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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

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What is a Metallic Whisker?

- Crystalline metallic crystals
- Spontaneously grow from metal surfaces (Sn, Zn, Cd)
- Reported average grow rate $\sim 250 \mu\text{m}$ per year
- $1 \mu\text{m}$ in diameter and a few millimetres in length

Able to form various shapes

Straight

Kinked

Spiral

Curved eruption

Electronic Failures Caused by Whiskers

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

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

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

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
- In relation to whisker growth

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

- 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

Many whiskers were present on the 40 mA/cm² samples!

Effect of Deposition Current Density on Deposit Microstructure

5 mA/cm²

25 mA/cm²

40 mA/cm²

Top surface morphology

Cross Section freeze fracture

Strange feature growths on low current density samples!

Effect of Deposition Current Density on Deposit Microstructure

5 mA/cm²

25 mA/cm²

40 mA/cm²

Top surface morphology

Cross
Section by
freeze
fracture

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

50 °C

80 °C

100 °C

5 µm

100 µm

3 µm

30 µm

100 µm

Effect of Post-Electroplating Heat Treatment on Whisker Growth

- Deposited at
- Thermal treat
temps for 0.5
storage at ro
- SEM analysi

100 °C

100 μm

100 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!**

50 °C

80 °C

100 °C

125 °C

150 °C

No whiskers!

Evolution of Whisker Growth at Room Temperature

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

4 weeks after deposition

Many larger eruptions and longer whisker filaments present!

4 months after deposition

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

Evolution of Whisker Growth at Room Temperature

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

5 months after deposition

Many larger eruptions and longer whisker filaments present!

8 months after deposition

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

Periodic Analysis of Whisker Growth Associated with Nodules

2 hours

Several specific nodules were monitored periodically

44 days

A whisker grew associated with the staircase structure

69 days

More whiskers grew associated with the staircase structure

"Staircase structure" first appeared

29 days

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

FIB cross-sectioned

- 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 Whisker Growth

2. Whiskers growing from the flat deposit surface

Stored at RT for 6 months

FIB cross-sectioned

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