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Assessing the Risk Posed By Tin Whiskers

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http://www.calce.umd.edu

Formed 1986

ISO 9001 Certified, 1999

What is CALCE?

http://www.calce.umd.edu

Center for Advanced Life Cycle Engineering (founded 1986) is dedicated to providing a knowledge and resource base to support the development and sustainment of competitive electronic components, products and systems.

Areas of research

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

~26 Faculty and Research Staff
~19 M.S. students
~66 Ph.D. students

Education
- MS and PhD EPS program
- International visitors
- Web seminars
- Short courses for industry

EPS Consortium
- 40-45 companies
- Pre-competitive research
- Risk assessment, management, and mitigation for electronics

PHM Consortium
- Pre-competitive research
- Research in fundamental methodologies to develop and implement prognostics and health management systems.

CALCE
Center for Advanced Life Cycle Engineering
~$5 million/yr

Research Contracts
- Larger programs
- Some past programs:
- Power Electronics (Navy)
- Embedded Passives (NIST)
- Risk Management (USAF)
- Life Assessment (NASA)
- MEMS (NASA,NSWC)

Lab Services
- Small jobs
- Fee-for-service
- Proprietary work
- Use of CALCE Tools & Methods
- Turnkey capabilities
- "Fire-fighting"

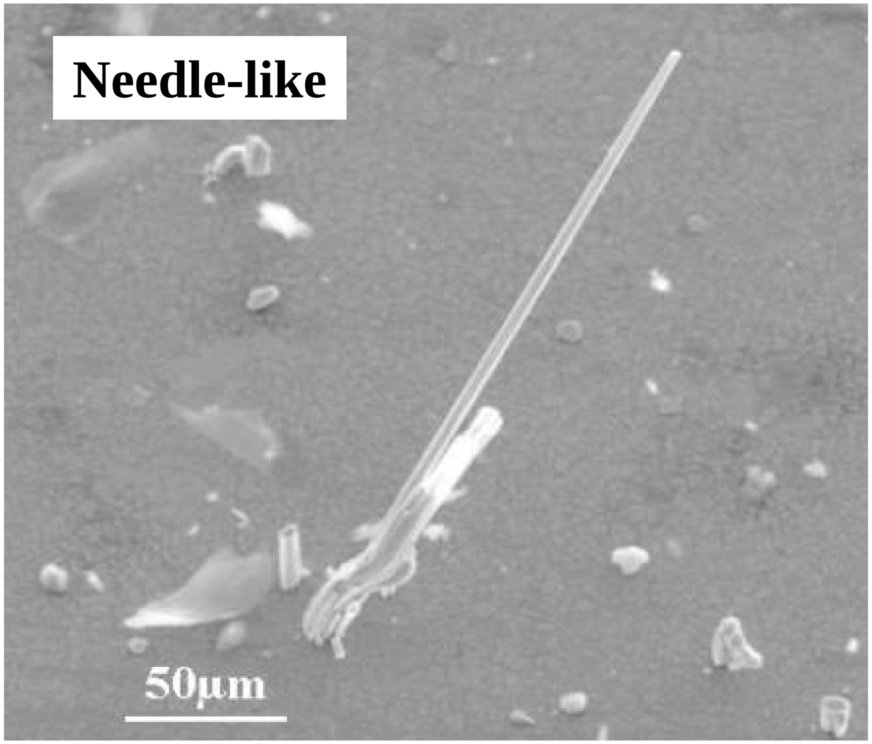
Long-term Pb-free Reliability Study
- Aging
- Intermetallic formation
- PCB surface finish
- ECM
- Solder interconnects

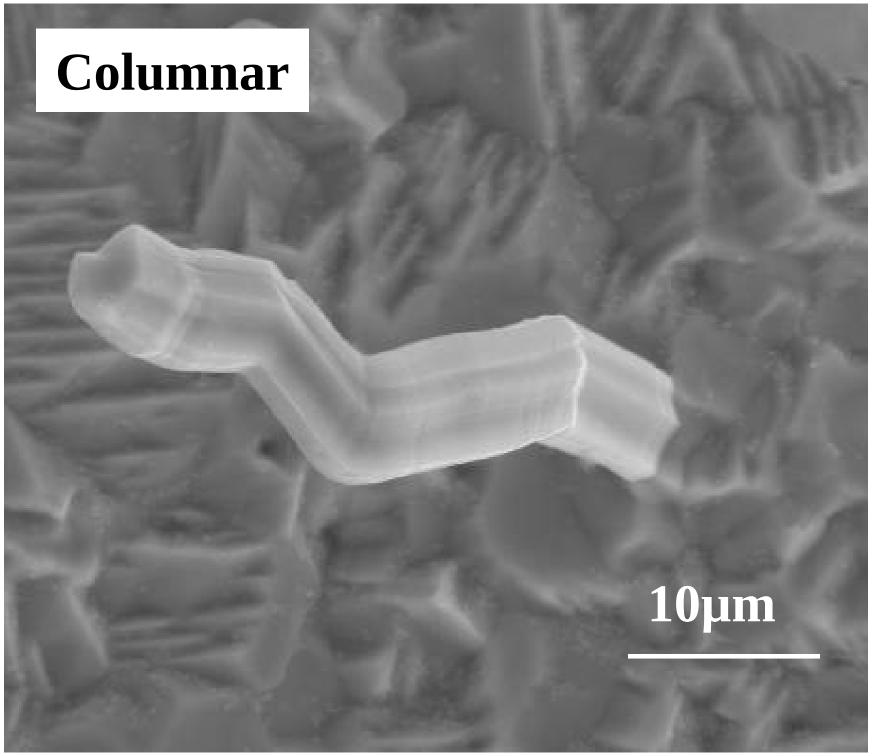
CALCE Consortia Members

- Arbitron
- Aavid Thermalloy
- ACEL, China
- Argon
- B & G , Sequel, CA
- BAE Systems
- Beihang University, China
- Boeing
- DBD, Germany
- Defense Logistics Agency
- Dell Computer Corp.
- EADS CCR, France
- Emerson
- EMC Corp.
- Ericsson AB, Sweden
- ERS
- Faraday
- General Dynamics, AIS
- GE Corp.
- Goodrich Engine Control, UK
- Grundfos, Denmark
- Hamilton Sundstrand
- Harris Corp.
- Hewlett-Packard Co.
- Honeywell
- Instit. Nokia de Tecnologia, Brazil
- Lutron
- Medtronic, Inc.
- Mercury Computer Systems
- Motorola
- NASA
- NAVAIR
- Northrop Grumman Corp.
- Naval Surface Warfare Center
- Nokia Research Center, Finland
- Philips Electronics, The Netherlands
- Qualmark
- QinetiQ Aquila, UK
- Reactive Nano Tech
- Research In Motion, Ltd., Canada
- ReliaSoft Corporation
- Rockwell Collins, Inc.
- Rolls Royce
- SAIT, Korea
- Samsung Memory, Korea
- Samsung Techwin Co., Ltd., Changwon-si, Korea
- Sandia National Labs
- Schlumberger Oil Field Services
- Seagate Technology Inc.
- Siemens AG, Germany
- Smiths Aerospace
- Sun Microsystems (StorageTek),
- Tessera
- TRW Automotive, UK
- Toshiba, Japan
- U.S. AMSAA
- U.S. Army Research Lab.
- U.S. Army Picatinny
- Whirlpool Corp.

What are Tin Whiskers?

Tin whiskers are conductive columnar or cylindrical filaments, usually of mono-crystalline tin, that spontaneously form on tin based finished surfaces. Tin growths can range in length from a few microns to over 1 mm. Whiskers are also known to form on Cd and Zn finished surfaces.





** Images are the examples of tin whiskers observed in CALCE experiments*

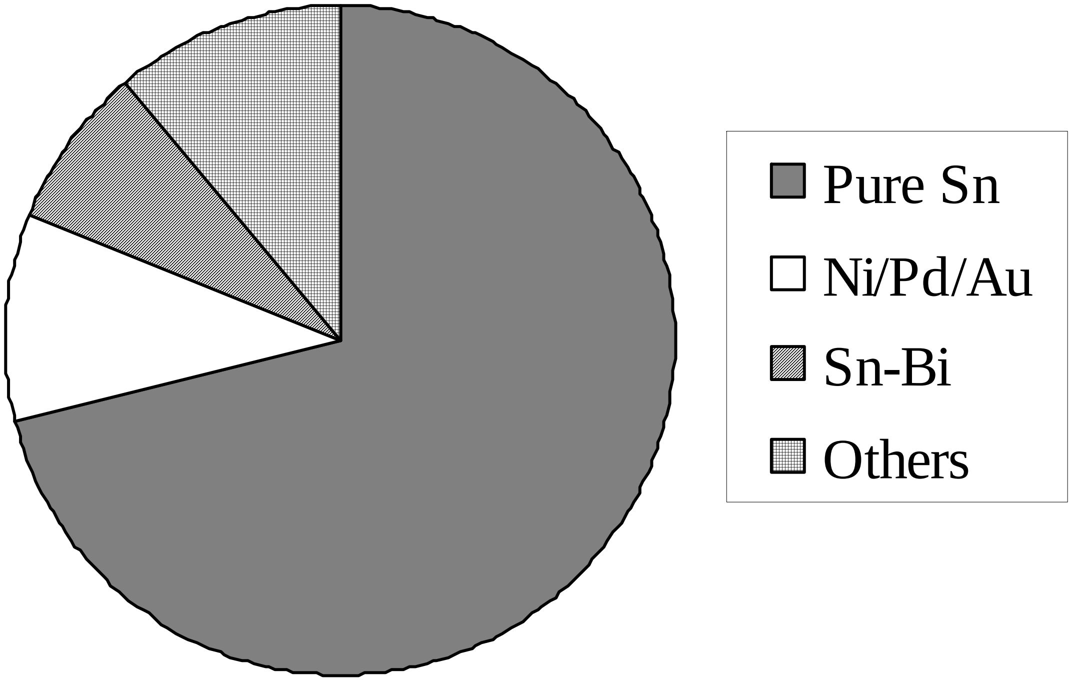
Pb-free Legislation in Europe

- Waste Electrical and Electronic Equipment (WEEE) legislation aims to increase recycling and recovery of end-of-life electronics.
  - Producers (manufacturers, sellers, distributors) will be responsible for financing the collection, treatment, recovery, and disposal of WEEE from private households deposited at collection facilities by 13 August 2005.
- Restriction of Hazardous Substances (RoHS) legislation prohibits the use of lead and other harmful substances (i.e., mercury, cadmium, chromium, PBBs, PBDEs) in new electrical and electronic equipment put on the market after 1 July 2006.
  - Pb-free is defined as <0.1% Pb by weight in a homogeneous materials
  - Self-certification, market surveillance
  - Provides exemptions (e.g. high lead solders for die attach)
  - Defense and aerospace not in scope
  - Batteries not in scope
- Both articles were issued by the European Union (EU) January 2003.

European Union. (13 February 2003). "Directive 2002/95/EC/ of the European Parliament and of the Council of 27 January 2003 on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment," *Official Journal of the European Union*, pp. L37/19-L37/23, <http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_037/l_03720030213en00190023.pdf>, (reviewed on 6 August 2005).

Part Manufacturers

Under pressure to comply with impending government regulations, electronic part manufacturers converted to Pb-free finish that would be compatible with conventional Sn37Pb solder assembly process and the likely Pb-free solder assembly processes.



(Based on CALCE survey of 121 suppliers)

Tin as a Lead Free Alternative

Advantages

- Low cost
- Widely available
- Least requirement for change in existing process and equipment.
- Good corrosion resistance
- Good electrical conductivity

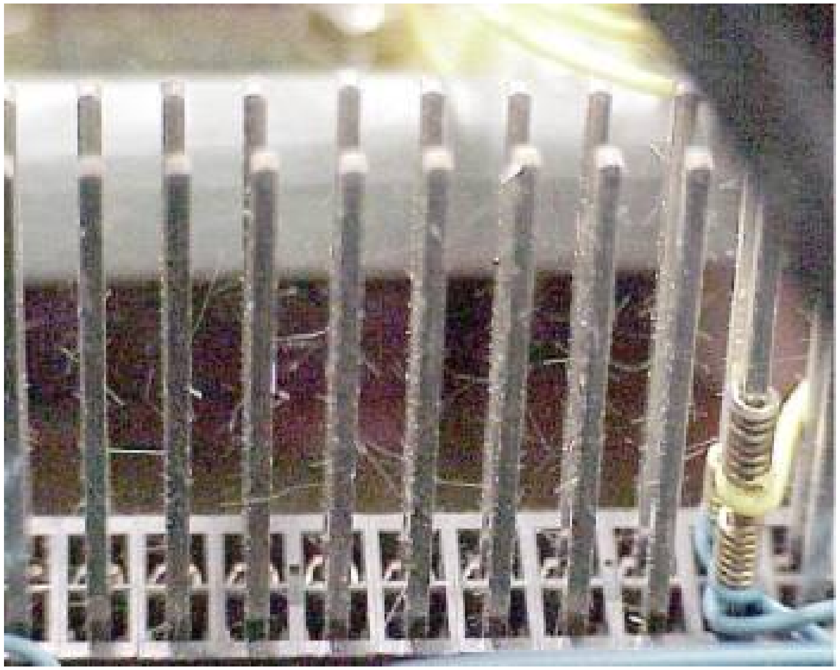
Disadvantages

- Cause of fretting corrosion in contacts
- Poor resistance to oxidation
- Whiskers

Risks from Tin Whiskers

- Various sectors of the electronics industry, including military, medical, telecommunications and commercial applications, have experienced field failures induced by tin whiskers.

Pure tin plated connector pins



10 years in the field (reported in 2000)
[Courtesy of NASA Goddard]

- 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

CALCE Tin Whisker Alert

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

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Electronic Products & Systems Center

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Tin Whisker Alert

A failure mode is re-emerging that has been responsible for the loss of billions of dollars worth of satellites, missiles and other equipment - electrically conductive 'tin whiskers'. Tin whiskers can develop under typical operating conditions on any product type that uses lead-free pure tin coatings. Driven by the accelerating movement to lead-free products, tin whiskers pose major safety, reliability and potential liability threats to all makers and users of high reliability electronics and associated hardware. Existing approaches are not sufficient to control tin whiskering in high-reliability systems. The risk is here now, and unless decisive action is taken soon to fund development and implementation of a strategic action plan to devise short-term stopgap procedures and medium-term investigation of mitigation alternatives, serious consequences are inevitable.

CALCE, concerned equipment manufacturers and users issued a general alert in summer of 2002 regarding the danger posed the conversion to pure tin and tin based Pb-free finishes.

Potential Tin Whisker Locations

Whiskers may grow from almost any tin plated surface, including

- Terminals of package electrical device,
- Metal cans (inside/outside)
- PWB finishes,
- Mechanical fasteners,
- Connectors, and
- Shielding

Tin Whiskers Failures

Reported Field Failures		
Application	**Failure site**	**Reported year /reference**
Nuclear Power Plant	Discrete Device to Board	2005[12] 1999/[10]
Military Aircraft	Relay Armature	2002 [11]
Power Supplies	Varistors	2002 [13]
Heart pacemaker (medical)	Housing of crystal	1986/[6]
F-15 radar (military)	Hybrid microcircuit lids	1986/[7]
U.S. missile program (military)	TO-3 transistor	1993/[8]
Commercial satellite (commercial)	Spacecraft control processor	1998/[9]

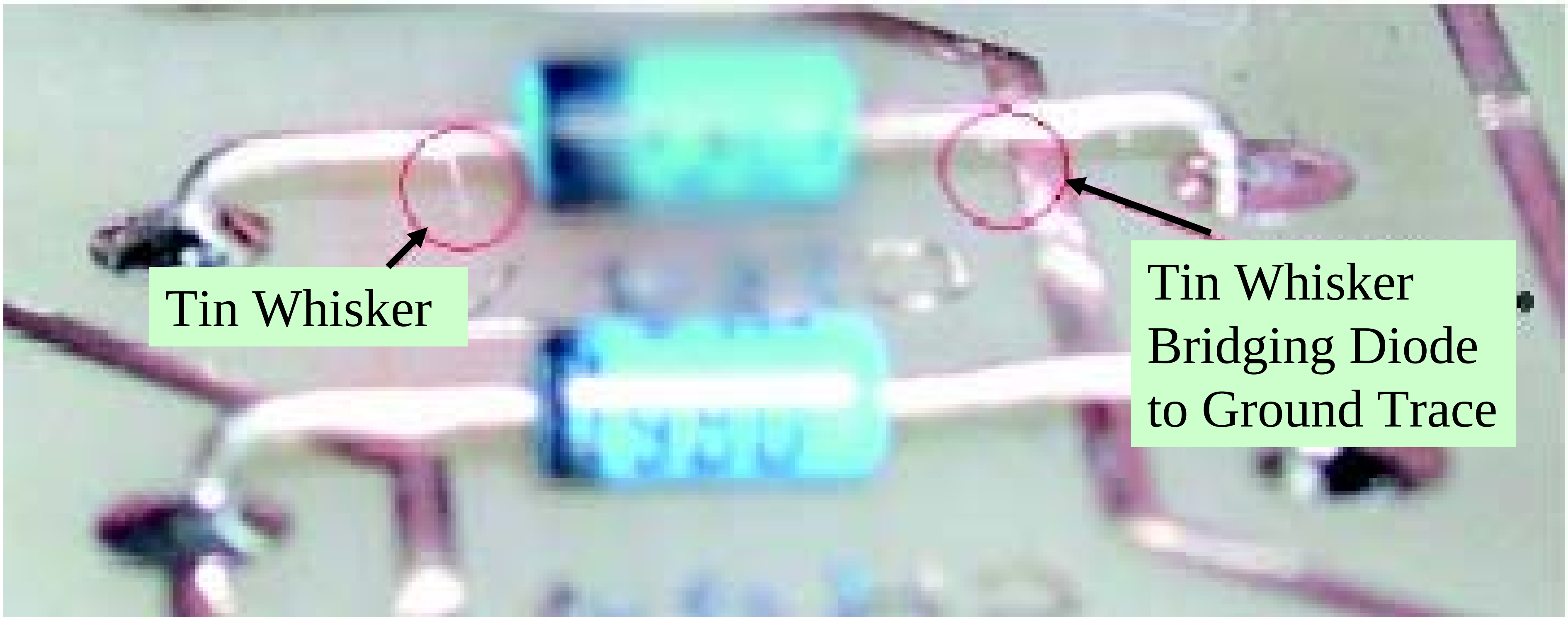
Good source of information

http://nepp.nasa.gov/whisker/failures/index.htm

Failed Relay Due to Tin Vapor Arcing

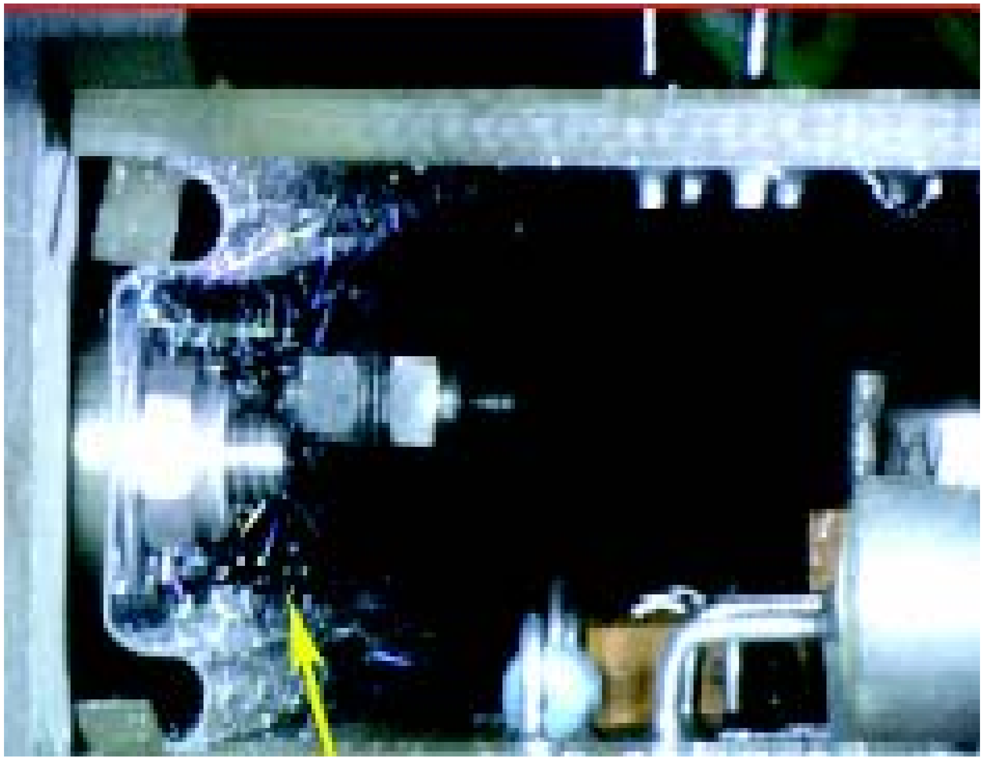
- Davy, G., (Northrop Grumman Electronic Systems), “Relay Failure Caused by Tin Whiskers,” http://nepp.nasa.gov/whisker/reference/tech_papers/davy2002-relay-failure-caused-by-tin-whiskers.pdf, June 10, 2004.

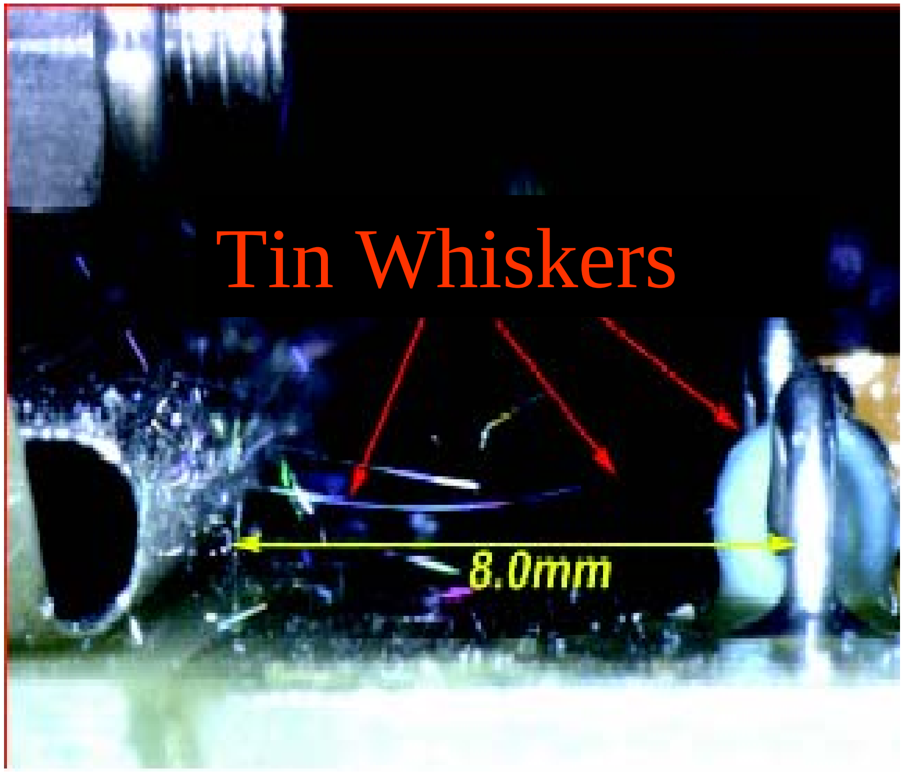
Tin Whisker Bridging a Diode and Trace



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

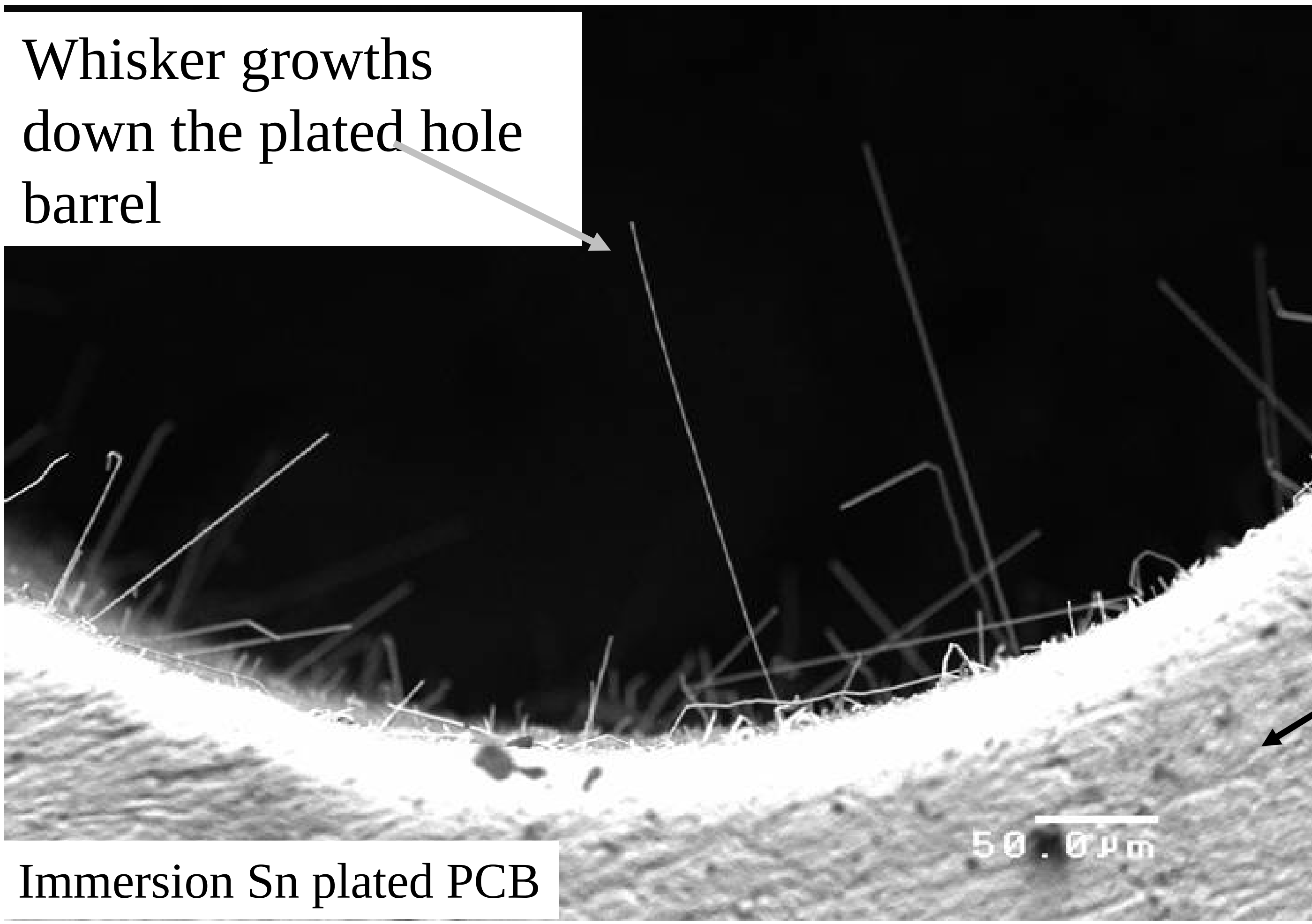
Whiskers on Card Guides





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

Whisker Growth on Immersion Tin PCB Finish



Suppliers' Tin Whisker Testing

Only 33% of the surveyed component suppliers (end of 2004) indicated tin whisker testing as part of their qualification testing for lead-free parts.

- Even though the parameters still vary among companies, three types of testings (temperature/humidity exposure, temperature cycling, and ambient storage) have generally been selected.
- Component suppliers have set their own failure criteria for the tin whisker length

Supplier	Part type	Selected testing conditions	Note/Acceptability criteria for tests
Advanced Micro Devices	Memory devices	- Preconditioning (255+5/-0°C) - TC (-40~150°C) up to 1000 cycles - Biased HAST(130°C/85%RH) for 96 hrs - HTOL (150°C) up to 500 hrs - High temperature storage (150°C) up to 1000 hrs	No whisker growth has been observed (50X magnification) for for the matte tin plating chemistry qualified for memory products.
Lelon Electronic	Capacitor	- TC (-55 to –65)°C~ (85to 95)°C, 20 mins cycle time, 500 cycles - Ambient temperature and humidity (25+/-5°C, 30~80%RH, 1000 hrs) - Elevated TH (60+/-5°C, 87-92%RH, 1000 hrs)	Whisker length smaller than 30µm is acceptable
Agere	Leaded packages	- Pre-treatment (simulated reflow -various peak reflow temperatures, including 260°C) - TH (60°C/93%RH)	Annealing (150°C, 1 hour) is under investigation as a whisker mitigator. Matte tin with nickel under-layer is recommended.

Pb in Lead Finishes-RoHS Exemption Requested

Due to the potential risks associated with tin whiskers, additional Pb-free exemptions were applied to the European Commission in Feb. 2005.

- Lead in tin whisker resistant coatings for fine pitch applications
- Lead in connectors, flexible printed circuits, flexible cables

Company/Organization's Comments Regarding Exemption Request	
HP	Defined fine pitch parts as those with electrical terminations spaced with centers 0.65-mm or less apart, for the purpose of the exemption
Sony	Proposed the exemption of fine pitch flexible connectors with an inner distance between pins <= 500µm
EICTA/ AeA Europe	Described their support the request for the use of Sn-Pb plating in fine pitch flexible applications and Pb in plating of Fe-Ni alloy fine-pitch electronic components
JBCE	Indicated the area of concerns as where the external stress is applied, including contact, press-in, bending, and thread fastening areas
FCI	Described that fine pitch (<1mm) connectors are at high risk. An example, where whisker formed in 2 days at the location which pure tin is scraped in contact application.
JEITA	JEITA claims that all manufacturers of electrical equipments, electronic devices, and parts in Japan, support their application for an additional exemption of this matter.

Communication and Information Resource Center Administrator (reviewed on March 4, 2005), "Request for Exemptions," http://forum.europa.eu.int/Public/irc/env/rohs/library?l=/requests_exemptions/resistant_applications&vm=detailed&sb=Title.

The Swatch Group Is Going Back to Pb Solder

- In May 2006, it was announced that Swatch Group was going to put the Pb back.
- Swatch, the Swiss watchmaker with nearly $4B sales and one quarter of the world's watch production, diligently conducted lead-free R&D for 2 years, went into Pb-free production 13 months in advance of the RoHS deadline, and then met disaster.
- Tin whiskers were shorting circuits both in the quartz crystal resonator and fine pitch electronic systems. The critical dimension at which tin whisker shorting became a production-line-stopping problem was 0.8mm, that is, 32 mils. They used 99.5Sn 0.5Cu, no Ag, so not the SAC alloy, which also contains silver.
- Now the Swatch Group is applying for an exemption from RoHS so they can go back to Pb. The Swatch Group even tentatively "offered" to consider using the 90% tin alloy which is allowed under RoHS.

Evertiq, online european electronics web site, http://www.evertiq.com/newsx/read_news.aspx?newsid=3868&cat=7, posting date May 12, 2006

EU TAC Grants Exemption for Pb on Fine Pitch Parts

http://circuitsassembly.com/cms/content/view/3827/95/

EU TAC Adds 6 Uses to RoHS Exemption List

By Mike Buetow

Friday, 18 August 2006

BRUSSELS -- The European Union's Technical Adaptation Committee has ruled to exempt lead and cadmium in a half-dozen applications from the RoHS Directive.

Among the expemtions granted was for lead in finishes of fine-pitch components (other than connectors) with a pitch of 0.65 mm or less with NiFe copper lead frames. This could mean a new lease on life for millions of components.
The TAC also OK'd the use of lead in solders for soldering to machined through-hole discoidal and planar array ceramic multilayer capacitors.

The TAC can exempt a banned substance on technical grounds (such as the impracticality of the material's removal or substitution), on the lack of existing or commercially viable substitutes, or if the substitute would cause even greater harm to the environment or consumer safety than the original substance.

Pb-free Legislation in China

"Administrative Measure for the Control of Pollution Caused by Electronic Information Products" (Administrative Measure) formulated by the Ministry of Information Industry (MII), was issued February 28, 2006.

- Covers same materials as EU RoHS but State may added others.
- Defines what products are covered
  - Electronic Information Products refers to the following products and their accessories manufactured by using electronic information technology: electronic radar products, electronic communication products, broadcast television products, computer products, household electronic products, electronic measurement instrument products, electronic products for professional use, electronic component products, electronic application products, electronic material products, etc.
- There are no exemptions
- Labeling and marking is required
- Certification by a Chinese Lab is required
- Becomes effective March 2007

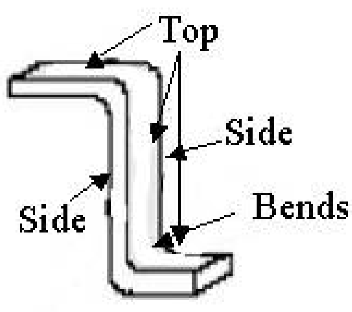
Relevant Industry Standards

- JESD22A121, Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes, JEDEC, May 2005.
- JEDEC Standard No. 201, Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes, March 2006
- JP002, Current Tin Whiskers Theory and Mitigation Practices Guideline, JEDEC/IPC Joint Publication, March 2006
- GEIA-STD-0005-2, 'Standard for Mitigating the Risks of Tin in High-Reliability Electronic Systems', June 2006
- IEC 60068-2-82 Ed. 1.0, Environmental Testing- Part 2-82: Test-Test Tx: Whisker test methods for electronic and electric components, **initiate March 2004 and anticipated early 2007**.

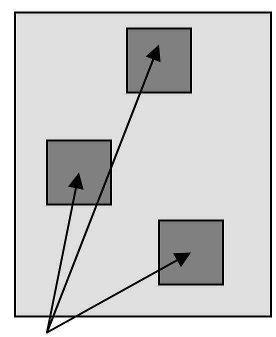
JESD22-A121 Whisker Characterization Method

<table>
<tr><th colspan="2">JESD22A121 standard</th><th>Screen inspection</th><th>Detailed inspection</th></tr>
<tr><td rowspan="2">Total required area</td><td>component</td><td>96 leads from 6 components</td><td>18 leads from 3 components</td></tr>
<tr><td>coupon</td><td>75 mm^2</td><td>5.1 mm^2 (=1.7 mm^2 x 3 sites)</td></tr>
<tr><td rowspan="2">Item to be recorded</td><td>component</td><td colspan="2" rowspan="2">1) Maximum whisker axial length for each site
2) Classification of whisker density (i.e., high, medium, or low)
– Based on one lead (site) identified as having the greatest number of whiskers.
– Not required count whiskers which exceeded 45</td></tr>
<tr><td>coupon</td></tr>
</table>

<component>



<coupon>



Detailed inspection area (1.7 mm^2)

JESD201 Environmental Acceptance Requirement

JESD201 provides a environmental acceptance standard with a disclaimer. "…, the testing described in this document does not guarantee that whiskers will or will not grow under field life conditions."

Product class	System types	Tolerance level
Class 3	Mission/life critical applications, such as military, aerospace, and medical applications	Pure tin and high tin content alloys are not acceptable
Class 2	Business applications such as telecom infrastructure equipment and high-end servers.	- Long product lifetimes and minimal downtime - Products such as disk drive typically fall into this category - Breaking off of a whisker is a concern
Class 1	Industrial products	- Short product lifetimes - No major concern with tin whiskers breaking off
Class 1A	Consumer products	- Short product lifetimes - No major concern with tin whiskers

Industry Standard for Tin Whisker Testing

Test Conditions (pre-conditioning is also specified in each case)		JESD22-A121		JESD201	
		Inspection intervals	Minimum duration	Class 1, 2 and 3 products	Class 1A products
Ambient	30±2°C and 60±3%RH	1000 hours	3000 hours	4000 hours min. with 3 consecutive measurements showing no whisker growth	1000 cycles
T/H	60±5°C and 87+3/-2%RH				
TC	[-55 (+0/-10)°C or -40 (+0/-10)°C] to 85 (+10/-0)°C, air to air, 5 to 10 minutes soak, up to 3 cycles/hour	500 cycles	1000 cycles	1500 cycles	1000 cycles

- JESD22-A121 standard
  - This is not a qualification standard. (neither an acceptance test)
  - The maximum whisker length and a range of whisker density (i.e., high, medium, low) are to be measured and reported.
- JESD201 Acceptance criteria
  - Proposed testing does not guarantee that whiskers will or will not grow under field life conditions.

JESD201 Acceptance Criteria

Device Considerations (Package Type, Lead Pitch or Operating Frequency)	**Maximum Allowable Total Axial Whisker Length**			
	Class 3	**Class 2**	**Class 1**	**Class 1A**
Discrete Package (2 leaded devices)	Pure tin and high tin content alloys are not allowed	45 µm	67 µm	50 µm for Temperature Cycling and High Temperature/Humidity Storage 20 µm for ambient storage
Multi-Leaded Packages			67 µm	
High Frequency Devices			50 µm	

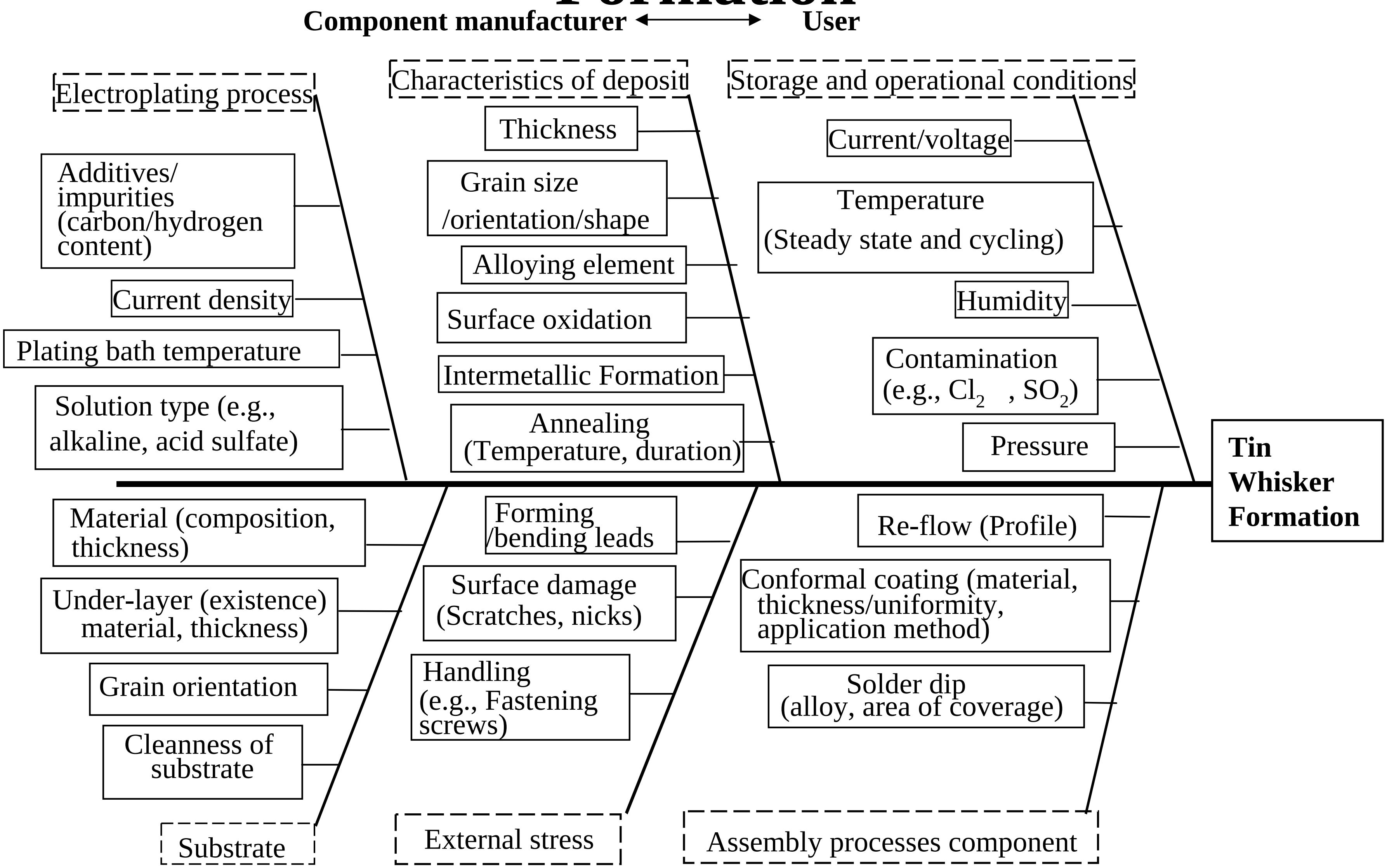
GEIA-STD-0005-2

- This is a commercial standard being developed by the Lead-free Electronics in Aerospace Project-WG (LEAPWG), participants from the Aerospace Industries Association (AIA), the Avionics Maintenance Conference (AMC), and the Government Engineering and Information Technology Association (GEIA)
- This standard is applicable to aerospace and high performance electronic applications which procure equipment that may contain Pb-free tin finishes
- There are many aspects to controlling the use of tin. For the purposes of this standard, the activities have been grouped into four categories:
  - Documentation of uses of pb-free tin
  - Detecting and controlling pb-free tin introduction
  - Tin whisker risk mitigation
  - Tests and analyses of tin whisker risk and mitigation effectiveness.

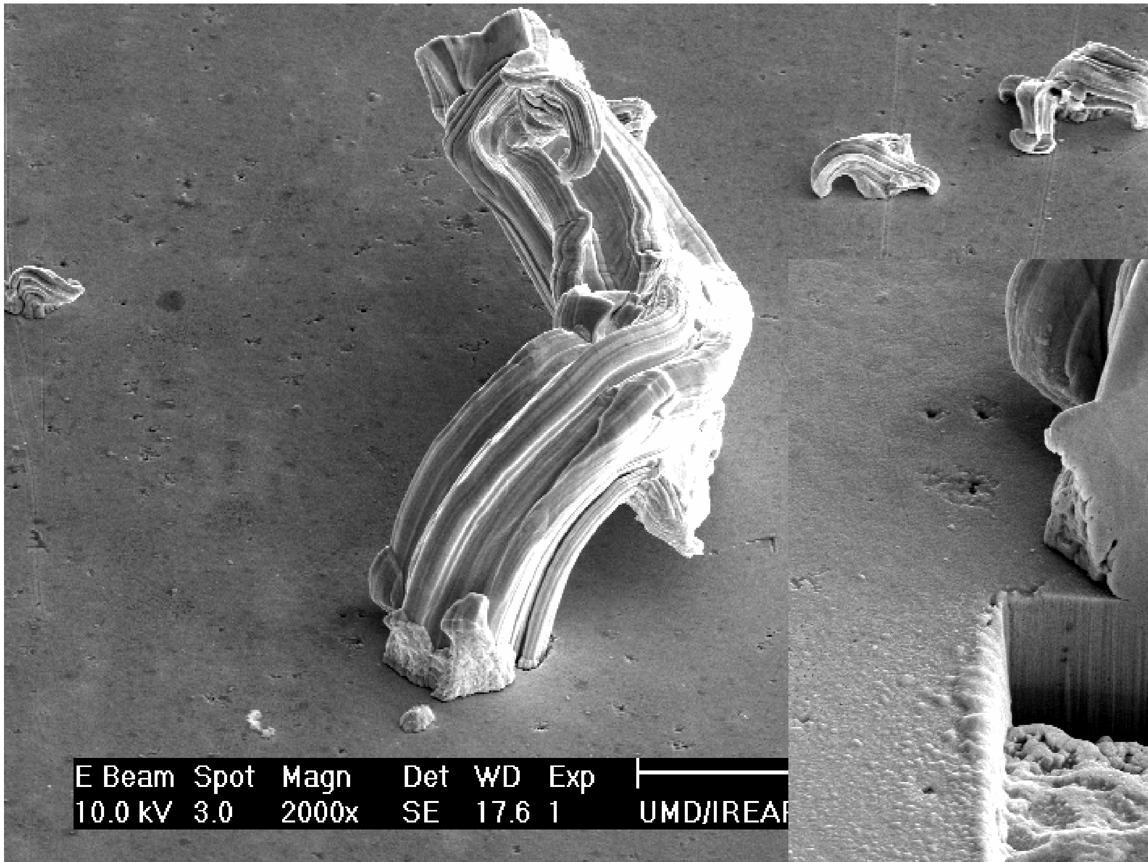
GEIA-STD-0005-2 Defined Levels and Actions

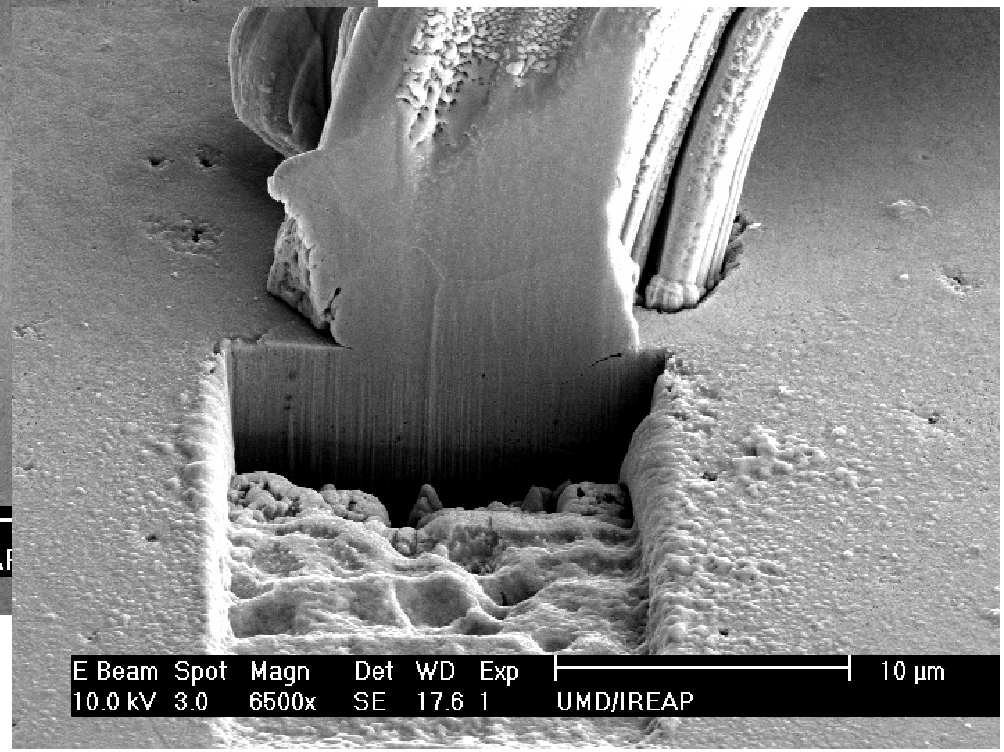
- Level I
  - Tin may be used
- Level II A
  - No requirements on documenting finish
  - Supplier will evaluate whisker risk
- Level II B
  - Use of tin will be documented
  - Materials will be monitored
  - Whisker mitigations approaches will be provided.
- Level II C
  - Only permissible use of tin as an exception with permission from customer
  - Materials will be monitored
  - Whisker mitigation approaches will be provided
- Level III
  - Tin is not allows
  - Incoming materials will be monitored

Cause and Effect Diagram for Tin Whisker Formation



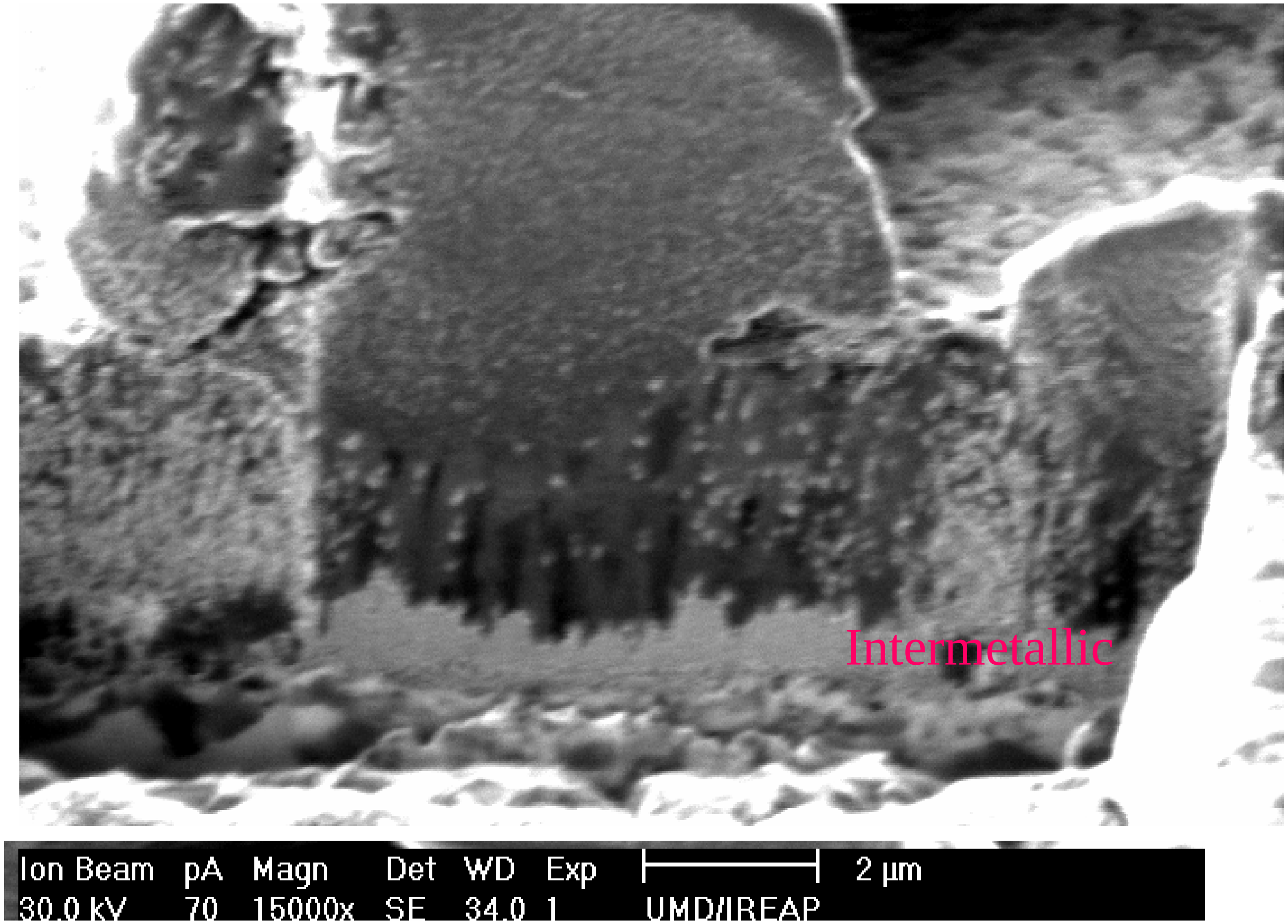
Close-Up of A Whisker





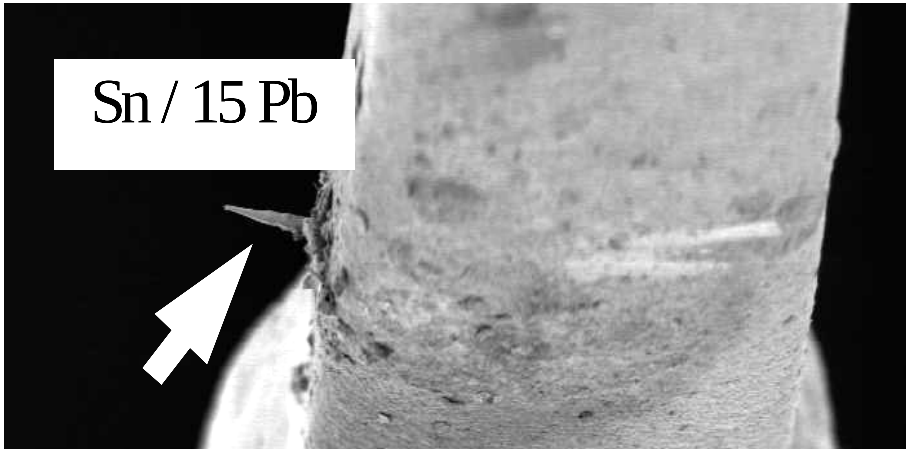
- No obvious signs of tin depletion near the whisker site
- Growth near a grain boundary

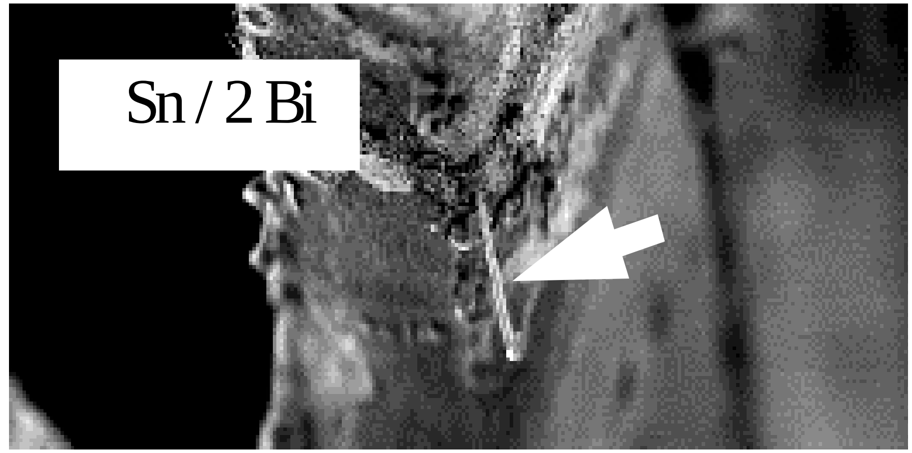
Section of a Whisker Root

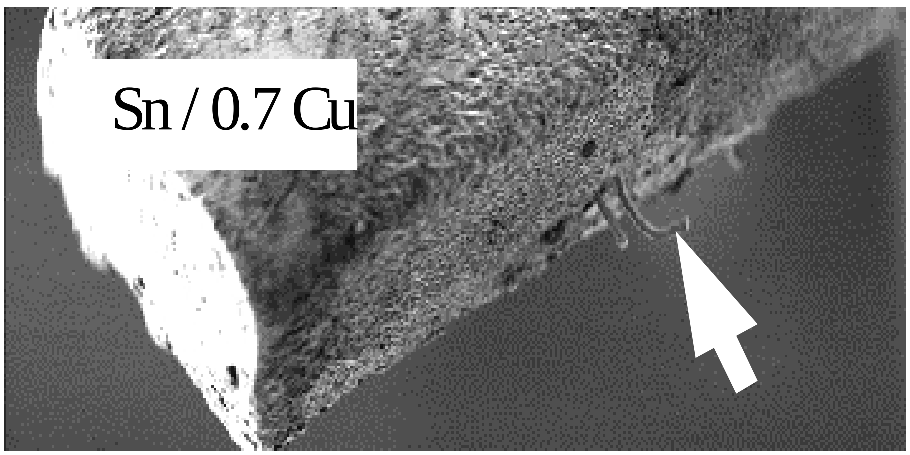


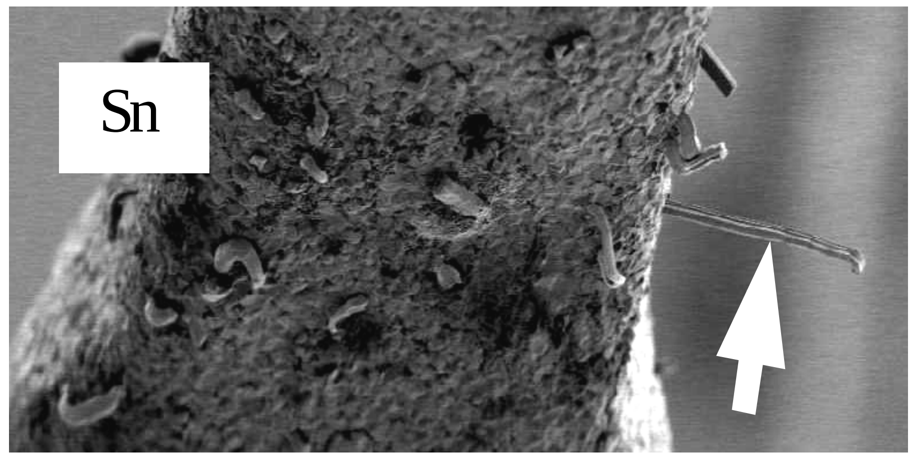
Columnar grains and uneven intermetallic grow are likely contributors to the whisker growth.

Whiskers Grown from Various Plating Types









[Courtesy of Motorola]

One reported observation based on 13-week period for the longest whiskers showed:
Sn-15Pb (40µm) < Sn-2Bi < Sn < Sn-Cu (170µm)

Stresses Within the Finish can Arise From

- Intermetallic compound formation between the plating material and substrate, resulting in compressive stress within the plating
- Mismatches in coefficient of thermal expansion (CTE) of the tin-based plating material and substrate, or under-layer
- Presence of residual stress from the electroplating process itself
- Extrinsic compressive stress, such as mechanical bending and forming
- Damage of the component surface, such as scratches and nicks, which create stresses that function as a nucleation point for whisker formation
- Oxide formation on the tin surface.

CALCE Growth Experiment-1

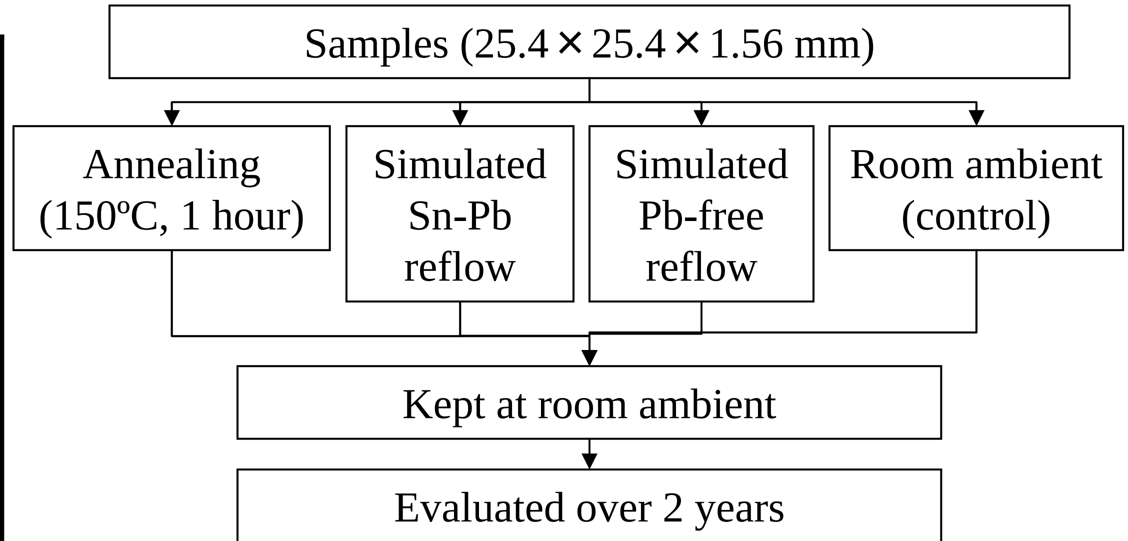
Test Samples and Test Flow Chart

Sample matrix

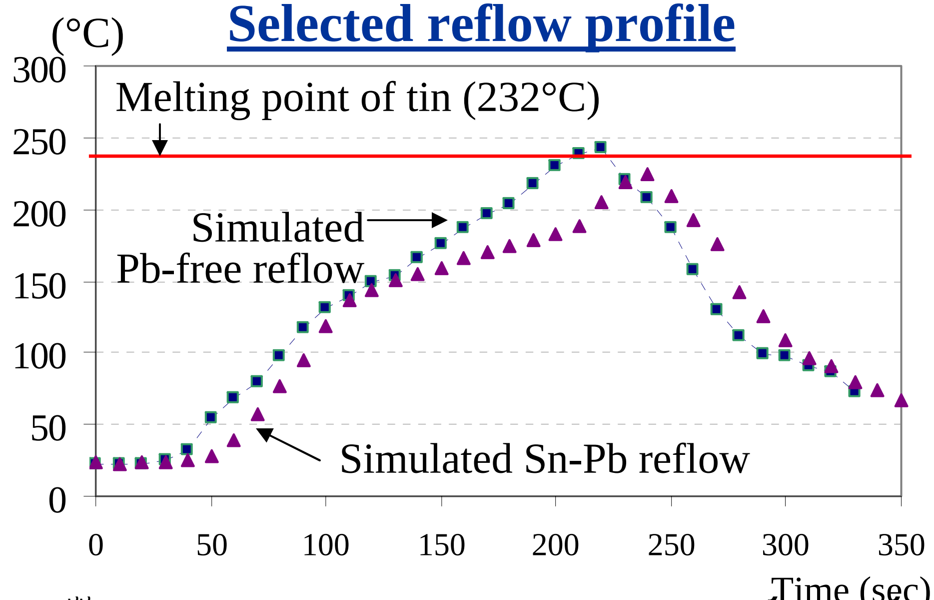
	Plating type (thickness)	Base material
1	Matte tin (5µm)	Alloy 42 (Fe-42Ni)
2		Brass (type 260)
3		Copper (Olin 194)
4	Bright tin (5µm)	Alloy 42 (Fe-42Ni)
5		Brass (type 260)
6		Copper (Olin 194)

Plating parameters:
- methane sulfuric acid (MSA)-based
- current density (5~20A/cm²)
- plating bath temperature (60~70ºC)

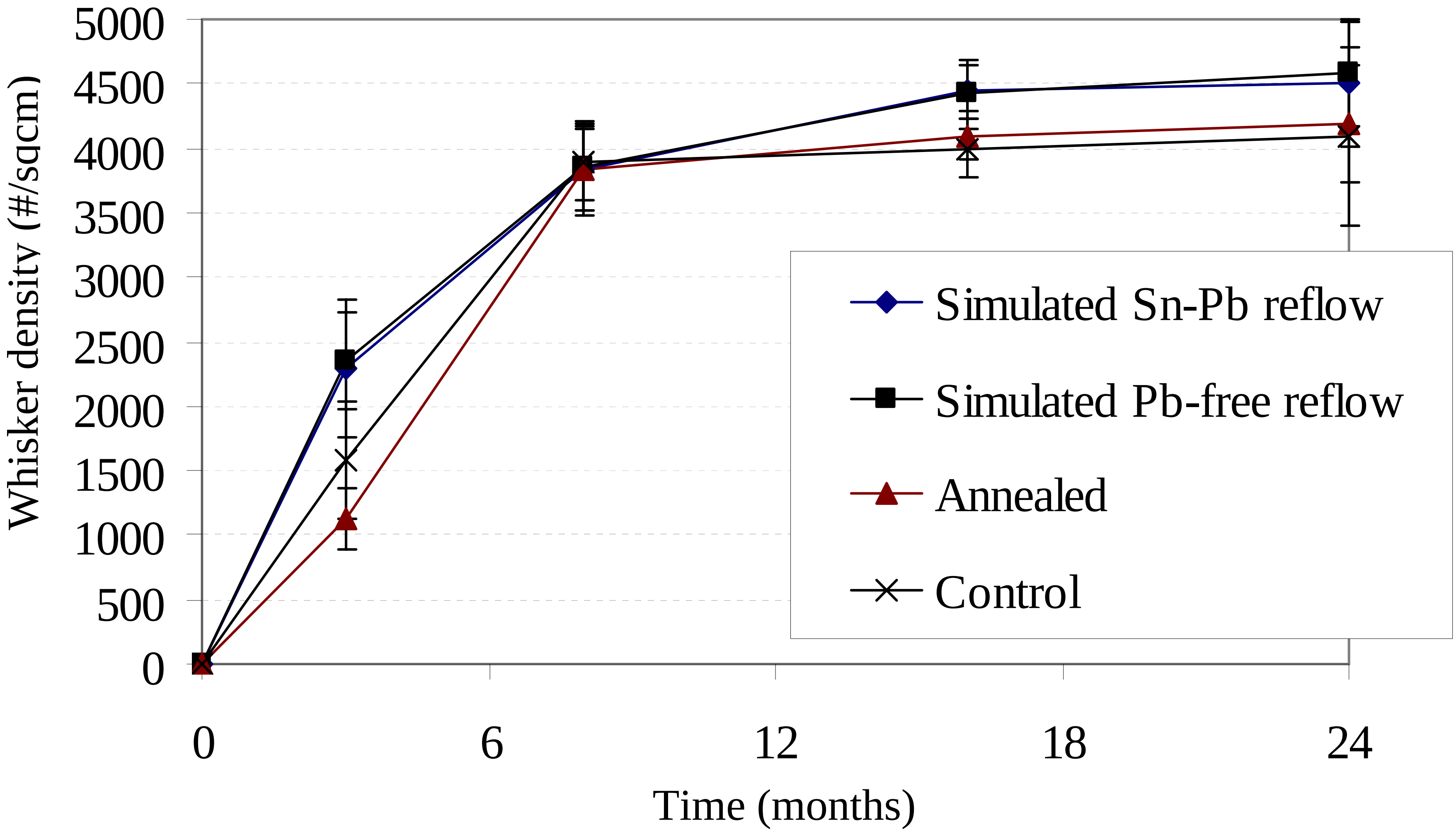
Test flow chart



Selected reflow profile

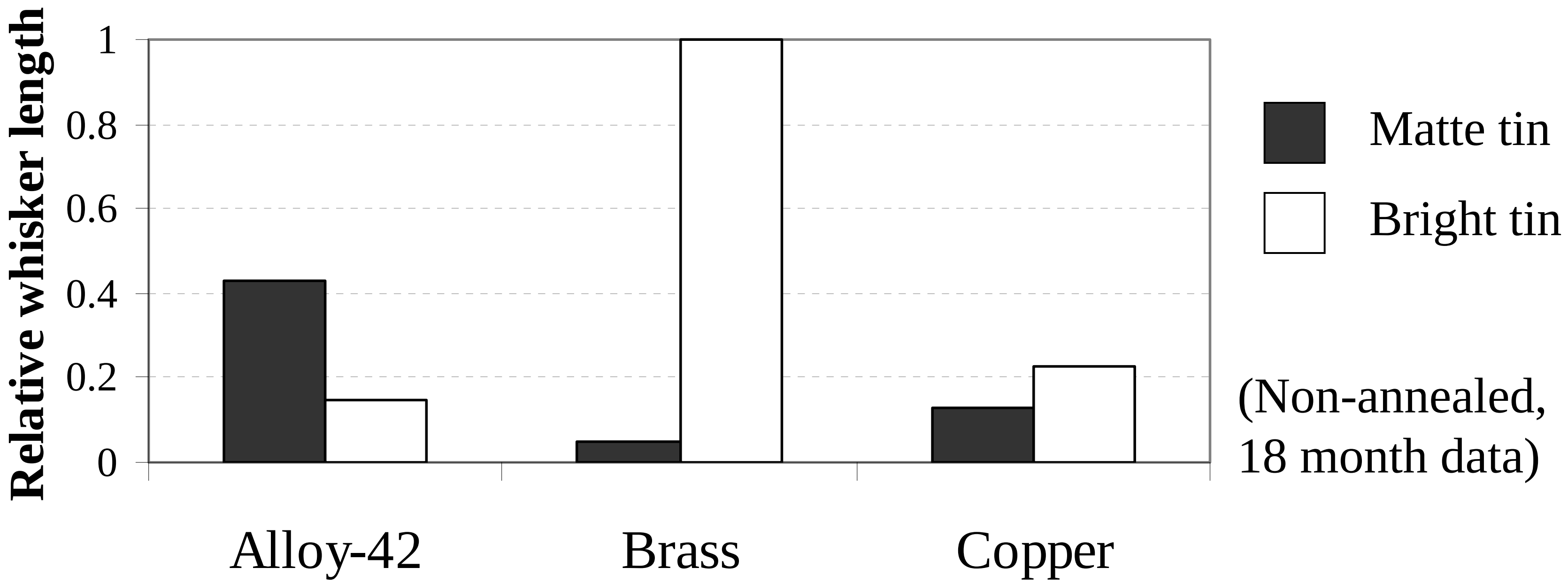


Long-Term Whisker Density
(Matte Sn over Cu)



Bright Tin versus Matte Tin:
Whisker Length Results

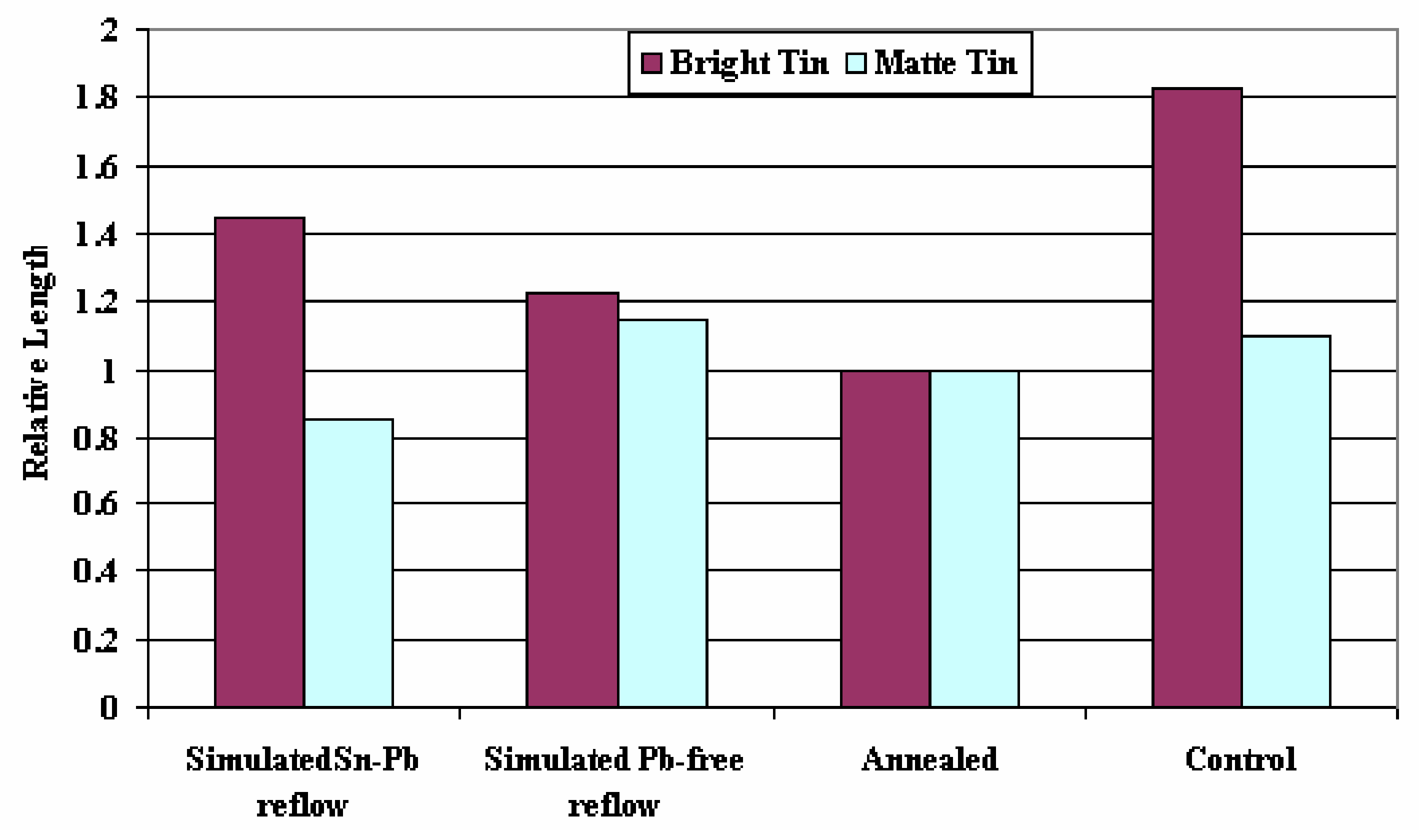
For different substrate material



Bright tin does not necessarily result in longer whisker growth, as compared to matte tin.

Note: Data was normalized based on the longest whisker observed (i.e., whisker on bright over brass in this case)

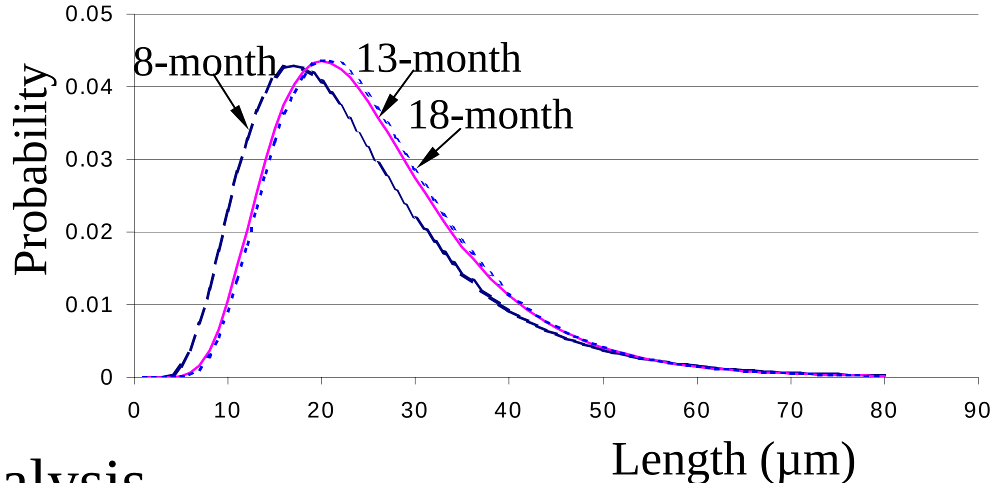
Effect of Reflow Temperatures on Whisker Formation on Copper Substrate



Conflicting results have been presented on the impact of exposure to solder reflow temperatures on whisker formation.

Whisker Length and Growth Angle Measurement

- Whisker length analysis (Best fit to lognormal distribution)



- Growth angle analysis
  - Angle growth demonstrates orientation preference. For this case, angle distributed preferably in the range of 40 ~ 90°
  - Whisker growth angle appears to be independent of time

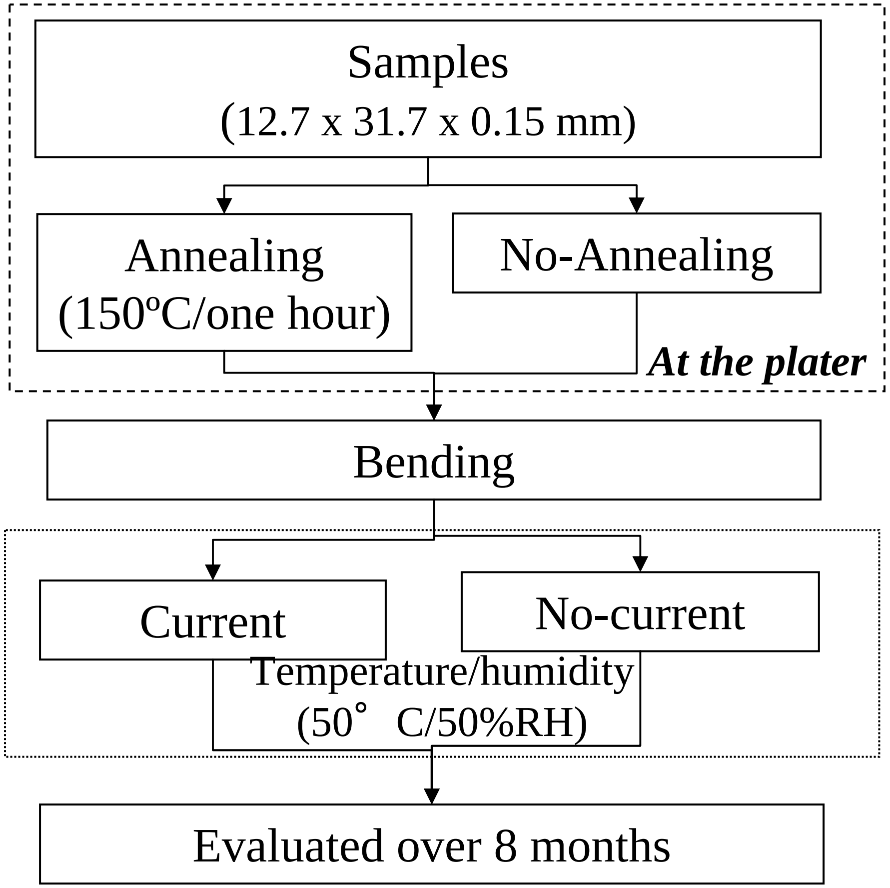
Angle range (°)	0~10	10~20	20~30	30~40	40~50	50~60	60~70	70~80	80~90
Percentage (%)	2.8	4.3	7.9	6.7	11.4	13.0	18.1	20.5	15.4

CALCE Growth Experiment-2

Test Samples and Test Flow Chart

- Samples
  - Matte and bright tin (5µm thick)
  - Copper (type: Olin 194) substrate
  - 3 samples per condition
- Measurements
  - Surface observations were conducted using ESEM*, before exposure and after 8 months of exposure to electrical current and temperature/humidity (50ºC/50%RH)
  - Maximum observed whisker length, length distribution, and whisker density are recorded.

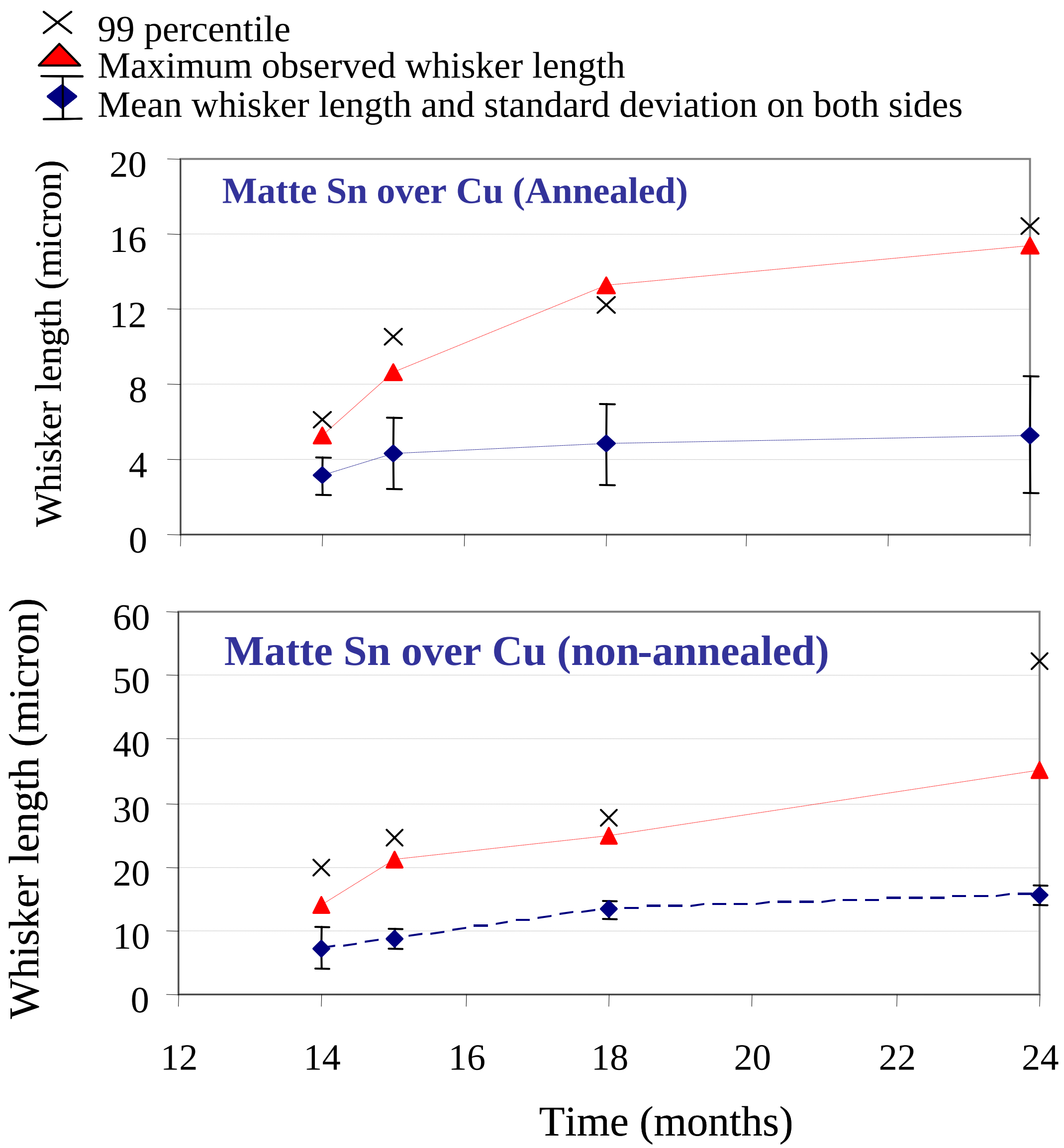
Test flow chart



*ESEM (Environmental Scanning Electron Microscopy)

Effectiveness of Annealing

Copper Olin 194, Coupon 25.4 × 25.4 × 1.56 mm, Annealing 150ºC 1 hr, 1 week after plating



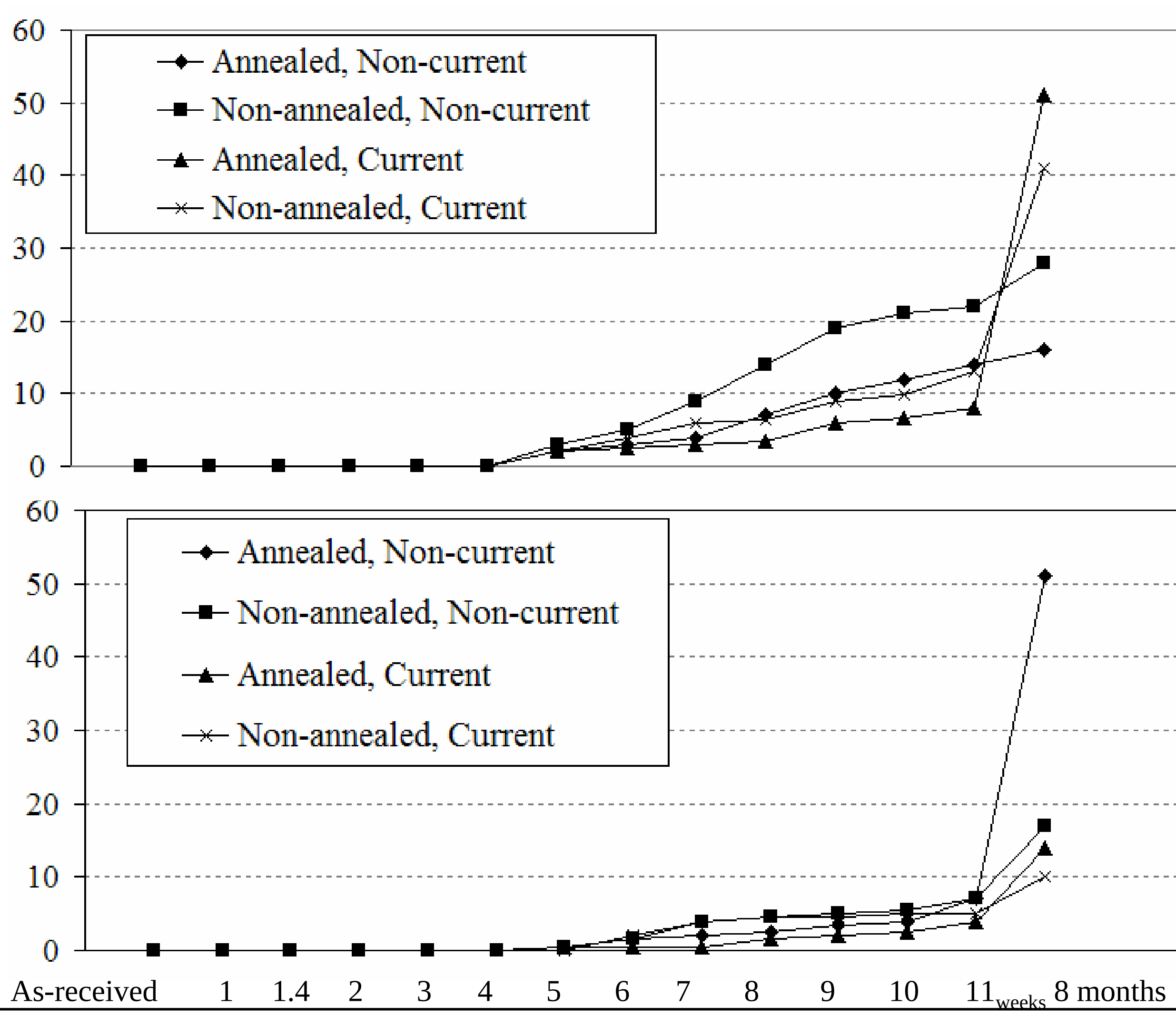
- Three substrates: brass, copper, and alloy 42 were finished with 5 μm of bright tin or 5 μm of matte tin.
- Lognormal distribution was found to provide a best fit to the measurement data on whisker length on tin platings. (both bright and matte tin, over different substrate materials)
- Annealing (150ºC for one hour) provided retardation of whisker length on matte tin plated copper, as compared to control (non-annealed) after two years of room ambient storage:
    - 72 % reduction in maximum whisker length
    - 79 % reduction in estimated growth rate (based on change in mean whisker length)
    - Annealing did not reduce whisker length for matte tin over brass.

Effect of Direct Current

Substrate Olin 194, Coupon: 1.25”x0.5”x0.006”, Annealing 150^oC, 1 hr immediately after plating, Condition 50^oC/50% RH

Bright Sn 5µm

Matte Sn 5µm



Electric Current (48 amp/cm^2) increased whisker length on bright tin specimens but not on matte tin. Annealing adversely effected matte tin. Temperature humidity resulted in longer whisker than observed in the sample period with under room ambient conditions.

Whisker Growth and Loading Conditions

Based on CALCE testing and published literature, whisker growth appears to follow a incubation period, relatively rapid growth period, slow growth period.

- Room Ambient
  - Whiskers found to grow under room ambient conditions.
- Elevated Temperature and Humidity
  - High growth rates observed for elevated temperature and humidity condition 50^oC/50%RH, and 60^oC/93%RH. Longest whiskers by Vo et. al. (iNEMI) testing found under this condition as compared to temperature cycling.
- Temperature Cycling
  - Growth data has been presented for temperature cycle loading conditions. After a relatively short incubation period rapid growth appears to be followed by very slow growth. Particularly effective with Alloy 42 lead frames.
- Shock and Vibration
  - Mechanical compression load have been shown to induce whisker growth.
  - Whiskers found to be quite robust from being dislodged under vibration, shock, and forced air loading. Zequn Mei (Cisco) reports whisker survived three exposures to 1500 G shock loads and sinusoidal loading 20 G between 20 to 2000 Hz. No data on growth rate under this condition.

Possible Mitigation Strategies

- Part selection strategies
  - Avoiding pure tin and tin-rich lead-free finished parts
  - Selecting matte or low-stress tin as the finish material
  - Select thicker plating > 8 μm
  - Selecting parts with a nickel or silver under layer
  - Selecting annealed parts

- Assembly process strategies
  - Solder dipping tin finished parts
  - Minimizing compressive loads on the plated surface
  - Applying a conformal coat

Avoid Tin and Tin-based Pb-free Finished Parts

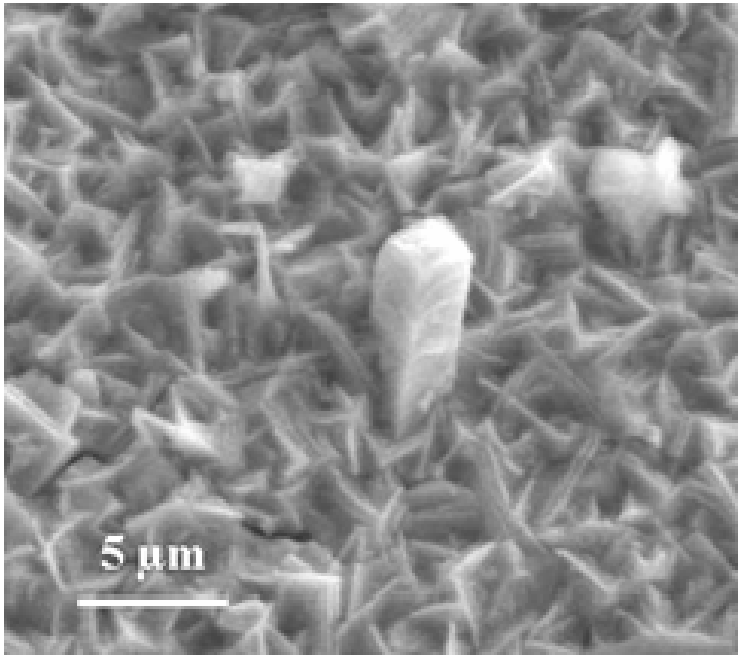
- This strategy is unlikely to be effective, due to the global conversion to Pb-free electronics.
- Due to tin whisker risks, some companies in high-reliability segment prohibit using pure tin finish.
  - Boeing Satellite prohibits the use of pure tin in the internal and external surface finish of electronic hardware. To meet this criteria, they also announced a supplier control policy, which excludes the manufactures providing pure tin finish as an option.
  - Raytheon Systems Ltd. indicates that the use of pure unalloyed tin is prohibited and shall not be used on any material supplied to them.

However,

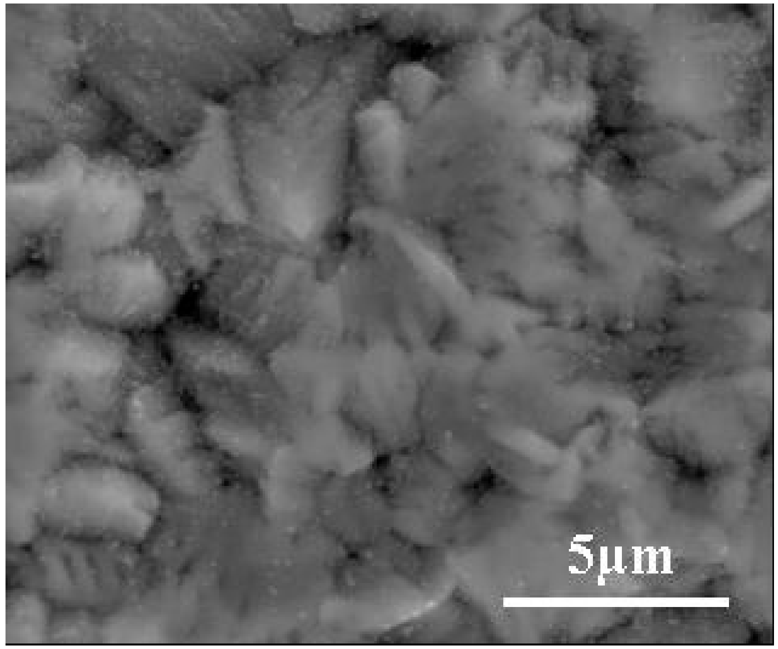
- Boeing Satellite System, for instance, continuously reported that reliance on part manufacturer's certifications for assurance "pure tin coatings are not used" may not ensure absence of pure tin plating.
  - As a corrective action, X-ray Fluorescence (XRF), which can detect the elemental composition and thickness of plating, was instituted for all lots at in-coming inspection, as well as all terminals in inventory prior to this inspection.

Tin Whisker Mitigation

7 month old growth Cu coupons with 8mm of Sn-3Pb and matte Sn (with and without Ni barrier)



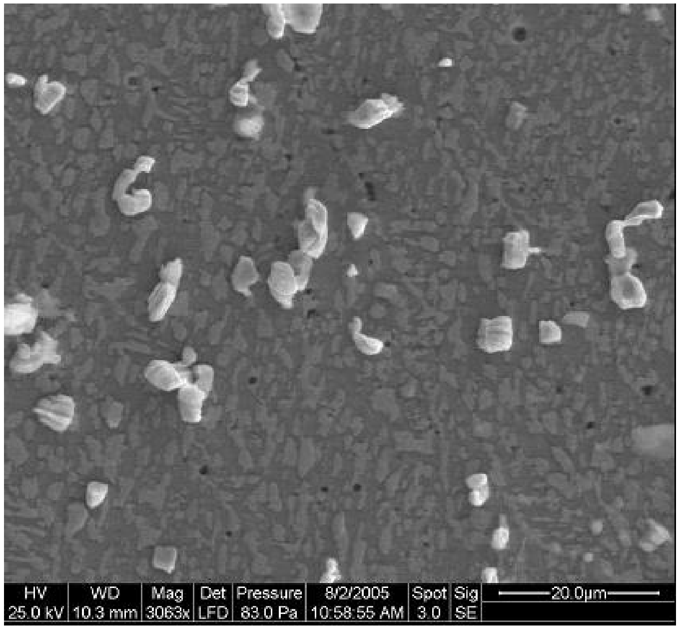
Sn3Pb (No growth > 10 µm)



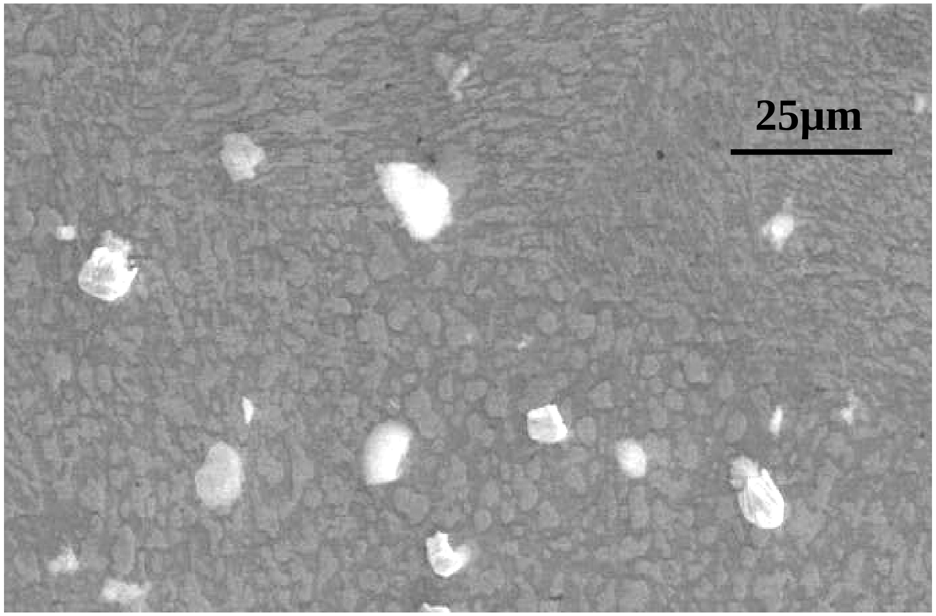
Matte Sn/ 1.6 µm Nickel Underlayer (No growth > 10 µm)

Tin Whisker Mitigation

- 2 Year Old Brass, 5mm bright Sn finish coupons with applied mitigation processes



Solder Dip (No growth > 10 μm)



AEM Process (No growth > 10 μm)

Solder Dip Services

http://www.sixsigmaservices.com/leadtinningservice.asp, accessed 1/23/2006

http://www.corfin.net/faq.htm, accessed 1/23/2006

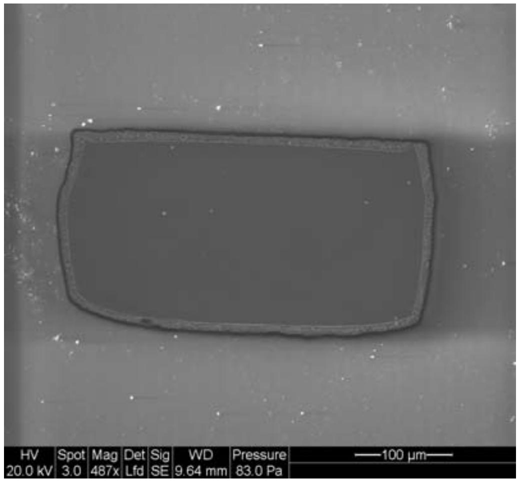
Further Information on AEM

http://www.aem-usa.com/hi-rel-services.html#lead

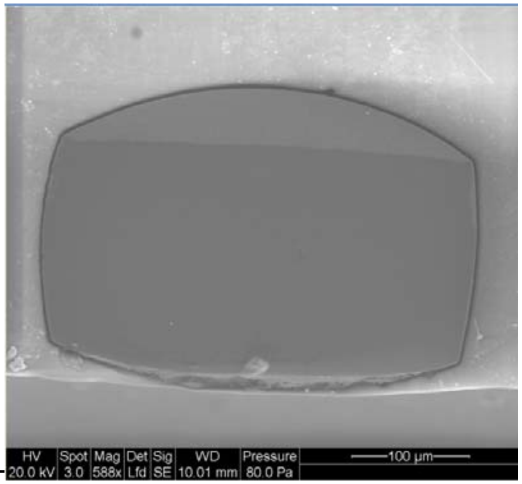
Solder Dip Study

- Participants: Raytheon Company, Navy BMP Program, Corfin Industries, SST Electrical Test Laboratory and CALCE.
- The program assessed the viability post manufacturing solder dipping of part leads to replace the original plating with tin lead eutectic plating.
- CALCE provided technical guidance and failure analysis support.
- 23 Part types examined including SOIC, PLCC, CLCC, QFP, CERDIP, TSSOP, SOP, TO92, SOD-123, SOT-23, and TO-220.
- All the post-dipped parts passed the dip-and-look solderability tests (Method 1 of JEDEC Solderability Standard JESD22-B102D [30]), with terminations showing uniform solder coverage after the tests
- Non-uniform lead cross-sections, delamination, and passivation cracking observed.

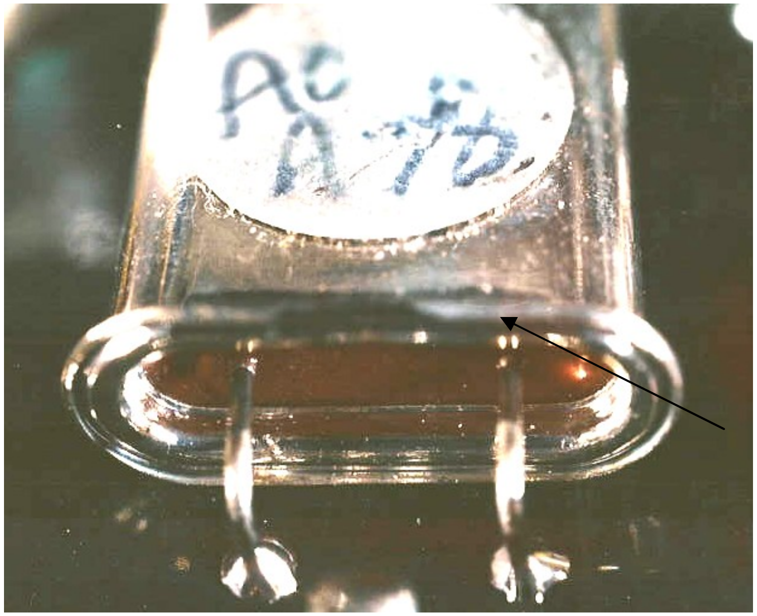
Lead cross section (before dipping)

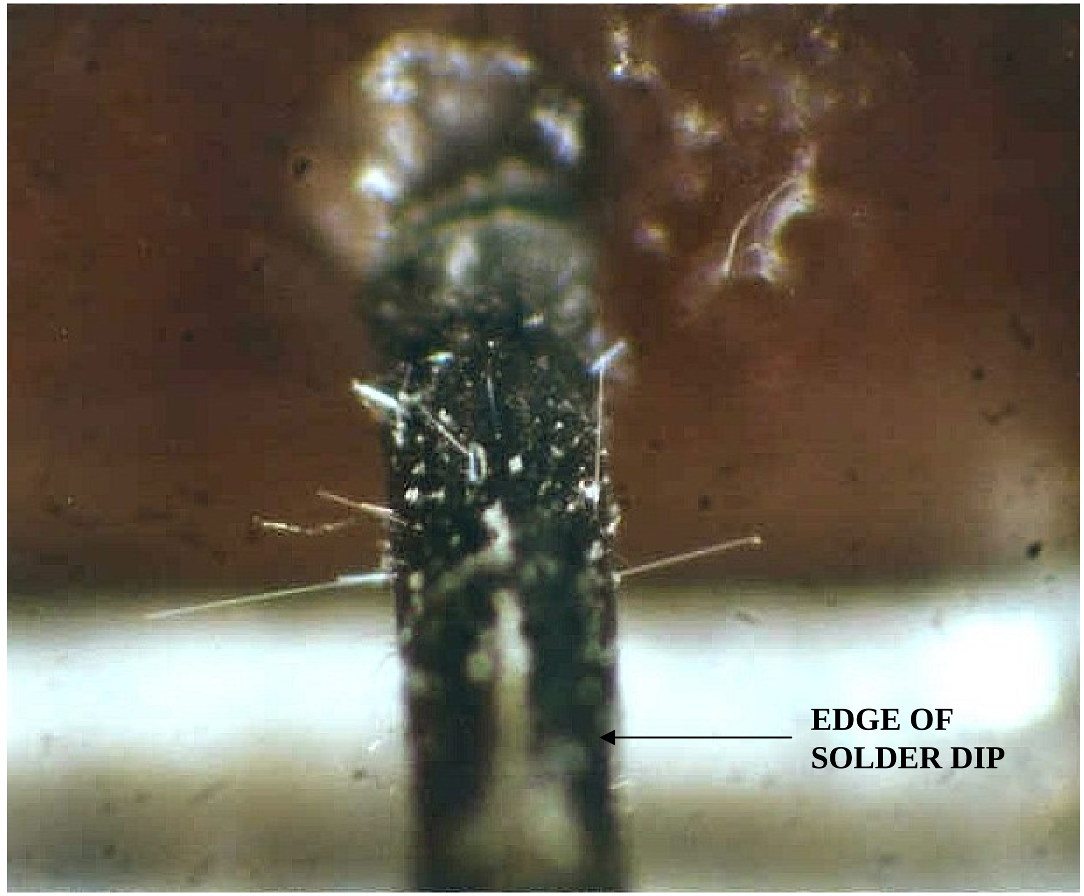


(after dipping)



Solder Dip Mitigation Risk

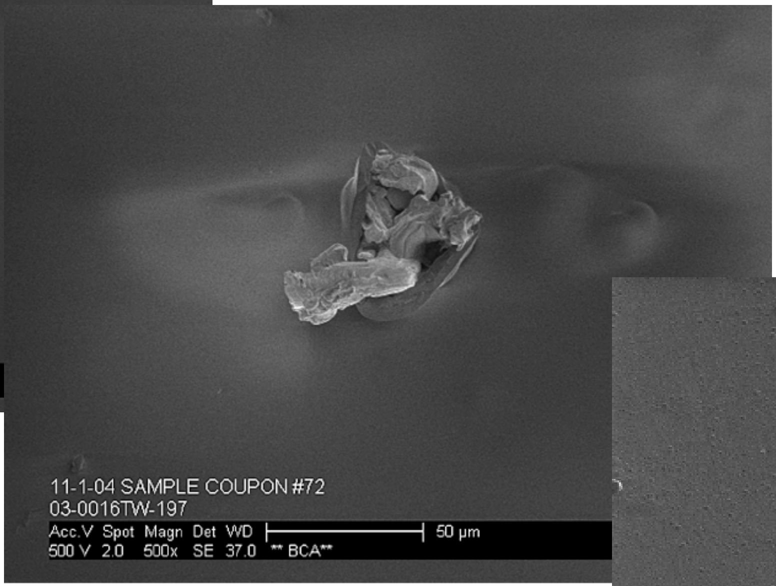




TIN WHISKER GROWTH NOTED FROM SEAL TO ABOUT 20 MILS FROM EDGE OF SOLDER COAT. ELECTRICAL FAILURE WAS TRACED TO A 60 MIL WHISKER THAT SHORTED LEAD TO CASE.

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 4 years. 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.

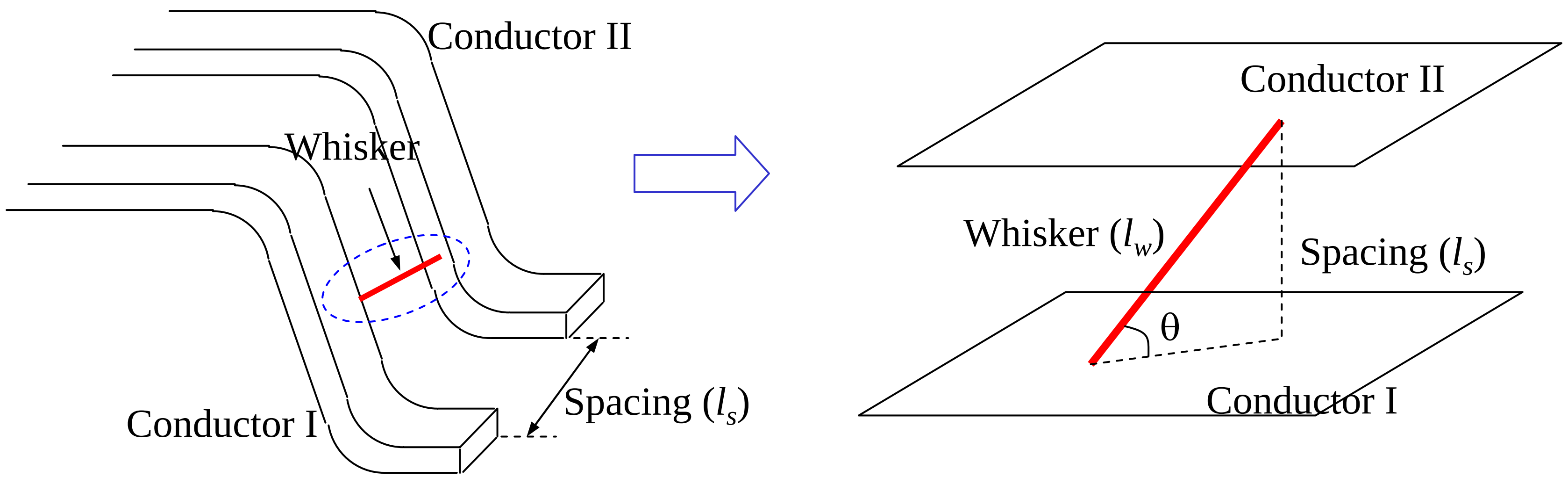
Photos courtesy of Tom Woodrow, Boeing

Assessing Tin Whisker Risk

- Risk must be assessed based on product, application, and tolerance to failure.
- Application risk assessment for tin whiskers requires
  - Identification of potential whisker failure sites
    - Adjacent conductor pairs with at least one surface coated with pure tin or a Pb-free tin finish
  - Whisker growth characteristics of potential whisker failure sites
    - Whisker density
    - Whisker length
  - Effectiveness of mitigation processes (if any)
    - Part selection
    - Solder dipped
    - Conformal coating

Whisker Risk Assessment Assumptions

- Full surface area of a conductor is considered
- Bridging spans shortest distance between conductors
- Whisker growth can be extrapolated from measured data.
- Failure occurs when
  - $l_w * Sin(\theta) \geq l_s$, where l_w is the length of a whisker, θ is the whisker growth angle, and l_s is the spacing between the two adjacent conductors



Approach to Quantify Tin Whisker Risk

Conductor geometry
whisker growth data

Monte Carlo simulation

Final simulated risk
at a specific time

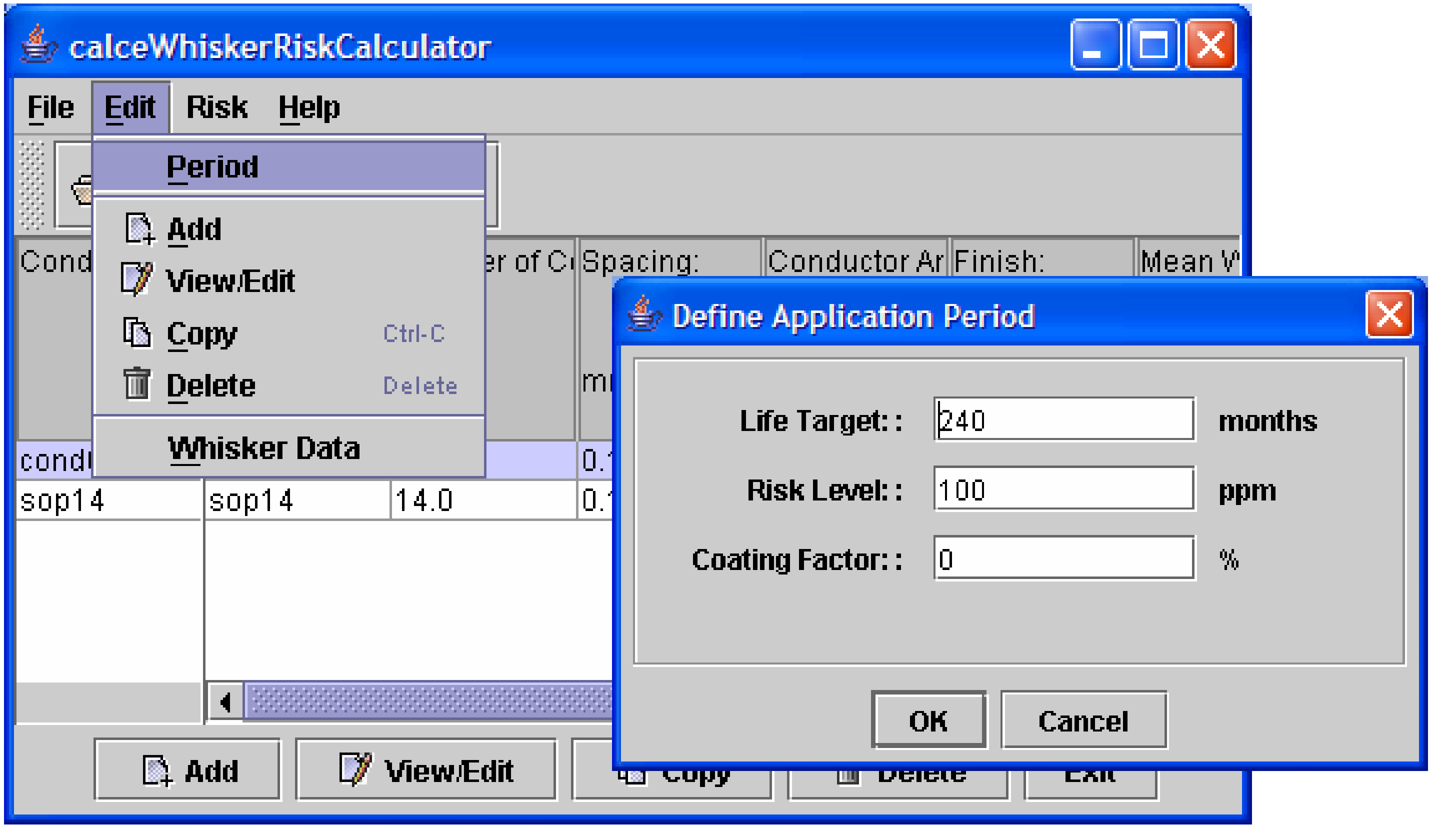
$$= \frac{\textit{simulated failures}}{\textit{simulation number}}$$

User Inputs

- Number of conductor pairs per part
- Spacing between adjacent conductors
- Area available for whisker growth
- Lead finish type
  - Bright tin over brass (whisker growth data built into software)
  - Matte tin over copper (whisker growth data built into software)
  - Custom (User has to input whisker growth data including
    - mean whisker density
    - standard deviation of whisker density
    - mean whisker length
    - standard deviation of whisker length)
- Conformal coating
- Life target
- Risk level

Repeat for each conductor pair within defined system

Conducting A Risk Assessment Software: ‘calceWhiskerRiskCalculator

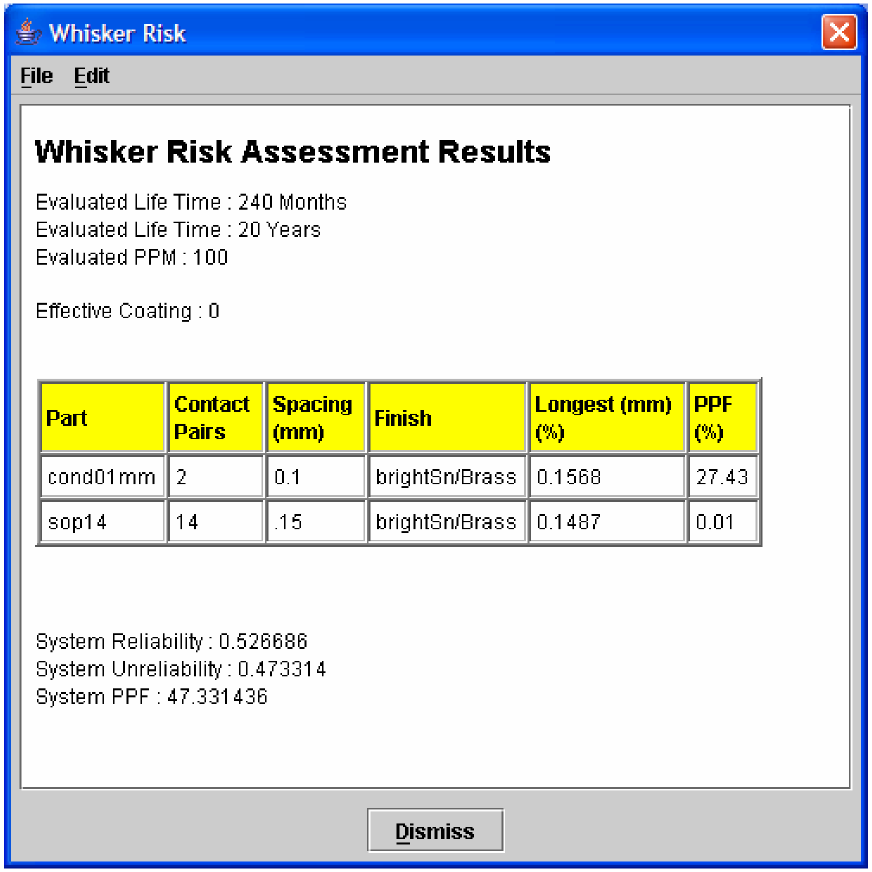


- A database of whisker growth tables is used to determine the whisker growth characteristics.
- The risk level is calculated using Monte Carlo methods.

Calculating the Total Risk for the Product

$$P_{Product} = 1 - \prod_{j=1}^{m} (1 - P_{Risk}^{j})$$

- $P_{Product}$ is the total bridging risk posed by whiskers on the product
- P^{j}_{Risk} is the total risk for a part type j
- m is the number of the part types



Whisker Risk

File Edit

Whisker Risk Assessment Results

Evaluated Life Time : 240 Months
Evaluated Life Time : 20 Years
Evaluated PPM : 100

Effective Coating : 0

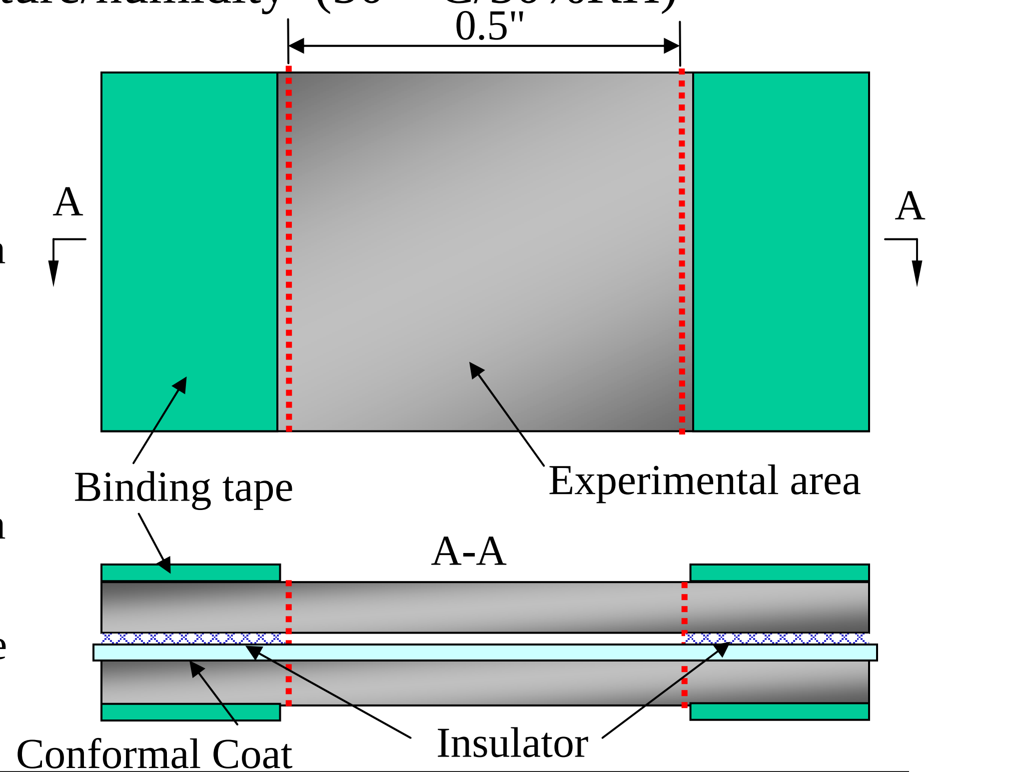
Part	Contact Pairs	Spacing (mm)	Finish	Longest (mm) (%)	PPF (%)
cond01mm	2	0.1	brightSn/Brass	0.1568	27.43
sop14	14	.15	brightSn/Brass	0.1487	0.01

System Reliability : 0.526686
System Unreliability : 0.473314
System PPF : 47.331436

Dismiss

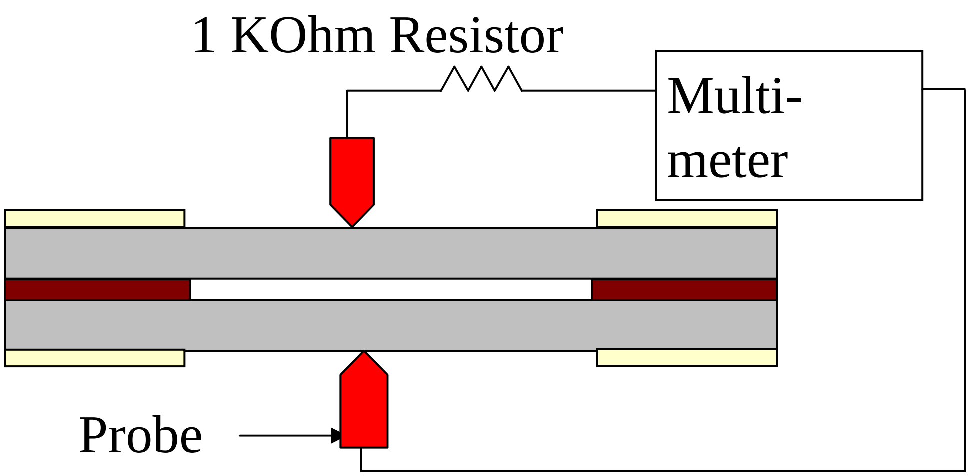
Validation of Risk Assessment

- Two coupons, separated by two insulators, were paired together to form an experimental set
- The coupons (1"×0.5"×0.0625") in length, width and thickness were bright tin (5μm in thickness) plated over brass
- Insulators were Kapton films
- The sets were always stored in temperature/humidity (50° C/50%RH) environment
- There were three groups of sets
  - Non-conformal-coated sets
    - Thickness of the insulators was 75 μm
  - Urethane-coated sets (thickness of insulators were 25 μm)
    - Inner surfaces of the set was coated with average thickness of 100 μm
    - Thickness of the insulators was 25 μm
  - Parylene-coated sets
    - Coating and insulator thickness was the same as urethane-coated sets



Experimental Results for Non-coated Test Vehicles

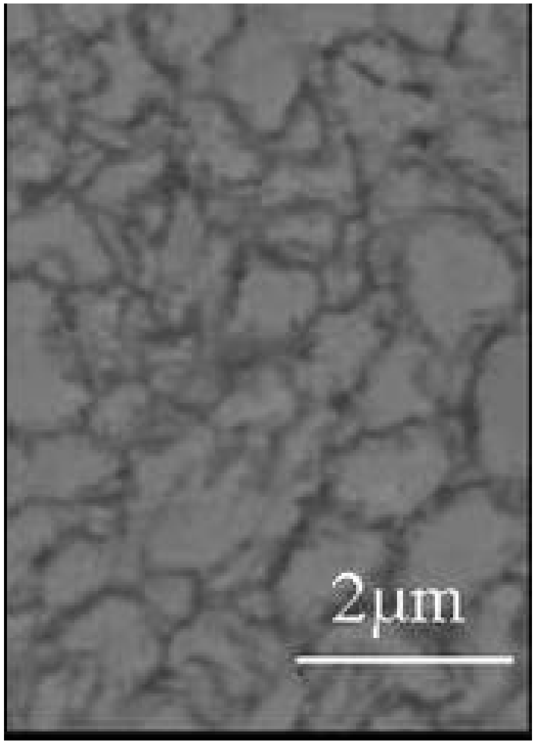
- Resistance between the two coupons in a test vehicle was selected as the monitoring parameter.



- The first case of drop in resistance was observed after 8 months from the start of the experiment.
- The number of test vehicles indicating tin whisker bridging have increased
- Currently 19 of the 40 samples show a drop in resistance.

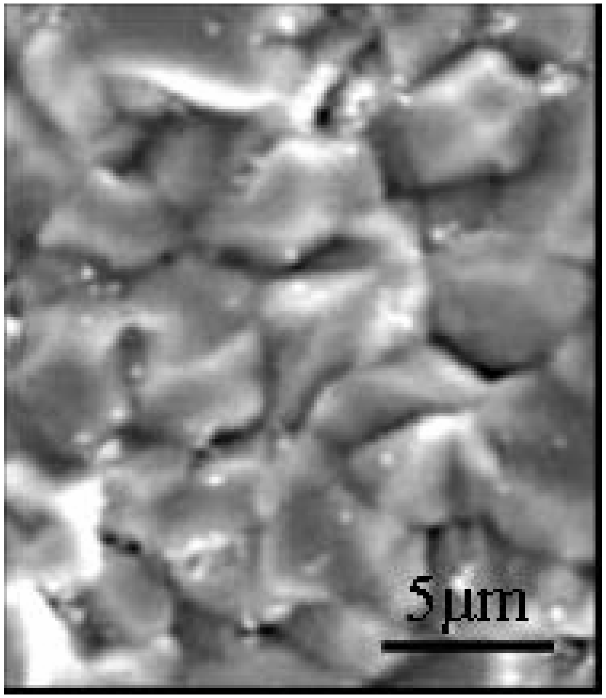
Matte vs. Bright Tin

•Bright tin



- Grain Size: 0.5 – 0.8 μm
- Carbon Content: 0.005% - 0.05%
- Shiny appearance

•Matte tin



- Grain Size: 1 – 5 μm
- Carbon Content: 0.005% - 0.05%
- Dull appearance

"Recommendations on Lead-Free Finishes for Components Used in High-Reliability Products (Version 3, updated May 2005), iNEMI Tin Whisker User Group http://thor.inemi.org/webdownload/projects/ese/tin_whiskers/User_Group_mitigation_May05.pdf

Matte vs Bright Tin Controversy

- There are no standards used by platers for matte and bright tin finish.
- Plating suppliers judge "matte" or "bright" by reflectivity.
- Many platers concur that matte and bright refer to cosmetic aspect of finish and there are many ways to achieve each.
- In 2005, "bright" tin finishes having low carbon content (similar to matte) were introduced.
- Under testing, these finishes over nickel have performed better than matte over nickel.
- These finishes also have many horizontal grain boundaries, which lead to reduced stress in the finish layer.

Comments from CALCE Tinwhiskerteam list server:
http://calcetalk.umd.edu/pipermail/tinwhiskerteam/2006-July/000609.html

Part Selection Considerations

Terminal/Substrate	Level I	Level II	Level III
SnPb >3%	Low	Low	Low
Sn (unqualified)	Medium	High	High
Sn Matte	Low	Medium	High
Sn Matte/ Ni Underlayer	Low	Medium	High
Sn Matte Annealed (150C 1 hr)	Low	Medium	High
SnBi / Cu	Low	Medium	High
SnBi / Alloy 42	Low	Medium	High
SnCu	Medium	High	High
SnAg	Low	Medium	High
NiPdAu	NA	NA	NA
NiPd	NA	NA	NA

Level I- Product have medium < 5 year life expectancy.

Level II - Products require a very high level of reliability but fails may be tolerable due to redundancies and ability to repair/replace.

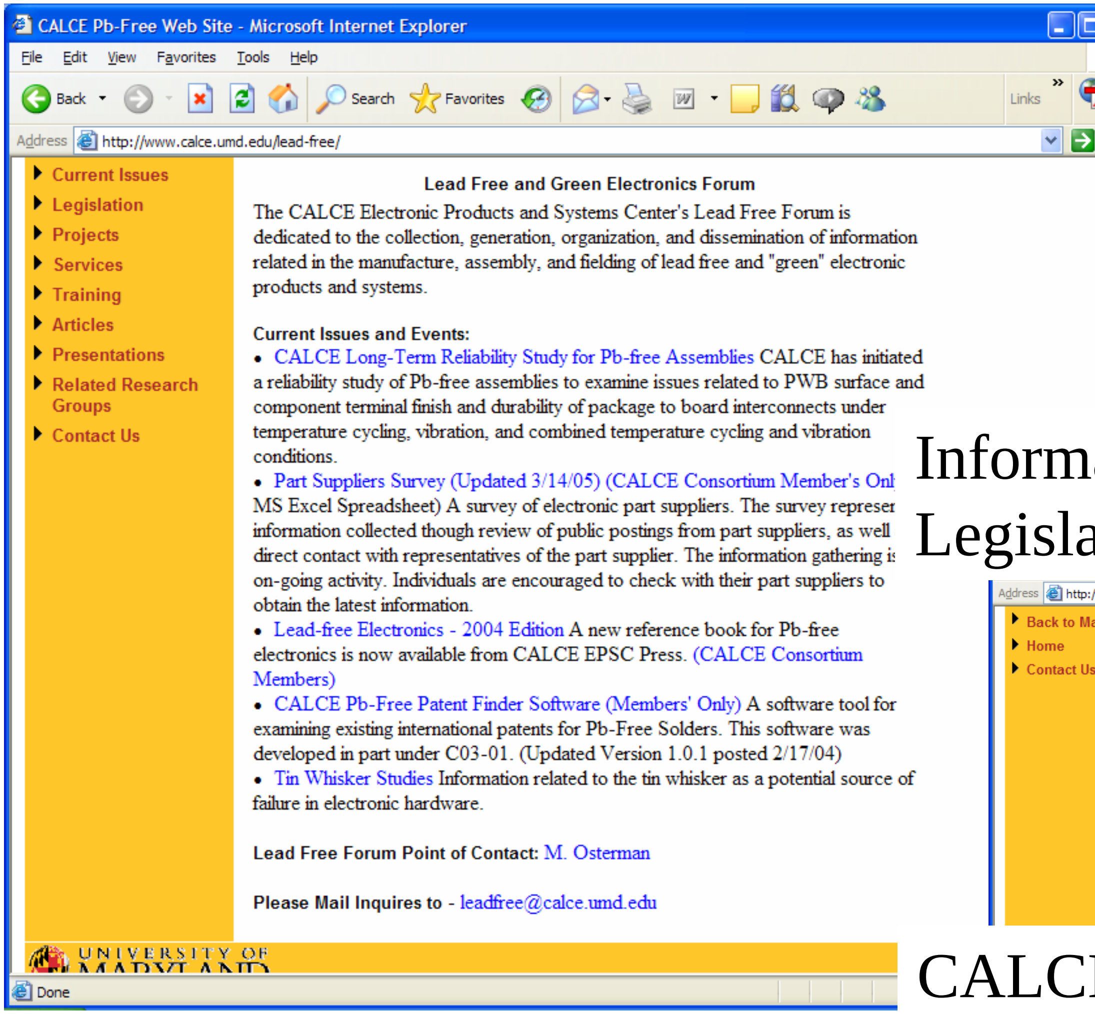
Level III - Products are required to be ultra-reliable and have no/very limited ability to repair or replace. Usually, long service life.

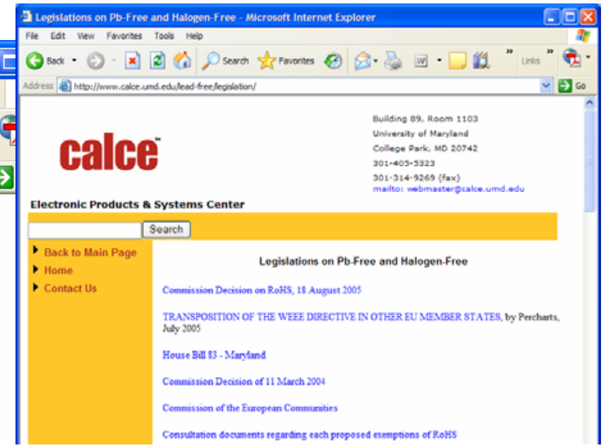
General Recommendations

- Define a tin and tin based Pb-free policy.
- Determine your level risk tolerance based your products
- Avoid pure tin and high tin content Pb-free finished parts
- If unavoidable,
  - Know where tin is being used in your product
  - Select parts with matte tin (> 1μm grain size)
  - Select thicker finish 8 μm nominal
  - Select parts with nickel under layers
  - Make sure supplier conducts whisker testing and surveillance
  - SnBi has been shown to be effective but raises other issues particularly with backward compatibility
  - SnAgCu dipped may provide some protection as a Pb-free solution
  - For long life and mission critical applications, consider use of conformal coating

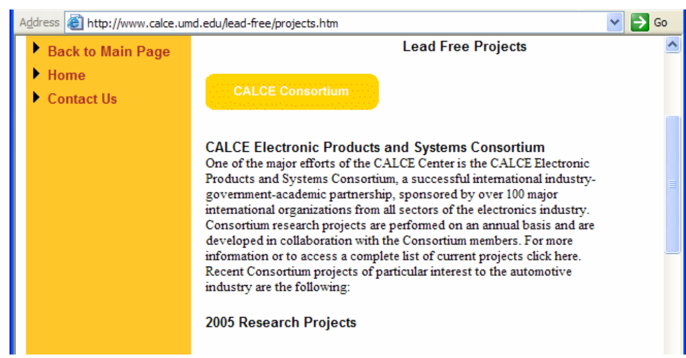
Pb-free and Green Electronics

http://www.calce.umd.edu/lead-free/





Information on Government Legislation



CALCE Pb-Free/Green Electronics Projects