Tin whisker mitigation: research into mechanisms and strategies. Part 1, Effect of plating methodologies

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Tin Whisker Mitigation Methodologies
Loughborough University
24th November 2016
Whiskers Research at Loughborough

**WHISKERMIT**
2010-2013

- Process optimisation (commercial bright tin)
- In-service mitigation strategies
- Development of novel conformal coatings for whisker mitigation
- Incorporation of particulates
- Conformal coating
- Electrochemical oxidation to mitigate whisker growth
- Deposition current density
- Deposit thickness
- Pulse plating

**WHISKERMIT 2**
2014-present
Tin Whisker Mitigation - Research into Mechanisms & Strategies

PART 1: EFFECT OF PLATING METHODOLOGIES

PART 2: POST-PLATING MITIGATION METHODS
Part 1: Outline of presentation

- Introduction
- Experimental approach
- Deposition onto copper
- Deposit characterisation
- Deposition onto brass
- Effect of electroplating parameters
- Pulse plating
- Summary
Tin whiskers

- Crystalline growths from a metal surface (e.g. Sn, Zn and Cd)
- Uncertain incubation period before growth
- Numerous growth morphologies possible
- A few micrometres in diameter and up to several millimetres in length
- Although investigated for ~70 years, whisker related problems are increasing due to environmental legislation and device miniaturisation
Factors that influence whisker growth

- Electroplating bath chemistry
  - Pure tin or tin alloy (Sn-Pb, Sn-Bi, Sn-Cu etc.)
  - Bright or matte tin
- Electroplating parameters
  - Current density, temperature, agitation
- Deposit characteristics
  - Grain size and morphology, orientation, deposit thickness, Sn oxide
- Substrate
  - Cu, brass, alloy 42
  - Intermetallic formation, elemental diffusion from substrate
- Environmental conditions
  - Temperature, humidity, thermal cycling, applied external stress
Experimental approach

• All samples were electroplated using a commercial bright tin electroplating bath (Tinmac)
• Effect of deposition current density, deposit thickness and substrate composition investigated
  – 5, 10, 20, 30, 40 and 50 mA cm$^{-2}$
  – 2, 5 and 10 µm
  – Copper, brass (63Cu/37Zn) and Alloy 42 (58Fe/42Ni) substrates
• 3 samples per condition electroplated late 2011
• Selected samples stored at 55°C/85% humidity
Sn on Cu: whisker growth after ~2 years

Samples from batch #3 stored in oven for 5000h at 55°C/85% RH

<table>
<thead>
<tr>
<th>Deposit thickness</th>
<th>10 mA cm⁻²</th>
<th>20 mA cm⁻²</th>
<th>30 mA cm⁻²</th>
<th>40 mA cm⁻²</th>
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<tbody>
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<td>#1</td>
<td>#2</td>
<td>#3&lt;sub&gt;HT&lt;/sub&gt;</td>
<td>#1</td>
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<tr>
<td>2 µm</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5 µm</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 µm</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Whisker growth on Sn deposits on Cu

Examples of whisker growth present on Sn deposits on copper (batch 2) after storage at room temperature for 5 years. No long filament whiskers observed.
Whisker growth on oven stored samples

Overall, whisker growth on the heat treated samples remains comparable to that on the samples stored entirely at room temperature.
Sn deposits on Cu - summary

- Sn deposits on copper produced in this study demonstrate low levels of whisker growth, even after 5 years storage, despite being produced from a bright tin electroplating bath.
- Variation in whisker density between samples from different batches.
- Only significant whisker growth observed for thinnest deposits (2 µm) electroplated at lowest current density (10 mA cm\(^{-2}\)).
- No increase in whisker growth with storage at 55°C/85% RH for 5000 hours.

Why such low whisker growth?

Characterisation of deposit microstructures.
Effect of deposition current density

Facetted cuboidal grains formed at 5 mA cm\(^{-2}\)

Reduction in grain size at higher current densities
Effect of deposition current density on microstructure

As deposition current density increases:
- Grain size reduces and becomes less facetted.
- Deposit becomes increasingly columnar.
- All deposits show a strong 001 orientation.

FIB cross-section (after 1 month)

Grain orientation map (deposit surface)

EBSD Deposit orientation
Effect of storage at elevated temp/humidity

5 µm tin 20 mA cm\(^{-2}\)
2 years room temperature storage

10 µm tin 20 mA cm\(^{-2}\)
2 years storage includes 5000 hours at 55\(^\circ\)C/85\% RH

- Cu\(_3\)Sn layer develops during storage at 55\(^\circ\)C
- IMC layer is more planar compared with that developed at room temperature
- No acceleration in whisker growth observed compared with samples stored at room temperature

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From the literature


“The very low whiskering of the deposit is attributed to a combination of the mixed equiaxed and columnar grain structure and the preferential <112>-<101>-<103> multi-peak texture of the deposit”

WO 2010/002377 A1: Preventing or mitigating growth formations on metallic films, J.W. Osenbach, 2010

Patent suggests that tin deposits having a <001> preferred texture are less susceptible to whisker growth
Acceleration of whisker growth

- To more fully investigate the effect of process variables (and study mitigation techniques) more rapid whisker growth was required
- Deposition onto brass is known to promote rapid and profuse whisker growth

For tin deposits on brass, whisker growth is primarily driven by zinc oxide formation at the deposit surface rather than intermetallic growth at the Sn-brass interface.

5 μm tin deposit on brass, electroplated at 10 mA cm⁻²
~29 months after tin deposition

Zn oxide
Blocky Cu₅Sn₅ intermetallic
Zn incorporation into whiskers?

- Auger analysis carried out to investigate the composition of the whiskers formed on Sn deposits on brass.

Prior to sputter

<table>
<thead>
<tr>
<th>Kinetic energy (eV)</th>
</tr>
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<tbody>
<tr>
<td>50</td>
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</table>

C | Sn | Zn | O

Zn present on whisker surface

After sputter

<table>
<thead>
<tr>
<th>Kinetic energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
</tr>
</tbody>
</table>

Sn | O | Zn

Zn absent after oxide removed

Whiskers are pure Sn
Effect of deposition current density

Evaluation of whisker density for 2 µm tin deposits on brass
Analysis approx. 33 months after tin deposition
Storage at room temperature
Effect of deposition current density

**2 µm deposits**

- Filaments
- Eruptions
- Eruptions/nodules < 10 µm

- 10mAcm-2
- 20mAcm-2
- 30mAcm-2
- 40mAcm-2

**10 µm deposits**

- Filaments
- Eruptions
- Eruptions/nodules < 10 µm

- 10mAcm-2
- 20mAcm-2
- 30mAcm-2
- 40mAcm-2

Analysis approx. 33 months after tin deposition
Storage at room temperature
Further reductions in deposition current density to 5 mA cm\(^{-2}\) generate increasing densities of long filament whiskers.

Further increases in deposition current density to 50 mA cm\(^{-2}\) result in low densities of large eruptions.
Effect of deposit thickness

(a) 2 µm, 10 mA cm⁻²
(b) 2 µm, 40 mA cm⁻²
(e) 10 µm, 10 mA cm⁻²
(f) 10 µm, 10 mA cm⁻²

Analysis approx. 33 months after tin deposition
Storage at room temperature

Whisker density (whiskers/mm²)

- Blue bars: 2µm deposits
- Red bars: 5µm deposits
- Green bars: 10µm deposits

Deposition current density
Whisker growth after ~ 5 years

Whisker growth for the batch 3 samples has been evaluated after ~5 years storage at room temperature.
Effect of deposition current density

- Results demonstrate that the growth of filaments, eruptions and nodules, whisker growth is reduced as the deposition current density is increased.
- At higher deposition current densities the growth of nodules and eruptions is favoured.
- Whisker growth reduces as the deposit thickness increases.

казано, что рост нитей, вулканических образований и каемок уменьшается с увеличением плотности тока приложения. В некоторых случаях, рост каемок уменьшается с увеличением толщины покрытия. Меньше каемок можно достичь при электролизе на более высокой плотности тока приложения.
Effect of Pulse Plating

- Pulse plating may be used to manipulate the grain structure and orientation of the tin deposit.

5 µm tin on copper
10% duty cycle
20 Hz frequency

- Results, for tin deposits on brass, showed that whisker growth could be influenced by control of pulse plating parameters (duty cycle and pulse frequency).
Effect of pulse plating on whisker growth

Deposits produced using a 10% duty cycle and 2.5 Hz showed reduced whisker growth compared with direct current deposits.

BUT, pulse plating could also result in greatly accelerated whisker growth compared with direct current deposits → low pulse frequencies preferable.
But

- The observed influence of current density on whisker growth may only be applied with regards to the electroplating bath used for the current study.
- Other electroplating bath formulations may demonstrate a different relationship between current density, deposit microstructure and whisker growth.
- E.g. it is often thought that fine grained columnar structures and higher deposition current densities are more prone to whisker growth.
- Elevated temperature and humidity may also affect other tin deposits in a different way.
Whisker growth on consumer products

Examples of tin whiskers found on the connector pins of an electroplated SCART connector

XRF analysis showed that the connector was electroplated with ~5 µm of bright tin

...... analysis also showed that the substrate was composed of ~63% Cu and 37% Zn

i.e. ideal conditions to generate whisker growth
Summary

• Bright tin electrodeposited onto Cu does not always result in significant whisker growth

• In the present study, whisker growth was reduced by increasing deposit thickness and by deposition at higher current densities

• Large eruptions, rather than filament whiskers were preferentially formed at high deposition current densities

• Exposure of Sn deposits on Cu to 55°C and 85% humidity did not accelerate whisker growth
Any questions?

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