Investigation of zinc whisker growth from electrodeposits produced using an alkaline non-cyanide electroplating bath

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Investigation of Zinc Whisker Growth from Electrodeposits Produced Using an Alkaline Non-Cyanide Electroplating Bath

By Liang Wu

Co-authored by:
Dr Geoffrey D. Wilcox
Dr Mark A. Ashworth

Department of Materials, Loughborough University, UK
What is a Metallic Whisker?

- Crystalline metallic crystals
- Spontaneously grow from metal surfaces (Sn, Zn, Cd)
- Reported average grow rate ~ 250 µm per year
- 1 µm in diameter and a few millimetres in length

Able to form various shapes

- Straight
- Kinked
- Spiral
- Curved eruption

NASA Photo Gallery; nepp.nasa.gov/whisker/photos/index.html
NASA: “50 Electronic Failures occurred due to Whisker Growth from 1986 – 2006; ~10% of the Problems We Know About!”
# Electronic Failures Caused by Zn Whiskers

<table>
<thead>
<tr>
<th>Year</th>
<th>Whiskers on</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>Local Power Range Monitoring Detectors</td>
<td>Dresden nuclear Power Station</td>
</tr>
<tr>
<td>1990</td>
<td>Rotary Switch</td>
<td>Apnea Monitors</td>
</tr>
<tr>
<td>1990</td>
<td>Local Power Range Monitoring Detectors</td>
<td>Duane Arnold Nuclear Power Station</td>
</tr>
<tr>
<td>1995</td>
<td>Framework</td>
<td>Telecom Equipment</td>
</tr>
<tr>
<td>1996</td>
<td>Chassis</td>
<td>Computer Routers</td>
</tr>
<tr>
<td>1998</td>
<td>Chassis</td>
<td>Computer Hardware</td>
</tr>
<tr>
<td>1999</td>
<td>Xsistor Package + Standoff</td>
<td>Missiles</td>
</tr>
<tr>
<td>1999</td>
<td>Chassis</td>
<td>Computer Routers</td>
</tr>
<tr>
<td>2001</td>
<td>Bus Rail</td>
<td>Space Ground Test Equipment</td>
</tr>
<tr>
<td>2003</td>
<td>Floor Tiles</td>
<td>Computer Data Centre in Canada</td>
</tr>
<tr>
<td><strong>2004</strong></td>
<td><strong>Floor Tiles</strong></td>
<td><strong>Computer Data Centre in USA</strong></td>
</tr>
<tr>
<td>2004</td>
<td>Floor Tiles</td>
<td>Computer Data Centre in Australia</td>
</tr>
<tr>
<td>2012</td>
<td>Floor Tiles</td>
<td>Computer Data Centre in North East England</td>
</tr>
</tbody>
</table>

Many long zinc whiskers on zinc coated steel [1]

Zinc-electroplated connector shell [2]
Electronic Failure Mechanisms

**Type 1:** Grown whiskers to bridge components

Type 1: A whisker grew and connected two diodes used in a nuclear power plant

**Type 2:** Airborne whiskers settle on components

Type 2: Whiskers formed inside an air-spaced capacitor and became airborne whiskers

- Produce a bridge between components
- Short circuiting, voltage variance and other signal disturbance
- Electrical equipment failure

NASA Photo Gallery: nepp.nasa.gov/whisker/photos/index.html
Objectives

- Observe Zn whisker growth
  - Growth rate and morphology
  - Growth mechanisms
- Characterise the Zn electrodeposits
  - Surface morphology
  - Grain size and structure
- Investigate the influence of some key parameters on whisker growth
  - Deposition current density
  - Deposit thickness
  - Post-electroplating thermal treatment
Experimental Approaches

- Electroplating bath
  - Alkaline cyanide-free zinc plating solution
    - pH ~ 10
  - Chemicals
    |              | Amount  |
    |--------------|---------|
    | Zinc         | 11 g/l  |
    | Sodium hydroxide | 130 g/l |
    | Conditioner  | 30 ml/l |
    | Brightener   | 1.5 ml/l|
    | Purifier     | 1 ml/l  |
    | Initial additive | 7 ml/l |

- Sample geometry
  - Mild steel substrate
    - Zn coating
      - ~ 5 µm thick (by electroplating)
    - ~ 1 mm thick

- Sample storage
  - Room temperature (~ 20°C)
Effect of Deposition Current Density on Whisker Growth

- 5 µm thick coating deposited at different current densities
- SEM analysis 16 months after deposition

<table>
<thead>
<tr>
<th>Deposition current density/mA.cm⁻²</th>
<th>Filament-type whiskers</th>
<th>Eruption-type whiskers</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>93</td>
<td>28</td>
</tr>
<tr>
<td>10</td>
<td>928</td>
<td>496</td>
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<tr>
<td>15</td>
<td>1626</td>
<td>108</td>
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<tr>
<td>20</td>
<td>2081</td>
<td>105</td>
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<td>25</td>
<td>2596</td>
<td>496</td>
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<tr>
<td>30</td>
<td>2408</td>
<td>406</td>
</tr>
<tr>
<td>35</td>
<td>2533</td>
<td>3961</td>
</tr>
<tr>
<td>40</td>
<td>None</td>
<td>5000</td>
</tr>
</tbody>
</table>

Recommended current density range: 30 mA/cm² - 40 mA/cm²

Many whiskers were present on the 40 mA/cm² samples!
Effect of Deposition Current Density on Deposit Microstructure

Top surface morphology

Cross Section by freeze fracture

5 mA/cm²

25 mA/cm²

40 mA/cm²

Strange feature growths on low current density samples!
Effect of Deposition Current Density on Deposit Microstructure

As current density increases: grain diameter decreases and more columnar structure
Effect of Deposit Thickness on Whisker Growth

- Deposited at 25 mA/cm² with different thicknesses
- SEM analysis 13 months after deposition

As deposit thickness increases
- Fewer filament-type whiskers
- Fewer eruption-type whiskers

Lower deposition current density & thicker deposit result in fewer whiskers!
Effect of Post-Electroplating Heat Treatment on Whisker Growth

- Deposited at 25 mA/cm²
- Thermal treated at different temps for 0.5h and then storage at room temperature
- SEM analysis after 14 months
Effect of Post-Electroplating Heat Treatment on Whisker Growth

- Deposited at 25 mA/cm²
- Thermal treated at different temps for 0.5h and then storage at room temp.
- SEM analysis after 14 months

100 °C

100 µm

100 µm

100 µm

100 µm

1 µm

1 µm

30 µm

100 µm
Effect of Post-Electroplating Heat Treatment on Whisker Growth

- Deposited at 25 mA/cm²
- Thermal treated at different temps for 0.5h and then storage at room temperature
- SEM analysis after 14 months

Short period of heat treatment at high temp. markedly reduces whisker growth!
5 µm alkaline zinc on mild steel electrodeposited at 25 mA/cm²

- Whiskers were present 4 weeks after deposition;
- 4 months after deposition, all the whiskers were growing associated with “nodules”.

Many larger eruptions and longer whisker filaments present!
Evolution of Whisker Growth at Room Temperature

5 μm alkaline zinc on mild steel electrodeposited at 25 mA/cm²

- Whiskers growing from the flat deposit surface were present 5 months after deposition;
- The presence of nodules markedly shortens the incubation time.

5 months after deposition

8 months after deposition

Many larger eruptions and longer whisker filaments present!
Periodic Analysis of Whisker Growth Associated with Nodules

Several specific nodules were monitored periodically.

A whisker grew associated with the staircase structure.

“Staircase structure” first appeared.

More whiskers grew associated with the staircase structure.
Staircase Structures

Appear ~ 1 month after deposition

only present on the surface of nodules

Staircase structures are pre-cursors to whisker growth associated with nodules
Recrystallisation occurs Associated with Whisker Growth

1. Whiskers growing associated with the nodules
   Stored at RT for 6 months

   • A cavity was observed beneath the nodule
   • Columnar grain structure in the flat deposit layer and also in the nodule
   • Grains near whisker root were recrystallised
Recrystallisation occurs associated with whiskers growing from nodules and the flat deposit surface.
Summary

- Whisker growth from nodules was observed only 4 weeks after deposition; whilst whisker growth from the flat deposit surface was not observed until 5 months after deposition.

- The presence of nodules and subsequent development of staircase structures markedly reduced the incubation time for whisker growth.

- Lower deposition current density, thicker deposits & heat treatment for 0.5h at high temperatures resulted in fewer whiskers.

- Recrystallisation is associated with whisker growth from both nodules and the flat deposit surface.
Questions

- Thank you for listening!
- Any questions or comments?

‘Question mark’ tin whisker from Dr Mark Ashworth