Whisker Formation on Tin Plated Cu based Leadframes

Results and Conclusion

29 October 2004
Content

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• Experience E4
• Main cause whisker growth on Cu LF
• Countermeasures
• Conclusions
Introduction

Period of potential whisker growth

- **Cu-based L/F**: no whisker growth
  - countermeasure baking
  - see this presentation

- **FeNi42 L/F**: no whisker growth
  - see FeNi42 presentation

Storage conditions:
- tin plating
- board assembly/soldering

Service life conditions:
- whisker
- no whisker growth

- product end of life

- ≤ 2 years
- ~ 15 years
Experience in Tin plating within E4

**Electrolytes**

**Production line**
- Shipley ST-200
- Shipley ST 300
- Schlötter Slototin 40
- Pyramid Pyra Tin Lux
- Technic Technistan EP
- OMG Reel Satin 2544 LF
- Lucent Satin bright Tin

**Lab scale**
- Shipley ST-150
- Shipley ST-200
- Shipley ST 300
- Schlötter Slototin 40
- Pyramid Pyra Tin Lux
- Technic Technistan EP
- OMG Reel Satin 2544 LF
- Atotech HSM

**Leadframe Material**

<table>
<thead>
<tr>
<th>ASTM / material number</th>
<th>Brand name / short notification</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C14415</td>
<td>K 81 / CuSn0.15</td>
<td>0.1 Sn; &lt;0.02 Ni/Zn</td>
</tr>
<tr>
<td>C18070</td>
<td>K 75 / CuCrSiTi</td>
<td>0.3 Cr; 0.35 Si; 0.07 Ti</td>
</tr>
<tr>
<td>C19210</td>
<td>K80 / CuFeP, KFC</td>
<td>0.1 Fe; 0.03 P</td>
</tr>
<tr>
<td>C18090</td>
<td>K62, CuSn1CrNiTi</td>
<td>0.6 Sn; 0.4 Ni; 0.3 Cr; 0.3 Ti</td>
</tr>
<tr>
<td>C19400</td>
<td>Olin 194, K 65 / CuFe2P</td>
<td>2.4 Fe; 0.12 Zn; 0.03 P</td>
</tr>
<tr>
<td>C50710</td>
<td>MF 202 / CuSn2ZnP</td>
<td>2.0 Sn; 0.2 Ni; 0.15 P; 0.15 Zn</td>
</tr>
<tr>
<td>C70250</td>
<td>Olin 7025, K 55 / CuNi3Si1Mg</td>
<td>3.0 Ni; 0.65 Si, 0.15 Mg; &lt;1.0 Zn</td>
</tr>
<tr>
<td>C22000</td>
<td>MS10</td>
<td>CuZn10</td>
</tr>
<tr>
<td></td>
<td>Alloy 42</td>
<td>FeNi42</td>
</tr>
</tbody>
</table>
Storage conditions

- Test data showed that whiskers grow longest at room temperature
- Explanation: irregular intermetallic growth

![Graph showing whisker growth under different conditions](graph.png)
Influence of Plating Thickness

- Observation of strong dependency on thickness may result in acceleration factor according to thickness
- Similar results available for 4 Cu-materials and 3 electrolytes
Whisker Mechanism on Cu based leadframes

Whiskers grow because of compressive stress in the plating which is caused by irregular growth of intermetallics.
Protection by Postbake (1h, 150 °C)
(Within 24 hours of plating)

• Because of higher temperature diffusion will shift from grain boundary to bulk diffusion and thus regular intermetallics
• Recrystallization of Sn
• Diffusion barrier for further intermetallic growth
• Annealing of stress
• Postbake does NOT change CTE mismatch!

No whisker!

Cu₆Sn₅/Cu₃Sn
Sn deposit
Cu based LF
Morphology of the Intermetallics

1 h 150 °C

Bulk Diffusion
Recrystallization

Same amount of intermetallics!

4 h 125 °C

Grain Boundary Diffusion
Less Recrystallization

42 days 55 °C

1 year RT
Postbake Characteristics

- Postbake results in double layer of Cu$_3$Sn and Cu$_6$Sn$_5$
- The average layer thickness of the resulting intermetallic is 0.7 µm (+0.2/-0.3)
- Sn grain size 5 to 25 µm
- No additional intermetallic after 12 months storage at ambient
Protection by underlayer

Whisker on Cu
Changing underlayer results in other than Cu$_6$Sn$_5$ intermetallics, no stress build-up!

Ni underlayer:  Ag underlayer:

Cross-sectioned view of 5µm Sn on Cu-based leadframe with 2 µm Ni underlayer

Surface after stripping Sn showing intermetallics: upper half Ag underlayer, lower half Cu substrate (5 weeks@R.T)
Protection by underlayer

Sn-plating on Cu-base-material is prone to whiskers. Ni-underlayer will eliminate whisker risk.
Whisker on Cu

Sn-plating on Cu-base-material is prone to whiskers.

Ag-underlayer will eliminate whisker risk.

A bake process will eliminate whisker risk.
Cu Leadframes and Temperature Cycling

- Small whiskers can occur due to limited mismatch of CTE
- Postbake does NOT change this mismatch
## Test Results

<table>
<thead>
<tr>
<th>Test condition</th>
<th>Preconditioning</th>
<th>Non postbaked Cu leadframes</th>
<th>Postbaked Cu leadframe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Max. Whisker Length (µm)</td>
<td>Time (h)/ # Cycles</td>
</tr>
<tr>
<td>20-25 °C, 30-80 % r.h.</td>
<td>-</td>
<td>~ 90</td>
<td>&gt; 5000</td>
</tr>
<tr>
<td>20-25 °C, 30-80 % r.h.</td>
<td>simulated reflow @ 215 °C</td>
<td>0</td>
<td>&gt; 8000</td>
</tr>
<tr>
<td>20-25 °C, 30-80 % r.h.</td>
<td>simulated reflow @ 260 °C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20-25 °C, 30-80 % r.h.</td>
<td>assembly @ 215 °C</td>
<td>0</td>
<td>&gt; 8000</td>
</tr>
<tr>
<td>20-25 °C, 30-80 % r.h.</td>
<td>assembly @ 260 °C</td>
<td>0</td>
<td>&gt; 8000</td>
</tr>
<tr>
<td>20-25 °C, 30-80 % r.h. with 5 V bias applied</td>
<td>assembly @ 215 °C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>55 °C/85% r.h.</td>
<td>-</td>
<td>~ 60</td>
<td>&gt; 5000</td>
</tr>
<tr>
<td>60 °C/93% r.h.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>simulated reflow @ 215 °C</td>
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<td>assembly @ 260 °C</td>
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</tr>
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<td>55 °C/85% r.h.</td>
<td>assembly @ 260 °C</td>
<td>0</td>
<td>~ 5000</td>
</tr>
<tr>
<td>60 °C/93% r.h. with 5 V bias applied</td>
<td>assembly @ 215 °C</td>
<td>~ 30</td>
<td>~ 1000</td>
</tr>
<tr>
<td>-40 °C/125 °C, TST, &gt;7' dwell</td>
<td>-</td>
<td>~ 30</td>
<td>1000</td>
</tr>
<tr>
<td>-55 °C/85 °C, TST, 10' dwell</td>
<td>-</td>
<td>~ 30</td>
<td>1000</td>
</tr>
<tr>
<td>-55 °C/85 °C, TST, 10' dwell</td>
<td>simulated reflow @ 215 °C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-55 °C/85 °C, TST, 10' dwell</td>
<td>simulated reflow @ 260 °C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-55 °C/85 °C, TST, 10' dwell</td>
<td>assembly @ 215 °C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-55 °C/85 °C, TST, 10' dwell</td>
<td>assembly @ 260 °C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-40 °C/125 °C, TST, 20' dwell</td>
<td>assembly @ 215 °C</td>
<td>&lt; 10</td>
<td>~ 6600</td>
</tr>
<tr>
<td>-40 °C/125 °C, TST, 20' dwell</td>
<td>assembly @ 260 °C</td>
<td>&lt; 10</td>
<td>~ 6600</td>
</tr>
</tbody>
</table>

* whiskers found after severe corrosion and exceeding 3000 h test time.
**NEMI DoE3 Test results 60°C/93%RH**

**60C/93RH STORAGE**
**6000 HRS INSPECTION**

Finishes Ranked by Max. Whisker Length
Isothermal Storage 6000hrs

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Plating</th>
<th>Max. Whisker Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDA194</td>
<td>Matte Sn/2-3Bi</td>
<td>360</td>
</tr>
<tr>
<td>CDA194</td>
<td>Matte Sn</td>
<td>270</td>
</tr>
<tr>
<td>Cu 7025</td>
<td>Matte Sn</td>
<td>200</td>
</tr>
<tr>
<td>CDA194</td>
<td>150C 1hr Matte Sn</td>
<td>160</td>
</tr>
<tr>
<td>CDA194</td>
<td>Hot-dipped Sn</td>
<td>150</td>
</tr>
<tr>
<td>CDA194</td>
<td>Matte Sn/2-3Cu</td>
<td>150</td>
</tr>
<tr>
<td>CDA194</td>
<td>245C reflow Matte Sn</td>
<td>110</td>
</tr>
<tr>
<td>CDA194</td>
<td>Matte Sn 3 - 5um</td>
<td>110</td>
</tr>
<tr>
<td>CDA194</td>
<td>Sn/2-4Ag</td>
<td>100</td>
</tr>
<tr>
<td>CDA194</td>
<td>SnPb</td>
<td>75*</td>
</tr>
</tbody>
</table>

*on areas with no Pb
60 °C/93 %RH
Corrosion

Toe area of QFP after > 3000 h 60 °C/93%RH

Shoulder area of QFP after > 3000 h 60 °C/93%RH
60 °C/93 %RH
X-sections

Parallel cross-sections after aging > 3000h
Foot  Shoulder

Perpendicular cross-sections on foot area after aging > 3000h
Conclusions

- Compressive stress is the driving force in pure tin layers (without compressive stress no whiskers).
- Whisker growth on Copper leadframes is mainly caused by large, irregular intermetallic $\text{Cu}_6\text{Sn}_5$ growth at interface substrate / plating layer.
- Storage in ambient atmosphere produces longest whiskers on copper leadframe (compared to all other tested storage conditions).
- The thicker the Sn-layer the shorter is the whisker.
- Countermeasures are postbake, Ni-, Ag-underlayer.
- Postbake 1h, 150°C is performed after plating.
- Temperature cycling may cause a maximum whisker length of 30 $\mu$m on Cu leadframes.
- Maximum specified whisker length is 50 $\mu$m for accelerated tests.
- After 2 years storage at ambient and/or soldering on board matt tin plated Cu-L/F, with above mentioned countermeasures, does not show evidence of whiskers.