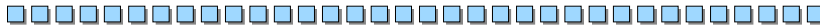
Final Presentation

HDP USER GROUP INTERNATIONAL



## HDP User Group International, Inc.

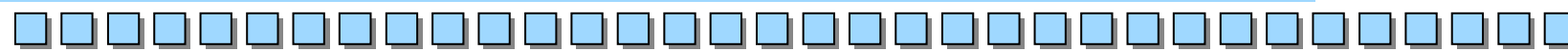
# Low Temperature Pb-free Solder Reliability Characterization

Jerry Gleason, Valeska Schroeder,
Helen Holder, Greg Henshall, HP
February 26, 2003



## Outline for final presentation

HDP USER GROUP INTERNATIONAL



- ❑ Overview of Low Temp. Pb-free project
- ❑ Summary of test results and failures
- ❑ Failure analysis of BGA-172 and 208
- ❑ Summary of project results

(Additional details are available in the appendix.)

# Project Objective

The objective of this collaborative HDPUG member project is to evaluate the interconnect reliability of Pb-free components assembled with a low temperature (170 - 180 C.) lead-free soldering process as an alternative to the mainline NEMI industry process (250 - 260 C. ).



# Review of potential Low Temperature Pb-free solder advantages

✓ **Potential cost ($) reductions**

- Lower cost board materials (lower temperature rating)
- Lower cost component packages (lower temperature rating)
- ~ 50% energy savings in reflow ovens (170 - 180 C. max., instead of 250 - 260 C.)
- Higher oven throughput (lower temperature for all components)
- Minimal package moisture (MSL) preconditioning required
- Capital and space saving by eliminating wave soldering

✓ **Increased product reliability**

- Lower stress on Silicon devices during oven reflow -> longer life
- Reduced package delamination and popcorning
- Higher BGA ball standoff with no collapse (fatigue life ~ $h^2$)
- Simplified, higher yield and reliability rework processes, especially for BGAs

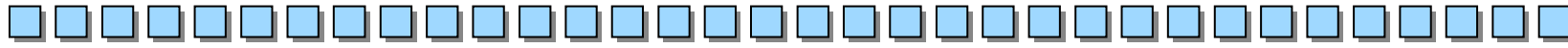
✓ **Broadened design flexibility**

- Enables 2-level step or hierarchical soldering processes
- Compatible with temperature sensitive / optical components

✓ **Compatible with most Pb-free finishes**

- SnAgCu BGA balls, Sn, NiAu, PdNi, NiPdAu lead finishes

## Definition of solder joint reliability -



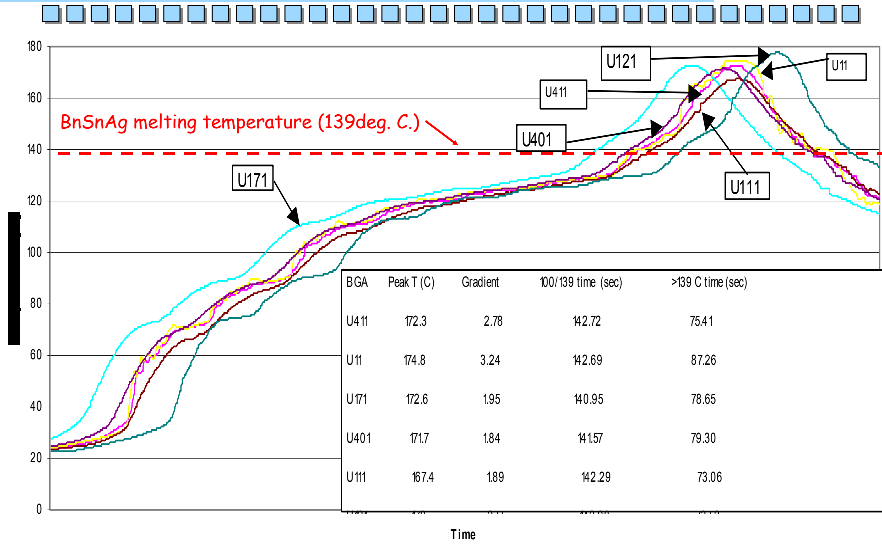
"Reliability of the solder joint of a particular package is defined as the ***probability*** that the solder joint will perform its intended function for a specified period of time, under a given operating condition, without failure." - John Lau



## Test conditions and parameters for Low Temperature Pb-free solder reliability tests

- Acatel LFQ-1 board design (11.2" x 16" x 0.062", 6 layers, FR-4)
- Board finish: Entek-106 OSP for all boards, including control boards
- Sample size: 32 components per device type, including control parts
- Solder Paste: Indium Corp. SMQ81 Sn57Bi-1Ag; Reflow in Air (not $N_2$)
- Solder paste for control components: Alpha UP-78 Sn-Pb in Air (not $N_2$)
- Board Assembly: 10 Pb-free + 10 SnPb control (by Flextronics Corp.)
- Continuous resist. monitoring of all daisy chains (320 + 320 = 640 channels)
- Temperature Cycle: 0 $^oC$ to 100 $^oC$, 33 cycles / day (12/10/12/10 min.cycles)
- Test Duration: 8144 Accelerated Thermal Cycles

## *Reflow Profile for Low Temp. Pb-free Solder Process

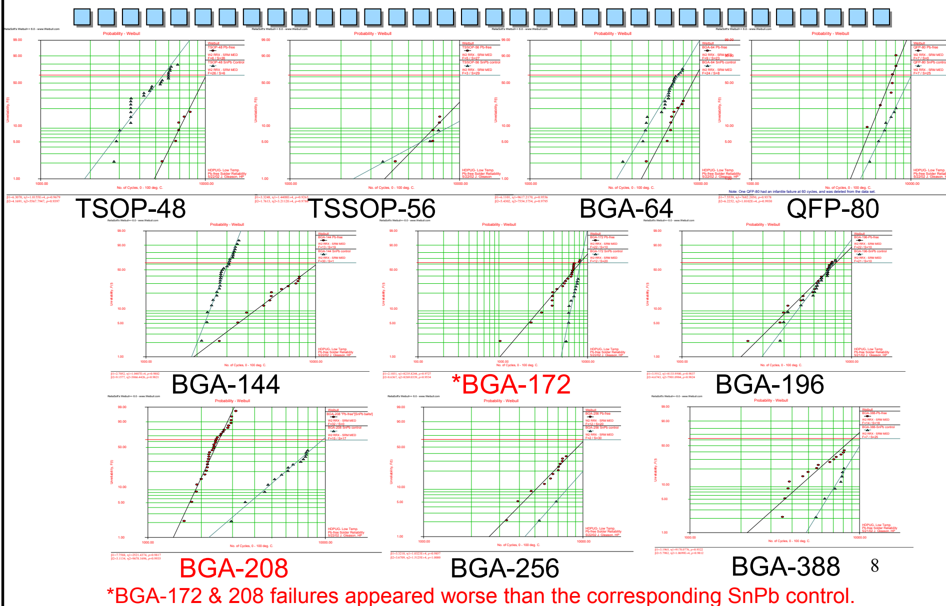



| BGA | Peak T (C) | Gradient | 100/139 time (sec) | >139 C time (sec) |
|---|---|---|---|---|
| U411 | 172.3 | 2.78 | 142.72 | 75.41 |
| U11 | 174.8 | 3.24 | 142.69 | 87.26 |
| U171 | 172.6 | 1.95 | 140.95 | 78.65 |
| U401 | 171.7 | 1.84 | 141.57 | 79.30 |
| U111 | 167.4 | 1.89 | 142.29 | 73.06 |

*Low temperature SMT assembly performed by Flextronics



## Summary of Low Temp. Solder Weibull Plots




*BGA-172 & 208 failures appeared worse than the corresponding SnPb control.

## Summary of low temperature Pb-free and SnPb solder joint failures

- Completed 8144 ATC cycles of 0 – 100 C. (Cycle: 12, 10, 12, 10 min.)
- Summary of Accelerated Thermal Cycle failures:

| Low Temp. Pb-free components | Control-SnPb | **Low Temp. paste with SnPb balls |
|---|---|---|
| *15 BGA-388, 1.27 mm | 6 BGA–388 | 32 BGA-208 |
| *12 BGA-256, 1.27 mm | 2 BGA-256 | Total: 32 opens (100%) |
| | 14 BGA-208 | |
| 21 BGA-196, 1.0 mm | 21 BGA-196 | |
| 22 BGA-172, 1.0 mm | 13 BGA-172 | |
| 14 BGA-144, 0.8 mm | 30 BGA-144 | |
| 9 BGA-64, 0.8 mm | 21 BGA-64 | |
| 8 QFP-80, 0.5 mm | 7 QFP-80 | |
| 5 TSSOP-56, 0.5 mm | 3 TSSOP-56 | |
| 4 TSOP-48, 05 mm | 27 TSOP-48 | |
| Total: 110 "opens" (34%) | Total: 144 "opens" (45%) | |

Solder volume was only 1/3 to ½ of desired level!

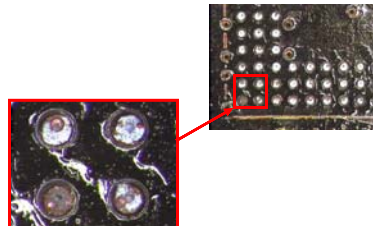
*Note: The 1.27 mm pitch BGAs were assembled with the solder volumes assuming the balls would melt. The SAC solder balls did NOT melt, and therefore did not contribute to the solder joint volume.

**Note: Early failure analysis showed that the BGA-208s were mislabeled. These were SnPb control components! The BGA-172 opens required further failure analysis.



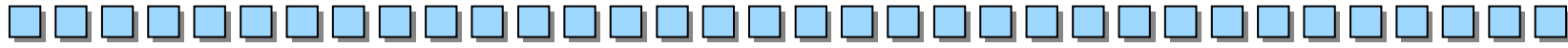
## Failure Analysis photos of BGA-172 joints

Cracks in solder balls due to large void failures



Dye & Pry showing open corner solder ball

## Failure Analysis of BGA-172 (continued)

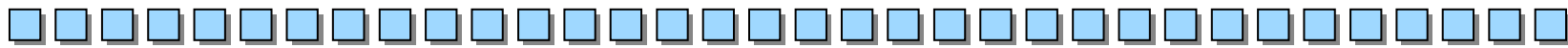


Large voids in solder balls and slight mis-alignment

Large voids causing rupture in solder balls

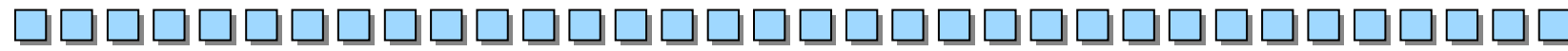


## Failure Analysis of BGA-172 (continued)



Partial cracks near ball to package interface (not open)

## Summary of FA for BGA-208 and BGA-172



- The BGA-208s failed prematurely (2/3 at 1500 cycles) because their balls were SnPb rather than SnAgCu. SnPbBi has a melting phase at 96 C., and therefore remelted on each 0 – 100 C. ATC cycle!

- The BGA-172 failures are more complex (2/3 at ~ 8000 cycles, but a projected ~ 1% fail at 1000 cycles). Dye & Pry tests and cross-sections show large voids that were likely caused by the out-gassing from the micro-vias in combination with some component mis-alignment. Even though large cracks were found at the SAC ball-to-package interface, the cracks did not appear to propagate through the top of the solder balls.



## Summary and Conclusion

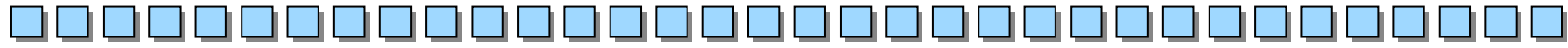
- 1.27 mm pitch BGAs (256 & 388) were assembled with only 1/2 to 1/3 of the necessary solder volume, so early failures were expected. However, both packages still performed quite well.

- All shock and vibration tests have been passed Class B (Portable) Environment Tests with no failures. (See Appendix.)

- Weibull plots based on 0 – 100 C. ATC tests demonstrate that the Low Temperature Pb-free BiSnAg solder joints have comparable solder fatigue resistance compared to SnPb control components, except for the BGA-172s and BGA-208s, which were discussed.

- Based on this limited sample size, we conclude that Low Temperature Pb-free solder fatigue resistance is comparable to SnPb solder fatigue, provided lead is not present in the solder joints. Modeling is needed to predict solder joint reliability in the field.

## Thanks to all of our HDPUG project partners!



- Alcatel
- Amkor
- ChipPac
- Flextronics
- HDPUG staff
- Intel
- ST Micro
- Texas Instruments