





- What are Metal Whiskers (Tin and Zinc)?
- Why are Whiskers a Concern?
- Some Whisker Mitigation Strategies
- Closing Comments

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

OSS Group, Inc.

2

<u>الا</u>

3

1AG= X 230.



But FIRST... A Public Service Announcement



<u>BEWARE! ZINC Whiskers May Be</u> Growing on Your Raised Floor Structures



http://nepp.nasa.gov/whisker/other_whisker

Metal Whisker Discussion





What are Tin (and Zinc) Whiskers?



 "Hair-Like" Crystal Structures that May Grow from Mostly Pure Tin (or Zinc) Finished Surfaces

GROWTH: PROCESS Incubation Period (Days – Yrs)+ Growth Period (Mos – Yrs) + Growth Cessation (???)

Grow from Base Not the Tip

LENGTH:

DIAMETER:

Typically < 1mm (Up to 10 mm)

Few Microns (mm)

Growth Mechanism(s) <u>UNKNOWN !!!</u>

Fundamental Research is INCOMPLETE

DENDRITES are <u>NOT</u> Whiskers



April 27, 2004





Metal Whisker Failure Modes

Electrical Short Circuits

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

Debris/Contamination

- Shorts in Areas REMOTE From Whisker Origins (e.g., Zinc Whiskers on Raised Flooring)
- Interfere with Sensitive Optics or MEMS

METAL VAPOR ARC

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







Converging Issues Fuel Hi-Rel User Concerns

• The PAST:

- Metal Whiskers (Sn, Zn, Cd, other) Known SINCE 1940s!!!
- HUNDREDS of Independent Studies of TIN Whiskers Alone
- Numerous "Disparities" Exist in Published Literature
- The PRESENT: Combination of CONCERNING Factors







Where Have Tin Whiskers Been Observed In Electronic Assemblies?

A Few Examples...



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

April 27, 2004

Metal Whisker Discussion

9





Pin #7

Microcircuit Leads ("Matte" Tin-Plated) Observed in 2002

Pin #6

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





<u>Exterior</u> 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!!!





<u>INTERIOR</u> Surfaces of <u>Electromagnetic Relays</u> (*Tin-Plated Steel Armature*) ~14 Years Old Observed in 2002



Beware What May be <u>INSIDE</u> your Devices (Up to 3 mm Long Found in This Part)



200 microns

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

> <u>Conductive Epoxy Mounted</u> Inside Hermetically Sealed Hybrid

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







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



2 mm Long Whiskers Found Growing Toward INSIDE of Package

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



April 27, 2004

40.0×

 $1 \, \text{mm}$

INSIDE



HaG= > 240. PHOTO- 2

Terminal Lugs

("AS-RECEIVED"/ Observed in 2001)

Pure Tin-Plated

FHT- 5.00 KV

100 pm H 100

3Г1

TRATE AL

dii= 21

3/13700

Whiskers up to 0.25 mm Long Inside Crimp Barrel And in the Exterior Seam





Results

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 **SEM/EDS** Analysis Benign
- Why might Pb "Inhibit" Whisk
 - 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 Bonafide <u>Sn-Pb</u> Whisker Induced Short



10 microns

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

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

Heat Sink

Sn/Pb Solder Die Attach

Insulator

"Splatter" Remants from a Melted Sn-Pb Whisker?

Semiconductor





Some Whisker Mitigation Strategies

<u>Long-Term Effectiveness</u> of these Practices Has NOT Been Quantified MORE Research is NEEDED to Identify Strengths and Weaknesses

- **AVOIDANCE:** Do NOT Use Pure Tin Coated Components
 - Stick with Tin-Lead (Sn/Pb) or Other Finishes When Available
 - Often Requires Requires Rigorous Procurement Controls and "Incoming Inspection" to VERIFY Materials Meet "Spec"
- MODIFY Sn FINISH: "Post-Procurement" Processing
 - Hot Solder (Sn/Pb) Dip Sn Surfaces
 - Strip and Re-Plate with Sn/Pb or Other Finish Prior to Assembly
 - Heat Treat (Anneal) or Reflow to Reduce Intrinsic Stress
- **INSULATE:** Apply Barriers On Top of Exposed Sn Surfaces
 - Conformal Coat
 - Tapes

No One Practice Fits All Applications Combine MULTIPLE Mitigation Strategies to Increase Effectiveness

April 27, 2004





NASA Goddard Whisker Mitigation Study Conformal Coat (Uralane 5750 Polyurethane)

Whisker Farm = "Bright" Tin-Plated Brass Coupon ¹/₂ Without Uralane Coating, ¹/₂ With Uralane Coating



HOWEVER, Whisker Escapes thru <u>THIN</u> (~2 to 6 **m**m thick) Conformal Coat In ~ 1 Year

Extensive Whisker Formation (~2mm) on NON-Coated Side

2 mils of Uralane Keeping Whiskers Beneath Coating For 4+ Years (Ongoing)





Hot Solder Dip – Limitations?

Bright Tin-Plated Kovar Leads (WITH Nickel Underplate)

ONE Year After Assembly

Leads were <u>Hot Solder Dipped</u> (Sn63Pb37) <u>within 50 mils</u> of Glass Seal BEFORE Mounting





<u>NO Whiskers</u> on Hot Solder Dip Region

Metal Whisker Discussion





Conclusions

Failures Due to Metal Whiskers Are <u>STILL</u> a Significant Concern

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 <u>SUBSET</u> of Published Literature Can Be <u>DANGEROUS</u>





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

- Comprehensive Model(s) for Tin, Zinc <u>AND</u> 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! -- <u>This is COUNTER to Pb-Free NOW Movement!</u>
- 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





Develop Whisker Risk Assessment & Mitigation Strategies

- **RESEARCH & EXPERIMENTATION**
 - Study EFFECTIVENESS of Mitigation Strategies
- EDUCATION
 - Learn the STRENGTHS & WEAKNESSES
 - Detail the LIMITATIONS & APPLICABILITY
- DOCUMENT
 - Develop Mitigation Strategy Guidelines





Contact Information



Acknowledgments: NASA Goddard Metal Whisker Investigation Team

Mike Sampson Dr. Henning Leidecker Jong Kadesch

NASA Goddard NASA Goddard Orbital Sciences Corporation

NASA Goddard Tin (and Other Metal) Whisker WWW Site

http://nepp.nasa.gov/whisker





Backup Material



Factors that "May" Influence Metal Whisker Growth



	Plating Chemistry Pure Sn Most Prone Some Alloys (Sn-Cu, Sn-Bi, rarely Sn-Pb) Use of "Brighteners" Incorporated Hydrogen Codeposited Carbon pH		Substrate Material (Brass, Cu, Alloy 42, Steel, etc.) Substrate Stress (Stamped, Etched, Annealed) Intermetallic Compound Formation Substrate Element Diffusivity into Sn	
	Plating Process Current Density	Increase STRES	SS or ISION	Environment
	Bath Temperature Bath Agitation	Within the De	posit	Temperature Temperature Cycling (CTE Mismatch) Humidity (Oxidation, Corrosion)
C	Deposit Characteristics Grain Size/Shape Crystal Orientation	GREATER WHISKER		Applied External Stress (Fasteners, bending, scratches) Current Flow or Electric Potential???
	Deposit Thickness Sn Oxide Formation	PROPENSI	ТҮ	
		HOWEVI	ER	

Many Experiments Show Contradictory Results For These Factors





What Kinds of Electronic Systems Have Been Impacted in the Field?

A Few Examples...





A "Few" Reported Whisker Problems (Only the Last 15-20 Years Considered)



	Year	Application	Industry	Failure Cause	Whiskers on?
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	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	MIL/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

April 27, 2004

Metal Whisker Discussion



A "Few" MORE Whisker Issues (Only the Last 15-20 Years Considered)



	Year	Application	Industry	, Failure Cause	Whiskers on?
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

NOT Just a Problem of "The Past"