National Aeronautics and Space Administration

Lead-free Electronics

Impact for Space Electronics

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Overview

- Background
- Technical Implications
- Challenges
- Whiskers
- Tin Pest
- NASA Pb-free Policy
- Issues Encountered
- Mitigation Strategies Conclusions

Background

- The European Regulations known as RoHS, the Restrictions on the use of Hazardous Substances, were adopted in February of 2003 and took effect on July 1, 2006
- Amongst other materials , RoHS severely restricted the use of lead (Pb) in electronics in items sold within the European Union
- Although RoHS is European, it has affected the world market, most commercial electronic items are now advertised as Pb-free
- The US is not directly covered by RoHS and neither are space applications, even in Europe

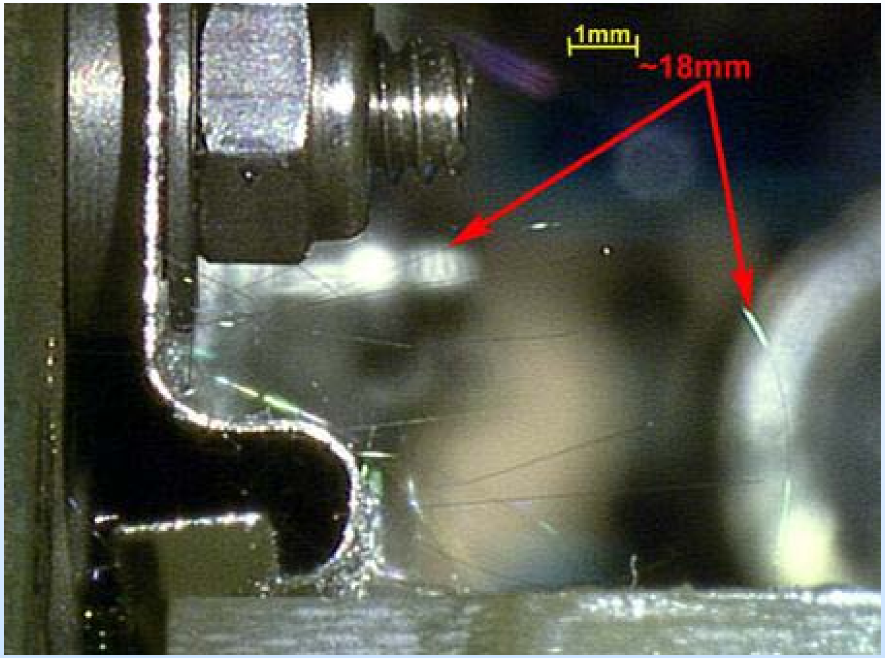
The Technical Implications

- Pb is used as a constituent in solder alloys used to connect and attach electronic parts to printed wiring boards (PWBs)
- Similar Pb bearing alloys are electroplated or hot dipped onto the terminations of electronic parts to protect the terminations and make them solderable
- Changing to Pb-free solders and termination finishes has introduced significant technical challenges into the supply chain
- Tin/lead (Sn/Pb) alloys have been the solders of choice for electronics for more than 50 years
- Pb-free solder alloys are available but there is not a plug-in replacement for 60/40 or 63/37 (Sn/Pb) alloys, which have been the industry workhorses

The Challenges

- **Pb-free solder alloys:**
  - Most are multi-element, 3 or more metals
  - The most popular alloys are based on Tin (Sn) Silver (Ag) and Copper (Cu) and are known as SAC
  - Many SAC based alloys are available with subtle differences in composition, intended to produce properties similar to or better than Sn/Pb
  - Physical properties of most SAC alloys are cause for concern
- **Pb-free termination finishes:**
  - Again there is no one replacement for Sn/Pb
  - Tin is the preferred choice for high volume commercial but tin is prone to "whiskering"
    - Tin Pest formation can be a problem below 13°C
  - Gold can be a good if expensive choice for space applications, when available, and if properly handled to avoid embrittlement form Sn/Au intermetallic formation

Tin Whiskers Are Real



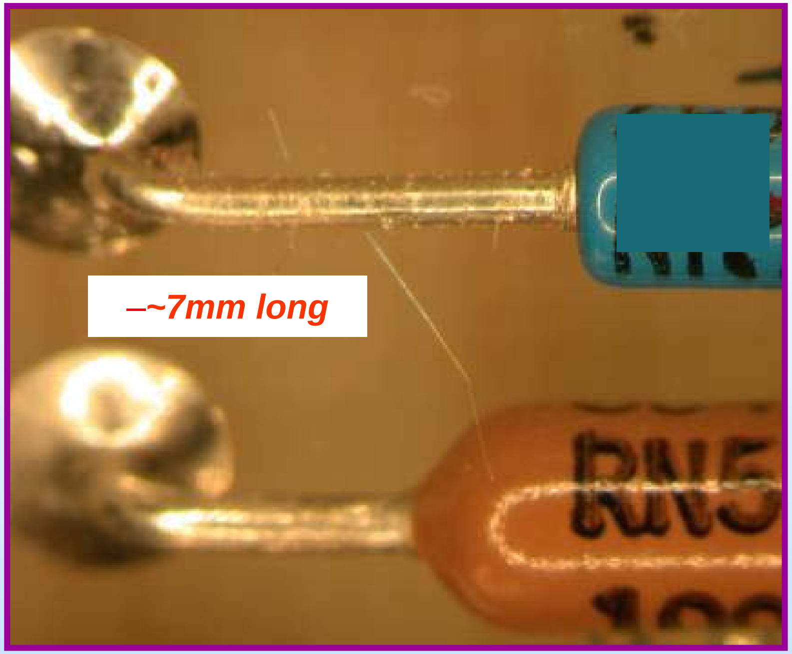


Photo Credit: James D. Stewart,
M&P Failure Analysis Laboratory
The Boeing Company Logistics Depot

Space Shuttle OV105 Card Guide

– *Image Courtesy of: T. Riccio (STPNOC)*

– *Nuclear Power Plant Electronics, Diode Leads*

– ***Trend Observed – The Older the Hardware, the Longer the Whiskers. In Both Cases, the Hardware is ~20 years old***

To be presented at the 1st NASA Electronic Parts and Packaging (NEPP) Program Electronic Technology Workshop June 22-24, 2010, NASA GSFC, Greenbelt, MD.

All These Sn-X Alloy Systems Have at Least One Documented Case of Whisker Growth

	Alloy System	Empirical Evidence for Whisker Tendencies
1.	Sn	Lots of Data – Significant Whisker Tendencies
2.	Sn-Pb	Lots of Data – Greatly Reduced Whisker Tendencies
3.	Sn-Ag	Minimal data – “Maybe” High Temp Application Makes Worse
4.	Sn-Au	Few Experiences Citing Whiskers
5.	Sn-Al	1 Study – Lots of whiskers
6.	Sn-Bi	Minimal data
7.	Sn-Cu	Some data – suggests increased whisker tendency
8.	Sn-Lu	Only 1 Study – Significant Whisker Tendency
9.	Sn-Mn	Only 1 Study – Significant Whisker Tendency
10.	Sn-Sb-X	Few Observations –Film Caps & High Temp Solder Applications
11.	Sn-Ag-Cu	Minimal Data – 1 Field Concern Not in Public Domain
12.	Sn-Ag-Cu-Ce	Only 2 Studies – Significant Whisker Tendency

Key:
Ag = Silver *Al = Aluminum* *Au = Gold* *Bi = Bismuth*
Ce = Cerium *Cu = Copper* *Lu = Lutetium* *Mn = Manganese*
Sb= Antimony *Sn = Tin* *X = any element*

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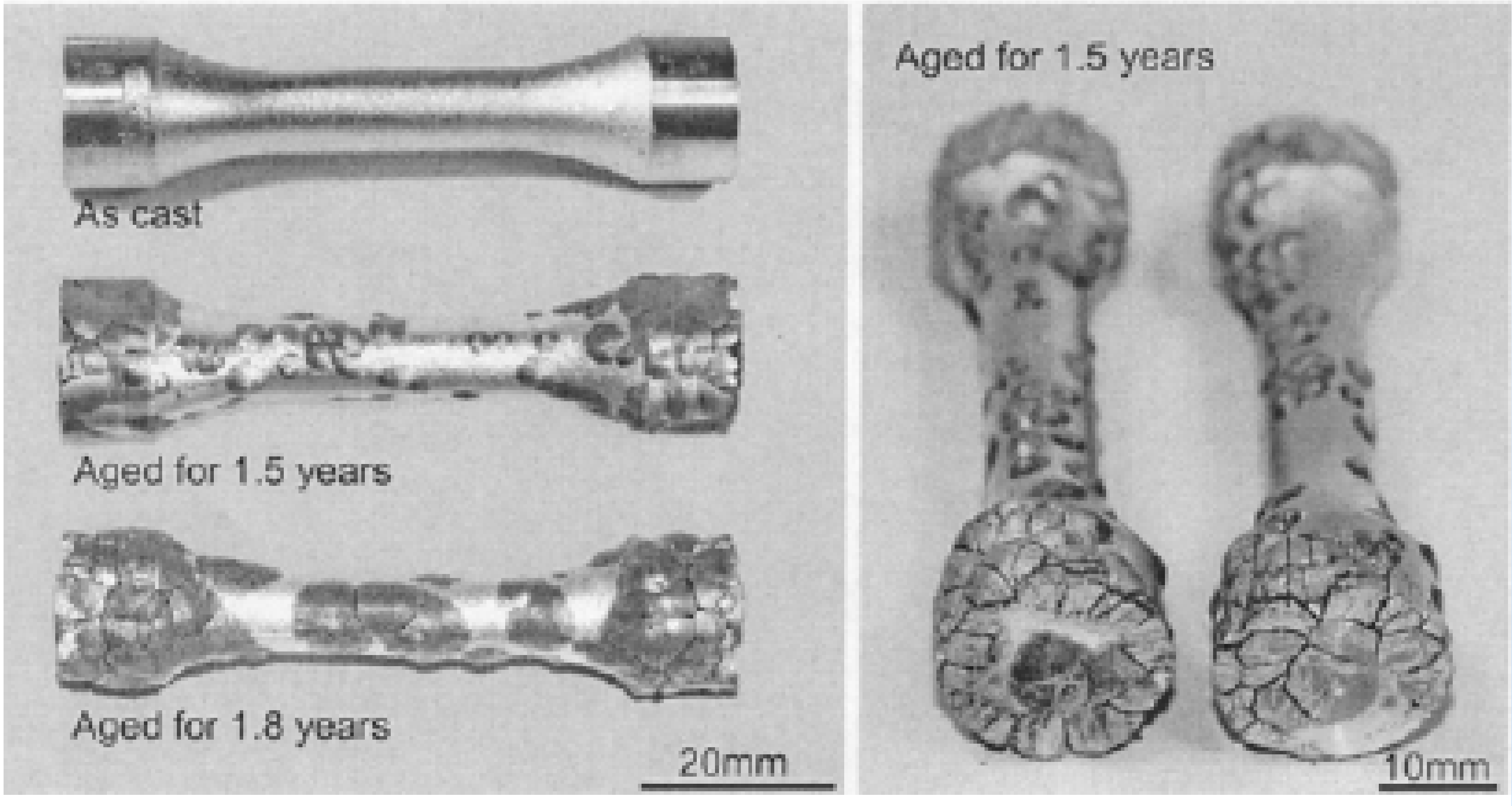
Tin Pest



As cast
Aged for 1.5 years
Aged for 1.8 years
20mm
Aged for 1.5 years
10mm

The NASA Pb-free Policy

- Policy is contained in NPD 8730.2, NASA Parts Policy, 11/3/08
- Requires traditional tin-lead solders except when justified by technical need (eg. high melt point)
  - Approved GEIA-STD-0005-1 plan to define rules and controls
  - SAC and other “new” alloys require exceptional rationale
- Require all tin-based platings and protective finishes to have ≥ 3% Pb content (No pure tin) unless :
  - A persuasive rationale is provided
  - Tin whisker (and tin pest when applicable) mitigation strategy is supported by data and approved by NASA
  - GEIA-STD-0005-2, “Control Level 2C” = tin ID’d by part number, maybe Level 2B (ID by part type) for higher risk apps.

BUT implementation will not be that simple

So What is Pure Tin?

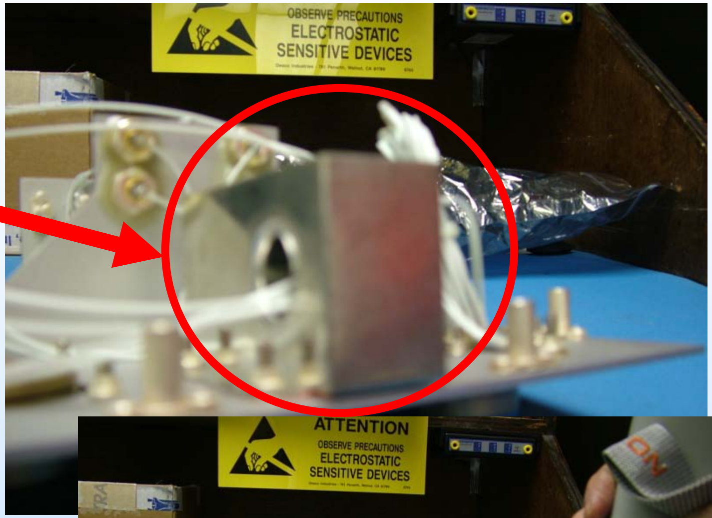
- Some Specifications and Standards Say <97% Tin
  - NASA wants the other 3% minimum to always be Pb
- Measurement methods are not "pin-point" accurate
  - Only chemical methods give 1 decimal place %
  - XRF studies show significant equipment variation
- Granular structure of tin-lead can lead to large variations in apparent composition when illuminated with a small spot size (EDS)
  - Checking multiple sights and averaging can overcome this but might then fail to detect genuine tin rich areas
- Calibration standards are needed
- JEDEC JC13.1 has developed a standard Pb measurement test method JESD213 for XRF
- A similar test method is needed for EDS but numerous technical and practical issues to be overcome

Issues Encountered

- **Parts built with tin-based Pb-free solders for years**
  - Example High Temp Solders (Sn-Ag, Sn-Sb, etc.)
  - Acceptance at part level risks precedence for board level
  - Can require mitigation for external uses BUT internal to a part?
  - We know little about whisker risk from these alloys
  - Tin pest risk is low for most
- **Incoming Surveillance for Prohibited Materials is NOT "Plug and Play"**
  - Standard Reference Materials are Needed
  - Equipment selection is critical (Navy "XRF shootout")
  - XRF can be quick but EDS needed to resolve marginal results
  - EDS is costly and difficult, tends to resolve tin or lead but not both simultaneously
  - Operator Training is ESSENTIAL!!!
  - GIDEP documents B6K-P-07-01 and LL-U-07-024

Analysis Tools are NOT "Plug and Play"

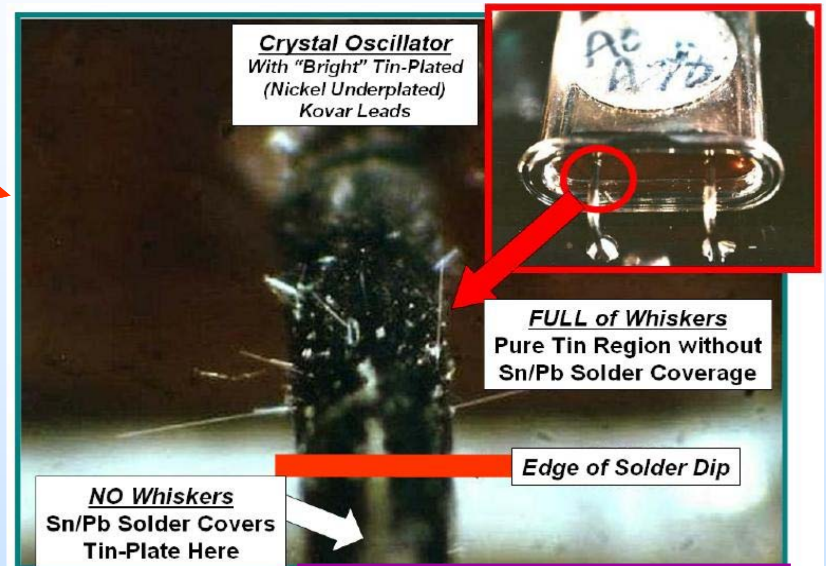
- **Component: Current Sensor**
  - **"Pure Tin" Final Finish**
  - **Nickel Underplate**
  - **Brass Package (Cu-Zn)**
- **Portable XRF Analysis Results**
  - *Sn – 9.05%*
  - **Ni – 23.68%**
  - **Cu – 52.88%**
  - **Zn – 12.20%**
- **XRF penetrated to the base metal**
- **Inadequate Training Resulted in**
  - **Contractor Incorrectly "Accepting" a Pure Tin Plated Component**

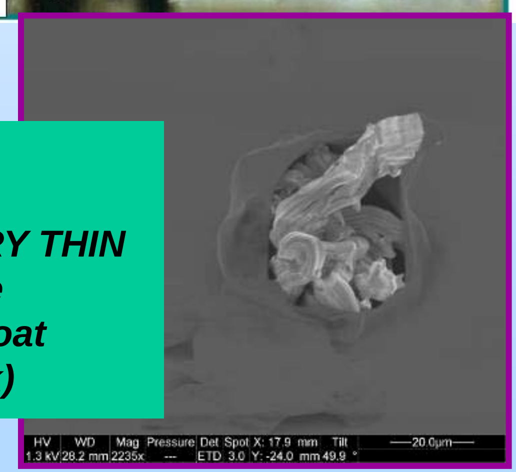


–***Test Standards, Reference Material Standards And Training are NEEDED***

Pure Tin Mitigation Strategies

- GEIA-STD-0005-2, Level 2C requires >1 mitigation strategy for a good reason:
  - Hot Sn/Pb solder dip
  - Nickel underplate
    - Seems to suppress
    - Not always effective
  - Conformal Coat
    - Cannot cover everywhere
    - Don’t want it under some parts
    - Holes and thin spots
  - Annealing
    - May have some benefit if done soon after plating
  - Reflow - ?
  - Dings and scratches can undo annealing and reflow benefits





–Tin Whisker Pushing Out Through VERY THIN Polyurethane Conformal Coat (~2.5µM thick)

Much More Work Needed

Conclusions

- **NASA and other Aerospace enterprises can afford to wait to go Pb-free for solders**
  - **Let high volume commercial business debug the processes and select the solders**
- **More immediate action must be taken to avoid whisker surprises (and pest)**
  - **Any use of commercial parts risks exposure to pure tin termination finishes**
- **A Lead-Free Control Plan is needed even if the intent is to stay with leaded solder**
  - **The supplier documents the controls and mitigations they will use to meet the customer's requirements**
- **All spaceflight entities need a Pb-free policy**

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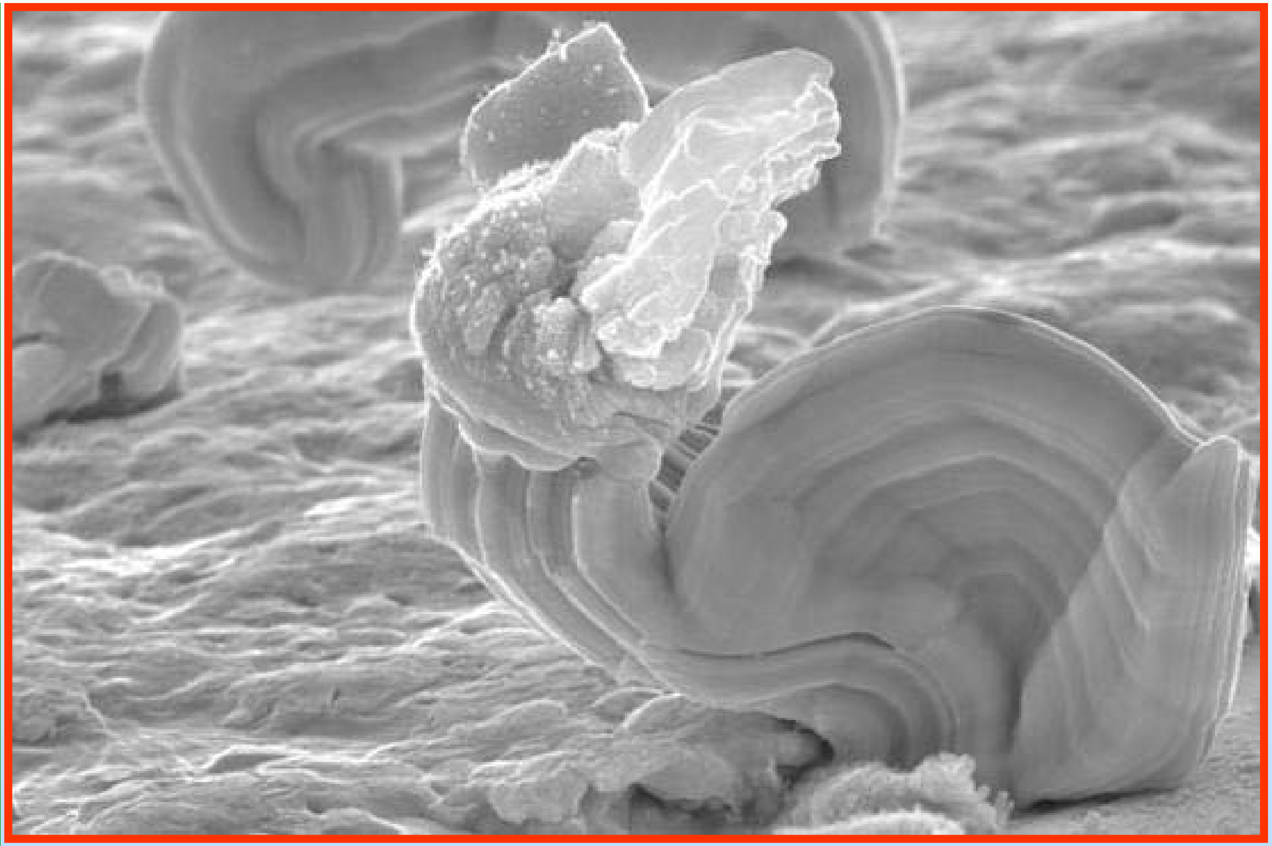
Tin and Other Metal Whiskers Website: http://nepp.nasa.gov/whisker/



Cute Whiskers

"Not So" Cute Whiskers

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