NORTHROP GRUMMAN

DEFINING THE FUTURE

Effects of Tin Mitigation Processes on Whisker Growth and Solder Joint Reliability for Chip and Small-Outline Package Components

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Topics

- Study Overview
  - Objectives and Test Plan
  - Variables and Components Covered
  - Pass/Fail Criteria
- Results & Discussion
- Conclusions & Recommendations

Objectives—to answer these questions

- What is the risk for tin whisker growth?
- Do tin mitigation processes introduce mechanical damage or degradation to the parts?
- Are tin mitigation processes effective in reducing or preventing tin whisker growth?
- Are the quality and reliability of the solder joints affected by tin mitigation processes?

What is “Tin Mitigation”?

- Process or action that results in decreased risk for failure caused by tin whiskers
- Examples: find substitute parts, replace tin material, encapsulate
- In this paper, tin mitigation refers to the act of replacing pure tin layer with tin-lead
  - 2 processes: solder dip to component body or Pb addition

Test Plan

Baseline –visual inspection, SEM/EDX to verify pure tin → Tin mitigation process → Post-process evaluation–visual inspection, SEM/EDX, cross section →

Install on PWB → Temp cycle & constant temp/humidity (JESD) tests → Post-test evaluation–visual inspection, SEM/EDX, Xray, electrical test (module)

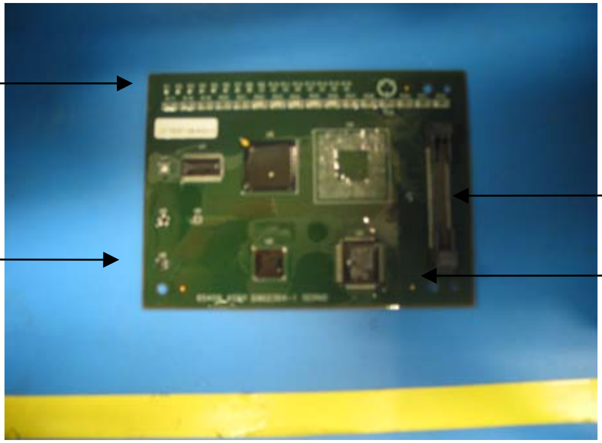
Variables tested

- 19 different component PNs in 8 part “families”
- Component finish: lead-free (pure tin, SnBi, NiPdAu, flash gold) vs. tin mitigated (SnPb)
- 3 tin mitigation process suppliers
- PWB materials: epoxy/glass and teflon based
- PWB pad finishes: immersion silver vs. electroless nickel-immersion gold (ENIG)
- Solder reflow environment: air vs. nitrogen environment
- Conformal coating (urethane) vs. no conformal coat

Types of Components tested

<table>
<tr><th>Part Type</th><th>Description</th><th>Termination Materials/ Finish</th><th>Mitigation Process</th></tr>
<tr><td>TSSOP</td><td>48-leads, plastic gullwing flatpack</td><td rowspan="2">Copper leads, matte tin plating</td><td rowspan="7">Sn63 solder dip</td></tr>
<tr><td>PLCC</td><td>32 J-leads, plastic surface mount QFP</td></tr>
<tr><td>SOT23</td><td>3 leads plastic surface mount package</td><td>Copper or Kovar/Alloy 42 leads, matte tin plating</td></tr>
<tr><td>DFN8</td><td>8 lead, plastic sfc mount pkg</td><td rowspan="2">Copper leads, matte tin plating</td></tr>
<tr><td>QFN64</td><td>64 lead frame chip scale pkg</td></tr>
<tr><td>0402 chip</td><td>Ceramic capacitor</td><td rowspan="2">Nickel barrier, pure tin</td></tr>
<tr><td>1206 chip</td><td>Ceramic capacitor</td></tr>
<tr><td>0402 chip</td><td>Ceramic resistor</td><td rowspan="2">Silver thick film metallization, nickel barrier, pure tin</td><td>Sn63 solder dip</td></tr>
<tr><td>1206 chip</td><td>Ceramic resistor</td><td>Solder dip/lead addition</td></tr>
<tr><td>Connector</td><td>125 pin plastic surface mount</td><td>Phosphor bronze leads, pure tin with light gold on contact areas</td><td>Sn63 solder dip</td></tr>
<tr><td>1206 chip</td><td>Ceramic filter</td><td>Pure tin & AgPd finish</td><td>None</td></tr>
<tr><td>SOIC</td><td>6 pin plastic GaAs MMIC switch</td><td>Plastic minimold, SnBi finish</td><td>None</td></tr>
<tr><td>SOIC</td><td>48 pin plastic surface mount</td><td>NiPdAu</td><td>None</td></tr>
<tr><td>QFN</td><td>12 pin plastic GaAs MMIC</td><td rowspan="3">Pure tin finish</td><td rowspan="3">None--pure tin control</td></tr>
<tr><td>SOT23 &343</td><td>3 or 4 leads, plastic package</td></tr>
<tr><td>LPCC</td><td>8 lead plastic package</td></tr>
<tr><td>Large module</td><td>Encapsulated surface mount DC-DC converter module</td><td>External pins SnPb, internal components pure tin plated</td><td>None</td></tr>
<tr><td>BGA</td><td>256 ball plastic encapsulated</td><td>SnAgCu balls,
underlayers: Ni = 5-10µm,
Au = 0.5µm min Cu = 35µm</td><td>Reballed with SnPb</td></tr>
</table>

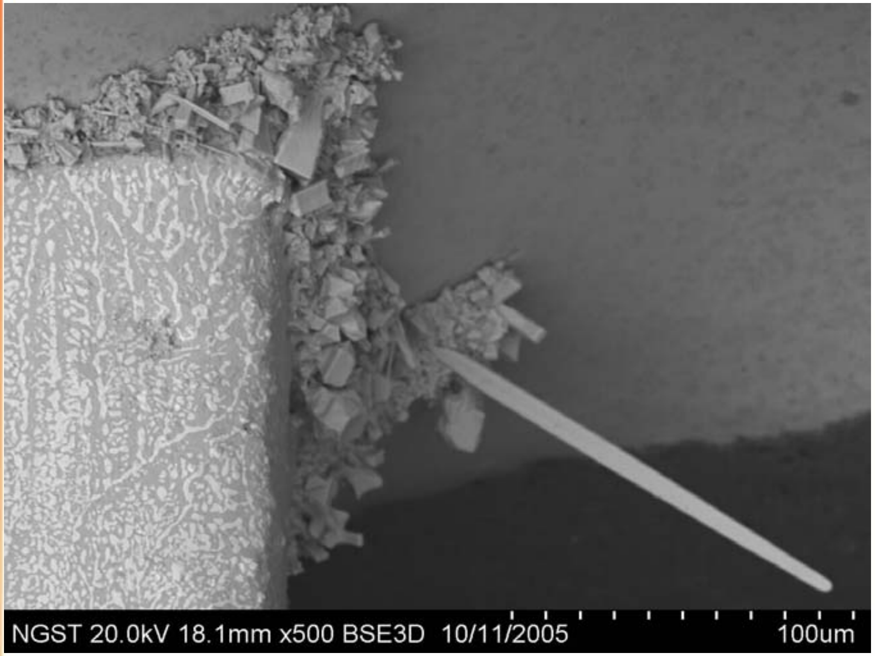
Test article

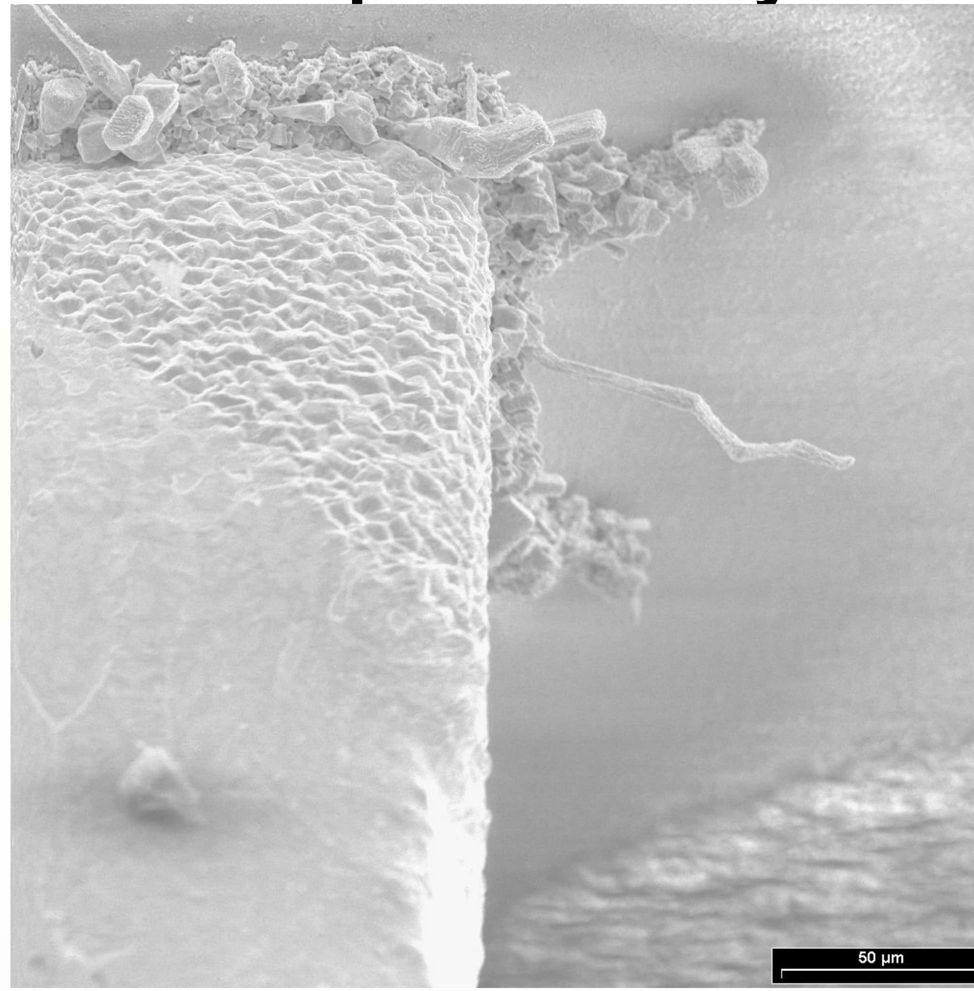


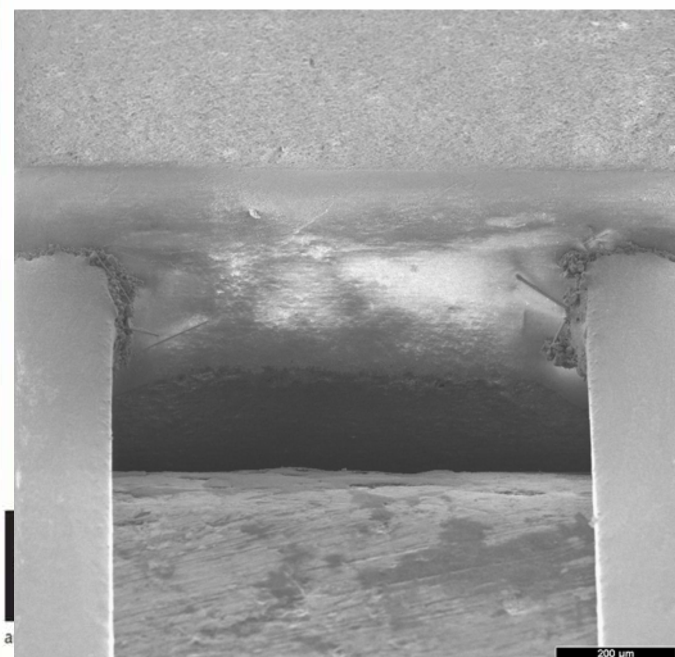
- CCA with up to 32 leadless surface mount chip components, 9 multi-leaded surface mount components and one surface mount connector.
- No through-hole components
- PWB was 3”x4” in size and 0.032” thick with 2 layers
- Pad patterns and materials were representative of JSF PWBs
- Pure tin and other lead-free parts tested without mitigation
- CCAs built at 2 locations (air and nitrogen purged ovens); 30 submitted for testing

Evaluation of Parts before & after solder dip

Why dip all the way to the component body?

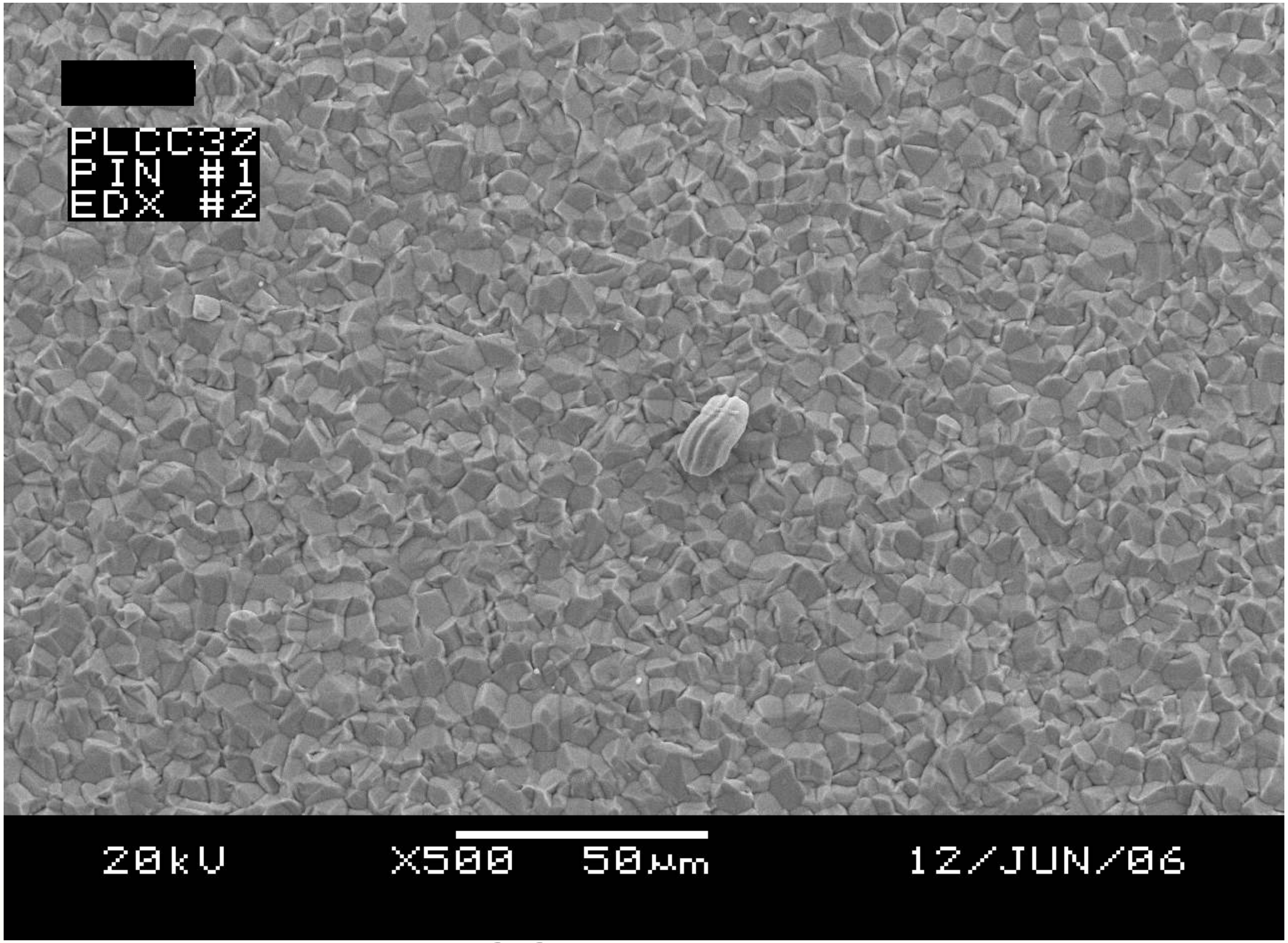






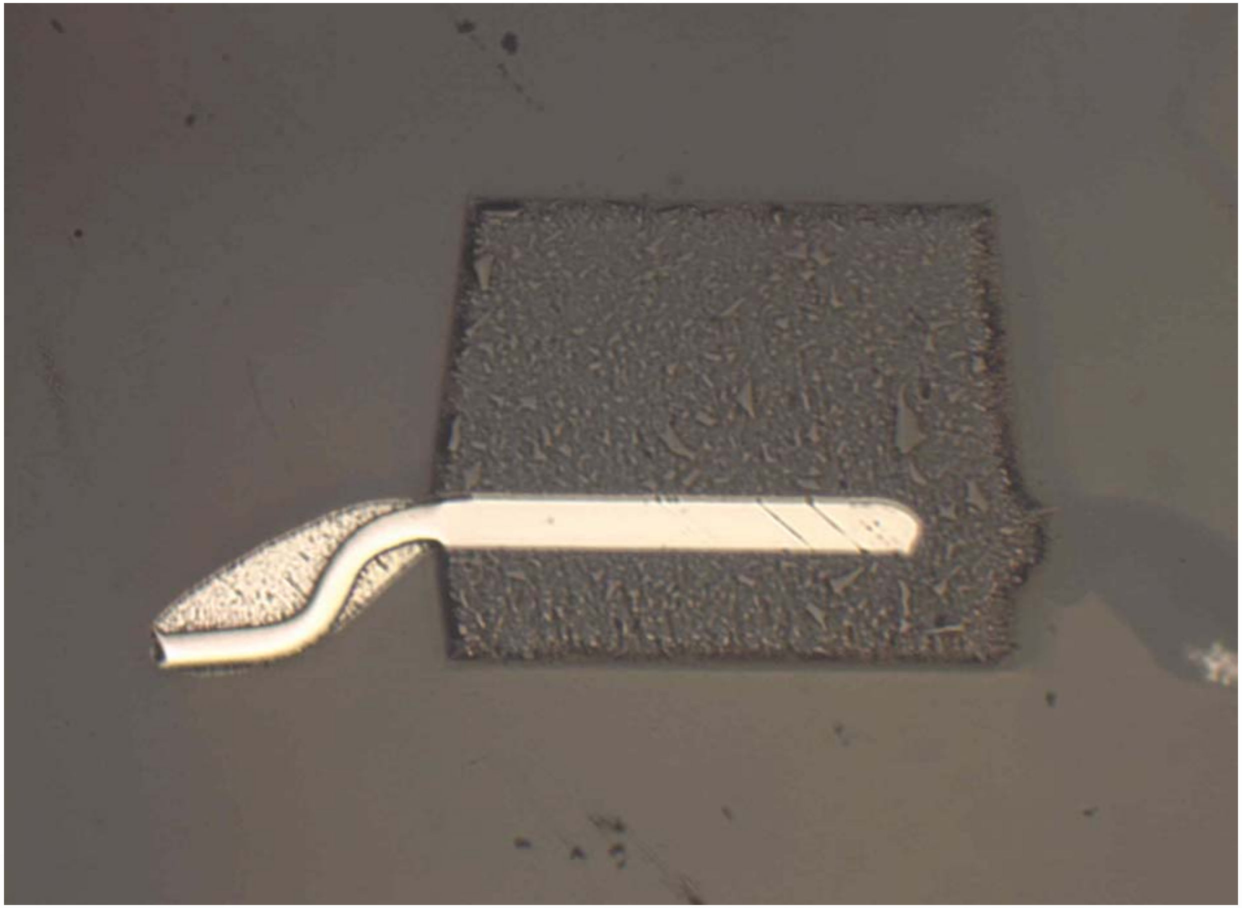
Tin whiskers on incompletely dipped IC components

Pre-test evaluation



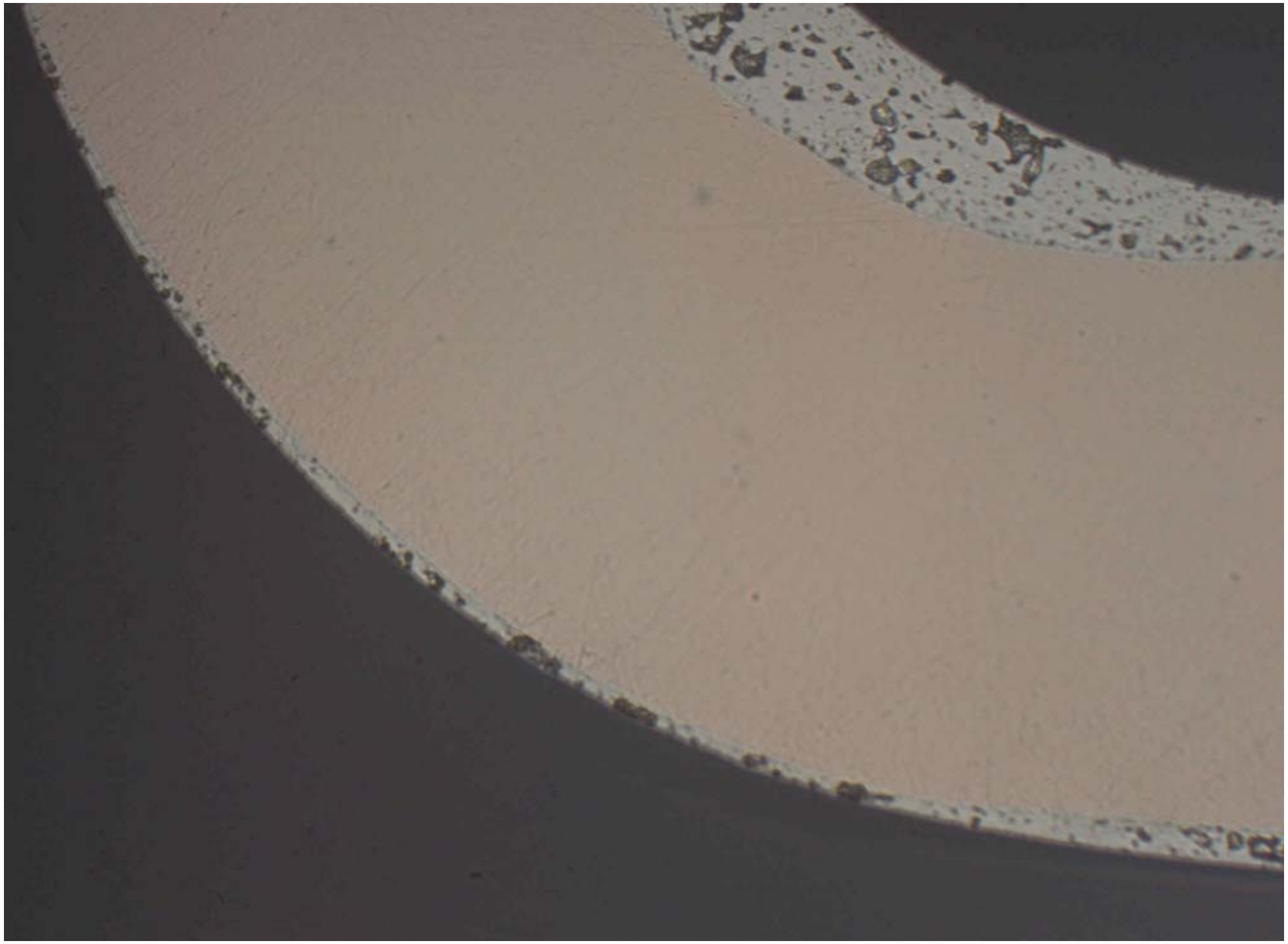
Tin whisker on PLCC component prior to solder dip

Post solder dip, pre-test evaluation



Cross section of SOT23 component after solder dip—excessive solder

Post solder dip, pre-test evaluation

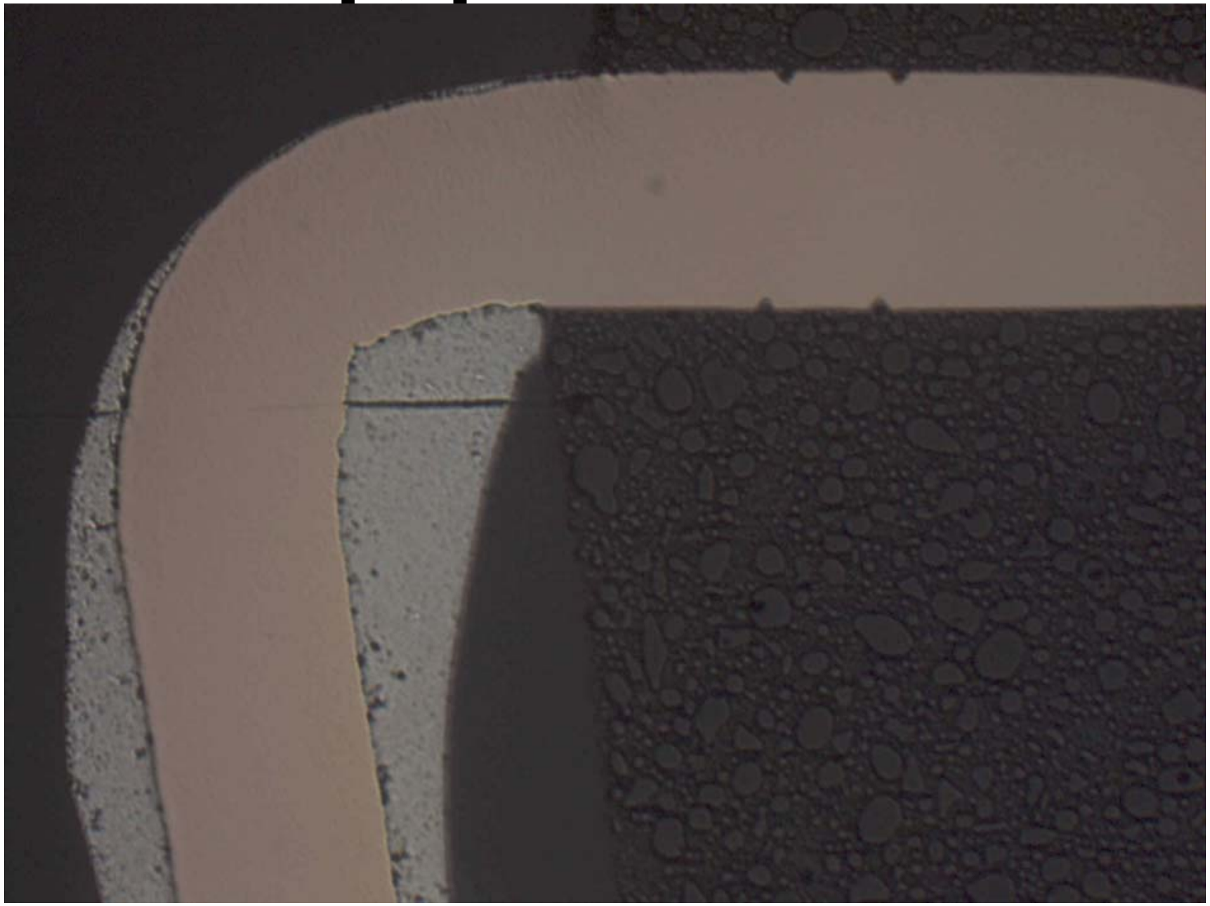


Cross section of TSSOP lead after solder dip—no residual tin

Post solder dip, pre-test evaluation

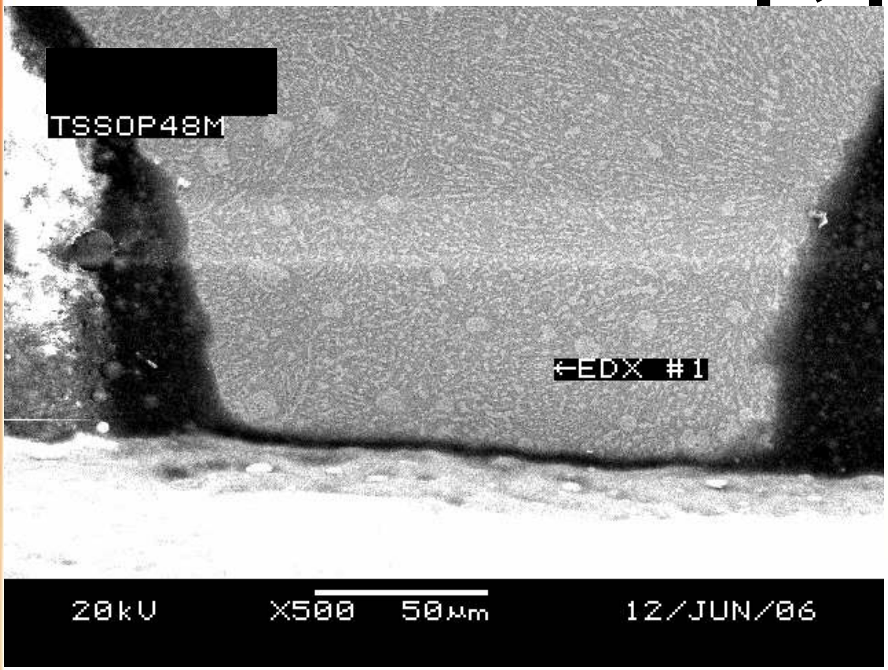
Cross section of SOT23 lead after solder dip—no perceptible residual tin

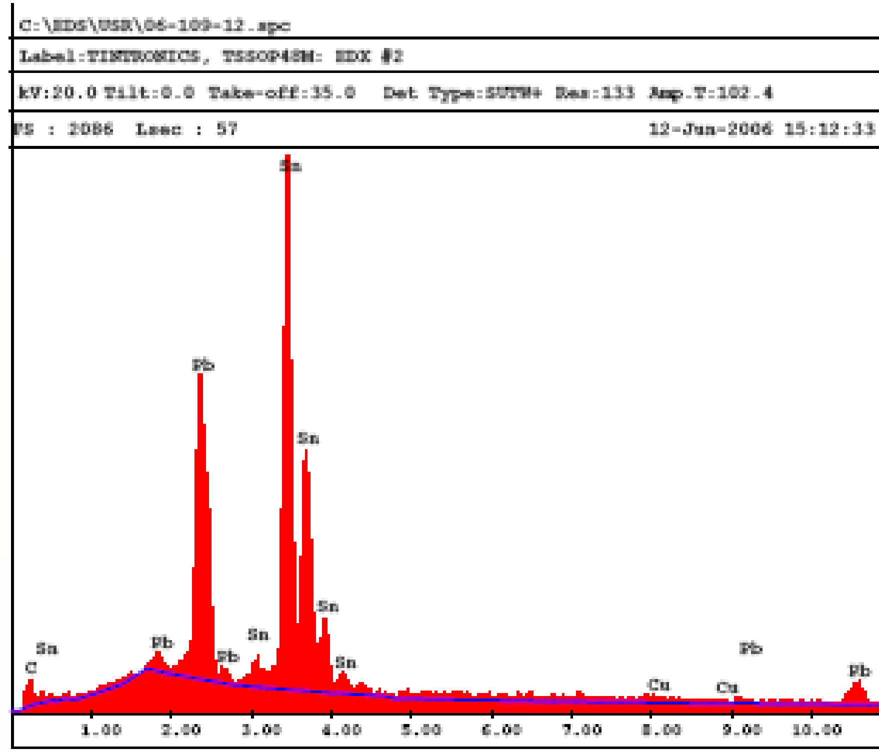
Post solder dip, pre-test evaluation



Cross section of PLCC/J leads shows no damage or delamination but some cases of excessive solder

Post solder dip, pre-test evaluation





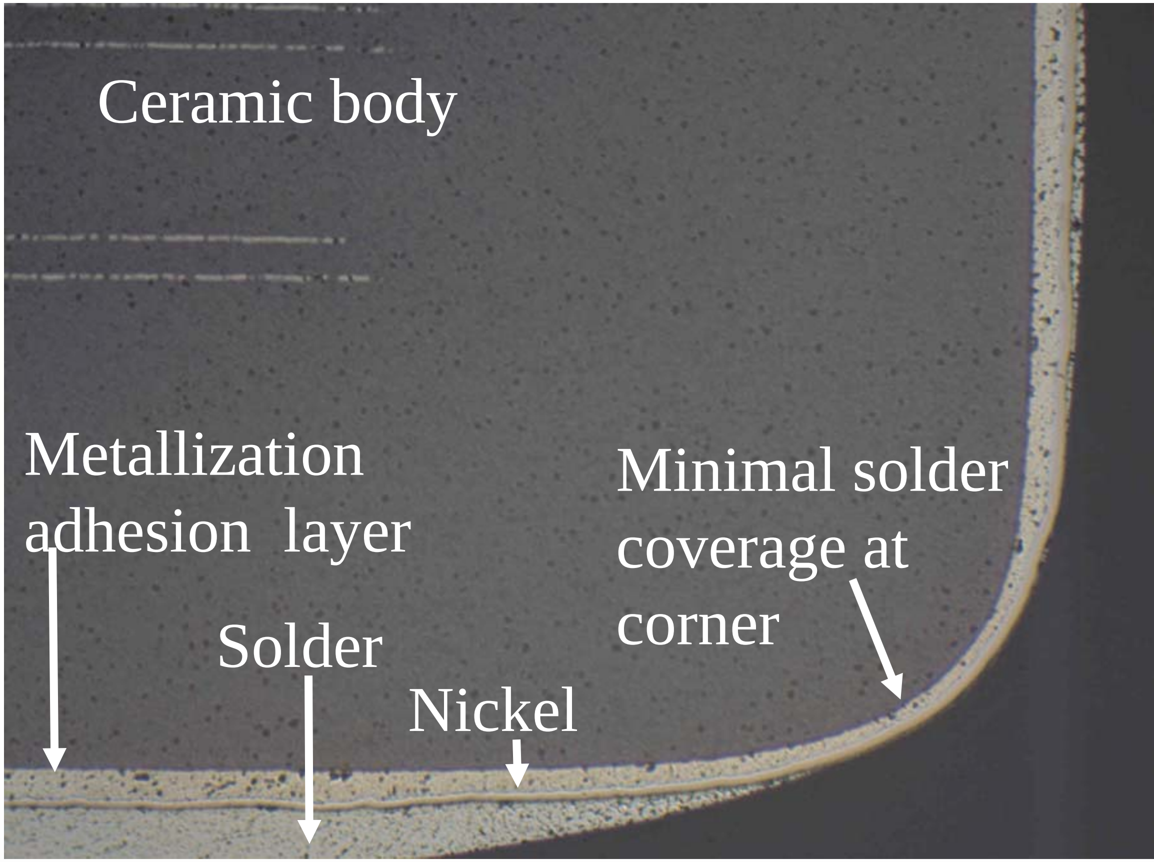
EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Element	Wt %	At %	K-Ratio	Z	A	F
C K	2.55	23.28	0.0088	1.3557	0.2555	1.0000
SnL	59.86	55.36	0.4959	1.0068	0.8228	1.0000
CuK	1.21	2.09	0.0133	1.1594	0.9294	1.0165
PbL	36.38	19.27	0.3262	0.8960	1.0007	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
C K	5.96	2.14	7.09	2.78
SnL	311.75	16.51	0.79	18.88
CuK	5.35	8.08	11.45	0.66
PbL	21.06	6.46	3.65	3.26

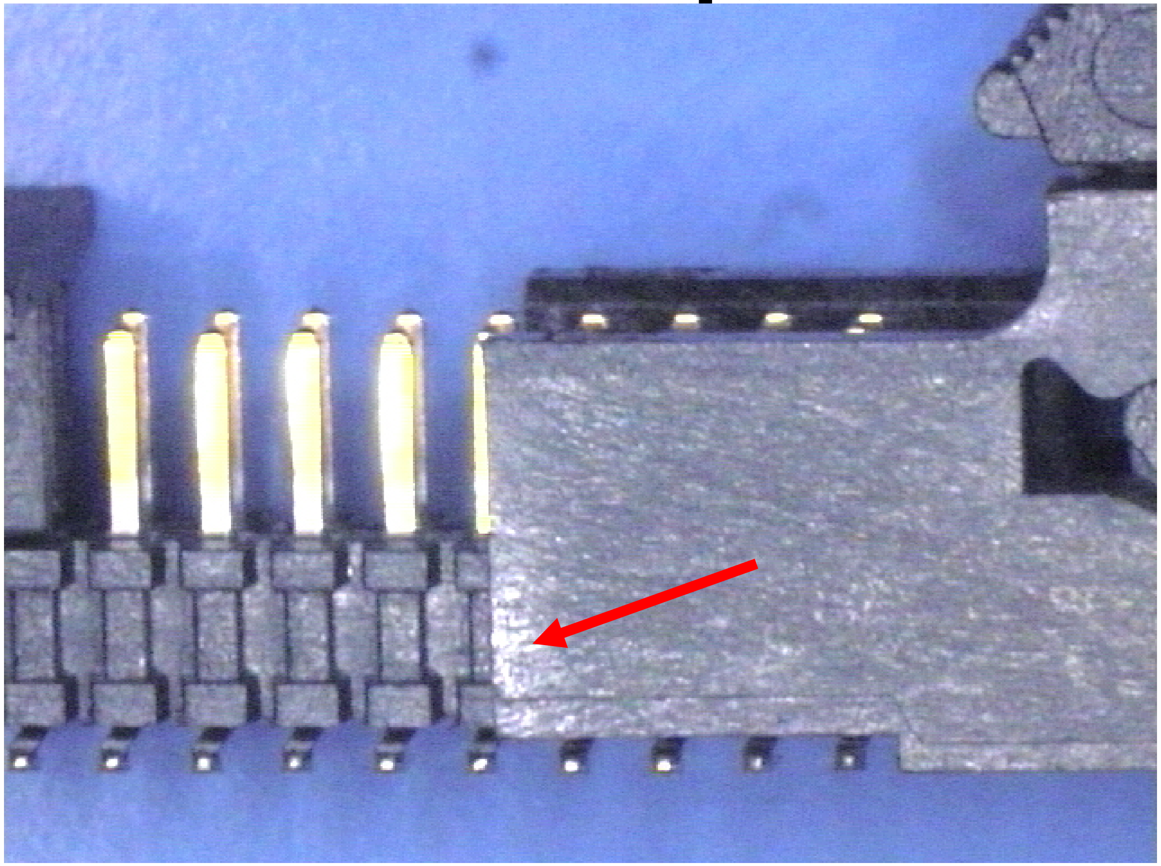
SEM examination of TSSOP showed no damage at lead egress. EDX was consistent with Sn63.

Post solder dip, pre-test evaluation



Cross section of ceramic chip part shows no cracks or damage to ceramic. Minimal solder coverage at corners—possible solderability issue

Post solder dip, Pre-test evaluation

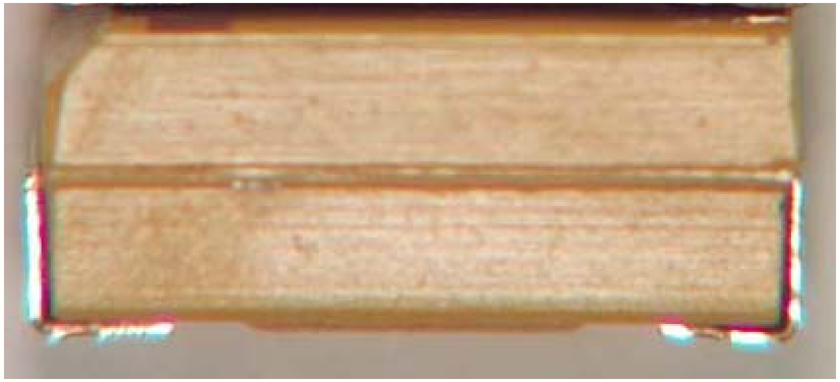


Area where connector leads are housed in plastic—very difficult to replace tin coating with SnPb after connector has been built

Pure tin surfaces on connector leads were not fully mitigated due to lead/body configuration.

Another concern: solder may wick up onto contact surfaces

Post solder dip, Pre-test evaluation



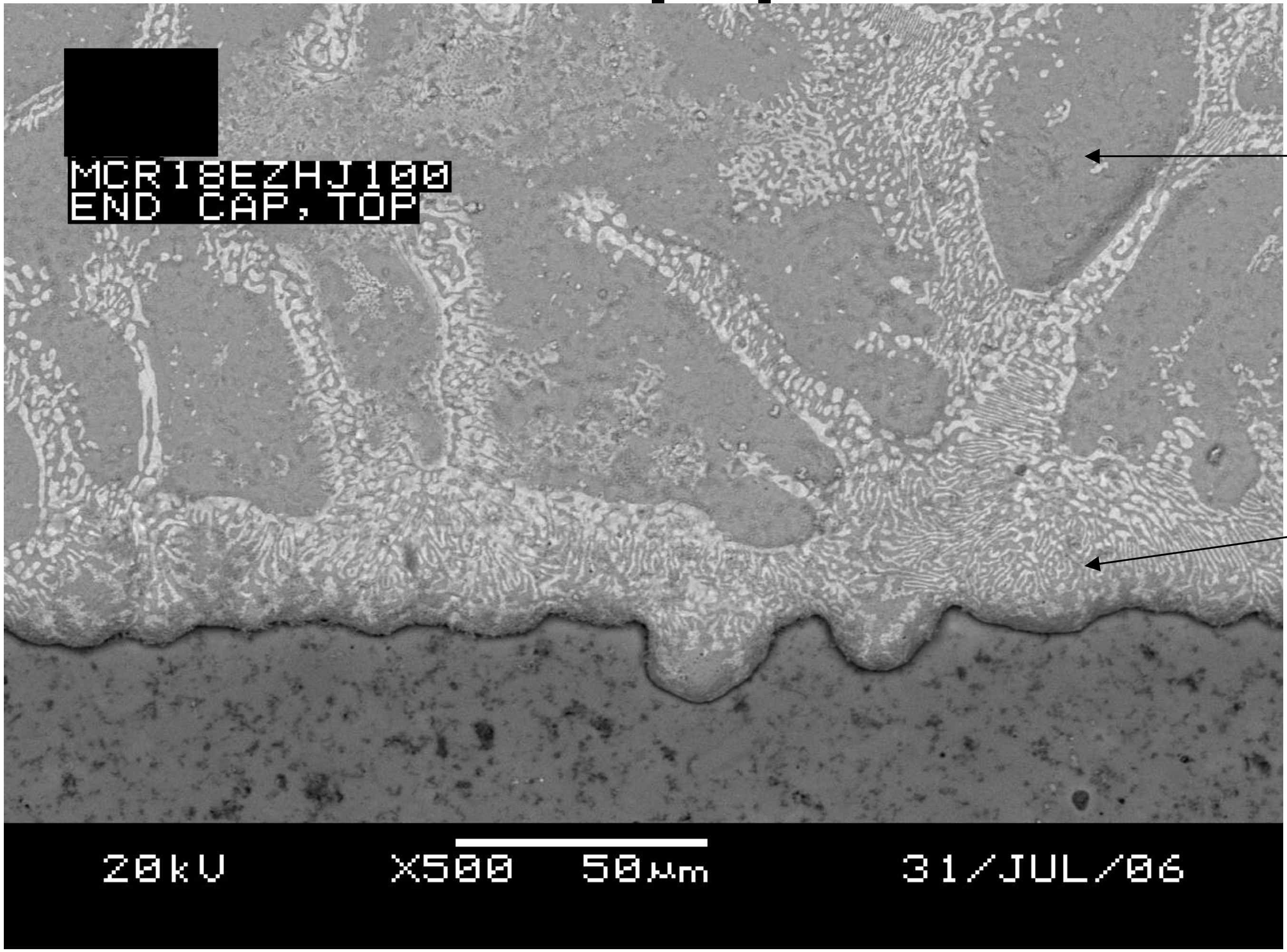
Tantalum capacitor with "wrap-around lead configuration

EDX analysis of pulled back leads revealed that solder dipped part had incomplete solder coverage

Tin surfaces on wrap-around leads of "low profile" capacitors were not fully mitigated due to tight of space between lead & body

"Pb addition" process yielded Pb across all surfaces of leads

Post solder dip, pre-test evaluation



Darker areas = Pb

Lighter areas = Sn

SEM image of chip part after Pb addition—segregated tin/lead

Evaluation of tin whisker growth after CCA installation and environmental test

Pre-test evaluation

- All baselined PLCC, TSSOP, SOT23, chip parts were pure tin.
- Tin whiskers observed on PLCC and TSSOP baseline parts.
- Largest whisker on baseline parts was about 40 µm long.
- Damaged, poor plating/coating quality was observed on connectors, 0402, 1206, PLCC & SOT23 components.
- On PLCC, TSSOP, SOT23 and chip parts mitigated by solder dipping, pure tin material was completely removed and replaced with SnPb.
- No mechanical damage such as internal cracks, discoloration or delamination, was observed on the tin-mitigated parts.
- Solder dipping does not completely remove pure tin from “low profile” leaded components or connectors.
- Some parts showed excessive solder on the leads after the solder dipping process.

JESD201 defines 4 classes of hardware:

Class	Description	Guidelines on Pure Tin Usage	Max. Tin Whisker
3	Mission/Life Critical applications such as military, aerospace and medical.	Pure tin and high tin alloys are typically not allowed or acceptable	
2	Business Critical applications such as telecom infrastructure, high-end servers, automotive	Tin whisker mitigation practice is expected. Long product lifetimes and minimal down time required.	40 to 45 µm
1	Industrial/consumer products with medium lifetimes.	Medium product lifetime, no major concern with tin whiskers breaking off	50 to 100 µm
1A	Consumer products with short lifetimes	Short product lifetimes, minimal concern with tin whiskers breaking off	50 to 75 µm

Test & Inspection Conditions

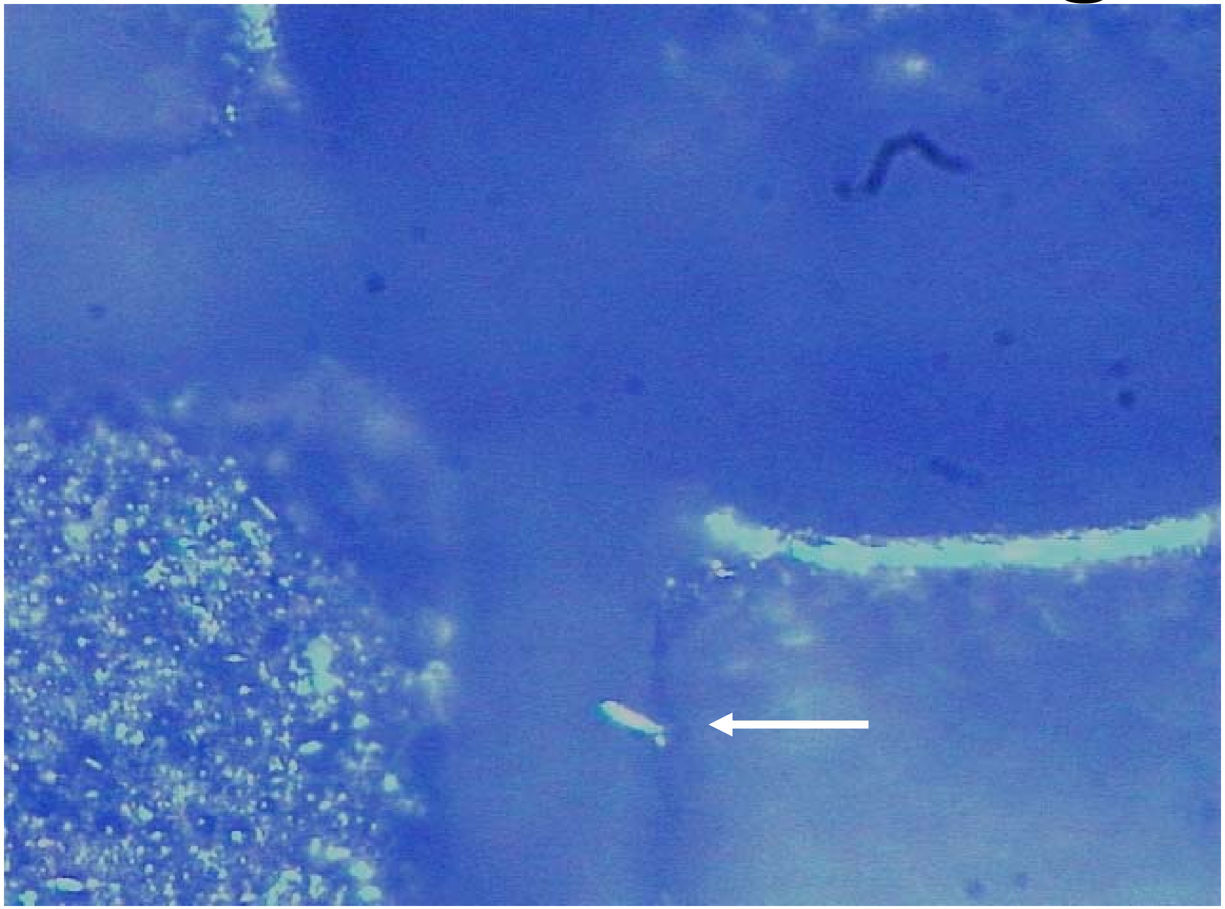
Category Description	Details	Reference
Test Conditions & Duration: 1.Temperature cycling 2.Ambient temperature/ humidity storage 3.High temperature/humidity storage	 -40°C to 85°C, 1000 cycles 30°C, 60% RH, 3000 hours 60°C, 87% RH, 3000 hours	JESD 22A121
Sample Size	•Multi-leaded components: minimum of 96 terminations/6 components •Leadless components: minimum of 18 terminations/9 components	JESD201
Inspection magnification	Minimum 50X for optical inspection, 250X for SEM.	JESD 22A121
Whisker density classification	see table below	JESD 22A121

Whisker Density	# Whiskers per lead
Low	**< 10**
Medium	**10-45**
High	**> 45**

Results—tin whisker growth

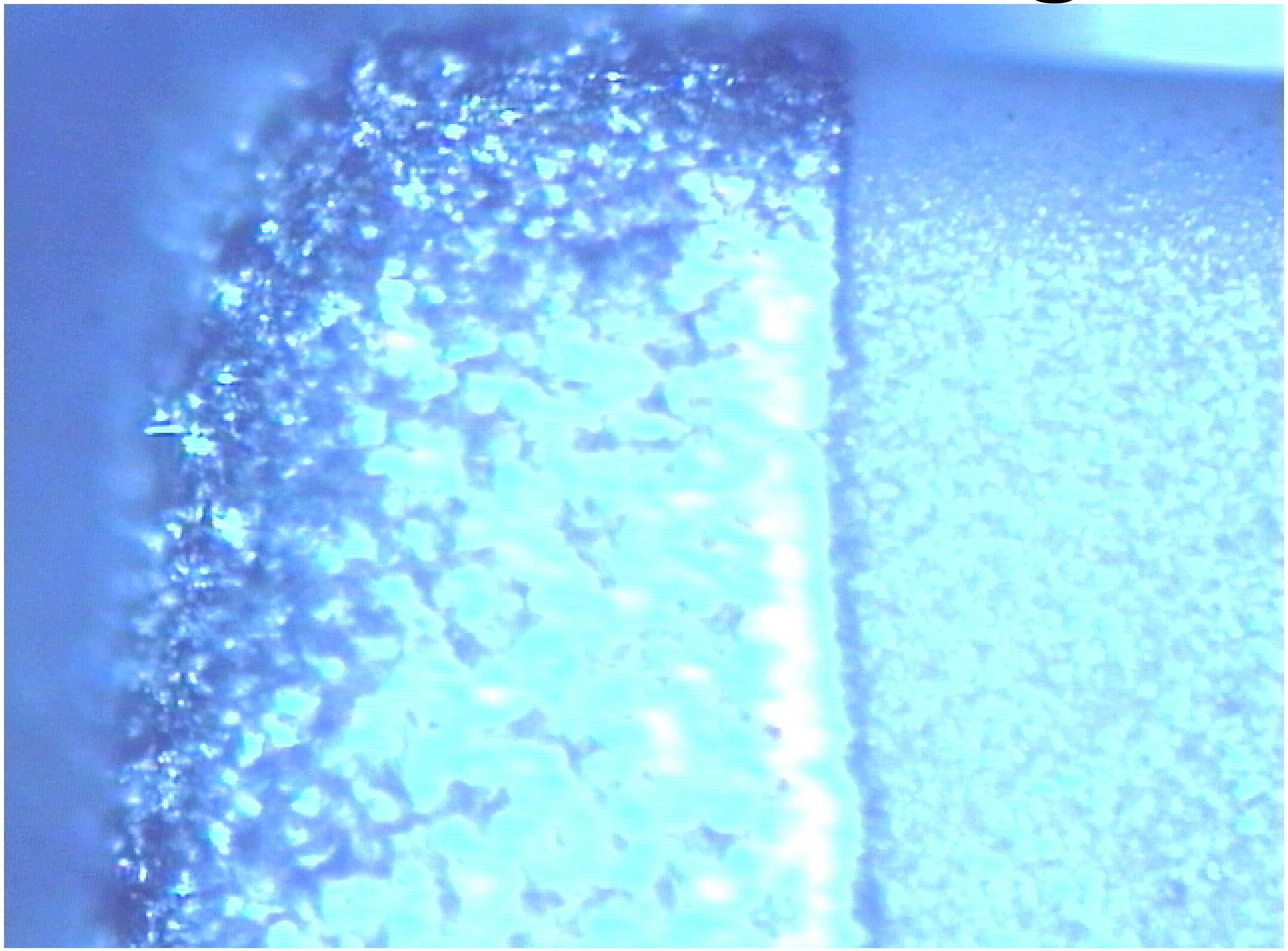
Tin whiskers on connector lead prior to solder dip

Results—tin whisker growth



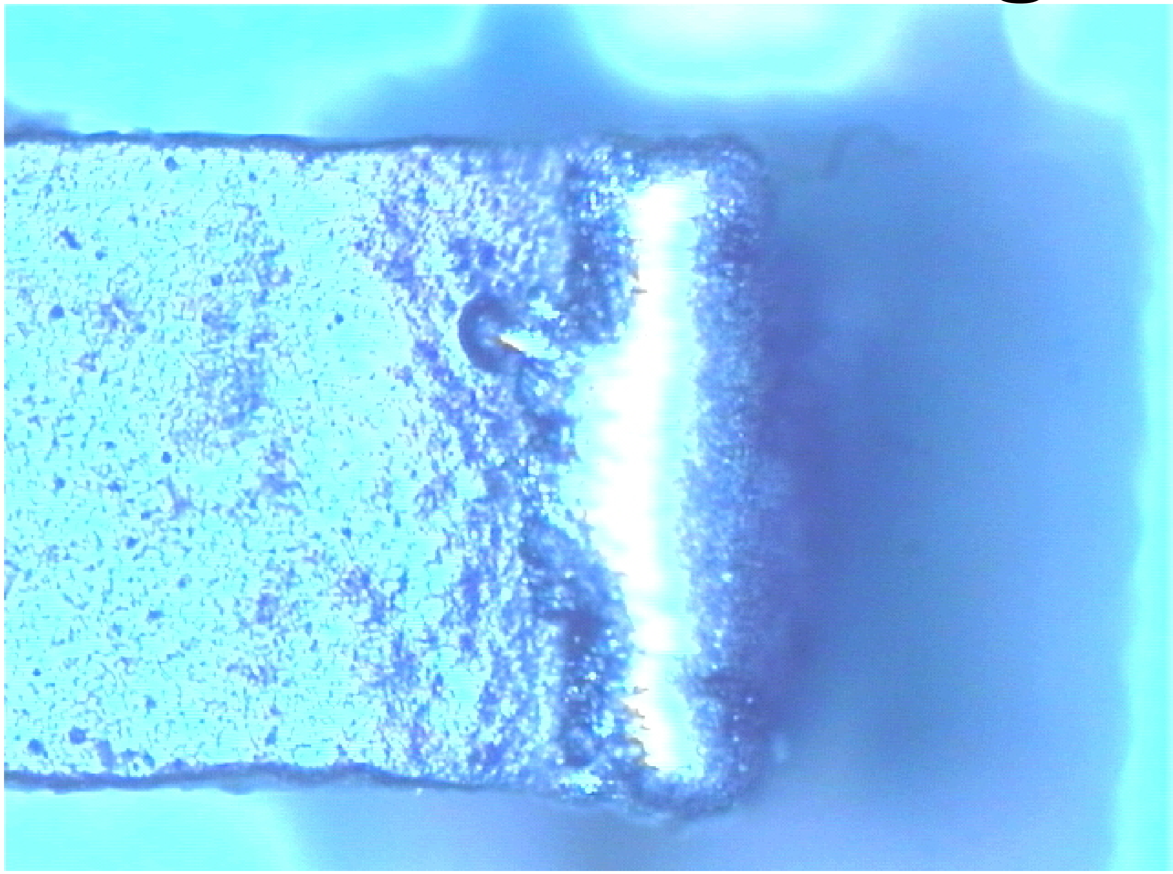
25 µm whisker on pure tin PLCC piece part during 60°C, 87% RH test.

Results—tin whisker growth



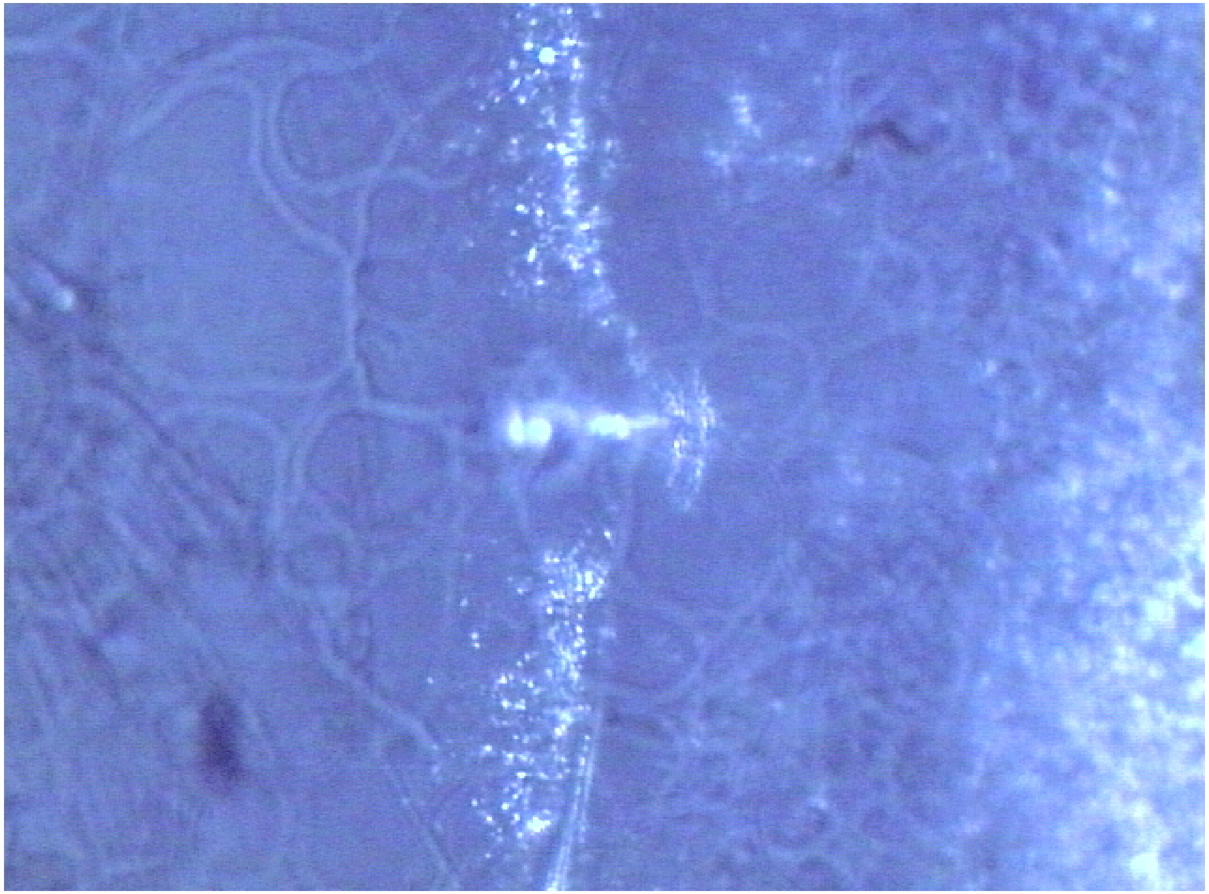
Whiskers and nodules on tin plated control part--1206 capacitor--after 1000 temp cycles.

Results—tin whisker growth



Pure tin control part: 0402 resistor after 3000 hours 60°C, 87% RH. High densities of nodules and whiskers were observed, up to 100 µm

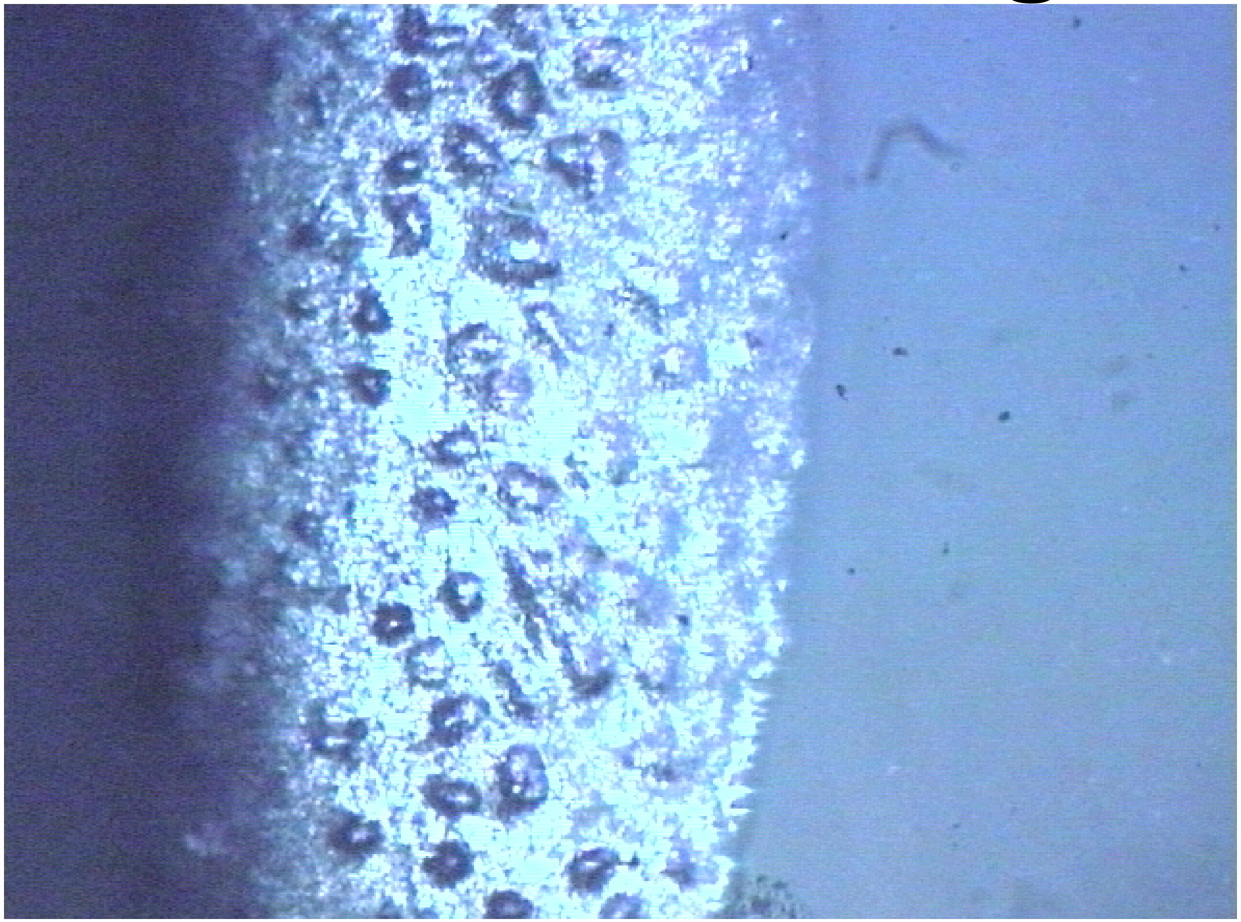
Results—tin whisker growth



36 µm whisker piercing conformal coat on 0402 resistor after 3000 hours 60°C, 87% RH

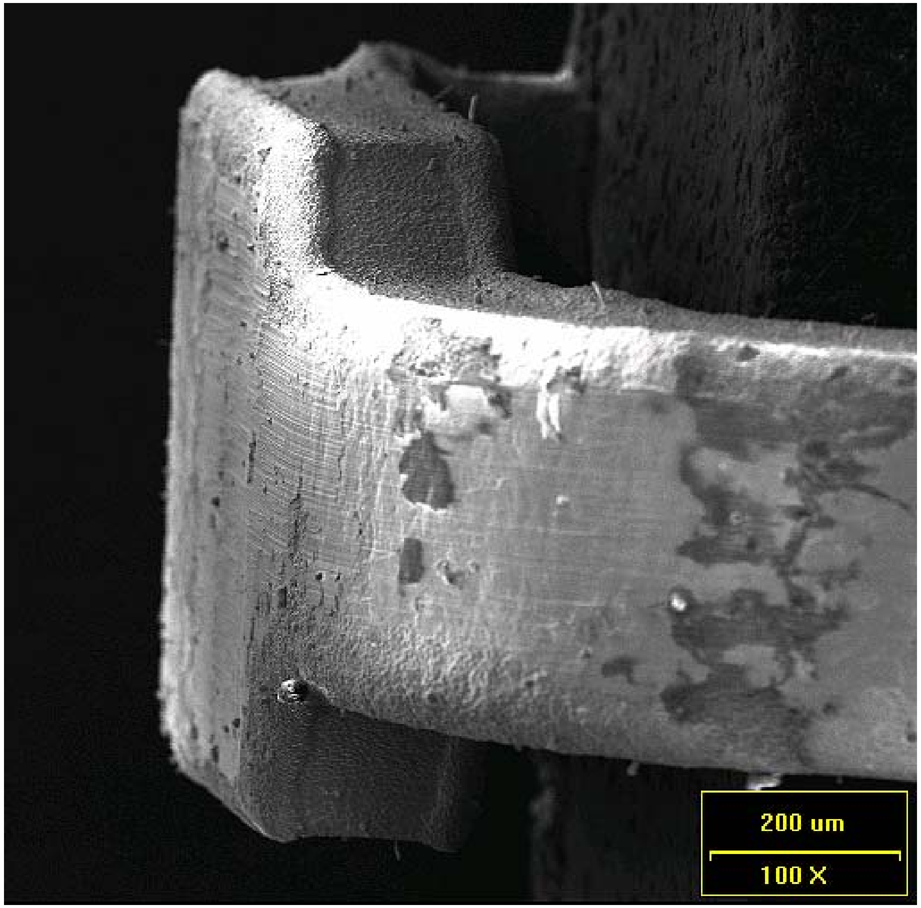
Presence or absence of urethane conformal coating did not significantly affect whisker length or density

Results—tin whisker growth



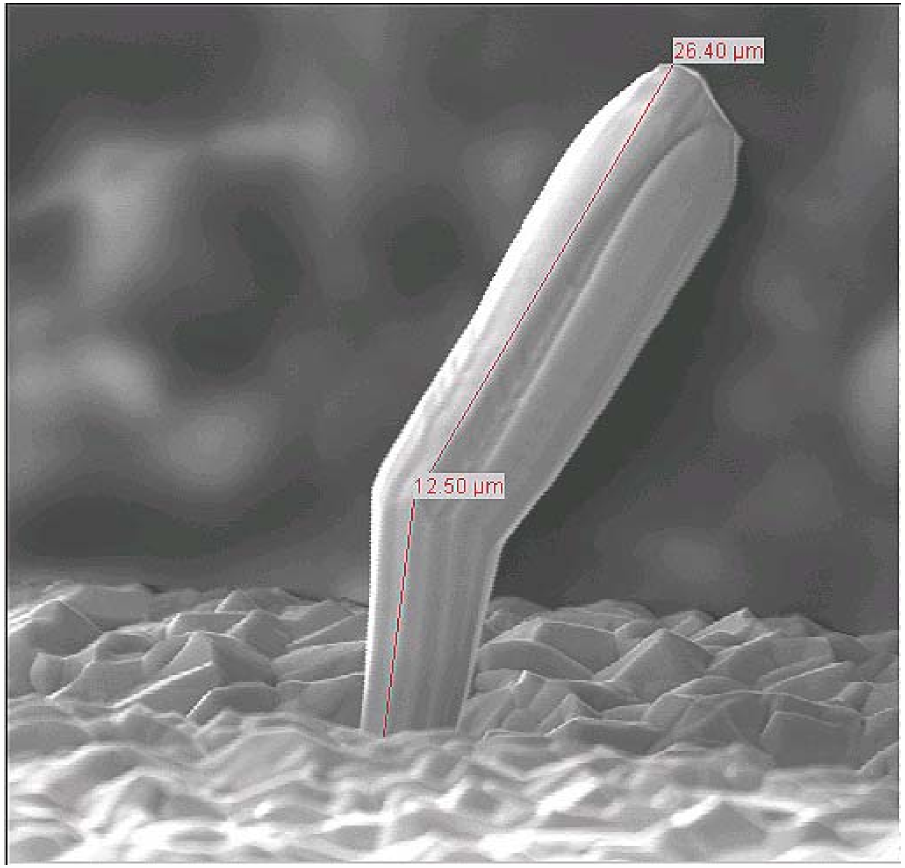
"Hillocks" on tin mitigated 1206 part after 1000 temp cycles

Results—tin whisker growth



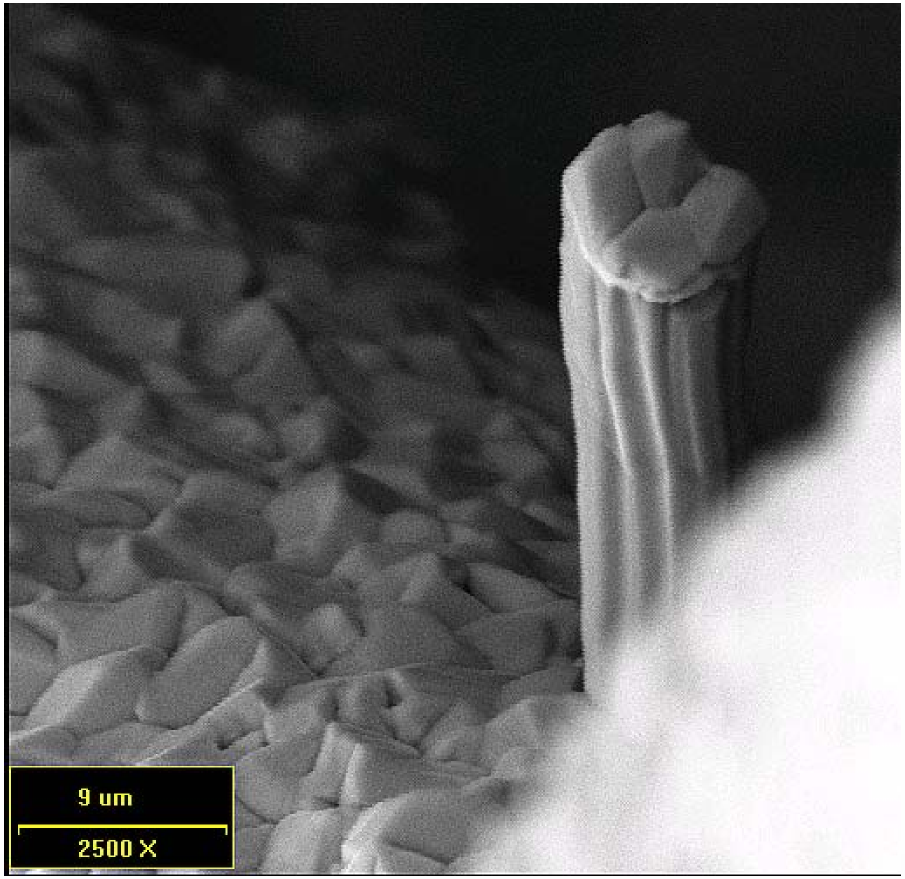
Whiskers and nodules on pure tin PLCC after 3000 hours 30C, 60% RH

Results—tin whisker growth



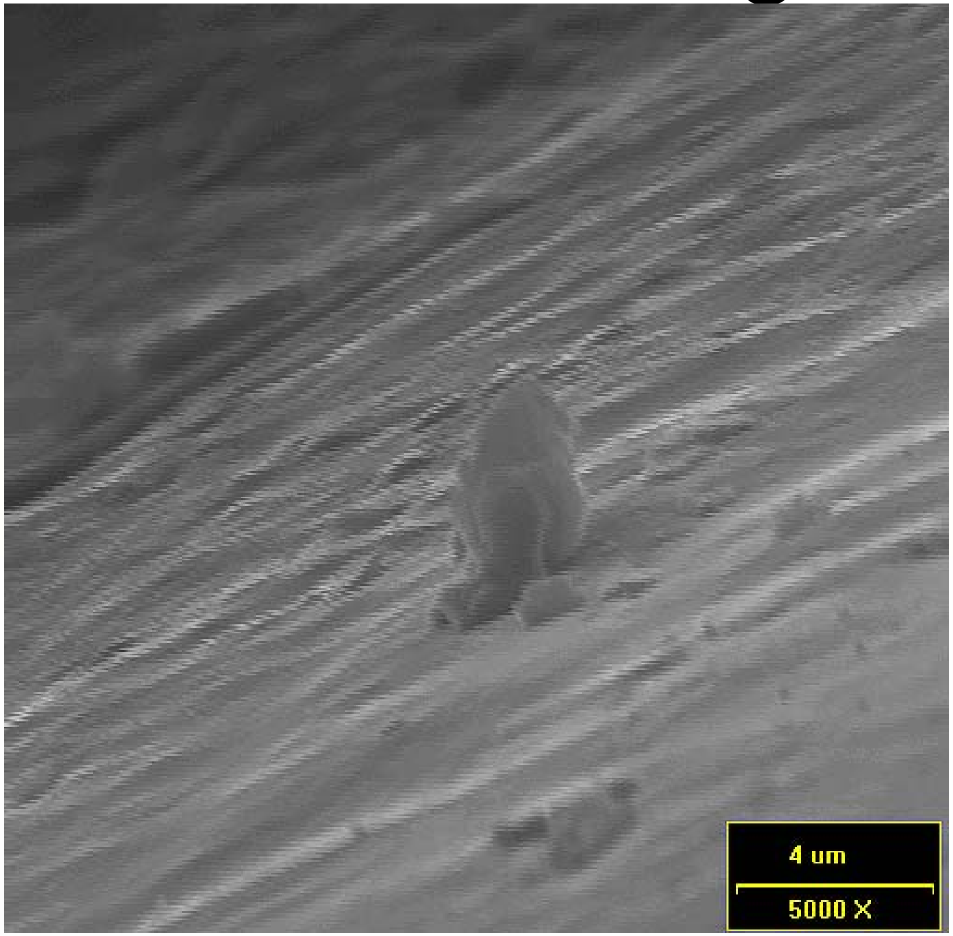
39 µm tin whisker growing from PLCC piece part after 3000 hours 30C, 60% RH

Results—tin whisker growth



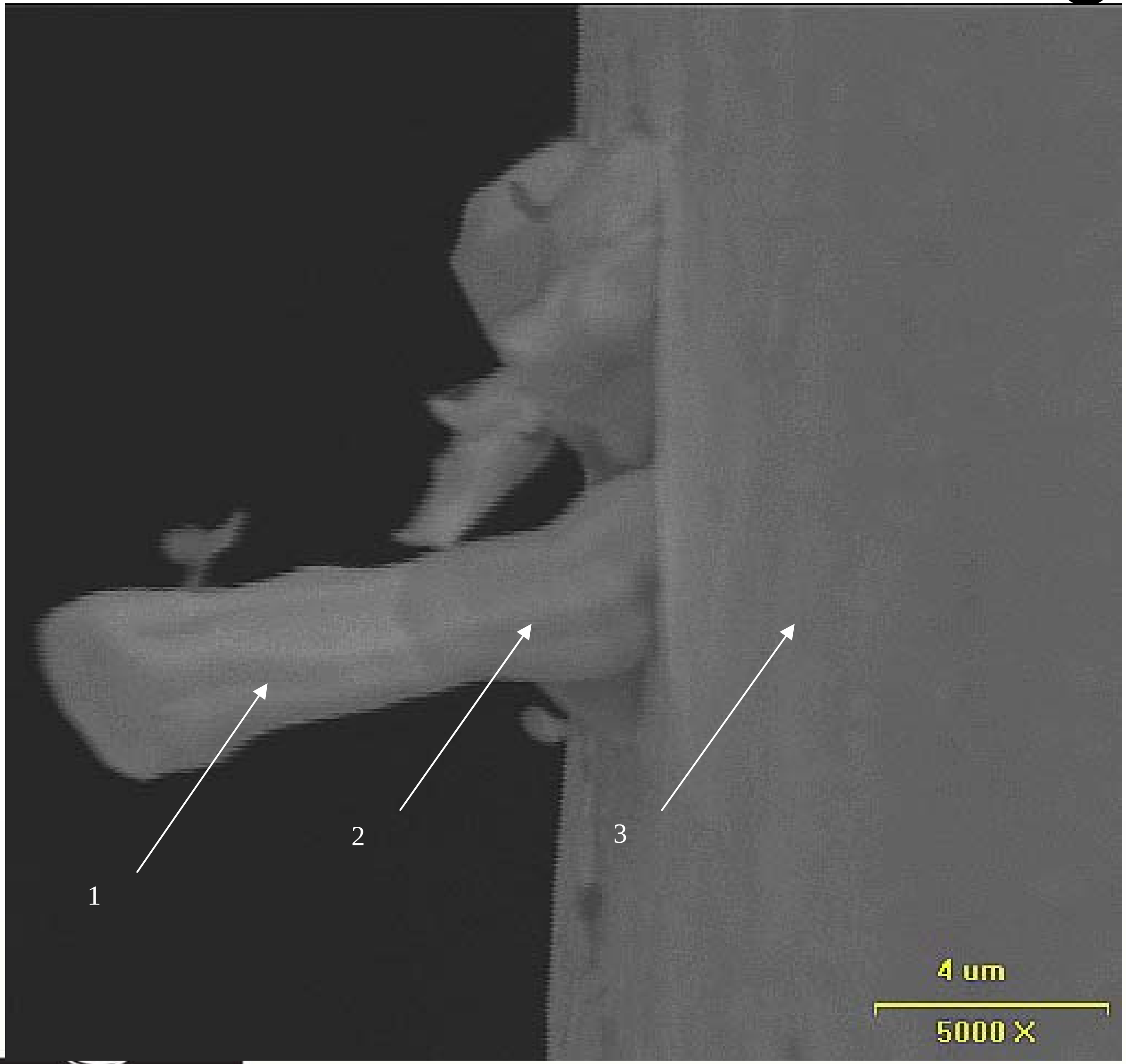
36 µm tin whisker on pure tin PLCC part after 3000 hours 30°C, 60% RH

Results—whisker growth



4 µm Pb whisker on tin mitigated 0402 chip after 1000 temp cycles

Results—whisker growth



≈10 μm whisker growing from tin mitigated TSSOP part after 1000 temp cycles

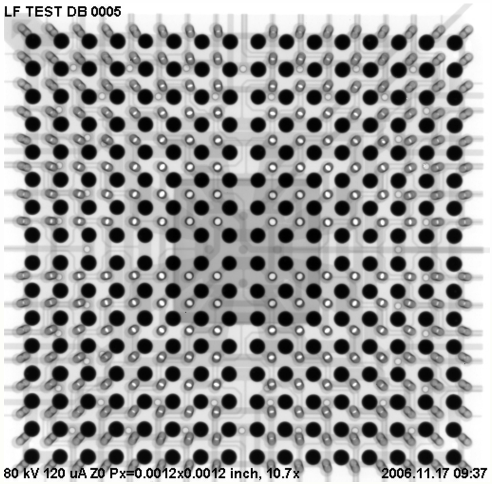
Area 1 = Pb

Area 2 = Sn

Area 3 = SnPb

Results—Xray evaluation

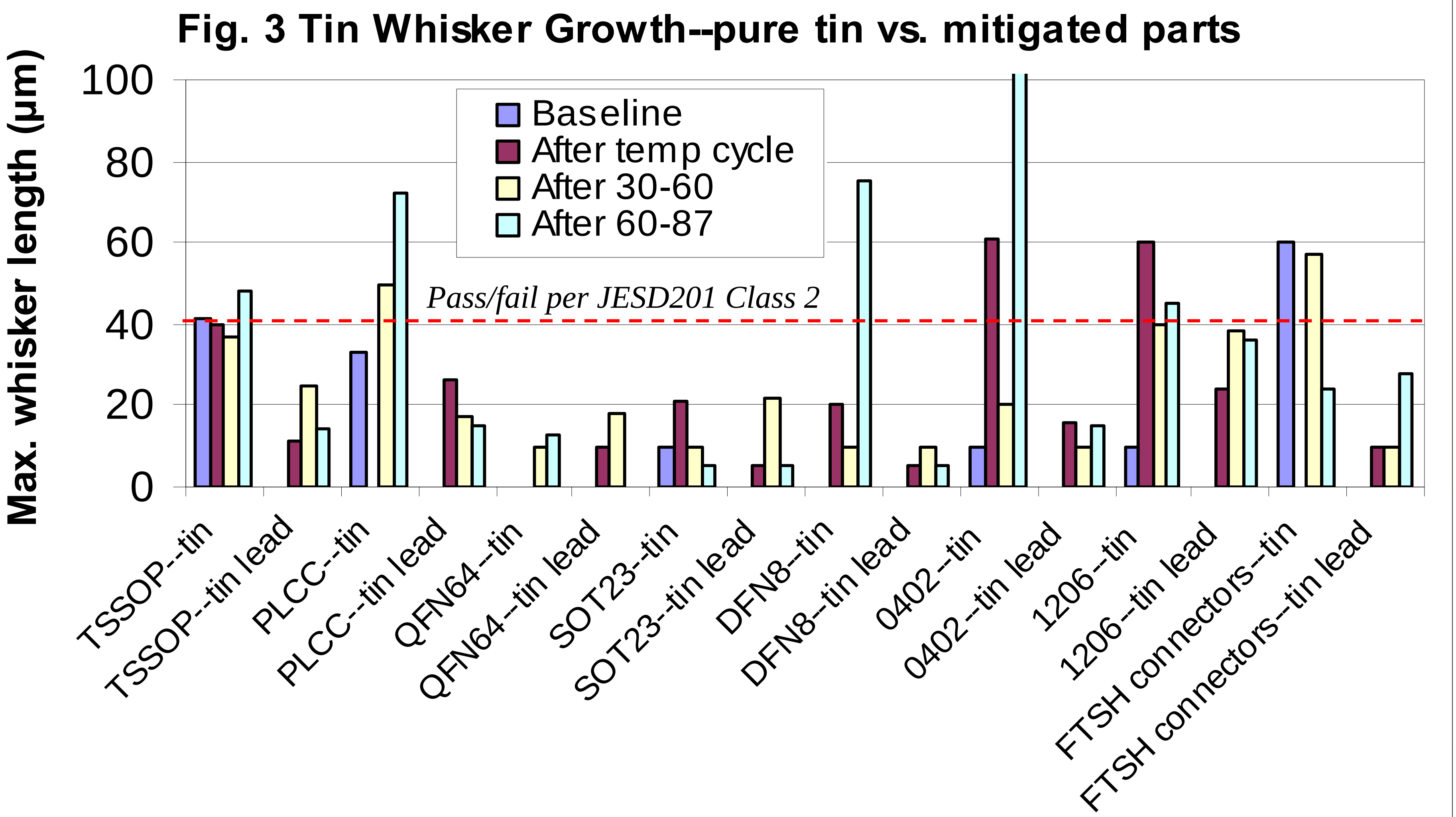
- Encapsulated modules and reballed BGAs could not be visually or SEM inspected
- X-ray analysis was attempted to discern whisker growth, with resolution down to approximately 10 µm.
- No whiskers were detected; BGA solder balls looked OK
- Encapsulated modules passed electrical test.
- Ceramic-filled coating and encapsulation may inhibit proliferation of whiskers



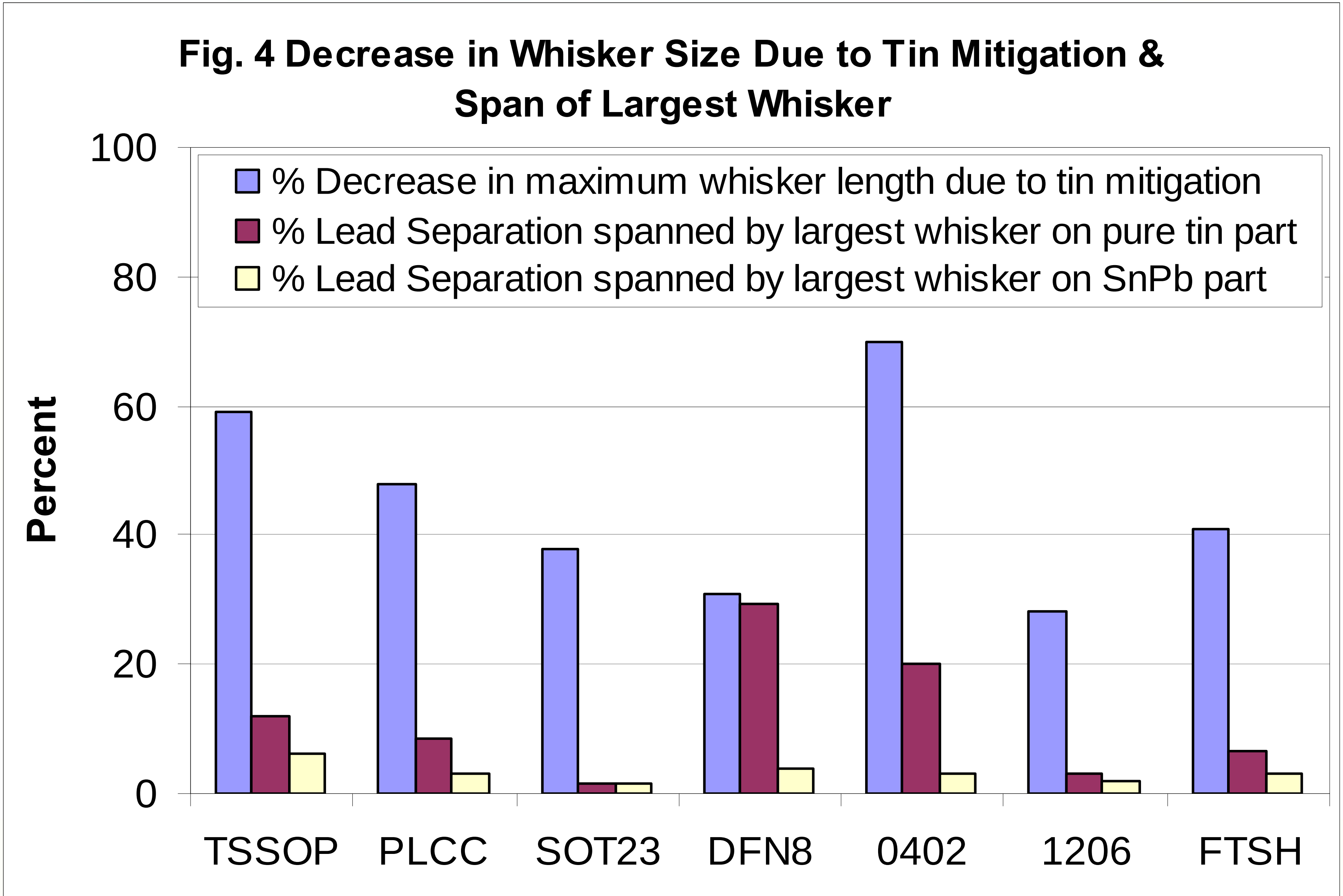
Summary of Whisker Density Data

		Whisker Density			
Part type ↓	Finish	Baseline	Post-Temp cycle test	Post-30°C, 60% RH test	Post-60°C, 87% RH test
TSSOP	Pure tin	Medium	High	High/Med	High/Med
	SnPb	None	Low/Med	Medium	Medium
PLCC	Pure tin	High	NA	High	High
	SnPb	None	Low/Med	Low	Low
SOT23	Pure tin	Low	Medium	Medium	Low
	SnPb	None	Low	Low	Low
DFN8	Pure tin	NA	High	Low	Medium
	SnPb	NA	Low	Medium	Low
QFN64	Pure tin	NA	NA	Low	Low
	SnPb	NA	Low	Low	None
0402 chip	Pure tin	Low	High	High	High
	SnPb	None	Low	Medium	Low
1206 chip	Pure tin	High	High	High	High
	SnPb	None	Medium	Medium	Low
connector	Pure tin	Medium	High	Medium	Low
	SnPb	Medium	Medium	High	Low

Tin mitigation greatly reduces but does not eliminate whiskers.



Tin mitigation reduces length of whiskers by 3X to 15X



Largest whiskers spanned only 30% of span between conductors.

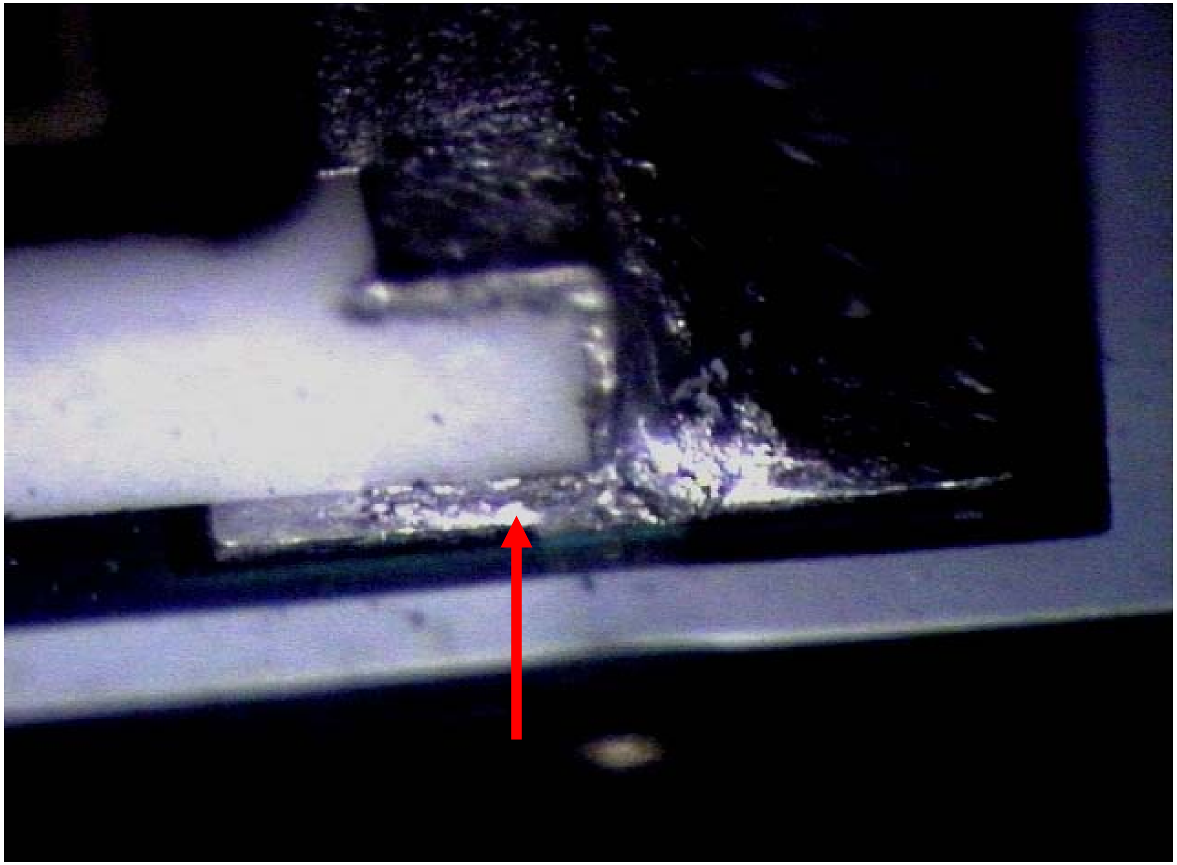
Test results: tin whisker growth

- Temp cycling and temperature/humidity storage induced whisker growth.
- Whiskers grew on all pure tin parts and most tin mitigated parts
- No whiskers were observed to “short” between leads; the largest percentage of lead separation spanned by a tin whisker was about 30%.
- Whiskers pierced and grew along surfaces beneath urethane conformal coating.
- Among 7 part types tested in significant numbers, the decrease in maximum whisker length effected by tin mitigation was 30 to 70% relative to the pure tin components.
- No significant differences in whisker density or size were noted among parts mitigated by tin mitigation suppliers/processes.
- No significant differences in whisker density or size were noted on parts installed on PWBs with different materials, pad finish or with air or nitrogen reflow atmosphere.

Tin mitigation severely limits whisker growth but does not completely eliminate tin whisker formation

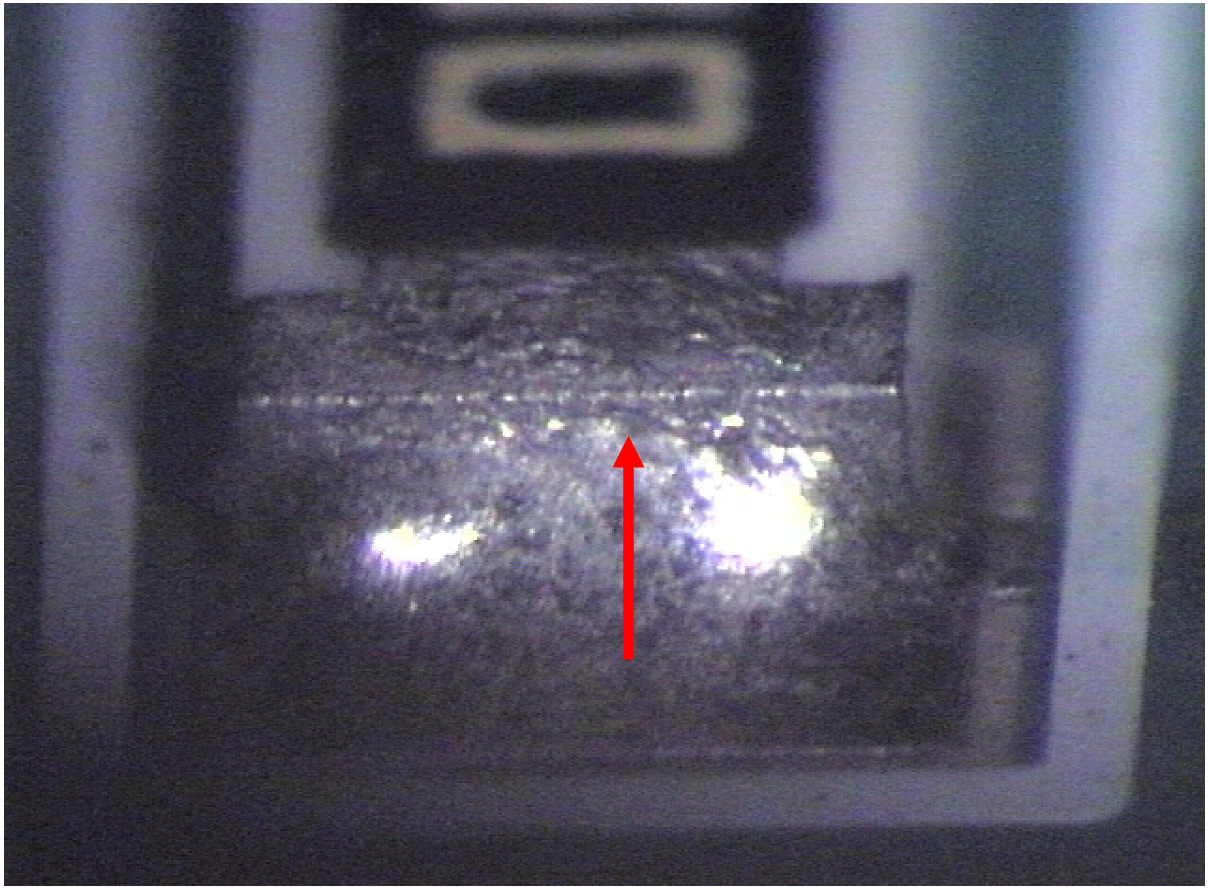
Evaluation of solder joint reliability after temperature cycling

Results--Solder joint evaluation



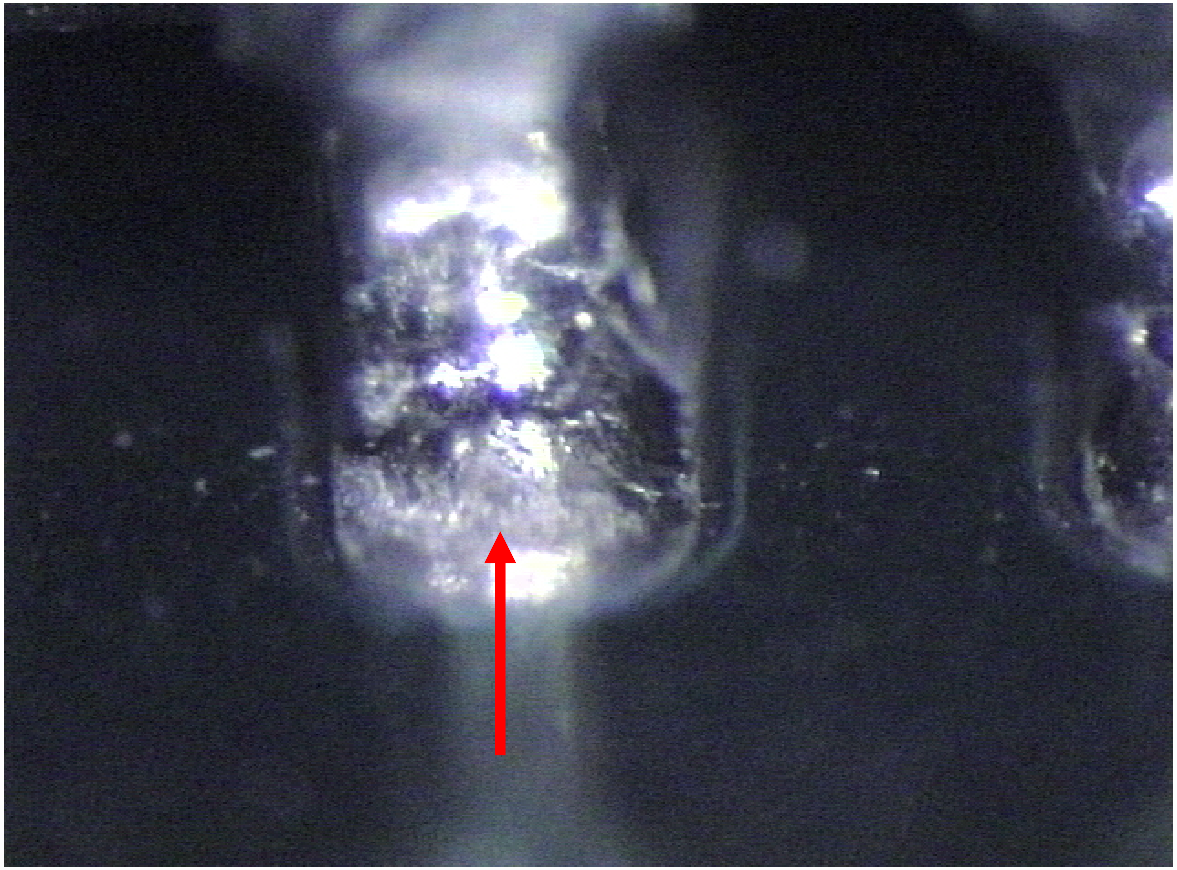
Cracked solder joint on 1206 chip resistor after 1000 temp cycles

Results--Solder joint evaluation



Cracked solder joint on 1206 chip resistor after 1000 temp cycles

Results--Solder joint evaluation



Cracked solder joint on PLCC solder joint after 1000 temp cycles

Results—solder joint reliability after 1000 cycles -40 to 85° C

- All part types except the DFN8 showed some cracks in the solder joints
- Small qty of cracked solder joints appeared severe enough to impact CCA reliability. No parts showed cracks on 100% of the leads.
- No cracks or other anomalies were observed on the component bodies.
- Damage was more widespread on larger components than smaller ones.
- Solder joints on PLCCs installed on epoxy PWBs with silver finish reflowed in air showed more cracks than on the other types of boards.
- Among all part types, there were no consistent trends between solder joint quality and PWB material, PWB pad finish or reflow condition.
- No anomalies were noted on parts with non pure tin lead-free finishes (SnBi, NiPDAu and AgPd). In very small sample sizes, parts with these finishes showed similar solder joint quality as tin mitigated components.

Robust solder joints can be made with components that have been through tin mitigation processes.

Discussion—Component Reliability

- Most likely degradation mechanisms:
  - Degraded solderability
  - Damaged interfaces, materials, and interconnects.
  - Degraded electrical performance, i.e. die-level
- Solder dip usually helps with solderability since there is a fresh coat of SnPb
- No component damage noted in SEM, Xray or cross section
  - Navy ManTech study also showed no degradation
- Automated solder dip process recommended
  - Much better controls than manual dipping

Well-controlled tin mitigation processes will not adversely affect the types of parts studied in this report.

Findings & Conclusions

- Automated solder dip/Pb addition effectively replaced Sn with SnPb on exposed Sn leads
- Tin mitigation processes did not induce damage on parts.
- Cracked solder joints were observed on about ½ of the parts.
- No catastrophic solder joint failures on tin mitigated parts or lead-free parts after 1000 temperature cycles.
- Whiskers grew on almost all of the parts, even SnPb surfaces.
- Maximum whisker length on tin mitigated parts was 30 to 70% smaller than on pure tin parts.
- Pb and "mixed" SnPb whiskers were also observed.
- Whiskers grew beneath and through conformal coatings.
- Tin mitigation supplier, PWB material, pad pattern or solder reflow condition had little effect on tin whisker growth or solder joint cracking.

Tin whisker tests failed on all but 2 pure tin component types and passed on all tin-mitigated component types

Recommendations

- Approve pure tin and SnBi parts for limited use as long as their leads/ terminations are mitigated prior to installation.
- Approve NiPdAu parts—no mitigation needed.
- Parts selection team should request/require JESD201 test data from component suppliers for all pure tin parts.
- Low profile components, encapsulated parts and many connectors cannot be completely mitigated
  - Need to be evaluated on a case-by-case basis.
- Mechanical parts, radial leaded parts, parts with glass seals or special sensitivities to heat or ESD (<100 V) were not covered by this study
  - Need to be evaluated separately.

Recommendations on dealing with Lead-Free Parts

Option	Advantages	Disadvantages
Find alternate equivalent part	**May be "drop-in"**	**May require approval**
"Last time buy" on part before it becomes lead-free	**Guaranteed quantities**	**Up-front cost** **Accurate forecast may not be possible**
Redesign	**Can change parts**	**Cost, schedule**
Mitigation	**Avoid redesign & last time buys**	**Extra handling, processing & cost** **May not eliminate all risks**
Qualify new parts/finishes	**Avoid redesign & last time buys**	**May not be offered by suppliers** **Extensive cost & technical obstacles**