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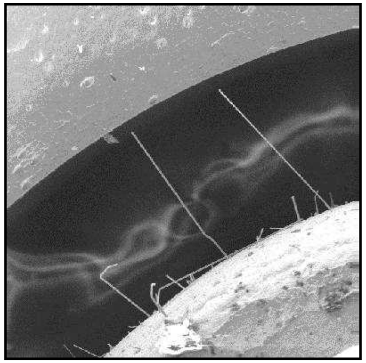
The Sn Whisker Issue in High-Reliability Electronics*

N. Rob Sorensen and **Paul Vianco‡**
Sandia National Laboratories
Albuquerque, NM

‡Contact: ptvianc@sandia.gov
Ph.: 505-844-3429
FAX: 505-844-4816



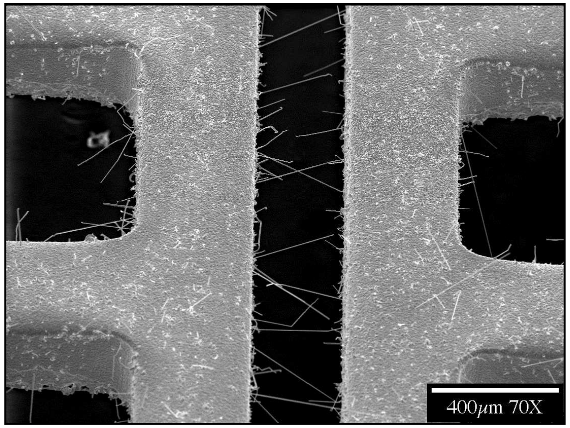
*Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

DoD Fusing Group Briefing October 30, 2007

Sandia National Laboratories

Outline

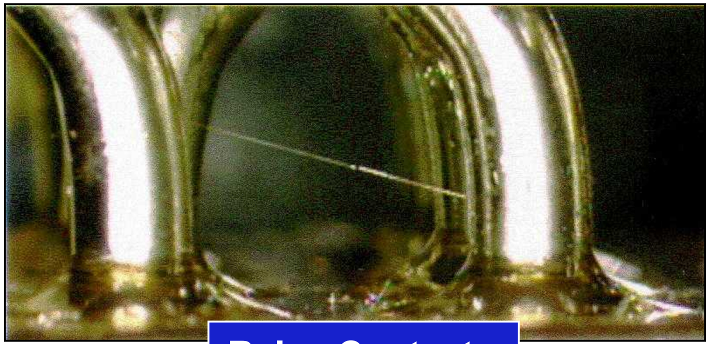
- **Sn whisker phenomenon**
  - History
  - Mechanism details
  - Economic drivers
- **Mitigation strategies**
  - Part tracking
  - List of approaches … examples
  - Economics/warranty concerns
- **Standards and practices**
  - JEDEC standards
  - Company lead (Pb)-free control plans
- **Efforts at Sandia National Laboratories**
  - Component acceptance protocols
  - Materials modeling



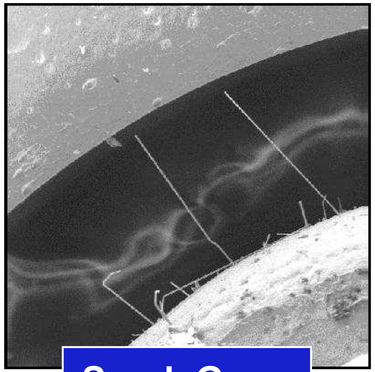
Sn Whisker Phenomenon

Tin whiskers are filaments that grow from the surface of 100% Sn electroplated coatings.

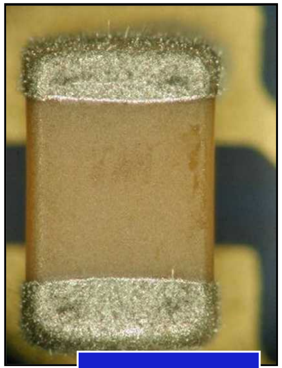
- **A 60 year history**
- ***Documented source of failures***
- **Mechanism details (e.g., the rate kinetics remain largely unsolved)**
- **A stochastic phenomenon**
- **There are now accelerated test protocols to establish a likelihood for whiskers to form, but do not include acceleration factors or rate-determining parameters.**



Relay Contacts



Spark Gaps

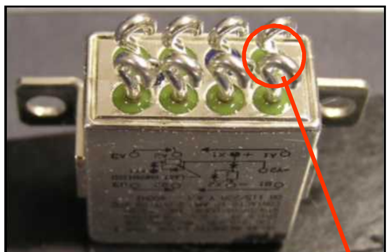


Chip Devices

Sn Whisker Phenomenon

There are two concerns raised by Sn whiskers regarding the long-term reliability of military and space electronics:

1. “Direct” electrical short-circuits

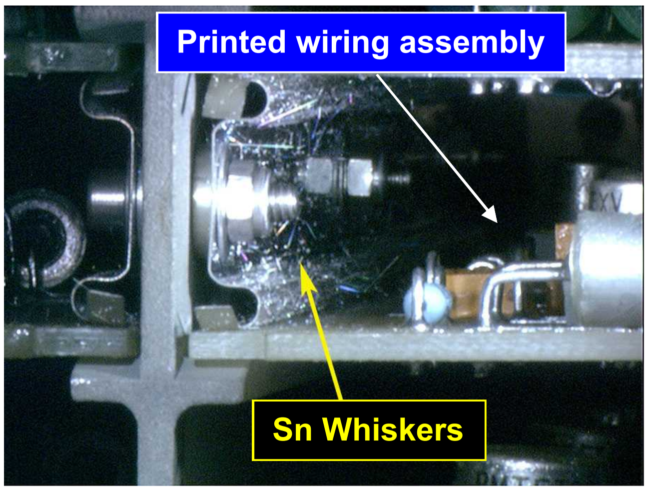


Relay

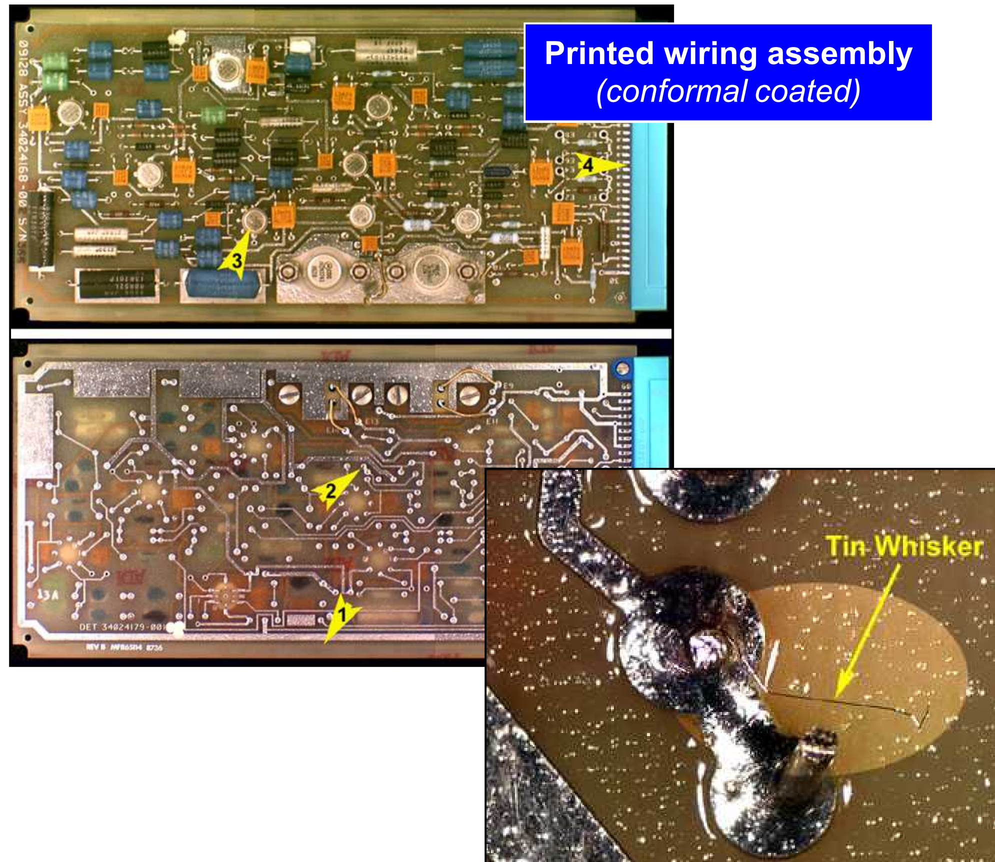
Whisker induced plasma arcing.
Courtesy: Gordon Davy, Northrop Grumman

Sn Whisker Phenomenon

2. “Indirect” short circuits caused by particle contamination



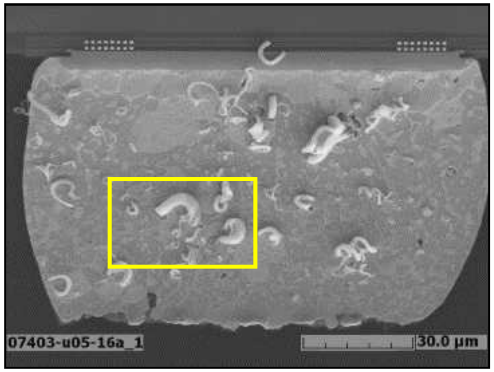
Courtesy: NASA



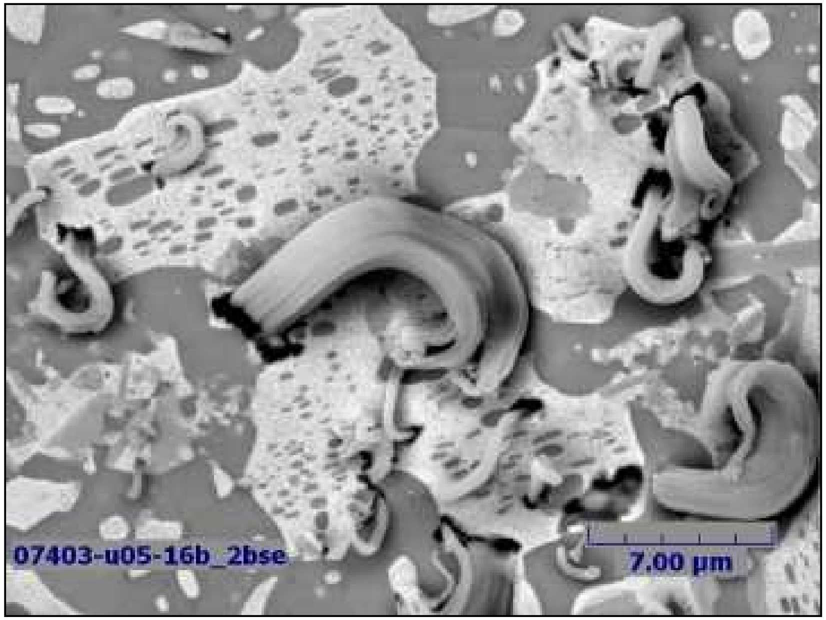
Space shuttle avionics: Sn whisker growth from circuit card guides

Sn Whisker Phenomenon

Whiskers can be formed by a number of metals: Cd, Zn, Pb, and Au to name a few, as well as under a variety of circumstances.



Courtesy: Sandia National Laboratories

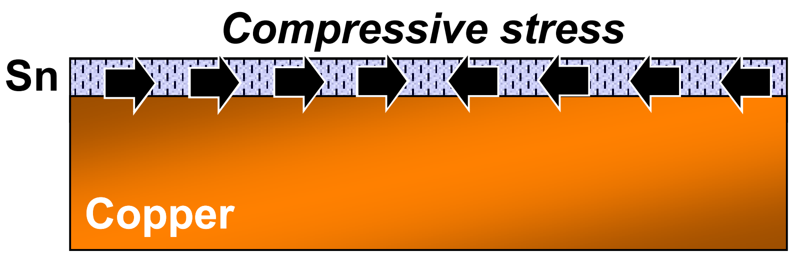


Example: Pb whiskers that grew out of the Pb-rich phase of Sn-Pb solder in a metallographic cross section mount.

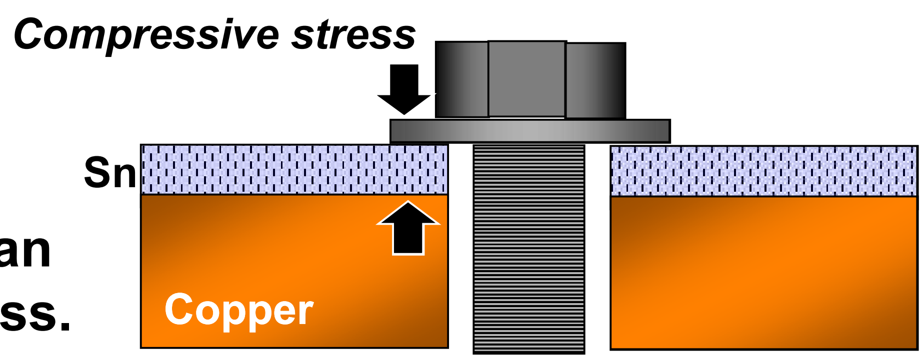
The somewhat "universality" of metal whiskers is important in terms of identifying variables that are key towards determining the exact mechanism(s) responsible for this phenomenon.

Sn Whisker Phenomenon

Although the mechanism details remain elusive, it is accepted that a compressive stress is the primary driver of Sn whisker growth.



The stresses can be intrinsic to the particular layer.



The stresses can be extrinsic, generated by an applied mechanical stress.

Sn Whisker Phenomenon

Several factors affect the intrinsic stresses of Sn layers:

1. **Electroplating bath organic additives.**

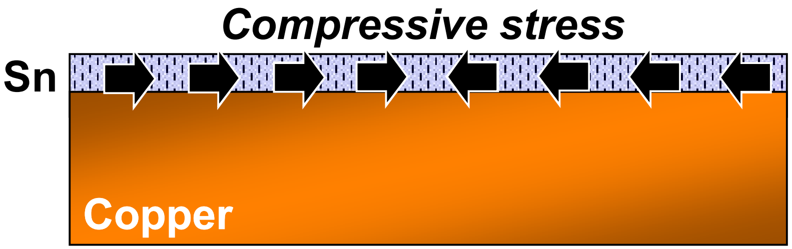
   Matte Sn is preferred to a bright Sn finish because the latter uses extensive additives to provide a shiny surface.

2. **Plating parameters (rate of metal deposition)**

   Faster plating rates produce higher residual stresses.

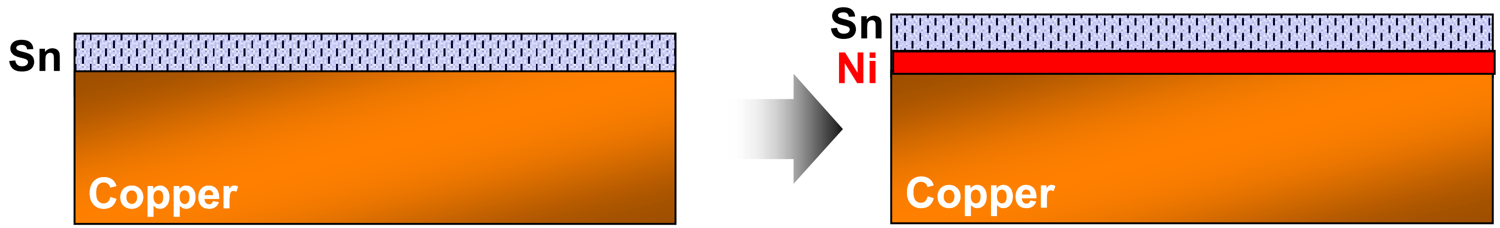
3. **Sn layer/base material interface reactions**

   Intermetallic compound (IMC) layer growth and solid-state diffusion of substrate atoms can generate compressive stresses in the Sn layer.



Sn Whisker Phenomenon

The use of a Ni barrier layer, when placed between the Sn layer and Cu or Cu-based base materials, will lessen the likelihood of Sn whiskers to develop from the finish.



4. A mismatch of thermal expansion coefficients often exists between the electroplated Sn coating (23.5 ppm/C) and common, low-expansion base materials (6 - 8 ppm/C).

   Temperature cycling can result in compressive residual stresses in the Sn layer that lead to the formation of Sn whiskers during service life.

Sn Whisker Phenomenon

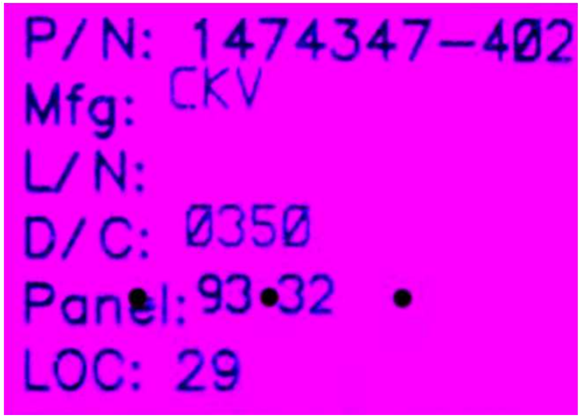
- **Consumer products now drive the global electronics industry.**

  … it is no longer military electronics!

- **One-hundred percent (100%) Sn is the most economical surface finish for components used in consumer electronics.**


Mitigation Strategies

- Part numbers have not necessarily been revised to reflect the change from Pb-bearing coatings to 100% Sn finishes.



Product non-conformance and invoice errors are common place.

- Incoming inspection techniques, including x-ray fluorescence (XRF), are required to verify surface finish compositions.

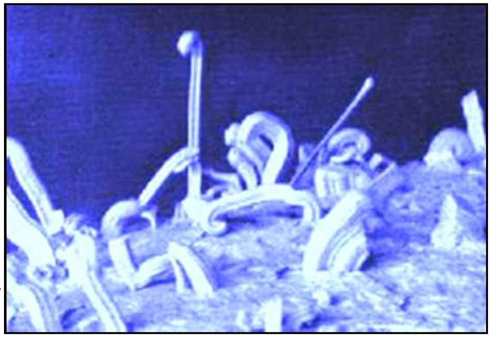
Mitigation Strategies

There are several mitigation techniques that can be exercised to reduce the potential reliability impact of 100% Sn coatings.

1. Avoid using parts with pure Sn coated products
2. Pb-contamination during the assembly process

3. Fuse 100% Sn coatings on devices before assembly
4. Increase process temperatures for stress relief
5. Use of a conformal coating

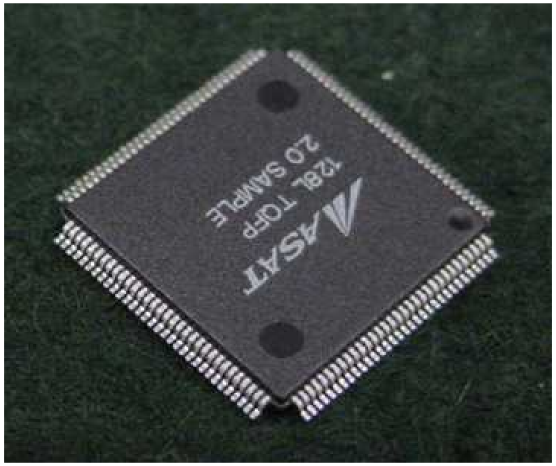
6. Solder dip I/Os using SnPb solder
7. Strip the Sn coatings
8. Plating process intervention



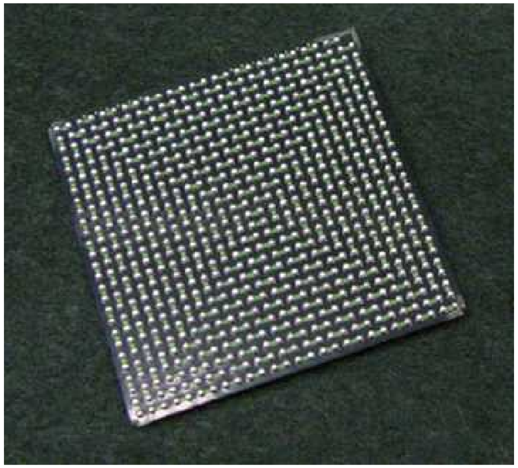
… in the order of most to least preferred.

Mitigation Strategies

- **Because consumer products are currently driving the electronics industry, it is becoming increasingly more difficult to find components with Sn-Pb finishes.**
- **Components with Sn-Pb coatings are quickly becoming "special order" commodities with a 30% price premium.**



Quad flat-pack:
100% Sn finish

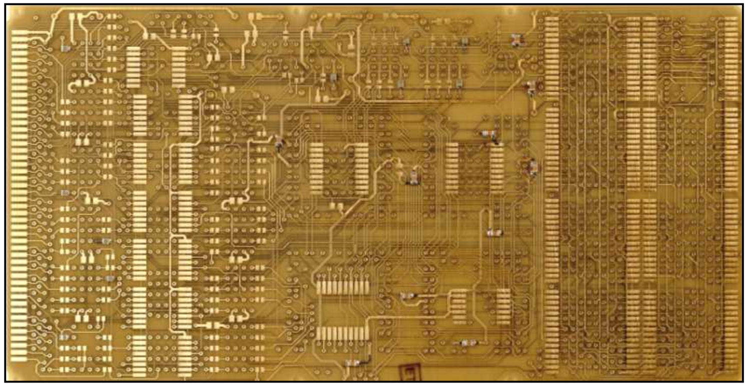


Ball-grid array (BGA):
Sn-Ag-Cu balls

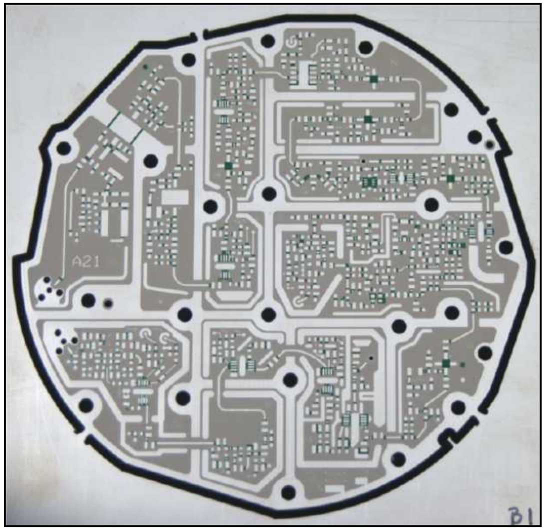
Mitigation Strategies

There are alternative finishes to 100% Sn for Pb-free applications:

- **Electroless nickel, immersion gold: printed circuit boards**
- **Electroplated nickel and gold: component I/Os**
- **Nickel-palladium-gold: component I/Os and printed circuit boards**
- **Immersion Ag: printed circuit boards**
- **Immersion Sn: printed circuit boards**
- **Sn-Bi: component I/Os**



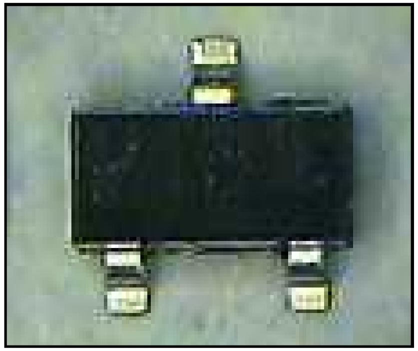
Electroless nickel, immersion gold



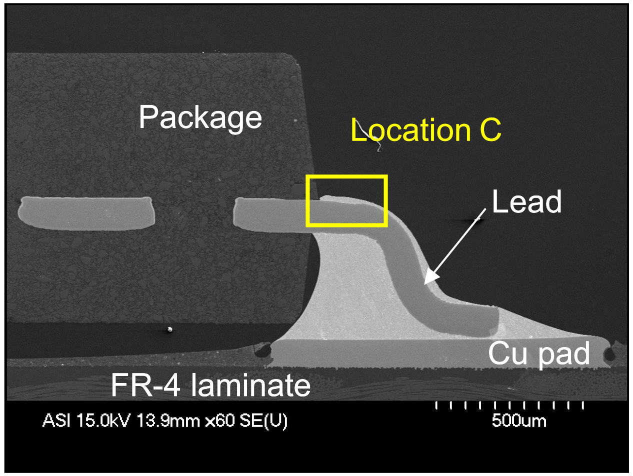
Immersion silver

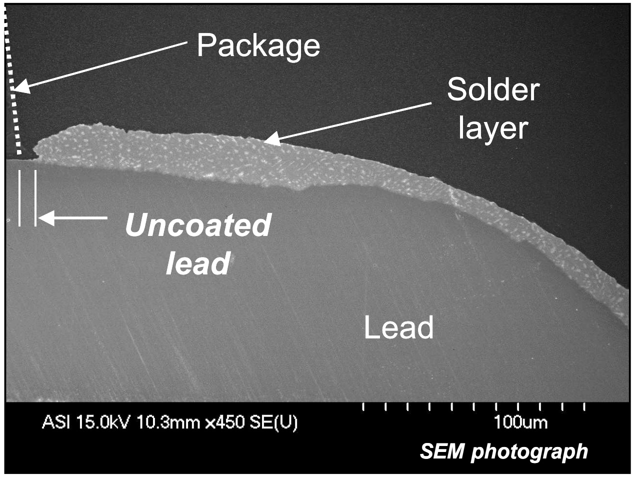
Mitigation Strategies

In the case of smaller components - e.g., SOTs, chip devices, etc. - there is the likelihood that the Sn-Pb solder reflow process will contaminate the 100% Sn coating, thereby preventing whiskers.



SOT 23

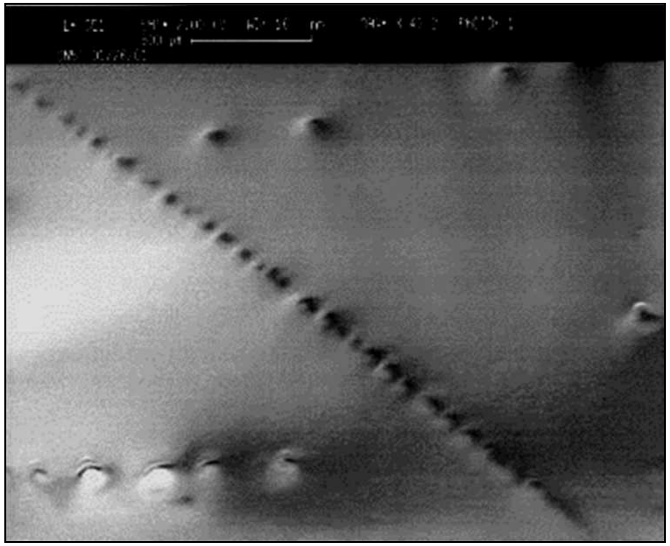


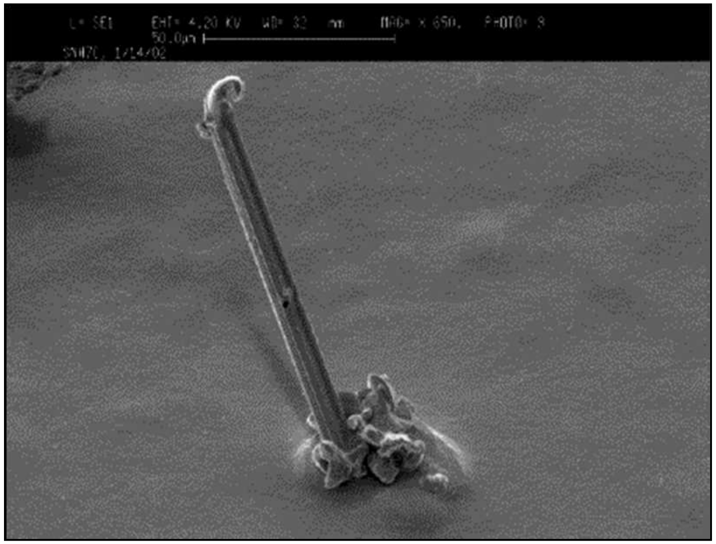


Courtesy: Sandia National Laboratories

Mitigation Strategies

- **Conformal coatings slow Sn whisker growth (Paralyene).**
- **Thicker coatings are more effective (see below).**
- **Sn whiskers are not able to re-penetrate a conformal coating.**





Courtesy: NASA

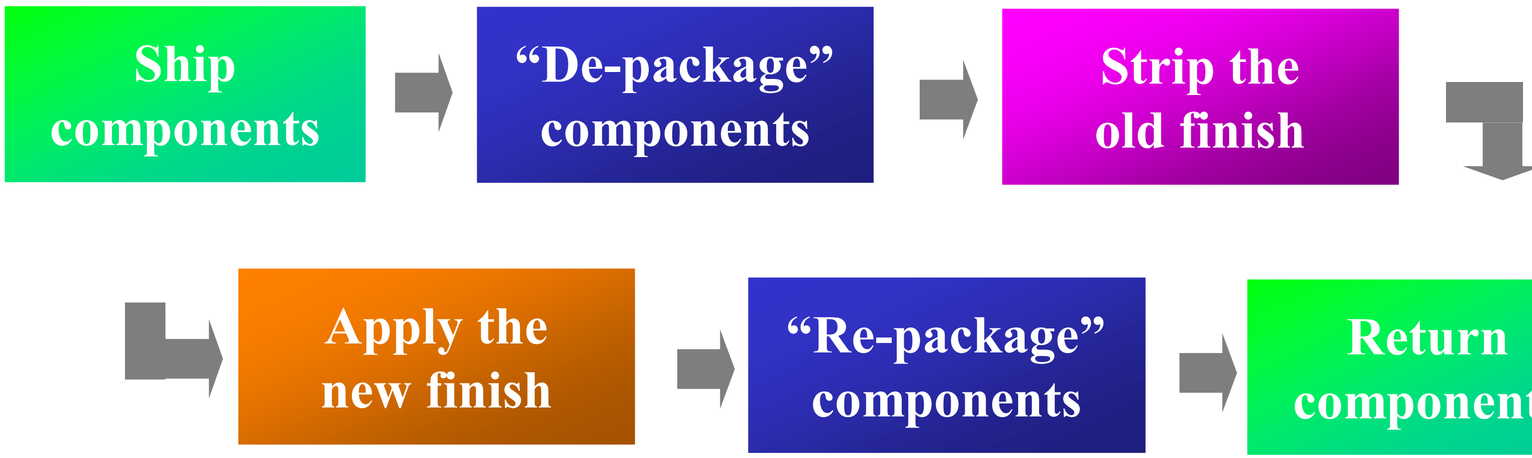
0.002 in thick polyurethane

0.0001 in thick polyurethane

- **But, not all high-reliability electronics can be conformal coated due to rework issues, RF performance, etc.**

Mitigation Strategies

Hot solder dipping or **chemical stripping-and-re-plating** are two approaches for replacing 100%Sn coatings.



However, the drawbacks are many:

1. Loss of vendor/supplier warranties
2. Schedule delays
3. Handling damage/dropout
4. Re-acceptance/re-qualification procedures
5. Added costs

Standards and Practices

- **JP002:** "Current Tin Whisker Theory and Mitigation Practices Guidelines."
- **JEDEC JESD22-A121:** "Test Method for Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes."
- **JEDEC JESD-A201:** "Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes."
- **GEIA-STD-0005-2:** "Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems."
- **GEIA-STD-0006:** "Requirements for Using Solder Dip to Replace the Finish on Electronic Components."

The technical work that was the basis these documents was performed by the iNEMI Tin Whisker User Group

Standards and Practices

- A number of the large original equipment manufacturers (OEMs) in the aerospace and defense industries have established in-house practices/documents, usually part of an overall Pb-free control plan methodology:
  - Lockheed Martin
  - Rockwell Collins
  - Honeywell Aerospace
  - Northrop Grumman
  - Raytheon

- The challenge is to implement surface finishes requirements through a very complex supply chain that includes relatively "resource-limited" second- and third-tier companies.

Efforts at Sandia National Laboratories

Funding resources:

- **Enhanced Surveillance Campaign**
  (DoE nuclear weapons program)

- **DoD/DoE MOU Project (50/50 match)**
  [DoE, nuclear weapons program;
  DoD, OUSD(AT&L)/DS/SL&M]

1. Component acceptance protocols (R. Wavrik, SNL)

Determine the susceptibility of components to Sn whiskers and investigate potential mitigation strategies for their use in both the conventional and nuclear munitions stockpiles.

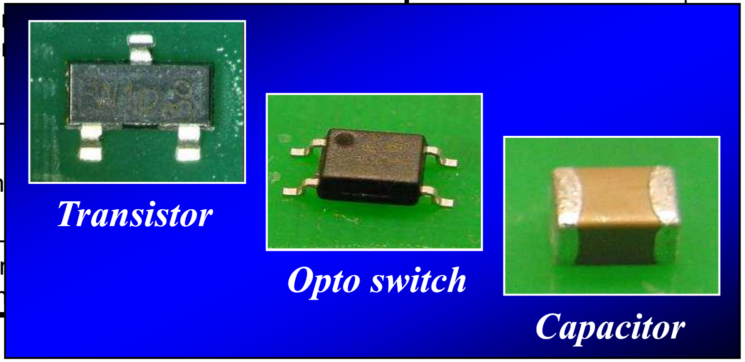
2. Materials modeling (with U. of Rochester, NY)

Understand the underlying materials mechanism responsible for Sn whisker growth and then develop a materials model, the goal of which is to predict (to a first-order) the growth of Sn whiskers.

Efforts at Sandia National Laboratories

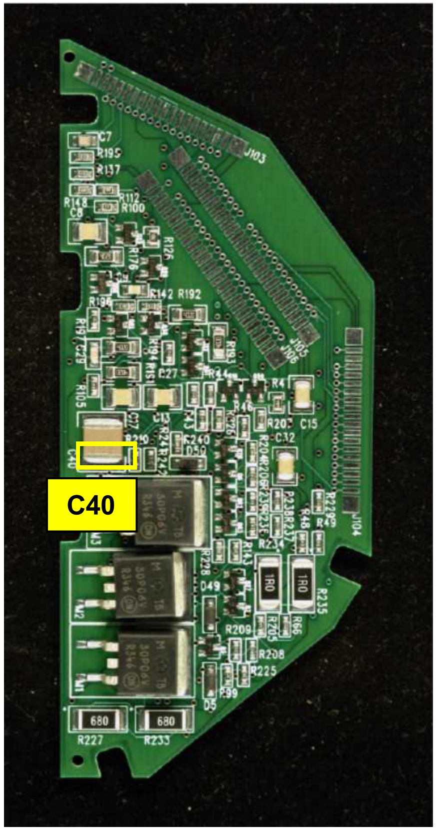
Long-term Sn-whisker experiments (JEDEC standards) - knowing the propensity for whisker formation - provides an engineering database for addressing long-term reliability concerns in munitions stockpiles.

TEST	CONFIGURATION	TEST CONDITION	STATUS (10-5-04)	Follow on Work
New	Taken from reel	room temperature	no tin whiskers at 4 mos nor 8 mos..	recheck reel at 12 mos
Accelerated tests	bare components	-55 to 125 C, 500, 1000, 2000 cycles	**tin whisker growth**	Complete
	bare components	2000 TC + 700 HAST	no tin whiskers	Complete
	board mounted	-55 to 125 C, 500, 1000, 2000 cycles	no tin whiskers	Complete
	board mounted	2000 TC + 700 HAST	no tin whiskers - evidence of copper growth (lead/package & lead/PCB interfaces). Sorenson evaluating material	Complete
	board mounted conformal coated	-55 to 70 C, 1000 cycles	no tin whiskers	+ 1000 TC. Remove conformal coat for inspection
Long term storage	bare components	roof top storage	2 month inspectio 4 month inspectio	WHISKERS ON 6/26
	board mounted			
	board mounted conformal coated			
	fused components			
Fusing - bare components	220 C - 1 min	-55 to 125 C, 1500 cycles + 700 hrs HAST	no tin whiskers, in	
	230 C - 1 min			
	240 C - 1min			
	240 C - 30 min			
Pb Migration	board mounted	room temperature	no major migratio of leads, no tin wh	

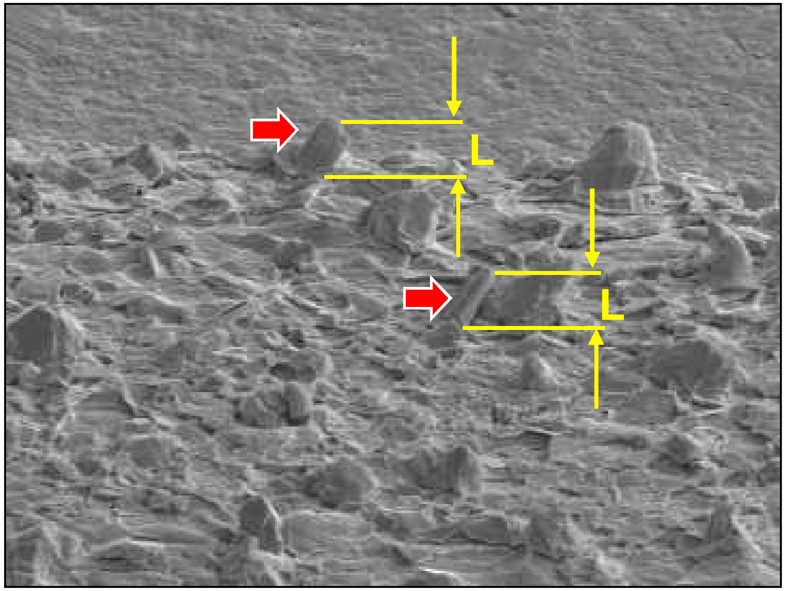


Efforts at Sandia National Laboratories

Develop a materials (computational) model to predict the reliability risk associated with the growth of Sn whiskers.



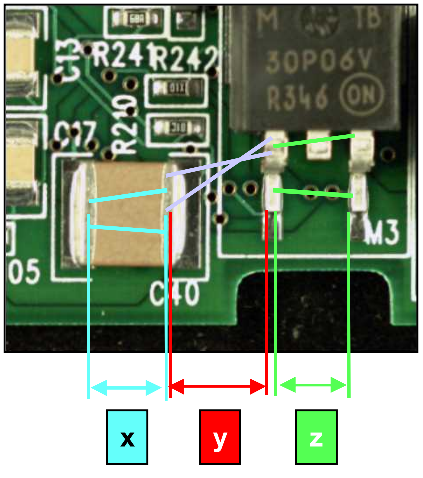
Printed Wiring Assembly



C40, 2000TC (-55° C/125° C)

Computational model predicts the length of the Sn whiskers:

$dL/dt = f(\text{temp., time, stress})$



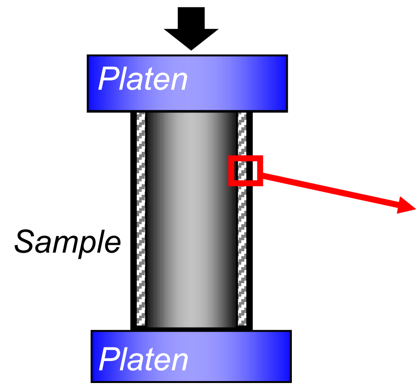
Sn whisker growth paths leading to electrical shorts

The predictive tool is used to assess the likelihood that Sn whiskers will cause a functional failure.

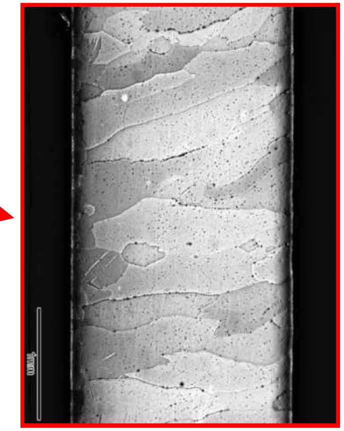
Efforts at Sandia National Laboratories

Sandia task:

- Controlled grain size v. thickness
- Creep deformation is the underlying whisker mechanism
- Determine creep rate kinetics for predicting whisker growth rates



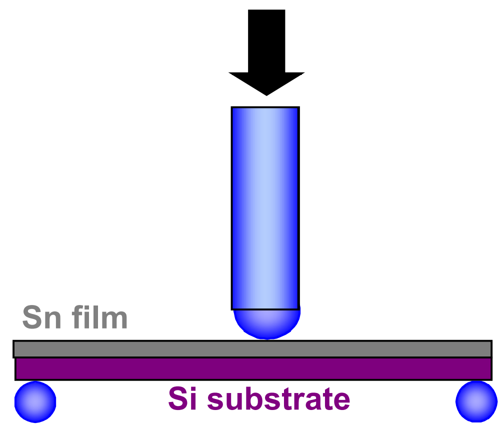
Compression creep test



Grain size simulation.

U. of Rochester task:

- Impression technique
- PVD thin films of Sn
- Electroplated Sn films
- Effects of temperature and time
- Effects of applied stress
- Microstructure analysis



Impression technique on a Sn-coated Si disk

Summary

- The high-reliability military, space, and satellite electronics industries are being impacted *indirectly* by the global conversion to Pb-free consumer products.

100% Sn finishes on components

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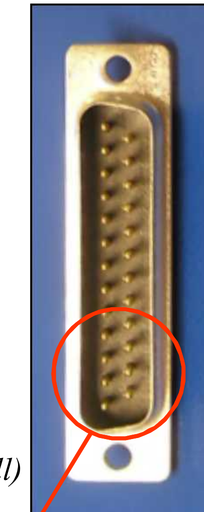
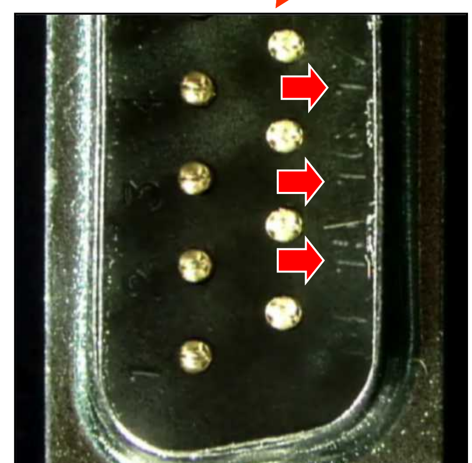
Sn whisker reliability concern



D-connector (Sn-plated shell)



(courtesy of NASA Goddard)

- The reliability issues of 100% Sn finishes can be addressed by the following approaches:
  - Supply chain management (short term)
  - Mitigation strategies (intermediate term)
  - Fundamental understanding (long term)