Tin Whiskers: Attributes and Mitigation

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Mission Success Starts With Safety
Outline

• Why ANOTHER Paper on Tin Whiskers?

• What are Tin Whiskers?
  – Examples
  – Failure Modes
  – Attributes

• Experience History

• Tin Whiskers on Ceramic Capacitors (MLCCs)

• Whisker Mitigation Strategies

• Conclusions
Why **ANOTHER** Paper on Tin Whiskers?

**The PAST:**
- Tin Whiskers Known for ~60 Years
- HUNDREDS of Independent Studies
- Numerous Disparities exist in Published Literature

**The PRESENT: Combination of Concerning Factors**
- Pending Pb-Free Legislation COULD Introduce More Whisker Prone Items
- Continuous Reduction in Circuit Geometries and Power Reduction
- Lack of Fundamental Understanding of Whisker Growth
- Lack of “Accelerated” Test Methods
- “New” Discoveries of Whiskers on Items thought to be “Immune”

**This WORK Provides:**
- One Reference to Collate Known/Unknown Attributes of Tin Whiskers
What are Tin Whiskers?

• “Hair-Like” Structures of Tin that May Grow Spontaneously from Items with Tin Finishes
  – Other pure metal (Zn, Cd) electroplates and alloys like Sn-Cu, Sn-Bi and even some Sn-Pb finishes may also form whiskers but not as readily as pure Sn

• Growth Process is Driven by Mechanical Stress Relief Mechanism
  – COMPRESSIVE Stress WITHIN Sn Layer
  – Electrical Bias, Contamination NOT Needed
  • Whiskers are NOT Dendritic Growths

Dendrites vs. Whiskers
Whisker Shapes and Dimensions

- Filaments
- Straight/Kinked
- Length: up to 1 cm

- Nodules
- Solid
- Striated
- Pyramids
- Diameter: 0.006 µm to 10 µm
Sneaky Tin Whiskers!!!

- **Growth Rate**
  - Up to 9 mm/yr
  - Typically Substantially SLOWER!!!

- **Incubation Period (Dormancy)**
  - As Short as a Few Days after Plating
  - **AS LONG AS MANY YEARS!!!**

*These Attributes are UNPREDICTABLE thus Presenting a MAJOR Challenge*
Examples of EEE Components with Tin Whiskers

**Active Components**

- "Matte" Tin DIP IC Leads
- Hybrid Package Lid
- Transistor Header
Examples of PASSIVE EEE Components with Tin Whiskers

It’s about MORE than Just Active Components

Terminal Lugs

SMT Fuses

Test Points

Relay Terminals

Ceramic Caps

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Tin Whisker Failure Modes

- **Electrical Short Circuits**
  - Permanent (if current < 10’s of mA)
  - Intermittent (if current > 10’s of mA)

- **METAL VAPOR ARC in VACUUM**
  - If $V > \sim 13\ V$ and $I > 10$’s of Amps, then Whisker can Vaporize into Highly Conductive Plasma of Tin Ions
  - Plasma can Form Arc Capable of Carrying HUNDREDS OF AMPERES
  - Arc is Sustained by Tin Evaporated from Surrounding Areas

- **Debris/Contamination**
  - Interfere with Sensitive Optics or MEMS
  - Can Cause Shorts in Areas Remote From Whisker Origins
“Reported”
Tin Whisker-Induced Field Problems

Tin Whiskers are NOT Just of Interest to Lab Researchers

Space Application

Medical Application
Heart Pacemaker RECALL

Defense Application

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One Model for Whisker Growth Mechanism

1. Substrate Elements (Cu, Zn, etc.) Diffuse Into Sn and Form Intermetallic Compounds (IMCs) Along Sn Grain Boundaries
2. As a Result, Stress Builds in Sn Layer
3. To Relieve Stress, Whiskers EXTRUDE Thru Ruptures in Sn Oxide
Factors That May Contribute Compressive Stress to Tin Layer

- **Plating Chemistry/Process**
  - Electroplating Current Density
    - Higher Current Density --> Higher Residual Stress
  - Tin Grain Size and Shape
    - Submicron Grains
    - "Matte" vs. "Bright" Finish
  - Use of "Brighteners" and Presence of Impurities (Codeposited Carbon/Hydrogen)
  - Plating Thickness
    - >0.5 \( \mu \text{m} \) and <8 \( \mu \text{m} \) more prone
  - Alloy composition
    - Pure Sn, Sn-Cu, Sn-Bi, and rarely Sn-Pb
- **Substrate (Including Base Metal and Barrier Plating Layers)**
  - Material (Copper, Brass, Nickel, others)
  - Substrate Preparation (Stamped, Formed, Annealed)
Factors That May Contribute Compressive Stress to Tin Layer

- Intermetallic Compound (IMC) Formation
  - Substrate Element Diffusion into Tin Layer
  - Metallurgical Interactions

- Environmental Stresses
  - Temperature (50°C More Favorable)
  - Temperature Shock/cycling (CTE Mismatches)
  - Humidity (High RH Observed to Increase Whiskering)
  - Applied Pressure (Torque on Fasteners)

**HOWEVER....**

*Many Experiments Show Contradictory Results For These Factors*
Tin Whiskers and Multilayer Ceramic Capacitors (MLCCs)
Past Research

- Only a Few Dedicated Studies of Whisker Propensity of MLCCs
- Studies Assert MLCCs are NOT Prone to Whisker Because of:
  - “Large” (>5 µm), Well-Polygonized Sn Grain Structure
  - “Matte” Tin Plating
  - Nickel Barrier Layer (> 2 µm) Minimizes Diffusion
    - May produce “tensile” stress at Tin layer further reducing whisker propensity
  - Post-Plating Annealing Promotes Grain Growth & Reduces Residual Stress
- 1997 Study: 18 Years WHISKER-FREE Observations for MLCCs Stored at 50°C

HOWEVER....
RECENT Discoveries of MLCCs with Tin Whiskers
What Went Wrong???

- Q: “Didn’t We Order **Pd-Ag Terminated** MLCCs?”
- A: “YES! But the Supplier Shipped Us **PURE TIN** by Mistake!”

- Q: “Can We Still Epoxy Mount Them Inside Our Hybrid?
- A: “**Well????**”
Tin Whiskers and MLCCs

CASE 1: Hybrid Microcircuit Application

- User Application
  - Ordered Pd-Ag but RECEIVED Pure TIN
  - Conductive Epoxy Mount
  - Hermetic Hybrid Package (Nitrogen Backfill)

- MLCC Construction (0805 Commercial)
  - Barium Titanate Ceramic Body
  - Silver Frit Base Termination (17 μm)
  - Nickel Barrier Layer (6.5 μm)
  - Matte Tin Plated Final Finish (6.5 μm)
  - Average Grain Size > 5 μm

Manufacturer “A”
Tin Whiskers and MLCCs

CASE 1: User Test Environment

**PROFUSE WHISKERS**

**Condition 1:** Thermal Cycle: -40°C / +90°C (> 200 Cycles)

Max. Length ~ 250 µm

**Condition 2:** High Temp Storage: +90°C for 400 hrs

*NO WHISKERS*
Tin Whiskers and MLCCs

CASE 2: Recent Experiments @ The Aerospace Corp.

PROFUSE WHISKERS

- Pure Tin Commercial MLCCs \textit{(with NICKEL Barrier)}
  - Heat Treated @ 215°C for 5 seconds to “Simulate” Reflow Installation
  - Thermal Cycle Unmounted: -40°C / +90°C for 500+ cycles

Max. Length ~ 30 µm

Manufacturer “B”
Tin Whiskers and MLCCs

CASE 3: More Experiments @ The Aerospace Corp.

PROFUSE WHISKERS

- Pure Tin Military MLCCs (with NICKEL Barrier)
  - Thermal Cycle Unmounted: -40°C / +90°C for 100 cycles

Max. Length ~ 30 µm

NOTE: MIL Specs 55681 and 123 Allow Pure Tin “OPTION” (Termination Type “W”)

Manufacturer “C”
Tin Whiskers and MLCCs
CASES 4 & 5: More MLCC Whisker “Anecdotes”

• Case 4: Incorrect MLCC Shipped
  – Manufacturer “D”
  – User orders Pd-Ag MLCCs, but gets \textbf{PURE TIN} by Mistake
  – User Observes \textit{“Moss-Like” Growths on MLCCs} in Stock Storage

• Case 5: AFTER \textbf{Vapor Phase Installation}
  – Manufacturer “B”
  – Pure Tin Commercial 2220 and 1812 MLCCs
  – Vapor Phase Installation with Solder (63 / 37) \( @ 217^\circ C \)
  – Thermal Cycle/Shock (-55°C / +100°C) for 50 to 400 Cycles
  – RESULTS: \textbf{Whiskers up to 30 \( \mu m \)}}
Tin Whiskers and SMT Fuses
Evaluation PRIOR to Converting to Pb-Free

- SMT Fuse Construction Similar to MLCC
  - Prototype Pb-free Termination: “Matte” Tin Finish Over Nickel

- Whisker Evaluation Finds:
  - WHISKERS after Temp Cycle
  - No Whiskers after Temp/Humidity
  - No Whiskers after High Temp Storage

- Sn/Pb Control Samples Did NOT Whisker
Whisker Mitigation

**AVOID WHISKER PRONE PRODUCTS/PROCESSES**

- User Strategy Should Involve Application of **AS MANY MITIGATING PRACTICES AS POSSIBLE**
  - LOWER COMPRESSIVE STRESS in the Tin Plating Itself
  - Annealed or Hot Dipped Surfaces (Preferably with Sn/Pb Solder)
  - Careful Handling to Minimize Scratches, Marks, Indentations
  - Physical Barriers
    - Conformal Coat
    - Insulating Barriers, Cardboard
    - Increase Spacing of Surfaces of Opposite Polarity to > 0.5 inches

**Avoid Pure Tin if Possible**
Whisker Mitigation
Conformal Coat (Polyurethane)

- WILL NOT PREVENT WHISKER from Growing Through
- REDUCES Incubation Period: Whiskers appear SOONER!!
- HOWEVER, REDUCES Growth Rate
- Likely Prevents Whisker from Growing Back into Coated Surface

Whiskers Growing
BENEATH 2 mil Thick Coating

Whisker Growing Thru
~0.25 mil Thick Coating
Conclusions

• Electrical Shorting Due to Tin Whiskers Remains a Significant Problem
  – Problems **WILL INCREASE** with Increased Use of Pb-Free Coatings
  – Failures **ARE STILL OCCURRING**

• Accelerated Test to Determine Susceptibility to Whisker Formation Needs to be Developed
  – Must Include Acceleration Factors for BOTH Incubation and Growth

• Users Should Carefully Assess Application of Passives Containing Pure Tin Coating for Susceptibility to Tin Whisker Formation
  – Susceptibility Could be Lot-Related
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NASA Goddard Tin Whisker WWW Site
http://nepp.nasa.gov/whisker

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