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Produced by the NASA Center for Aerospace Information (CASI)
NASA-DoD Lead-Free Electronics Project

2009 Defense Manufacturing Conference

November 30, 2009
Overview

- Testing project will build on the results from the JCAA/JGPP LFS Project
- The primary technical objective of this project is to undertake comprehensive testing to generate information on failure modes/criteria to better understand the reliability of:
  - Packages (e.g., Thin Small Outline Package [TSOP], Ball Grid Array [BGA], Plastic Dual In-line Package [PDIP]) assembled and reworked with lead-free alloys
  - Packages (e.g., TSOP, BGA, PDIP) assembled and reworked with mixed (lead/lead-free) alloys.
- Project documents, test plans, test reports and other associated information will be available on the web:
Comparison of NASA-DoD LFE Project to predecessor JCAA/JG-PP LFS Project

- **Similarities**
  - Virtually identical test vehicle
  - Procedures identical for most tests
  - Same facility for assembly
  - SN100C being used for wave soldering

- **Differences**
  - Test articles will be thermally aged after assembly (100°C for 24 hours)
  - Increased rework
  - Increased solder mixing
  - Mechanical shock test procedure
  - Drop testing
  - Immersion Ag surface finish for most test vehicles (Limited number will have ENIG)
  - SAC305 being used for reflow soldering
  - SN100C being used for reflow soldering
Project Stakeholders
Contributions to the NASA-DoD Lead-Free Electronics Project ~$2 Million

- OEM In-Kind: 67%
- NASA: 22%
- DoD: 7%
- OEM Direct: 4%
Lead-Free Solder Alloys

Which ones?

- **SAC305 (Sn3.0Ag0.5Cu)**
  - Surface mount assembly
  
  This alloy was chosen for reflow soldering because this particular solder alloy has shown the most promise as a primary replacement for tin-lead solder. The team decided that they wanted to select at least one “general purpose” alloy to be evaluated and it was determined that the SnAgCu solder alloy would best serve this purpose. {EnviroMark™ 907 from Kester.}

- **SN100C (Sn0.7Cu0.05Ni+Ge)**
  - Plated through hole
  - Surface mount assembly

  This alloy is commercially available and the general trend in industry has been switching to the nickel stabilized tin-copper alloy over standard tin-copper due to superior performance. In addition, this nickel-stabilized alloy does not require special solder pots and has shown no joint failures in specimens with over 4 years of service.
Test Vehicles

- 193 Test Vehicles Assembled by BAE Systems (Irving, Texas)
  120 = "Manufactured"
  73 = "Rework"

Circuit Cards

- 14.5"X 9"X 0.09"
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170°C (Isola 370HR)
- Pho-Tronics
### Component Finish/Solder Combinations

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Finish</th>
<th>Reflow Solder</th>
<th>Wave Solder</th>
<th>Board Finish</th>
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### Profiles used during assembly

**Reflow Profile = SnPb**
- Preheat = ~ 120 seconds @140-183°C
- Solder joint peak temperature = 225°C
- Time above reflow = 60-90 sec
- Ramp Rate = 2-3 °C/sec

**Wave Profile = SnPb**
- Solder Pot Temperature = 250°C
- Preheat Board T = 101°C
- Peak Temperature = 144°C
- Speed: 110 cm/min
## Component Finish/Solder Combinations

### Lead-Free Manufactured Test Vehicles

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### Profiles used during assembly

**Reflow Profile = SAC305**
- Preheat = 60-120 seconds @150-190°C
- Peak temperature target = 243°C
- Reflow: ~20 seconds above 230°C
- ~30-90 seconds above 220°C

**Wave Profile = SN100C**
- Solder Pot Temperature = 265°C
- Preheat Board T = 134°C
- Peak Temperature = 157°C
- Speed: 90 cm/min
"Rework" Test Vehicles

- 73 Test vehicles being reworked (sub-set of the 193 assembled)
- 3 Locations completed the rework

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# Component Finish/Solder Combinations

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</table>

**Profiles used during initial assembly**

**Reflow Profile = SAC305**
- Preheat = 60-120 seconds @150-190°C
- Peak temperature target = 243°C
- Reflow: ~20 seconds above 230°C
- ~30-90 seconds above 220°C

**Wave Profile = SN100C**
- Solder Pot Temperature = 265°C
- Preheat Board T = 134°C
- Peak Temperature = 157°C
- Speed: 90 cm/min
Rework Procedure

- Components being reworked have been grouped by rework solder alloy / material (SnPb, Flux only, SAC305 and SN100C). The location performing the rework can choose what order to rework the solder alloy / material groups, but must use the numbered order below for specific component locations within the solder alloy / material group. When reworking a component, the component is to be removed and replaced before moving to the next component.
## Component Finish/Solder Combinations

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Finish</th>
<th>Reflow Solder</th>
<th>Wave Solder</th>
<th>New Component Finish</th>
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</table>

### Profiles used during initial assembly

- **Reflow Profile = SAC305**
  - Preheat = 60-120 seconds @150-190°C
  - Peak temperature target = 243°C
  - Reflow: ~20 seconds above 230°C
  - ~30-90 seconds above 220°C

- **Wave Profile = SN100C**
  - Solder Pot Temperature = 265°C
  - Preheat Board T = 134°C
  - Peak Temperature = 157°C
  - Speed: 90 cm/min
Rework Procedure

- Components being reworked have been grouped by rework solder alloy / material (SnPb, Flux only, SAC305 and SN100C). The location performing the rework can choose what order to rework the solder alloy / material groups, but must use the numbered order below for specific component locations within the solder alloy / material group. When reworking a component, the component is to be removed and replaced before moving to the next component.
NAVSEA Crane Rework Effort

- Built 30 test vehicles (sub-set of the 193 assembled)
  - Test vehicles were built with Lead-Free solder and Lead-Free component finishes only = similar to Manufactured test vehicles for Mechanical Shock, Vibration and Drop Testing
  - Lead-Free alloys, SAC305 and SN100C
  - Rework was done using only SnPb solder
  - Performed multiple pass rework 1 to 2 times on random Pb-free DIP, TQFP-144, TSOP-50, LCC and QFN components
  - Testing
    - Thermal Cycling -55°C to +125°C – Testing In-Progress with NASA-DoD test vehicles
    - Vibration Testing - TESTING COMPLETE
    - Drop Testing - TESTING COMPLETE
Testing Activities
NASA-DoD Test Vehicles

Specific testing details can be found in the Joint Test Protocol (JTP)

- Thermal Cycle Testing (-20/+80°C)
- Combine Environments Testing Raytheon
- Drop Testing Celestica
- Thermal Cycle Testing (-55/+125°C)
- Vibration Testing Boeing
- Mechanical Shock Testing Boeing
- Interconnect Stress Test (IST)
- Copper Dissolution Celestica
Thermal Cycle Testing (-20/+80°C)

Test Parameters
- 5 to 10°C/minute ramp
- 30 minute dwell at 80°C
- 10 minute dwell at -20°C

Test vehicles
- Mfg. SnPb = 5
- Mfg. LF = 5
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

Testing started - July 5, 2009
~ 1200 Thermal Cycles Completed
Phase 1 = JCAA/JGPP Lead Free Solder Project - Thermal Cycle Testing (-20/+80°C)

27,135 Thermal Cycles Completed

Under the conditions of this test, Sn3.9Ag0.6Cu (SAC) and Sn3.4Ag1.0Cu3.3Bi (SACB) were always more reliable than eutectic SnPb regardless of component type (CLCC, TSOP, BGA or TQFP).
Combine Environments Testing

Thermal Cycle with Vibration
- -55°C to +125°C
- 20°C/minute ramp
- 15 minute dwell at -55°C and +125°C
- Vibration for the duration of the thermal cycle
- 10 g<sub>rms</sub> pseudo-random vibration initially
- Increase vibration level 5 g<sub>rms</sub> after every 50 cycles
- 55 g<sub>rms</sub> maximum

Test vehicles
- Mfg. SnPb = 5
- Mfg. LF = 5
- Mfg. LF (SN100C) = 5
- Mfg. LF (ENIG) = 1
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

Raytheon
Combine Environments Testing - Status

“Manufactured” Test Vehicles
• 650 cycles completed on April 1, 2009
• Data Analysis In Progress
  – BGA’s failed = 81%
  – CLCC’s failed = 93%
  – CSP’s failed = 38%
  – Sn PDIP’s failed = 5%
  – NiPdAu PDIP’s failed = 3%
  – QFN’s failed = 27%
  – TQFP’s failed = 29%
  – TSOP’s failed = 24%
Combine Environments Testing - Status

"Rework" Test Vehicles
- 650 cycles completed on June 14, 2009
- Data Analysis In Progress
  - BGA's failed = 52%
  - CLCC's failed = 96%
  - CSP's failed = 28%
  - Sn PDIP's failed = 11%
  - NiPdAu PDIP's failed = 1%
  - QFN's failed = 22%
  - TQFP's failed = 15%
  - TSOP's failed = 48%
Drop Testing

NASA-DoD Test Vehicles
- Shock testing will be conducted in the Z-axis
- 500Gpk input, 2ms pulse duration
- Test vehicles will be dropped until all monitored components fail or 10 drops have been completed

Test vehicles
- Mfg. SnPb = 5
- Mfg. LF = 5
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

CELESTICA
Drop Testing

1. A BGA ball/component falls off a board
2. A Cu dog bone / via / trace electrically fails
3. The laminate cracks
Thermal Cycle Testing (-55/+125°C)

Test Parameters
- 5 to 10°C/minute ramp
- 30 minute dwell at 125°C
- 10 minute dwell at -55°C

Test vehicles
- Mfg. SnPb = 5
- Mfg. LF = 5
- Mfg. LF (SN100C) = 5
- Mfg. LF (ENIG) = 1
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

Testing started - July 17, 2009
~900 Thermal Cycles Completed
Thermal Cycle Testing (-55/+125°C)

Data Snapshot from “Manufactured” Test Vehicles
- No “Rework” Data

![Graph showing cumulative failure distribution with Weibull Fit parameters N=38057, beta=0.59, R²=0.76.](image-url)
Vibration Testing

Subject the test vehicles to 8.0 $g_{rms}$ for one hour. Then increase the Z-axis vibration level in 2.0 $g_{rms}$ increments, shaking for one hour per step until the 20.0 $g_{rms}$ level is completed. Then subject the test vehicles to a final one hour of vibration at 28.0 $g_{rms}$.

Test vehicles

- Mfg. SnPb = 5
- Mfg. LF = 5
- Mfg. LF (SN100C) = 5
- Mfg. LF (ENIG) = 1
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

Testing Started – July 8, 2009
Mechanical Shock Testing

Testing complete

Test vehicles
- Mfg. SnPb = 5
- Mfg. LF = 5
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Test Shock Response Spectra</th>
<th>Amplitude (G's)</th>
<th>Te (msec)</th>
<th>Shocks per Level</th>
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</thead>
<tbody>
<tr>
<td>Modified Functional Test for Flight Equipment (Level 1)</td>
<td>Modified Functional Test for Ground Equipment (Level 2)</td>
<td>20</td>
<td>&lt;30</td>
<td>100</td>
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<tr>
<td>Modified Crash Hazard Test for Ground Equipment (Level 3)</td>
<td>Level 4</td>
<td>75</td>
<td>&lt;30</td>
<td>100</td>
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<td>Level 5</td>
<td>Level 6</td>
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<tr>
<td>100</td>
<td>300</td>
<td>&lt;30</td>
<td>400</td>
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<table>
<thead>
<tr>
<th>Number of Test Vehicles Required</th>
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<tbody>
<tr>
<td>Manufactured</td>
</tr>
<tr>
<td>5</td>
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<tr>
<td>Trials per Specimen</td>
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## Mechanical Shock Testing

<table>
<thead>
<tr>
<th>Component</th>
<th>&quot;Manufactured&quot; Test Vehicles</th>
<th>&quot;Rework&quot; Test Vehicles</th>
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<tbody>
<tr>
<td></td>
<td>SnPb</td>
<td>Pb-Free</td>
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<tr>
<td>BGA-225</td>
<td>94</td>
<td>96</td>
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<tr>
<td>CLCC-20</td>
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<td>30</td>
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<td>CSP-100</td>
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<td>PDIP-20</td>
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<td>QFN-20</td>
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<td>TQFP-144</td>
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<tr>
<td>TSOP-50</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>
Copper Dissolution

- Printed Circuit Board (PCB) land and plated through-holes can be eroded or dissolved away in the presence of molten solder rendering the PCB non-functional. Significant dissolution can occur with the use of certain new Sn-rich alloys and is further exacerbated by higher process temperatures.

- Mini-wave soldering versus manual soldering
- Number of component removals: 1X versus 3X
- PDIPS on break off coupon and QFP pad pattern
- Metallographic Analysis:
  - As fabricated copper thickness
  - As assembled copper thickness
  - As reworked copper thickness

Test coupons
- Mfg. SnPb = 5
- Mfg. LF = 5
- Mfg. LF (SN100C) = 5
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

Rockwell Collins

CElestica
Copper Dissolution

Cracks generated from the lack of Cu knee (SAC405 solder) during Thermal Cycle Testing {0°C to 100°C}

The Cu layer was dissolved completely or partially in the knee regions of SAC405 PTH joints during rework. The cracks start growing from non-Cu knee regions after 1000 cycles. The direction of the cracks was close to 45° to the knee.
Kurt Kessel
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NASA Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM)
Kennedy Space Center, FL
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E-Mail: kurt.r.kessel@nasa.gov
Website: www.teerm.nasa.gov

NASA-DoD Lead-Free Electronics Project:

JCAA/JGPP Lead-Free Solder Project
http://www.teerm.nasa.gov/projects/LeadFreeSolderTestingForHighReliability_Proj1.html
On July 21, 1961 a Mercury/Redstone rocket carried Grissom on a 15-minute trip through space, successfully repeating the feat performed by Alan Shepard two months earlier.

The Liberty Bell 7 was pulled from a depth of 15,000 feet -- 3,000 feet deeper than the Titanic on July 20, 1999.
In response to concerns about risks from lead-free induced faults to high reliability products, NASA has initiated a multi-year project to provide manufacturers and users with data to clarify the risks of lead-free materials in their products. The project will also be of interest to component manufacturers supplying to high reliability markets.

The project was launched in November 2006. The primary technical objective of the project is to undertake comprehensive testing to generate information on failure modes/criteria to better understand the reliability of:

- Packages (e.g., TSOP, BGA, PDIP) assembled and reworked with solder interconnects consisting of lead-free alloys
- Packages (e.g., TSOP, BGA, PDIP) assembled and reworked with solder interconnects consisting of mixed alloys, lead component finish/lead-free solder and lead-free component finish/SnPb solder

**Subject Terms**

- Lead-Free
- Pb-Free