The Attraction of Sn Whiskers
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Tin Whiskers – Examples

- Since 1998, 3 satellites have been completely lost due to Sn whisker
- Failure of relays used on a military airplane used by the air forces of several countries
- Patriot missiles, phoenix missiles, military radar, heart pacemakers, medical monitors, power station reactor shutdown, watch oscillators
Current whisker work at NPL

- Sn whisker mitigation using conformal coatings
- Databank of Sn whiskers in commercial components
- Electrostatic attraction of whiskers
- Whisker contact resistance measurement
- Whisker oxide thickness characterisation
- Current carrying capacity of whiskers
- Whisker oxide breakdown
- Electrical resistance of whiskers
- Whisker growth under electric fields
- Whisker mitigation by coatings using an SOIC component test vehicle
Tin Whisker Databank

- Commercial components acquired on the open market or from partners stores
- Total 78 different components
  - 63 SOIC/SSOP
  - Optocouplers, tantalums, TQFP, DIP, SOT23/223
- 27 different manufacturers
- 14 countries of origin
- Visually inspect for Sn whisker every 12 months
- Partners
  - Aero Engine Controls
  - MBDA (UK) Ltd
  - BAE Systems
  - Thales Missile Systems
  - HMGCC
Databank Examples

- Whiskers on 5 terminations
- 10 components total
Databank Examples

- Whiskers on 8 terminations
- 10 components total
Data after 12 months study

- No whisker greater than 50% of lead gap spacing

Component types

- No whiskers: 68
- Whiskers: 10

Country of Manufacture

- No whiskers: 9
- Whiskers: 5

Manufacturer

- No whiskers: 20
- Whiskers: 7
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Whiskering chemistry

- Schloetter has provided special chemistry utilised in previous studio project
- Used by NPL in benchtop electroplating rig
- By plating very thin coatings (<2 μm) rapidly
- Whiskers up to 1 mm in length in less than 4 weeks

Source: NPL

Source: Balco
Whisker Resistance

- FIB was utilised to mount the whisker across four aluminium bond pads on substrate
- Supply voltage was swept from 0 to 1.6mV to maintain the current below 20µA to prevent damage to the whisker
- Four probe resistance measurement
Resistivity measurements

- Measurements revealed a linear response
- Resistance of two whiskers yielded different resistance values, but they did have different diameters

<table>
<thead>
<tr>
<th></th>
<th>Whisker FIB 1</th>
<th>Whisker FIB 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1 (up to 10 µA)</td>
<td>7.2994 Ω</td>
<td>108.558 Ω</td>
</tr>
<tr>
<td>Run 2 (100 µA)</td>
<td>7.2992 Ω</td>
<td>108.561 Ω</td>
</tr>
<tr>
<td>Run 3 (100 µA)</td>
<td>7.3040 Ω</td>
<td>-</td>
</tr>
<tr>
<td>Run 4 (100 µA)</td>
<td>7.3050 Ω</td>
<td>-</td>
</tr>
<tr>
<td>Average</td>
<td>7.3016 Ω</td>
<td>108.559 Ω</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.0033 Ω</td>
<td>0.002 Ω</td>
</tr>
</tbody>
</table>
Resistivity values

- The resistivity of whisker FIB2 compares well to that of pure Sn of $1.1 \times 10^{-7} \, \Omega \cdot m$
- Resistivity of FIB1 is over double this
- Further analysis of this whisker in the SEM revealed a defect
- Assuming the whisker to have resistivity of pure tin, then the resistance of this defect was calculated at ~4 ohms.

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<th>Whisker FIB2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diameter</strong></td>
<td>3.6 $\mu$m</td>
<td>0.81 $\mu$m</td>
</tr>
<tr>
<td><strong>Length</strong></td>
<td>303 $\mu$m</td>
<td>482 $\mu$m</td>
</tr>
<tr>
<td><strong>Cross Sectional Area</strong></td>
<td>$1.04 \times 10^{-11} , \text{m}^2$</td>
<td>$5.16 \times 10^{-10} , \text{m}^2$</td>
</tr>
<tr>
<td><strong>Resistance</strong></td>
<td>7.3016 $\Omega$</td>
<td>108.559 $\Omega$</td>
</tr>
<tr>
<td><strong>Calculated Resistance</strong></td>
<td>$2.505 \times 10^7 , \Omega \cdot m$</td>
<td>$1.160 \times 10^7 , \Omega \cdot m$</td>
</tr>
</tbody>
</table>
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### Current carrying capacity

- For FIB2 current gradually increased. The whisker failed at 13.3 mA.
- The resistance increased by 22% up to the final current.
- SEM suggest the whisker failed twice. The first failure occurred on the pad, such that when it melted, it fused to the substrate corresponding to the drop at 12 mA.
- As the current was further increased, the whisker failed near the pad edge, & a Sn droplet formed.
- The current at failure is ~26,000 A/mm².
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Whisker field effects

- Well known that whiskers deform in electrical fields
  - Have high aspect ratio, and are conductors
  - Susceptible to deformation
- Clearly the probability of shorting out between adjacent conductors will be increased if the whisker is pulled in the electric field
- Characterisation is problematic, as the tendency of the whisker to deform, is not only dependent on its integral strength, but how it is attached at the root to the substrate.
Initial Attraction Work

- Whiskers close to body of TH capacitor in dual beam FIB (focused ion beam)
- The whisker was 0.9mm in length and 1.2µm in diameter
- Tungsten probe at 10V
Electrostatic Attraction of Whiskers

- Whiskers attracted into contact with the probe from a maximum distance of 50µm (10V)
- This equates to a field strength of ~200V/mm
Electrostatic Attraction of Whiskers

- Increased attraction when in contact
Further Attraction Work

- Since the properties of the whisker are dependent on the attachment, any study needs to characterise whiskers in-situ.
- NPL has a plating chemistry that permits predictable whisker growth on copper Olin194
- Such samples were mounted in a rig that allowed an electric field to be applied and visual inspection, and hence characterisation of the deflection in the electric field.
Arrangement

Low pass filter

[Diagram of low pass filter with components labeled: DC PSU, R1, R2, 1 μF, Ampere Meter, Au Coated Probe, Whisker Disc.]

4 axis sample manipulator

[Diagram showing a 4-axis sample manipulator with connections to a vertical microscope and a horizontal microscope, labeled with components like Vertical Camera, Vertical Microscope, Horizontal Camera, Horizontal Microscope, Whisker Disc, Horizontal Projection, Gold Coated Probe, Vertical Projection.]
Effect of electric field

- Variation of the angle of a whisker tip, & the position of the tip, to the plate as a function of electrical field.
- The measurements assume a non-bending whisker, which is not the case.
- Distance between plates was set to approximately 600µm
Similar results observed with other whiskers
Stop motion video
Predicting whisker bending at the tip

Assuming a uniform field and constant capacitance in the gap the whisker deflection can be shown to follow this equation

\[ u_{\text{tip}} = \frac{4kV^2L^4}{\pi Es d_w^4} \]

\( u_{\text{tip}} \), deflection of tip
\( V \), voltage between parallel plates
\( L \), is the whisker length
\( E \), Young’s modulus (50GPa)
\( s \), separation of parallel plates
\( d_w \) is the whisker diameter
\( k \), constant \( (8 \times 10^{-13}) \) for the analytical solution shown in the figure
Summary of electric field effects

- Whiskers are attracted by electric fields
- Degree of attraction is a function of the electrical field strength, the angle of the whisker to the substrate from which it has grown and the dimensions of the whisker
- Polarity of electric field is not important. The force will be attractive in both cases.
- Electrostatic attraction increases likelihood of short occurring between whiskers and conducting surfaces at different electric potentials.
Summary of electric field effects

- Whiskers show deflection of >10 μm at 50V/mm.
- Comparable with other work: Kadesch et al
- The $V^2$ dependence significantly increases the probability of faster deflection as the whisker approaches the attracting electrode
  - Whisker can suddenly snap across to the other electrode bridging the gap.
- Opposing whiskers in the same vicinity are more likely to short because of this flexibility.
Component Whisker Project

- Development of whiskering assembly and monitoring equipment
- NPL have collaborated with CML Microcircuits (UK) Ltd to produce a SOIC test vehicle.
- This will allow the coating mitigation properties to be tested, in con-junction with its coverage capability.
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- Enthone
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- General Dynamics
- HMGCC
- Lockheed Martin
- Lucent
- MBDA (UK) Ltd
- Motorola
- NSWC Crane
- Philips CFT
- Raytheon Integrated Defense Systems
- Rockwell Collins
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- Rolls Royce Marine
- Sagem Defense
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- Semblant Ltd
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- Thales
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