Latest Findings in Tin Whiskers in Electronics Webinar
Thursday, October 29, 2015

Tin Whisker Mitigation

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About the Presenter:

Michael Osterman (Ph.D., University of Maryland, 1991) is a Senior Research Scientist and the director of the CALCE Electronic Products and System Consortium at the University of Maryland. Dr. Osterman served as a subject matter expert on phase I and II of the Lead-free Manhattan Project sponsored by Office of Naval Research in conjunction with the Joint Defense Manufacturing Technical Panel (JDMTP). He has consulted with several companies in the transition to lead-free materials and has developed fatigue models for several lead-free solders. He has lead CALCE in the study of tin whiskers since 2002 and has authored several articles related to the tin whisker phenomenon. He has written eight book chapters and over eighty articles, including the Best Session Paper Award in 41st International Symposium on Microelectronics, IMAPS 2008 and the Best Paper-Maurice Simpson Technical Editors Award in the Inst of Environmental Sciences, 2008. In 2008, a PhD. student working under Dr. Osterman won the co-sponsored SMTA and Circuits Assembly Charles Hutchins Educational Grant for work on BGA reballing. He has conducted multiple experiments on temperature cycling, vibration, and mechanical bend of electronic assemblies. He is a member of ASME, IEEE, IMAPS and SMTA.

What is CALCE?

http://www.calce.umd.edu

Center for Advanced Life Cycle Engineering (founded 1987) is dedicated to providing a knowledge and resource base to support the development and sustainment of competitive electronic components, products and systems. Focus areas:

- Physics of Failure
- Design of Reliability
- Accelerated Qualification
- Supply-chain Management
- Obsolescence
- Prognostics

Center Organization

16 research faculty
5 technical staff
40+ PhD students
20+ MS students
11 visiting scholars

Education

- MS and PhD programs
- International visitors
- Web seminars
- Short courses for industry

Electronic Products and Systems Consortium

- Risk assessment, management, and mitigation for electronics

Prognostics and Health Management Consortium

- Techniques based on data trending, physics-of-failure, and fusion

CALCE

Center for Advanced Life Cycle Engineering for Electronic Products and Systems

Research Contracts

- Large scale programs
- Medium to long-term durations
- Contractual agreements
- Examples:
  Software development,
  testing,
  training programs

Lab Services

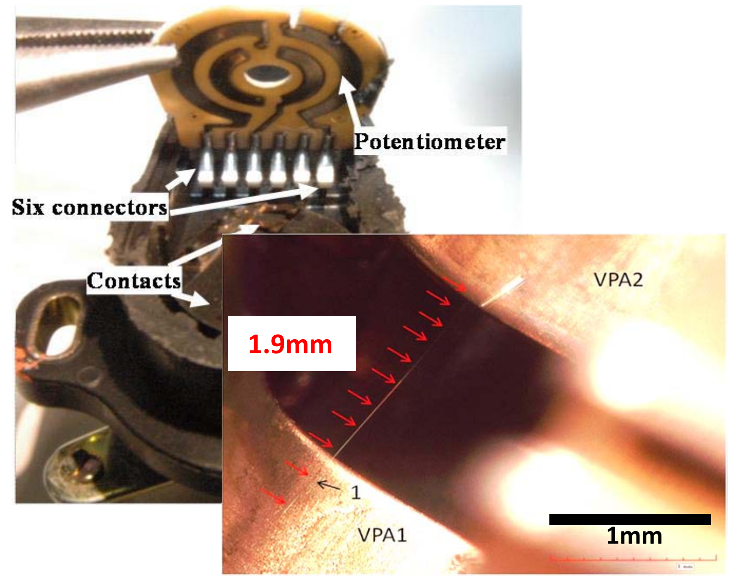
- Small to medium scale
- Rapid response
- Examples:
  Failure analysis,
  measurement,
  design review,
  supplier assessment

Standards

- Putting CALCE research to work for industry
- Examples:
  IEEE
  GEIA
  IPC
  JEDEC
  IEC

Tin Whiskers Failure Risk

- Tin whiskers are spontaneous growths from tin and high tin content alloy finishes.
- Major failure modes and mechanism of tin whiskers are:
  - Electrical short: permanent (typically <10mA), intermittent (typically >10mA)
  - Metal vapor (plasma) arcing in vacuum and low pressure
  - Contamination
- Various sectors of the electronics industry, including military, medical, telecommunications and commercial applications, have experienced field failures induced by tin whiskers.



Electrical Failure of an Accelerat Pedal Position Sensor Caused by Tin Whiskers, 5th International Symposium on Tin Whiskers

Damage from whiskers induced metal vapor arc in relay

* Davy, G., (Northrop Grumman Electronic Systems), "Relay Failure Caused by Tin Whiskers," http://nepp.nasa.gov/whisker/reference/tech_papers/davy2002-relay-failure-caused-by-tin-whiskers.pdf, June 10, 2004.

Mitigating Tin Whiskers

Mitigation ≠ Elimination

To mitigate – to make less severe or painful

Merriam-Webster Dictionary definition

SAE GEIASTD0005_2A, originally GEIA-STD-0005-2: "Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems" (first published 2006, revised 2012)

Provides a guideline of how big a risk suppliers and manufacturers should consider whisker and what actions they should be taking as a result

Classifies Control Level based on criticality of the product

Not a qualification or assessment standard – guidelines only

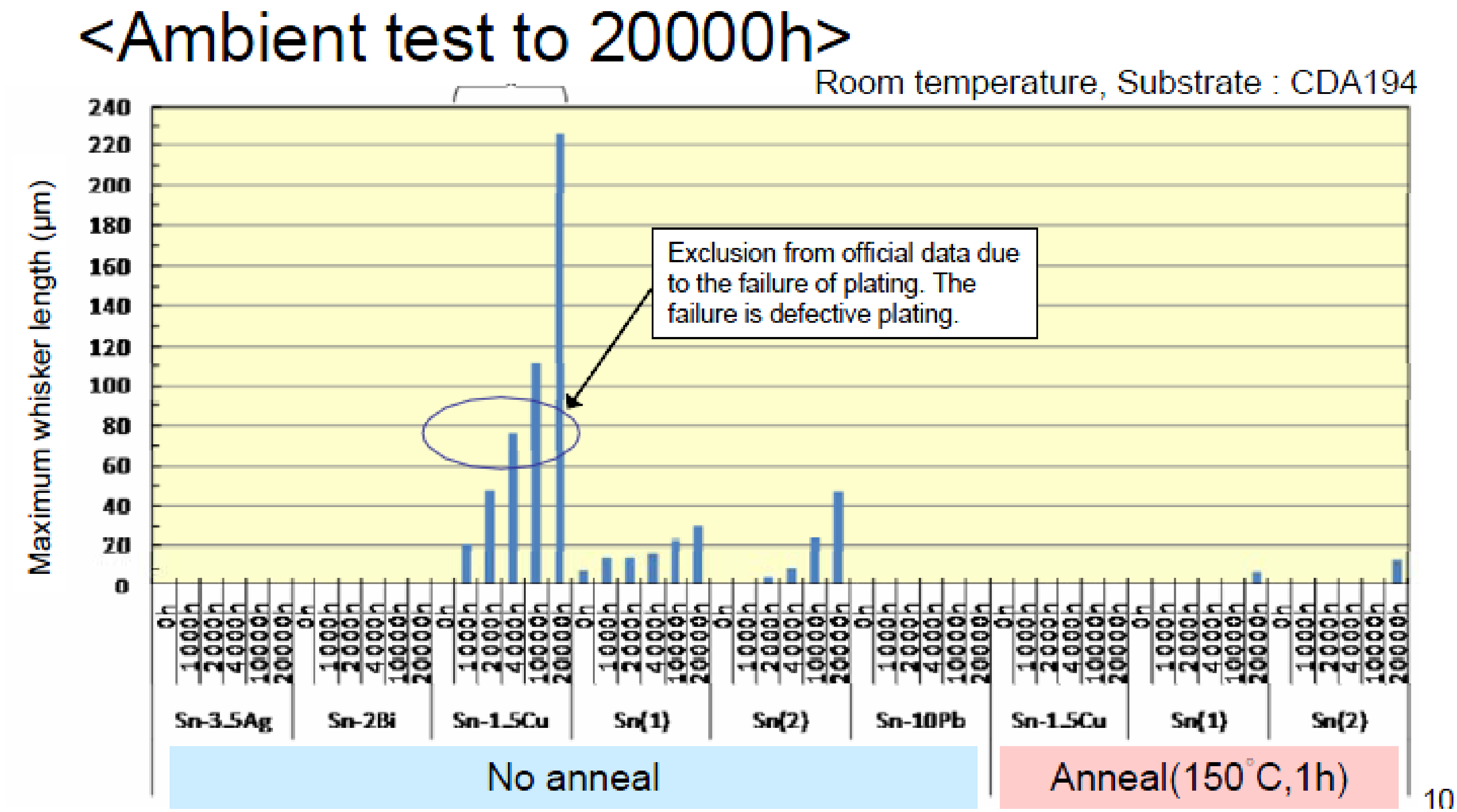
- **Part Selection Process –** Not considered mitigation if Lead-free Tin is used.
- **Part Reprocessing**
- **Assembly Level**

GEIA-STD-0005-2 Preferred Parts

- Annealing or fusing at part manufacturer, close to the time of plating
- Hot dipped Pb-free tin finishes (as opposed to plated finishes)
- Immersion Tin (for boards only; not applicable to component / part finish)
- Low profile parts, parts with short leads, or other geometries that have lower risk of whisker shorting
- Nickel Underplate (so long as not under bright tin)
- SnAg finishes (with minimum 1.5% Ag), particularly when hot dipped
- SnBi (with minimum 2% Bi)
- SnPb (with minimum 1% Pb)
- Successful passage of JESD201 testing at Class 2 level

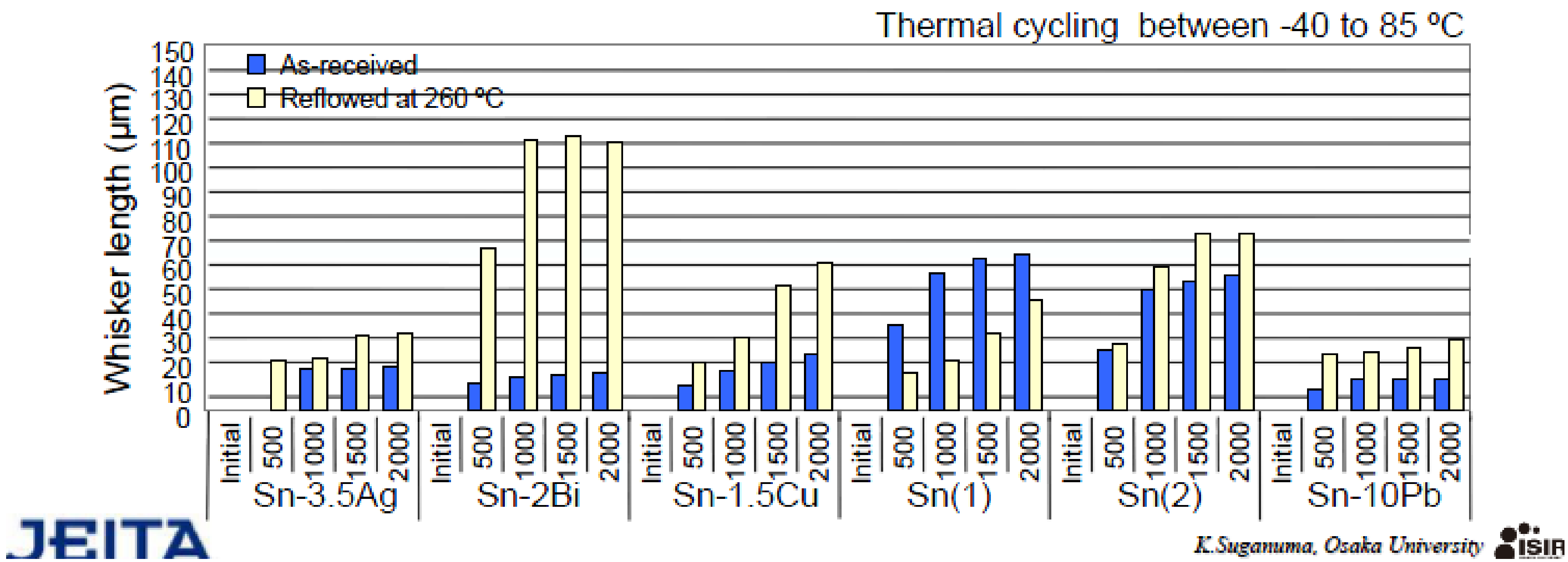
JEITA Study on Whisker Growth

In an examination alloying and heat treatment of tin whisker formation, JEITA researchers found that Ag and Bi additions prevent growth fro 20000 hours and annealing delayed onset of whisker growth for 20000 hours. The target plating thickness was 10 μm.



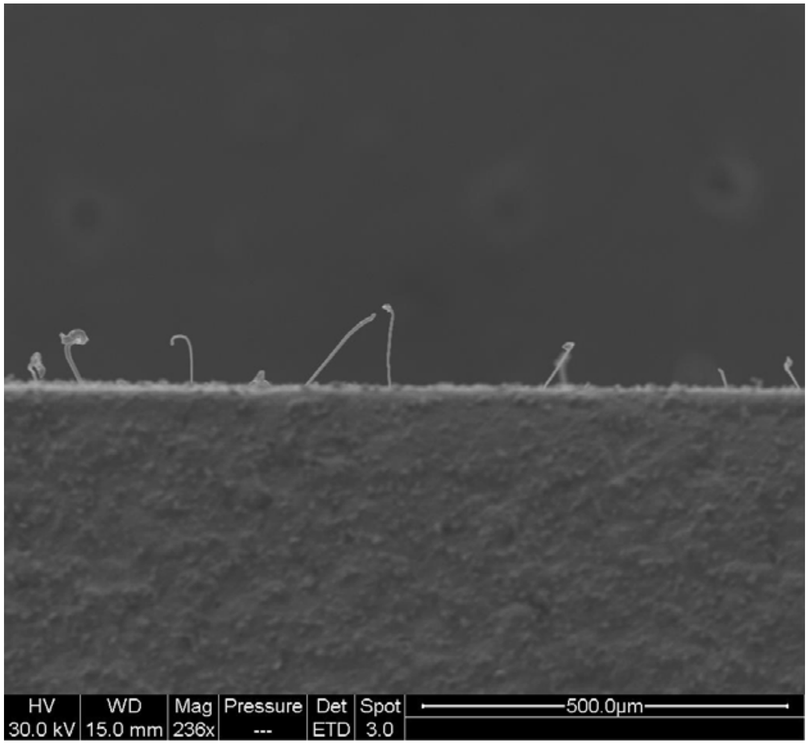
Tin-Bismuth Finishing, ISHIHARA CHEMICAL CO., LTD., 2010

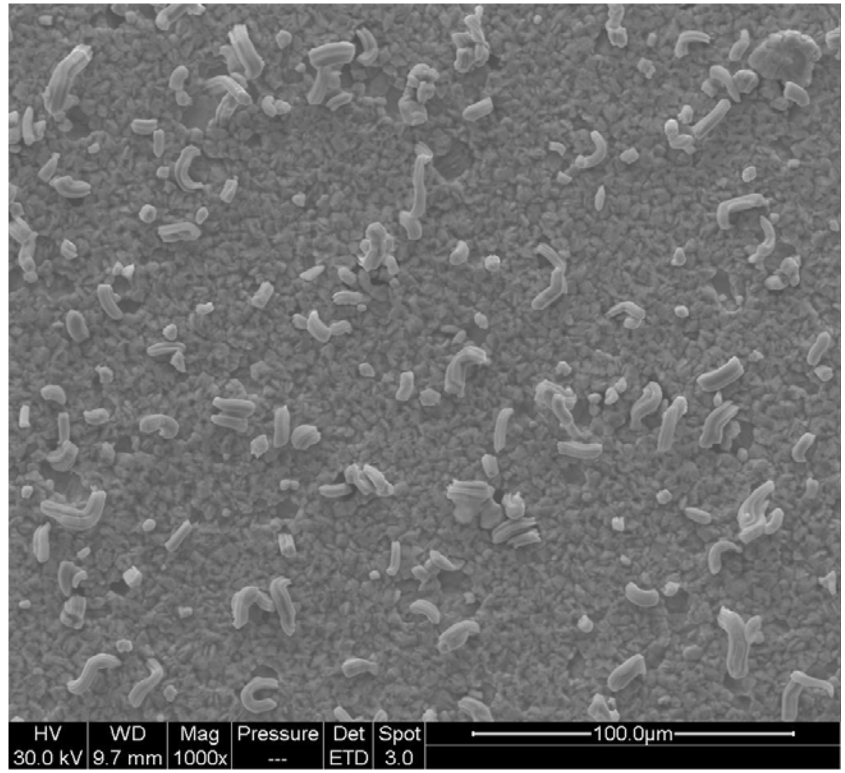
Temperature Cycling Results



Katsuaki Suganuma, Whisker research efforts and finding by JEITA, **4th International Symposium on Tin Whiskers, College Park, MD, June 2009**

Substantial Growth On Samples with and without Nickel Underlayer





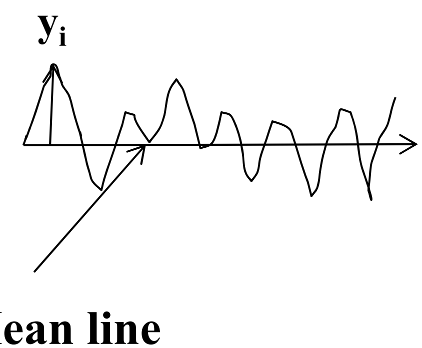
Whisker growth occurred on samples with and without nickel barrier. Statistics were obtained from the samples periodically during environmental exposures.

Influence of Surface Roughness

In 2010, Dr. Milad, Uyemura, presented finding on influence of surface roughness with 3 mm tin on a C19700 alloy lead frame material.

Ra is the arithmetic average of absolute values

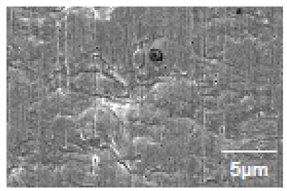
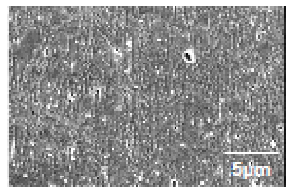
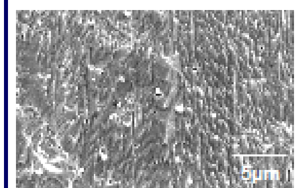
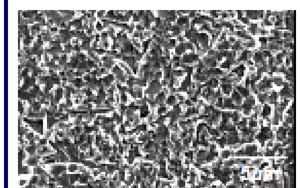
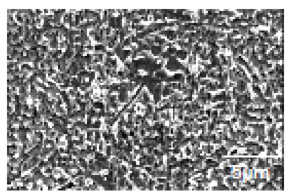
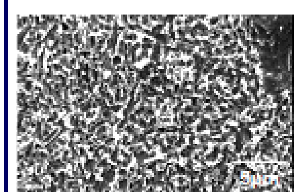
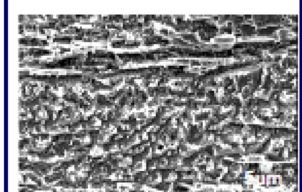
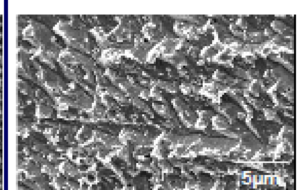
$$Ra = \frac{1}{n}\sum_{i=0}^{n}|y_i|$$



UYEMURA

Shape vs. Ra
the copper substrate surface

Ra (μm)

0.087(substrate)	0.120	0.187	0.249
			
0.288	**0.358**	**0.402**	**0.487**
			

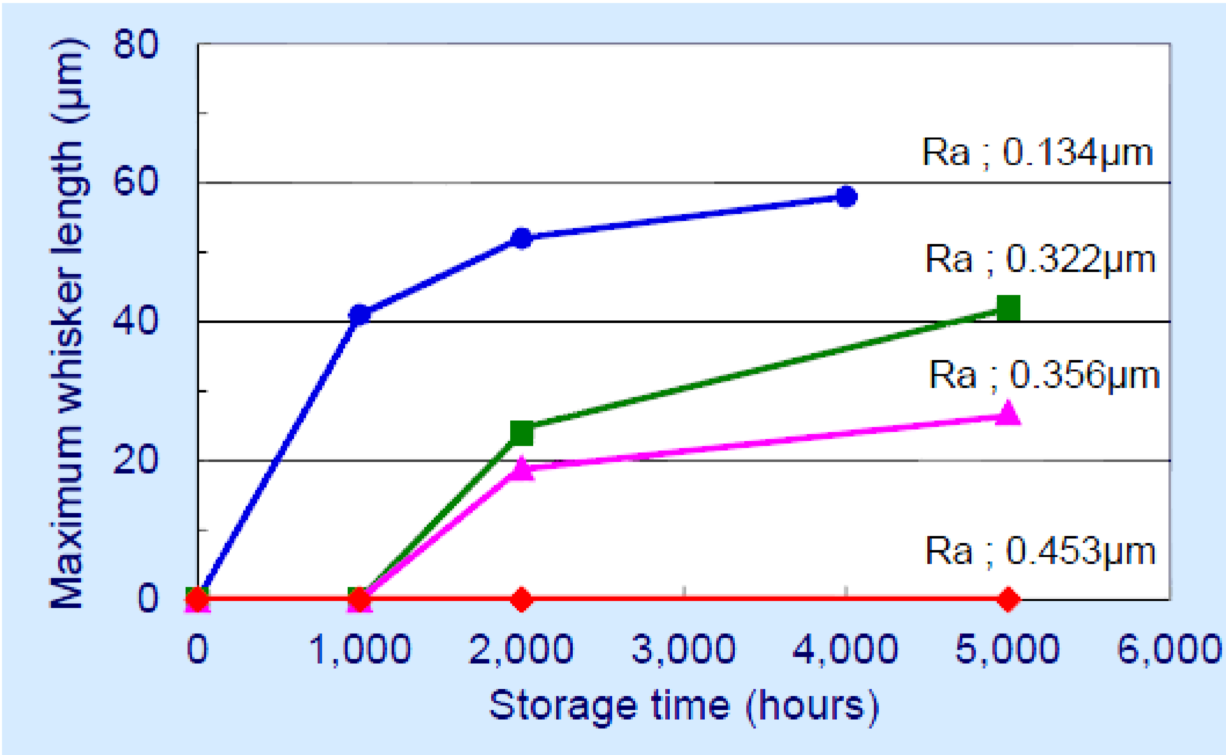
C. Uyemura & Co., Ltd. Page-14

Masanobu Tsujimoto and George Milad, Study of Tin Whisker Inhibiting Systems , Controlling the copper substrate roughness, Controlling the tin deposit crystal structure, IPC Whisker Conference, Dec 2010

The relation of Maximum whisker length vs. surface roughness

Samples : Tin thickness 10µm

Storage condition : 30ºC / 60%RH / 5,000hours



C. Uyemura & Co., Ltd. *Page-19*

Masanobu Tsujimoto and George Milad, Study of Tin Whisker Inhibiting Systems , Controlling the copper substrate roughness, Controlling the tin deposit crystal structure, IPC Whisker Conference, Dec 2010

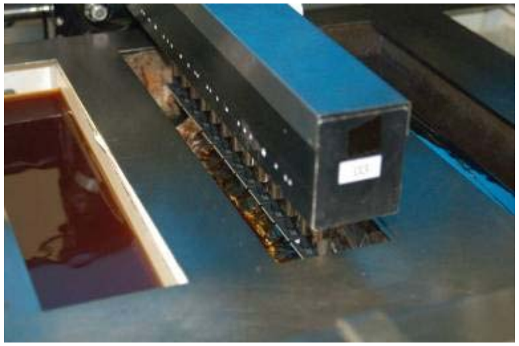
GEIA-STD-0005-2 Accepted Mitigations

- Hard potting or encapsulation
- Physical barriers
- Circuit design and analysis showing
  - low impact of tin whisker short or FOD
  - that areas sensitive to tin whisker shorts or FOD have at least a 1 cm gap for Level 2B
- SnPb soldering process with validated complete coverage
- Parylene conformal coating with validated coverage and gap size greater than
  - 150 microns for Level 2B
  - 250 microns for Level 2C
- Other, non-parylene, conformal coating with validated coverage and gap size (prior to coating) greater than
  - 250 microns for Level 2B
  - 500 microns for Level 2C
- Pb-free tin electronic components with gaps greater than 2000 microns (78.7 mils) that have been installed with SnPb and are physically isolated from any Pb-free tin mechanical piece parts for Level 2B
- Mitigation or combination of mitigations approved by the customer

Solder Dip Process

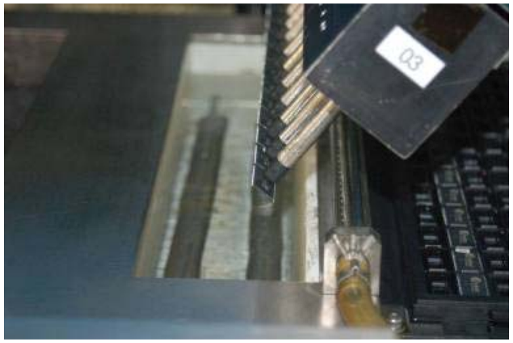
(a) Pick up parts

(b) Flux

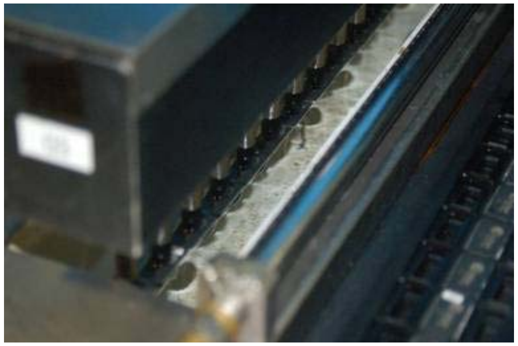


(c) Preheat

(d) Solder dip

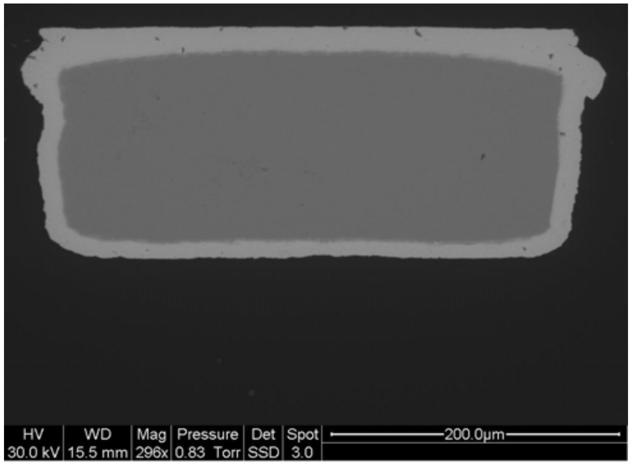


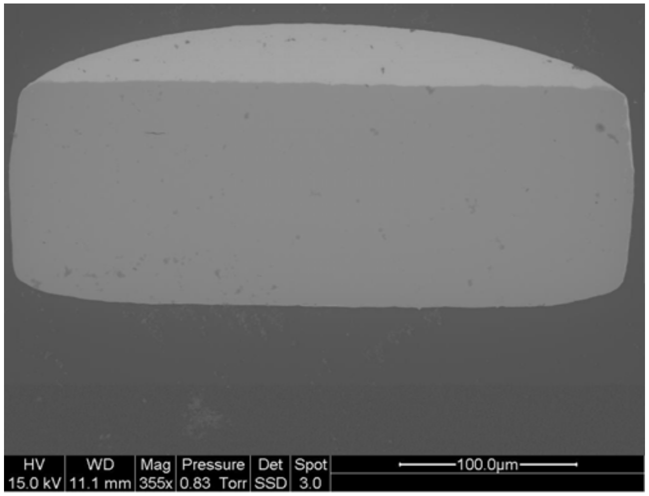
(e) Cool down

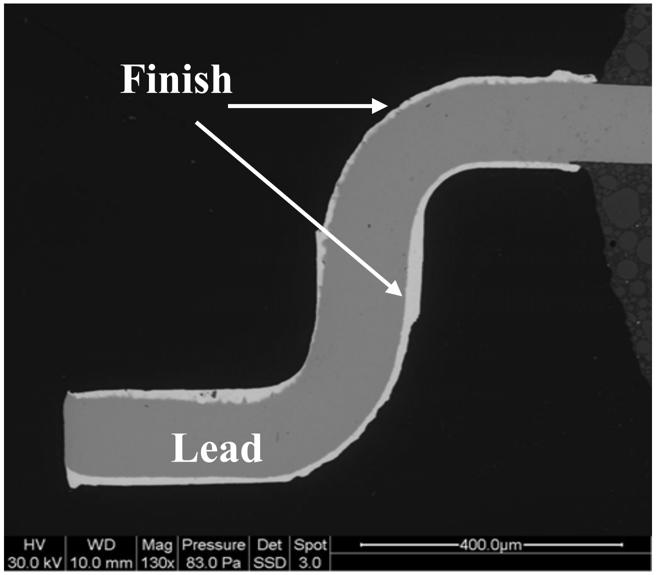


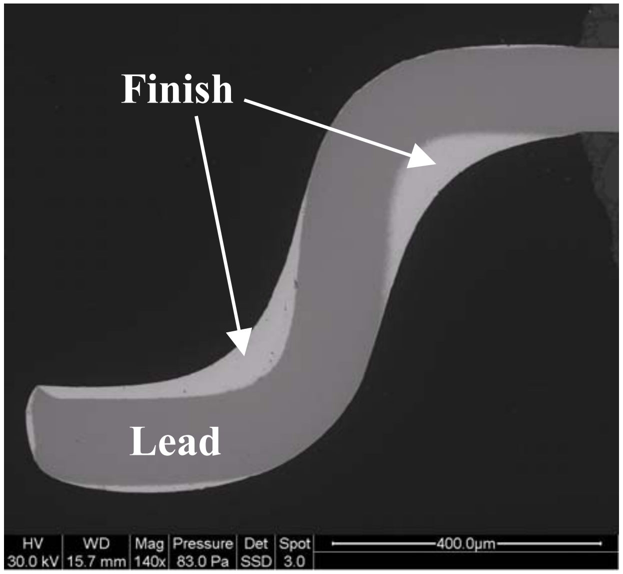
(f) Clean

Solder Dip Finish Coverage









Side view of lead finish

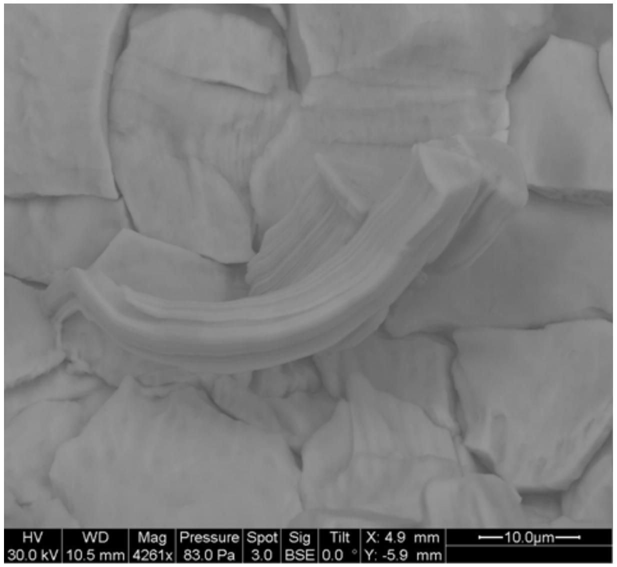
Side view of lead finish

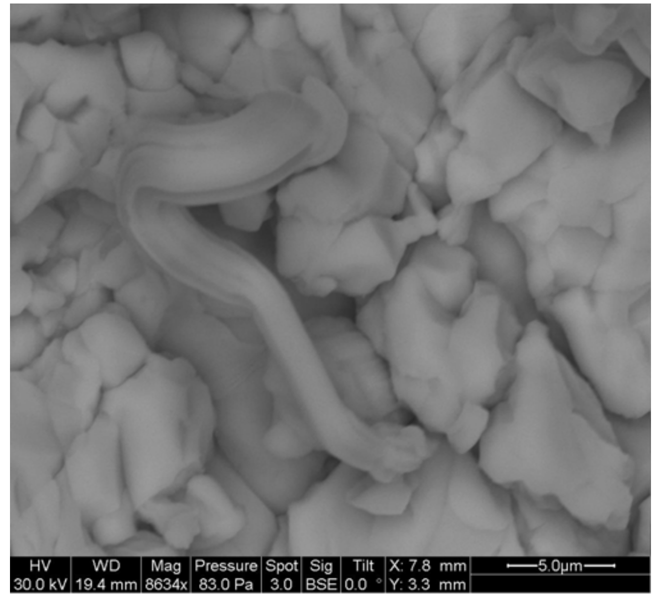
Alloy 42 Leads After 1000 Temperature Cycling

Sn

Max Length 50 µm

Density $300/mm^2$





SnBi

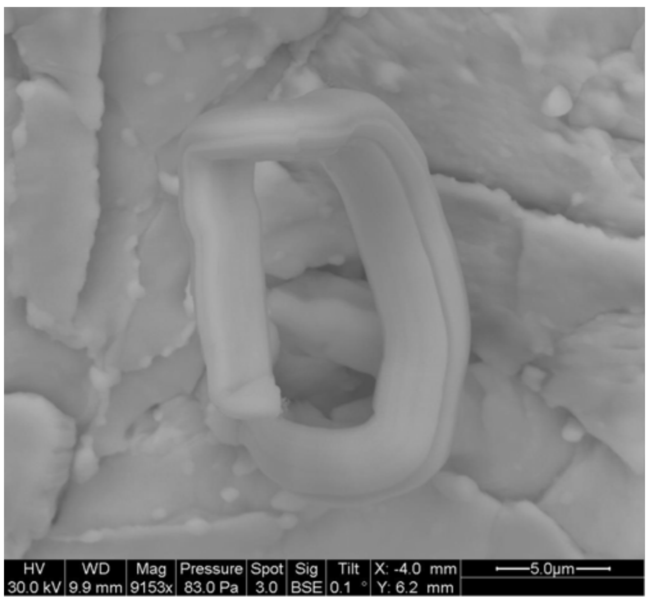
Max Length 37 µm

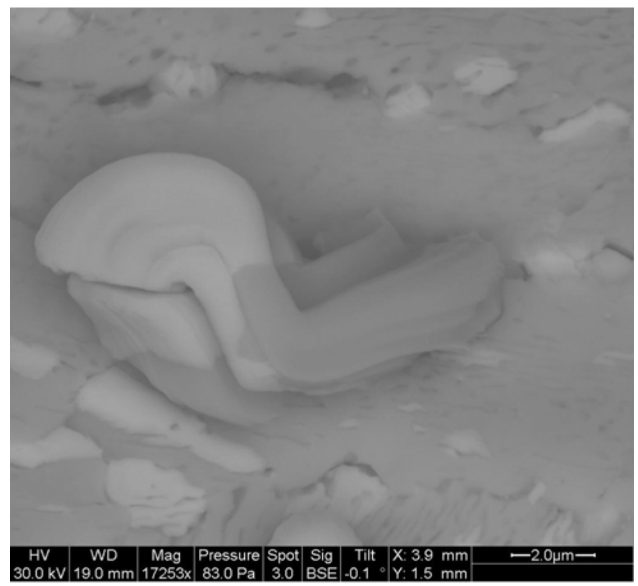
Density $1200/mm^2$

SAC dipped

Max Length 50 µm

Density $600/mm^2$



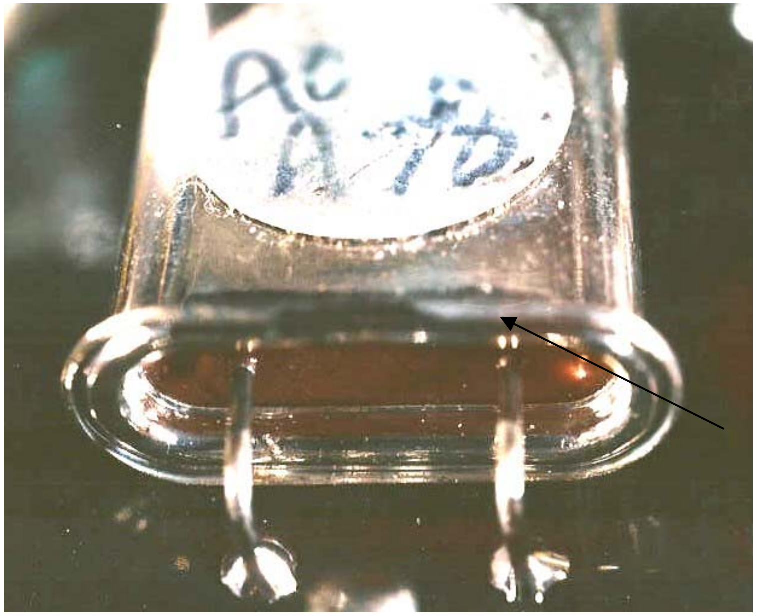


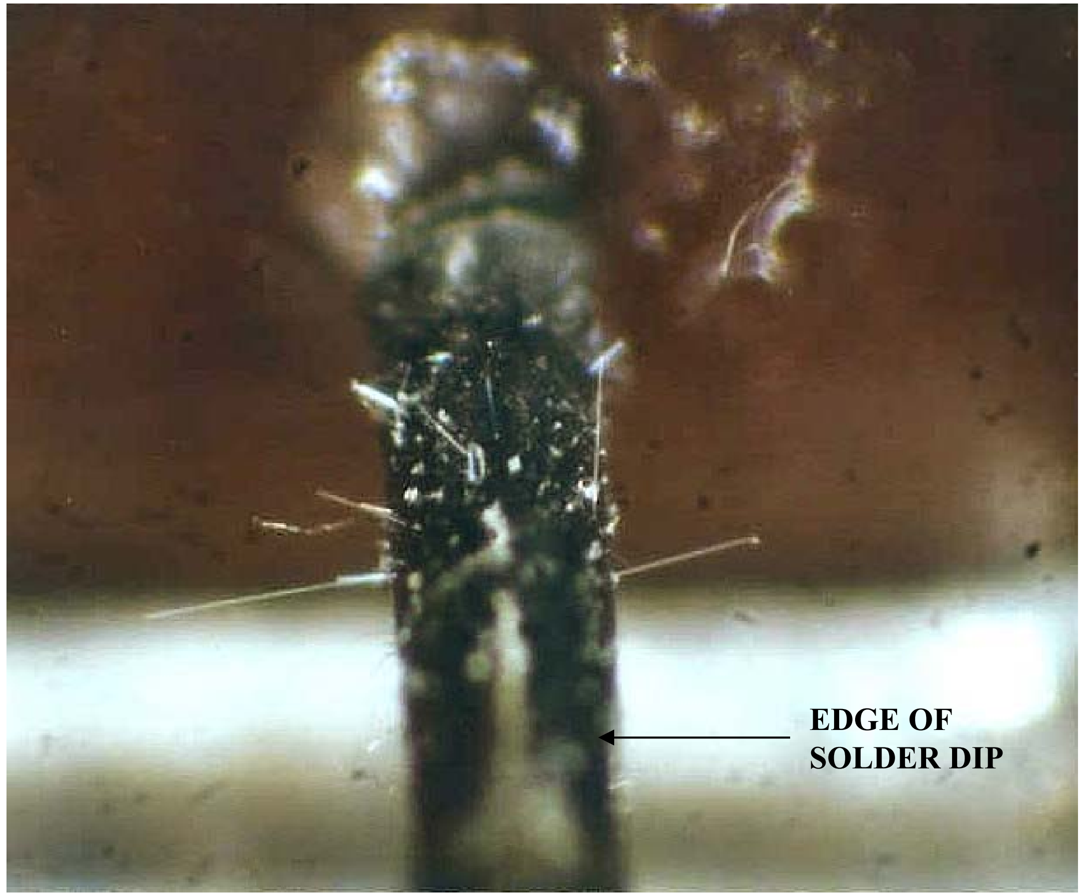
SnPb dipped

Max Length 37 µm

Density $1400/mm^2$

Solder Dip Mitigation Risk





TIN WHISKER GROWTH NOTED FROM SEAL TO ABOUT 20 MILS FROM EDGE OF SOLDER COAT. ELECTRICAL FAILURE WAS TRACED TO A 60 MIL WHISKER THAT SHORTED LEAD TO CASE.

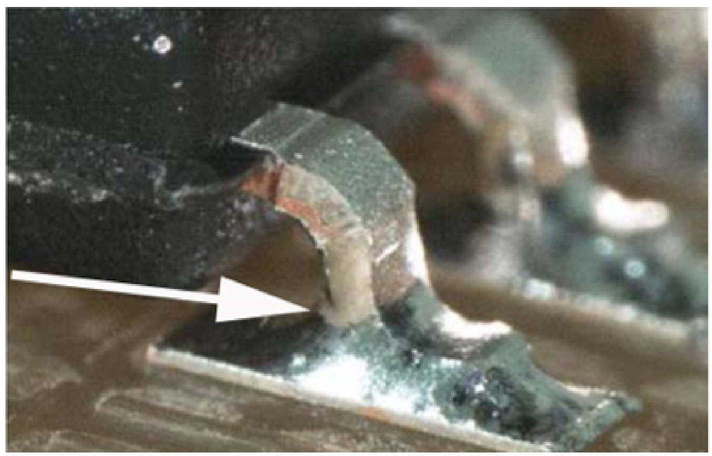
Solder Coverage Mitigations

Mitigation by Soldering with SnPb Solder

Raytheon

- This is a self mitigation or lead poisoning (Pb poisoning) technique
- Uses the tin / lead soldering process to add lead (Pb) to the solder joint and eliminate the risk of tin whiskers
- Still has the risk of insufficient solder flow down component lead surfaces

The arrow at right marks the point at which lead (Pb) containing solder stops



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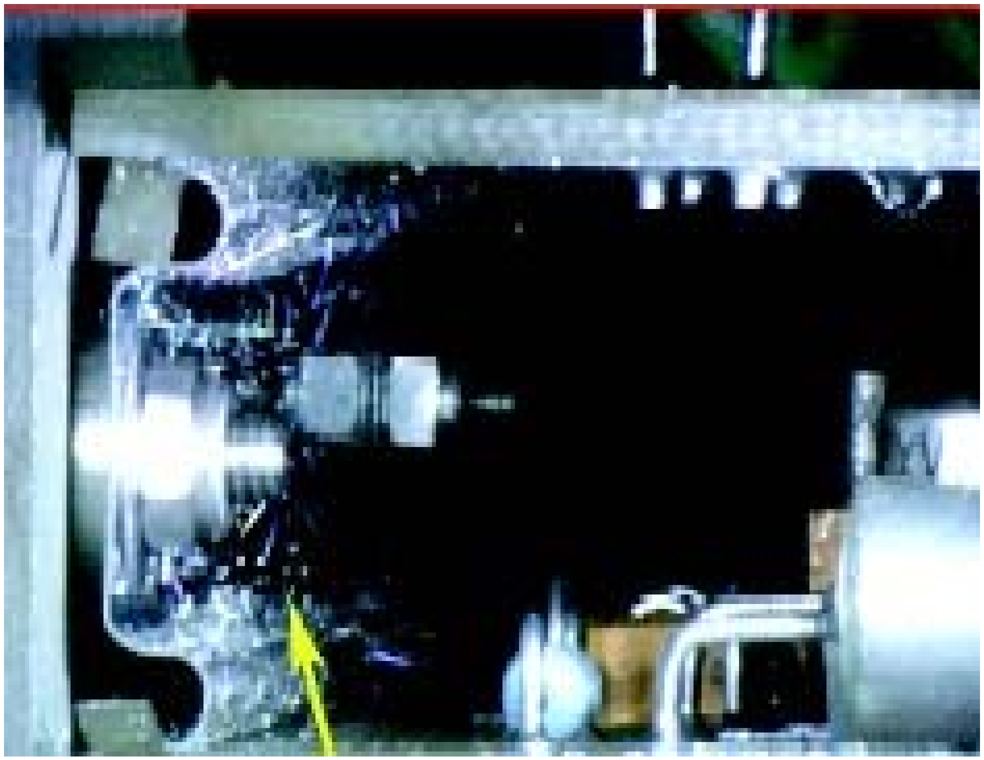
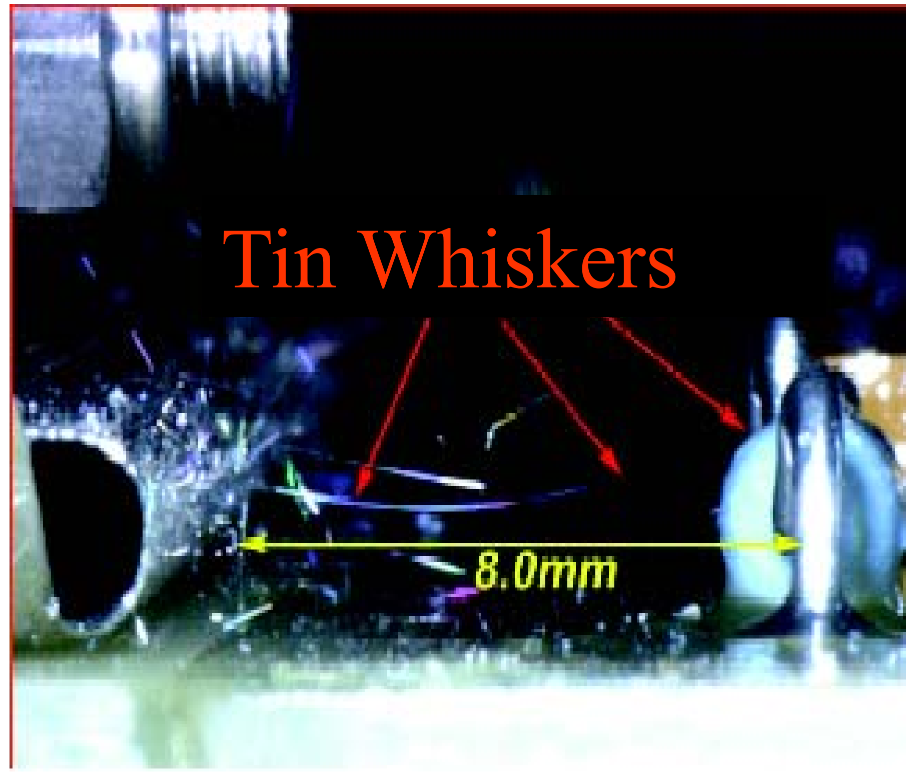
Vertical Termination Height to Horizontal Termination Length found to be a potential criteria to assess self mitigation.

Presented by Tom Hester Raytheon at
7th International Symposium on Tin Whisker (2013)
Held on November 12-13, 2013 in Costa Mesa, CA, USA November 12-13, 2013

Good Argument for Conformal Coating

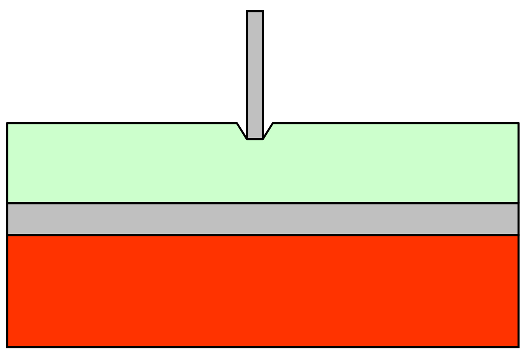




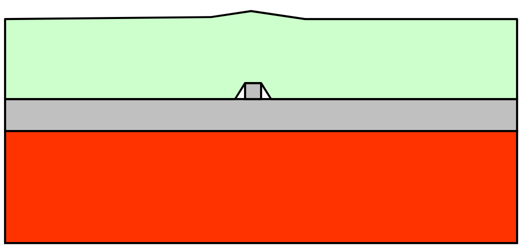
H. Leidecker, J. Brusse, "Tin Whiskers: A History of Documented Electrical System Failures", Technical Presentation to Space Shuttle Program Office, NASA, April 2006

Tin Whisker Failure Risk Mitigation Using Conformal Coating

– The conformal coating has been considered as a mitigation strategy for preventing the electrical shorts by tin whiskers.
– Recent research indicates that under elevated temperature and humidity or in areas of thin covering, whiskers can grow and penetrate conformal coatings.
– For long environmental exposure changes in the effectiveness of conformal coating may be compromised.



Prevent Contact

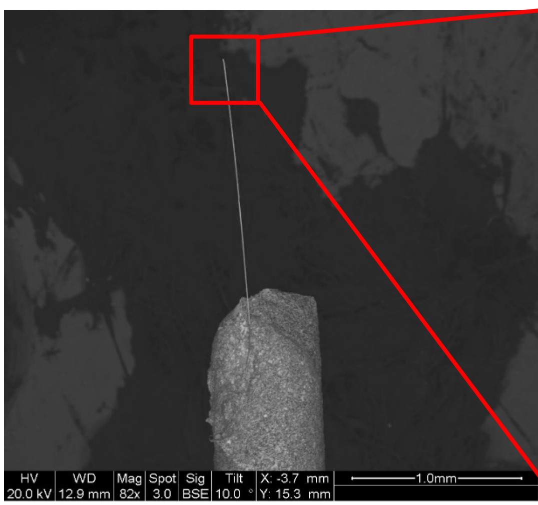


Contain Whisker

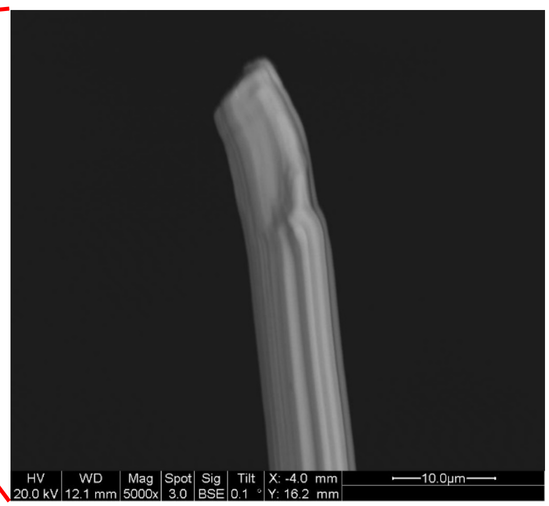
Whisker Penetration Test

- Nine whisker probes with various whisker lengths and diameters prepared for whisker probing test.
- The modulus of conformal coating measured using Nanoindenter prior to exposure the environmental loading to estimate the initial penetration depth by whisker probes.

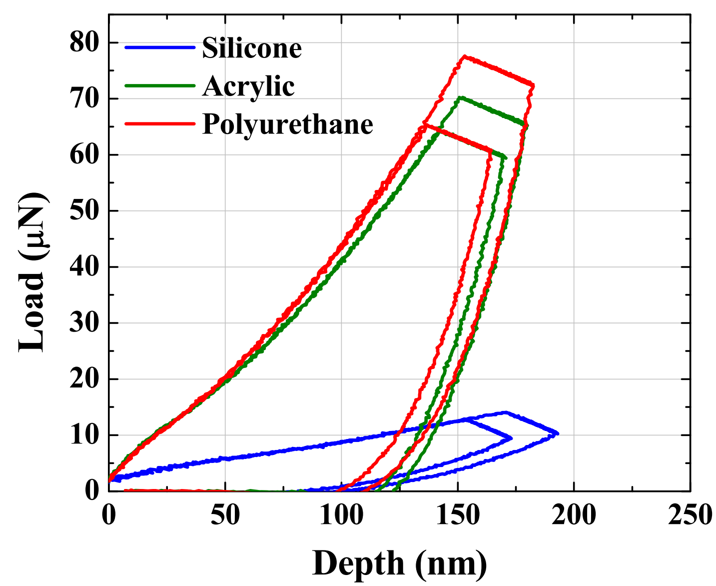
	Young's Modulus (GPa)	Thickness (µm)
AR	0.08	1.4
UR	0.09	0.4
SR	0.02	8.4



Whisker probe



Whisker Tip

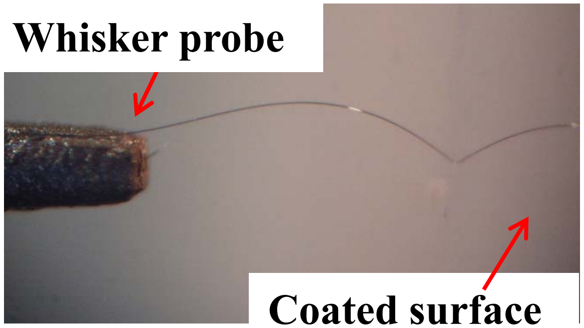


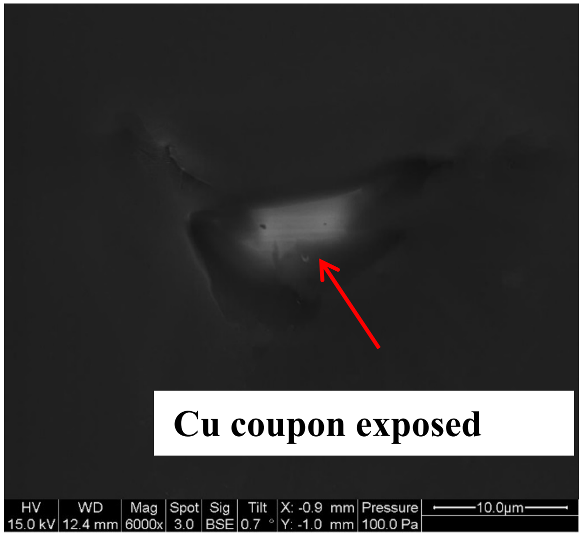
Depth versus load curve

Whisker Probing on Coated Surface

- Every coated surface on single coupon was probed using whisker probes and applied the voltage ramp 0 - 100 V by parameter analyzer.
- No breakdown occurred and no visible marks found on any of the tested coated surfaces; SR, UR, and AR.
- However, breakdown was shown when tungsten(W) probe used, because the substrate coupon was exposed as a result of surface damage by sharp tip of probe.

Probing by whisker probe





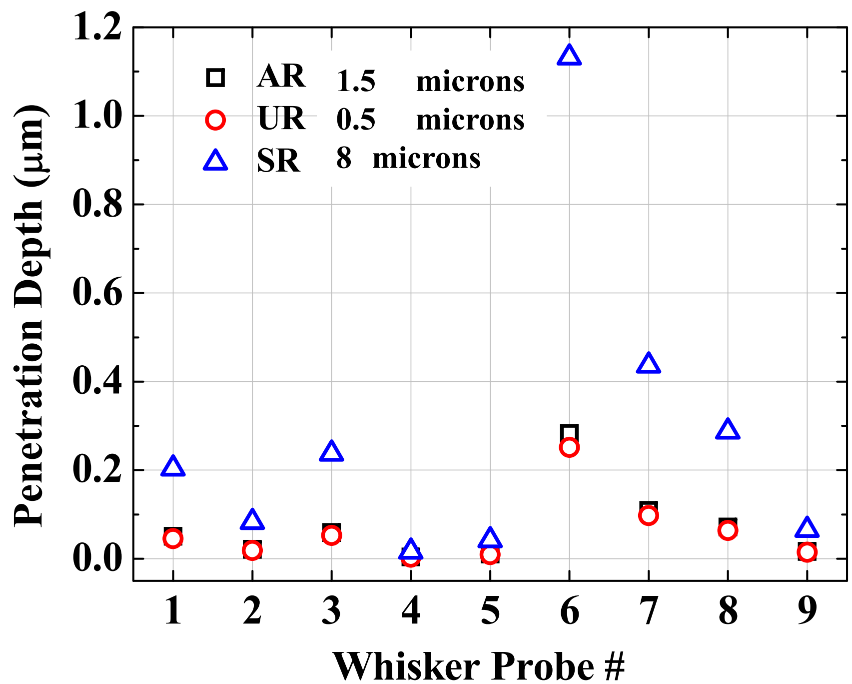
Surface damage by W probe tip

Depth of Penetration by Whisker Buckling Model

- The depth of penetration depending on the whisker probes calculated based on Buckling model [1].

$$D = \frac{(1-\nu^2)\cdot \pi^3 \cdot E_w \cdot d^3}{32 \cdot E_c \cdot L^2}$$

D = Depth of penetration
ν = Poisson's ratio of coating
E = Young's modulus (w:whisker, c:coating)
d = Diameter of whisker
L = Length of whisker

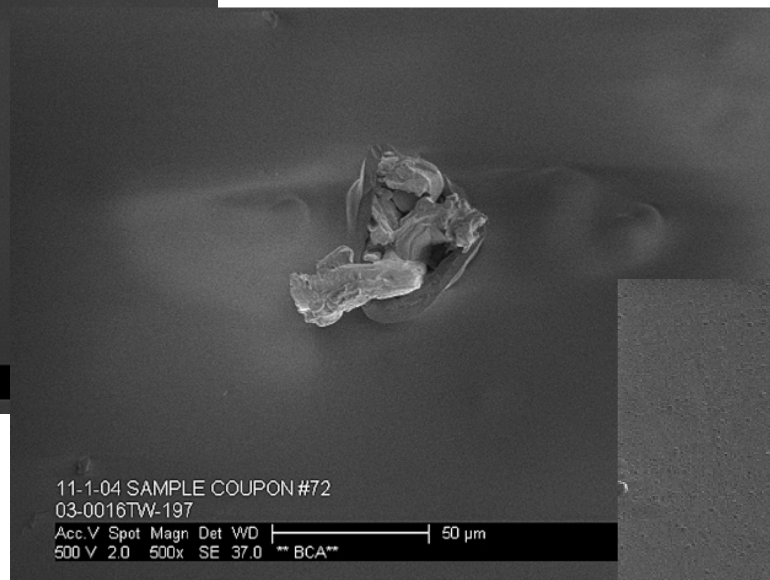


- Theoretically prepared whisker probes should not create electrical shorts, even on thin UR coating.

[1] Model reported by J.S. Kadesch and H. Leidecker,, "Effects of Uralane Conformal Coating on Tin Whisker Growth", ***Proceedings of IMAPS Nordic, The 37th IMAPS Nordic Annual Conference, pp. 108-116, September, 10-13, 2000.***

Tin Whisker Mitigation with Conformal Coat

Urethane Acrylic
~ 33 µm



Silicone ~ 33 µm

Parylene C ~ 20 µm

NASA has test coupons coated with a 50 µm Urethane that has effectively contained whiskers for over 12years. While conformal coating provided substantial protection against shorts due to tin whiskers, it cannot be assumed to be complete. Above photos show tin whiskers penetrating various coatings.

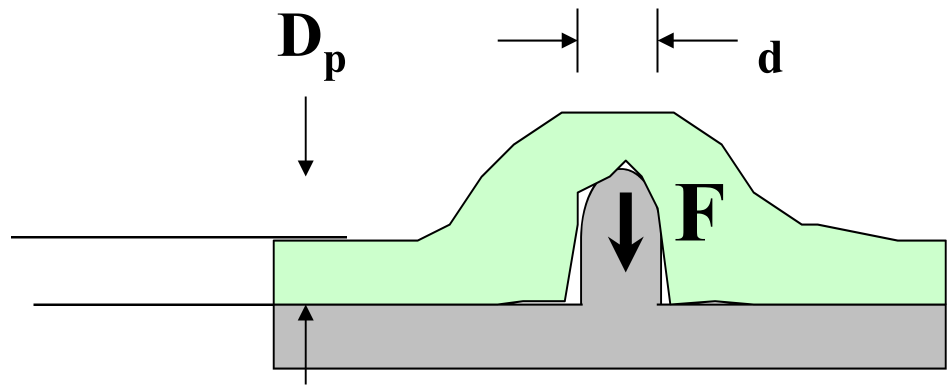
Photos courtesy of Tom Woodrow, Boeing

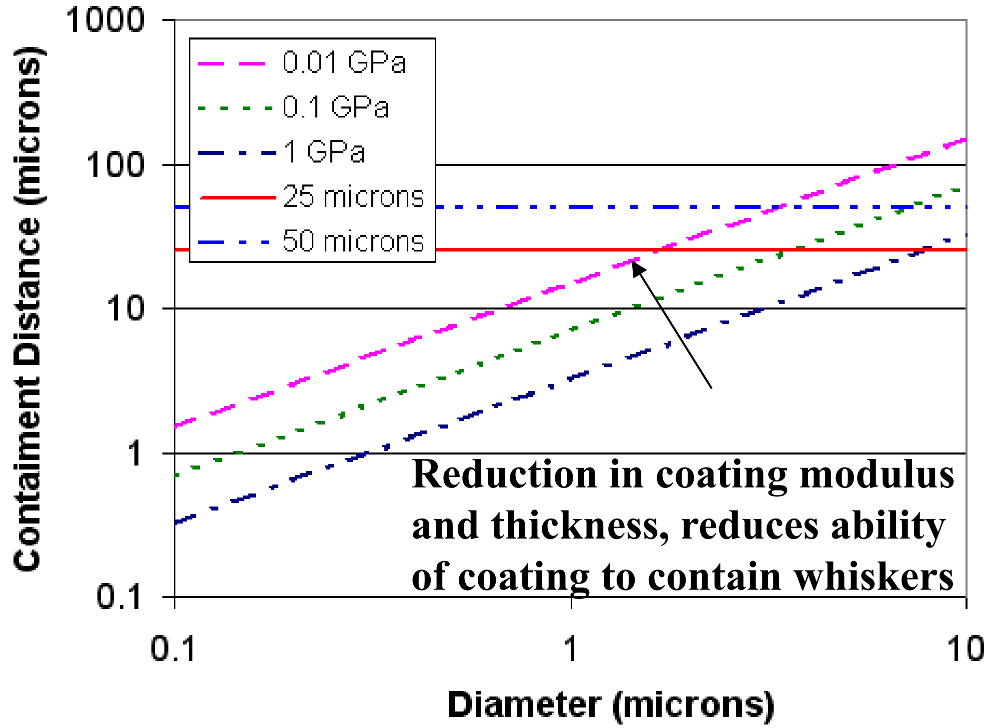
Whisker Containment

Assuming the buckling force still limits growth, the equations providing by Kadesch and Liedecker can be reformulated to give a rough estimated of the containment capability of conformal coating. The containment depth can be expressed as

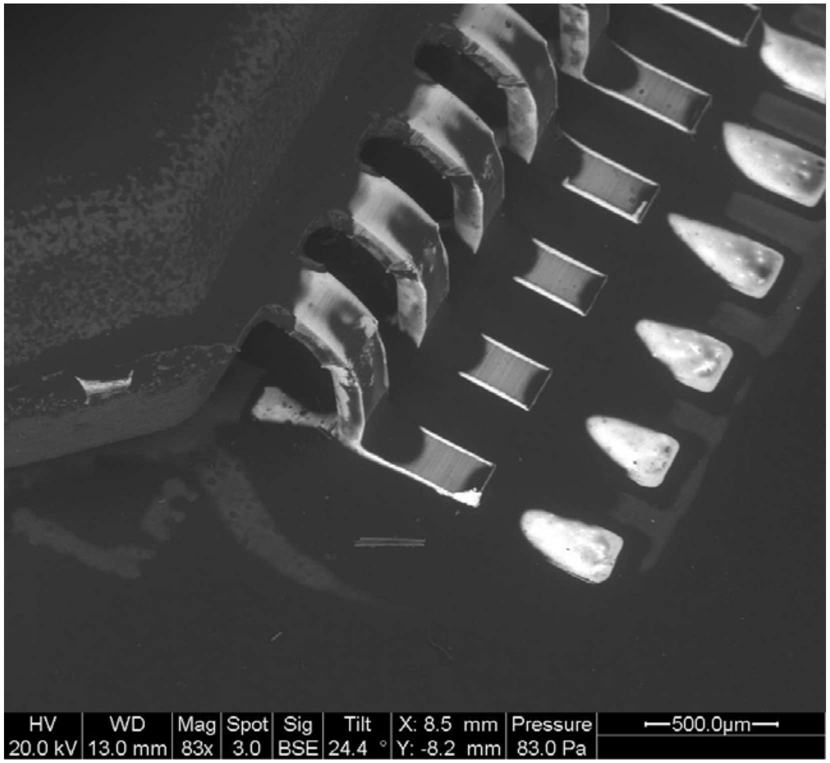
$$D_p \approx \pi d \left(\frac{(1-\nu^2)E_w}{32E_c} \right)^{\frac{1}{3}}$$

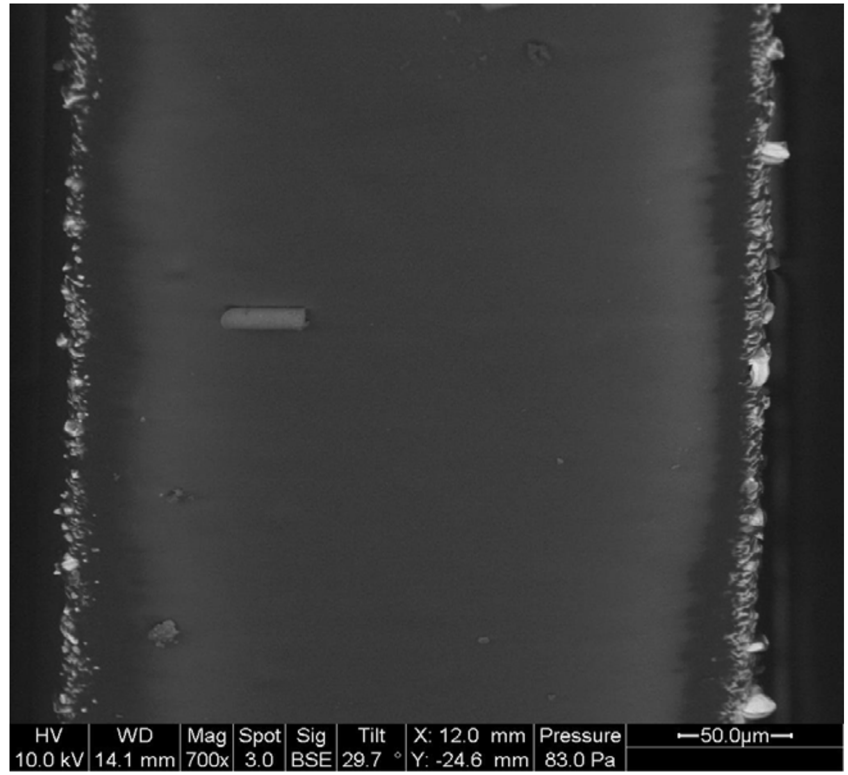
The model does not consider ductility, strength, or thinning of coating nor the peel strength, and may not be strictly correct but it does provide a starting point. Further, detailed model will be needed to better understand the physics of containment.





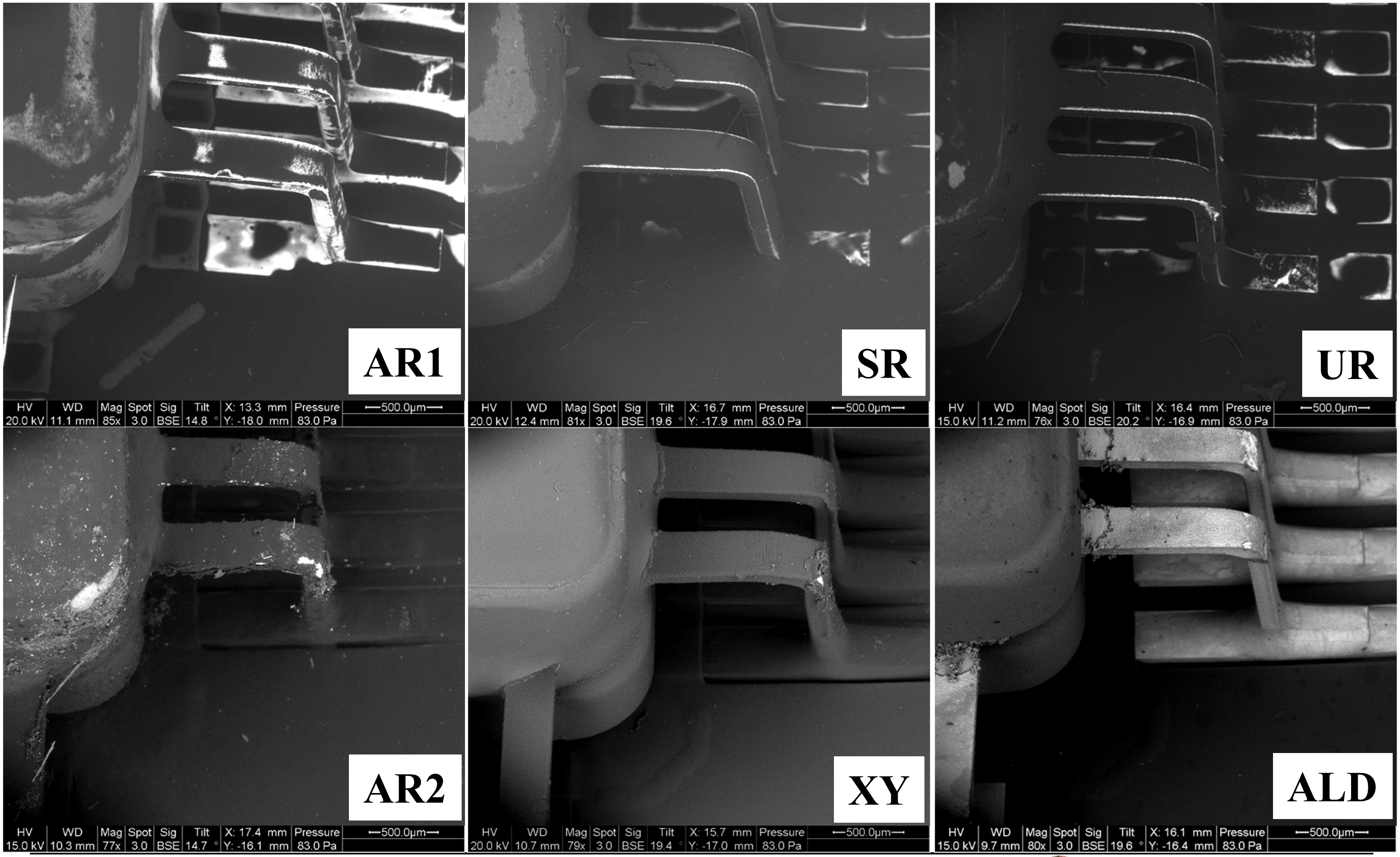
Coverage Issue



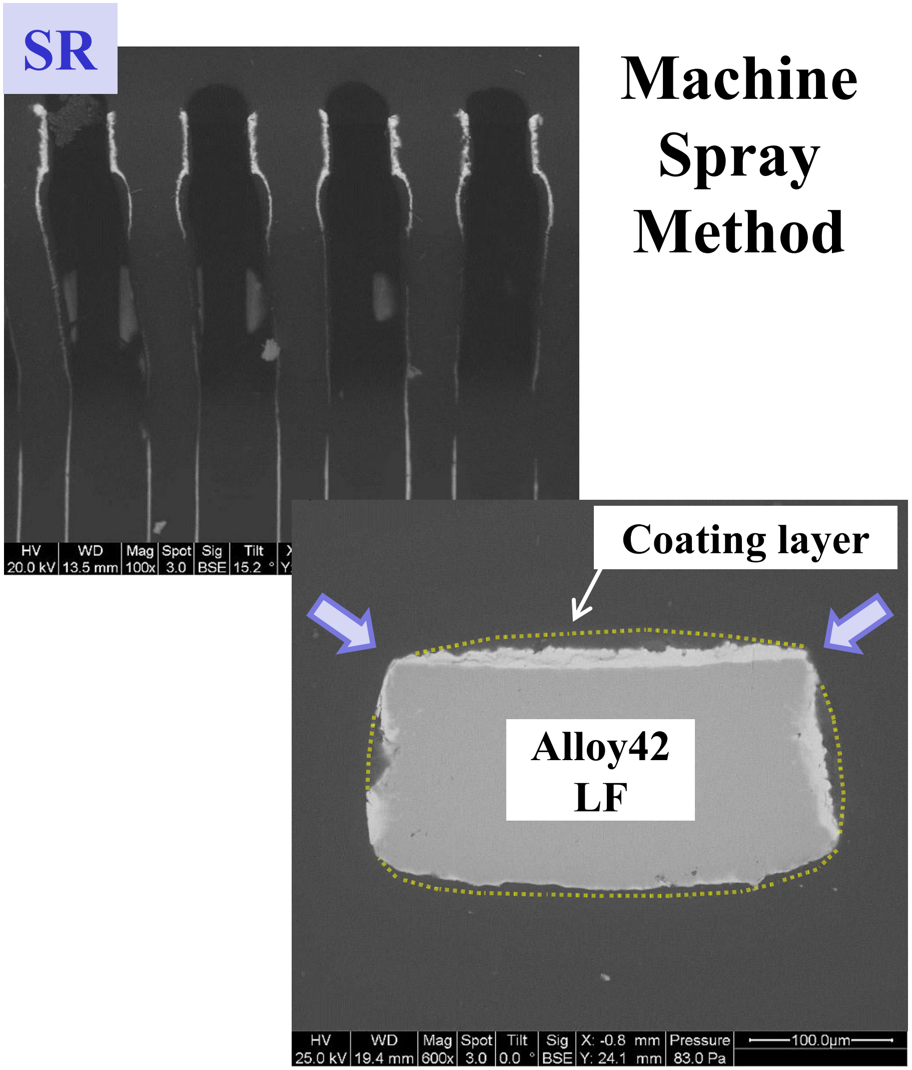


Research has demonstrated thickness of coating plays a significant role in ability of coating to contain and prevent whisker penetration. For conformal coats, coating thickness is measured on flat areas. As a result, effectiveness of conformal coating as a whisker mitigation is compromised.

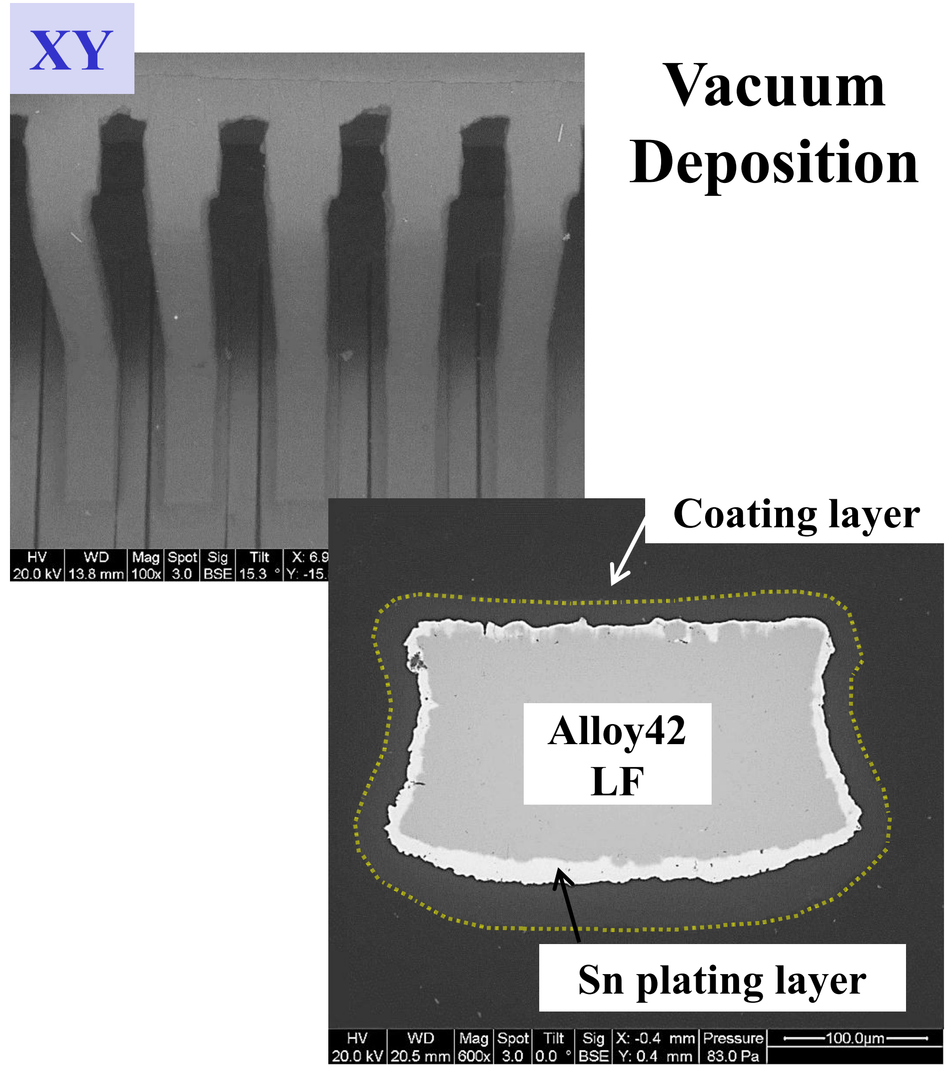
Comparison of Coatings



Coating Coverage on Leads (Shoulder)

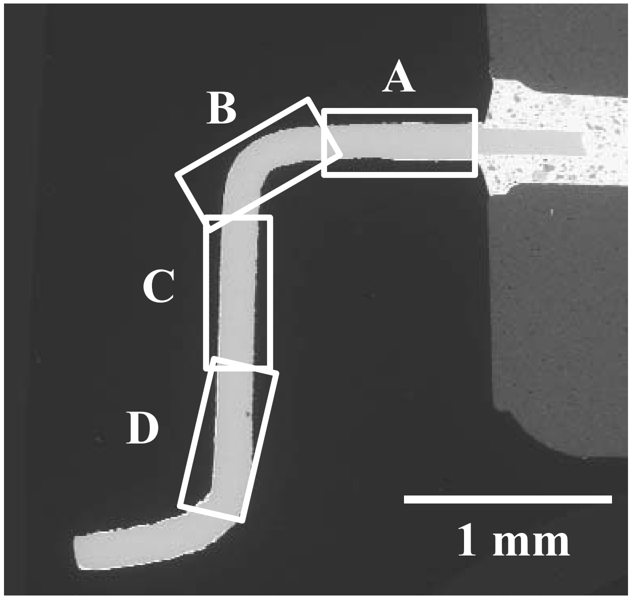


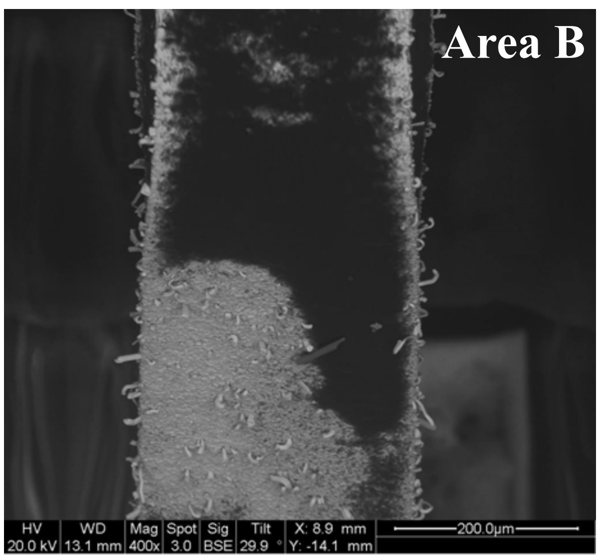
Machine Spray Method

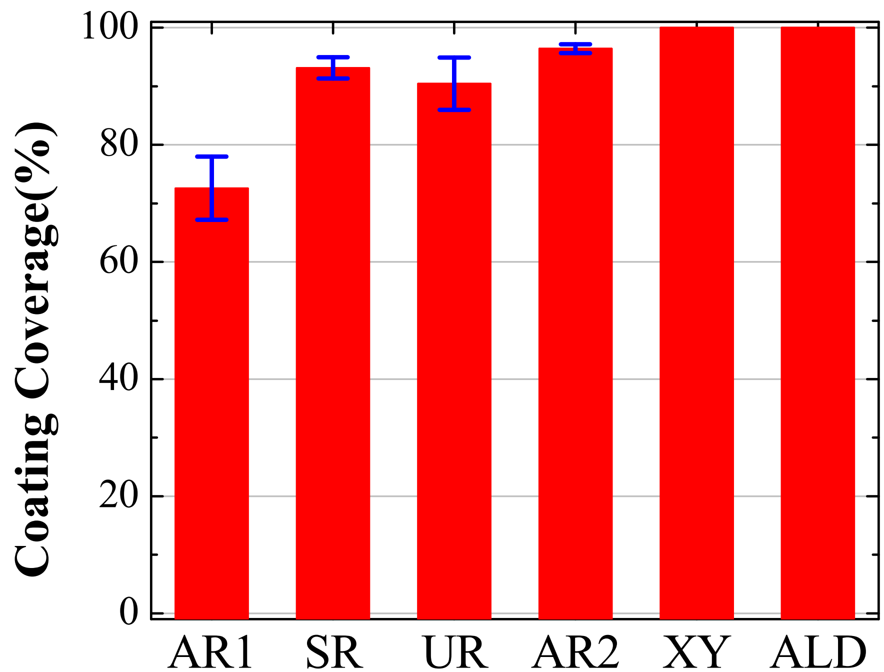


Vacuum Deposition

Quantitative Analysis of Coating Coverage





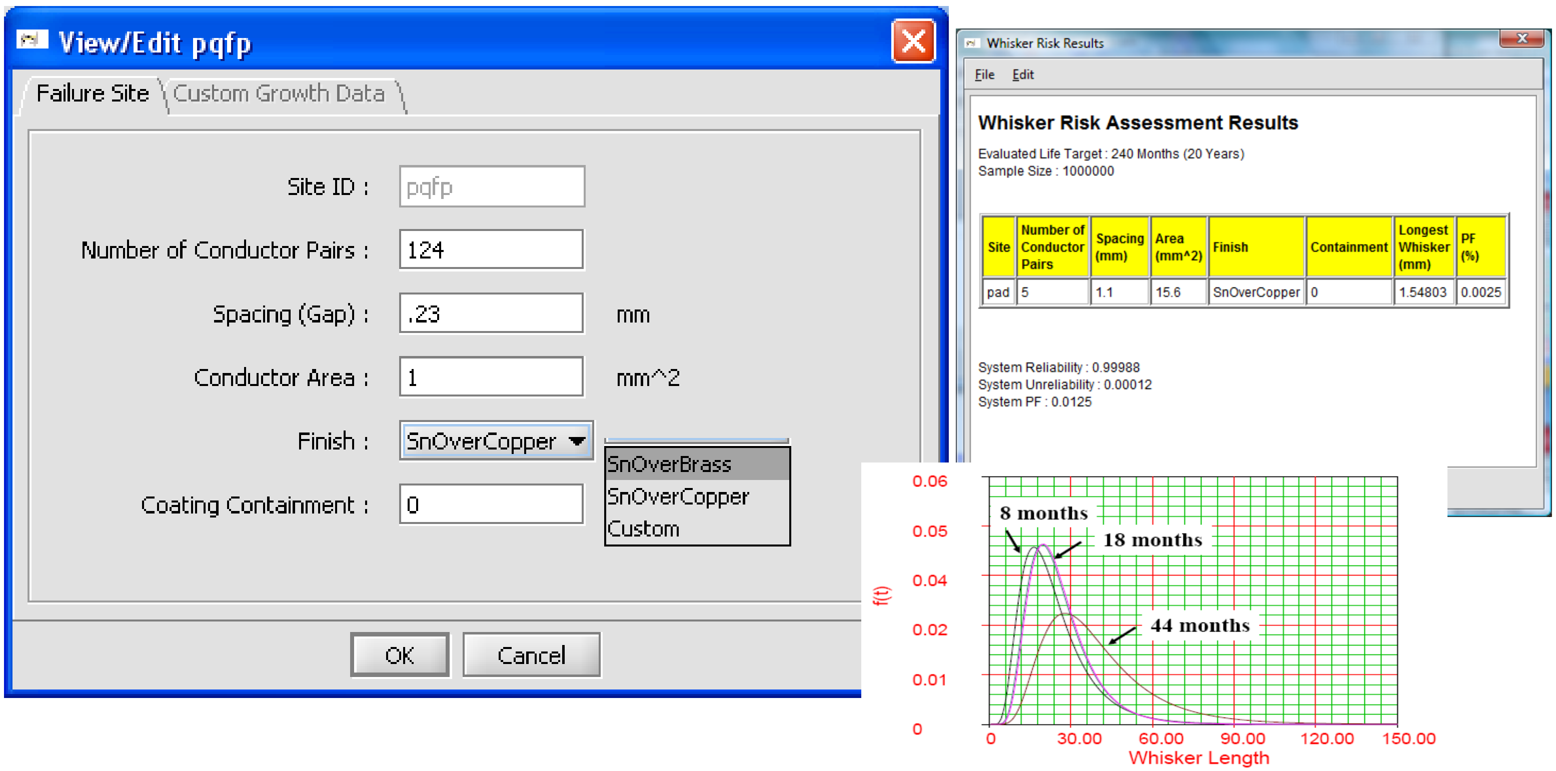


$$\text{Coating coverage} = \frac{\text{Dark area}}{\text{Total lead area}}$$

- The result from the quantitative image analysis is consistent with the initial inspections.

Tin Whisker Risk Assessment

Tin whisker risk is estimated using whisker growth statistics (length and density), and component and assembly conductor materials and dimensions. Distribution of whisker lengths on tin plated surfaces found to follow a lognormal distribution. A monte carlo algorithm can be used to evaluate the risk.

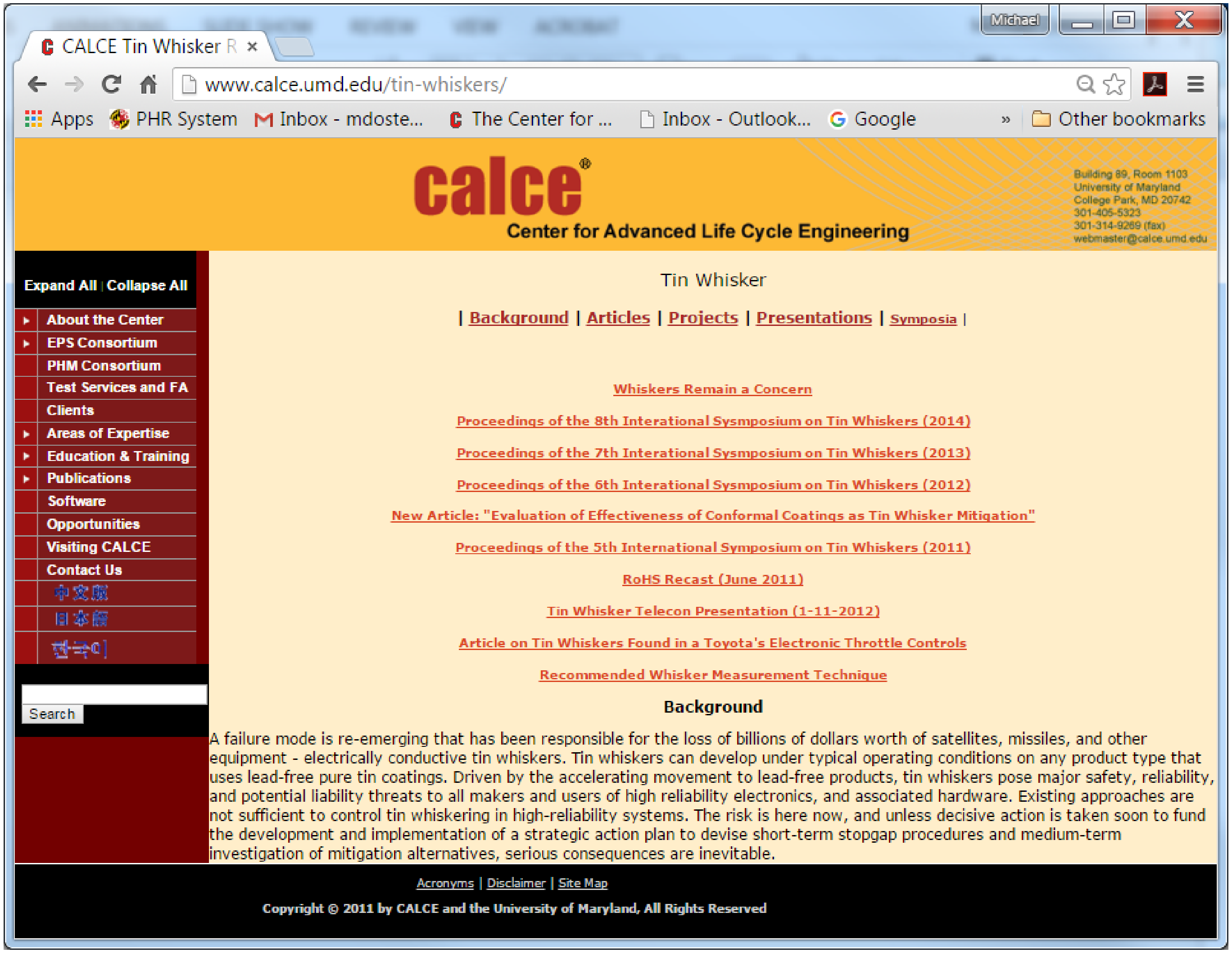


More Information at http://www.calce.umd.edu/software/

Summary and Conclusions

- All pure tin and Pb-free tin alloy finishes appear to be susceptible to whisker formation.
- Part supplier mitigation strategies show varying levels of effectiveness
  - Annealing of tin over copper may delay whisker growth.
  - Nickel underlayer provides some mitigation to whisker formation but does not necessarily prevent whisker formation.
  - Increased surface roughness shows promise in delaying whisker growth
- Solder Dip in Tin-Lead Solder found to be effective. But, may not be applicable to all parts and be careful about coverage.
- Solder Assembly must confirm solder coverage.
- Conformal coat reduces the probability of whisker short but may not completely contain whiskers.
  - Coverage in application remains a critical concern.
    - Parylene found to have the best coverage.
    - Sprayed coatings may have poor coverage.
- Failure risk due to tin whisker formation is application dependent and should be assessed based on defined geometries and whisker growth characterizations.
- OEMs should develop a plan for mitigating risk due to tin whisker formation.

For More Information on Tin Whiskers



http://www.calce.umd.edu/tin-whiskers/

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