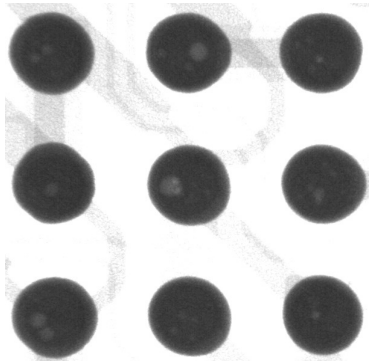
SAC0307_Flux A



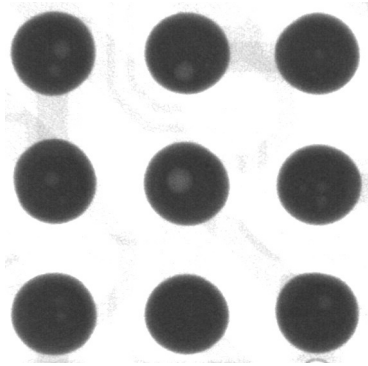
Sn100C _Flux A



SAC0307_ B



SAC0307_ C

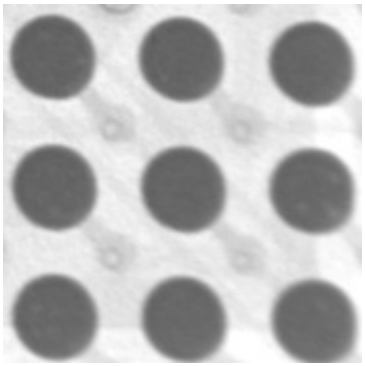


SN100C_ D

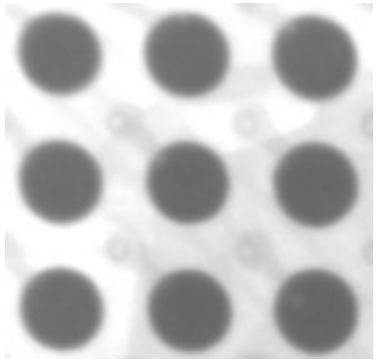
- Flux chemistry affects voiding characteristics more than alloy composition.

Alternative Lead-Free Alloys in Components

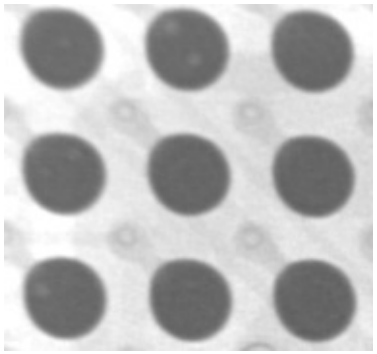
- No major assembly process issues
- No significant difference in voiding under x-ray for different alloys.
- Homogeneous alloy mixing typically has less voiding than inhomogeneous alloy mixing.



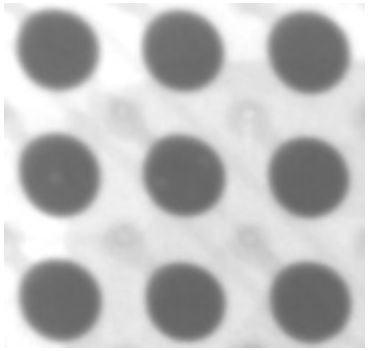
14- SAC305/ SAC305



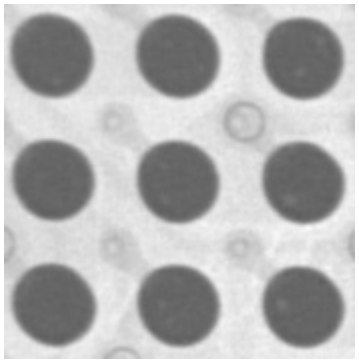
2- SN100C/SN100C



5- SAC105/SAC305

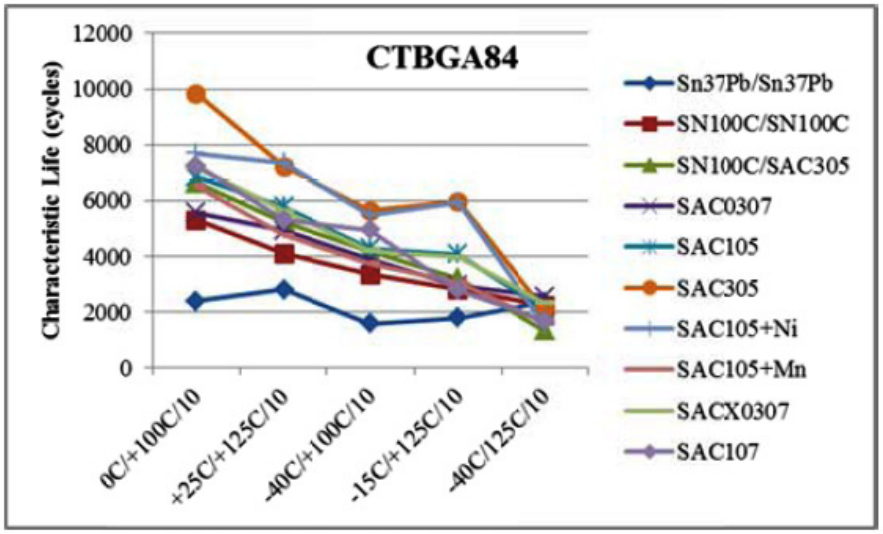


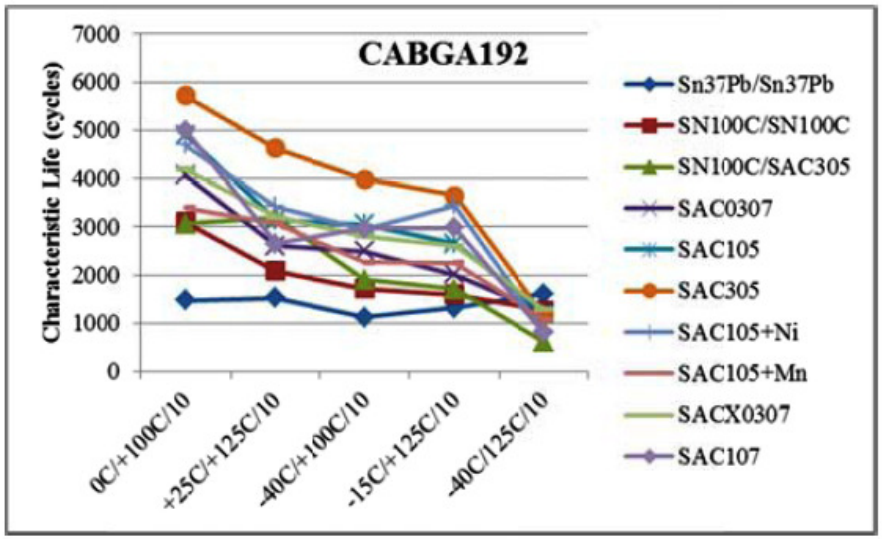
6- SAC205/SAC305



8- SAC405/SAC305

Alternative Alloys Reliability



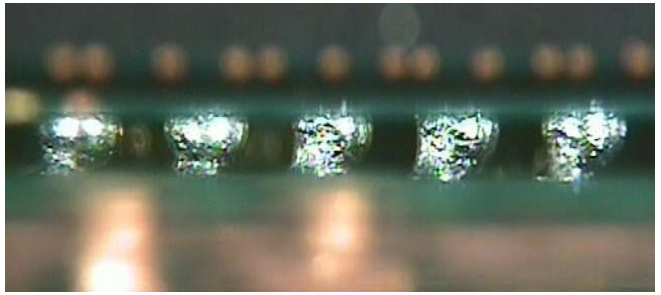


Source: "iNEMI PB-FREE Alloy Characterization Project, Part III- Thermal Fatigue Results for Low Ag Alloys", SMTAI'12

- In the short dwell thermal cycles there is a correlation between characteristic life and Ag content. Higher Ag content is better. Lead-free is better than SnPb.
- At -40°C/125°C, the differences between the Pb-free solder alloys diminish. It appears that all alloys are heading towards the characteristic life of Sn37Pb.

Challenges of Managing Multiple Alloys

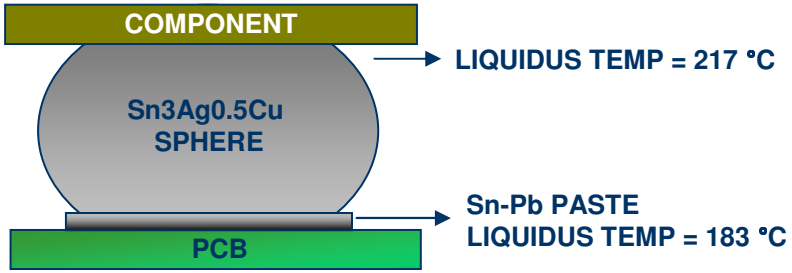
- Reliability of alternative lead-free BGA spheres with lead-free Sn3.0Ag0.5Cu paste.
  - Limited data is available on the thermal cycle performance of these alloys which is key to many of the high reliability community not building hand-held consumer products.
- Area array ball metallurgy changes impact the downstream manufacturing process.
  - Melting point differences
    - Reduced silver content can increase the melting point of the solder by as much as 10ºC.
  - Mixed alloy considerations
    - Improper/unmelted solder joint
    - Yield, reliability.
  - Part change notice (PCN) monitoring
  - Rework and return processes

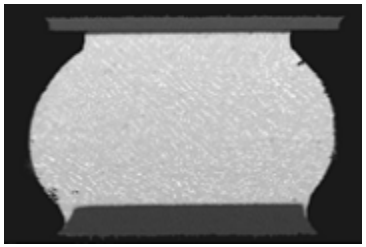


Unmelted solder joints

Mixed Alloy PCB Assembly Challenges

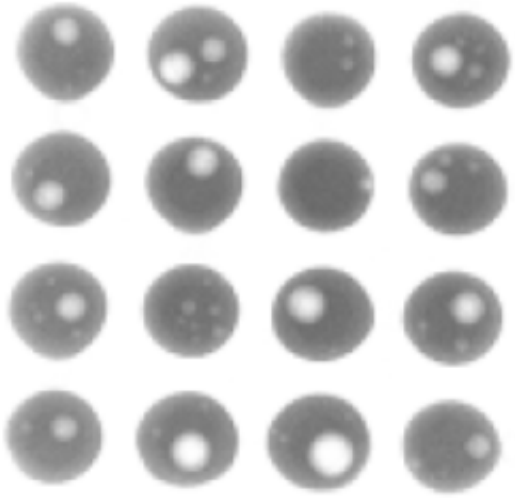
- **What is Mixed Alloy / Backward Compatibility?**
  - Area Array devices with Pb-free spheres attached with Sn/Pb solder paste.
- **Mixed Alloy PCBA Challenges**
  - Clear identification & communication of condition from supply base (PCN process)
  - Reflow profile definition to achieve homogeneous mixing of multiple alloys
  - Proliferation of unique sphere metallurgies (SAC305, SAC310, SAC101, etc…)
  - Profile limitations (time & temperature) for PCBs, components, flux systems.
  - Mixed Alloy processing is NOT recommended

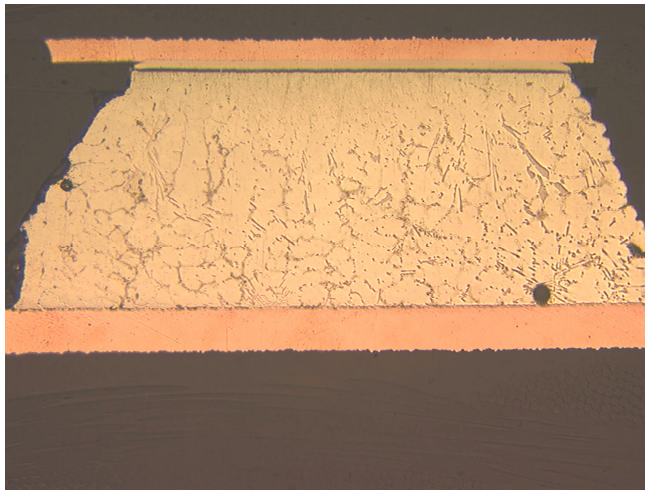


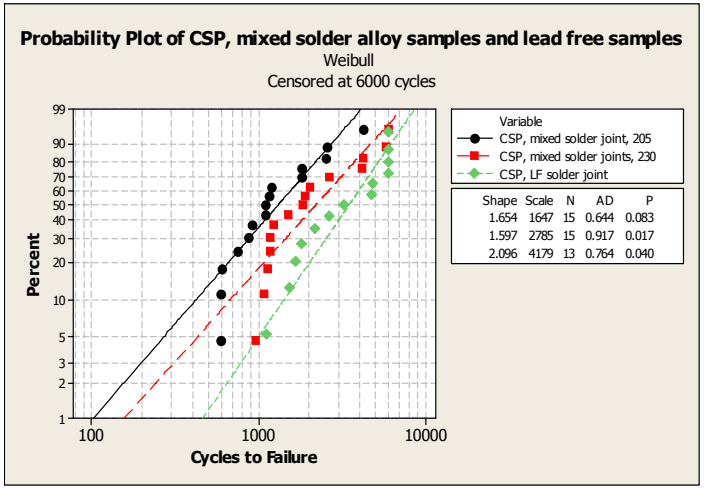


	Tin-Lead (63Sn37Pb)	SAC305 (Sn3Ag0.5Cu)
ALLOY MELTING POINT	183°C	217-220°C
TYPICAL REFLOW PEAK	210-220°C	235-260°C
COMPONENT RATING *(IPC/JEDEC J-STD-020D)*	225 +0/-5°C (240°C FOR SMALL & THIN COMPONENTS)	245°C (260°C FOR SMALL & THIN COMPONENTS)

Mixed Alloy PCB Assembly Concerns







- Mixed alloy solder joints usually results in more voiding.

- Inhomogeneous solder joint- Incomplete mixing solder joint is generally less reliable than homogeneous solder joint.

Conclusions

- SnAgCu (SAC305/SAC405) are common alloys for solder paste. The use of SAC305 is more popular due to cost pressure.
- SnAgCu (SAC 305, SAC 105) are common alloys for lead-free BGA components.
- There is increased interest in low silver content/lower cost solder alloys. Reliability and process yield are the key factors for its adoption.
  - Reliability of alternative alloys is a major concern, especially for high end products
- Compatibility issues and reliability risks must be carefully assessed. PCN monitoring, rework and remanufacturing needs to be taken into consideration.

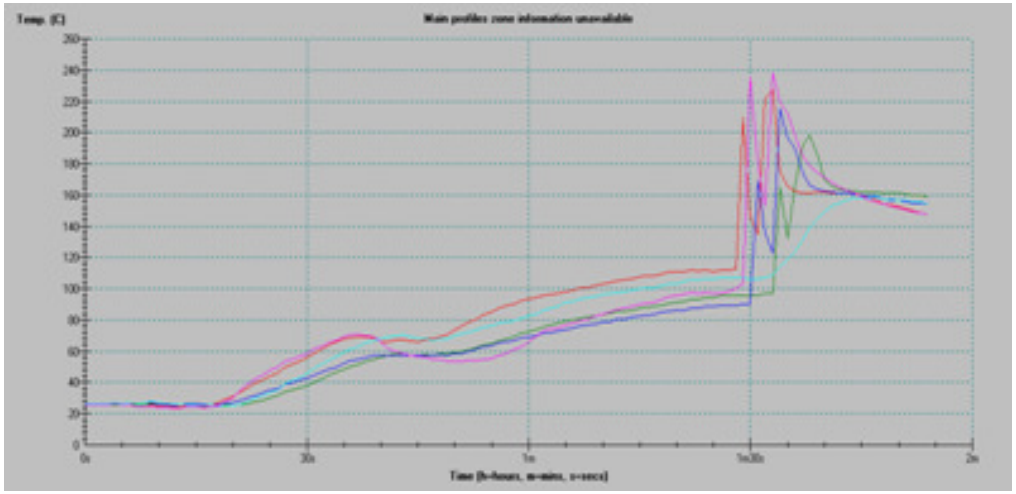
Lead-Free Solder Alloys in Wave Soldering Process

Common Lead-Free Solder Bars

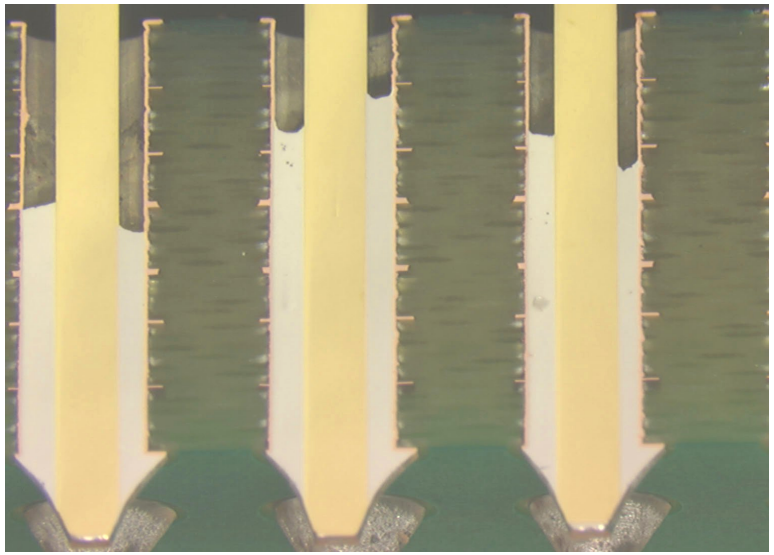
- SnAgCu (SAC305), SnCuNi (Sn100C) and SnCu are the common Lead-Free Alloys in wave soldering process.
- SnCuNi (and SnAgCu) are the common lead-free alloys in PTH minipot rework process.

Challenges in Lead-Free Wave Soldering

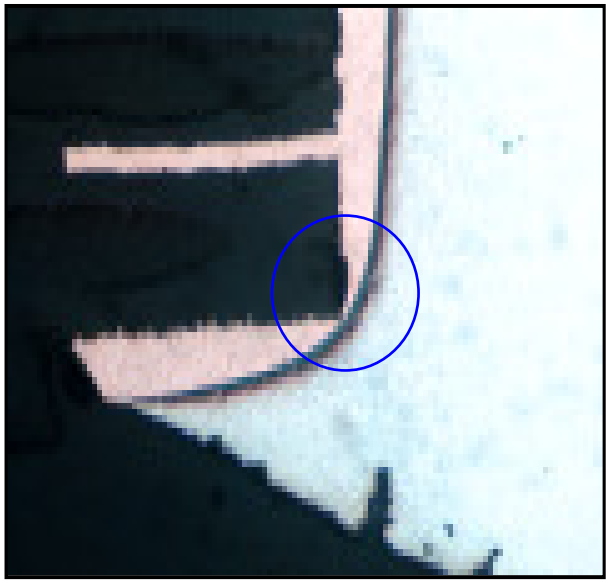
- Narrower Process Window
  - PCB & exposed SMT component temperature limitations decrease wave solder process window
  - Lead-free solder pot temperature: 260 - 270°C (mp: 217°C for SnAgCu and 227°C for SnCu/ SnCuNi). Tin-lead solder pot temperature: 245-250°C (TL(mp)is 183°C).
- Flux Materials
  - The existing wave flux materials, especially VOC-free and halogen-free flux materials are not well designed for lead free high temperature process
- Lead-Free Alloy Surface Tension and Wettability.



Challenges in Lead-Free Wave Soldering (Cont'd)



Hole Fill



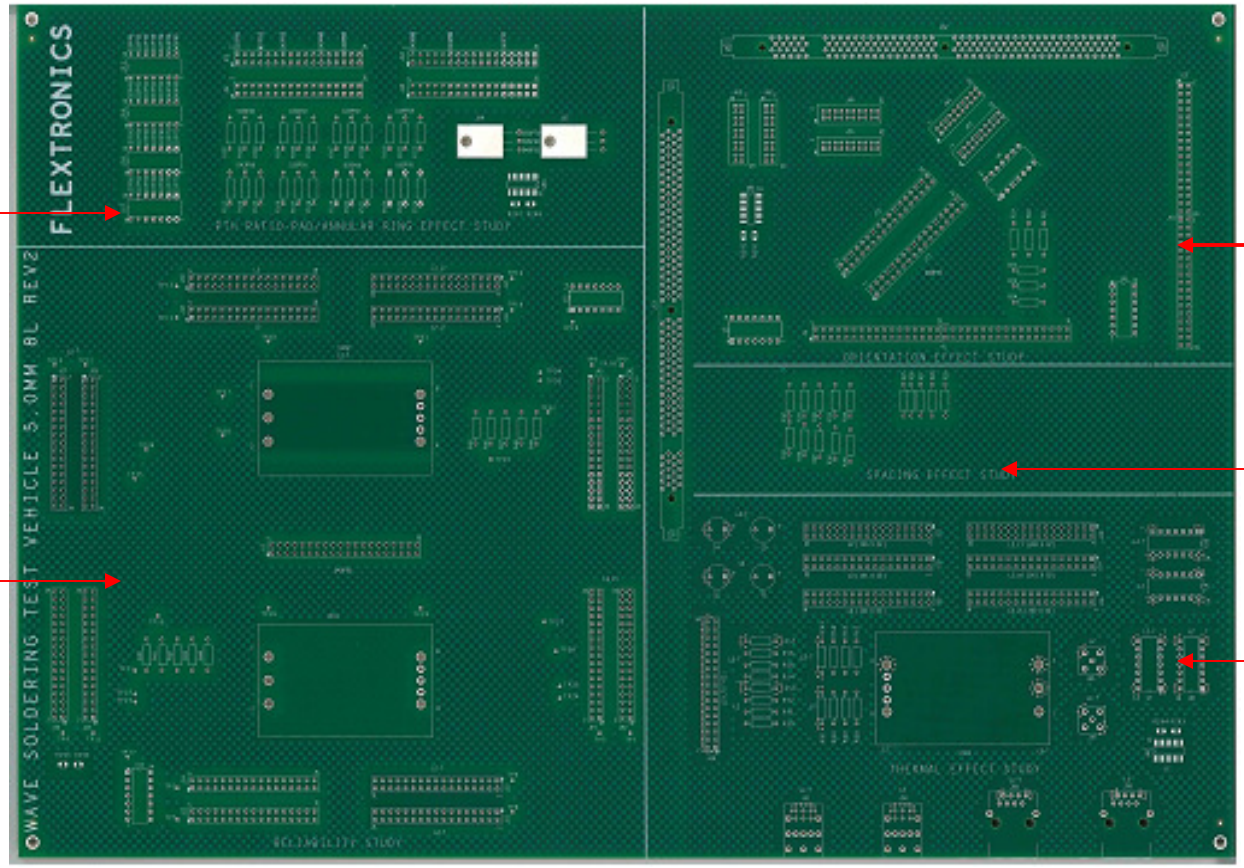
Copper Dissolution

- Achieving a good hole-fill on a thick board is still a process challenge using lead-free wave soldering, especially at components connected to heavy copper ground planes.
- Copper dissolution can happen during lead-free wave soldering.

Wave Test Vehicle and Components

• Different PTH Designs (P/H ratio, annular ring, pad diameter)

•Daisy chains (PTH and SMT)



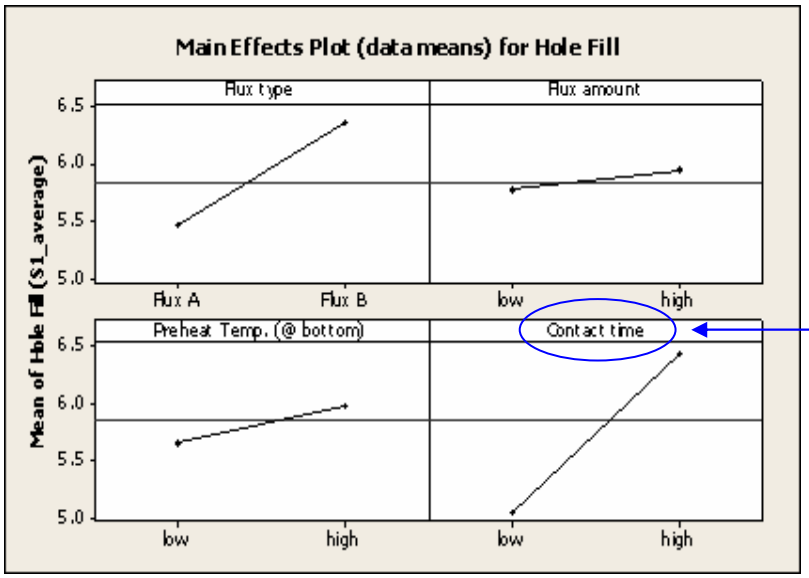
•Different orientations

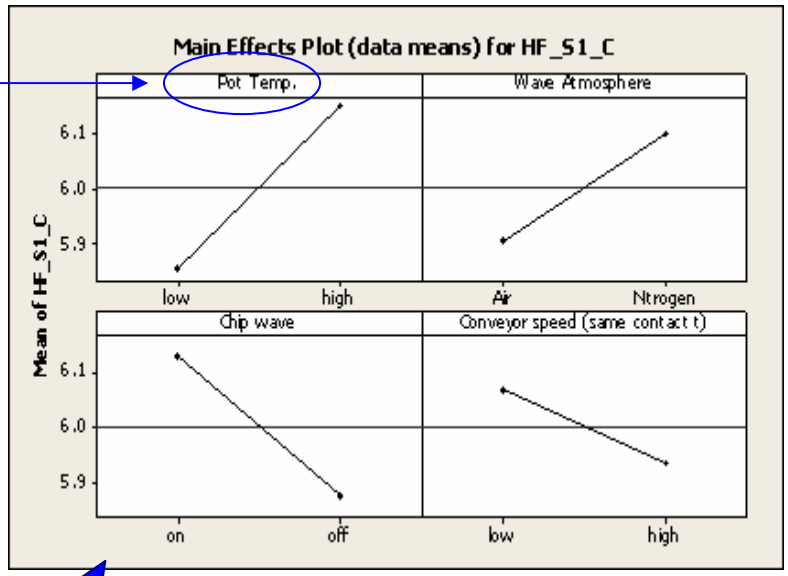
•Different Comp. Spacing

•Different # of ground planes & Copper thicknesses

• PCB Dimension: 406mm x 305 mm x 5.0mm (16”x12”x.200”)
• Components: Pin headers, DIMM connectors, BNC connectors, RJ45 connectors, DC-DC components, PDIP14, Axial resistors, TO-220, Al. cap., SMT components (0603, 0805, 1206, SOT, SOIC), etc...

Optimizing Hole Fill

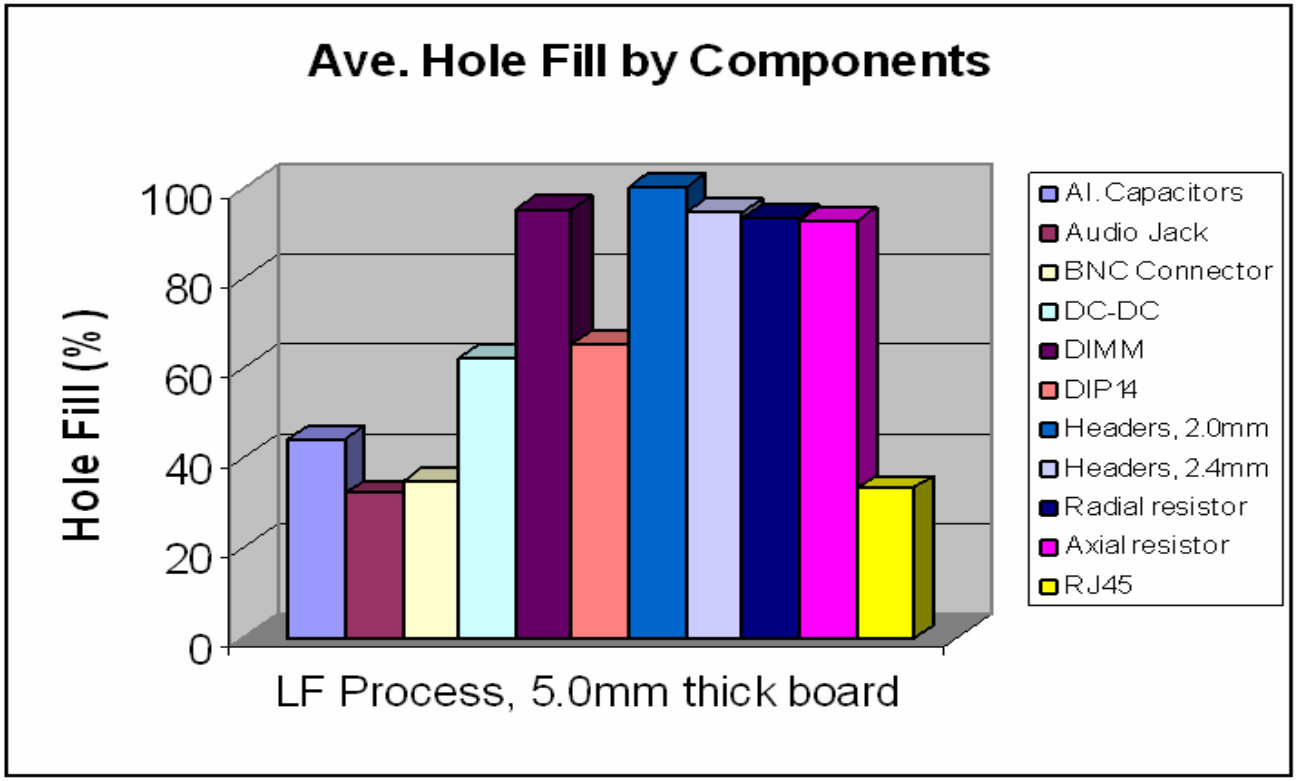




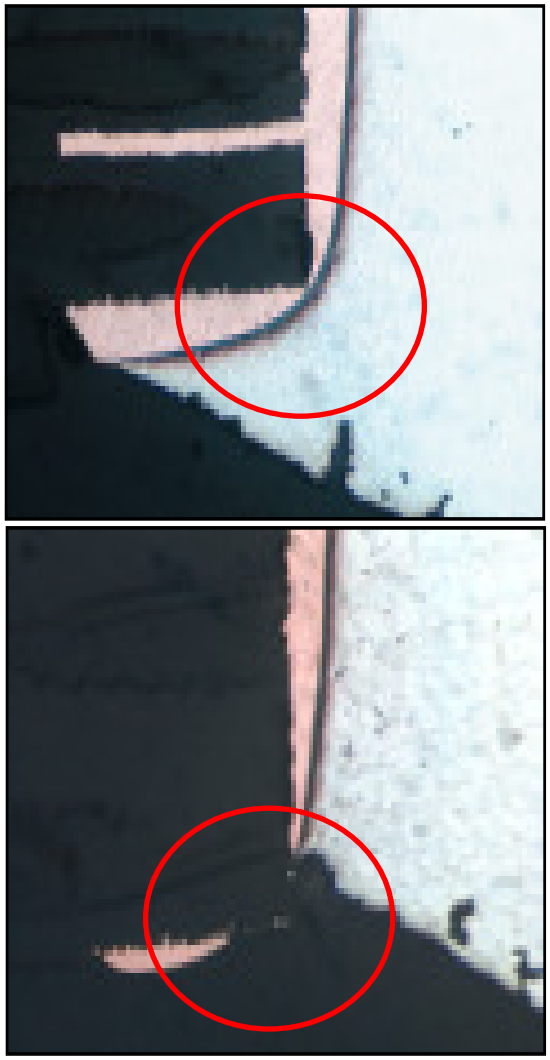
Most significant factors:
Contact time, pot temp

- Pot temperature, contact time, flux materials, flux amount, wave atmosphere, wave configuration/equipment, etc… are critical factors for hole-fill optimization.

Hole Fill vs. Component Types



Copper Dissolution



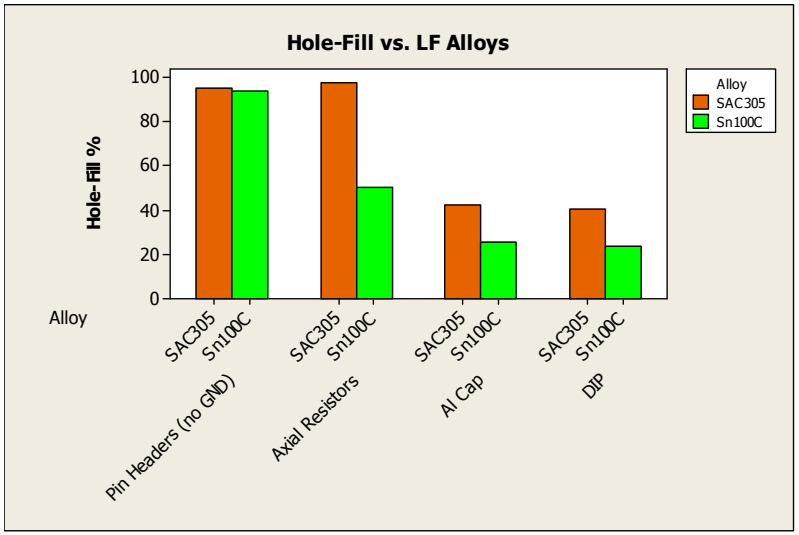
Cu dissolution

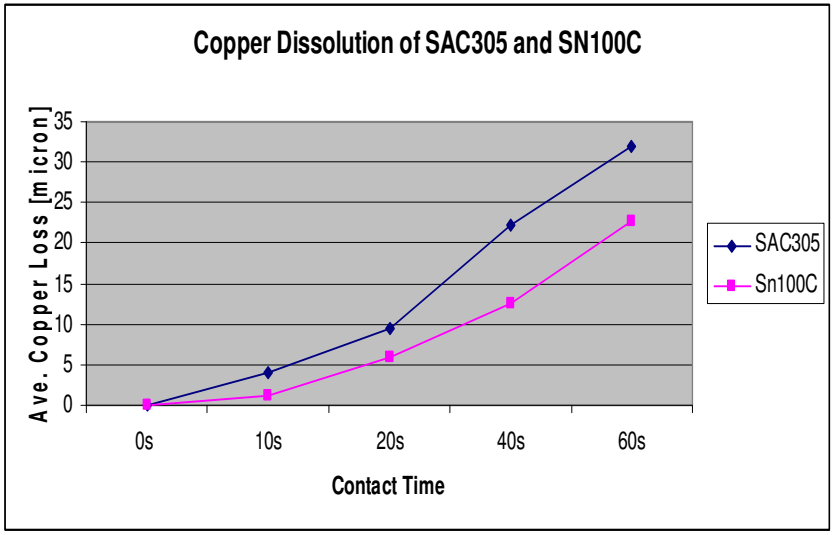
- Cu dissolution is a metallurgical reaction where the copper (Cu) dissolves into a tin-rich liquid (SAC305).
  - This reaction occurs at wave solder & PTH rework, however dissolution at wave solder seems to be less pronounced.
- Cu dissolution can vary between adjacent PTHs.
- Cu dissolution is a function of:
  - Solder temperature & alloy (Tin%) *(lower temperature = less dissolution)*
  - Solder dwell / contact time *(less contact time = less dissolution)*
  - Solder flow rate & direction *(lower flow = less dissolution)*
  - Other factors (plating chemistry, processes, batch variation, etc…).

Hole-Fill vs. Copper Dissolution

- For achieving better hole fill higher pot temperature and longer contact time should be used.
- However, high temperature and longer contact time result in more copper dissolution.
- Hole-fill and copper dissolution go hand-in-hand, but in opposite direction. Higher Ag contents help with hole-fill, but it would cause a higher copper dissolution rate. Additive elements (such as Ni, Ge, Sb, etc…) added to the solder alloy that will inhibit dissolution, may also inhibit wetting of the solder to the PTH.

Hole-Fill vs. Copper Dissolution (Cont'd)

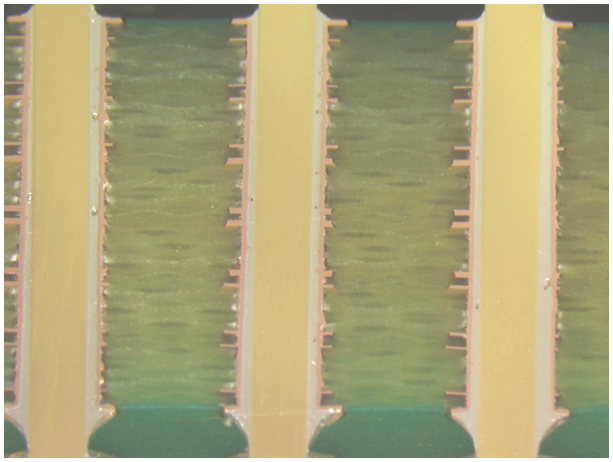


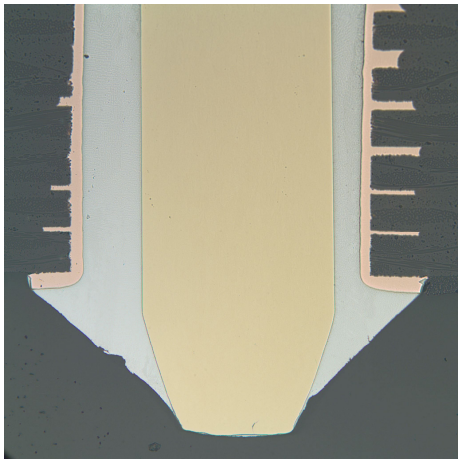


- The no silver alloy shows less hole fill using same settings.

- Higher temperatures and longer contact time increases the amount of Cu dissolution seen.
- SAC 305 has higher copper dissolution rate.

PTH Hole-Fill and Copper Dissolution Verification





- Hole-fill should be checked by X-Ray Inspection.
    - Minimum hole-fill requirement
        - 100%?, 75%?, 50%?, 0.047” solder wetted length?
- Cross section should be done for copper dissolution verification.
    - Minimum remaining copper thickness requirement
        - 0.5 mil after rework? 1X rework? 2X rework?
- The requirement for hole-fill and copper dissolution, product reliability and cost will drive the selection of the LF alloys used in wave soldering process.

Drivers for Alternative Alloys

- The driver for the alternative alloys is cost saving and/or reliability, depending on the product applications.
- For consumer electronics applications, users are looking for cost effective replacement alloys due to the high cost of silver and the high silver content.
- For the high reliability products, the main concern is the reliability under static and dynamic mechanical loading conditions.

Conclusions

- Tin-silver-copper family and tin-copper family are two dominant wave alloy systems in the industry.
- Sn3.0Ag0.5Cu (SAC305) has been commonly used alloy, but the industry is looking to alternative alloys.
  - The driver for the alternative alloys is cost saving and/or reliability, depending on the product applications
- It is expected that use of low silver content and lower cost wave solder alloys with an equivalent performance (in term of hole-fill, copper dissolution, yield and reliability) will increase in the future, especially for cost sensitive products.
  - Additional elements to the solder alloy often have opposite effect on wetting and Cu dissolution
- Reliability of the PTH solder joint under dynamic mechanical stress is an important consideration.
- Compatibility issues and reliability risks must be carefully assessed. Rework and remanufacturing need to be taken into consideration.

We will continue to deliver!

Thank You