Successes and concerns in lead-free manufacturing

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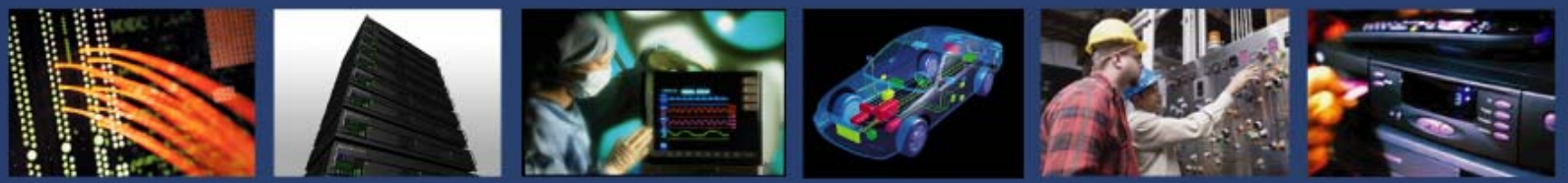
Agenda

- 1. SMT:
  - Spreading, soldering temperatures, voiding
- 2. Wave
  - Holefill, voiding
- 3. Rework
  - Rework Temperatures
  - Rework (Cu dissolution) issues
- 4. Process/ Equipment Segregation
  - Segregation for wave soldering and rework
- 5. ROHS Component Materials segregation
- 6. Assembly: Forward/ Backward compatibility issues
- 7. ROHS compliance assessment
- 8. Lead-free product
- 9. Conclusions

Solectron Chemical Recommendation

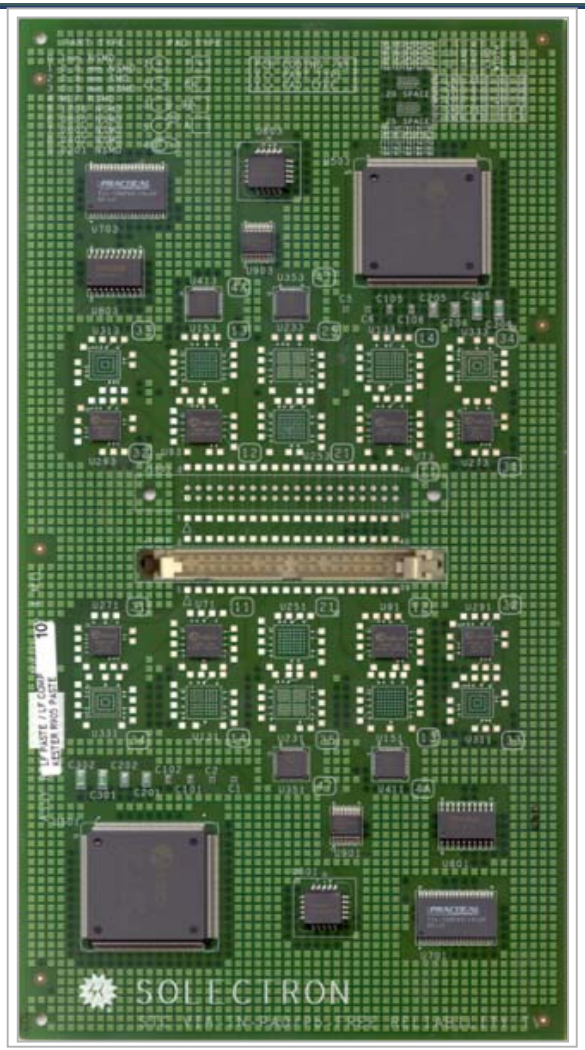
- Solder paste – Sn3Ag0.5Cu
- Wave solder – Sn3Ag0.5Cu
- Hand solder – Sn3.5Ag rework wire
- BGA rework –Sn3Ag0.5Cu solder paste or paste flux.

Melting point of these SnAgCu alloys (217C) are 34C above that of tin-lead (183C) so increased board and component assembly temperatures



Lead-free SMT processes

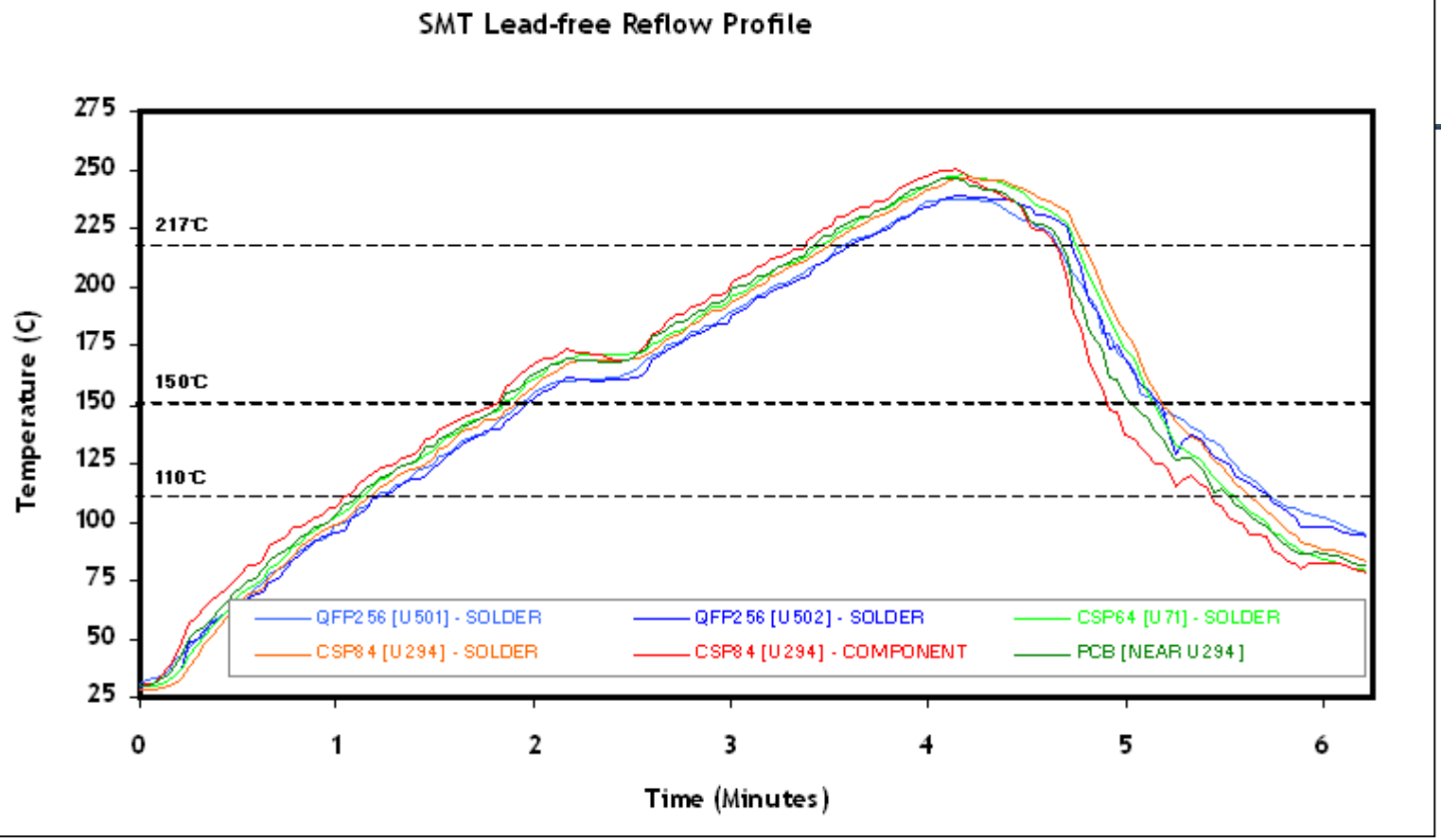
Solectron Lead-free SMT Reliability Test Vehicle



List of Devices on the Test vehicle

- *0.5mm pitch CSP 84 I/O*
- *0.8mm pitch CSP 64 I/O*
- *0.5mm pitch MLF 44 LD*
- *0.4mm pitch QFP 256 LD*
- *0.65mm pitch SSOP 20 LD*
- *0.8mm pitch TSOP 44 LD*
- *1.27mm pitch SOIC 20 LD*
- *1206, 0805, 0603 and 0402 chip resistors*

93mil thick FR4 board



Thermocouple Location	Peak Temperature [°C]	Max Rising Slope [°C/sec]	Preheat Zone (110-150°C) [sec]	Soak Zone (150-217°C) [sec]	Time Above Liquidus (>217°C) [sec]
QFP256 [U501] - Solder	238.1	1.7	43.3	98.5	65.6
QFP256 [U502] - Solder	239.0	2.2	44.8	97.2	68.3
CSP64 [U71] - Solder	248.0	2.2	43.8	96.2	77.8
CSP84 [U294] - Solder	247.1	2.0	44.5	94.1	79.0
CSP84 [U294] - Component	250.1	2.6	46.2	94.2	76.7
PCB [Near U294]	247.3	2.1	44.5	94.2	77.2

For SnAgCu reflow

Typical Time over 217°C= 45 to 90 seconds

Typical Min. Solder Joint temp: 235°C

Typical Max. Solder Joint temp: 250°C

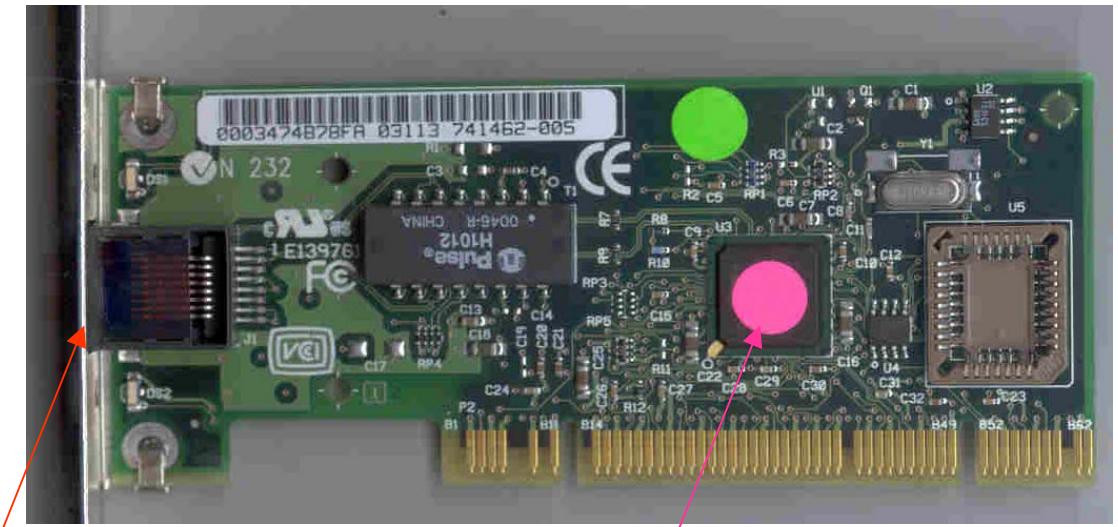
Component assembly temperatures for lead-free soldering

- One of the main challenges is the availability of components that can withstand the higher melting temperatures required for lead-free manufacturing.
- Today's tin-lead attachment (Sn37Pb) alloy melts at 183°C with typical reflow temperatures of 205-220°C.
- SnAgCu lead-free alloy's melting point is 217°C with typical reflow temperatures of 235-250°C.
- Due to these higher lead-free soldering temperatures, component suppliers need to re-qualify their parts

  (J-STD-020C: Moisture/ Reflow Classification for Non-hermetic Solid State Surface Mount Devices)

Increased temperatures for lead-free SnAgCu soldering

Image of fully assembled board (Solectron/ Intel study: Ref. IPC Annual Meeting, 2002) 63mil thick board, FR4, Imm. Ag finish



Topside

RJ45
Connector

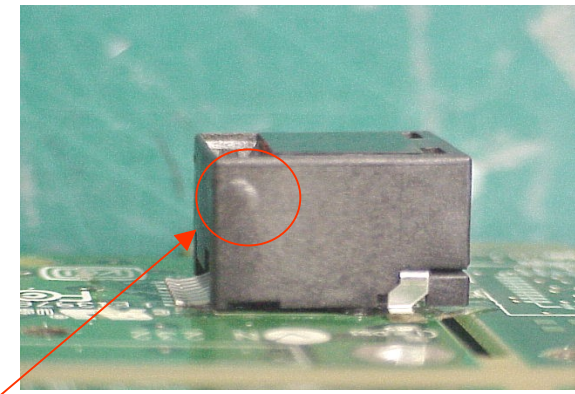
Lead-free
BGA

Bottomside

Tin-Lead and Lead-Free Assembly Results

Tin-lead assembly

Phase 1A (Tin-lead paste assembly and BGA rework): no issues



Lead-free assembly

Phase 1B Part 1: 30 Boards

- Non-wetting at some center LED center leads
- RJ45 connector Popcorning
  - RJ45 Popcorning Root Cause was Moisture Absorption.
    - DOE Performed to Eliminate Popcorning by Baking Components. All Remaining Parts Baked Prior to Assembly (80°C for 48 Hours)
    - No further issues in subsequent builds
- PCB Silkscreen Discoloration
  - Slight Silkscreen Discoloration Was Determined to Pass Customer Workmanship Standards Criteria.

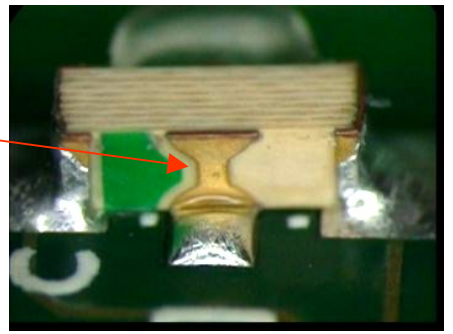
Phase 1B Part 2: 90 boards

- Non-wetting at LED center lead. No other issues
- BGA rework successful (Passed X-Ray inspection, ICT, FT)

Lead-Free Assembly Results

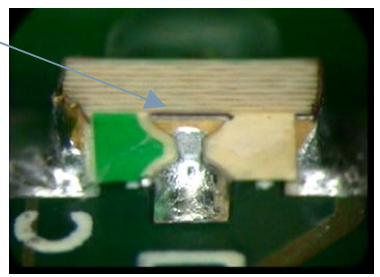
Phase 2: 252 boards

- Non-wetting at LED center lead
- BGA rework successful (Passed X-Ray inspection, ICT, FT)



Phase 3A: 252 boards:

- Increased stencil aperture opening for LED center lead. LED solder joints had better solder fillets. No non-wetting defect at LED. All Future builds used increased stencil aperture opening.
- BGA rework successful (Passed X-Ray inspection, ICT, FT)

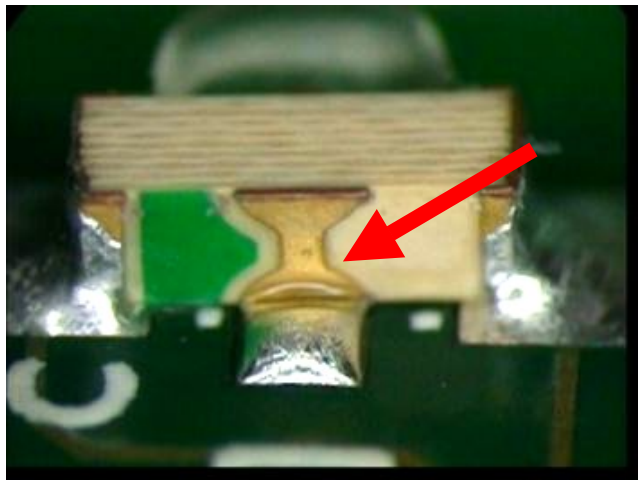


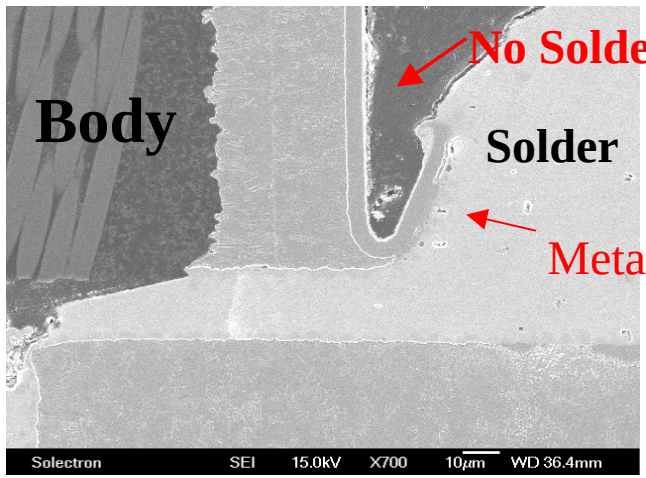
Phases 3B/4A/4B: 700 boards:

- Non-wetting at LED center lead using enlarged stencil aperture still present.
- BGA rework successful (Passed X-Ray inspection, ICT, FT)

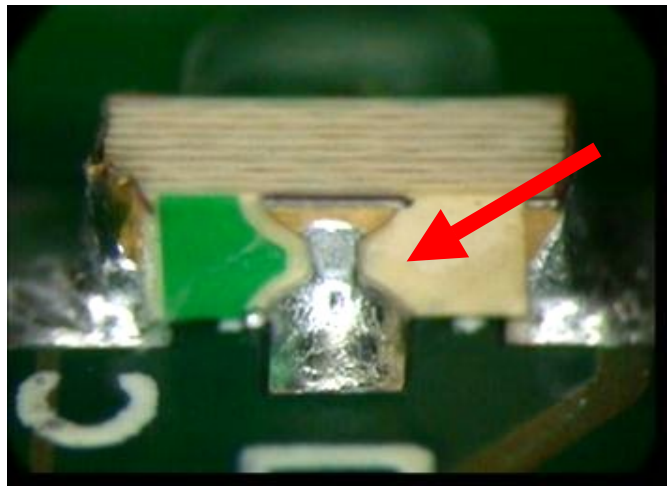
LED Wetting Pictures

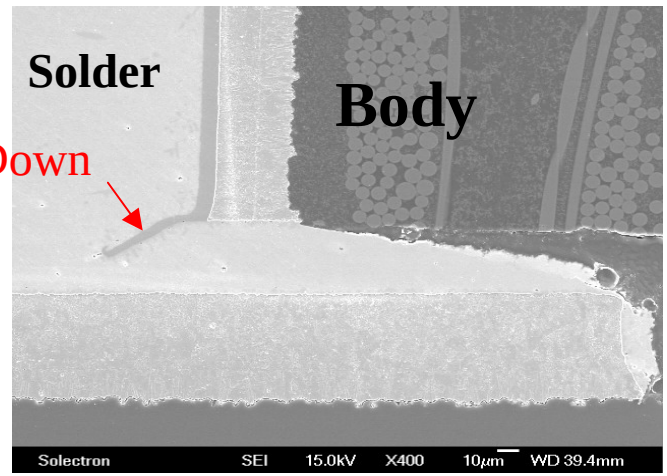
Non-Wetting on Center Lead





Good-Wetting on Center Lead





LED Non-Wetting Analysis

- Where the Pad Meets the Lead, There Is a "Metal Burr" Sticking up From the LED Component Lead Cutting.

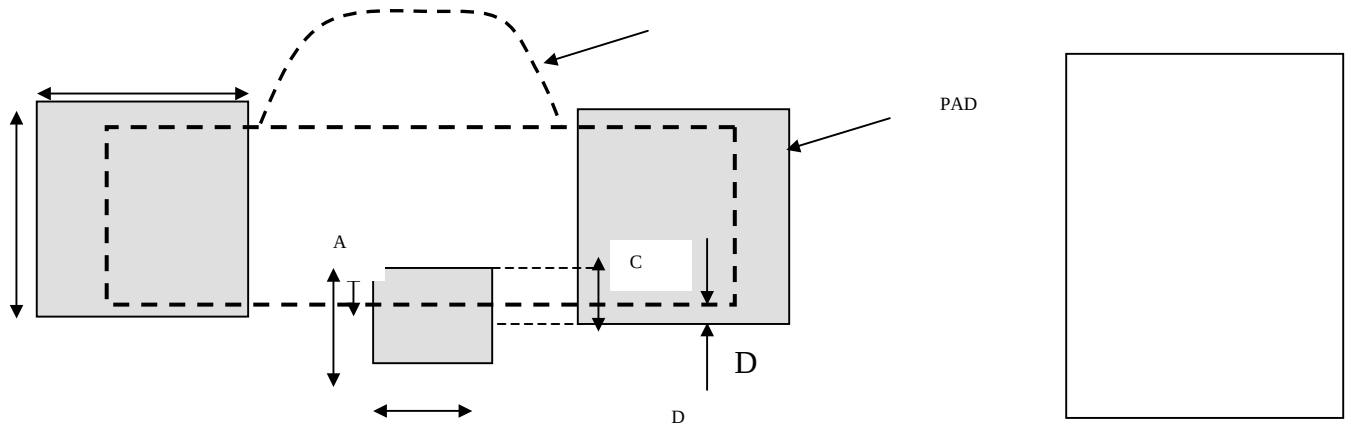
- The Lead-free SnAgCu solder paste has slower wetting compared to the SnPb paste and the surface tension of the SnAgCu is higher than tin-lead.

- The metal burr acts to increase the solder daming action with the higher surface tension SnAgCu solder.

- Component Spec Is 0.1mm Length for Burr and Can Not Be Eliminated. This is likely to be a contributor to the intermittent nature of this problem

LED Non-Wetting Analysis

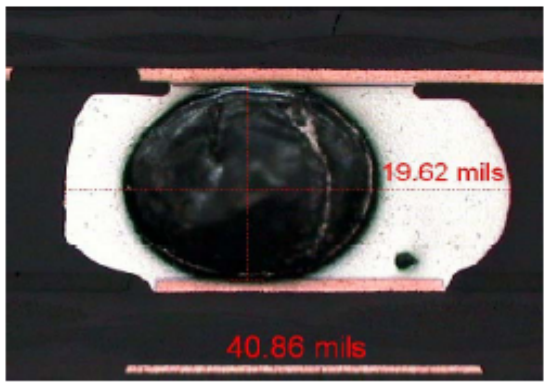
- The LED Center Lead to Pad Geometry shows the lead is barely sitting on the pad
- Component supplier recommends a center lead land Pattern 0.4mm Larger than the design used on this product
- The varying length and angle of metal burr together with the Lead to Pad Geometry causes this problem together with the higher surface tension and slower wetting of SnAgCu solder

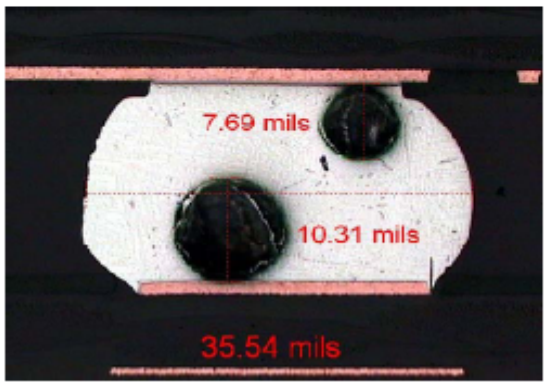


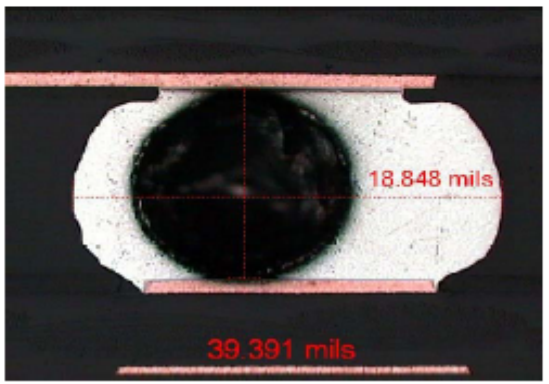
SnAgCu water soluble paste voiding (1.27mm pitch lead-free BGA)

Solectron surface mount test board

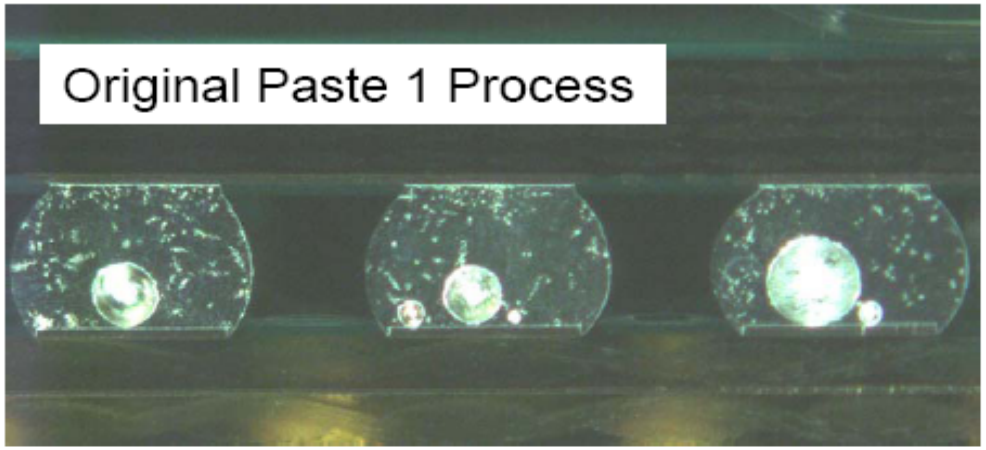
Paste	Measurement	Board 1	Board 2	Board 3	Board 4	Board 5
Paste 1	Average Void %	5.00	4.85	5.55	3.59	4.42
	Standard Deviation	7.08	7.28	7.18	6.10	7.48
	Largest void %	33.81	32.70	34.12	26.07	33.40

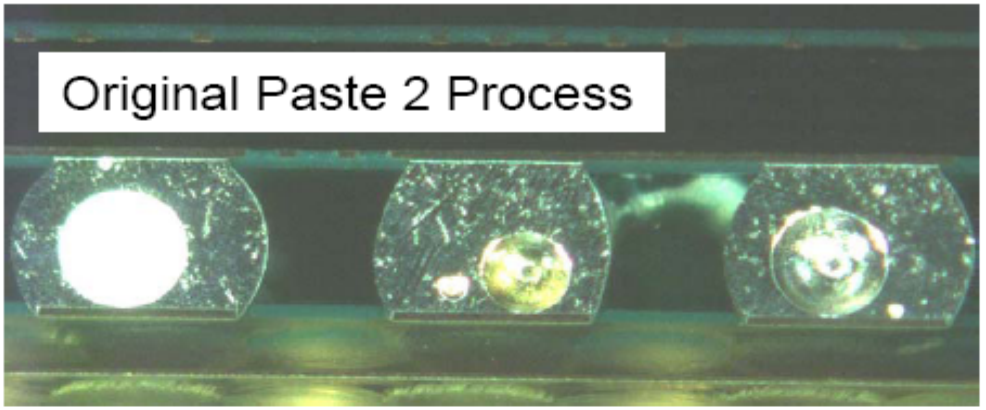


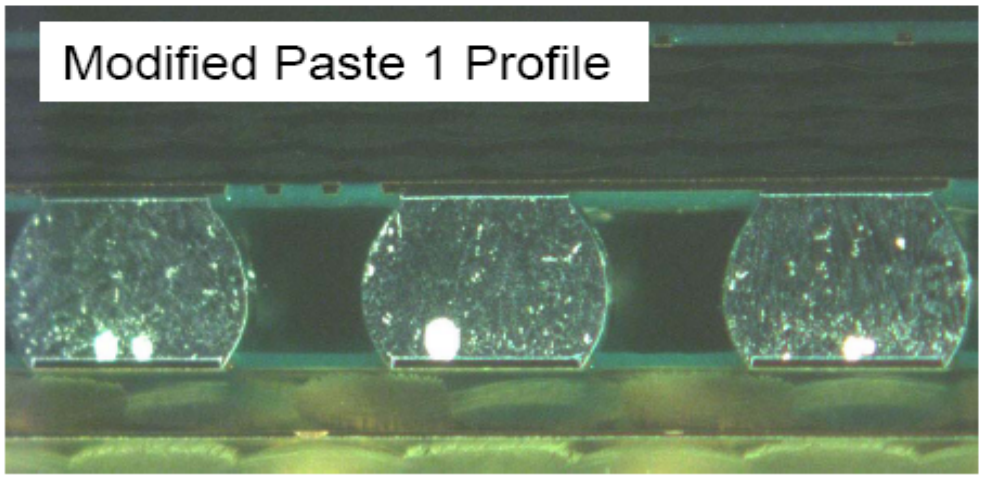


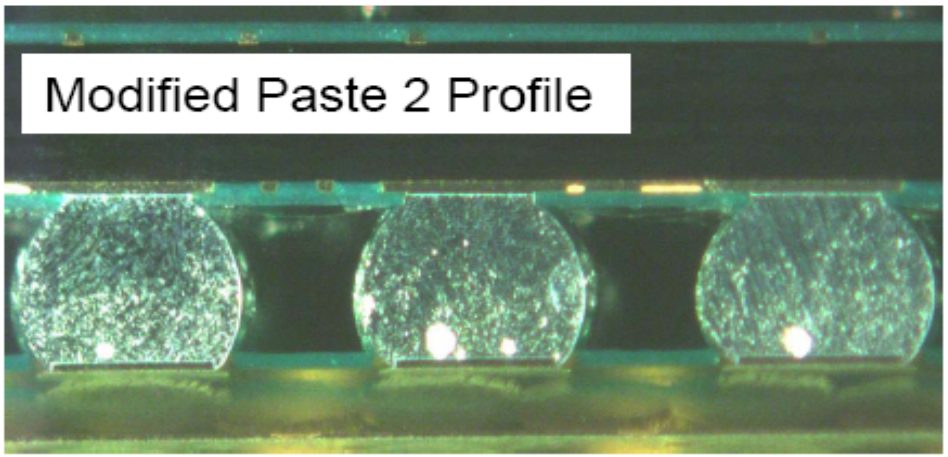


SnAgCu water soluble paste voiding (1.27mm pitch SnAgCu BGA): Original versus modified reflow profiles (Solectron SM test board)

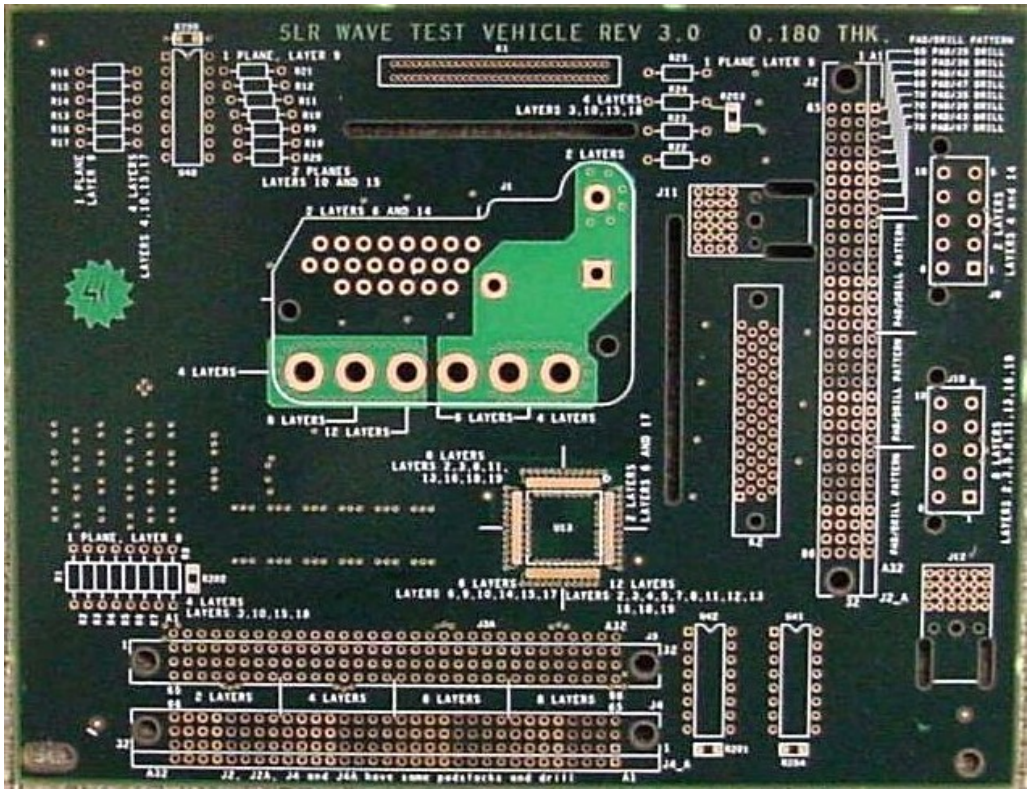








Solectron Wave Test Vehicle

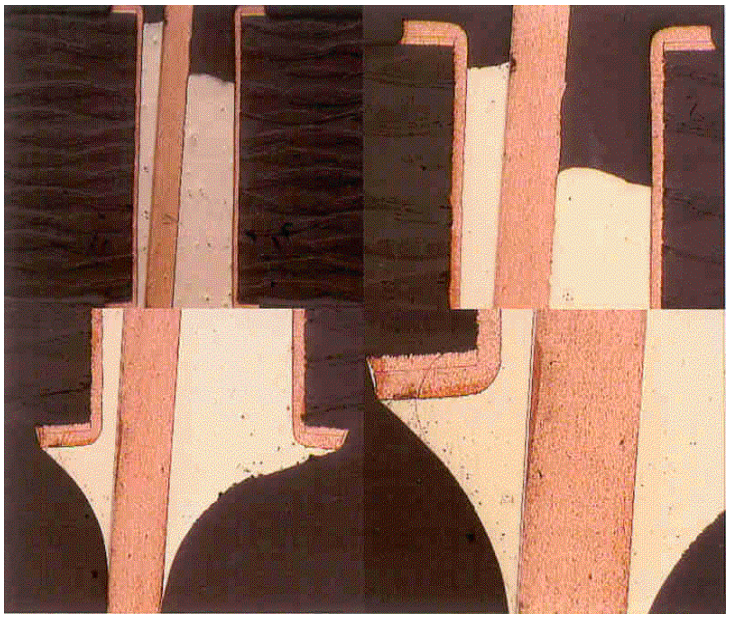


Top side

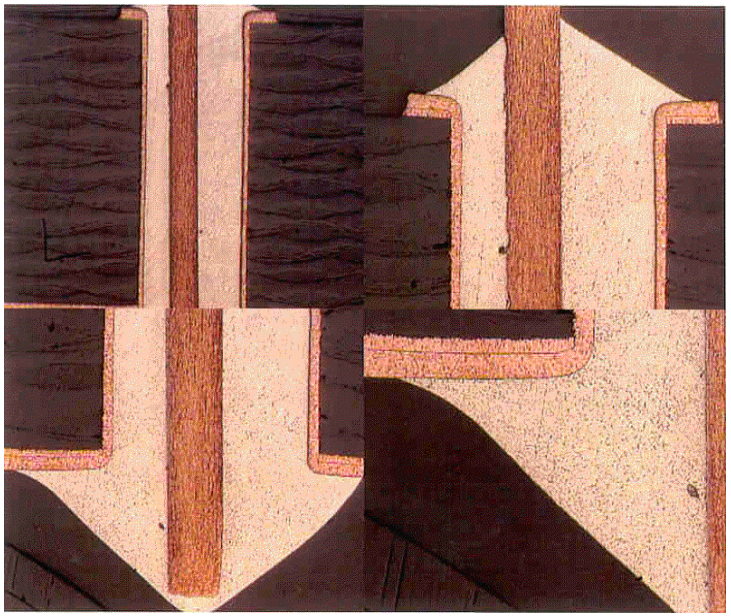
- **Size:** Single **(5.5” x7.0”) or Panel (4UP, 12” x 15”)**
- **Board Thickness: 62,** 93**, 125, & 180 mils**
- **Surface Finish:** OSP & Imm. Ag
- Various pad and hole diameters
- **Various copper layers:** 1, 2, 4, 6, 8 **(up to 12 layers for 0.180” thick board)**
- Various SMT and PTH pad spacing
- **Includes thermal relief design (for power brick design)**

Lead-free vs. Tin-lead

No-clean wave flux
93mil thick OSP coated test vehicle board
NiPd lead-free coated DIP16 component



Sn0.7Cu (Pot temp: 510°F/ 265°C)

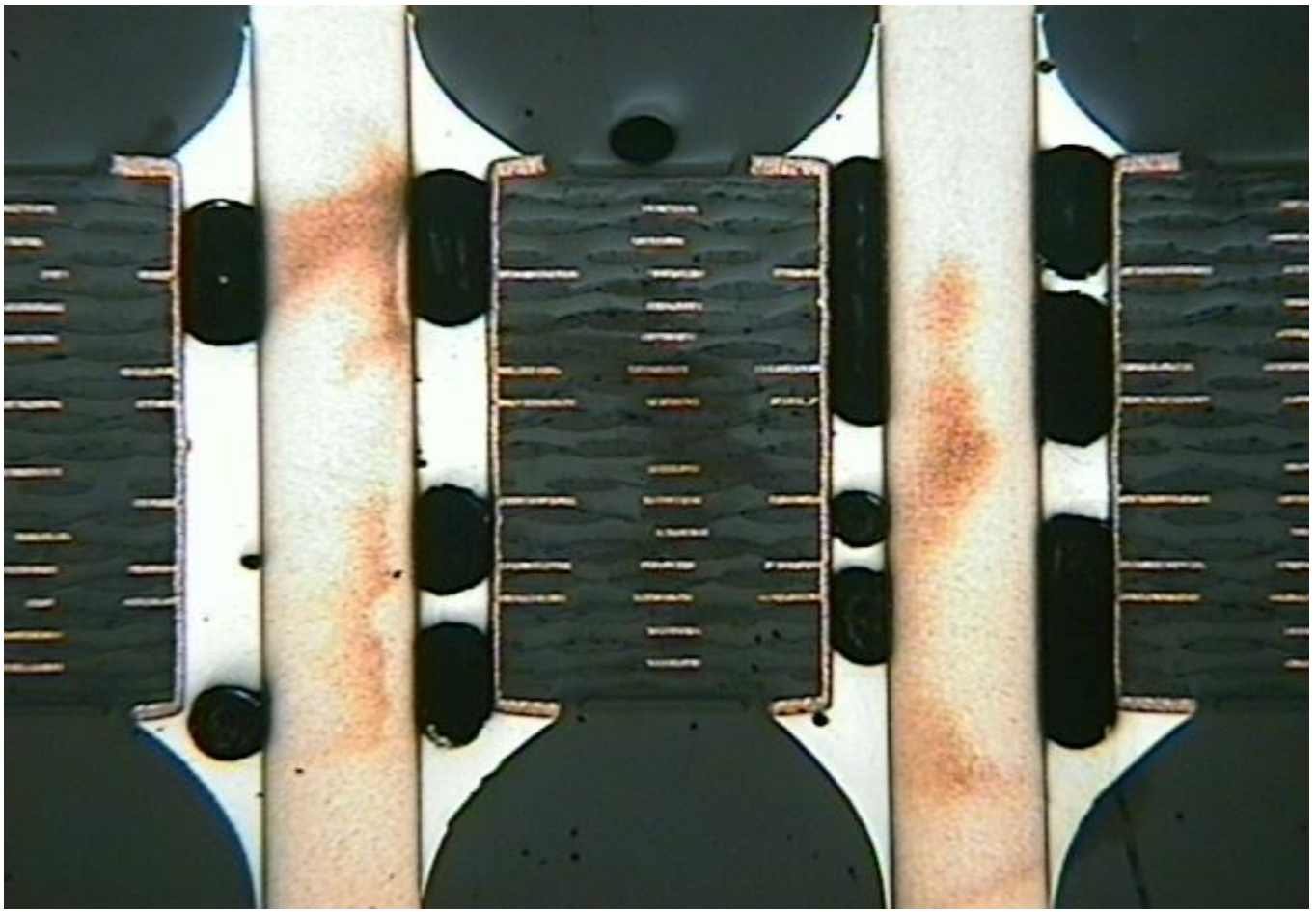


Sn37Pb (Pot temp: 490°F/ 255°C)

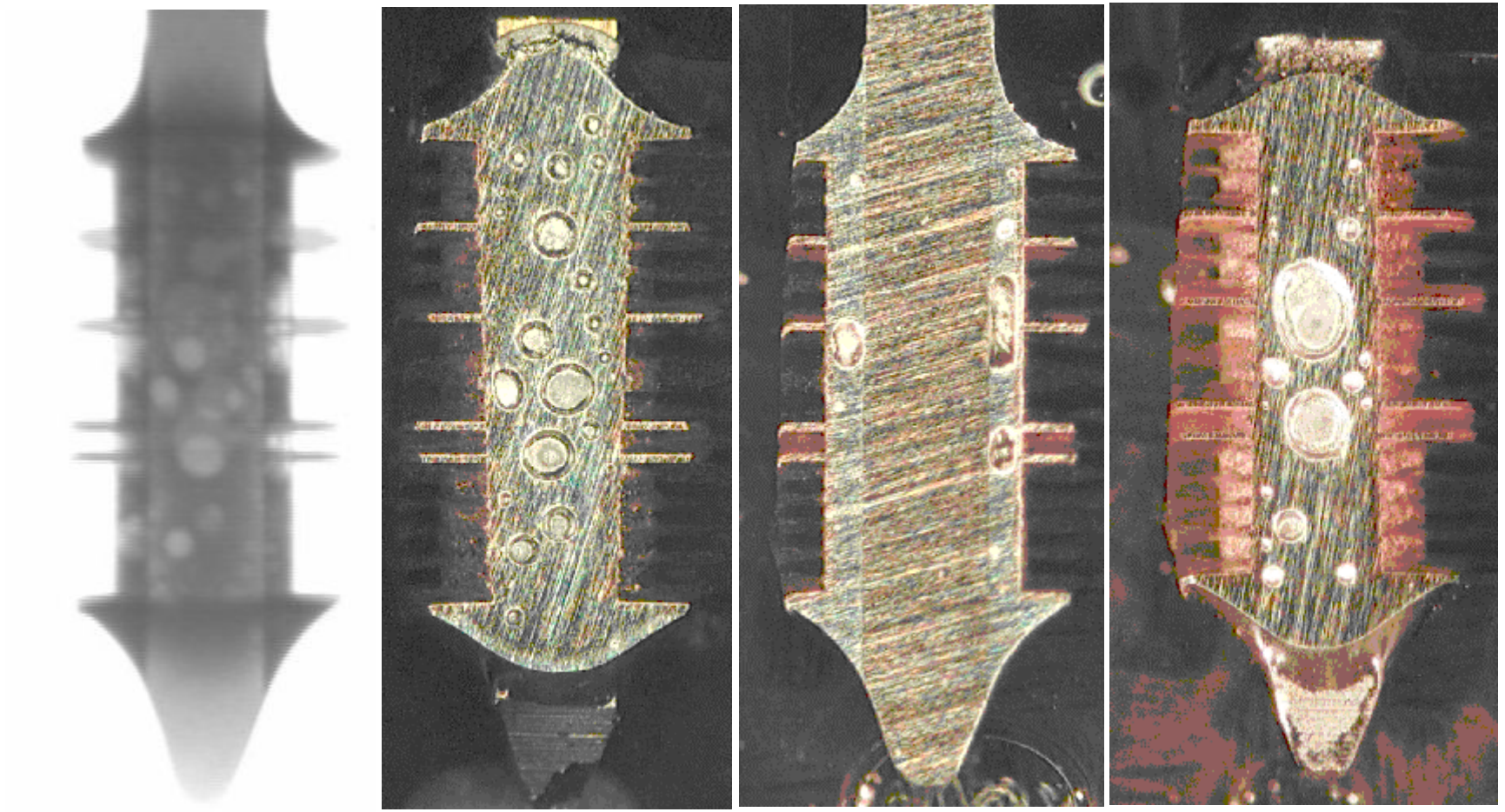
Example of Reduced holefill with lead-free solder

Solectron Lead-free Wave Test Board

SnAgCu wave alloy: Voiding

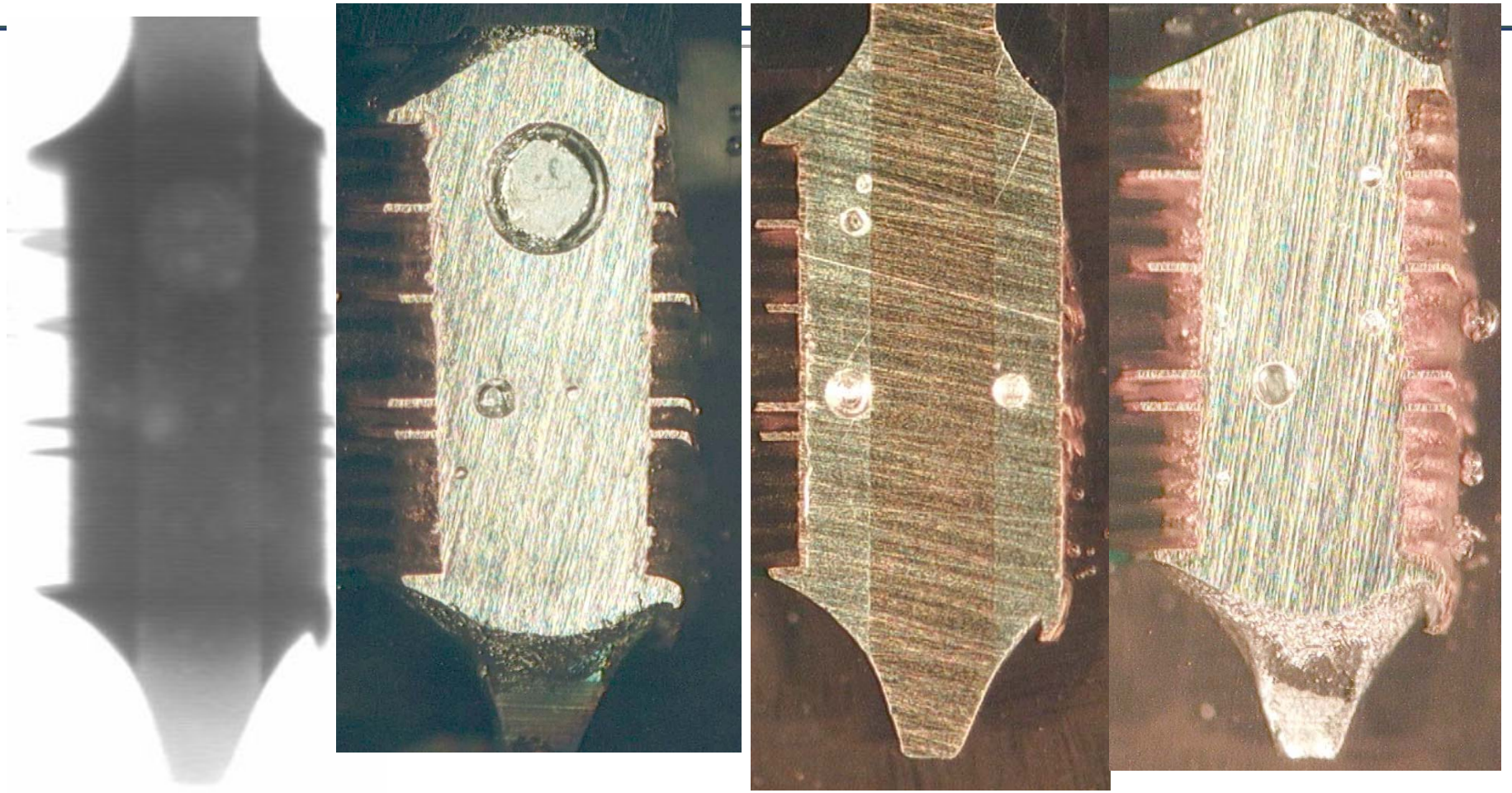
- 

Lead-free solder joints anomalies: Voids (ref: Solectron presentation: IPC/ Soldertec Conf. 2005)



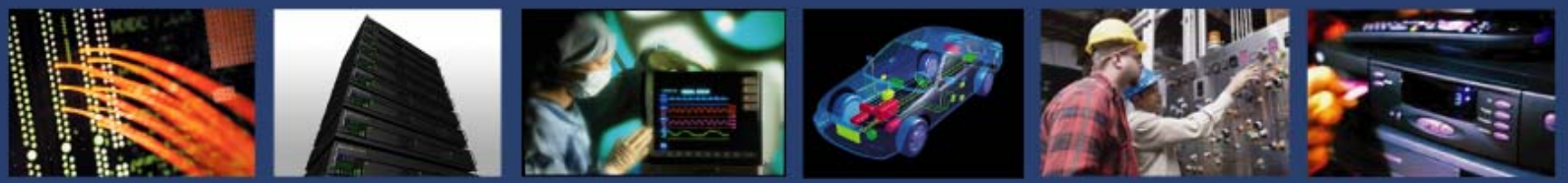
Worse case voiding with x-ray & cross section (Pin to hole Ratio: 0.65; 0.025” sq pin in a 0.035” dia hole)

Lead-free solder joints anomalies : Voids (Cont'd)



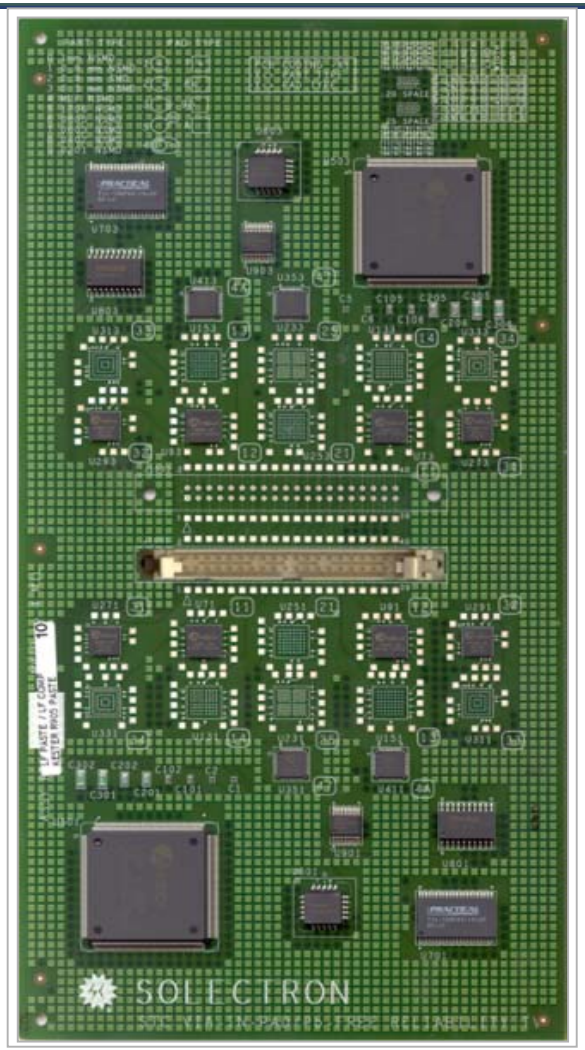
Better-case voiding with x-ray & cross section (Pin to hole Ratio: 0.36; 0.025" sq pin in a 0.047" dia hole)

All things being equal, larger barrel holes have less voids



Lead-free SMT Rework processes

Solectron Lead-free SMT Reliability Test Vehicle

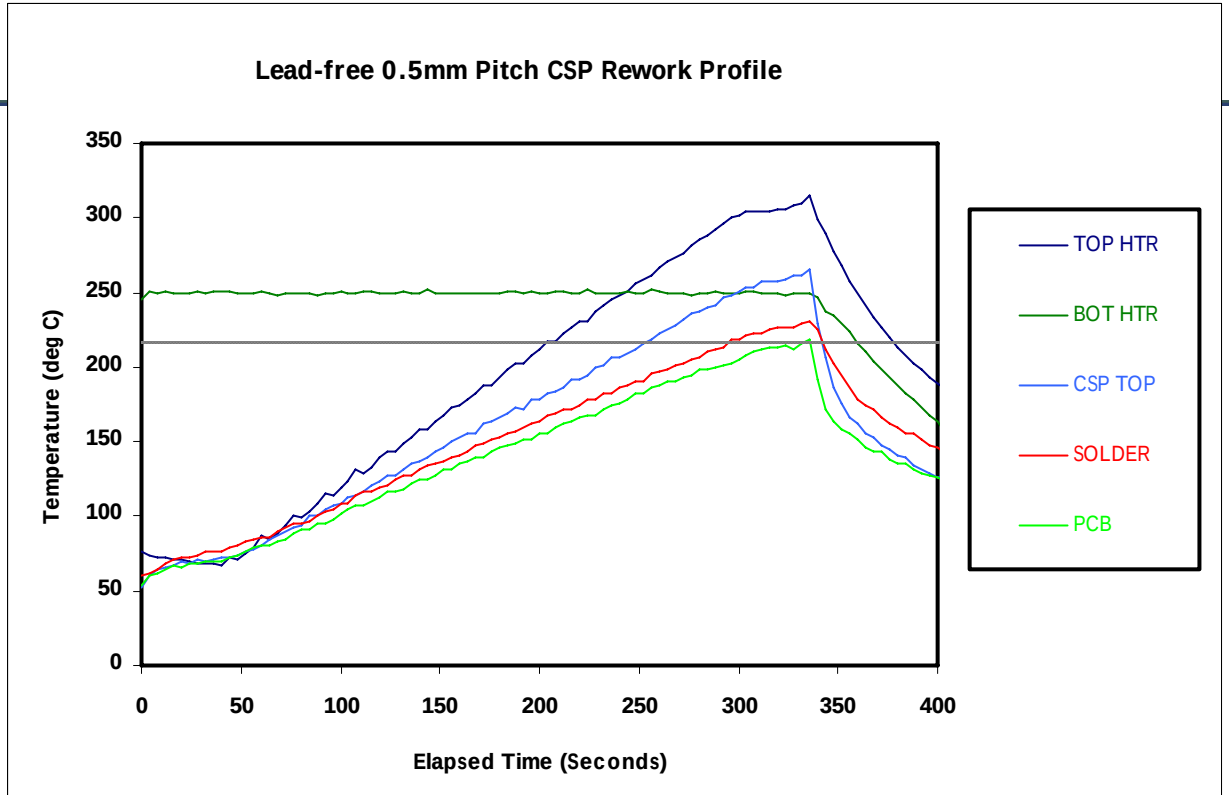


List of Devices on the Test vehicle

- *0.5mm pitch CSP 84 I/O*
- *0.8mm pitch CSP 64 I/O*
- *0.5mm pitch MLF 44 LD*
- *0.4mm pitch QFP 256 LD*
- *0.65mm pitch SSOP 20 LD*
- *0.8mm pitch TSOP 44 LD*
- *1.27mm pitch SOIC 20 LD*
- *1206, 0805, 0603 and 0402 chip resistors*

93mil thick FR4 board

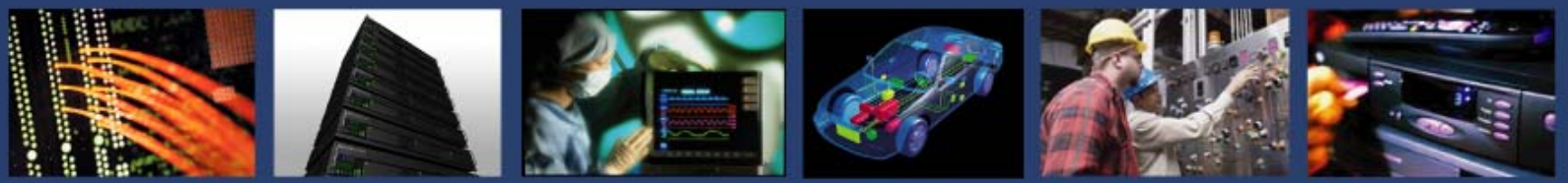
Lead-free 0.5mm CSP Rework



Thermocouple Location	Peak Temperature [°C]	Max Rising Slope [°C/sec]	Preheat Zone (110-217°C) [sec]	Time Above Liquidus (>217°C) [sec]	Max Falling Slope [°C/sec]
Solder Joint	231.0	0.5	194	47	8.6
Component Top	265.0	0.6	-	-	6.5
PCB [5mm away]	218.0	0.5	-	-	5.8

0.5mm CSP (1st Pass): Solder joint (247°C), Comp. Top (250°C)

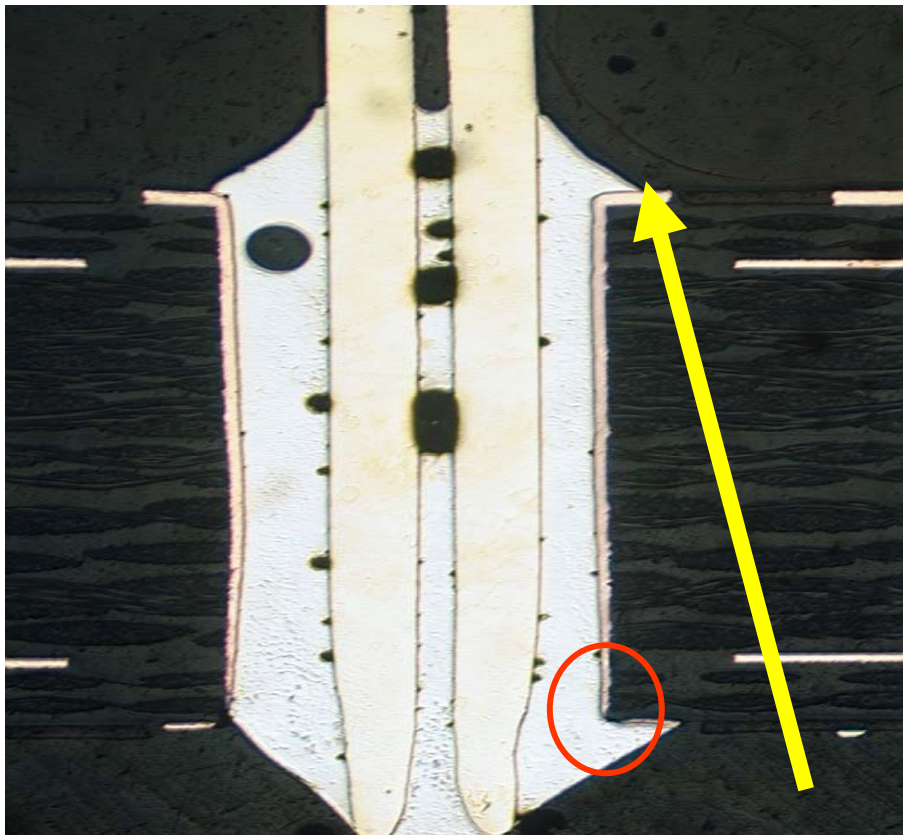
0.5mm CSP (Rework): Solder joint (231°C), Comp. Top (265°C)

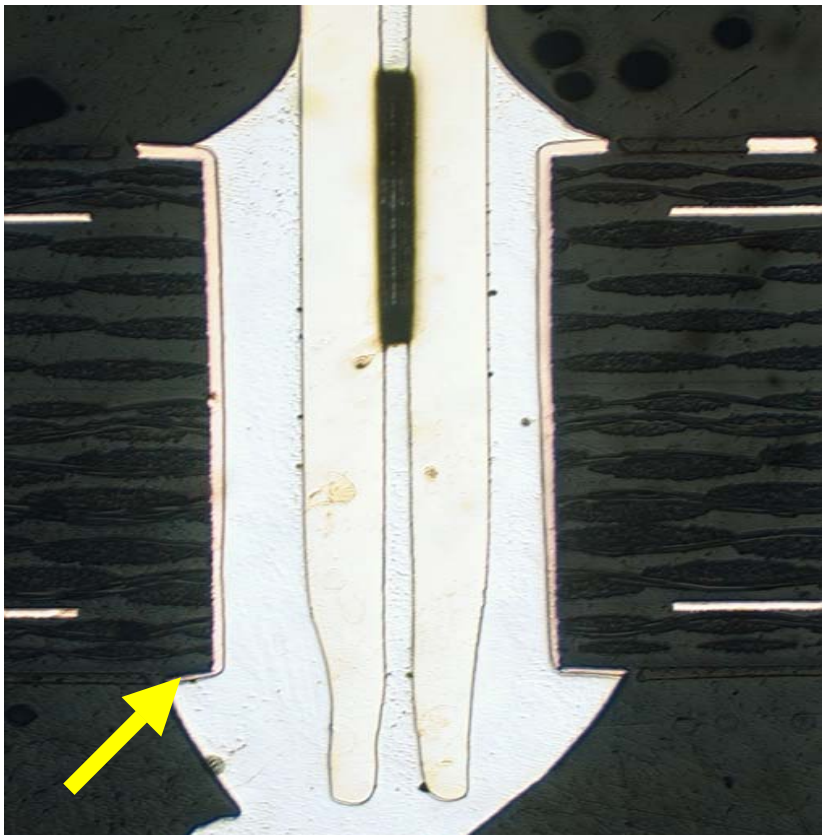


Lead-free Wave Rework processes

Lead-free PTH solder fountain (mini-pot) rework :
Sn3.0Ag0.5Cu alloy

Although able to create good hole fill with top and bottom side fillets, copper barrel knee dissolution is evident.

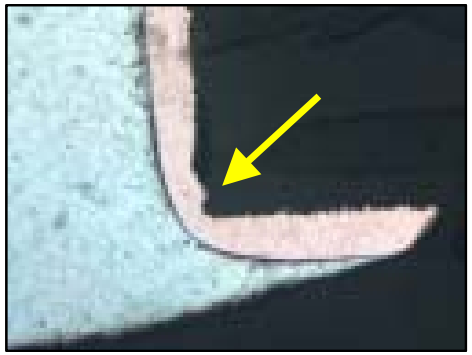




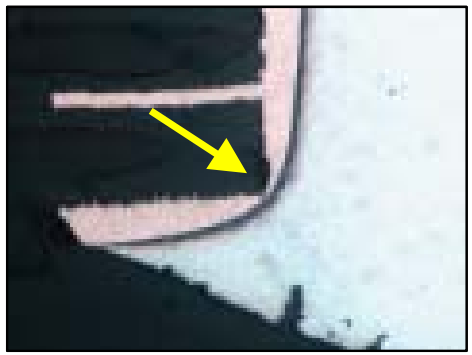
Notice the thickness of the topside annular rings as opposed to the bottomside.

Lead-free PTH solder fountain (mini-pot) rework : Issue with Sn3.0Ag0.5Cu alloy (Ref: IPC/ Soldertec 2005)

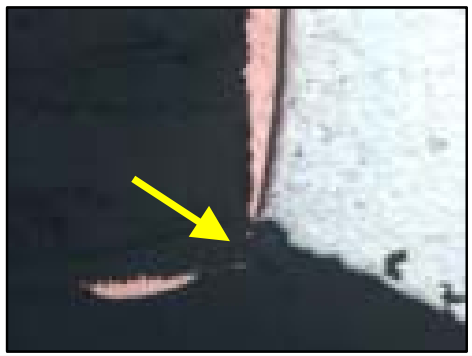
Dwell time: 20.1 sec



Dwell time: 22.4 sec



Dwell time: 35.6 sec

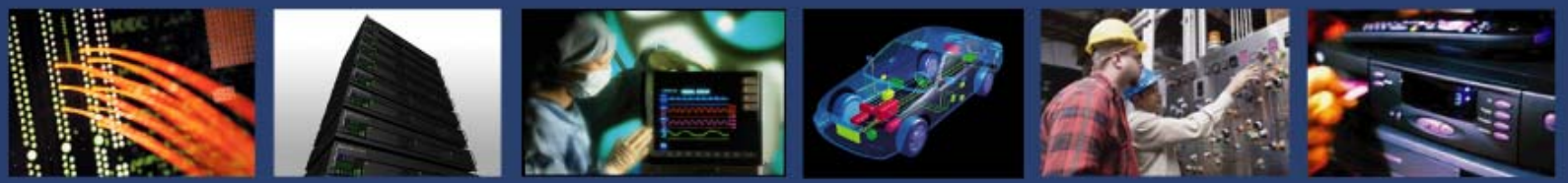


During rework with SnAgCu alloy with copper from the PCB: copper dissolves with increasing contact time.

Experience PTH barrel knee erosion after 20 seconds of solder pot dwell time.

Copper dissolution is a function of original barrel/pad thickness, solder temperature and alloy (tin percentage), dwell / contact time and solder flow rate and type of copper plating.

Studies are ongoing with dissolution rate comparison with various lead-free solder alloys and process optimization.



Lead-free Process/Equipment Segregation

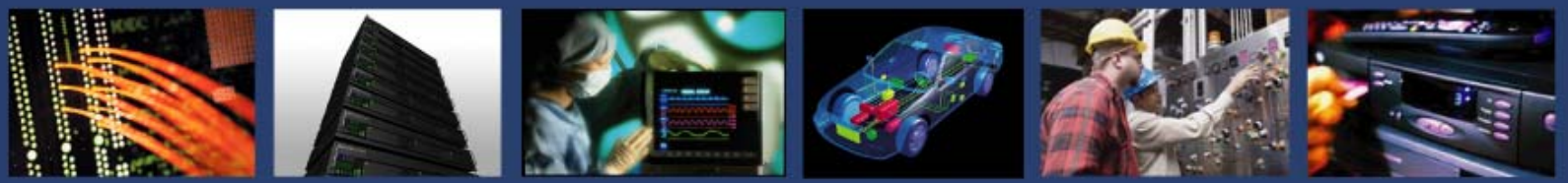
Designated production areas for lead-free wave and rework

- Dedicated lead-free wave solder machine
  - Logistics to separate lead-free SnAgCu and SnPb solder bar (including triangular shaped bar for lead-free)

- Rework solders must be compatible with the manufactured solder – need separate designated lead-free rework area in production and methods to deal with field returns.

- Planning of production line is essential for lead-free assembly.

- Lead-free component and board labeling will be needed to differentiate between SnPb and lead-free assemblies for assembly, repair and rework (Refer to JEDEC standard, JESD97: Marking, Symbols and Labeling for lead-free assemblies, components and devices and IPC 1066 standard for lead-free labeling)



Lead-free Component Segregation

Component Supplier Readiness: Overall View of Supply Base

- Tier 1 manufacturers have the infrastructure (resources, capital, etc..) to support RoHS transition

- Part numbers are changing for RoHS compliance depending on commodity and manufacturer

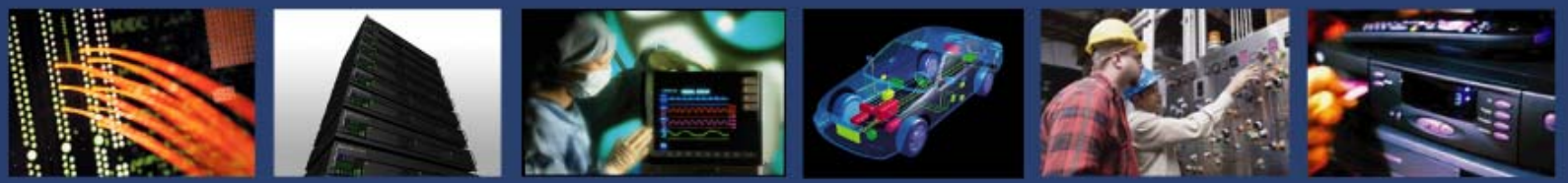
- No standard method of identification (marking/labeling) of RoHS compliant components

- IPC-1752 materials declaration standard now released to help with a standard method of reporting RoHS environmental data

ROHS Component Warehouse and Logistics Plan

- **Solectron has created new site part numbers for all RoHS compliant assemblies, all of their BOM components, regardless of the actions of component manufacturers or customers.**

  - Clear physical and financial separation of the supply chain (i.e. Inventory, Demand, Supply)
  - Fully utilize MRP (Material Requirement Planning) System
  - Will be able to use effective dates to phase in/ phase out part numbers
  - Clean BOMs (Bill of Materials), AMLs (Approved Materials Lists) and Orders
  - Lowest risk of mixing inventory in warehouses
  - Easier to capture and recover E & O (Excess and Obsolete) created by the switchover



Assembly Situations:
Forward/ Backward Compatibility

4 assembly situations

Today's situation

1. Tin-lead solder paste with tin-lead components: Generally O.K.

2. Tin-lead solder paste with lead-free components:
    - Danger with assembly of lead-free CSP/ BGAs: Insufficient collapse/realignment/ opens due to low temperature tin-lead assembly profile

Tomorrow's situation

3. Lead-free solder paste with tin-lead components:
    - Danger with tin-lead CSP/BGAs: Voiding/ bridging (CSP/BGA sphere reflows before solder paste)
    - Are tin-lead and lead-free components and boards rated to higher lead-free soldering temperatures

4. Lead-free solder paste with lead-free components.
    - Are lead-free components and boards rated to higher lead-free soldering temperatures

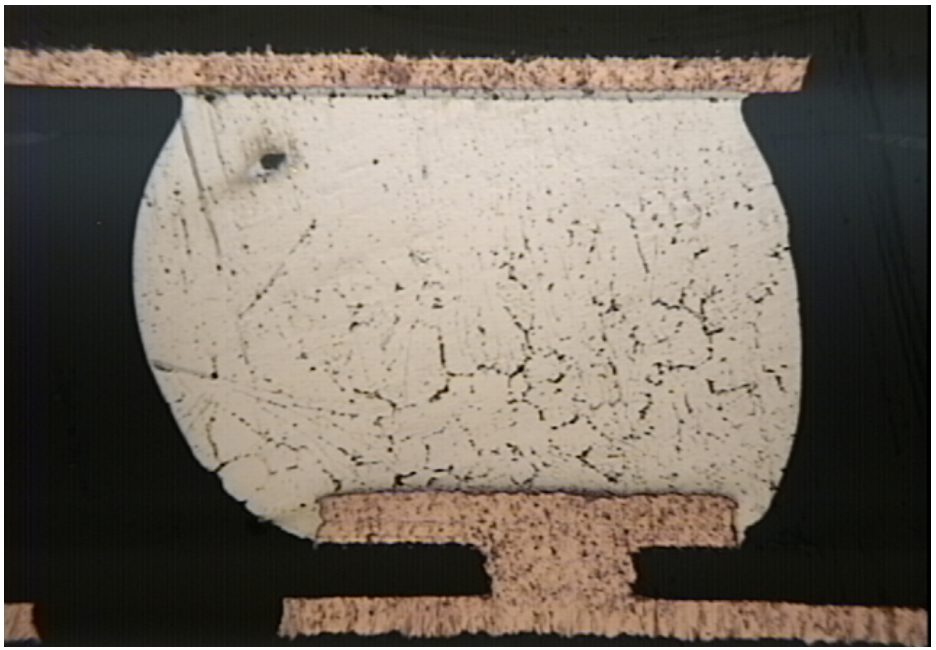
SnPb CSP Sphere component with SnPb Paste (Today's situation: O.K.)

Lead-free SnAgCu CSP Sphere component with SnAgCu Paste (Fully lead-free situation: O.K.)

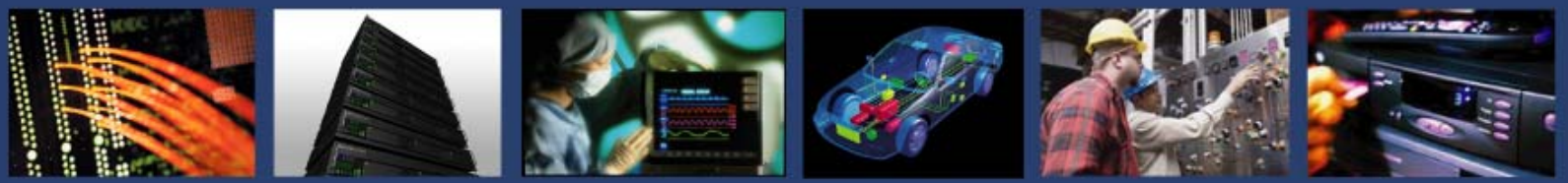
Backward Compatibility

Forward Compatibility

Lead-free SnAgCu CSP Sphere component with SnPb Paste
Lead-free CSP/BGA should not be used with tin-lead solder paste (incomplete mixing and collapse, open solder joints: avoid)



Tin-Lead CSP Sphere component with SnAgCu Paste.
Mixing lead-free SnAgCu paste with SnPb BGA/CSP creates increased voiding (avoid)



ROHS compliance

Solectron ROHS Cross Functional Organization/ Leadership

Function	Goals
Engineering/Design	• Develop and define RoHS technical process, equipment, tooling and chemistry • Sites qualification process FA testing and reporting
Materials/Warehousing	• Materials DFE services (Assess, status and convert BOMs) RoHS materials, warehouse and logistic management strategy and definition Materials compliance data management
Operations	• RoHS compliant manufacturing, training, equipment requirements and site readiness worldwide (PB-free)
Services	• RoHS compliant Repair services (PB-free) • Establish and support value added take-back logistics programs (WEEE)
IT	• Develop and deploy global IT solution for materials compliance management • Develop DFE (Design for Environment) materials BOM scrub assessment tools
Marketing	• Create RoHS DFE (design for environment) services, solutions and pricing • Train and enable sales and account mgmt teams on RoHS
Sales/Business Process	• RoHS complaint manufacturing services and quotation models • Lead and drive new RoHS value add manufacturing business
Government Affairs	• Develop and guide Solectron RoHS Strategies (Environmental Regulatory Expert) • Assess, analyze and anticipate future environmental laws
Legal/Contracts advisor	• Assess and guide Solectron's customer contracts in support for RoHS DFE and compliant manufacturing services.
Account / Program Management	• Develop and align RoHS product roadmap plans w/customer • Manage and coordinate customer transition to RoHS complaint products (DFE Services)

Solectron Lead-free ROHS Site Technology Deployment

Develop the equipment, process and technology solutions for RoHS.

Reliability testing and failure analysis was performed to prove out these solutions.

Each site required to build the same qualification test vehicles and pass lab testing and failure analysis:

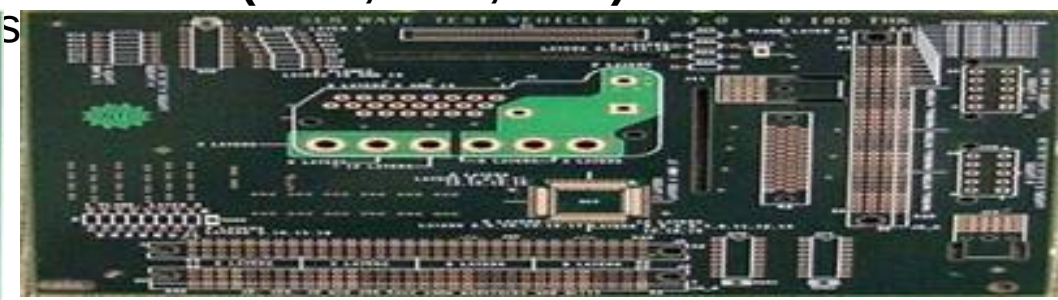
a. **SMT, Follow the lead-free SMT and rework qualification procedure**
   - Validate the process using approved specifications and SMT consumables
   - Ensure equipment performance and readiness

b. **Wave, Follow the lead-free wave solder process verification procedure**
   - Validate the process using approved specifications and Wave consumables
   - Ensure dedicated equipment deployment, performance and readiness

c. **Hand solder training, IPC – 610 D Standard rework training**
   - Global train-the-trainers program
   - Use of standard rework equipment and consumables

d. **Advanced rework training and qualification (BGA, CSP, PTH)**

SMT test board



Wave test board

Solectron's Lead-free RoHS Site Certification Process

- Test vehicle builds and analysis to validate proficiency in PCBA soldering and rework
- 200-question RoHS self-assessment checklist covering:
  - -Training
  - -Materials management
  - -Engineering and test capabilities
  - -Manufacturing process and control
  - -Quality assurance
- Corporate on-site audit of a site's RoHS preparations, controls, technical understanding and compliance readiness

29 Manufacturing Sites + 19 Service/ Repair Sites

Solectron Site Transition Procedure

1. Site must run qualification test vehicle

a. SMT
- Process (Training/ Support)
- Equipment

b. Wave
- Process (Training/ Support)
- Equipment

2. Product Review
- Complexity of Product and End-Of-Life of Product (2006)
- SMT (Quantity and Type)
- Wave (Quantity and Type)
- PCB (Material and Surface Finish)
- Components (Material and Surface Finish)

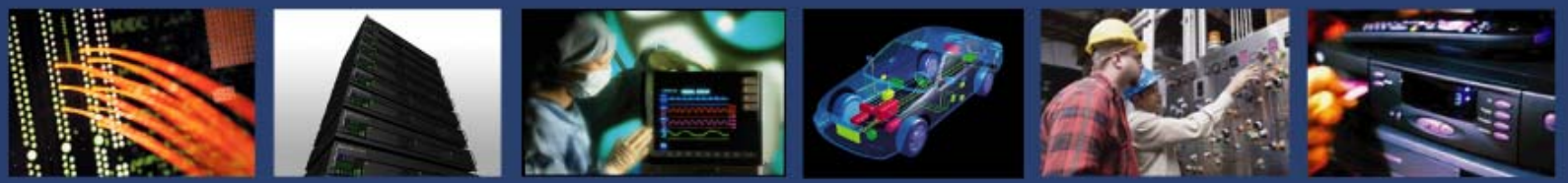
3. BOM Component Scrubbing (Temperature rating, lead-free specifications)
- Global Materials Component Engineering Support (Supplier Development Engineering),
- Consigned/ Turnkey

4. Prototype Builds (Manufacturing and reliability trials)

5. Pilot Builds (Manufacturing and reliability trials)

6. Production

A single product conversion may take 6 months or longer



Lead-free product

Solectron Lead-Free Production Experience

Over 25 million lead-free products built since 2000

11 sites and 3 continents

- **Jaguiriana, Brazil:** Mother boards Surface Mount and Wave

- **Timosoira, Romania:** Bluetooth Head set,Car kit,Set top box Surface Mount/Wave
- **Dunfermline, Scotland:** Cash Dispenser Surface Mount and Wave
- **Bordeaux, France:** Telecom, Consumer Surface Mount/ Wave
- **Budapest, Hungary:** Set top box Surface Mount

- **Ibaraki, Japan:** Disk Array System,Graphic Controller Wave/Surface Mount
- **Batam, Indonesia:** SCSI, Desktop, Mobile Hard Disk Drive, Head Printer Surface Mount
- **Singapore:** Camera Scan Engine Double Sided Surface Mount
- **Suzhou, China:** Notebook, cell phone, network card, fiber optic module Wave and Surface Mount
- **Shenzhen, China:** Printer card and cell phone Double Sided Surface Mount
- **Shanghai, China:** Digital camera Double Sided Surface Mount

Mainly cellphone/ laptop type products

Major customer Lead-Free product qualification collaborations (in progress):

Server/ Telecom Products

- Server (Charlotte, Singapore, Batam, Puerto Rico)
- Server (Guadalahara)
- Telecom (Ostersund) .
- Base Station (Suzhou)
- Controls (Batam)
- Personal Switch (Singapore)
- Storage (Milpitas)

Instrumentation Products

- GPS (Milpitas)
- Instruments (Milpitas / Suzhou)

Thicker boards are creating their own set of assembly challenges for lead-free which are being worked through.

Conclusions

- Lead-free processing indicates increased assembly temperatures with difficulty increasing in the order from SMT to wave to rework (PTH and BGA)
- Lead-free prototyping must be conducted to understand potentially ‘hidden’ issues which may not be clear from previous production and component BOM scrubbing activities
- Good planning and execution is essential in all functions of an organization to meet the environmental deadlines without disrupting businesses.
- Important to recognize that ensuring compliance requires a coordinated approach with clear communication throughout the electronics supply chain to be successful.
- Working through the above combination of factors will allow for a successful transition to lead-free soldering