Manufacturing and Reliability Evaluation of a Lead-free Electronics Network Card

Jasbir Bath, Solectron Corporation, Milpitas, CA, USA

Suan Kee Tan and Choong Hang Tang, Solectron Technology, Penang, Malaysia

Julie Furnanz and Chris Ruff, Intel Corporation, Hillsboro, OR, USA

Objective

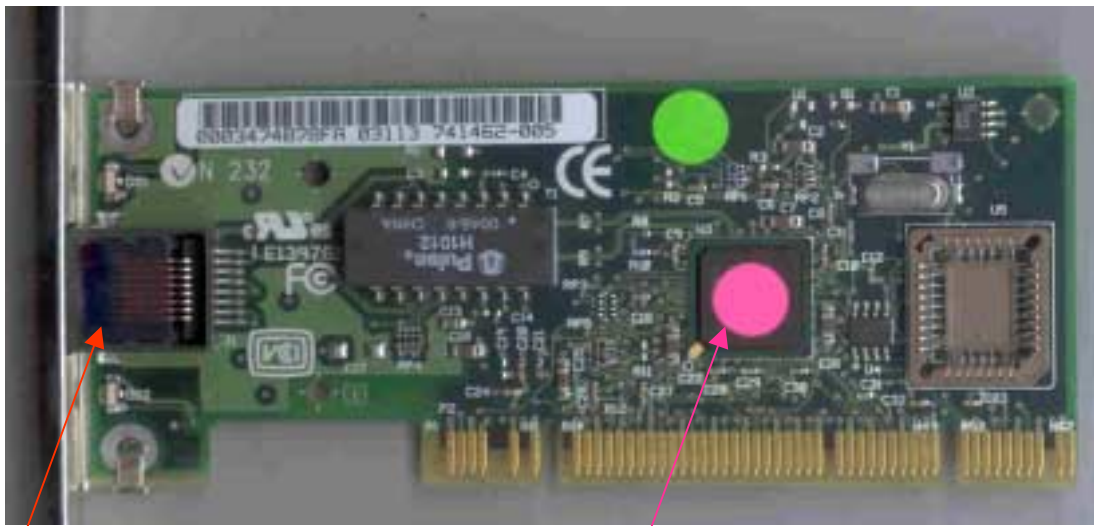
Enable a lead-free soldering process for the electronic network card at the contract electronic manufacturer by a partnership of OEM customer, contract manufacturer, board, component and solder paste supplier.

Board and component description

Network card technology description:

- SMT Only, Single Sided, 6 boards per panel (6up)
- FR4 epoxy glass board (Tg= 130 to 140^{o}C)
- 4 Layer PCB
- 63mil board thickness
- Mainly Immersion Silver board surface finish (some tin-lead HASL boards for tin-lead paste assembly)
- Variety of surface mount components on board including lead-frame and chip components and lead-free PBGA

Image of fully assembled board



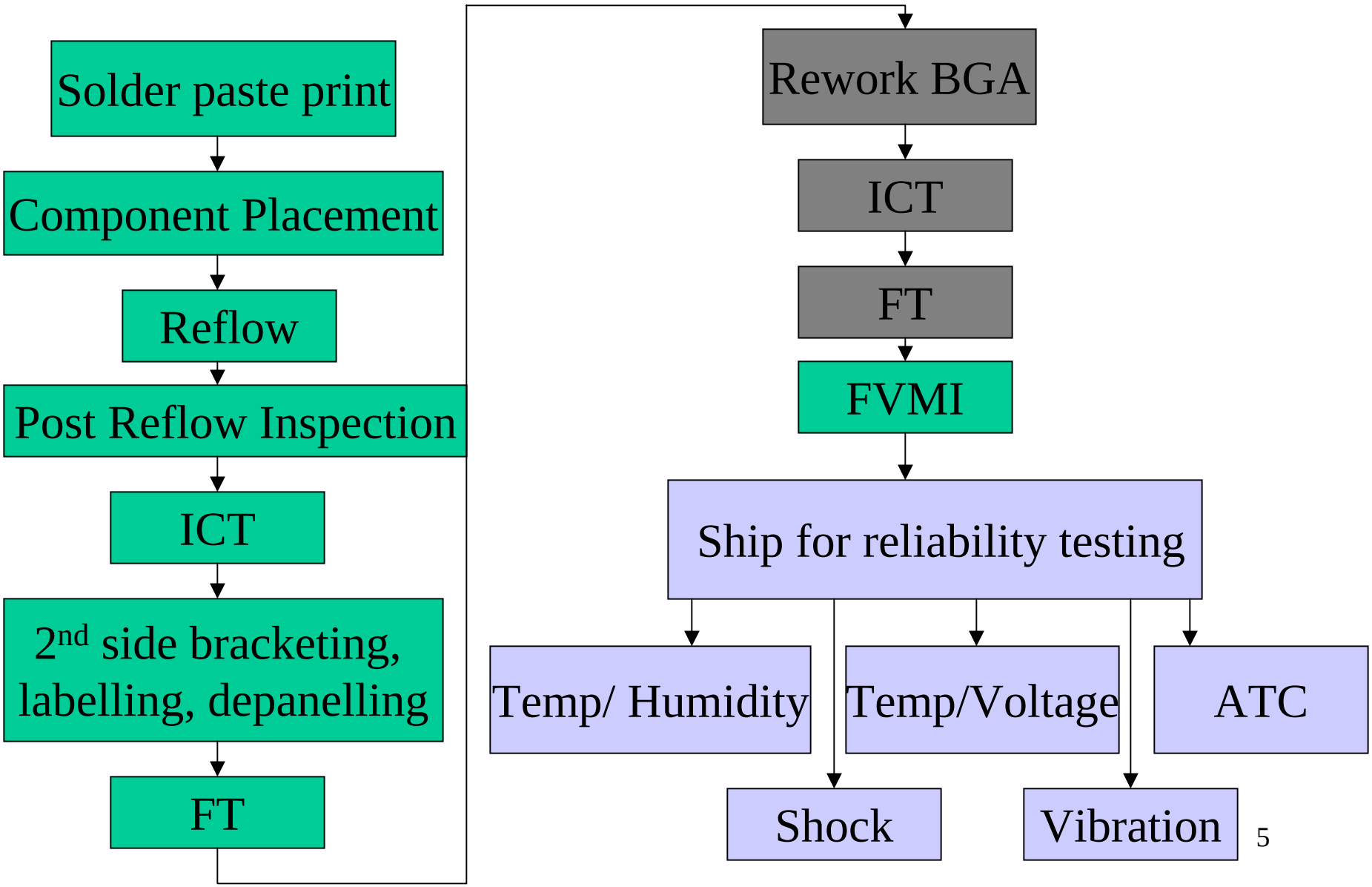
Topside

RJ45
Connector

Lead-free
BGA

Bottomside

Manufacturing and Reliability Flow Chart



Board assembly and rework plan

Phase	Paste	Board Finish	BGA	Boards built	Boards reworked	PCB supplier	Paste Lot	Production Line	Stencil Thickness
1A	Sn37Pb	Tin-lead HASL	SnPb	186	24	Supplier B		2	5mils
1B				120	18	Supplier A	1	2	
2				252	18	Supplier A	2	2	
3A				225	5	Supplier B		1	
3B				252	5	Supplier A	3	1	
4A				228		Supplier A		1	
4B				360	5	Supplier B		2	
5				90					5mils
5	Sn3.9Ag0.6Cu	Immersion Ag	SnAgCu	420			4		6mils
	Total SnAgCu boards built: 1947								

Approximately 2000 SnAgCu and 200 SnPb boards built evaluating PCB supplier, solder paste lot and production line

Production settings

- All Builds on Production Lines using Standard Assembly and Inspection Equipment
- Printing: No issues (Solder Paste Height within specification for tin-lead and lead-free solder paste)
- Placement: No issues
- Reflow: No issues (higher temperature profile needed for lead-free SnAgCu paste). Used nitrogen reflow atmosphere (< 100ppm O2) in 10 zone convection oven
- Rework: No issues (higher temperature profile needed for lead-free SnAgCu BGA rework)
- Visual Inspection: Joint Appearance Related to IPC-610 and Customer Workmanship Standard Acceptance Criteria

Tin-lead and Lead-free reflow profiles for board

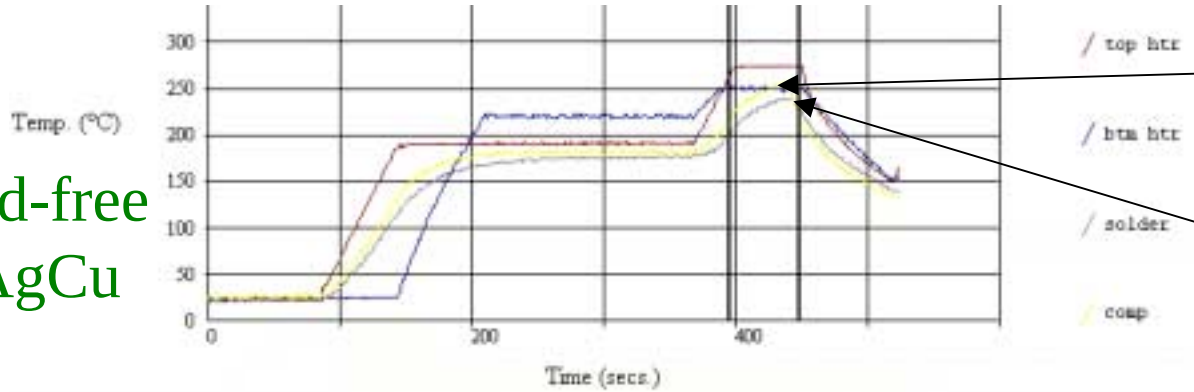
Tin-lead (Sn37Pb) paste reflow oven profile			Lead-free Sn3.9Ag0.6Cu paste reflow oven profile	
	Peak	Time over 183°C	Peak	Time over 217°C
Lowest solder joint temperature	214°C		237°C	
Highest solder joint temperature	219°C		245°C	
Lowest component body temperature	217°C		238°C	
Highest component body temperature	230°C	57-83 seconds	245°C	51-64 seconds
30-35°C increase in solder joint temperature for lead-free SnAgCu paste				
20-25°C increase in component body temperature for lead-free SnAgCu paste				

Tin-lead and Lead-free BGA rework profiles for board

Tin-lead (Sn37Pb) BGA rework profile			Lead-free Sn3.9Ag0.6Cu BGA rework profile	
	Peak	Time over 183°C	Peak	Time over 217°C
BGA solder joint temperature	208°C		240°C	
BGA component top body temperature	219°C		255°C	
		62 seconds		48-54 seconds
32°C increase in solder joint temperature for lead-free SnAgCu BGA rework				
36°C increase in component body temperature for lead-free SnAgCu BGA rework				

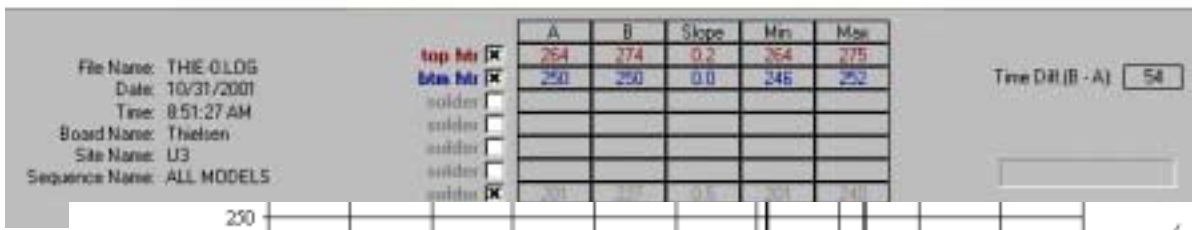
Lead-free and Tin-lead BGA Rework Profiles

Lead-free
SnAgCu

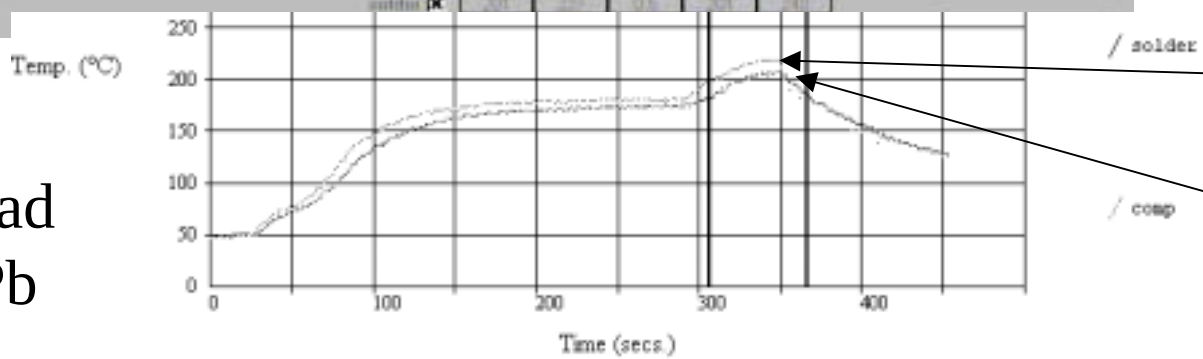


Component
top 255°C

Solder joint
240°C



Tin-lead
Sn37Pb



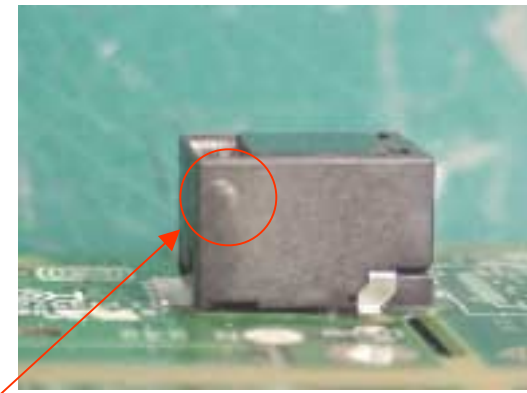
Component
top 219°C

Solder joint
208°C

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.

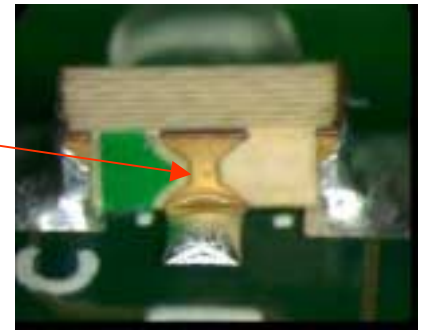
Phase 1B Part 2: 90 boards

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

Lead-Free Assembly Results

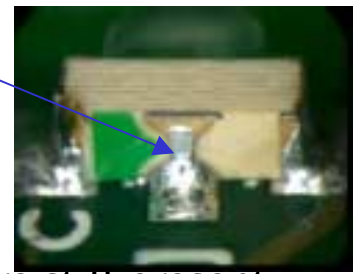
Phase 2: 252 boards

- 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)



Phase 3B: 252 boards:

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

Build 4A: 228 boards:

- Non-wetting at some LED center leads using enlarged stencil aperture
- BGA rework successful (Passed X-Ray inspection, ICT, FT)

Build 4B: 360 boards:

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

Lead-Free Assembly Results: LED Non-Wetting Defect

Enlarged Stencil Aperture Helps to Reduce Non-wetting defect at LED center lead but non-wetting still occurs intermitently:

Evaluate 6mil thick stencil which would deposit more solder paste

Phase 5A: 90 boards SnAgCu control run (original 5mil thick stencil):

- Non-wetting at some LEDs using enlarged stencil aperture

Phase 5B: 420 boards (new 6mil thick stencil):

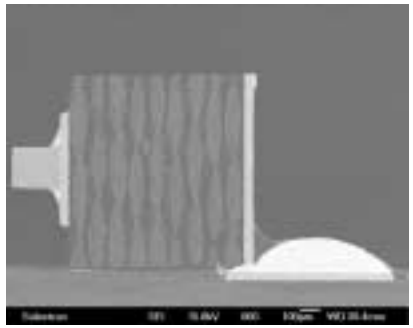
- Non-wetting at some LEDs using enlarged stencil aperture

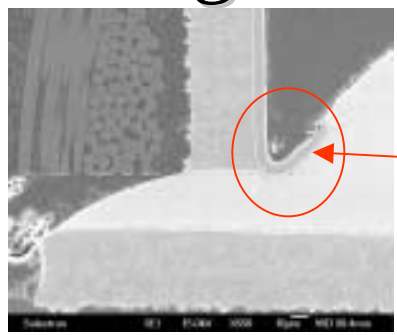
No difference in results for 5mil and 6mil thick stencil

Lead-Free Assembly Results: LED Non-Wetting Defect

Conduct cross-sectional analysis on known ‘good’ and ‘bad’ tin-lead and lead-free soldered LED components to understand the wetting behaviour for the center lead

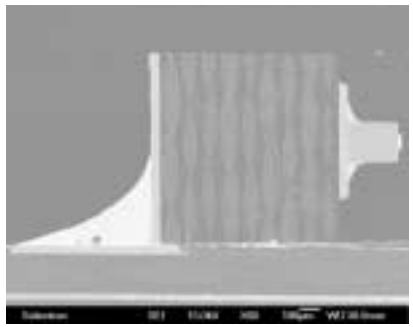
Lead-Free Assembly Results: SEM images of LED Non-Wetting Defect

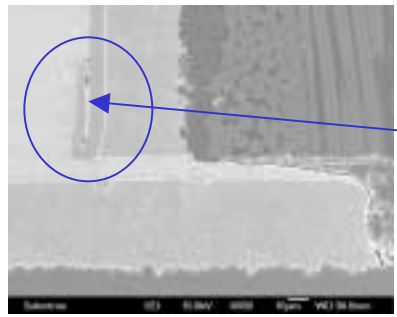




Metal burr at 45° angle

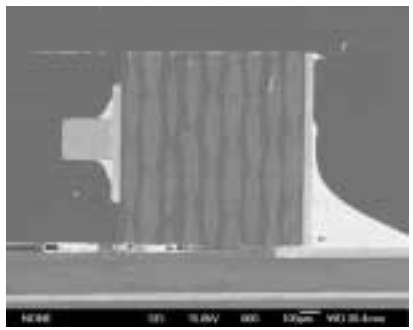
SnAgCu soldered LED:non-wetting solder joint (5mils stencil)

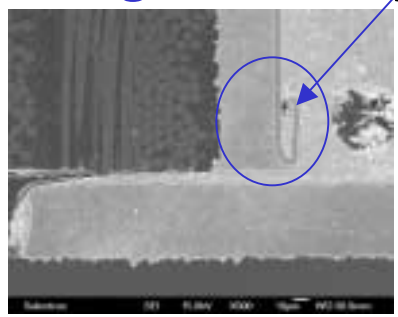




Metal burr against component

SnAgCu soldered LED – good solder joint (5mils stencil)

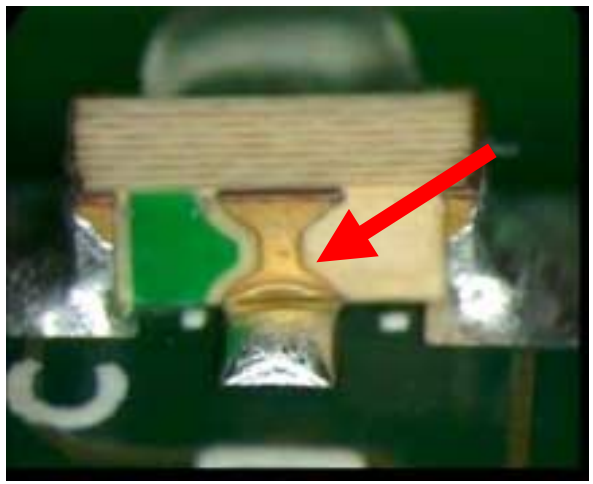


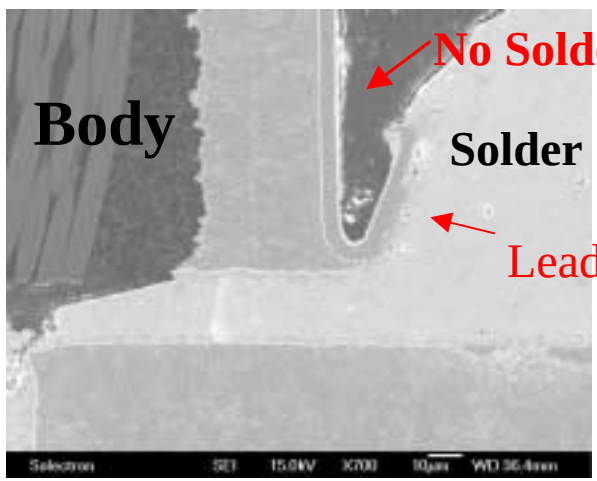


Sn37Pb soldered LED – good solder joint (5mils stencil)

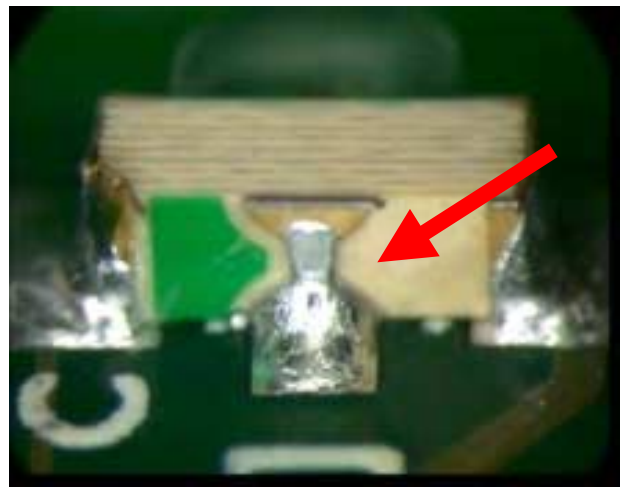
LED Wetting Pictures

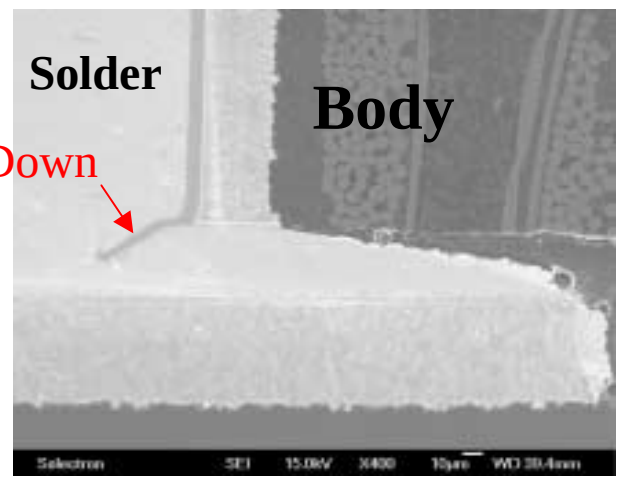
Non-Wetting on Center Lead





Good-Wetting on Center Lead



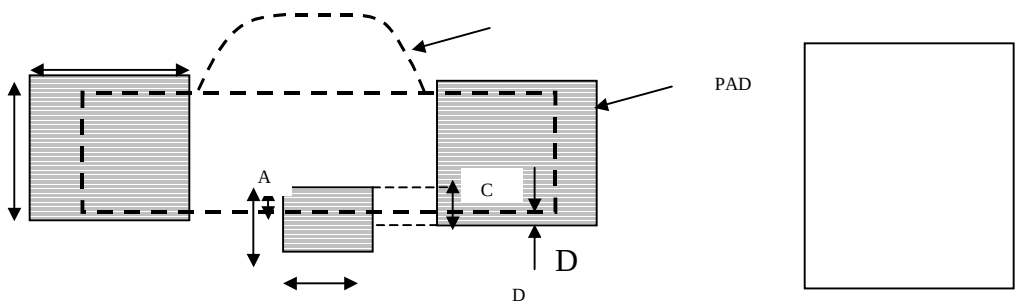


LED Non-Wetting Analysis

- 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.
- The Higher Liquidous Solder Tension of SnAgCu solder remains centered on the Pad Instead of Wetting up the Lead.
- The Picture of Good Wetting has the metal burr either flush against the lead or protruding horizontally or downwards
- 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 the SnAgCu solder



Reliability Testing

1. Temperature and Humidity in Non-Operating Conditions (85°C and 85%RH for 500 hours):

   148 SnAgCu boards passed

2. Temperature and Voltage in Operating Conditions

   (5°C, 25°C, 60°C at 4.7V/5V/5.3V power cycles/hour):

   3/3 SnAgCu boards passed

3. ATC (-40°C to 85°C for 1000 cycles):

   159/160 SnAgCu boards passed (Pass ATC requirements)

4. Unpackaged shock (3 drops in 6 directions):

   10/10 SnAgCu boards passed

5. Unpackaged vibration

   (Random profile from 5-500 Hz at 10mins/axis):

   10/10 SnAgCu boards passed

Summary of Assembly and Reliability Results

The defect level range for the assembled SnAgCu boards which included the boards with the LED visual defects were within the low defect level range accepted for existing tin-lead assemblies

The solder joint quality is within acceptable limits based on IPC610 and customer product visual inspection standard

Further investigations could be conducted to reduce the LED component defect further.

Reliability testing indicated the lead-free SnAgCu assembled and reworked boards were as reliable as tin-lead

Conclusions

- Lead-free Builds from Phase 1 to 4 have shown the feasibility of building and reworking SnAgCu soldered boards over different paste lots and PCB suppliers on different manufacturing lines.
- Issues highlighted include the reduced wetting at the LED component and blistering device at the connector which can be worked through with actions such as the use of different pad geometries for the LED component and baking for the connector component.
- The lead-free product defect per million rate is within the acceptable range for the tin-lead product production.
- The reliability of SnAgCu soldered joints meets product qualification requirements.

- Further investigations could be conducted to reduce the LED component defect further.

Acknowledgements

The authors would like to acknowledge their respective colleagues at Solectron Penang and Intel Kulim in Malaysia; and Intel Hillsboro/ Santa Clara in USA for their contributions to the lead-free product evaluation.