Quantifying the Role of Stress on Whisker Nucleation and Growth

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Outline

• Motivation
• Sources of Stress
• Creep of Tin
• Experimental Method
• Results to Date
• Discussion of Test(s)

• Conclusions
Motivation

• Previous work has shown an impact of mechanical stress on whisker growth

• Existing tin whisker test is too long for practical feedback control

• If stress is the primary driving force…
  – Quantifying the effect can lead to correlation to a deformation mechanism or metallurgical reaction mechanism
  – Quantifying effect can be used to engineer products to avoid “wrong” stress conditions
Elastic and Plastic Damage

- **Vacancy/Interstitial injection**
  - Irradiation of Sn enhances whisker growth
  - Oxidation increases vacancy concentration
- **Plastic deformation**
  - Contact forces
  - Trim and Form
Sources of Stress

- Inherent plating stress ✓ yes
- Mechanical stress ✓ yes/maybe
- Oxidation maybe
- Intermetallic ✓ yes
- Irradiation ✓ yes

Can we control these in an experiment???
Creep in Tin

• Creep rates have been measured in pure tin and nearly pure tin samples.
• McCabe et al, Met. Trans., v33A, 2002, pp1531
  – 1mm grain size
  – 99.86% pure tin
  – Room temperature data
  – Dislocation climb controlled mechanism
  – Activation energy ~73kJ/mole
  – Creep rate may be more stress sensitive when impurities are present
    • (solute drag mechanism)
Creep in Tin

  - 2mm grain size, 125 C test temp
  - Tin is 99.999% pure
  - Dislocation climb controlled creep in high stress regime
    - Activation energy ~ 96kJ/mole
  - Low stress regime, Coble creep (diffusion creep)
Creep in Tin

  - Bright tin plating, grain size < 1um
  - Creep rate measured using cantilever beam deflection
  - Room temperature
  - Activation energy not reported

- Despite diffusion controlled processes for each set of creep data, creep rates are very fast, even at room temperature.
- Creep rates are faster in tin/lead than in pure tin.
- We can predict stress relaxation by iteratively computing the creep strain rate as a function of remaining stress.
  - Presume a starting stress of 20 MPa (approximate flow stress of tin)
Creep Rate in Tin

NIST, Bright tin study on cantilevers, grains size <1um
McCabe, Cast tin study using bars in tension, grain size ~ 1mm
Experimental Approach

- Control outside sources of stress
- Plate Sn on samples
- Measure as plated stress
- Mechanically stress samples to varying stress levels
- Expose samples to 60 C/85%RH
- Analyze whisker nucleation and growth
Materials

• Base Metals
  – Thicker sheet
    • 0.3mm thick
    • C7025 (Cu-Ni-Si)
  – Thinner foil
    • 1 oz ED Copper foil
    • Pure Cu
  – Barrier
    • Bismuth (99.999%)
    • Vapor deposited
    • ~ 25nm thick
Bi-Sn Equilibrium diagram.
Smithells Metals Reference Book (8th Edition) Copyright (c) 2004 Elsevier

Sn-Bi phase Diagram

ECTC/iNEMI Tin Whisker Workshop, May 29, 2007
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• Sn Plating
  – Matte
    • Commercial MSA high speed tin
    • Temp = 70 C
  – Bright
    • Commercial MSA semi-bright high speed tin
    • Low carbon content & “whisker mitigated”
    • Temp = 23 C
  – Process
    • Chemistry per supplier’s recommendations
    • Current density = 100 ASF (10 ASD)
    • Lab plated with modest agitation
Plating Stress Analysis

- Stress due to plating was measured using Specialty Test and Development test method
  - www.specialtytest.com
- Bent beams plated with 3um of tin plating over Bi sputter coating
- No deflection is observed after Bi coating or after plating
  - Resolution at this plating thickness is limited
  - Stress = 0 +/- 3.5MPa
- No change in stress after 500 hours of room temperature storage
  - This suggests the Bi retards intermetallic formation
    - Need FIB sections to verify lack of IMC
4 Point Bend Fixture

Constant strain region

\[ e = \frac{1}{\left( \frac{2r}{t} + 1 \right)} \]

- \( r \) = radius of curvature, computed from spacing and diameter of pins
- \( t \) = thickness of sample (Cu + Sn)
- \( e \) = outer fiber strain
Three Different Fixtures Used
Bending Strains

• Foil and sheet stock samples provide greater range of achievable strains.
• Stress computed using $E = 50\text{GPa}$
• Highest stresses may be above flow stress of tin (20MPa?).

<table>
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<th>$r$ (mm)</th>
<th>$t$ (mm)</th>
<th>$e$</th>
<th>stress (MPa)</th>
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<td>0.0000150</td>
<td>0.75</td>
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<td>137</td>
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Results

- Samples analyzed after 500 hours of exposure
- Tensile and compression sides of bent strip analyzed
  - SEM and optical inspection
- Long whiskers only present on tensile side of bent strip
- Nuclei seen on both sides of strips.
Matte Sn over Bi, Tensile Side, 500 hours

400 um long whisker on tensile side of beam.

Initial stress = 9 MPa

Average growth rate = 800 nm/hour = 2.2 Å/s
Matte Sn over Bi, Tensile Side, 500 hours

200um long whisker on tensile side.

Stress = 54MPa (20MPa)
Tensile vs Compressive

Matte Sn over Bi, tensile side, 500 hours, stress=9MPa

Matte Sn over Bi, Compression side, 500 hours, Stress=9MPa
Tensile vs Compression

Matte Sn over Bi, Tensile side, 500 hours, Stress = 39MPa

Matte Sn over Bi, Compression side, 500 hours, Stress=39MPa
Tension vs Compression

Matte Sn over Bi, Tensile side, 500 hours, Stress=54MPa

Matte Sn over Bi, Compression side, 500 hours, Stress=54MPa
Bright tin whisker results

Bright Sn over Bi, Tension side, 500 hours, Stress=9MPa

Bright Sn over Bi, Compression side, 500 hours, Stress=9MPa
Results

• Stress results are unclear
• Whisker nucleation density similar for matte Sn
  – High density on tensile and compression sides
• Whisker density lower for bright Sn samples
  – Density is very low on tensile side, slightly less than matte tin on tensile side.
Discussion

• Creep rates in Sn are fast enough to reduce applied mechanical stress
• Yet whiskers form under action of continuously applied compressive stress
• Whiskers grew long on tensile side of matte Sn.
  – Local compressive stress due to grain orientation?
  – Local compressive stress due to oxidation?
Conclusions

• Unclear if mechanical stress can be used to accelerate whisker growth.
• Whiskers grew on tensile side – unclear why.
• Creep rates in tin are very fast and drastically alter stress state in tin within 1 hour after plating.
• Longer dwell times are needed to look for more correlation
• Alternate mechanical stress application method may be required to offset creep rates.
Simple Compression

- Smetana proposal
- Stress varies slightly during compression due to change in cross-sectional area.
- May be a challenging sample to make.

Sn plated Cu hollow cylinder

Dead weight loading
Thank You!

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