iNEMI

International Electronics Manufacturing Initiative

# Pb-Free BGAs in SnPb Assembly Process Study

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# Pb-Free BGAs in SnPb Process Study

## Project Justification

- ✓ For companies choosing to take the RoHS exemption and continue to manufacture SnPb products beyond July 1, 2006, there will be a growing issue with the lack of availability of SnPb components. Many companies may be compelled to use Pb-free BGAs in a SnPb process, for which the process and reliability have not yet been characterized.

## Project Objectives

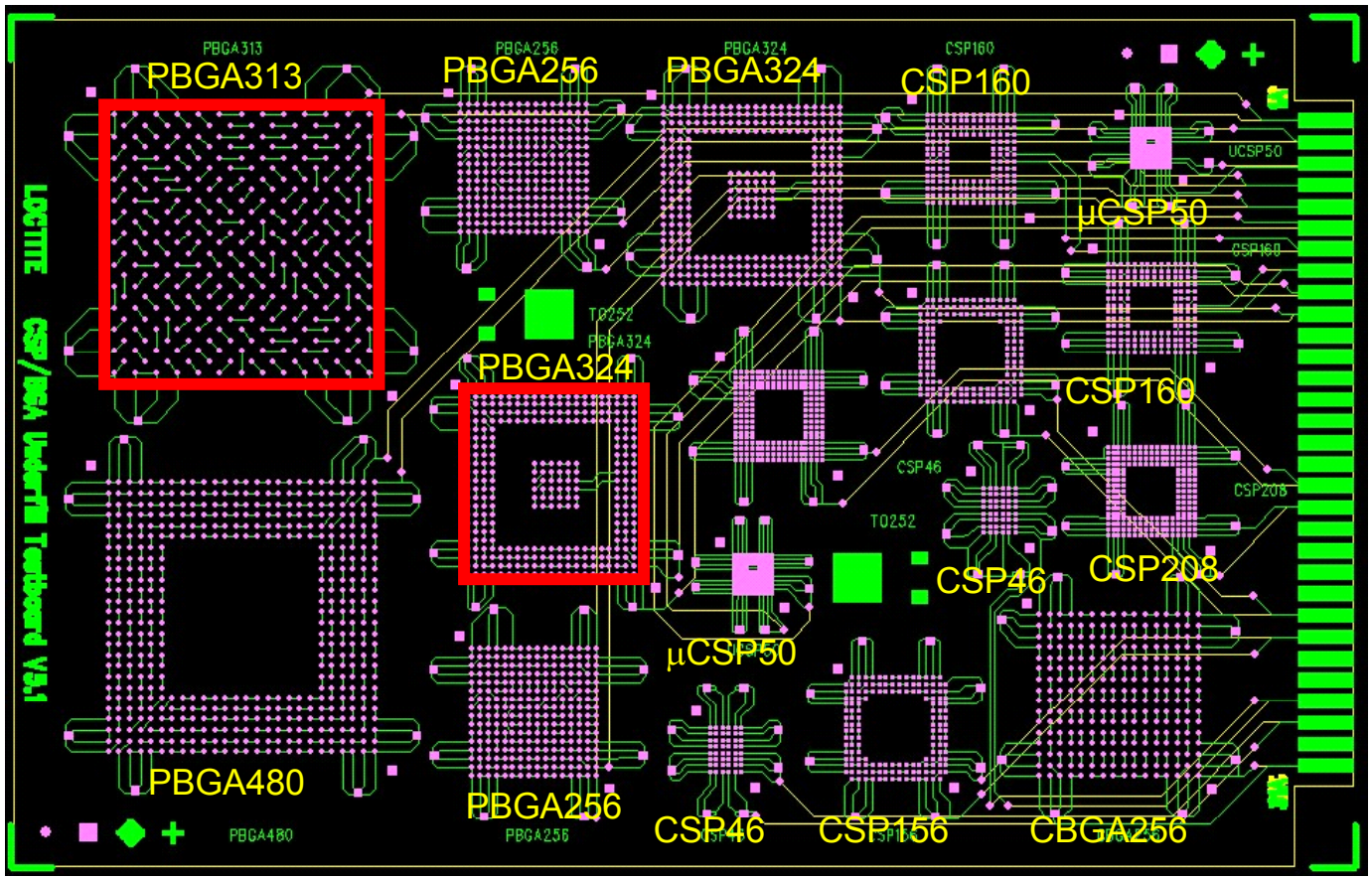
1) To assess the process parameters for assembling Pb-free SnAgCu BGAs under the temperature constraints of a conventional tin-lead (SnPb) assembly process.

2) To understand the reliability of mixed-alloy (SnAgCu in SnPb) solder joints.

3) To develop a “generic” process guideline and risk assessment for assembling Pb-free BGAs in a SnPb assembly process.

# Phase 1 Test Vehicle

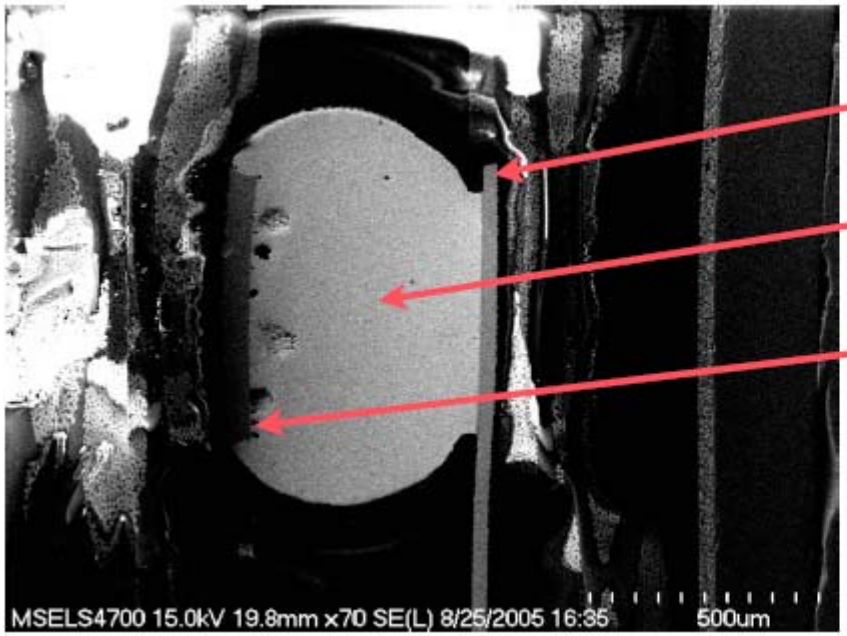
Phase 1: Characterization of peak temperature and time above Liquidus (TAL) for mixed (SnAgCu in SnPb) solder Joints




✓PBGA 313 and PBGA324 were selected for examination

# SEM and EDS Analysis of Phase 1 Assemblies

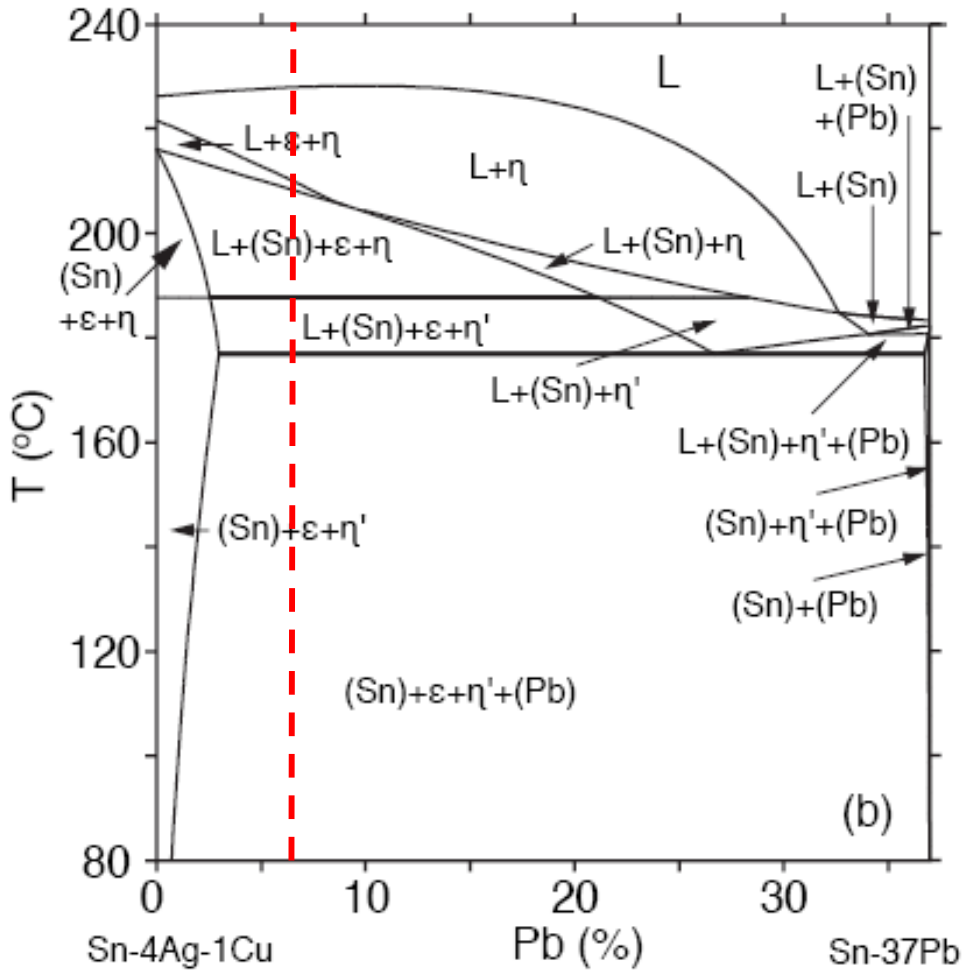
- Large BGA (PBGA313,Alloy: SAC405); Board Serial 3 diagonal target
- Considered 205, 225, 240°C, middle connection only




- Ni-Au finish on package side pad
- Pb-free ball & Sn-Pb eutectic paste with no clean flux
- Immersion Ag finish on board side pad

- Postulated Pb in the joint: 6wt.% (A preliminary measured composition was ~3.4wt.% from PBGA313 @240°C)

# Phase Diagram of SAC-Sn37Pb




*Ref. U.R. Kattner and C.A. Handwerker: Z. Metallk. 92 (2001) pp. 7*

# Solidification Paths of SAC with/without Pb

η: $Cu_6Sn_5$, ε: $Ag_3Sn$

| Sn-4% Ag-1% Cu (SAC) | | | |
|---|---|---|---|
| Lever | | Scheil | |
| 225 °C | L + η | 225 °C | L → η |
| 221 °C | L + η + ε | 221 °C | L → η + ε |
| 215 °C | (Sn) + η + ε | 215 °C | L → (Sn) + η + ε |
| **Sn-4% Ag-1% Cu with 16.2% Sn-37Pb contamination (SAC-Pb)** | | | |
| Lever | | Scheil | |
| 227 °C | L + η | 227 °C | L → η |
| 210 °C | L + η + ε | 210 °C | L → η + ε |
| 208 °C | L+ (Sn) + η + ε | 208 °C | L→ (Sn) + η + ε |
| | (η → η´) | | (η → η´) |
| 187 °C | L+ (Sn) + η´ + ε | 187 °C | L→ (Sn) + η´ + ε |
| 176 °C | (Sn) + (Pb) + η´ + ε | 177 °C | L→ (Sn) + (Pb) + ε |

*Ref. U.R. Kattner and C.A. Handwerker: Z. Metallk. 92 (2001) pp. 7*

# Predictions of SAC-Pb Microstructures

- The $T_{eu.}$ & $T_L$ values depending on alloys:
  - -Sn-37Pb: $T_{eu.}$ = 183 °C, $T_L$ = 183 °C
  - - SAC: $T_{eu.}$ = 217 °C, $T_L$ = 225 °C
  - - SAC-Pb: $T_{eu.}$ = 177 °C, $T_L$ = 227 °C

**Below 227°C, partially melted phases are present as primary phases**

**Expected primary phases of SAC-Pb include:**

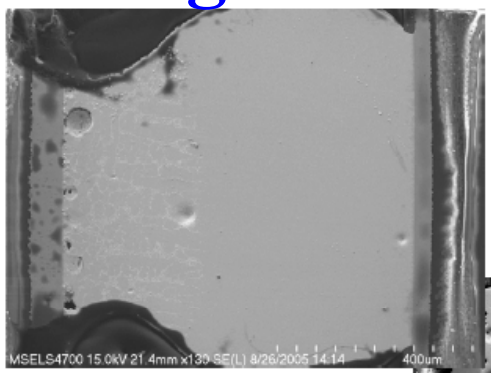
- (Sn) + η + ε @ 205 °C solder ball temperature
- η @ 225 °C solder ball temperature

- **Last phases of SAC-Pb to solidify: (Sn) + (Pb) + ε @ 177 °C**

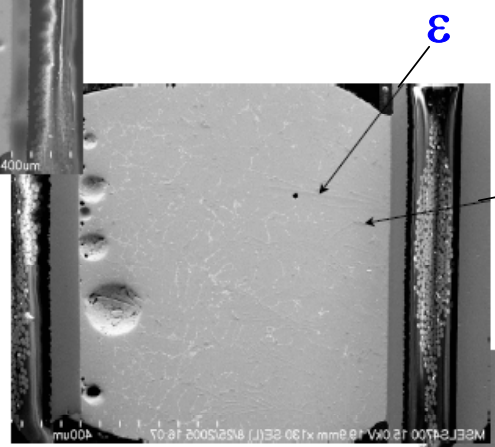
- **Expected eq. phases of SAC-Pb: (Sn) + (Pb) + η + ε @ R.T.**

# Microstructural Analysis

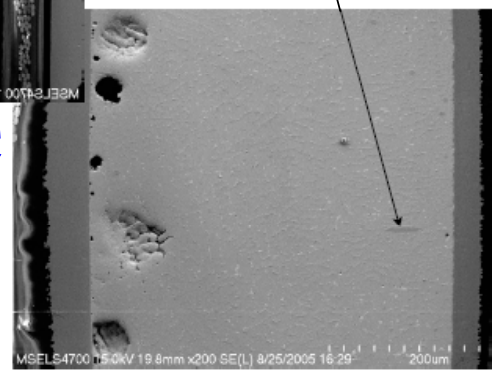
## Large BGA (PBGA313)



Reflow @ 205°C
Primary solids:
(Sn) + η + ε




Reflow @ 225°C
Primary solid: η



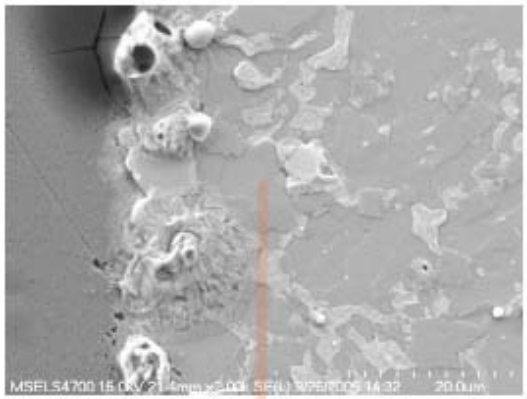

Reflow @ 240°C
Primary solid: none

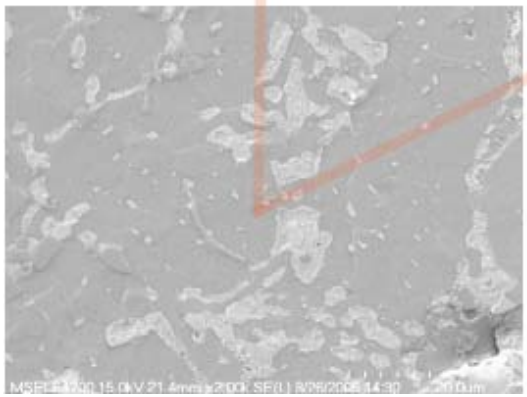
Observations

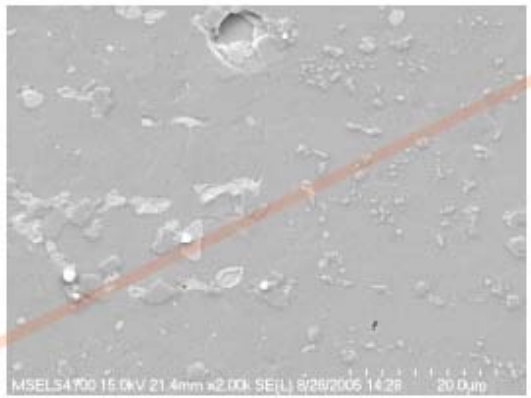
- Solder balls started to melt from the board side.
- The η and ε primary solids were often observed even above their melting temperature

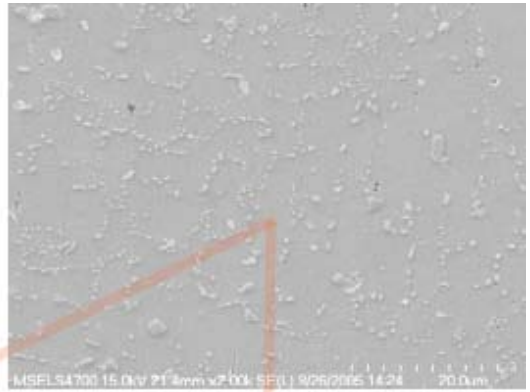
# Details of Large BGA (PBGA313) @ 205 ºC

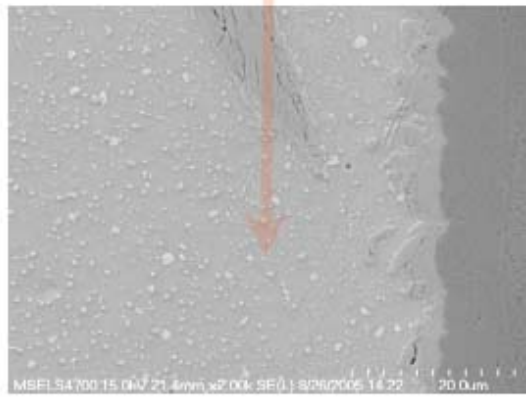
Board Side







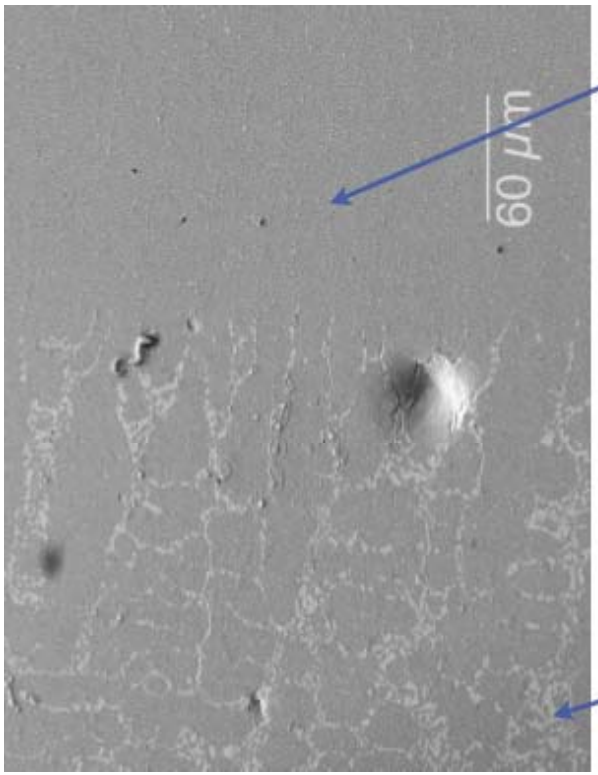




Component side

# Large BGA (PBGA313) @ 205 ºC

Component side




Board side

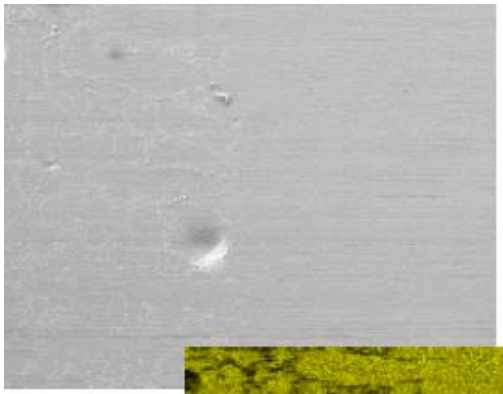
**(Sn) + η + ε**: starts to melt @ 217 ºC

non-melted SAC

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

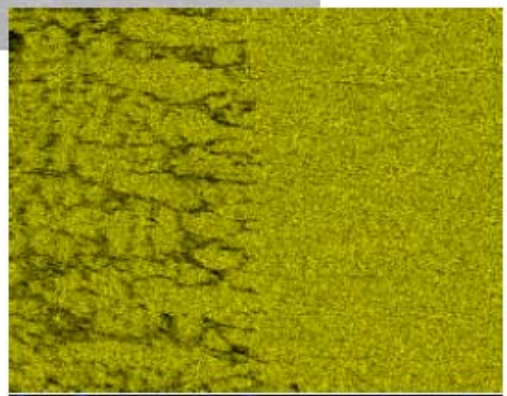
**(Sn) + (Pb) + ε**: starts to melt @ 177 ºC

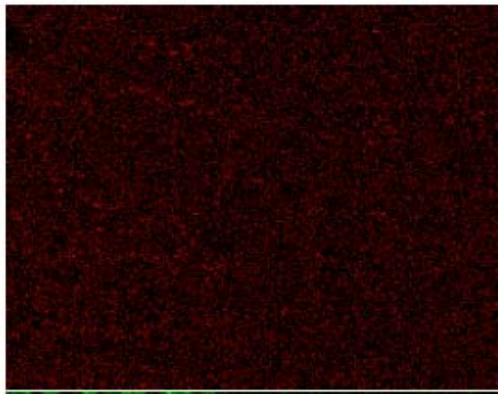
# Compositional Map of Large BGA (PBGA313) @ 205 ºC



Note: Ag concentration shown in lower left map is increasing due to dissolution of immersion Ag surface finish as well as dissolution of SAC.

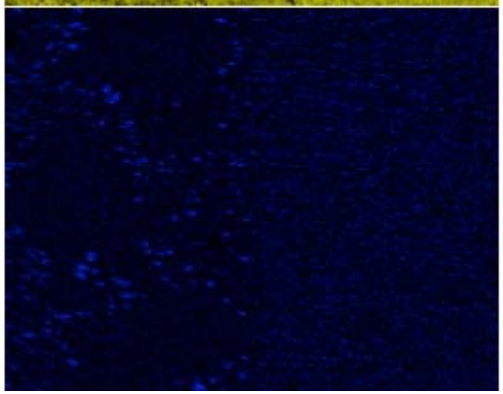
(Sn)

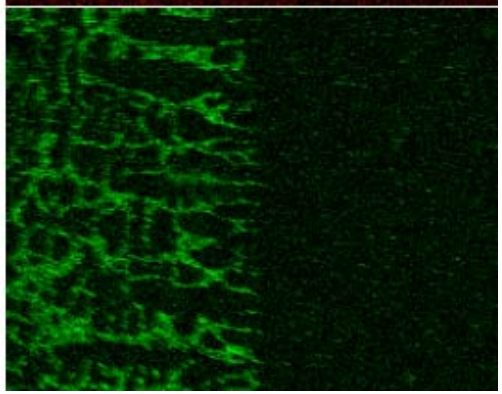




(Cu)

(Ag)

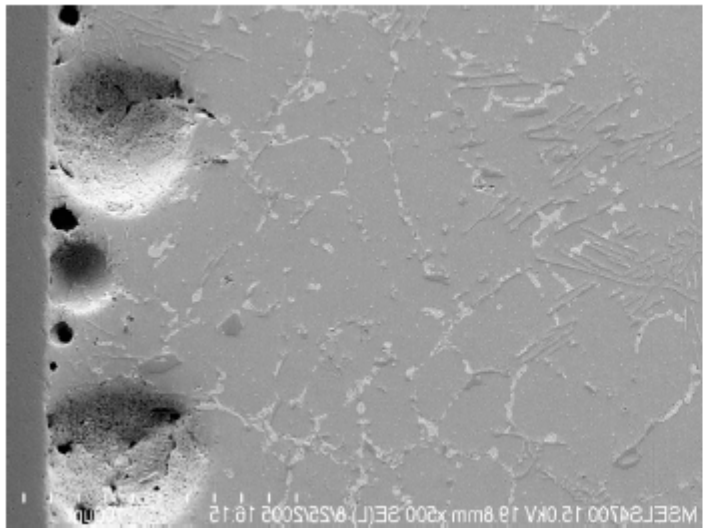


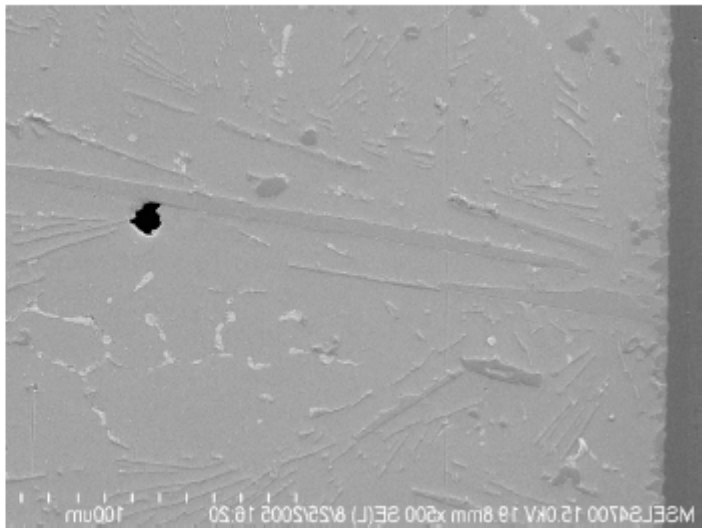


(Pb)

# Large BGA (PBGA313) @ 225 °C Observations

Board Side





Component Side

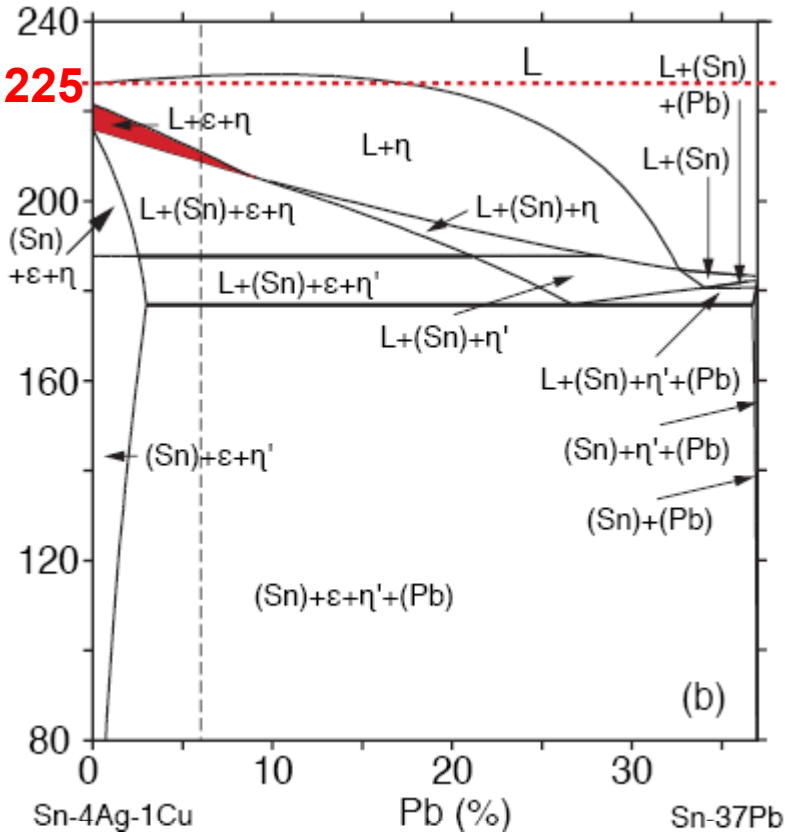
Observations

- (Sn)-$Ag_3Sn$ binary eutectic structure.
- $Cu_6Sn_5$ primary solid near the board side and $Cu_6Sn_5$ + $Ag_3Sn$ primary solids near the package side.
- The $Ag_3Sn$ IMC grew to abnormal size

# Large BGA (PBGA313) @ 225 ºC

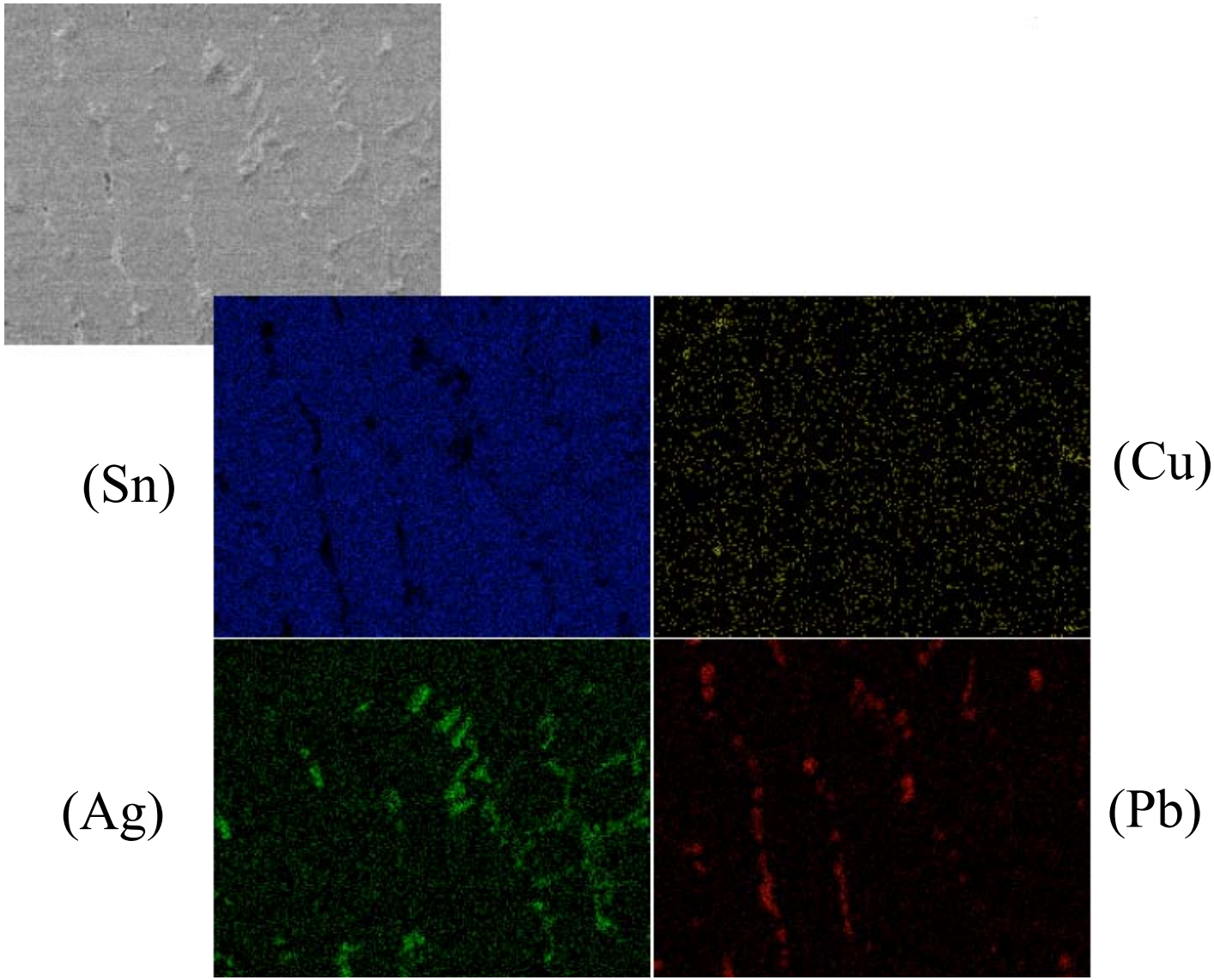
## Reflow Temperature vs. Solder Ball Temperature

For PBGA313 reflowed at 225 ºC, η is the only primary solid that should be observed based on the phase diagram.

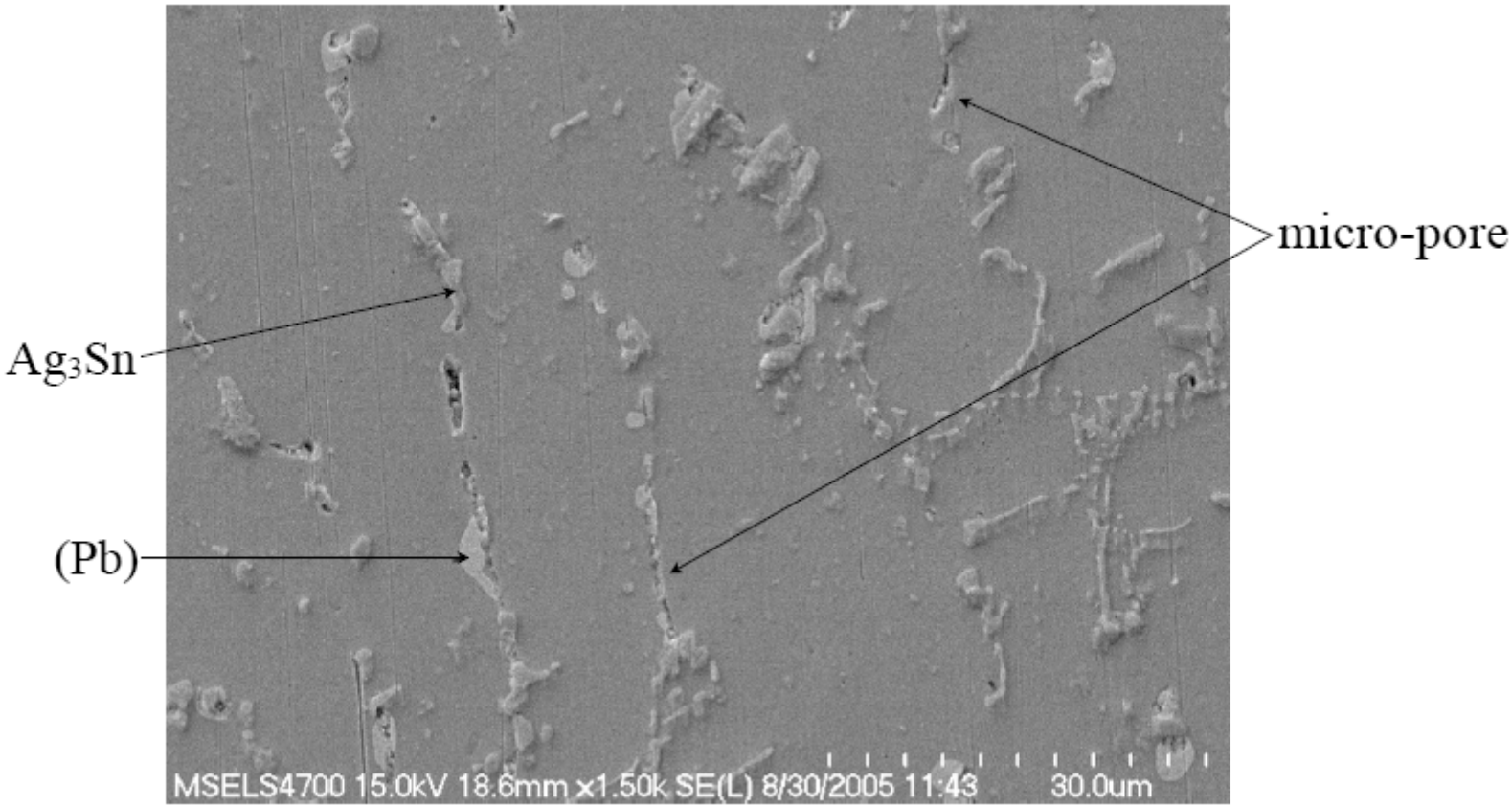



- The solder ball temperature may be placed in the phase region of L+ ε + η.
- In this phase region, the primary solid $Ag_3Sn$ grew to an abnormal size by a dissolution precipitation process with Ag partially from the Ag finish on board side pads.
- The solder ball temperature did not reach the reflow temperature.

# Compositional Map of Large BGA (PBGA313); 240 ºC



# Large BGA (PBGA313) @ 240ºC




Final solidified phases of SAC-Pb @ 177 ºC: (Sn) + (Pb) + ε

# Summary

- **Observed microstructures are in agreement with predictions based on the calculated solidification path: especially, the Scheil calculations.**

- **SAC-Pb formed the final frozen phases: (Sn) + (Pb) + ε with melting point: ~177 ºC (calculated), and micro-pores were observed in the same area.**

  - » Further investigation of porosity effects may be required, which results from different phase fractions compared to equilibrium microstructures.

- **At 205 ºC reflow temperature, there are significant differences in microstructure between the melted SAC-Pb and non-melted SAC. In addition, the primary ε phase will grow to an abnormal IMC size if the reflow temperature is not sufficient to melt it. These features may be unfavorable to the reliability of the solder joint.**

- **The growth of the $Cu_6Sn_5$ IMC has less influence on the microstructures than that of the $Ag_3Sn$ IMC.**

# Phase 2

## Reliability of the Pb-free BGAs in SnPb Assembly process Through ATC and Mechanical Testing

# Phase 2 Components Consideration

Phase 2: Reliability studies of mixed (SnAgCu in SnPb) solder joints

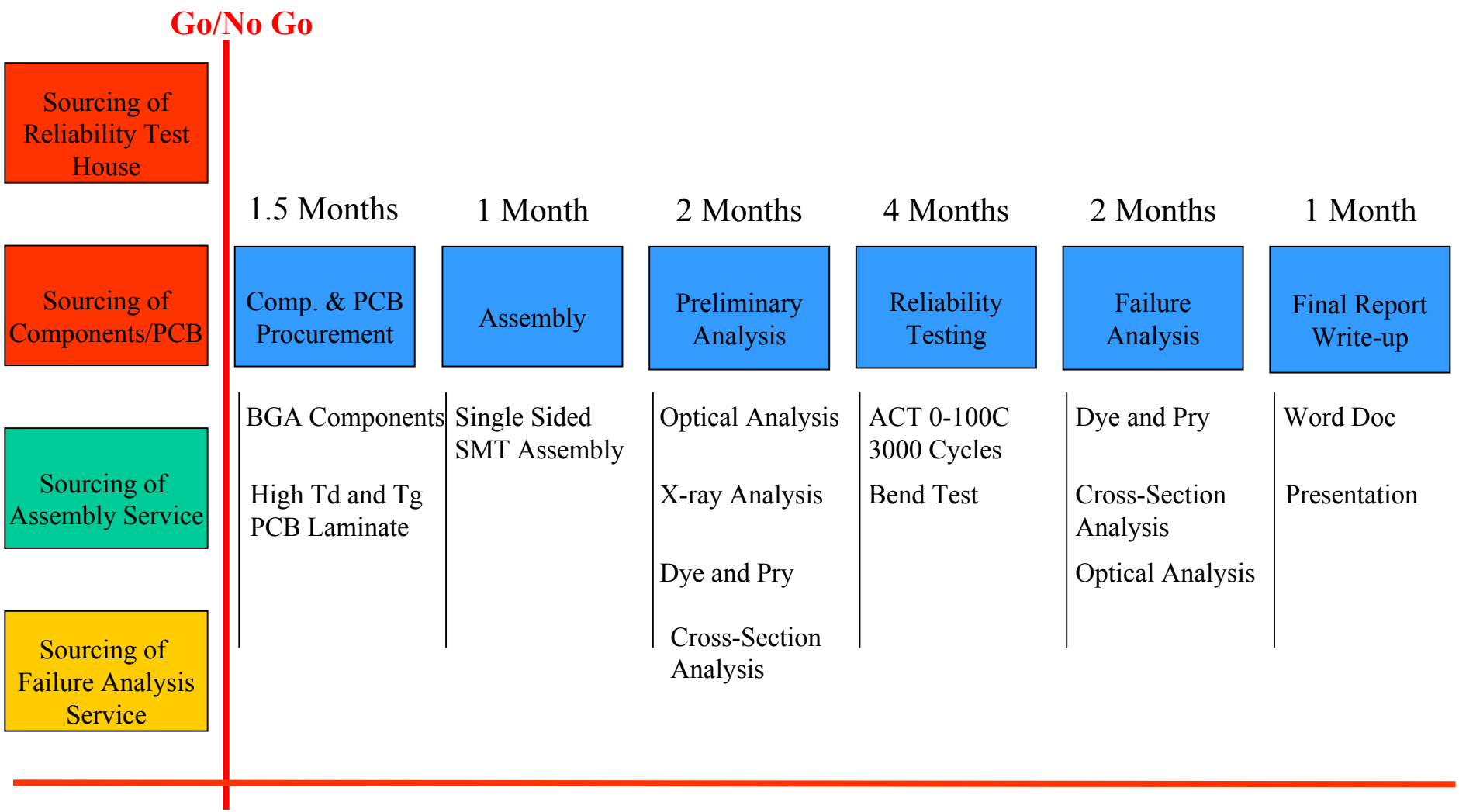
| Component Part Numbers | I/O | Pitch (mm) | Size (mm) | Ball Alignment | Quantity per Board | Total Parts |
|---|---|---|---|---|---|---|
| A-SBGA600-1.27mm-45mm | 600 | 1.27 | 45 | Perimeter | 3 | 400 |
| A-PBGA324-1.0mm-23mm | 324 | 1.00 | 23 | Perimeter | 3 | 400 |
| A-CABGA288 0.8mm-19mm | 288 | 0.8 | 19 | Perimeter | 3 | 400 |
| A-CTBGA132-0.5mm-8mm | 132 | 0.5 | 8 | Perimeter | 3 | 400 |

**Note:**

- **SnPb components of each type will be used for baseline runs.**
- **A range of different component sizes (in pitch) has been selected for study**

Reliability Studies: Accelerated Thermal Cycling Tests, Bend Tests and Microstructural studies through optical and electron microscopy.

# Phase 2 Est. Timeline - Diagram



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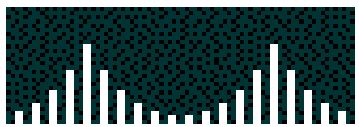

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