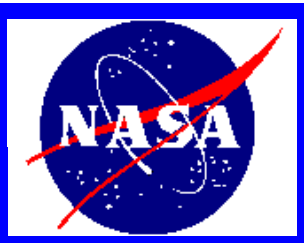

Tin Whiskers:
Attributes and Mitigation

Presentation to:

Capacitor and Resistor Technology Symposium 2002

New Orleans, LA

March 26, 2002

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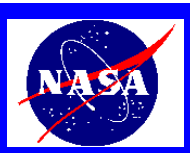


THE AEROSPACE CORPORATION

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

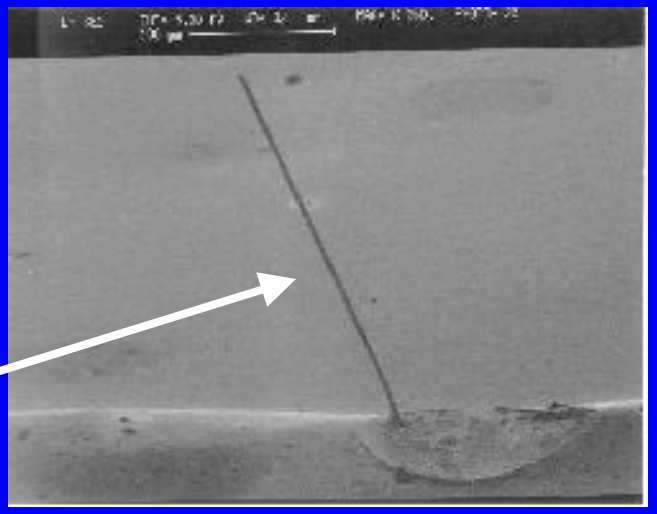
What are Tin Whiskers?

- "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

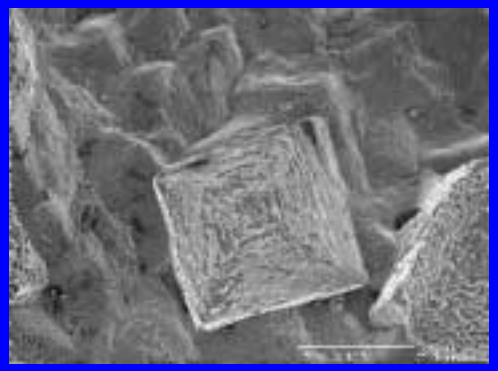
vs.

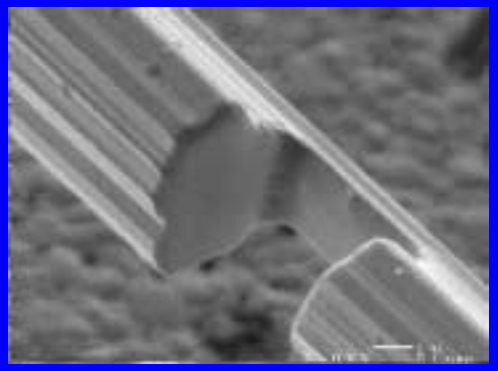
Whiskers



Whisker Shapes and Dimensions

- Filaments - Nodules - Pyramids
- Straight/Kinked - Solid - Striated
- Length: up to 1 cm - Diameter: 0.006 μm to 10 μm





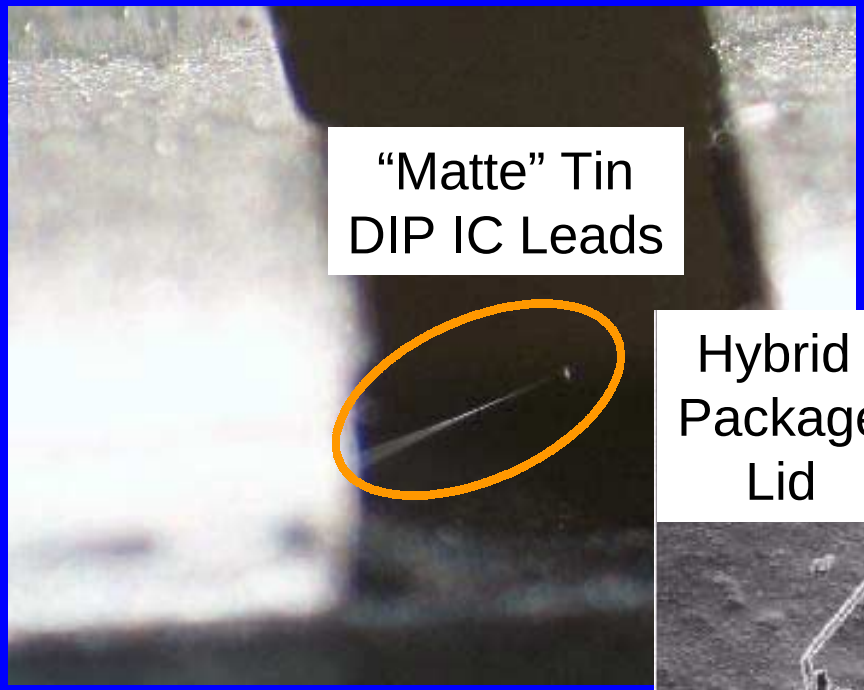
Sneaky Tin Whiskers!!!

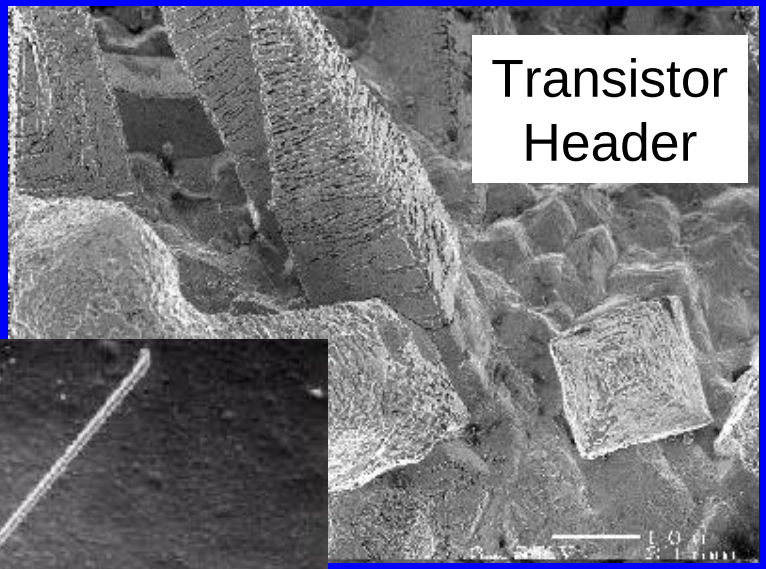
- Growth Rate
  - Up to 9 mm/yr
  - Typically Substantially SLOWER!!!
- Incubation Period (Dormancy)
  - As Short as a Few Days after Plating
  - ***AS LONG AS MANY YEARS!!!***

These Attributes are UNPREDICTABLE thus Presenting a MAJOR Challenge

Examples of EEE Components with Tin Whiskers

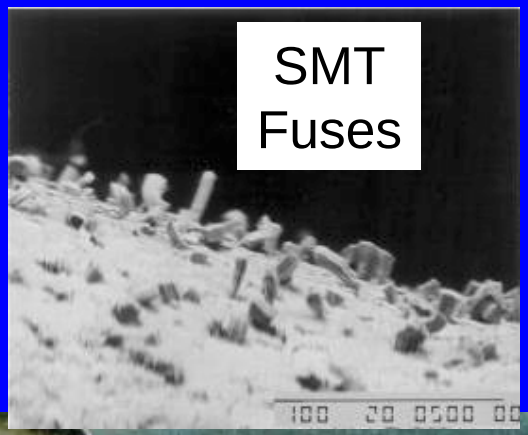
Active Components

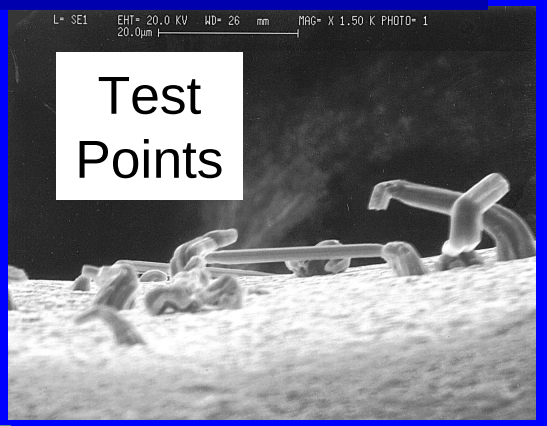


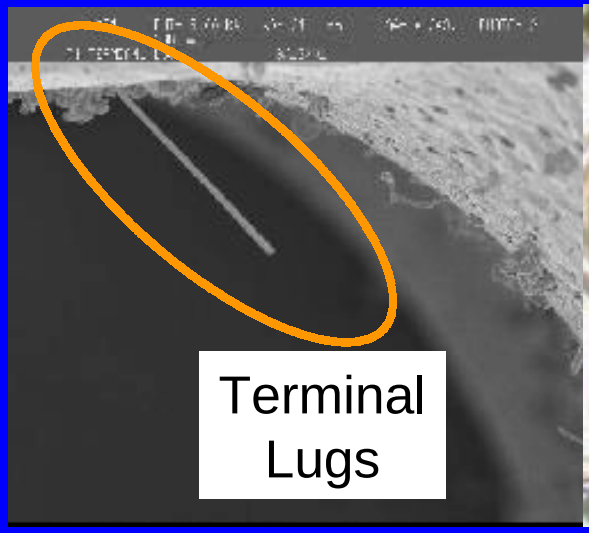


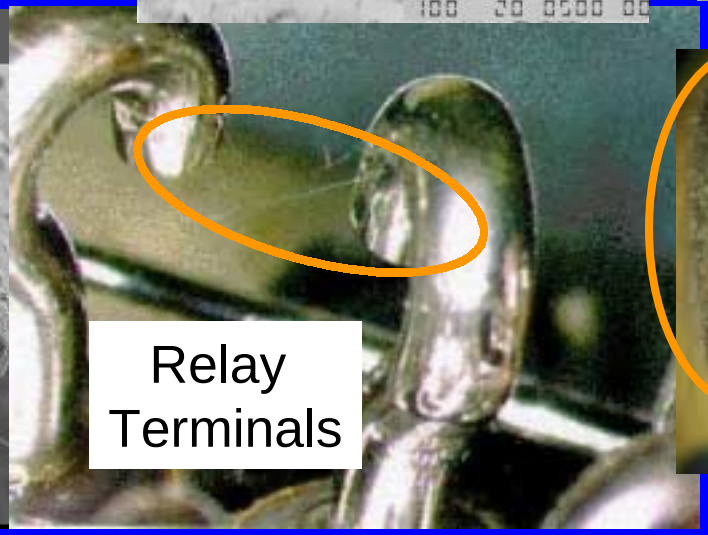
Examples of PASSIVE EEE Components with Tin Whiskers

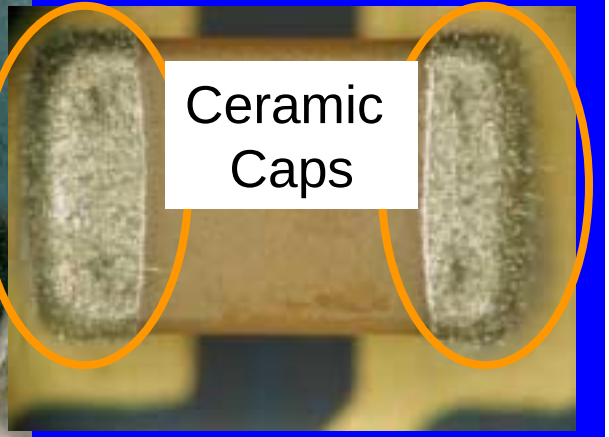
It's about MORE than Just Active Components



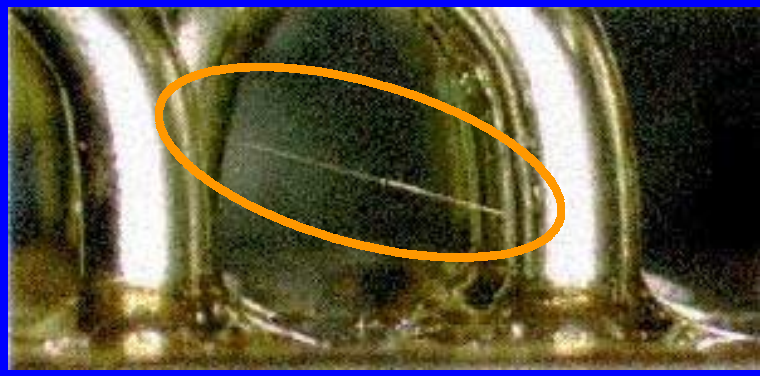






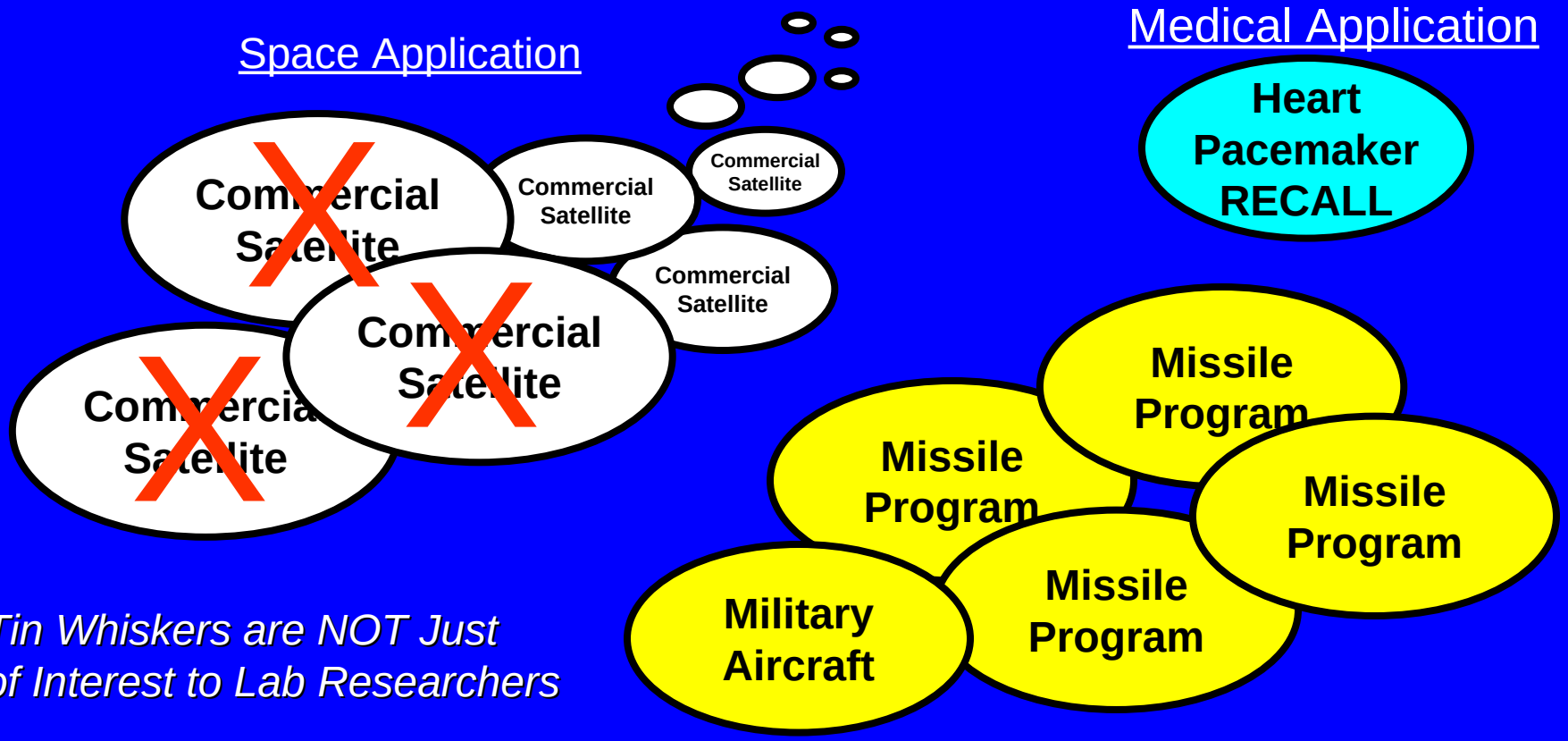


Tin Whisker Failure Modes



- ***Electrical Short Circuits***
  - Permanent (if current < 10's of mA)
  - Intermittent (if current > 10's of mA)
- ***METAL VAPOR ARC in VACUUM***
  - If V > ~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

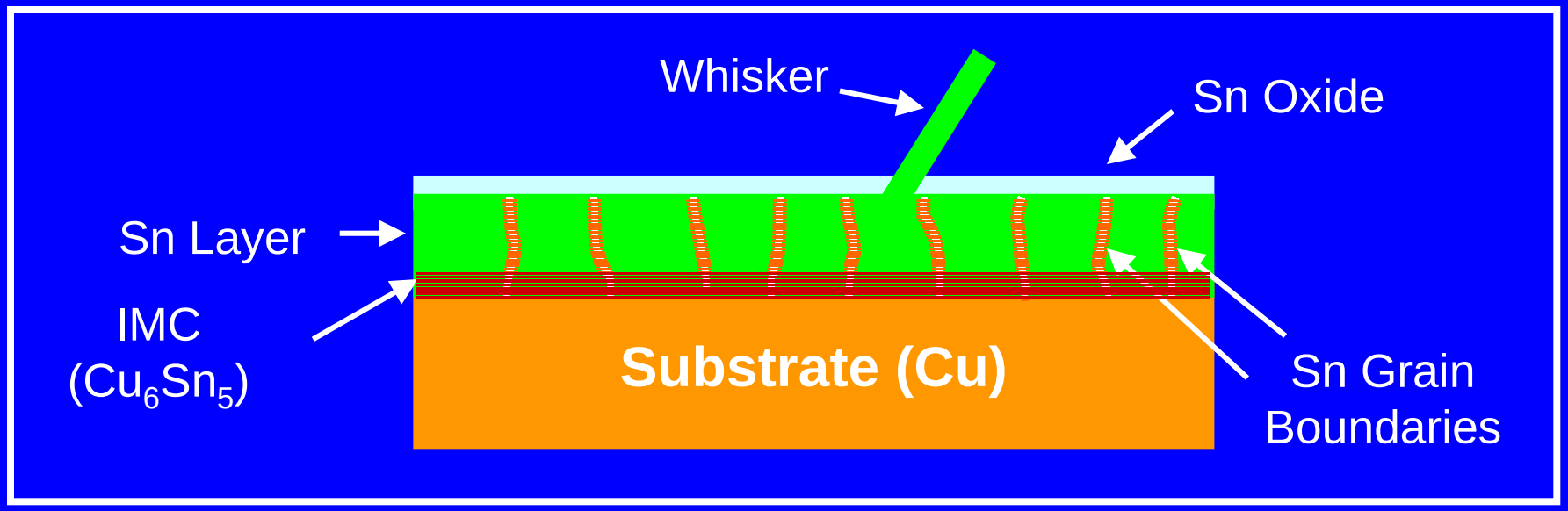
"Reported" Tin Whisker-Induced Field Problems



Tin Whiskers are NOT Just of Interest to Lab Researchers

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 μm and <8 μm 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

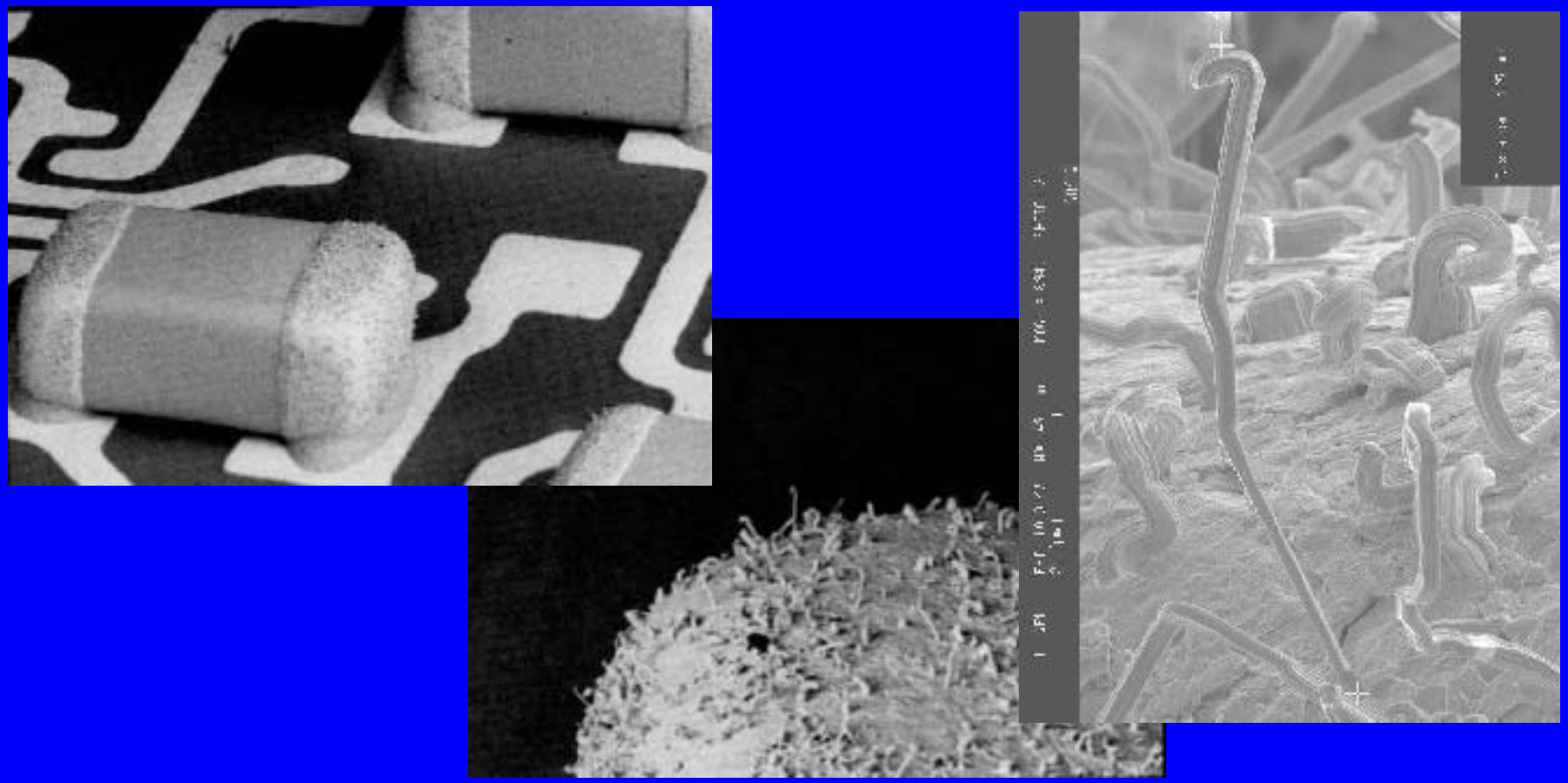
Tin Whiskers and Multilayer Ceramic Capacitors (MLCCs)

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 @ 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….

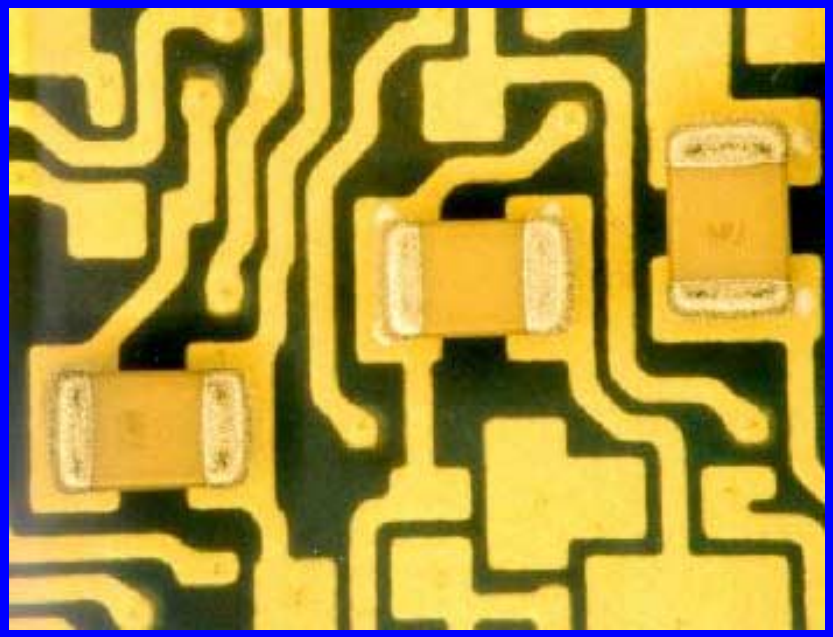
RECENT Discoveries of MLCCs with Tin Whiskers



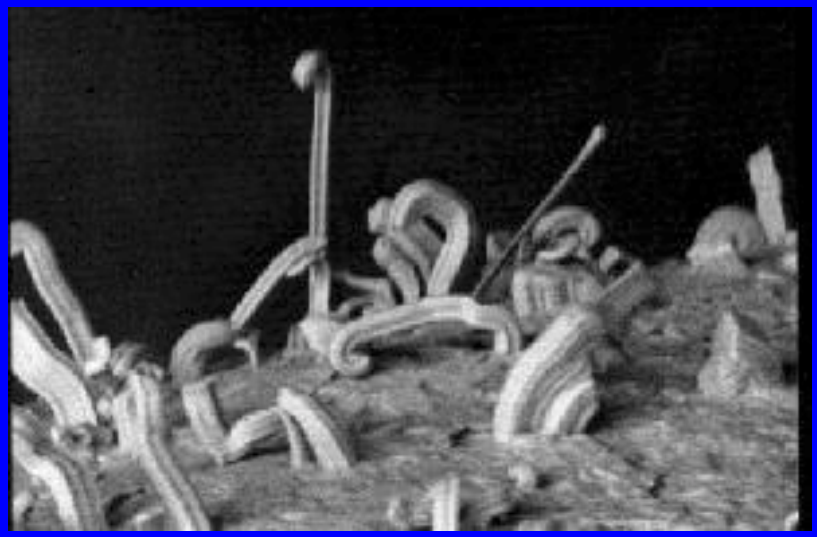
What Went Wrong???

- *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?



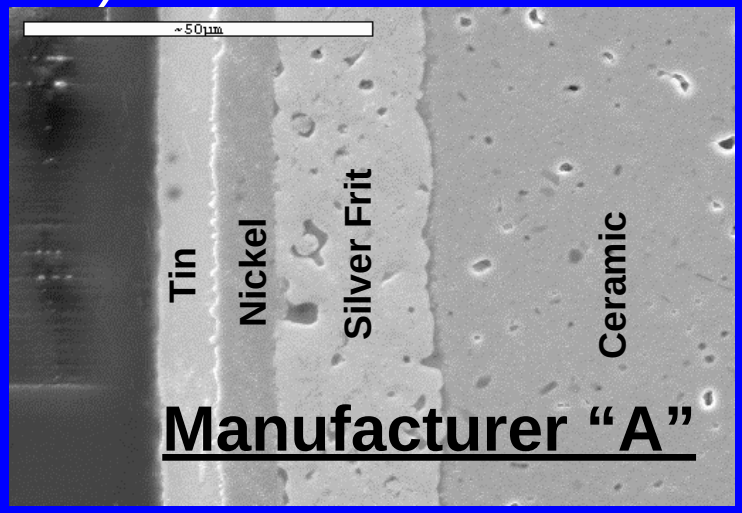
- ***A: "Well????"***



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



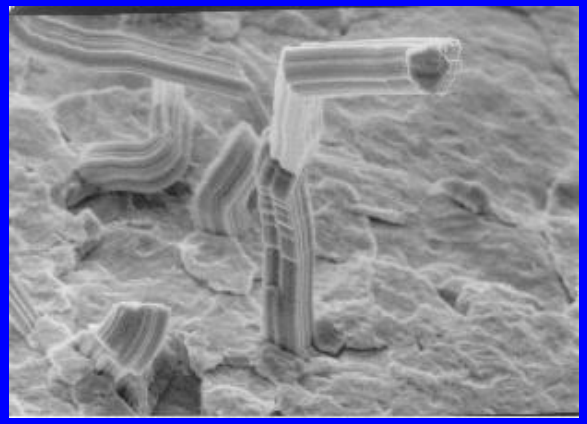
Tin Whiskers and MLCCs

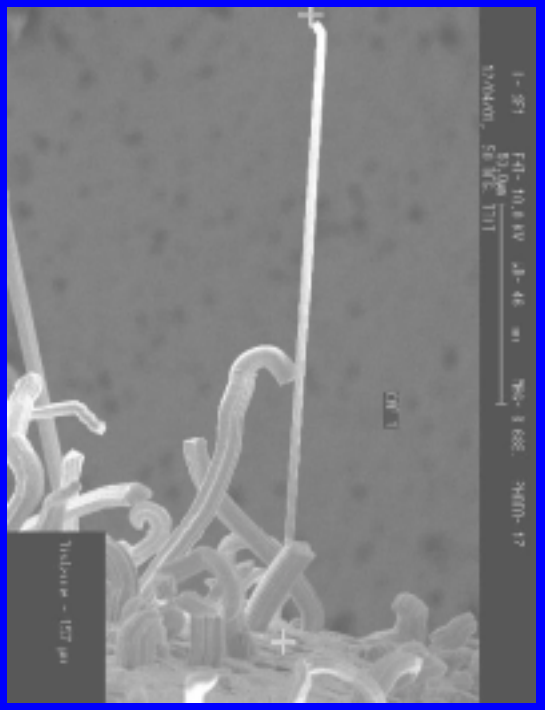
CASE 1: User Test Environment

PROFUSE WHISKERS

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

Max. Length **~ 250 µm**





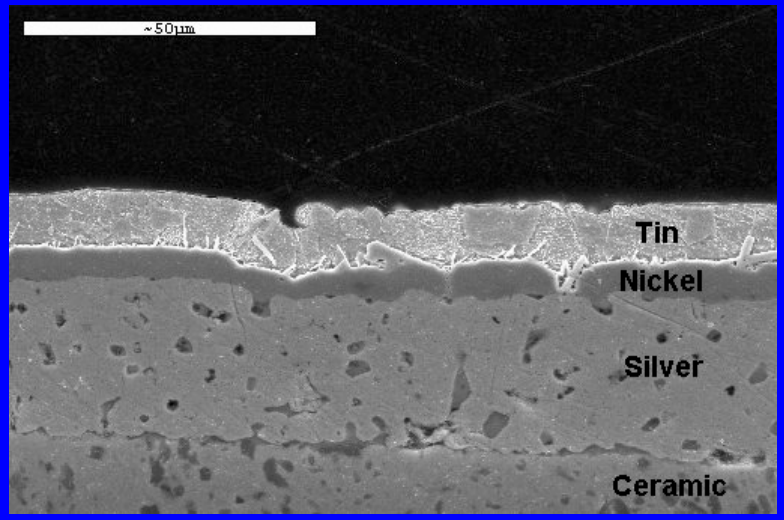
Condition 2: High Temp Storage: +90°C for 400 hrs
NO WHISKERS

Tin Whiskers and MLCCs

CASE 2: Recent Experiments @ The Aerospace Corp.

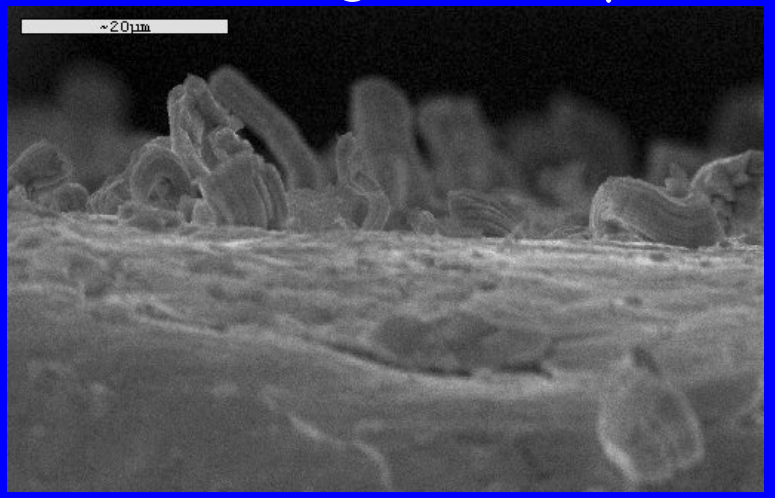
PROFUSE WHISKERS

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



Manufacturer "B"

Max. Length ~ 30 µm

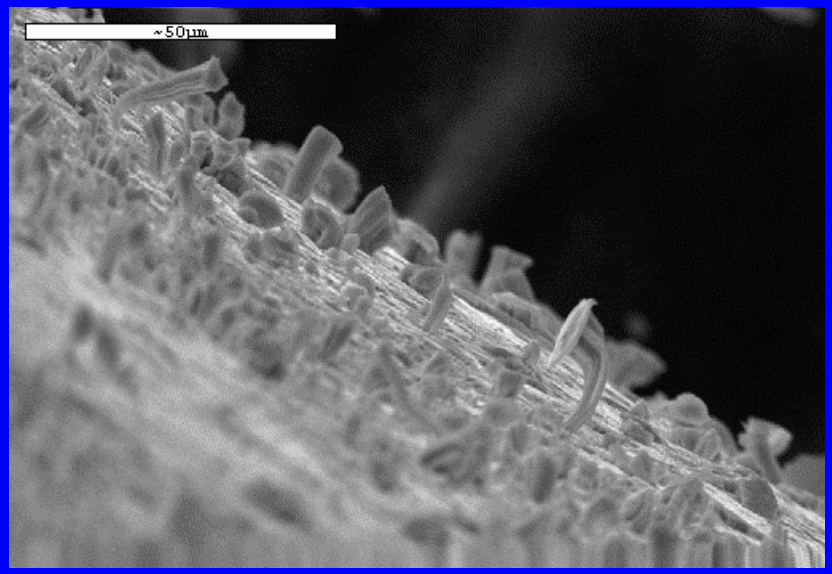


Tin Whiskers and MLCCs

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



Manufacturer "C"

Max. Length ~ 30 µm

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

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 ***PURE TIN*** by Mistake
  - User Observes ***"Moss-Like" Growths on MLCCs*** in Stock Storage

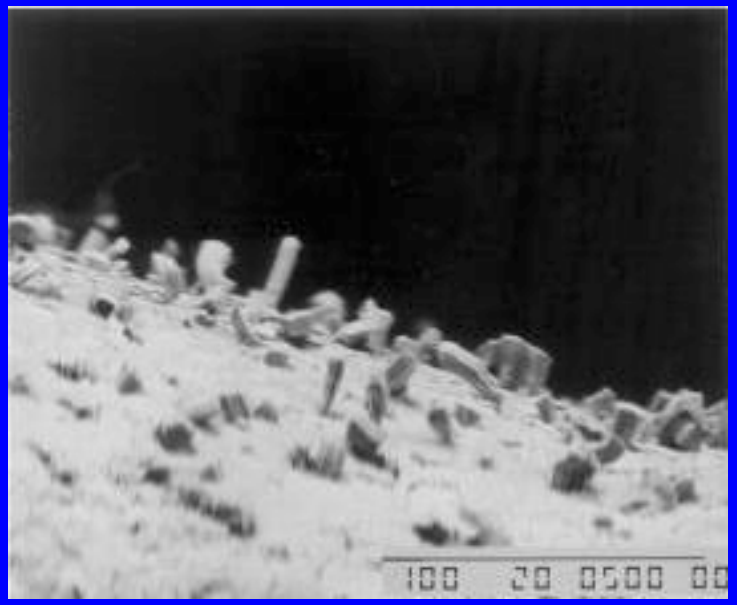
- Case 5: AFTER Vapor Phase Installation
  - Manufacturer "B"
  - Pure Tin Commercial 2220 and 1812 MLCCs
  - Vapor Phase Installation with Solder (63 / 37) @ 217°C
  - Thermal Cycle/Shock (-55°C / +100°C) for 50 to 400 Cycles
  - RESULTS: ***Whiskers up to 30 μm***

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:
  - ***<u>WHISKERS after Temp Cycle</u>***
  - No Whiskers after Temp/Humidity
  - No Whiskers after High Temp Storage
- ***Sn/Pb Control Samples <u>Did NOT Whisker</u>***

Whiskers AFTER Temp Cycle Only



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