Tin Whisker Mitigation
JMP Five Year Plan for FY11-15

SAND2010-1851P

Performing Organization: **Sandia National Laboratories**

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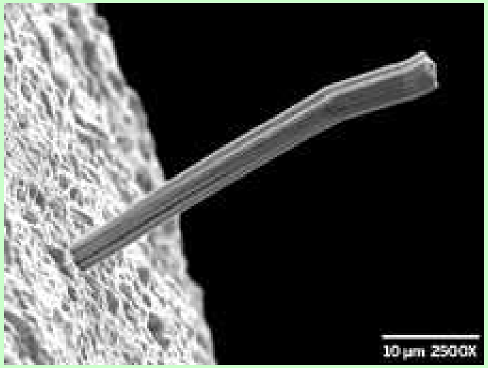
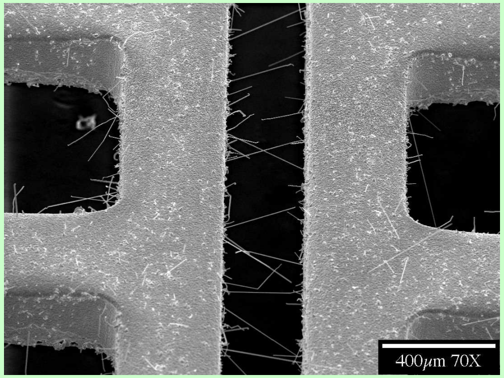
Tin whiskers - background

Reliability concerns

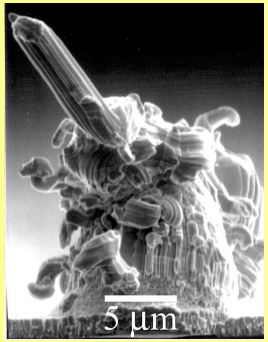


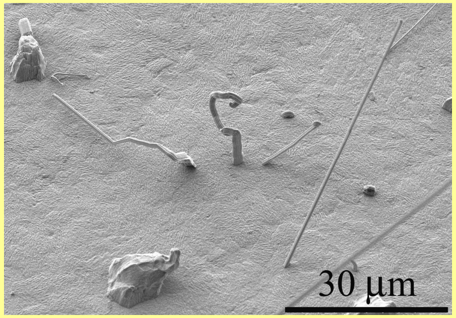
- Tin whiskers that grow from pure tin device leads can cause electrical short circuits.



Photos from nepp.nasa.gov

Complex growth mechanism





- Whiskers have a range of lengths shapes, whisker densities, and growth rates.

- Compressive stresses in tin are thought to cause whisker growth. (confirmed by P. Vianco, SNL.)

- “Tin whiskers continue to fascinate, perplex, and astound”. -Circuits Assembly, Nov 2009, 26-29.

Photos from nist.gov

- **Currently, tin whiskers cannot be eliminated, but can be mitigated.**

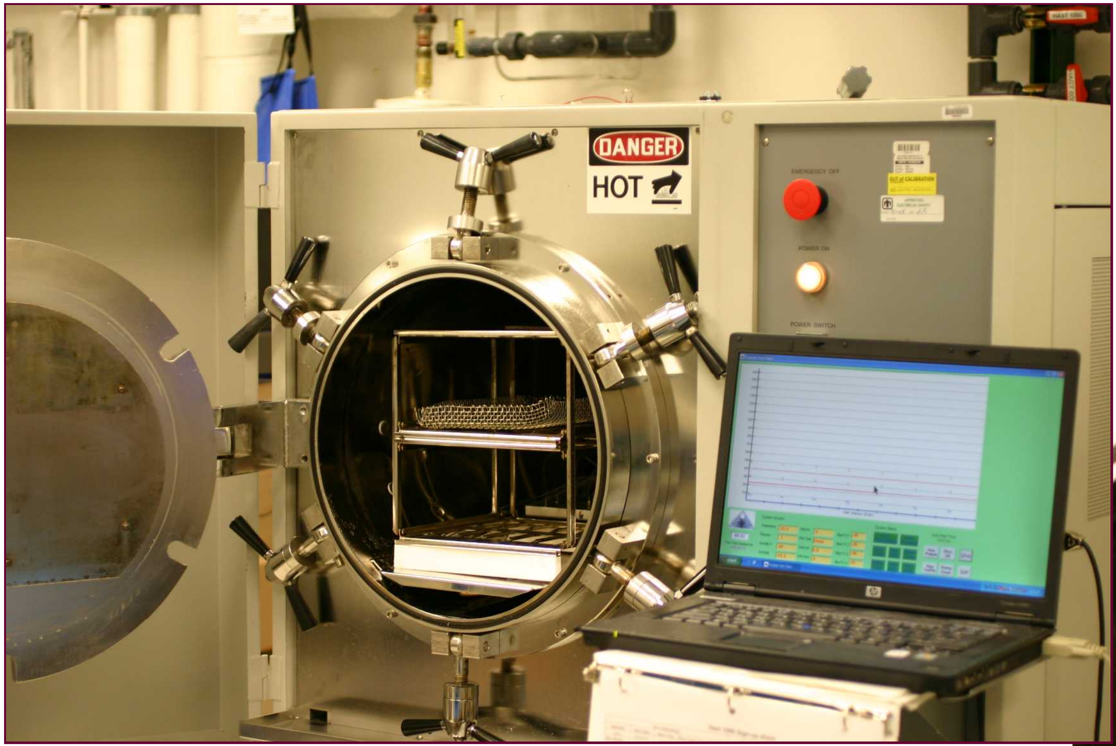
Tin whisker mitigation methods explored at SNL

- **SOLDER WICKING** – **Mount parts on boards with Sn-Pb solder.***
- **FUSING** – **Dip Sn-plated surfaces into an oil bath at 230°C.**
- **ANNEALING** – **150°C for 1 hour.**
- **HOT SOLDER DIPPING** – **Immerse leads into hot Sn-Pb solder bath.**
- **Pb PLATING** – **Commercial plating process.**
- **CONFORMAL COATING** – **Polymer coating to confine whiskers.**

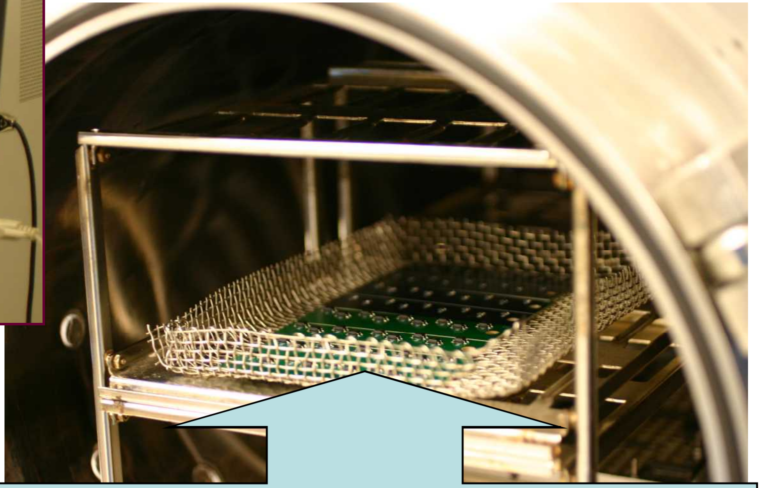
We have evaluated hundreds of components under accelerated and moderate test conditions.

* - We have recently begun an evaluation of Pb-free solders.

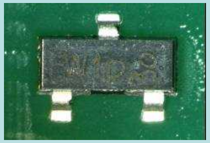
Accelerated Testing – HAST



HAST Chamber
60^{o}C, 93% RH*




1206 capacitor
Sn/Ni/Cu


SOT23 transistor
Sn/Fe-Ni


SO4 optocoupler
Sn/Cu

Components are mounted to PC boards then subjected to 4,000 HAST hours to promote whisker growth.

* - iNEMI test conditions

Temperature cycling and long-term storage

- **Temperature Cycling** – -40°C to 85°C, 10 min. dwell time (iNEMI test conditions.
    - Whisker inspections performed after 500, 1000, 2000 cycles

- **Long Term Storage** – Parts stored in a rooftop container at SNL. Whisker inspections performed at 4, 8, 12, 18, 24, 48, and 60 months

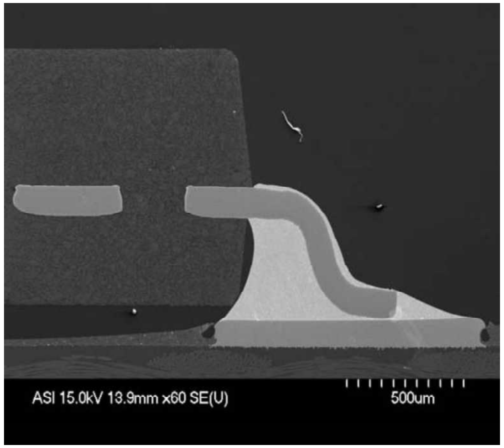
Note: Parts are not electrically biased in these tests.
Parts are tested in loose and mounted states.

Which mitigation methods worked best?

- **<u>Solder wicking</u> was the most effective mitigation method.**

Whiskers, if any, remained in the stubble stage, and are thus a low reliability risk.

- **<u>Conformal coating</u> shows potential if whiskers can be prevented from penetrating the polymer.**



We are now pursuing two mitigation methods:

I. Impenetrable conformal coatings
II. Pb-free solder wicking

Tin Whisker Mitigation Quad Chart

What are you trying to do in this task?

•Develop low-cost tin whisker mitigation methods for COTS components used in military applications.

•We are currently investigating two mitigation methods: (1) impenetrable conformal coating and (2) Pb-free solder wicking.

What makes you think you can do it?

•Our preliminary results have shown that tin whiskers do not penetrate conformal coatings that contain fillers.

•Fillers of the appropriate geometry can act as barriers to whisker growth.

•We have also demonstrated the effectiveness of Sn-Pb solder wicking, and now must test Pb-free solders.

What difference will it make?

- This work is applicable to military, aerospace, and consumer electronics.
- The implementation of tin whisker mitigation techniques is expected to substantially increase the system reliability.

What / When / To Whom Will You Deliver?

•We will deliver data on the long-term reliability of mitigated components.

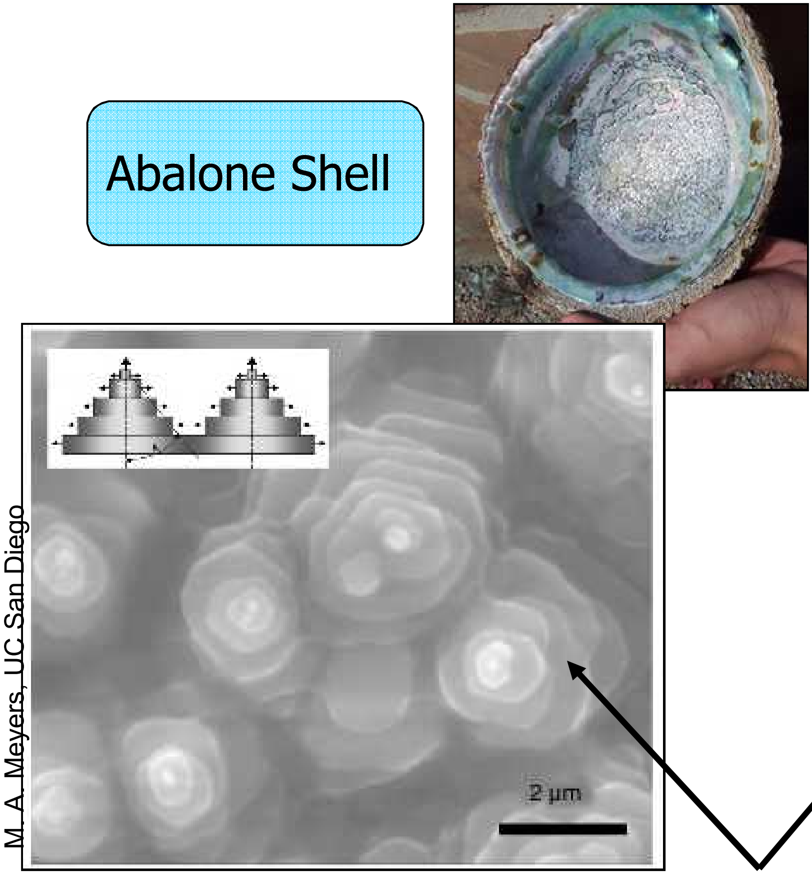
•Reach a TRL of 6 (current TRL=3).

•Transition the mitigation methods to industry for use in DoD products.

Impenetrable conformal coatings

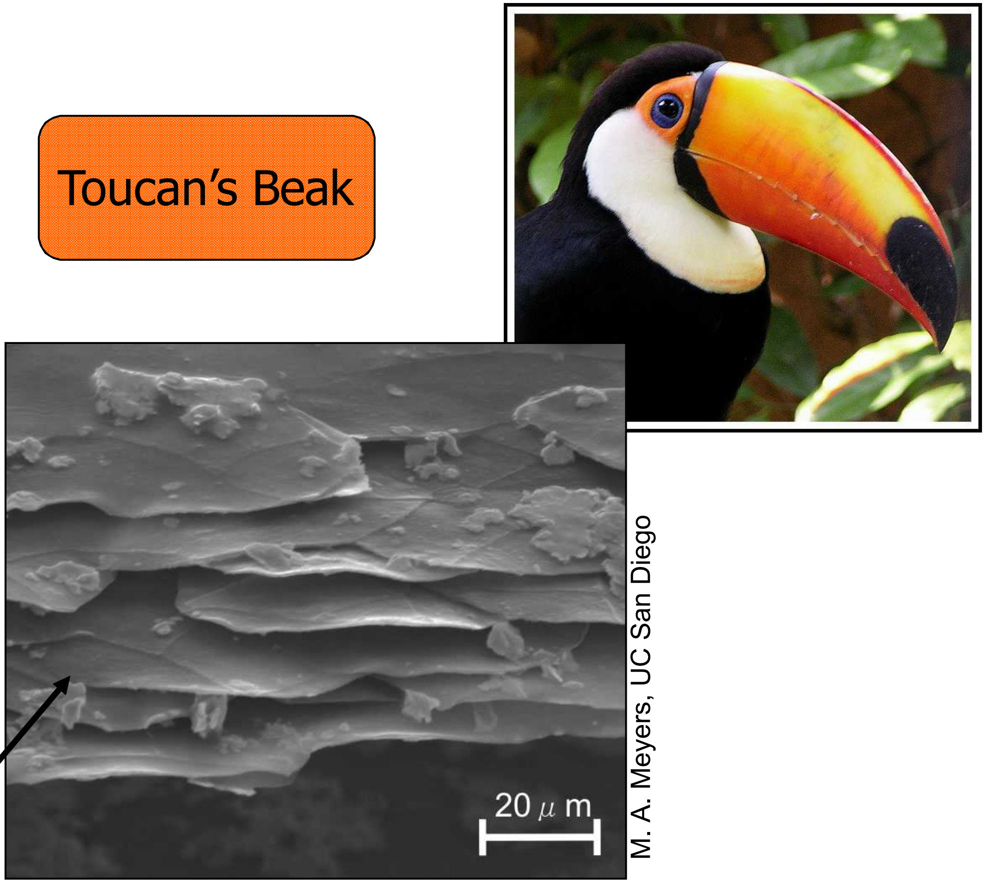
- Conformal coatings are needed that are hard enough to resist penetration by tin whiskers, yet non-brittle.
- Such composites are common in nature.

Abalone Shell



M. A. Meyers, UC San Diego

Toucan’s Beak

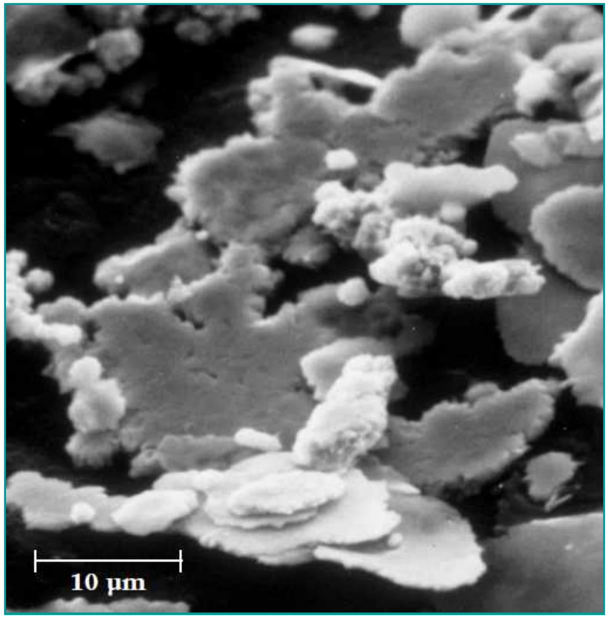


M. A. Meyers, UC San Diego

Layered ceramic platelets in a polymeric (protein) matrix

Our approach is to incorporate microflakes into polymers

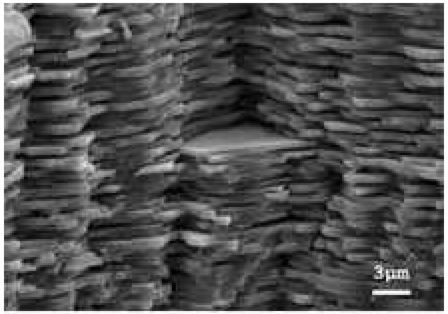
Nickel Microflakes



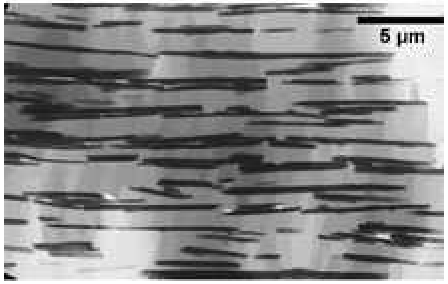
- 20:1 aspect ratio, ~1 µm thick.
- Stainless steel, silica, alumina flakes are also available commercially.

- Magnetic flakes, or those having magnetic cores, can be oriented in magnetic fields to form an impenetrable sheet.

- Alternating layers of aligned flakes and polymers have been produced without fields, and resemble the abalone shell's structure.



Abalone shell



Alumina flakes
in between biopolymer

We are the first to explore such composites as conformal coatings.

Preliminary Results

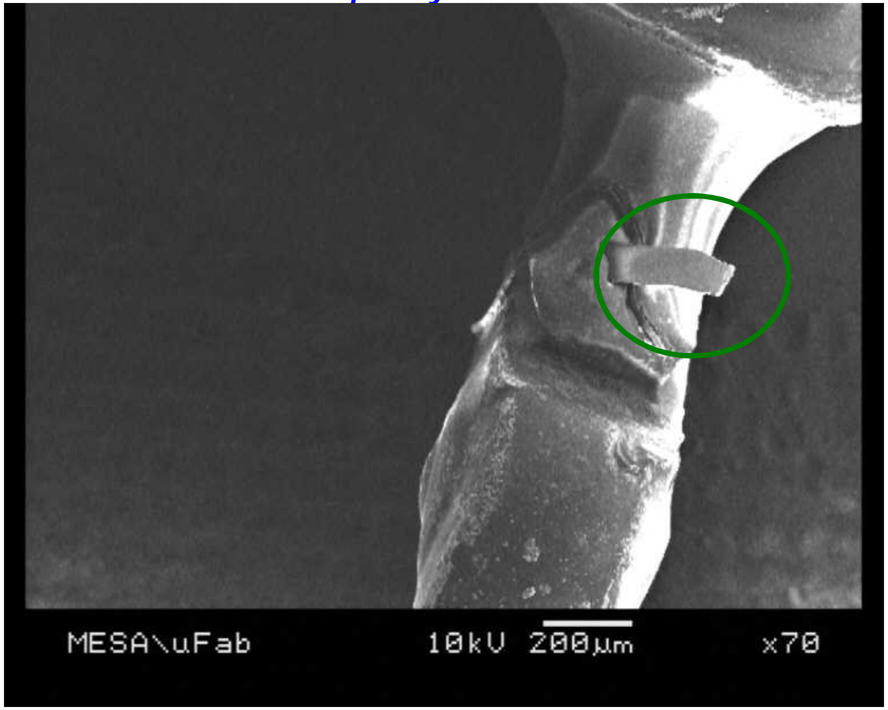
- Unfilled epoxy conformal coating

- Microflake-epoxy composites – flakes not oriented

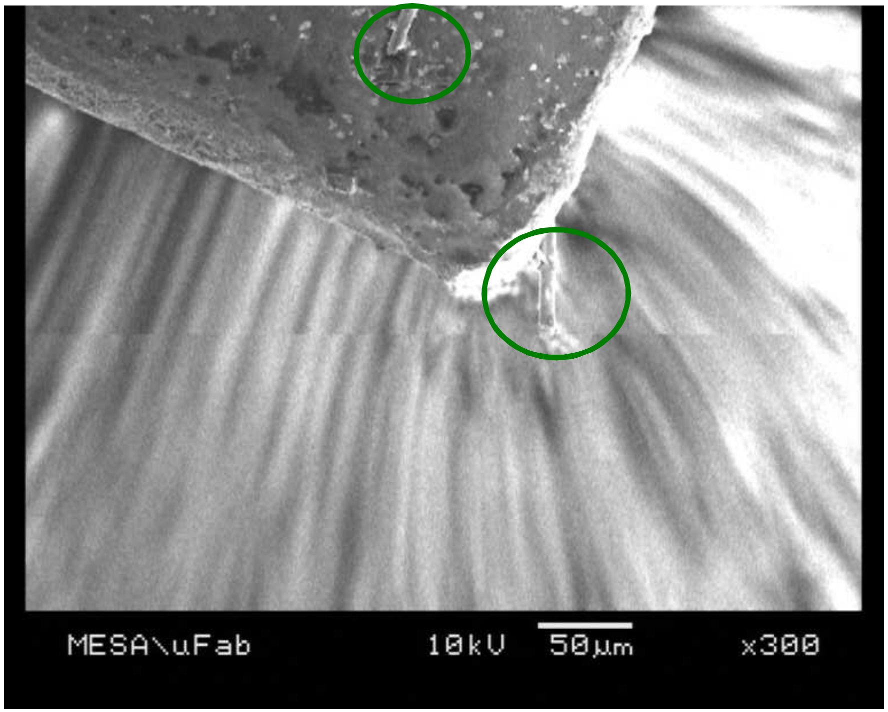
HAST results – unfilled conformal coating.

SEM images of optocoupler leads after 4,000 hours of HAST.

Unfilled epoxy coated



Uncoated

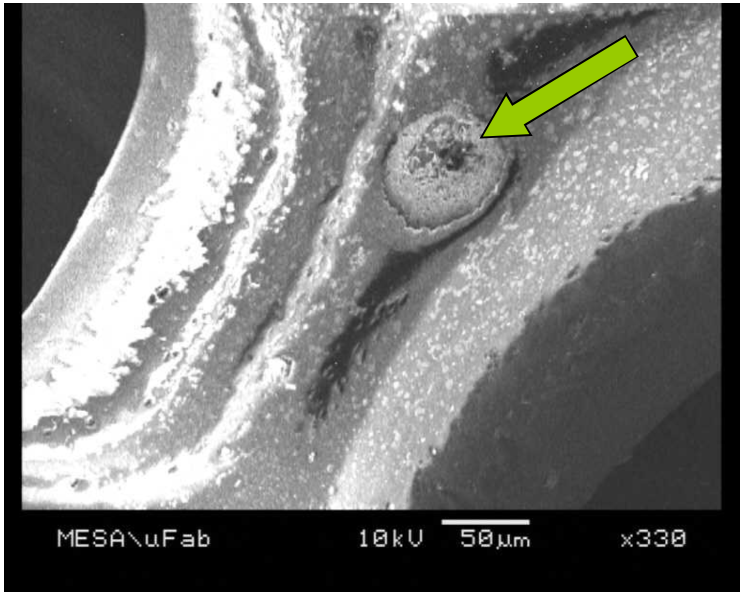


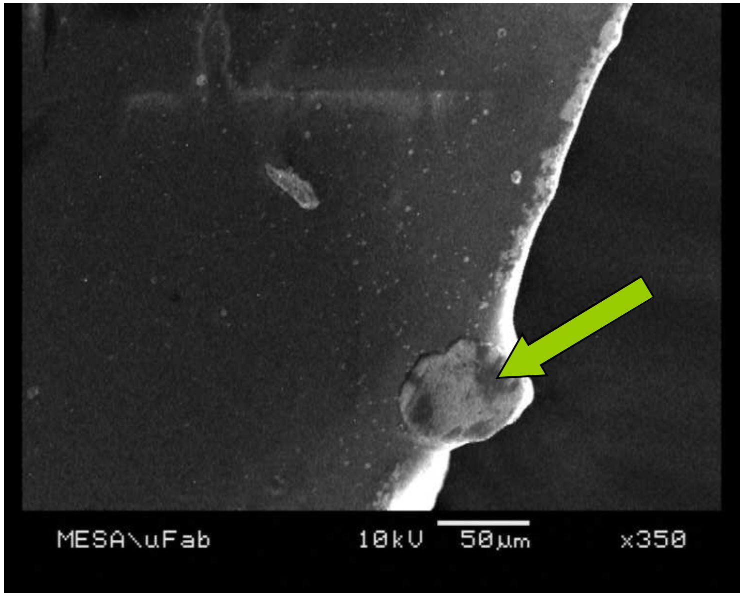
- A tin whisker has penetrated the epoxy coating on Sn/Cu leads.
- This is consistent with observations of silicone and Uralane 5750 coatings.

- Small tin whiskers grew on the uncoated Sn/Cu leads.
- Sn oxide may have increased the whisker incubation time.

HAST results – unfilled conformal coatings.

SEM images of optocoupler leads after 4,000 hours of HAST.





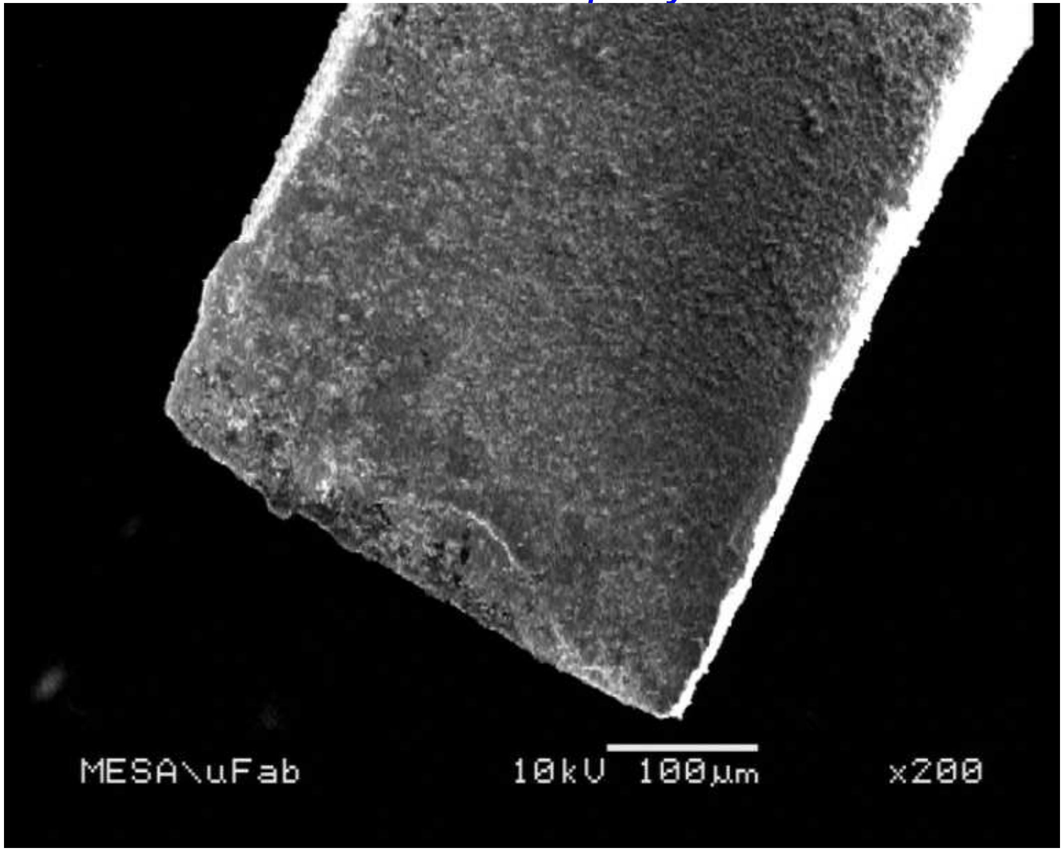
- In addition to whiskers penetrating the epoxy, we have observed Sn “stumps”.

- Impenetrable coatings are clearly needed.

HAST results – composite conformal coating.

SEM images of optocoupler leads after 4,000 hours of HAST.

Microflake-filled epoxy coated lead



- The first set of components coated with epoxy containing microflakes are currently being inspected.
- No whiskers have been observed!
- We are gearing up to produce samples of oriented flakes in conformal coatings on Sn films, then on device leads.

Future Work – composite conformal coating.

- We will orient the microflakes into sheet-like assemblies using biaxial ac magnetic fields.

- We will develop transparent coatings for easier monitoring of whisker growth.

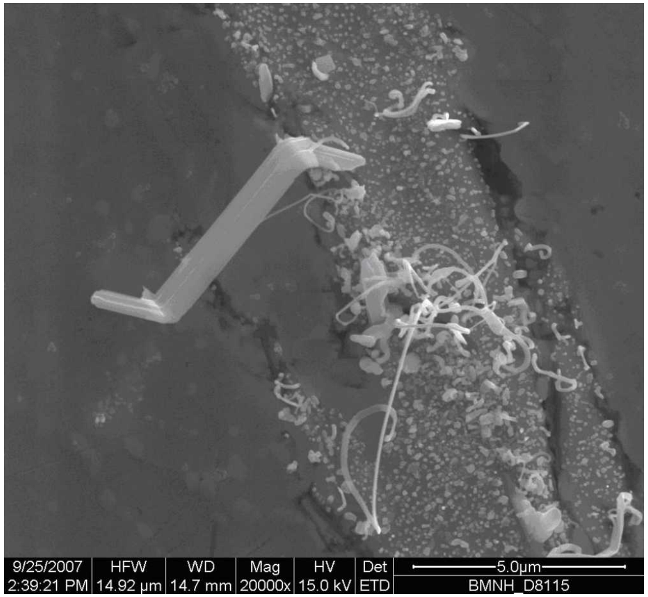
- Epoxy was used in our preliminary experiments, but other polymers will be explored (D. Adolf, SNL can provide guidance).

- Future experiments will induce whisker growth by other means (stress, surface defects), since HAST can cause polymer debonding.

Preliminary Results on Pb-free solder wicking

Tin whisker mitigation – Pb-free solder wicking: SnAgCu

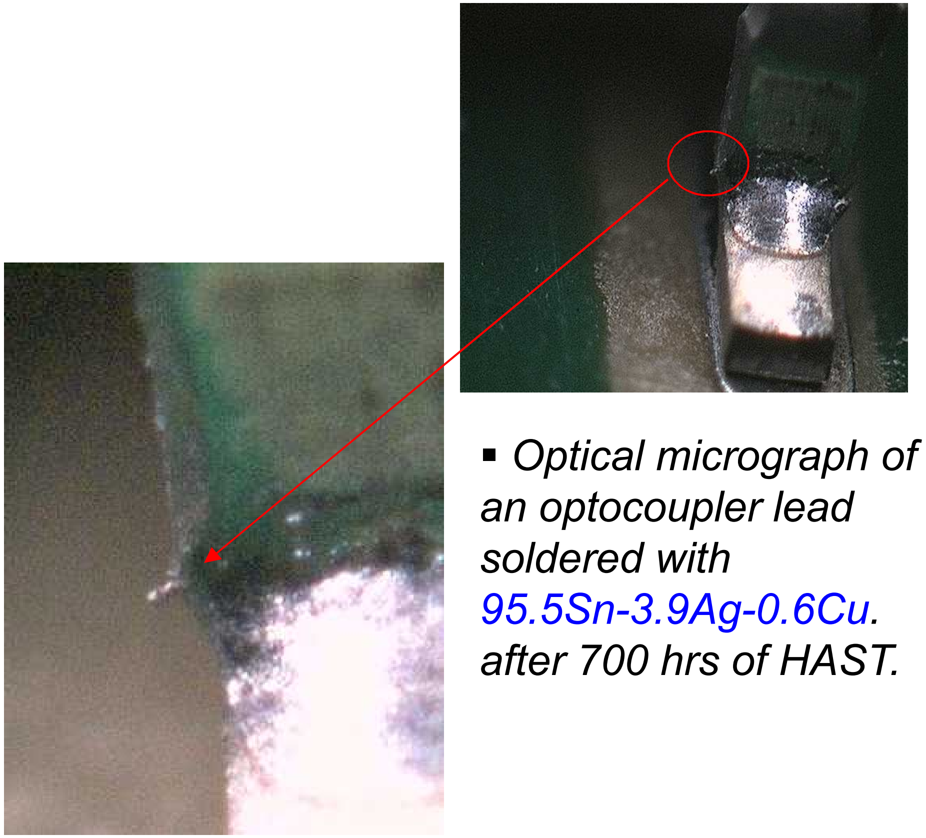
- Tin whiskers have been observed in Sn-Ag-Cu-Ce,Er,Y solders.*



▪ *Whiskers grew on the $ErSn_3$ phase after 312 hours at room temperature.*

* Y. Shi & H. Hao – Photo from nepp.nasa.gov

- We have seen evidence of tin whisker growth on Sn-Ag-Cu soldered leads.



▪ *Optical micrograph of an optocoupler lead soldered with 95.5Sn-3.9Ag-0.6Cu. after 700 hrs of HAST.*

- There are other Pb-free solders that may prevent whisker growth.

Tin whisker mitigation – Pb-free solder wicking: SnBiAg

- We are exploring bismuth-containing solders.

- 3 at.% Bi has been found to modify the grain structure of Sn electrodeposits from columnar to equiaxed.*

- Equiaxed grain structure enables stress relaxation, preventing whisker growth.

- **We have not observed whiskers on Sn-Bi-Ag soldered leads after 700 HAST hrs.**

- We are now in a good position to work more closely with other SNL P.I.s (P. Vianco) on whisker growth in Pb-free solders – modeling and experimentation.

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* - http://www.nist.gov/msel/metallurgy/thermodynamics_kinetics/lead-free_surface_finishes.cfm

Tin Whisker Mitigation – Major Results To Date

- **FY09-FY10:**
  - **Milestone 1: Completed an evaluation of the eutectic solder wicking method.**
  - **Accomplishment:**
    - **Demonstrated excellent tin whisker mitigation in HAST and LTDS environments.**
  - **Milestone 2: Completed preliminary investigation of composite conformal coatings for tin whisker mitigation.**
  - **Accomplishments:**
    - **Produced a nickel microflake-epoxy composite.**
    - **Composite-coated Sn leads completed 4,000 hrs of HAST – No whiskers observed.**
  - **Milestone 3: Initiated Pb-free solder wicking studies.**
  - **Accomplishment:**
    - **Sn-Bi-Ag and Sn-Ag-Cu soldered components completed 700 hrs of HAST**

  - **Presentations/Publications:**
    - **"Tin whisker mitigation," JL Aragon, JP Witham, RW Wavrik, LES Rohwer, *28th Compatibility, Aging, and Stockpile Stewardship Conference Proceedings*, 2009.**

Tin Whisker Mitigation Milestones/Deliverables for FY11-15

Task #	Milestones/Deliverables	Date	Metrics or Exit Criteria	DoD / DOE Linkage
1	***#1*** **Expand the scope of the mitigation studies to include new components/technologies (individual component and board level).** **Electrical test data of mitigated components.**	***1Q11***	**Report**	*AMRDEC/SNL*
	#2 **Complete accelerated testing of Sn whisker mitigated components. Impenetrable composites & Pb-free solders.**	***3Q11***	**Report**	*AMRDEC/SNL*
	#3 **Publish characterization report on new materials for mitigating Sn whiskers.**	***4Q11***	**Report**	*AMRDEC/SNL*
	#4 **Establish industry partners.**	***4Q12***	**Report**	*AMRDEC/SNL*
	#5 **Deliver data on the long term reliability of mitigated components.**	***1Q13-4***	**Report**	*AMRDEC/SNL*
	# 6 **Transition tin whisker mitigation methods to industry.**	***3Q15***	**Implementation Plan**	*AMRDEC/SNL*