NEMI Sn Whisker Modeling Group
Part 1: Overview and Results
*IPC/NEMI Meeting*

*Irina Boguslavsky. NEMI Consultant*
*Maureen Williams, NIST*

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*New Orleans, LA*
Overview

- The NEMI Tin Whisker Modeling Group was formed in July 2001 as a spin-off of the Test Group
- Both groups are working in parallel
- Tin Whisker Modeling Group (NEMI members only)
  - 14 companies including 1 Government agency
  - George Galyon, IBM (Chair)
  - Maureen Williams, NIST (Co-Chair)
2002 Members of Modeling Group

- AMD
- ChipPac
- Delphi Delco
- FCI
- Hewlett-Packard
- IBM
- Intel
- Indium

- Motorola
- NEMI
- NIST (Co-Chair)
- Shipley (Co-Chair)
- Solectron
- Texas Instruments
Objectives

• Determine underlying mechanisms of whisker formation
• Identify material properties of tin deposit and plating process parameters affecting whisker growth
• Predict incubation period, growth rate and maximum length of whiskers based on measurable deposit properties and modeling
• Based on that knowledge, develop an accelerated test to determine the potential for whisker formation
• Determine the acceleration factors to predict long term tendency to whisker
• Pre-dominant factor in whiskers growth is the stress in Sn layer
  – Stress increases with time, perhaps due to IMC formation
• Oxide layer on Sn may cause dual effect
  – Increase stress
  – Prevent Sn from extrusion (need to finds weak spot in oxide film)
• Certain combinations of crystal orientations of adjacent grains may be favorable for whisker formation
• Bath formulation and plating process parameters influence strongly propensity to whisker
• Impurities in bath have large effect on whiskering
• However, neither of those factors alone can explain and predict whisker growth
• All the factors mentioned in the previous slide affect whisker growth
• It is impractical to control all those parameters in manufacturing and later, during a part life-cycle, to prevent whiskering
• Considering whisker growth as a transport phenomenon, one should relate it to the material characteristics of tin deposit itself
• Addition of lead probably changes those characteristics and makes SnPb less susceptible to the external factors in regards to whisker formation
• Due to high mobility of tin atoms and different energetic states of atoms in various crystals and grain boundaries, diffusion will occur even with no enhancement by external factors and sometimes at the expense of depletion of adjacent grains or grain boundaries
Grain Sinking and GB Depletion

Whisker test conditions:
55C dry heat, 4 weeks

Substrate:
A 42

Note steps at the whisker base

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Pure Tin Grows Whiskers

• Bulk tin
• Vapor deposited tin films on inert substrates: paper, mica, plastics
• Metallurgically prepared polished 50%Sn/50%Al discs
• Electroplated foils delaminated from the substrate
• Electroplated tin and tin alloys
• No whiskers on high purity tin such as zone refined tin or on single crystal of tin
Whisker Types

Column

Hillock

Flower or OSE

Needle

Needle growing out of hillock

Needle growing out of OSE

SEM photos – courtesy of P. Bush, SUNY at Buffalo

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Whiskers on 90 Sn/10 Pb

Secondary Electron Image (SEI)

Backscattered Electron Image (BEI)

Substrate: C194

Test conditions: 1500 temperature cycles –55°C to +85°C

SEM photos – courtesy of P. Bush, SUNY at Buffalo

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Work Done by NEMI Modeling Group

- Verification of XRD method (powder diffraction) for crystal orientation and internal stress measurements

- Study of the oxide film after various aging conditions

- Attempt of modeling whisker growth and verification of the model using real life samples

- Effect of impurities on whisker growth

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Verification of XRD Method

Use of synchrotron radiation to determine the state of strain in tin coatings on integrated circuit packages.

Dr. Peter W. Stephens
Department of Physics & Astronomy
Stony Brook University
• Advances in x-ray technology, especially use of synchrotron radiation, permit microscopic studies of materials that were previously impossible/difficult.

• The premise of powder diffraction is to look at a statistical sample of grains. Complements measurements of individual grains/whiskers such as recently discussed by K.N. Tu.

• Preliminary work was done on sample N2, QFP package (14mm x 14mm, 100 leads), ~10 μm matte tin over alloy A42 (fcc, a=3.588). Temp. and humidity cycled 1,500 times.

• Microscopy (Peter Bush) shows grains 5 – 50 microns.

• Films are evidently one grain thick.
Is the sample a good powder (observe many small grains)?

Rock the sample at fixed diffraction angle.

**NO!** Large fluctuations imply that sample has relatively large grains. Also known from microscopy

Sn (220) reflection \( \_ = 0.83 \) Angstrom

.typ. 5-50 _m
Diffraction Pattern (low penetration)

FWHM = 0.016°

10 nm Sn film on IC lead

\( d = 1.15 \text{ Å} \).

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10 μm Sn film on IC lead

\[ d = 0.65 \text{ Å} \]

Puzzle: why did (220) get so weak? The rest of the pattern is about the same as 1.15Å.
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Diffraction patterns have been collected at three different wavelengths.

Used this data to measure strain at different depths of the sample.

Re-plotted three diffraction patterns as a function of \( \frac{\sin(\theta)}{\theta} = \frac{1}{2d} \), which should be the same for each diffraction line.

Larger angles => shorter \( d \)-spacing
XRD Study

Tin (200)
Motorola 14mm square pack

Nominal position, \( d = 2.9155 \)
Deeper penetration \( \rightarrow \) Smaller \( d \), negative strain.

\[
\frac{d}{d} = 0.0012
\]
XRD Study

Motorola 14mm square pack

- 1.15 Å
- 0.65 Å
- 0.5 Å

Tin (220), \( d = 2.0615 \)

\[ \Delta d / d = 0.0007 \]

\( \text{Ni}_{40}\text{Fe}_{60} \) (111)
Preliminary Conclusion of XRD Study

1. Sn films are severely textured. (220) or (321) appears to be the main growth direction.

2. Films are made of rather large grains, which makes accurate powder diffraction measurements difficult for characterization of both crystal orientation and deposit strain/stress.

3. It appears that the deeper material is compressed, perpendicular to the surface. Cannot tell if there is such compression along the surface direction. Estimated deep strain is equivalent to a stress of 
\(-0.001 \times 40 \, \text{GPa} = -40 \, \text{MPa} \) (compression)

4. More work requires more manpower.
Auger Analysis of Tin Oxide Film Thickness: Effect of Aging Conditions

Peter J. Bush
SUNY at Buffalo
Auger Study of Oxide Film (sample after ambient conditions)

Auger depth profile. Tin oxide layer thickness <200Å.
Auger depth profile. Tin oxide thickness is difficult to observe, but there appears to be a significant amount of carbon up to 4000Å deep in the film.

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Calculation of Stress Along Grain Boundaries

Modeling done by B. Radhakrishnan, ORNL
Stress along Grain Boundaries

• Estimation of normal force was done for the existing deposits with various degree of whiskering based on their XRD spectra (crystal orientation)

• The normal strain, $b_3$, was calculated for each grain orientation

• The difference in normal strain between two grain orientations is proportional to the stress acting to promote whiskers

• Larger the difference in normal strain, greater is the probability for initiating whisker growth (Lee and Lee, 1998)
## Calculated Results

<table>
<thead>
<tr>
<th>Orientation</th>
<th>e’_33</th>
<th>Intensity</th>
<th>Normal force</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Good practice</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

|       |         |           |              |
| 101   | 0.014080 | 800       | 0.0          |
| 211   | 0.013813 | 200       | 0.000267     |
| 112   | 0.008393 | 400       | 0.005687     |
| 111   | 0.008720 | 140       | 0.00872      |
| 103   | 0.007674 | 130       | 0.006406     |

40 whiskers per lead

|       |         |           |              |
| 220   | 0.007860 | 2300      | 0.0215       |
| 211   | 0.013813 | 2000      | 0.015547     |
| 321   | 0.010886 | 800       | 0.018474     |
| 101   | 0.014080 | 500       | 0.01528      |
| 200   | 0.029360 | 400       | 0.0          |

**No whiskers**

|       |         |           |              |
| 321   | 0.010886 | 1220      | 0.018474     |
| 111   | 0.008720 | 1180      | 0.02064      |
| 431   | 0.009578 | 600       | 0.019782     |
| 211   | 0.013813 | 440       | 0.015547     |
| 200   | 0.029360 | 200       | 0.0          |
Discussion of the Results

• For the “good practice” texture, set 1, the magnitude of normal strain difference is significantly smaller than for the set 2 (40 whiskers per lead) and set 3 (no whiskers). Sets 2 and 3 represent the same plating process
• The presence of <200> component (which has the highest normal strain) in set 2 and set 3 results in a larger magnitude of strain difference that in set 1 and, thus, higher probability of whiskering
• Volume fraction of <200> component in set 3 is lower than in set 2; therefore the probability of finding grains with high stress is lower
• Based on the components that have the highest volume fractions (probability of finding such pairs of grains in the samples is high), the stress value for set 1 is significantly lower than in sets 2 and 3.
• Good correlation of the modeling results with practice confirms the feasibility of the approach

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Modeling Group: Phase 1 DOE Matrix

- Deposit/bath chemistry: matte pure tin, MSA-based
- Standard plating parameters (fixed)
- Deposit thickness of 50-100 microinch
- Substrate C194
- Impurities (Fe, Cu, Ni, Zn, and Pb) were added as MSA or sulfate salts at the level of 300 ppm
- For Sn(IV) oxide formation (particulate matter), the bath was artificially aged by purging oxygen following by filtration through 10 μm filter

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## Effect of Impurities (Group H)

<table>
<thead>
<tr>
<th>Impurities (300 ppm)</th>
<th>Initial</th>
<th>Cu</th>
<th>Ni</th>
<th>Pb</th>
<th>Fe</th>
<th>Zn</th>
<th>Particles* &lt;10 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>27</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>Longest Whisker, μm</td>
<td>40</td>
<td>60</td>
<td>50</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Grain size</td>
<td>1-5</td>
<td>1-5</td>
<td>1-5</td>
<td>1-5</td>
<td>1-5</td>
<td>1-5</td>
<td>1-5</td>
</tr>
</tbody>
</table>

* - Sn(IV) oxide particles were artificially produced by purging air through solution followed by filtration with 10 micron filter

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Effect of Impurities on Whiskering

Aging conditions: 5 months at Ambient T and RH

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Sample Set H: Pure Bath

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Sample Set H: Cu Contamination

Evidence of grain surface morphology change
Sample Set H: Ni Contamination

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Sample Set H: Pb Contamination
Sample Set H: *Fe Contamination*

Evidence of diffusion at surface grain boundary
Sample Set H: *Particles Contamination*

Particles distributed on grain surfaces

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Morphology of Thin Tin

Supplier A

Supplier B

Sulfate

MSA

MSA

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Modeling Group Phase 1 DOE Findings

• Impurities in the plating solution may have accelerating effect (Fe, Zn, Cu, Sn(IV) oxide particles), no effect (Ni), or inhibit (Pb) whiskering

• Need to determine concentration of impurities in the deposit (co-deposited) to identify the mechanism of their influence

• In the case of impurity co-deposition, need to determine where in the crystalline structure those atoms are present
Modeling Group: Future Work

Maureen Williams, NIST