

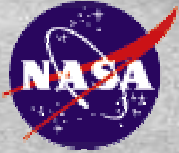
A Discussion of the Significance of Metal Whisker Formation to the High Reliability Community



November 2003

Jay Brusse

QSS Group, Inc. @ NASA Goddard

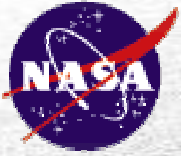


Outline

- **What are Metal Whiskers (Tin and Zinc)?**
- **Why Are Metal Whiskers A Concern?**
 - Failure Modes
 - Limited Fundamental Understanding
- **Metal Whisker Problems-PRACTICAL Examples**
 - Tin Whiskers!
 - TIN-LEAD WHISKERS!!
 - ZINC WHISKERS!!! - Beware Your Raised Floor Systems
- **Whisker Mitigation Strategies for USERS?**
- **Conclusions & Recommendations**

SEI
EHT = 20.3 KV AD= 12 mm MAG = X 230. PHOTO = 1
100 µm
1/26/01

Cover Photo: Zinc Whiskers on Zinc-Plated Steel Raised Floor Structures



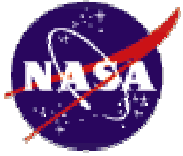
What are Tin (and Zinc) Whiskers?

- “Hair-Like” Single Crystal Structures that May Grow from mostly pure Tin (or Zinc) Finished Surfaces
- LENGTH: Up to 10 mm
(Typically < 1mm)
- DIAMETER: from 0.006 to 10 μm
(Typical $\sim 1 \mu\text{m}$)
- Grow from the Base Not the Tip
- Growth Mechanism(s): **UNKNOWN!**
Diffusion Processes within Finish or on Surface are likely involved, but what drives diffusion into specific grains and then launches them OUT from surface?

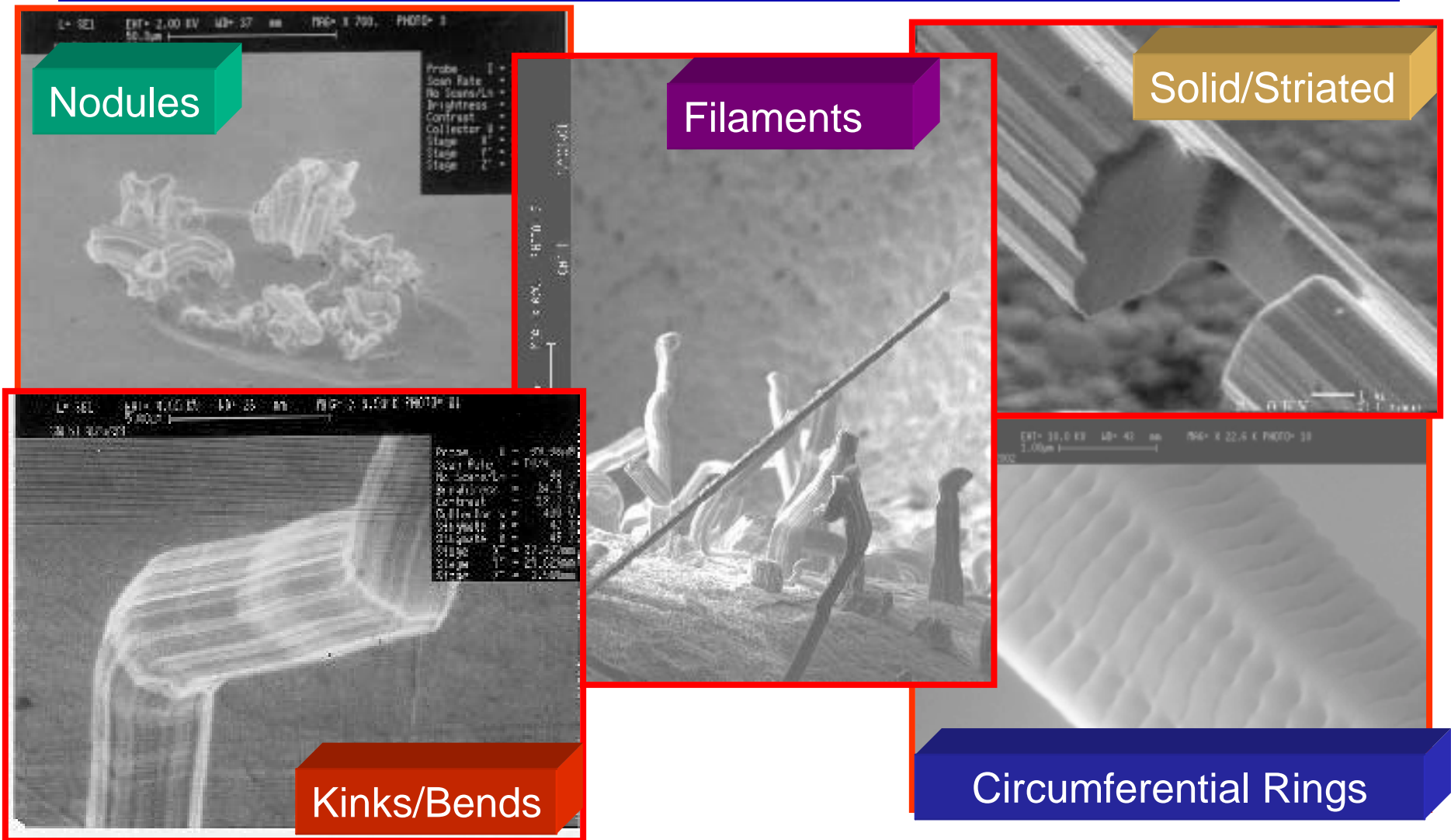
***Whiskers are
NOT Dendrites***

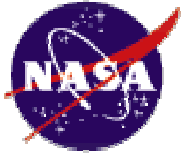


***Fundamental Research
is INCOMPLETE***



Metal Whisker Shapes & Features





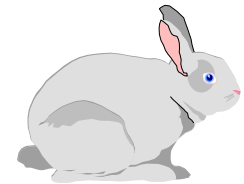
Sneaky Metal Whiskers!!!

Incubation Period

Initiation of growths may occur after MANY YEARS of Dormancy

Growth Rate

*Variable ! Sometimes Fast...
Sometimes **VERY SLOW***



Inspection is *DIFFICULT*

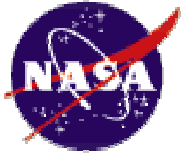
**Often INVISIBLE under Low Mag
Device Handling Can Hide Evidence
Sometimes Forests of Growths,
Sometimes "Needle in a Hay Stack"**



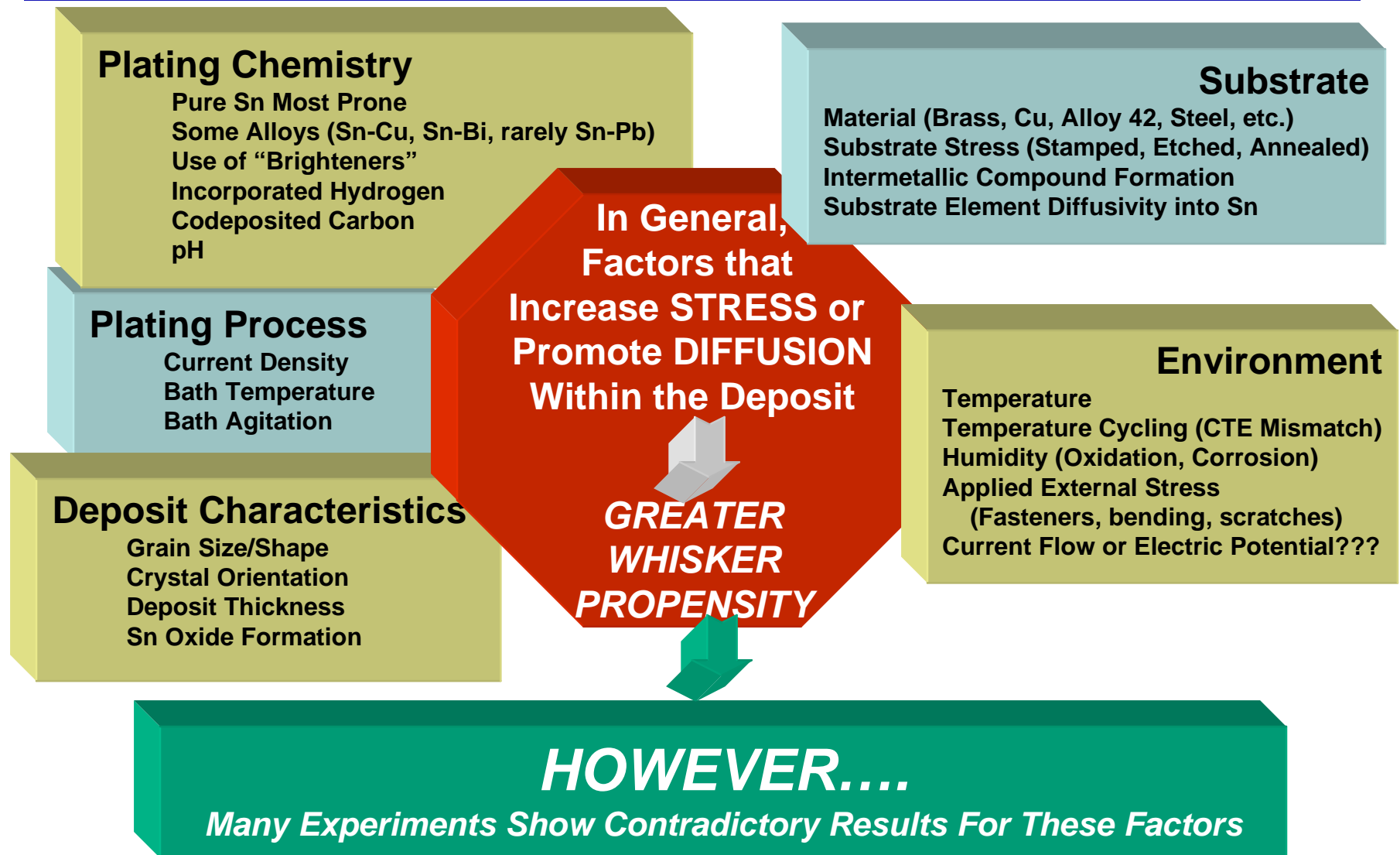
Challenges This Poses for Many Hi-Rel Applications

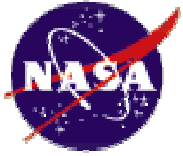
- Long Application Life (5, 10, 20 or 30 YEARS)
- Application May Not Be Field Serviceable (e.g., Space)
- Only One Chance for Success (e.g., Military, Space)





Factors that “May” Influence Metal Whisker Growth



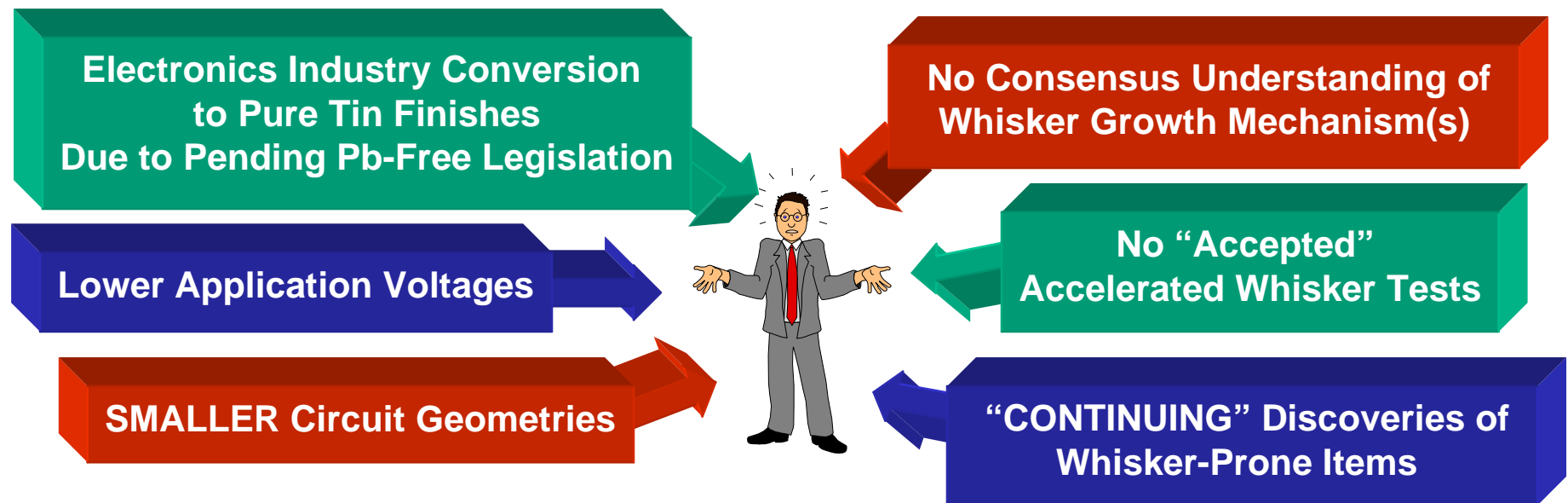


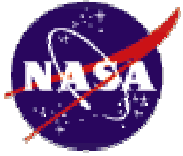
Converging Issues Fuel Hi-Rel User Concerns

- **The PAST:**

- Metal (Sn, Zn, Cd, other) Whiskers Known for ~60 Years
- HUNDREDS of Independent Studies of TIN Whiskers Alone
- Numerous “Disparities” Exist in Published Literature

- **The PRESENT:** Combination of CONCERNING Factors

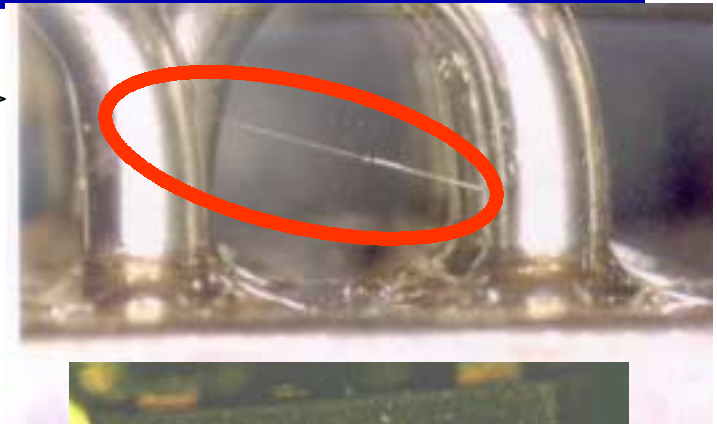




Whisker Failure Modes

Electrical Short Circuits

- Permanent (if current < 10's of mA)
- Intermittent (if current > 10's of mA) *Whisker Melts*



Debris/Contamination

- Interfere with Sensitive Optics or MEMS
- Shorts in Areas REMOTE From Whisker Origins
(Zinc Whiskers on raised flooring are a PRIME Example)



METAL VAPOR ARC

- Under Some Electrical/Atmospheric Conditions, Whisker Shorts May Vaporize into Conductive PLASMA of Metal Ions
- Plasma Forms Arc Capable of Carrying HUNDREDS OF AMPS!
With Resulting CATASTROPHIC DAMAGE



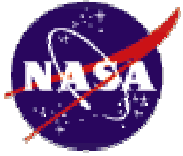


A “Few” Reported Metal Whisker Problems (Only the Last 15-20 Years Considered)



| | <u>Year**</u> | <u>Application</u> | <u>Industry</u> | <u>Failure Cause</u> | <u>Whiskers on?</u> |
|----|---------------|-------------------------|-----------------------|----------------------|---------------------------|
| 1 | 1986 | Heart Pacemakers | Medical (RECALL) | Tin Whiskers | Crystal Can |
| 2 | 1986 | MIL Aircraft Radar | Military | Tin Whiskers | Hybrid Package Lid |
| 3 | 1987 | MIL/Aerospace PWB | MIL/Aerospace | Tin Whiskers | PWB traces |
| 4 | 1988 | Missile Program “A” | Military | Tin Whiskers | Relays |
| 5 | 1989 | Missile Program “B” | Military | Tin Whiskers | Electronics Enclosure |
| 6 | 1990 | Apnea Monitors | Medical (RECALL) | ZINC Whiskers | Rotary Switch |
| 7 | 1992 | Missile Program “C” | Military | Tin Whiskers | Xsistor Package +Standoff |
| 8 | 1993 | Govt. Electronics | Govt. Systems | Tin Whiskers | Transistor, Diode, Lug |
| 9 | 1995 | Telecom Equipment | Telecom | ZINC Whiskers | Framework |
| 10 | 1996 | Computer Routers | Computers | ZINC Whiskers | Chassis |
| 11 | 1996 | MIL Aerospace | MIL Aerospace | Tin Whiskers | Relays |
| 12 | 1998 | Aerospace Electronics | Space | Tin Whiskers | Hybrid Package Lid |
| 13 | 1998 | Commercial Satellite #1 | Space (Complete Loss) | Tin Whiskers | Relays |
| 14 | 1998 | Commercial Satellite #2 | Space | Tin Whiskers | Relays |
| 15 | 1998 | Commercial Satellite #3 | Space | Tin Whiskers | Relays |
| 16 | 1998 | Computer Hardware | Computers | ZINC Whiskers | Chassis |
| 17 | 1998 | Military Aerospace | Military Aerospace | Tin Whiskers | Plastic Film Capacitor |
| 18 | 1999 | Eng Computer Center | Architectural | ZINC Whiskers | Floor Tiles |
| 19 | 199X | Telecom Equipment | Telecom | ZINC Whiskers | PSU Housing |
| 20 | 2000 | Missile Program “D” | Military | Tin Whiskers | Terminals |
| 21 | 2000 | Commercial Satellite #4 | Space (Complete Loss) | Tin Whiskers | Relays |

Many of these Incidents Involve “Multiple” Failures



A “Few” MORE Reported Metal Whisker Issues (Only the Last 15-20 Years Considered)



| | <u>Year**</u> | <u>Application</u> | <u>Industry</u> | <u>Failure Cause</u> | <u>Whiskers on?</u> |
|----|---------------|--------------------------|-----------------------|----------------------|--------------------------|
| 22 | 2000 | Commercial Satellite #5 | Space (Complete Loss) | Tin Whiskers | Relays |
| 23 | 2000 | Power Mgmt Modules | Industrial | Tin Whiskers | Connectors |
| 24 | 2001 | Commercial Satellite #6 | Space | Tin Whiskers | Relays |
| 25 | 2001 | Space Ground Test Eqpt | Ground Support | ZINC Whiskers | Bus Rail |
| 26 | 2001 | Nuclear Power Plant | Power | Tin Whiskers | Relays |
| 27 | 2001 | Hi-Rel | Hi-Rel | Tin Whiskers | Ceramic Chip Caps |
| 28 | 2002 | Commercial Satellite #7 | Space | Tin Whiskers | Relays |
| 29 | 2002 | Military Aircraft | Military | Tin Whiskers | Relays |
| 30 | 2002 | Electric Power Plant | Power | Tin Whiskers | Microcircuit Leads |
| 31 | 2002 | Hospital Computer Center | Medical | ZINC Whiskers | Floor Tiles |
| 32 | 2002 | Govt Computer Center | Commercial | ZINC Whiskers | Floor Tiles |
| 33 | 2002 | E-Comm. Comp Center | Commercial | ZINC Whiskers | Floor Tiles |
| 34 | 2002 | Library Computer Center | Public Service | ZINC Whiskers | Floor Tiles |
| 35 | 2002 | GPS Receiver | Aeronautical | Tin Whiskers | RF Enclosure |
| 36 | 2002 | MIL Aerospace | MIL Aerospace | Tin Whiskers | Mounting Hardware (nuts) |
| 37 | 2002 | Commercial Electronics | Power Supply | ZINC Whiskers | Mounting Hardware |
| 38 | 2003 | Commercial Electronics | Telecom | Tin Whiskers | RF Enclosure |
| 39 | 2003 | Telecom Equipment | Telecom | Tin Whiskers | Ckt Breaker |
| 40 | 2003 | NASA Data Center | Ground Support | ZINC Whiskers | Floor Tiles |
| 41 | 2003 | Missile Program “E” | Military | Tin Whiskers | Connectors |
| 42 | 2003 | Missile Program “F” | Military | Tin Whiskers | Relays |



**More About
This Concern
Later ...**

NOT Just a Problem of “The Past”

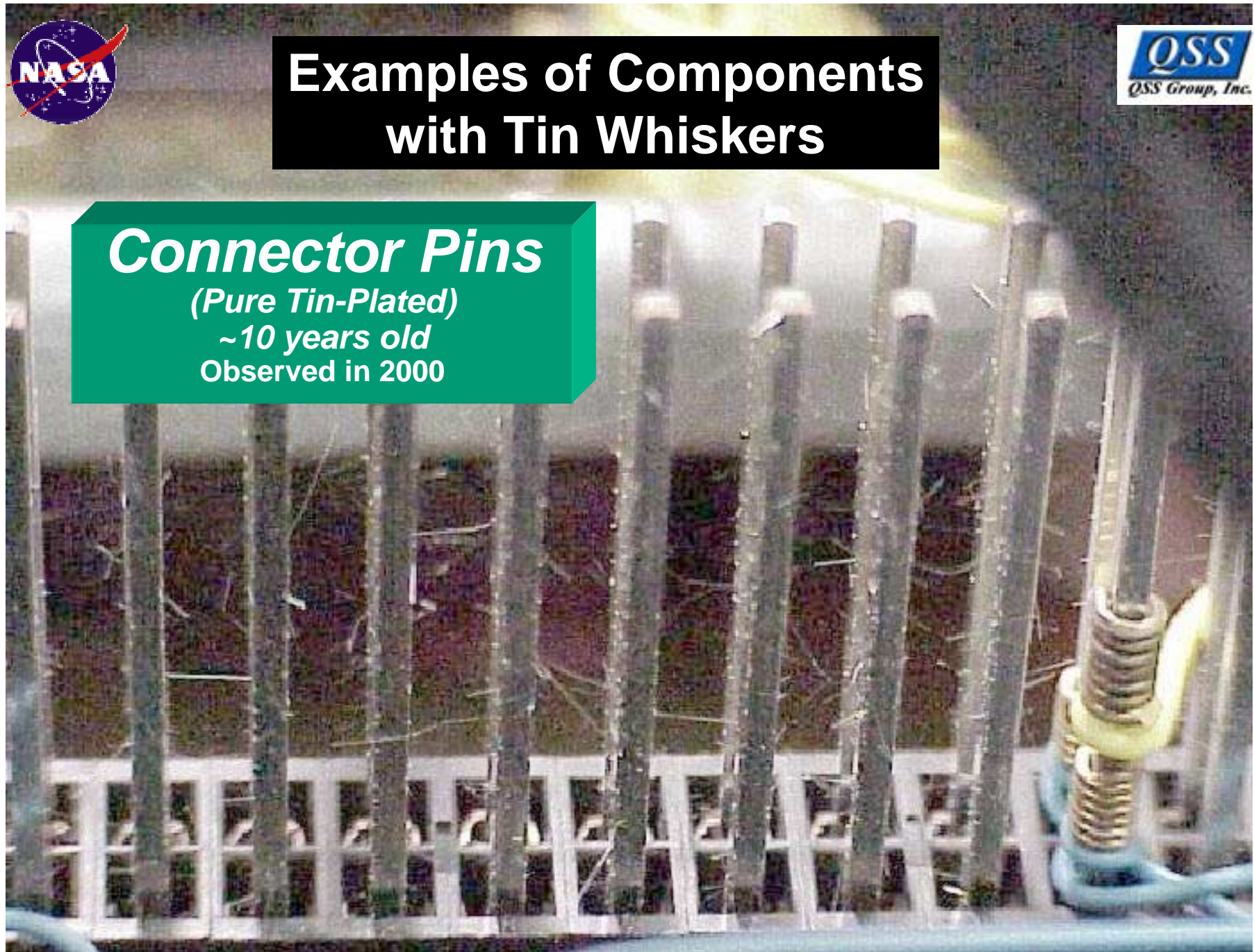


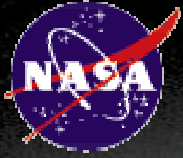
Examples of Components with Tin Whiskers



Connector Pins

(Pure Tin-Plated)
~10 years old
Observed in 2000





Examples of Components with Tin Whiskers



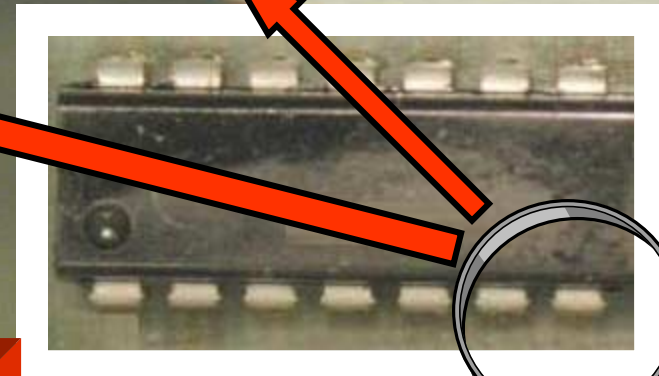
Pin #6

Microcircuit Leads

*("Matte" Tin-Plated)
Observed in 2002*

Pin #7

Whiskers from this Component Caused a FAILURE in the Electric Power Utility Industry > 20 YEARS!!! After Fielding the System





Examples of Components with Tin Whiskers



**Hybrid Microcircuit
Package Lid**
(Pure Tin-Plated)
Observed in 1998

**Whiskers up to 2 mm Long Found
Growing INSIDE Package**

**Whiskers Like these Reportedly Have
Broken Loose Inside Hybrids Creating
Intermittent Shorts/Field Failures**

40.0x

20.0 kV

1mm

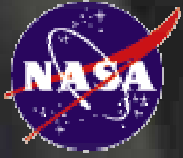


Examples of Components with Tin Whiskers



Exterior Surfaces of Electromagnetic Relays
(Tin-Plated Terminals, Case, Header)

Whisker Shorts Between Terminal to Terminal, Terminal to Header, Case to Other Component, Whisker to Whisker!!!



Examples of Components with Tin Whiskers



INTERIOR Surfaces of Electromagnetic Relays

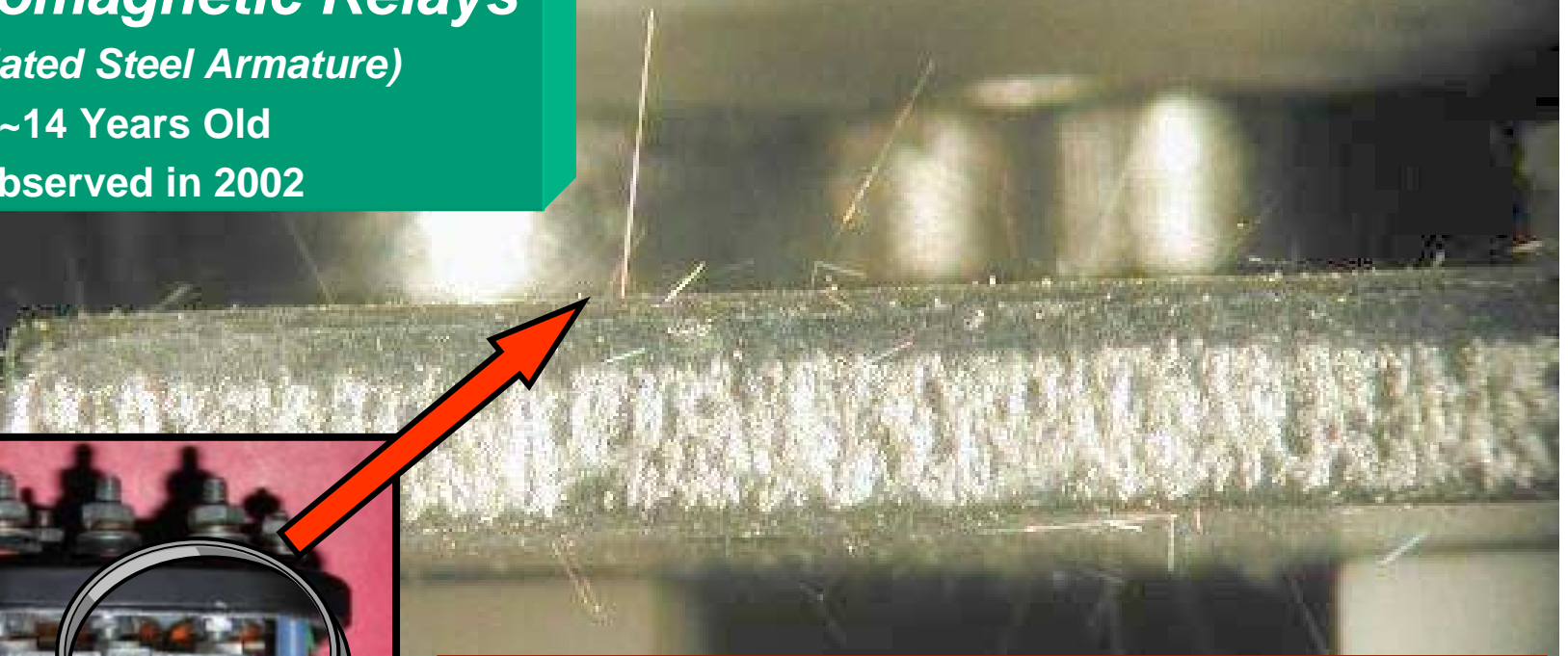
(Tin-Plated Steel Armature)

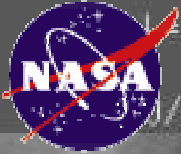
~14 Years Old

Observed in 2002



*Beware What May be INSIDE your Devices
(Up to 3 mm Long Found in This Part)*






SE1 EIT 4 10 KU UP 00 MAC U 00 0 PHOTO= 22
21
0/08/02 CAP#



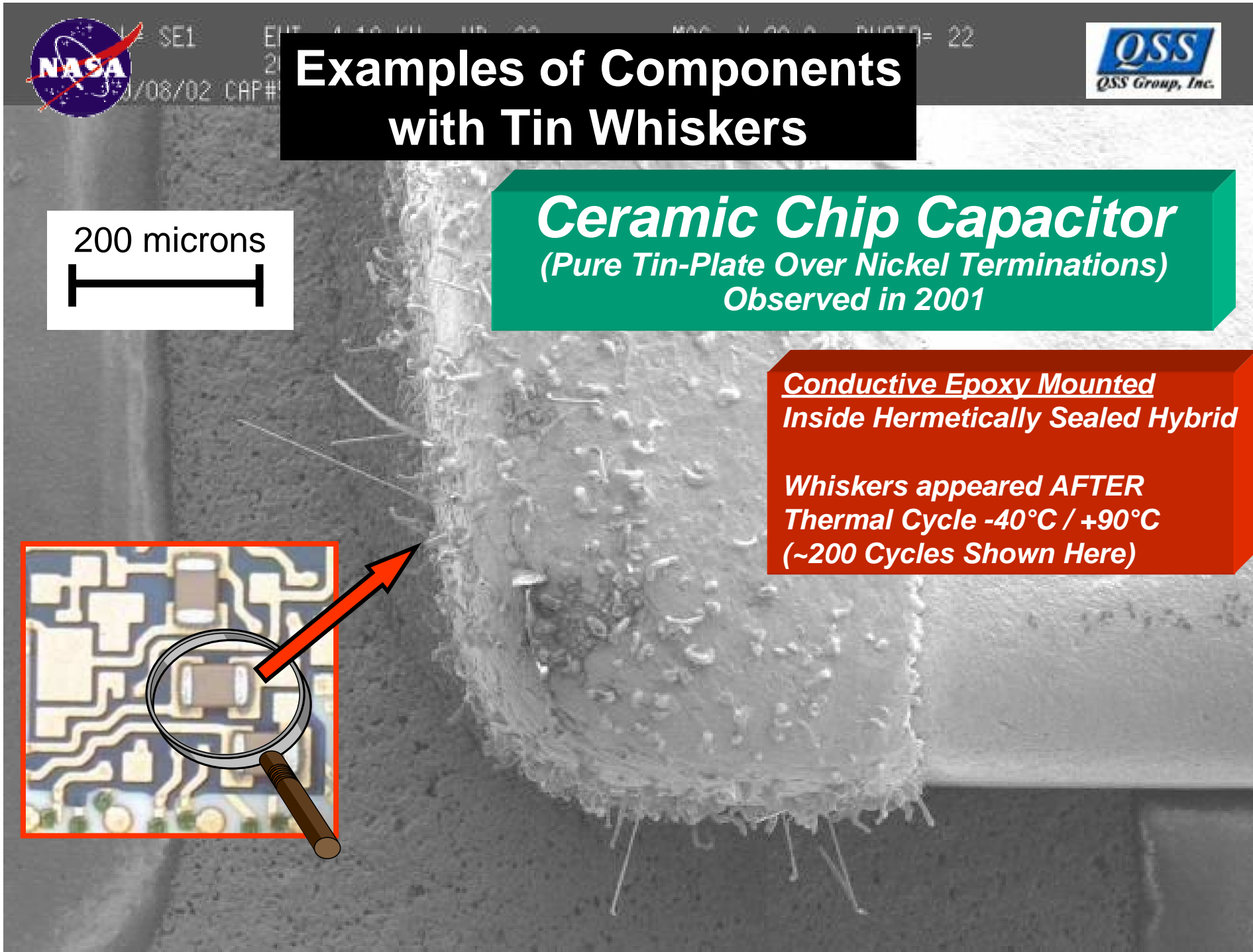
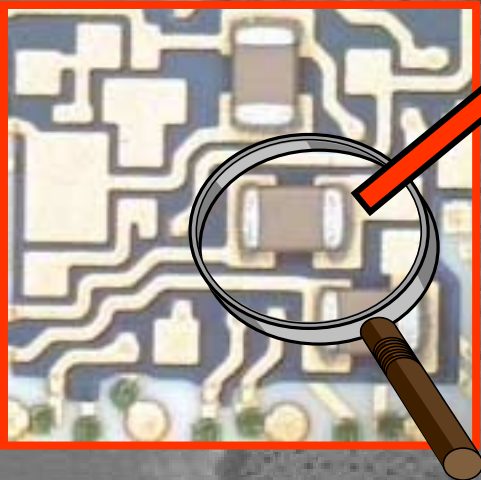
Examples of Components with Tin Whiskers

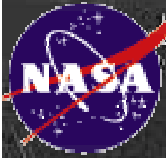
200 microns


Ceramic Chip Capacitor
(Pure Tin-Plate Over Nickel Terminations)
Observed in 2001

***Conductive Epoxy Mounted
Inside Hermetically Sealed Hybrid***

***Whiskers appeared AFTER
Thermal Cycle -40°C / +90°C
(~200 Cycles Shown Here)***





SEI

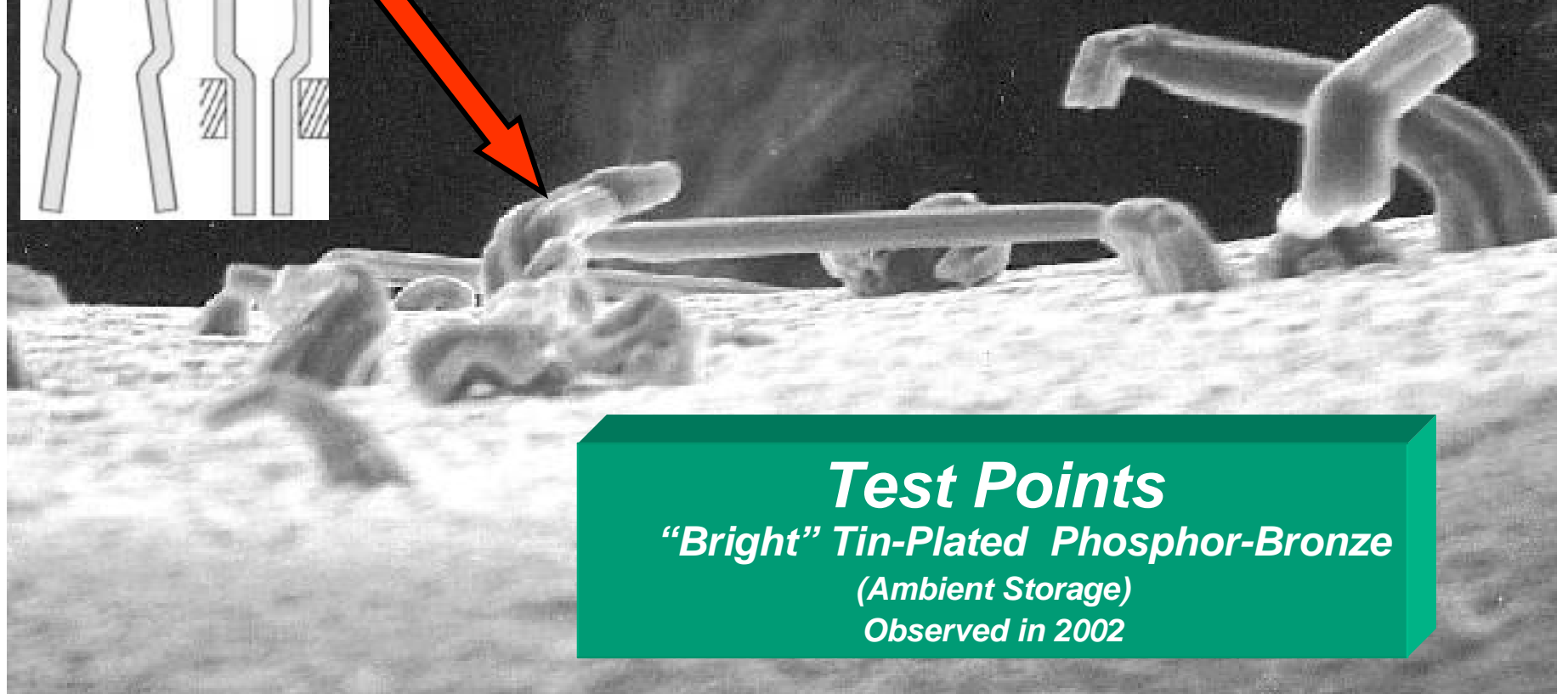
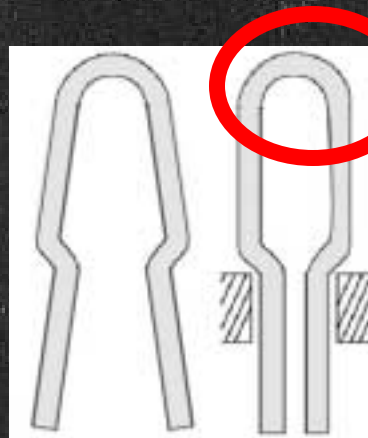
EHT= 20.0 KV
20.0µm

WD= 26 mm

MAG= X 1.50 K PHOTO= 1



Examples of Components with Tin Whiskers



Test Points
“Bright” Tin-Plated Phosphor-Bronze
(Ambient Storage)
Observed in 2002



Do Whisker “Free” Tin (or Zinc) Coatings Exist?

Answer

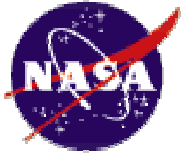
Most Likely “YES”!

Caveats

How Can One Judge Propensity?

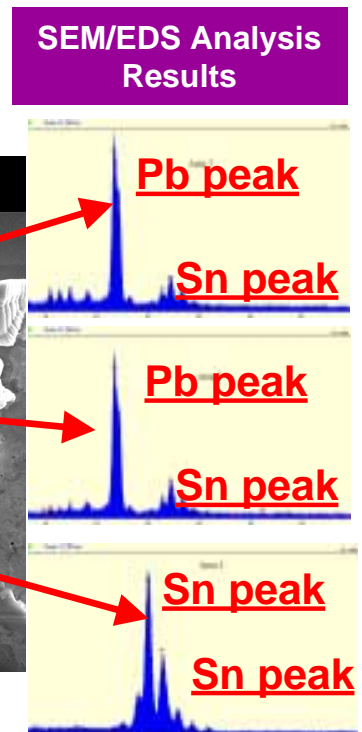
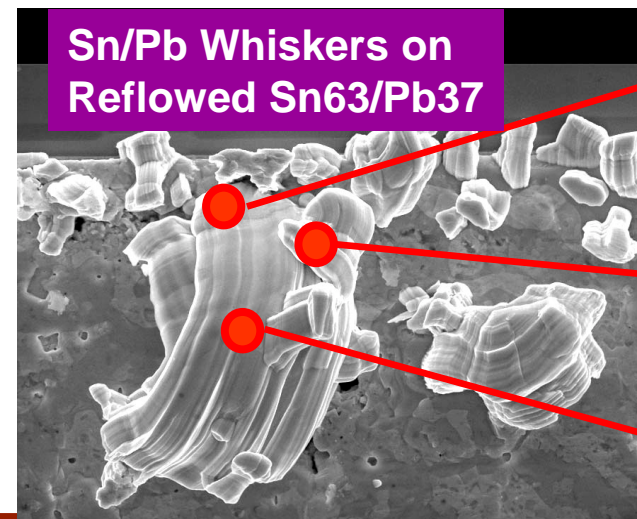
Without Validated Fundamental Models of Growth Mechanism,

- For How Long Will it be Whisker-Free?
- Under What Use Conditions? Environment? Mechanical Stress?
- Will “Subtle” Day to Day Process Variations in My Supplier’s Recipe Affect Whisker Propensity?

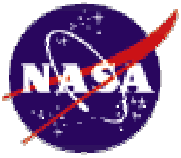


A Few Words About Tin-Lead (Sn/Pb) Whiskers

- Sn-Pb Finishes CAN Grow Whiskers, BUT...
 - Typical Lengths 5 - 15 microns which TODAY are **Generally** Benign
- Why might Pb “Inhibit” Whisker Formation?
 - Pb has low solubility in Sn (<1%)
 - Almost all Pb collects in Sn grain boundaries
 - Pb in grain boundaries may Limit Sn Diffusion



***But Sometimes Even SMALL Sn/Pb Whiskers
Can Be DANGEROUS!!!***



A Bona fide Sn-Pb Whisker Induced Short

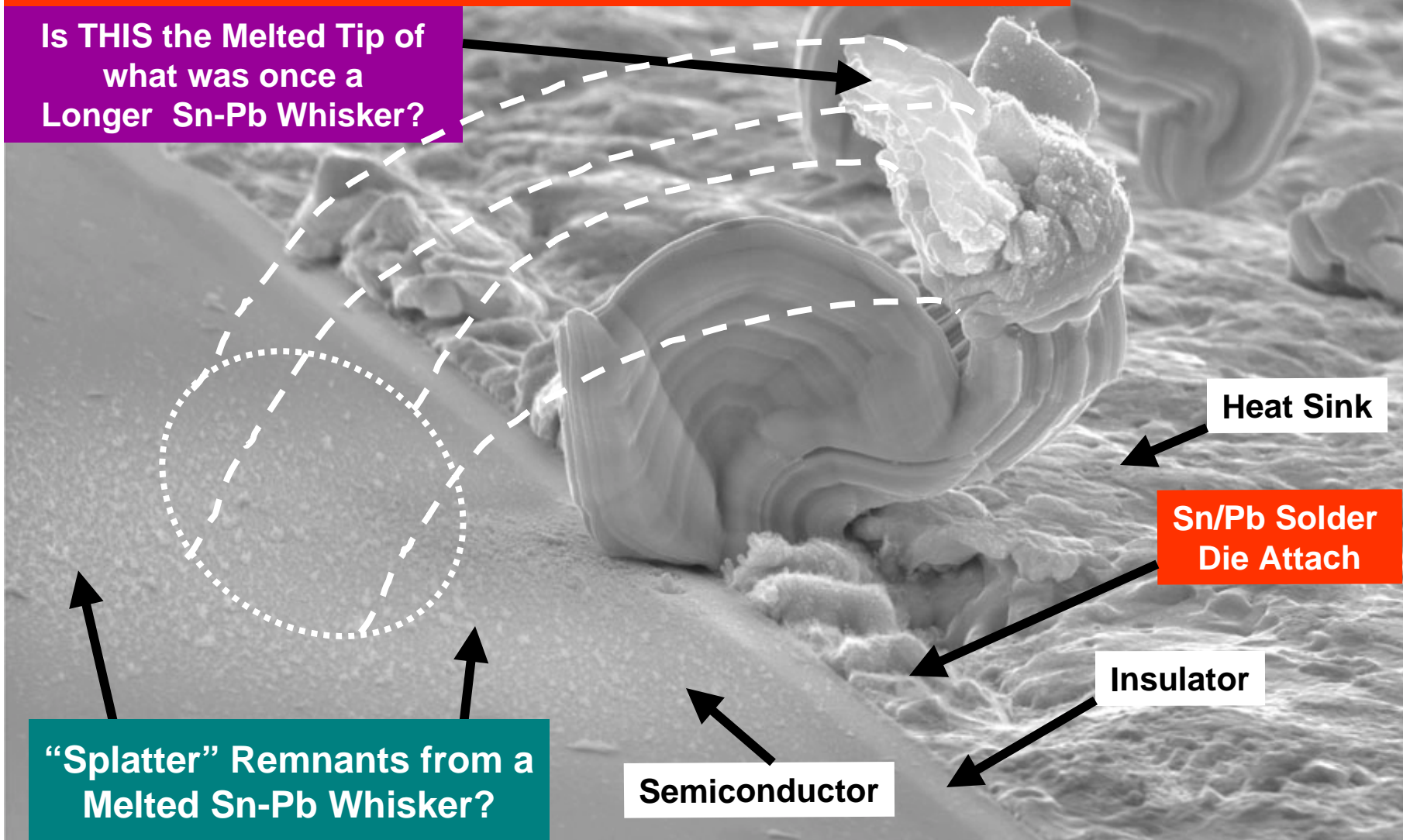


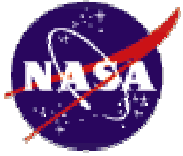
Whiskers from REFLOWED Sn-Pb Eutectic Solder (Sn63Pb37)
Min. Shorting Distance = 3 microns Heat Sink to Semiconductor

10 microns

Is THIS the Melted Tip of what was once a Longer Sn-Pb Whisker?

“Splatter” Remnants from a Melted Sn-Pb Whisker?



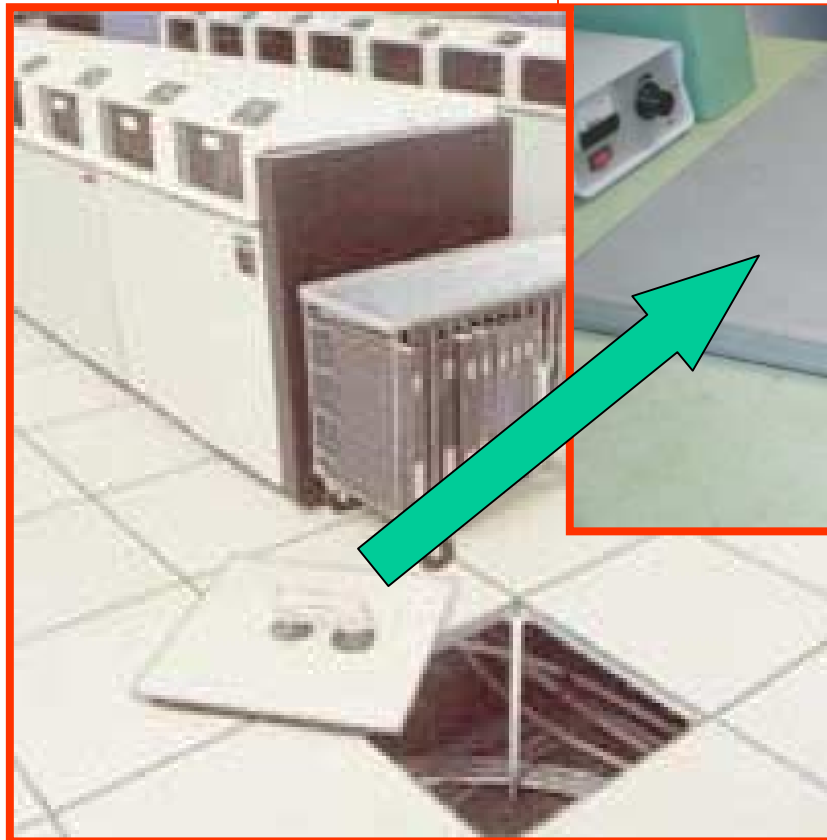


A Word or Two About One of Our
Most Recent Whisker Concerns



ZINC Whiskers on Raised Floor Structures

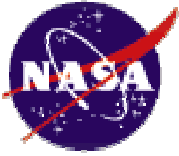
Zinc-Plated Steel Underside of Floor Tile



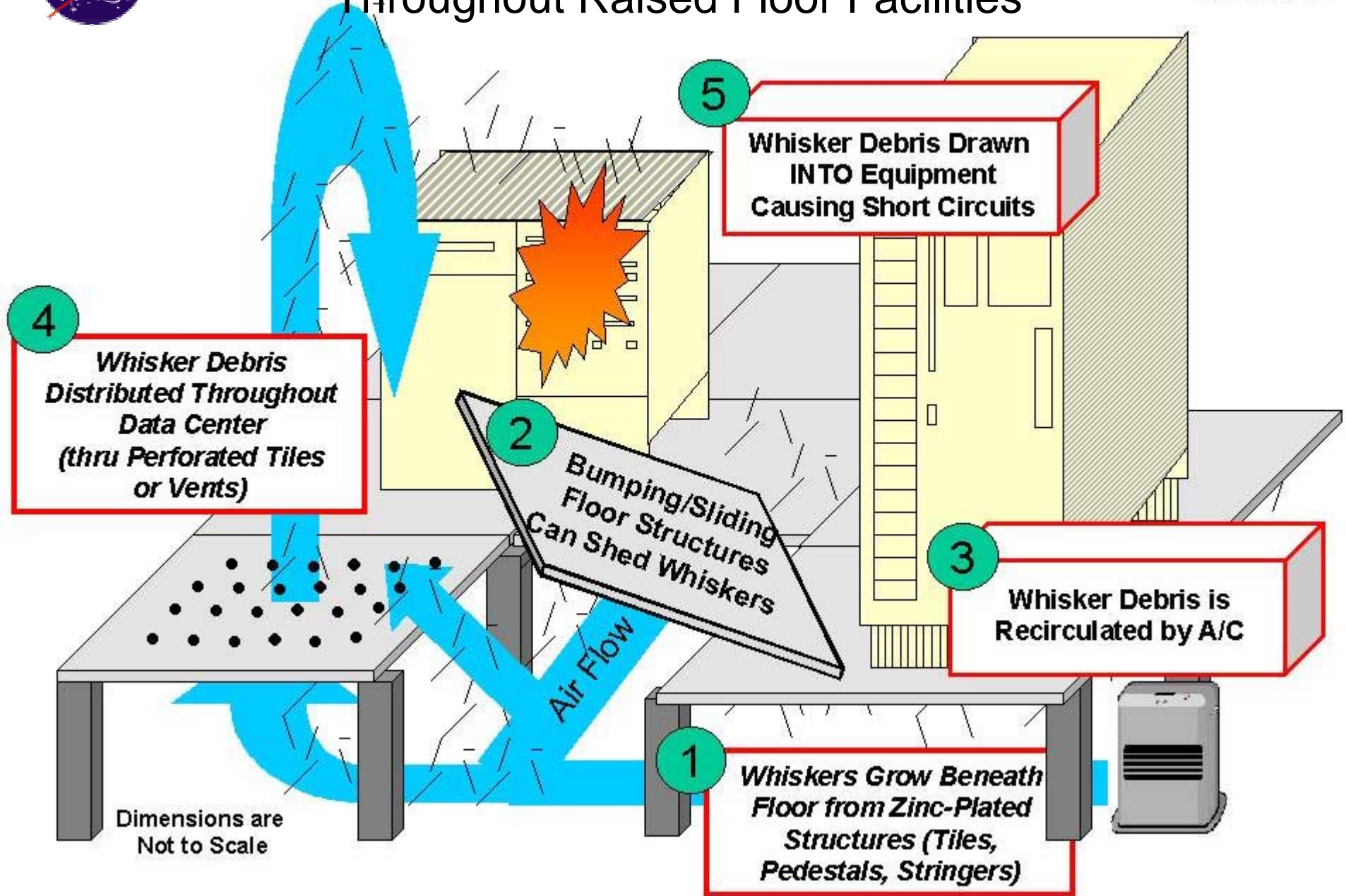
Typical "Raised" Floor Computer Room

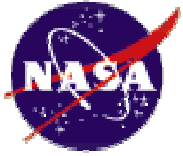


It's Growing ZINC WHISKERS!!
Estimate 1 - 10 MILLION Whiskers
on this Single Tile (4 sq ft area)

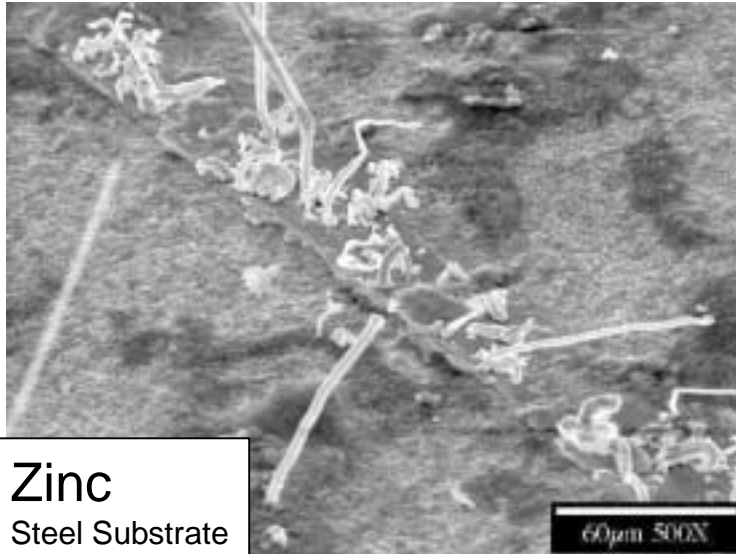


A Mechanism for Distribution of ZINC WHISKERS Throughout Raised Floor Facilities



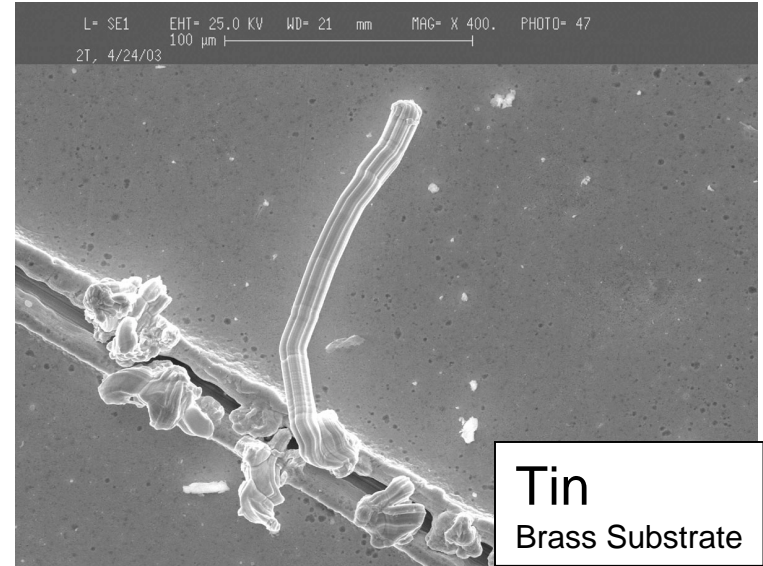


Zinc Whisker or Tin Whisker? Striking Similarities

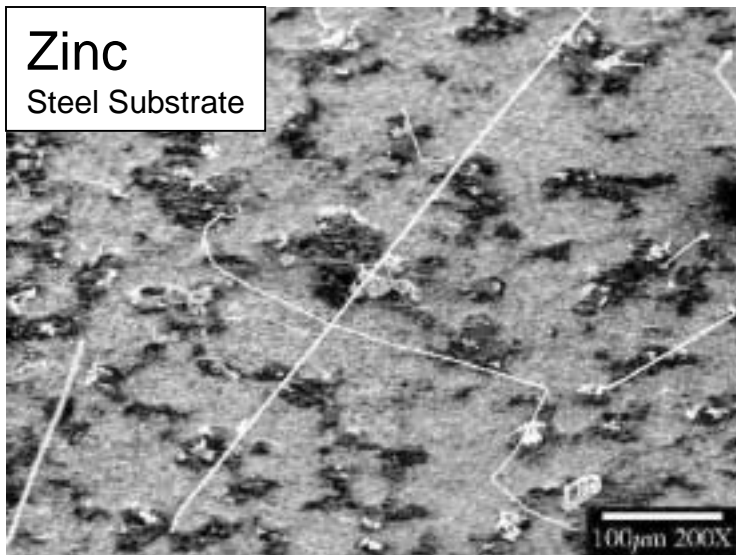


Zinc
Steel Substrate

Compare
↔

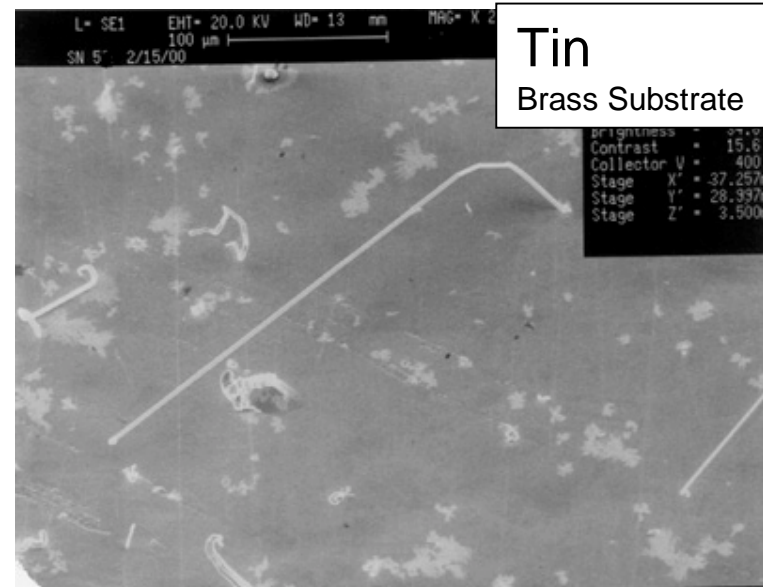


Tin
Brass Substrate

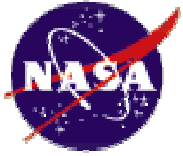


Zinc
Steel Substrate

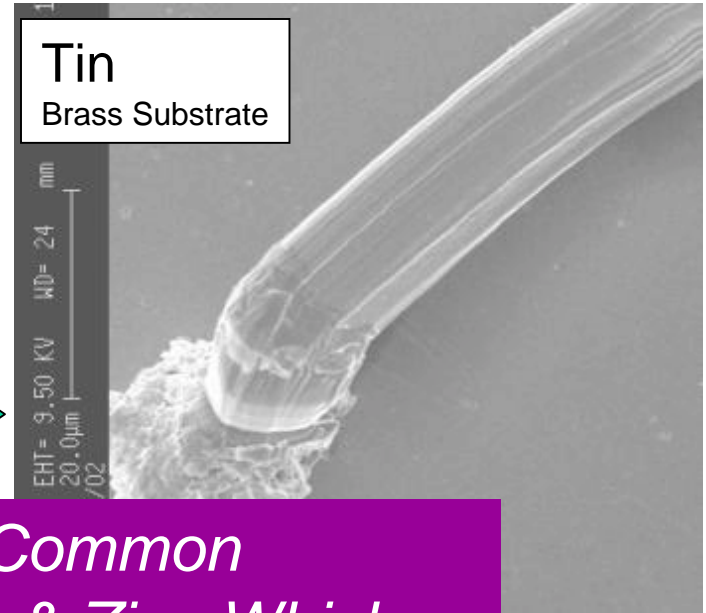
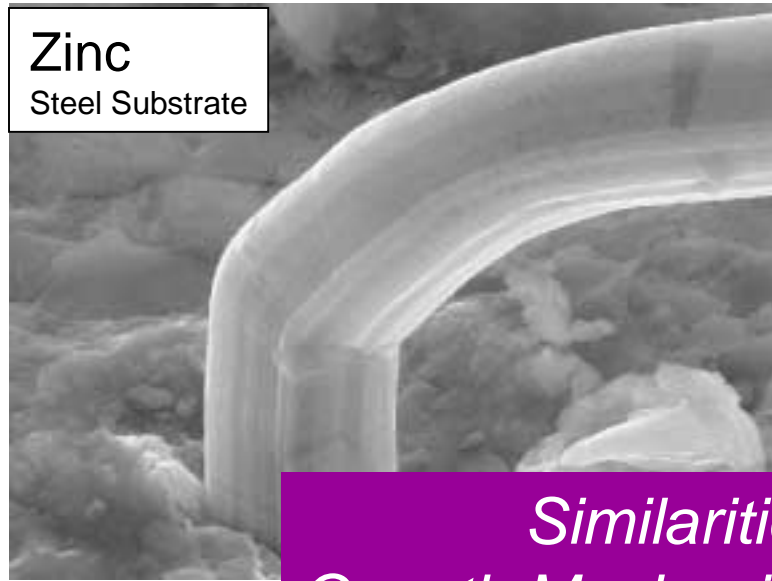
Compare
↔



Tin
Brass Substrate



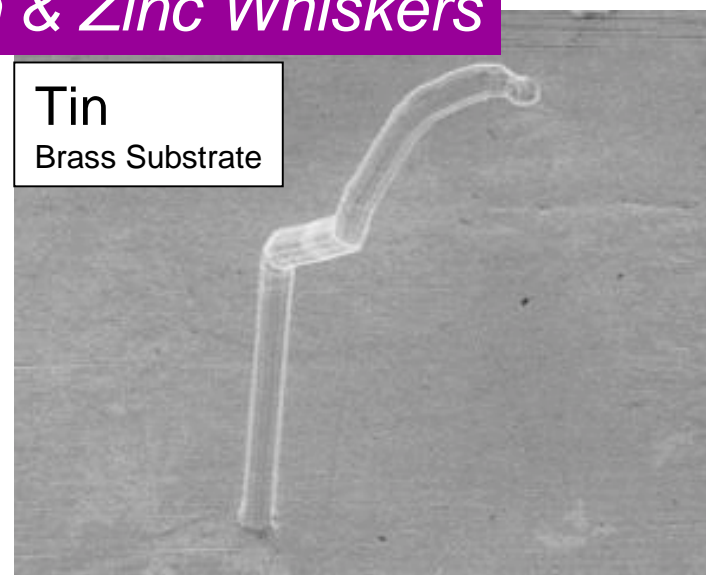
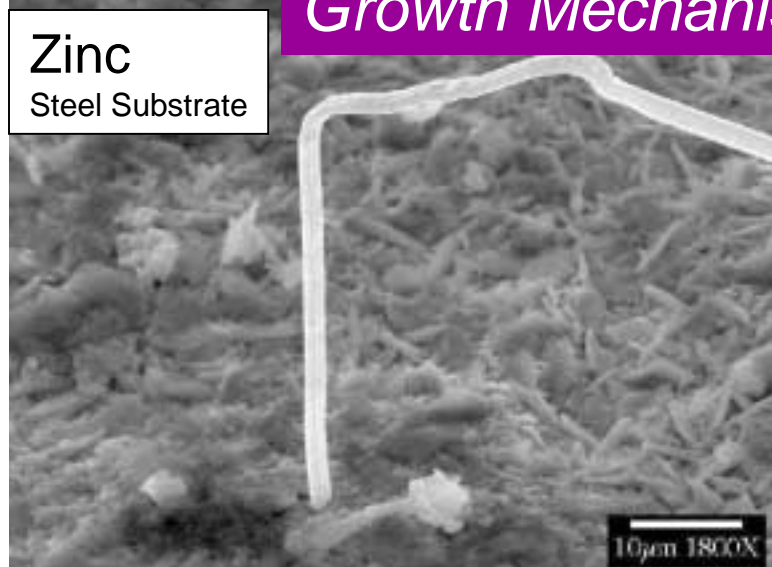
Zinc Whisker or Tin Whisker? Striking Similarities



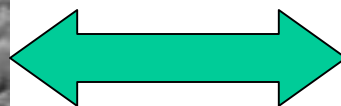
Compare

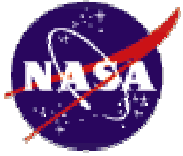


Similarities Suggest Common Growth Mechanism(s) for Tin & Zinc Whiskers



Compare





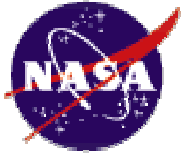
Conclusions

Failures Due to Metal Whiskers are STILL a Significant Problem

- **PROBLEMS WILL INCREASE** with Increased Use of Mostly Pure Tin and Zinc Coatings Until Significant Discoveries are Made Regarding Effective Mitigation Practices

Factors Affecting Tin Whisker Formation are NOT Completely Understood

- Influence of Individual Variables (Multi-Variable Interactions) Not Well-Understood
- Control of Variables for Experimentation is Very Complex
- Risk Assessment Based on **SUBSET** of Published Literature Can Be **DANGEROUS**



Recommendations

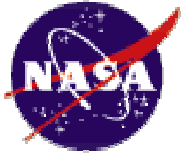


Develop CONSENSUS Model(s) of Whisker Growth Mechanism(s)

- **Comprehensive Model(s) for Tin, Zinc AND Cadmium Whiskers**
 - *Models that Hinge upon Unique Attributes of One vs. the Others May be Off the Mark*
 - *Models should also explain why many finishes appear to “not” be whisker prone*
- **Accepted Model Needed to have “Confidence” in Any Proposed Accelerated Test**

Develop PROVEN “Whisker Propensity” Test(s)

- **Fundamental Theory FIRST, then test/validate Theory... THEN develop Whisker Propensity Tests! -- This is COUNTER to Pb-Free NOW Movement!**
- **Environmental Testing vs. Finish Attributes? (grain size, orientation, etc.)**
- **Acceleration Factors **MUST** be Determined for Reliability Prediction**
- **Tailorable to Assess Varied Constructions, Materials AND Applications**



Recommendations

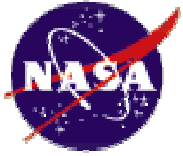


Share Whisker Experiences and Knowledge More OPENLY

- *Education vs. MIS-Information*
- *Cooperative Collaboration*
Amongst Developers, Makers, Users

Develop Whisker Risk Assessment & Mitigation Strategies

- *Plating Chemistry/Process Suppliers*
- *Component Mfrs*
- *Electronics System Assemblers*
- *End Users*



Contact Information



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Mike Sampson

NASA Goddard

Dr. Henning Leidecker

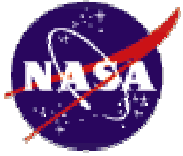
NASA Goddard

Jong Kadesch

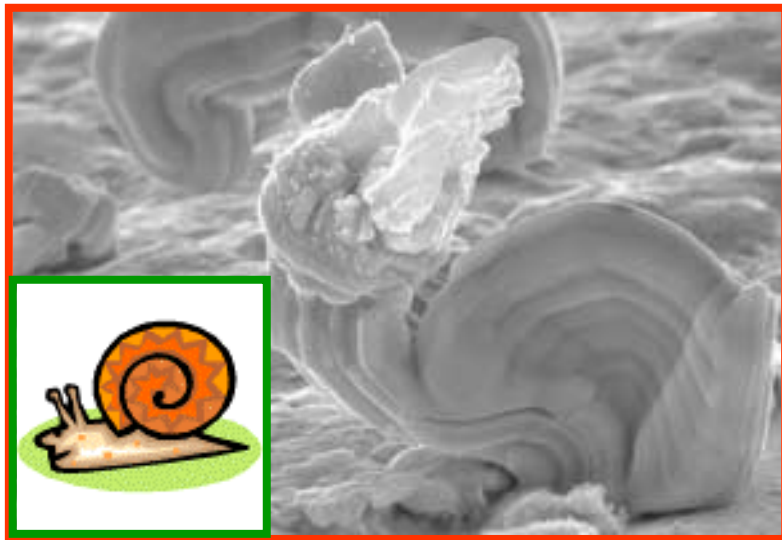
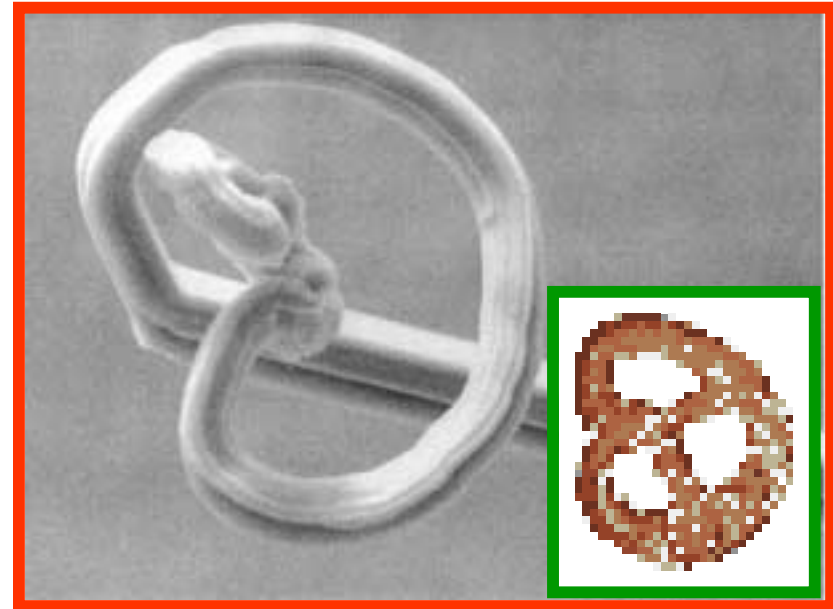
Orbital Sciences Corporation

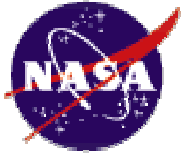
NASA Goddard Tin (and Other Metal) Whisker WWW Site

<http://nepp.nasa.gov/whisker>

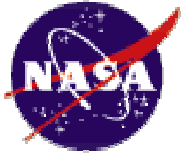


Time for Questions??





Backup Material



User Whisker Mitigation

Research on User-Mitigation Strategies is Limited

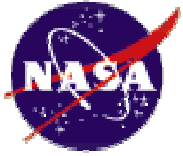
- Most Approaches Come with Benefits & Limitations
- Long-Term Effectiveness **NOT Quantified**

Strategies to Consider (Apparently Beneficial but Not Qualified)

- **REDUCE STRESS** in the Metal Plating
 - Hot Oil Reflow / Hot Solder Dip (Preferably with Sn/Pb Solder)
 - High Temp Anneal Substrate and Finish
 - Underplate with Diffusion Resistant Barrier May Delay Onset
- **USE PHYSICAL BARRIERS** to Insulate Against Potential Shorts
 - Conformal Coat or other Insulating Barriers
 - Increase Spacing of Surfaces of Opposite Polarity to > 0.5 inches
- **MINIMIZE REINTRODUCING STRESS** thru Handling, Assembly & Application

Combine **MULTIPLE** Mitigation Strategies to Increase Effectiveness

AVOID PURE TIN or ZINC, if Possible



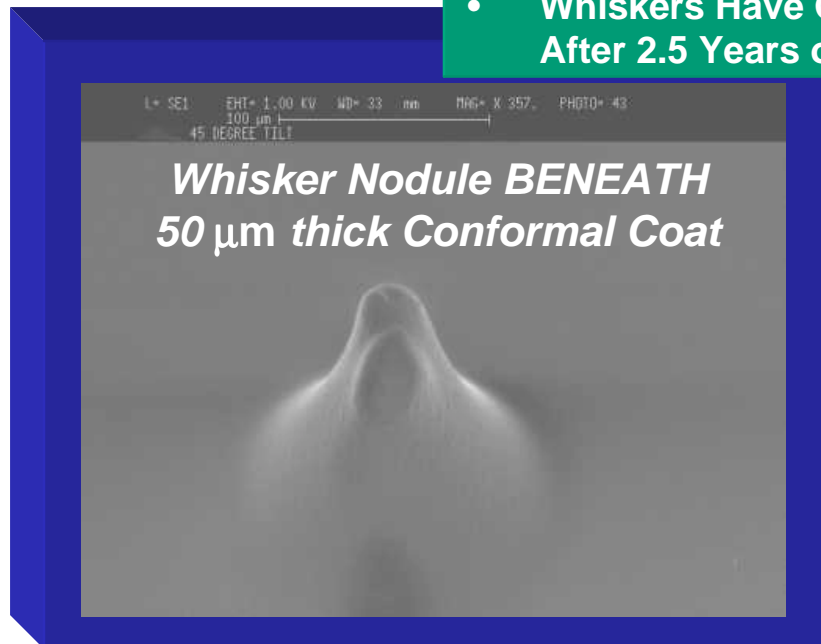
Whisker Mitigation

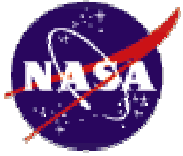


Conformal Coat (Uralane 5750 Polyurethane)

NASA Goddard Experiments (>3 Years Observation at 50°C & Room Ambient)

- **NO Whiskers THRU 50 μm Thick Uralane 5750**
- Conformal Coat REDUCES (but does NOT Eliminate) Rate of Whisker Growth Compared to Uncoated Specimen
- Whiskers Have Grown thru ~2 to 6 μm THIN Uralane 5750 After 2.5 Years of Ambient Storage

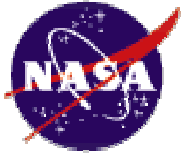




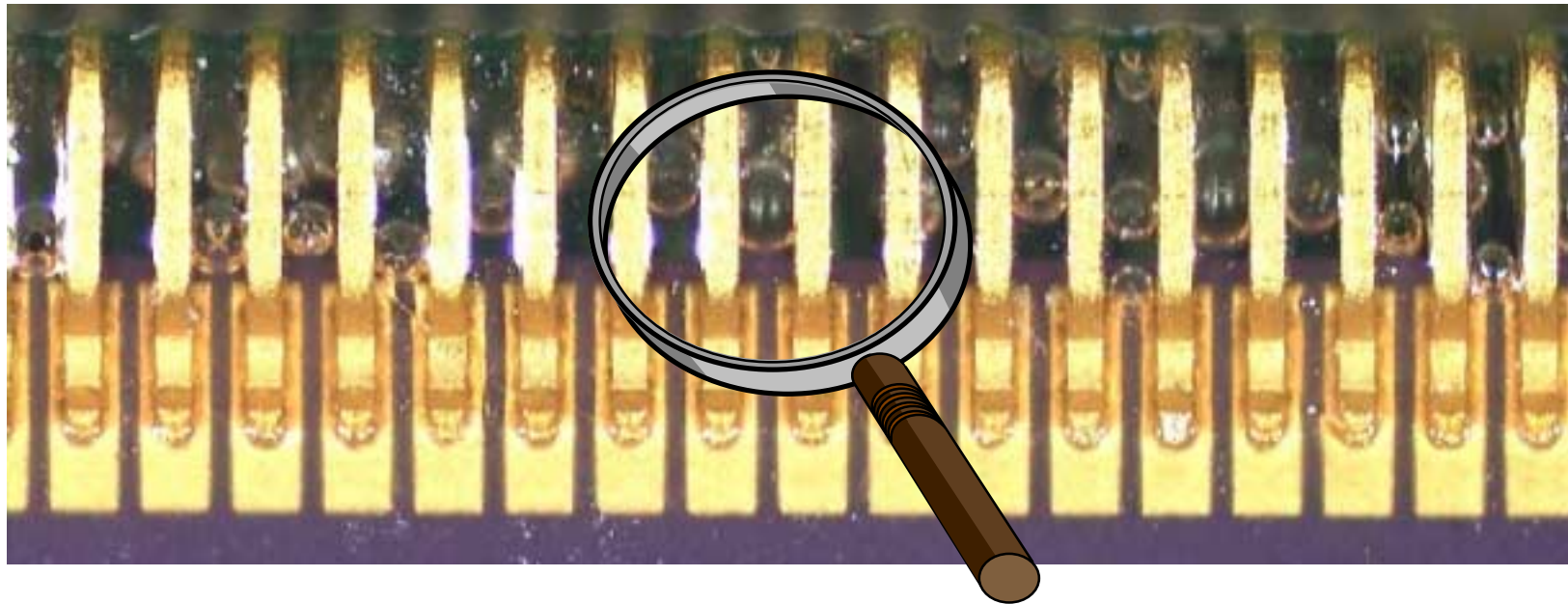
Some LIMITATIONS of Mitigation Strategies--Hot Solder Dip

Hot Solder Dip Does NOT Always Allow for COMPLETE Coverage

- Can't Dip to Component Body
- Risk of Heat Damage to Seals, Component Package, etc.



Some LIMITATIONS of Mitigation Strategies--Conformal Coat



- Air Bubbles Enable Path For Whisker Shorts??
- Can You Cover Underside of Flush Mount Devices??
- Can You Control Uniformity of Coverage/Thickness??