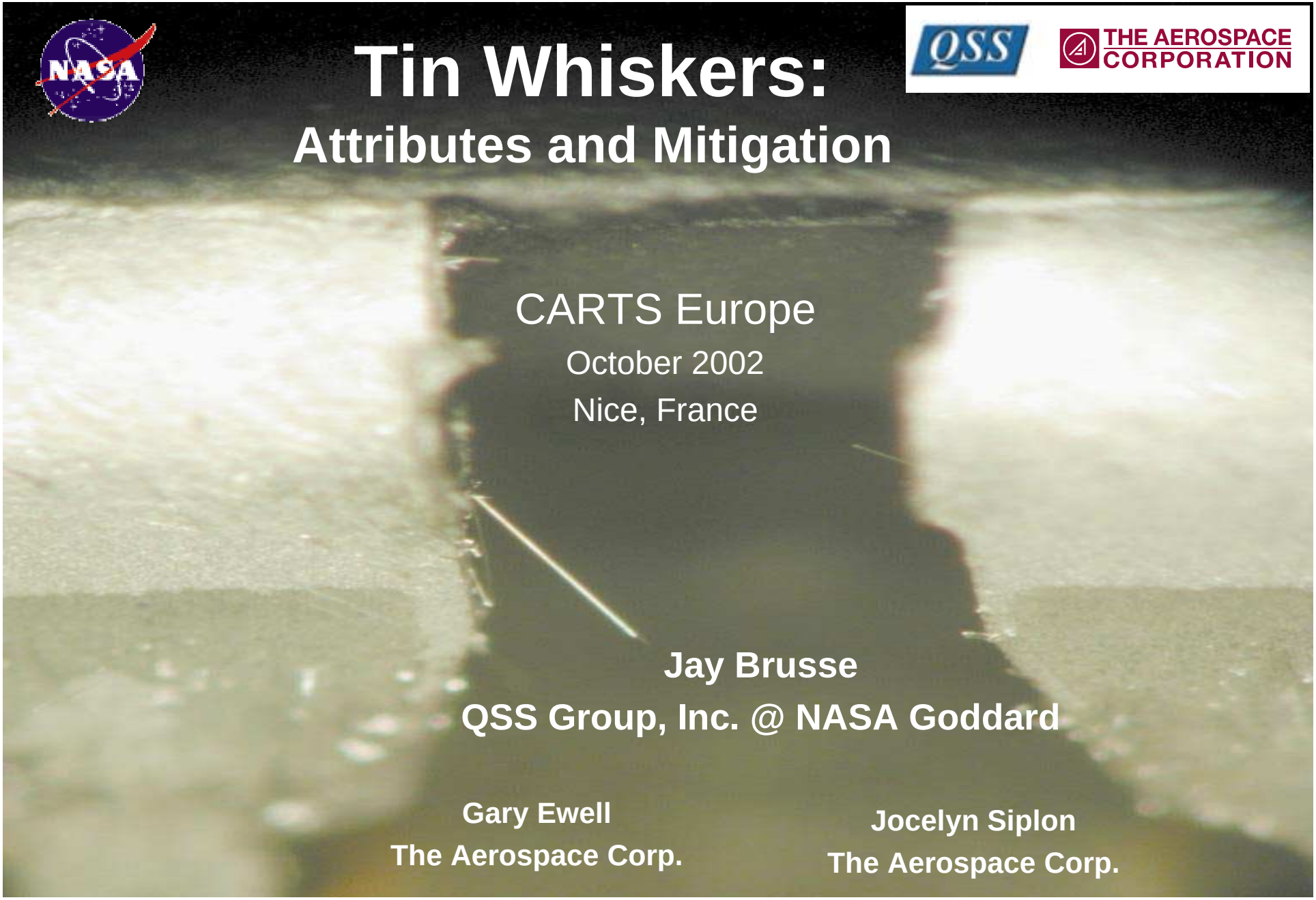


Tin Whiskers:
Attributes and Mitigation

CARTS Europe

October 2002

Nice, France

Jay Brusse

QSS Group, Inc. @ NASA Goddard

Gary Ewell

The Aerospace Corp.

Jocelyn Siplon

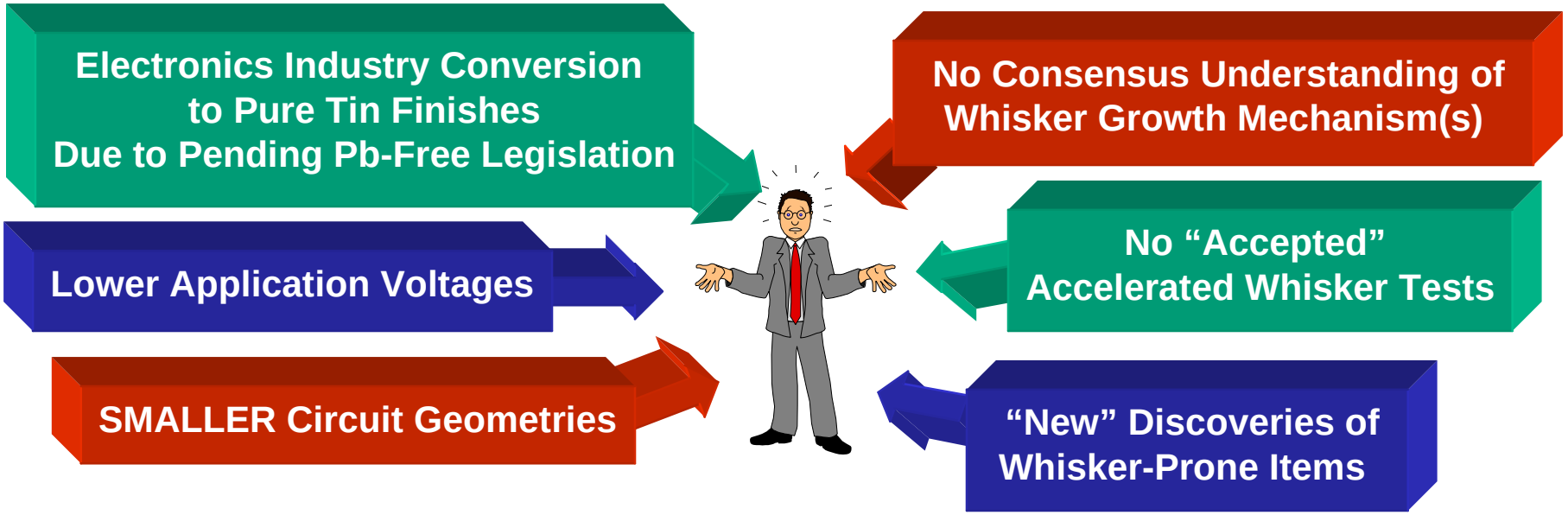
The Aerospace Corp.

Outline

- **Why ANOTHER Paper on Tin Whiskers?**
- **What are Tin Whiskers?**
  - **Attributes**
  - **Examples**
  - **Failure Modes**
- **Experience History**
- **Tin Whiskers on Ceramic Capacitors (MLCCs)**
- **Whisker Mitigation Strategies**
- **Conclusions & Recommendations**

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

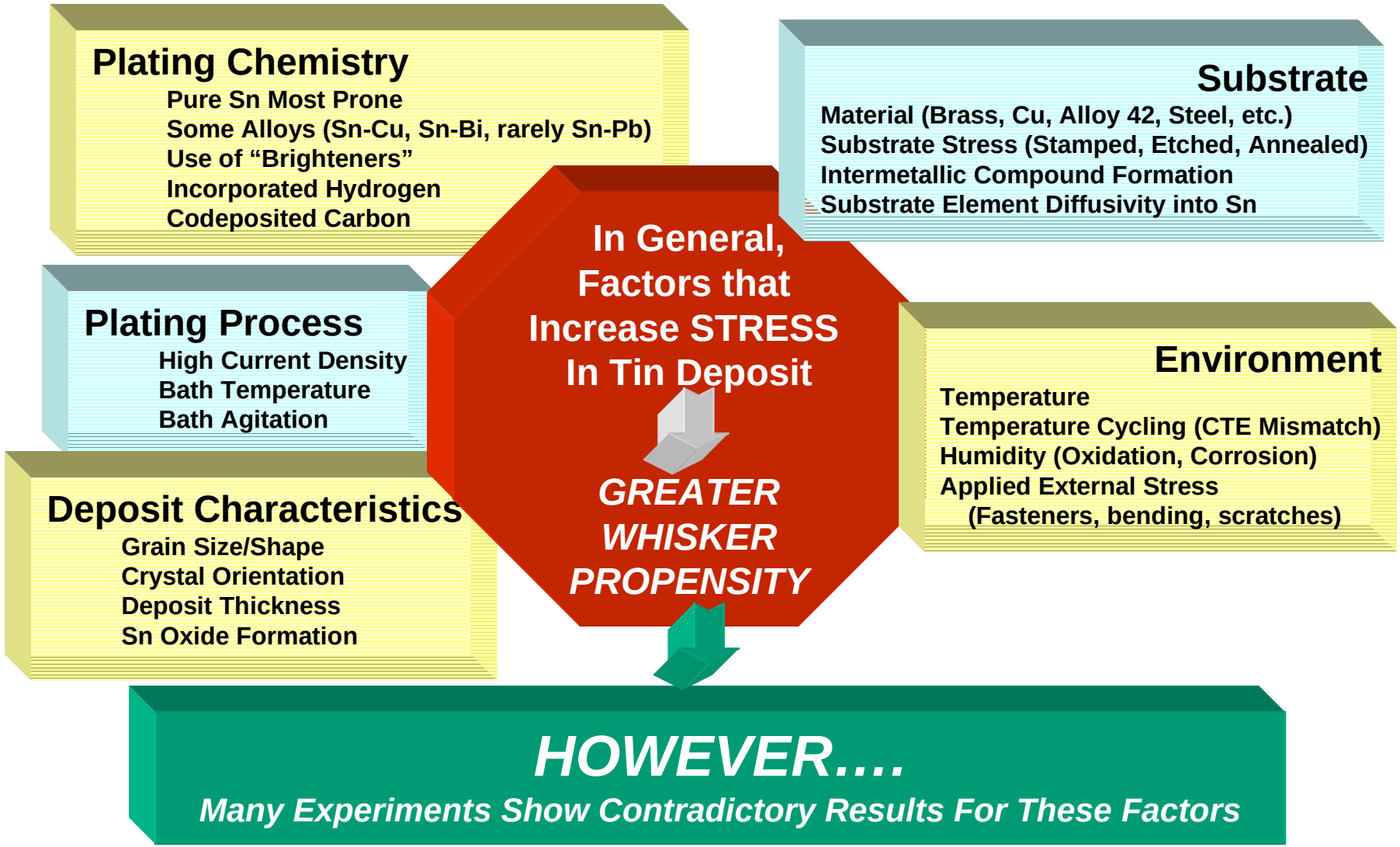


What are Tin Whiskers?

- **"Hair-Like" Single Crystal Structures that May Grow from Tin Finished Surfaces**
- **LENGTH: Up to 10 mm (Typically < 1mm)**
- **DIAMETER: from 0.006 to 10 μm (Typical ~ 1 μm)**
- **Grow from the Base Not the Tip**
- ***Mechanical Stress Relief* and Diffusion Processes in Tin Finish Drive Whisker "Extrusion"**

Fundamental Research is INCOMPLETE

Factors that Influence Whisker Growth



Sneaky Tin Whiskers!!!

Incubation Period (DORMANCY)

Initiation of growths may occur...

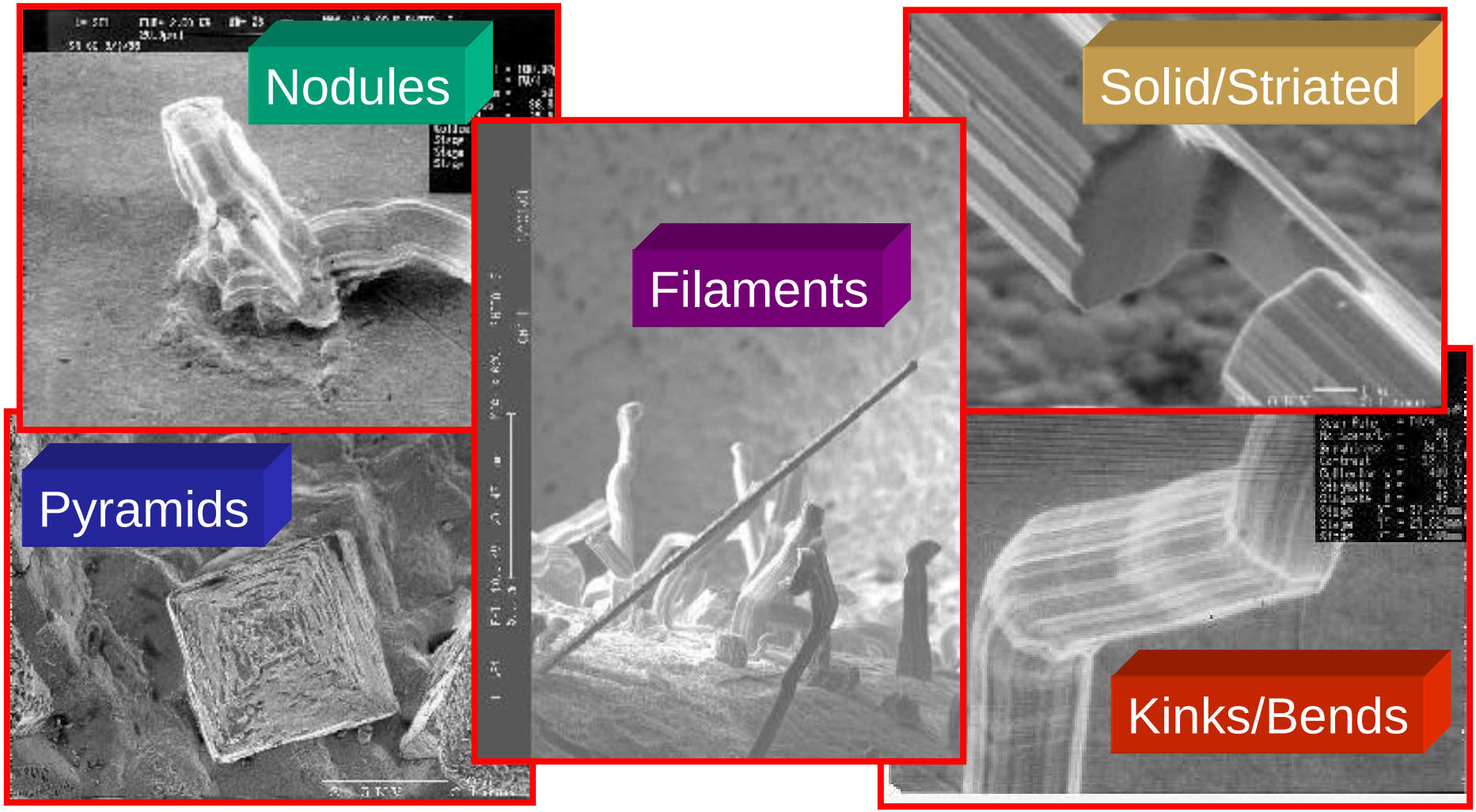
- As Short as a Few Days after Plating, or
- ***AS LONG AS MANY YEARS!!!***

Growth Rate

- Up to 9 mm/yr
- Typically Substantially SLOWER!!!

These Attributes are UNPREDICTABLE thus Presenting a MAJOR Challenge

Whisker Shapes & Features

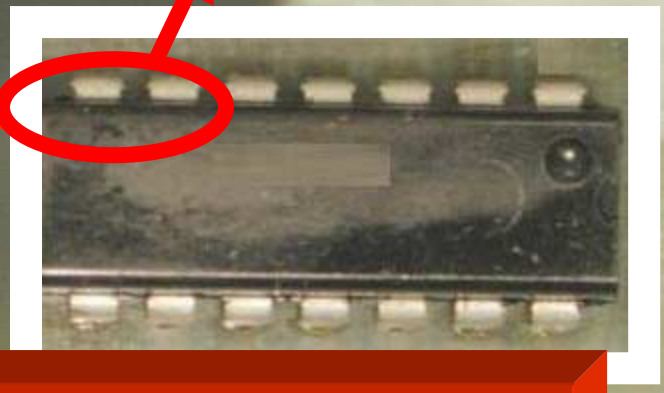


Examples of Components with Tin Whiskers

Microcircuit Leads
("Matte" Tin-Plated)

Pin #6

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

Whiskers up to 2 mm Long Found Growing INSIDE Package

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

Examples of Components with Tin Whiskers

Electromagnetic Relays

(Tin-Plated Terminals, Case, Header)

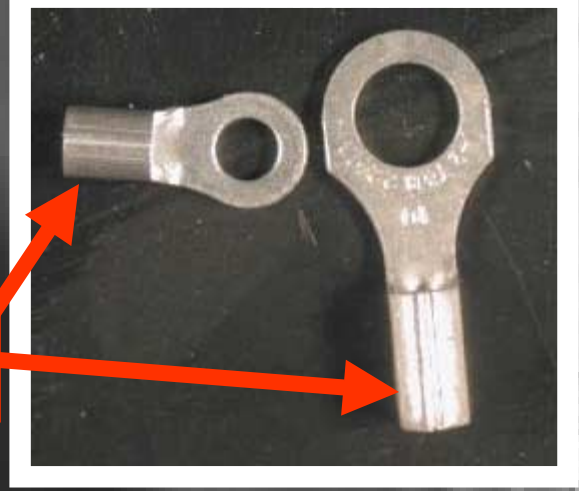
Whisker Shorts Between
Terminal to Terminal,
Terminal to Header,
Case to Other Component,
Whisker to Whisker!!!

Examples of Components with Tin Whiskers

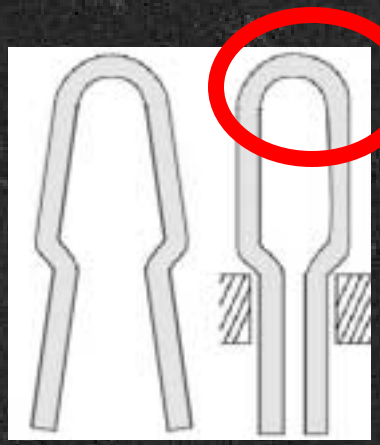
Terminal Lugs

("AS-RECEIVED")

Whiskers up to 0.25 mm Long Inside Crimp Barrel



Examples of Components with Tin Whiskers

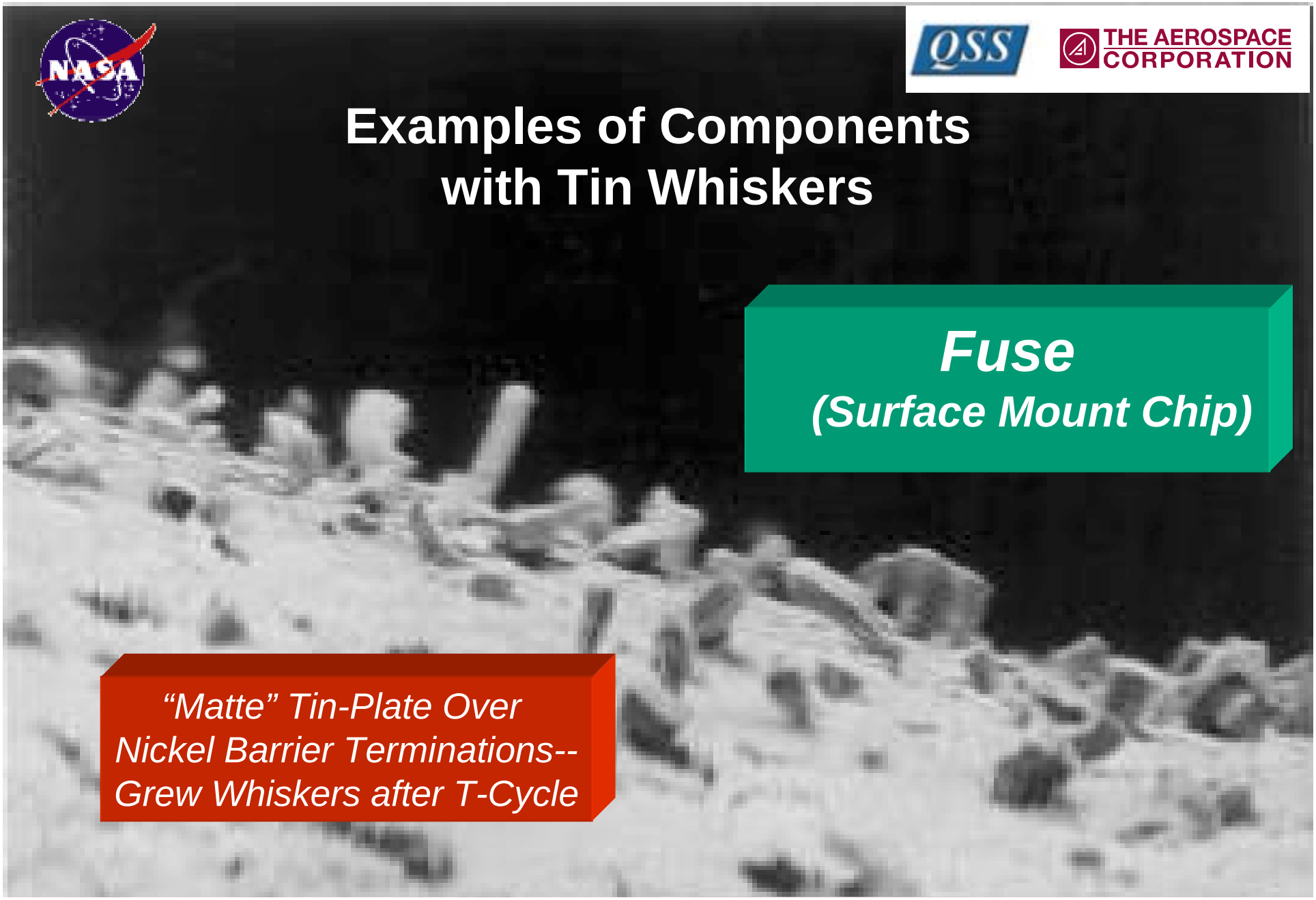


Test Points

"Bright" Tin-Plated Phosphor-Bronze

(Ambient Storage)

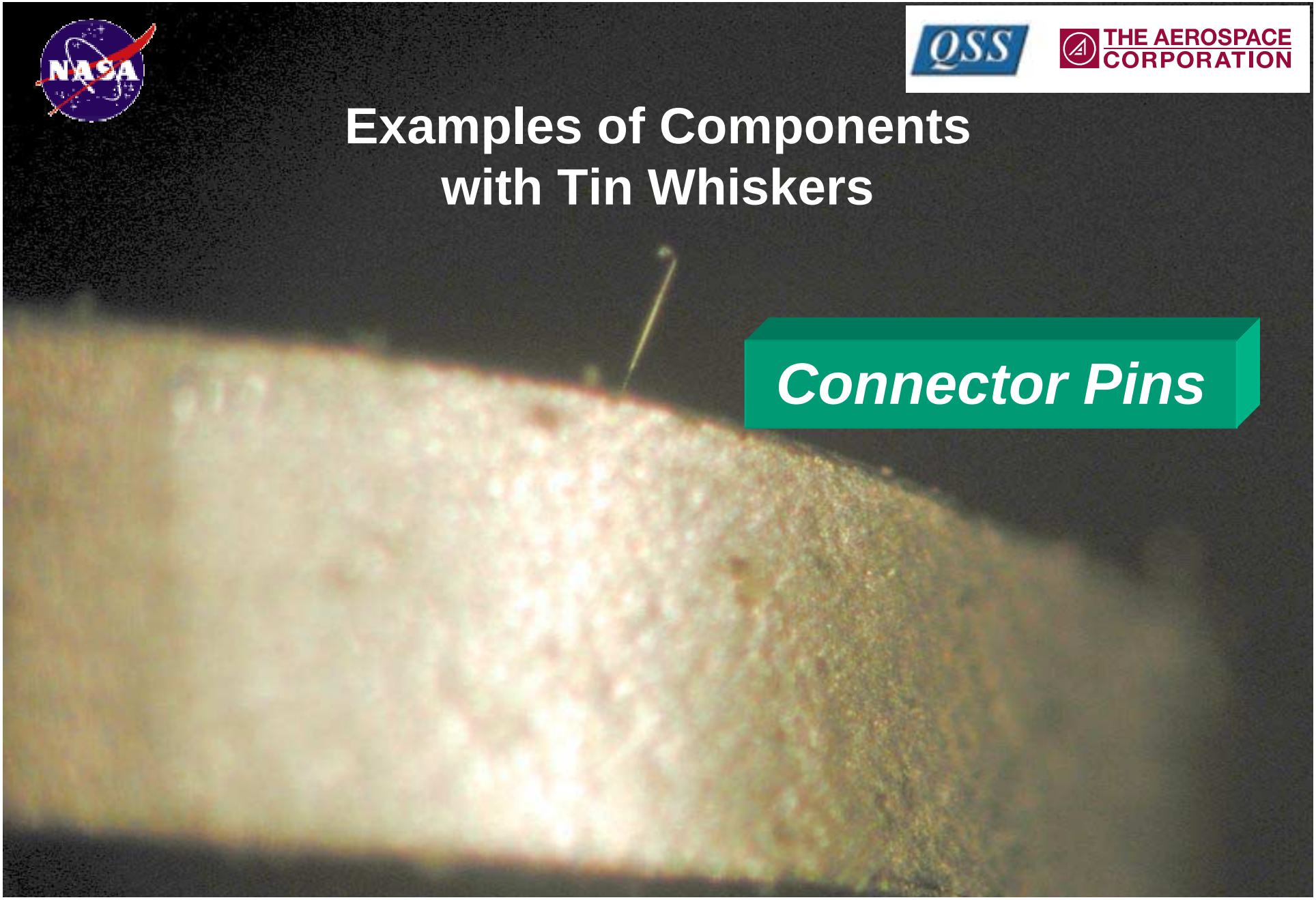
Examples of Components with Tin Whiskers



Fuse
(Surface Mount Chip)

"Matte" Tin-Plate Over Nickel Barrier Terminations-- Grew Whiskers after T-Cycle

Examples of Components with Tin Whiskers



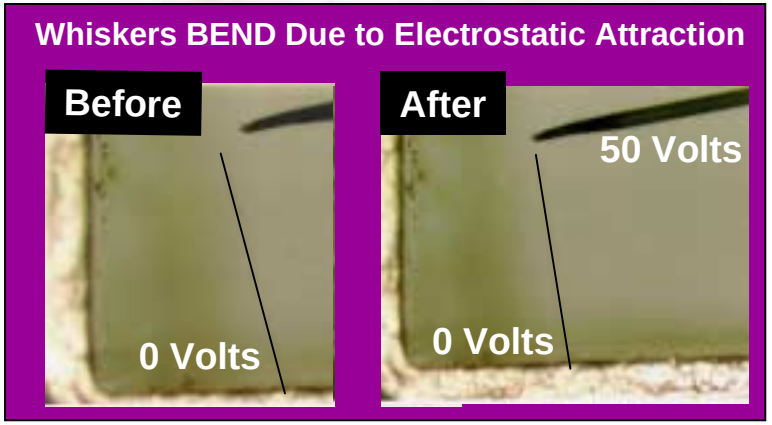
Tin Whisker Failure Modes

Electrical Short Circuits

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

Debris/Contamination

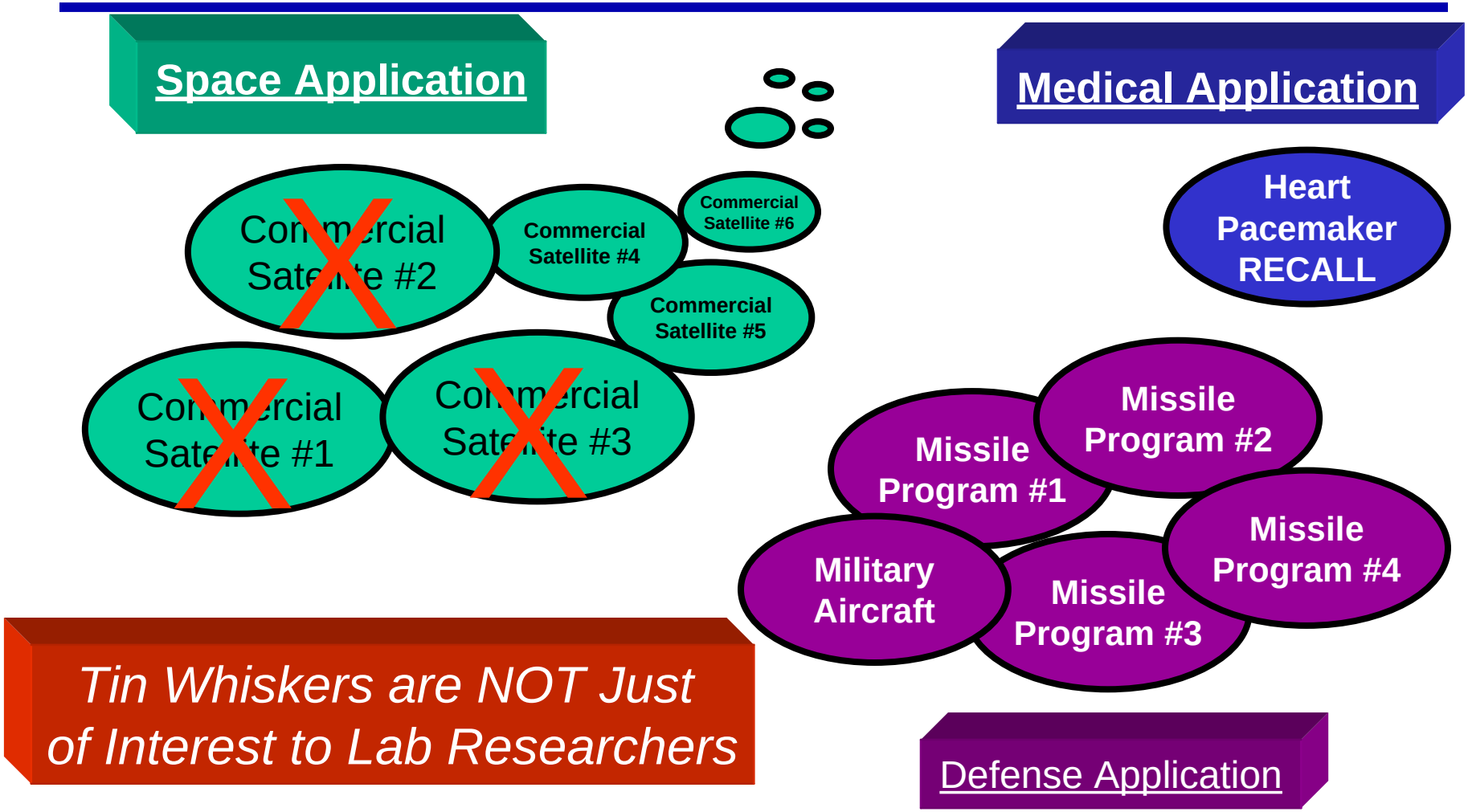
- **Interfere with Sensitive Optics or MEMS**
- **Shorts in Areas Remote From Whisker Origins**



METAL VAPOR ARC in VACUUM

- **Atmospheric Pressure < ~150 torr, Whisker Short can Vaporize into Highly Conductive PLASMA of Tin Ions if V > ~18 V and I > 10's of Amps**
- **Plasma can Form Arc Capable of Carrying *HUNDREDS OF AMPERES***
- **Arc Can Be Sustained by Tin Evaporated from Surrounding Areas**

"Reported"
Tin Whisker-Induced Field Problems

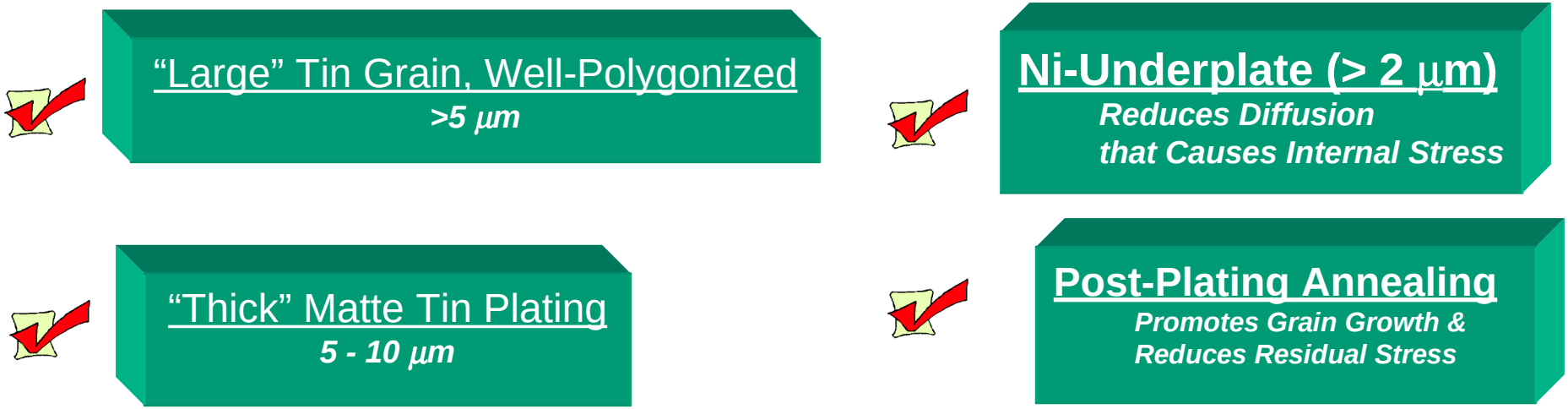


Tin Whiskers are NOT Just of Interest to Lab Researchers

Tin Whiskers and Multilayer Ceramic Capacitors (MLCCs)

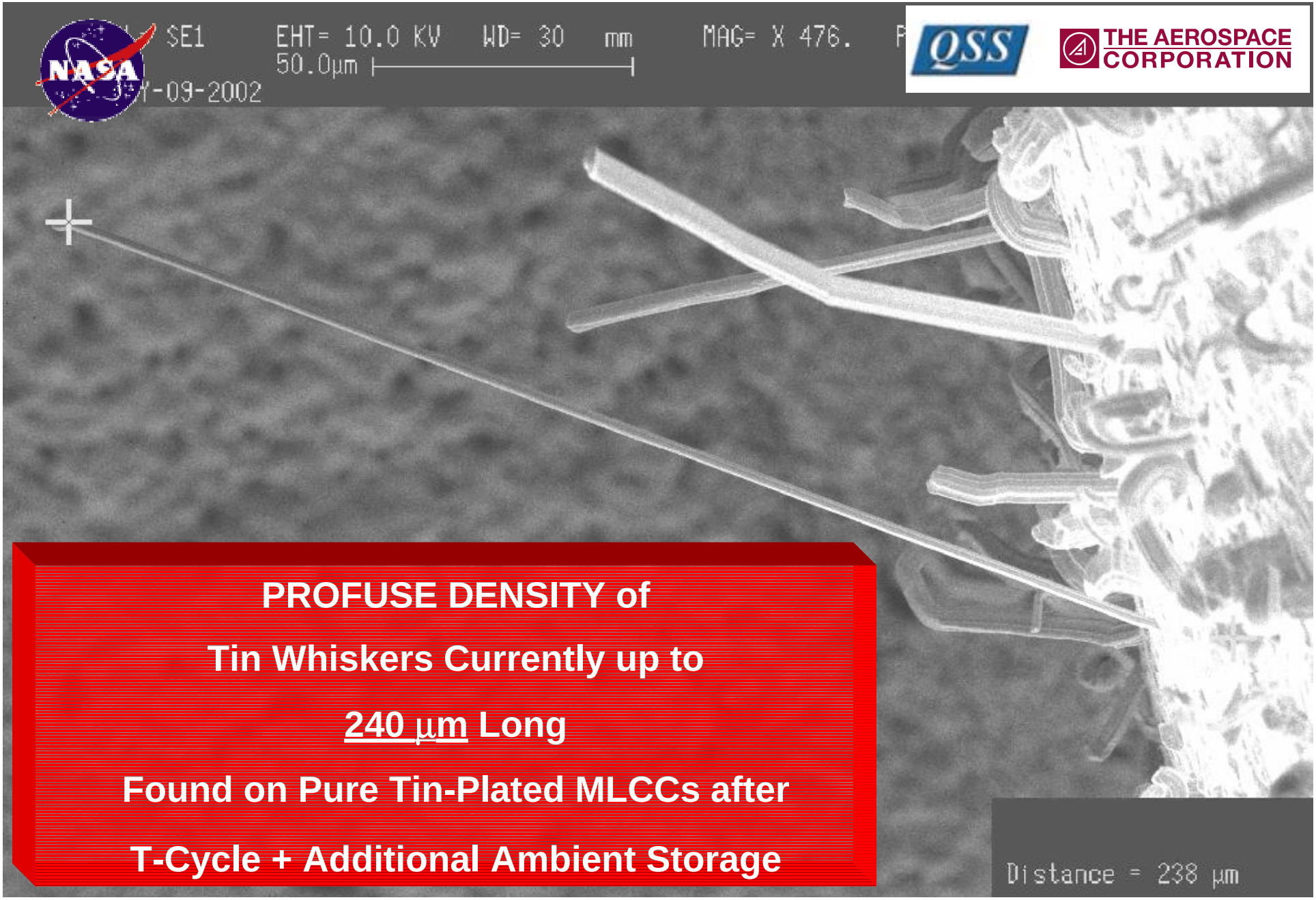
Past Research

- Two Previous Papers by MLCC Manufacturers (1990 & 1997) Assert *MLCCs Have Following Attributes that make them Highly Resistant to Whisker*



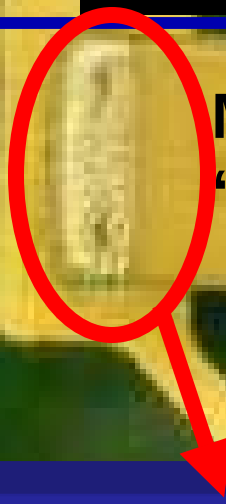
- ONE MLCC Mfr Experiment showed ***18 Years WHISKER-FREE*** Observations for MLCCs Stored Continuously at 50°C

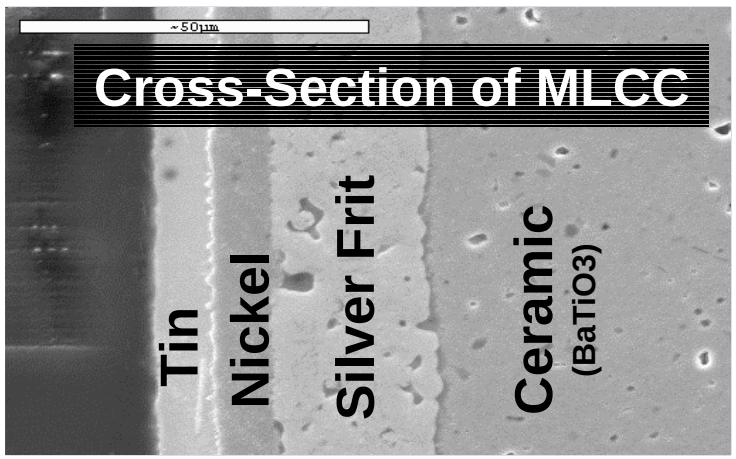
HOWEVER ...


SE1
EHT= 10.0 KV
WD= 30 mm
MAG= X 476.
50.0µm
-09-2002
QSS
THE AEROSPACE CORPORATION
PROFUSE DENSITY of
Tin Whiskers Currently up to
240 µm Long
Found on Pure Tin-Plated MLCCs after
T-Cycle + Additional Ambient Storage
Distance = 238 µm

Example #1: Tin Whiskers and MLCCs

MLCCs Inside Hybrid Microcircuit After T-Cycle





User Application:

- Hybrid Microcircuit (Herm-Sealed)
  - Gold Plated Substrate Pads
  - Substrate Line Spacing 125 µm (min.)
- **ORDERED** Pd-Ag Terminated MLCC, but Supplier Shipped ***PURE TIN***
- Silver Epoxy Mounting Method

MLCC Construction (0805 size):

•	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**

Example #1: Tin Whiskers and MLCCs

USER TEST ENVIRONMENT

Test Condition:

Temp Cycle: -40°C / +90°C (> 200 Cycles)

Followed by "Ambient" Storage for 1 Year

T-Cycle Alone Produced

Whiskers ~ 100 μm

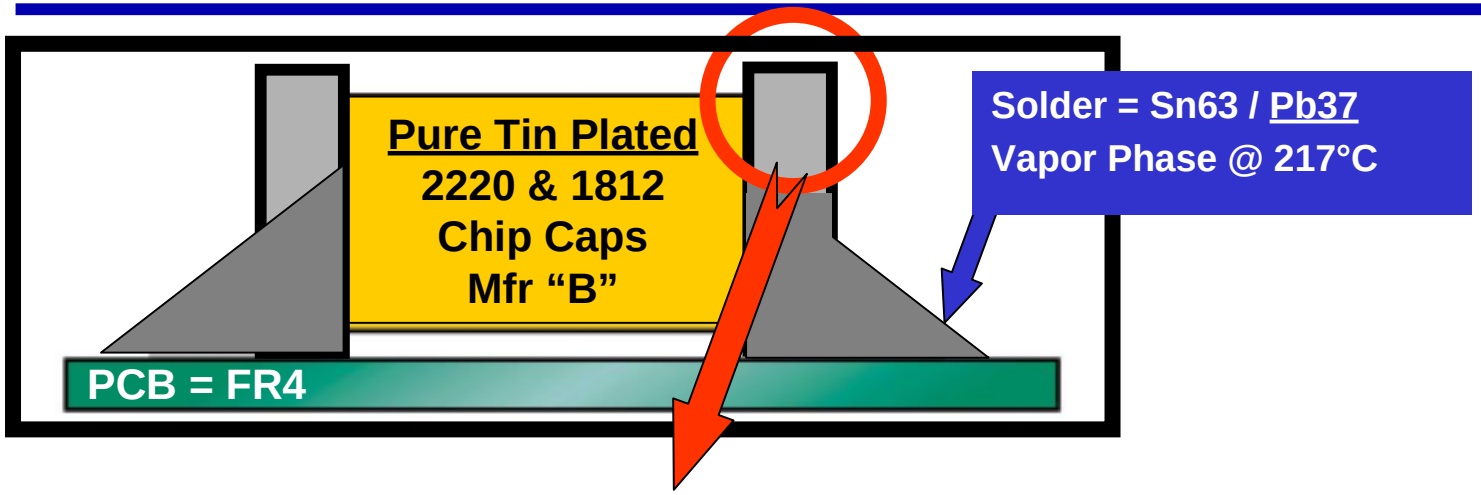
Density > 800/mm²

Additional 1 Year Ambient Storage
GROWTH Continues

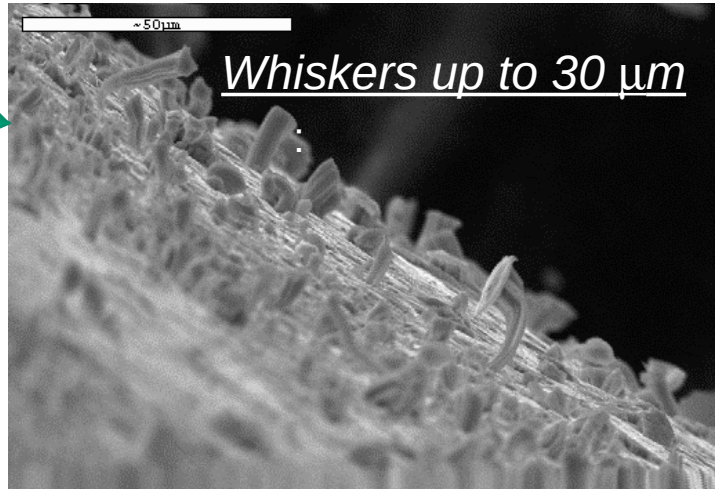
Currently 240 μm max

Example #2: Tin Whiskers and MLCCs

Whiskers AFTER Vapor Phase Installation and T-Cycle



Test Condition: Temp Cycle/Shock
-55°C / +100°C (50 - 400 Cycles)



Soldering Operations DO NOT Always Reflow ALL Tin Surfaces Nor Mix them with the Mounting Solder

User Whisker Mitigation

Research on User-Mitigation Strategies is Limited

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

Strategies to Consider (Complete Immunity NOT Guaranteed)

- *REDUCE STRESS* in the Tin Plating
  - **Hot Oil Reflow / Hot Solder Dip (Preferably with Sn/Pb Solder)**
  - **High Temp Anneal Substrate and Tin 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

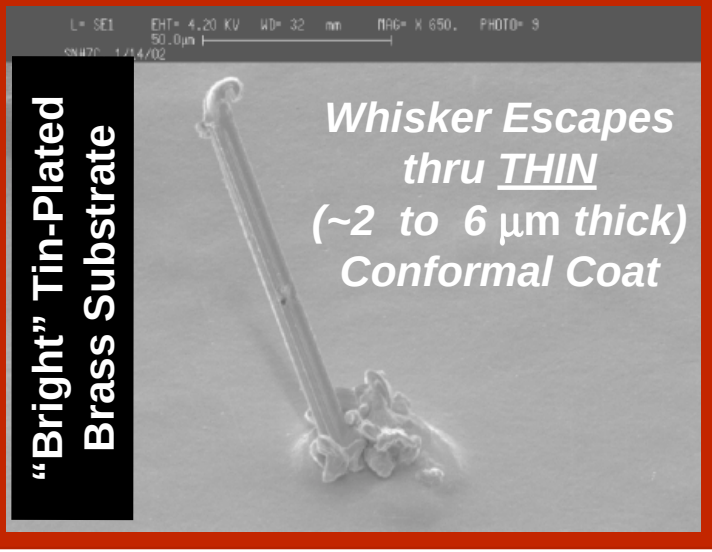
Combine MULTIPLE Mitigation Strategies to Increase Effectiveness

AVOID PURE TIN, if Possible

Whisker Mitigation
Conformal Coat (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**



Conclusions

Failures Due to Tin Whiskers are STILL a Significant Problem

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

Factors Affecting Tin Whisker Formation are NOT Completely Understood

- Risk Assessment Based on ***SUBSET*** of Published Literature Can Be ***DANGEROUS***

Tin-Plated Ceramic Chip Capacitors ARE Susceptible to Whisker Formation

- ***CONTRARY*** to Previously Published Claims

Even when PROHIBITED by Design and Procurement Practices, Pure Tin Finishes Continue to Appear in Electronic Equipment

Recommendations

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

- *MORE than One Mechanism is Likely*
- *Model Needed to have Confidence in Any Proposed Accelerated Test*

Develop PROVEN "Whisker Propensity" Test(s)

- *Environmental Testing vs. Finish Characterization??*
- *Acceleration Factors MUST be Determined*
- *Tailorable to Assess Varied Constructions, Materials AND Applications*

Share Whisker Experiences and Knowledge More OPENLY

- *Education vs. MIS-Information*
- *Collaboration*

Develop Whisker Risk Assessment & Mitigation Strategies

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

Contact Information

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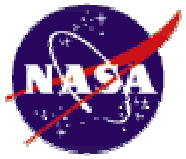
NASA Goddard Tin (and Other Metal) Whisker WWW Site

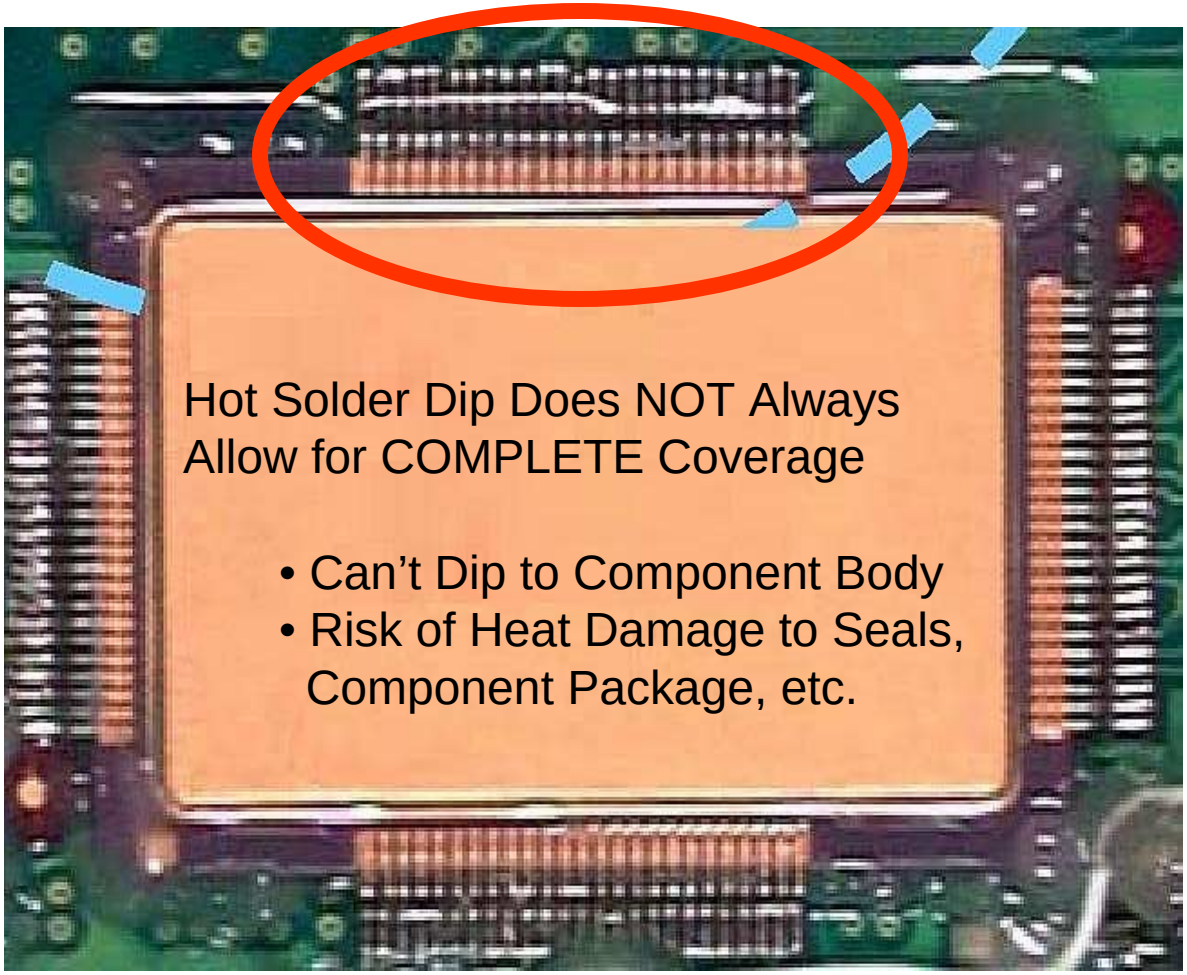
http://nepp.nasa.gov/whisker


SE1
EHT= 10.0 KV
WD= 43 mm
MAG= X 6.01 K P
5.00µm
-09-2002
QSS
THE AEROSPACE CORPORATION
GROWTH RINGS
Tin Whiskers Grown on Ceramic Chip Capacitor Via Temp Cycling (-40°C to +90°C)
During a reliability study at NASA's Jet Propulsion Laboratory,uniform whisker growth steps were observed and correlated with thermal cycles. This work is on-going and results will be published in the near future. The investigation was performed by Wayne Bosze and Saverio D'Agostino of the Electronic Parts Engineering Section.
Photo Courtesy of NASA Goddard Space Flight Center

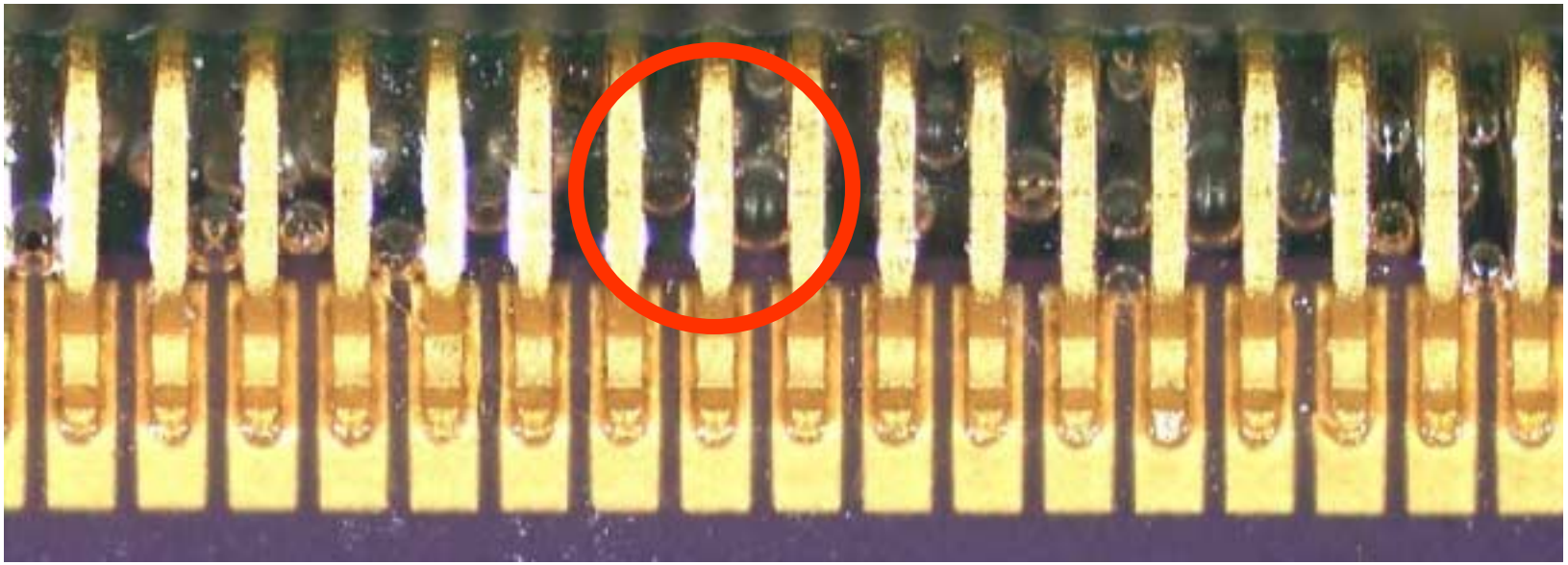


BACKUP MATERIAL

Some LIMITATIONS of Mitigation Strategies--Hot Solder Dip



Some LIMITATIONS of Mitigation Strategies--Conformal Coat

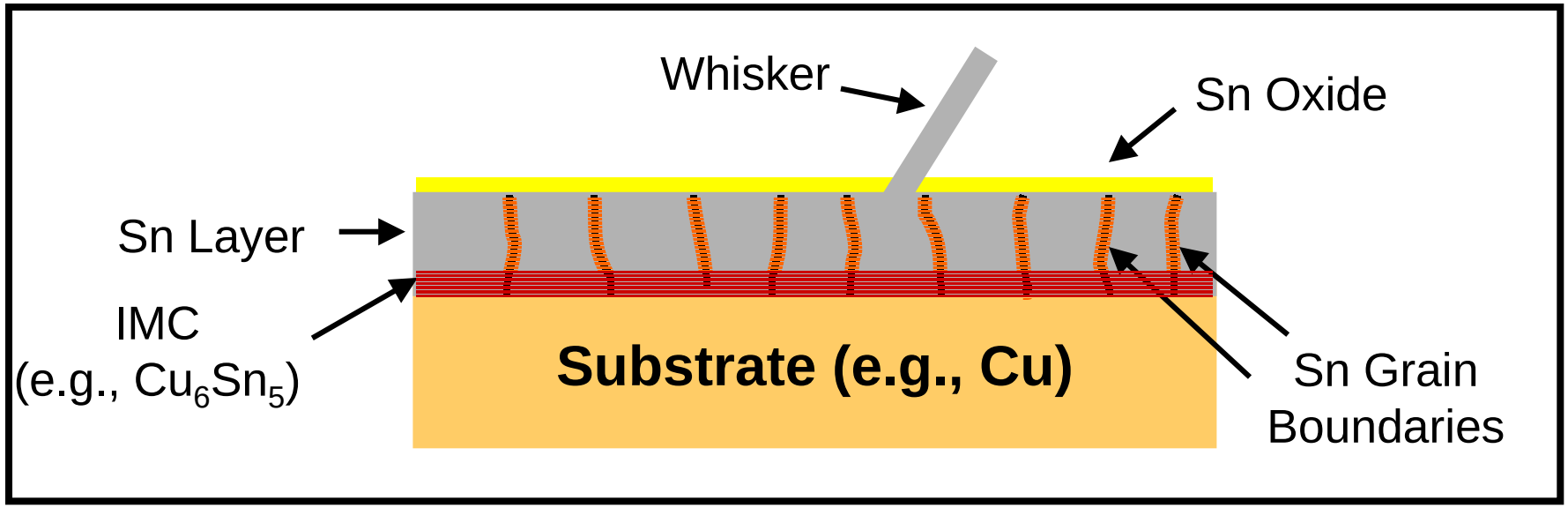


Conformal Coat

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

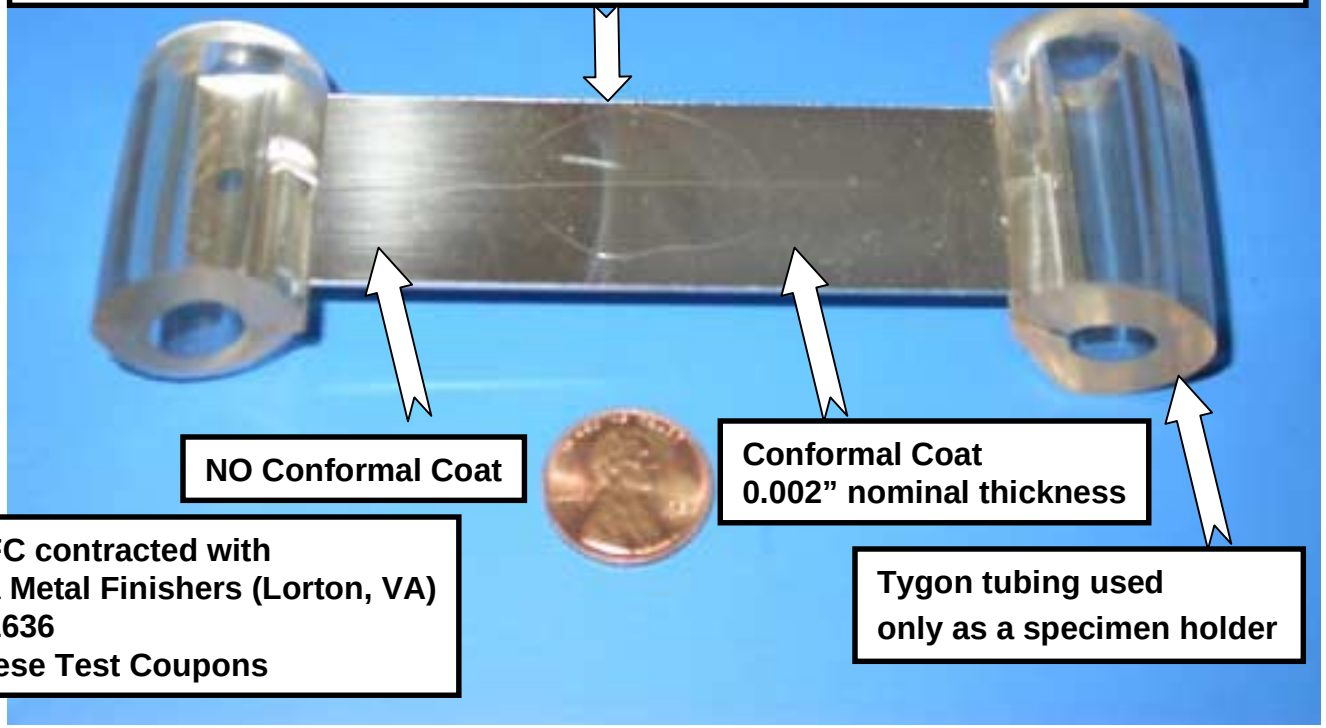
One Model for Whisker Growth Mechanism

1. Substrate Elements (Cu, Zn, etc.) Diffuse into Sn Along Grain Boundaries.
2. Intermetallic Compound (IMC) may form preferentially in Grain Boundaries
3. As a Result, Stress Builds in Sn Layer
4. To Relieve Stress, Whiskers EXTRUDE thru Ruptures in Sn Oxide



NASA Goddard Space Flight Center
Tin Whisker Test Coupon
December 1998

Substrate: Brass Type 260 (1” x 4” x 0.032”)
Underplate: some specimens with copper strike and copper plate to 0.0001" min
some specimens with NO copper underplate (i.e., tin direct on brass)
Finish: “Bright” Pure Tin Electroplate (200 ± 50 microinches)
Post-Plating Handling: “Intentional” Scratches (circle and perpendicular lines)



NO Conformal Coat

Conformal Coat
0.002” nominal thickness

Tygon tubing used
only as a specimen holder

NASA GSFC contracted with
Alexandria Metal Finishers (Lorton, VA)
(703) 643-1636
to build these Test Coupons