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

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**Abstract**
This paper reports the results of an evaluation of tin mitigation processes for components, i.e. converting parts with pure tin (Sn) and other lead-free (Pb-free) finishes to tin-lead (SnPb) finishes.

**Introduction**
Electronics suppliers are faced with a growing number of components offered only with Pb-free terminations. A popular Pb-free component finish is pure tin, which is compatible with Sn63 soldering processes but carries the stigma of whisker growth. "Tin mitigation" refers to the process of replacing pure tin finishes on external component terminations with SnPb finishes. The end goal of tin mitigation processes is to eliminate or greatly reduce risks for tin whisker growth on pure tin parts without compromising component and solder joint reliability. Tin mitigation adds at least one extra step to the assembly or component procurement process and should be avoided whenever possible. However, for "frozen" designs or cases where heavy expenditures have already been made on pure tin parts, it may be more cost effective to use mitigated pure tin parts. The mitigation process must be done properly to avoid degradation of component structures, solderability and reliability.

In this study, three groups of components were evaluated: pure tin piece-parts (control group), pure tin parts installed on CCAs with Sn63 solder, and pure tin parts mitigated with Sn63 solder installed on CCAs with Sn63 solder. The primary objectives of the testing and analyses were to determine if (1) tin mitigation processes introduced mechanical damage or degradation to the parts, (2) tin mitigation processes were effective in reducing or preventing tin whisker growth, (3) quality and reliability of the solder joints were affected by tin mitigation processes.

**Components, Test Conditions and Test Articles**
Nine types of commercially available lead-free components were evaluated: plastic TSSOP, PLCC, SOIC, SOT, DFN, QFN, BGAs, ceramic leadless chip parts and plastic connectors. Two sizes of chip capacitors and resistors, 1206 and 0402, were chosen to represent other chip sizes. The study did not cover radial-leaded, glass-sealed or mechanical parts.

Tin mitigation processes were performed by 3 third-party companies. Two of the companies performed automated solder dipping under well-controlled conditions, while the third company performed a proprietary process for adding lead to pure tin chip component terminations. The evaluation process followed these steps: 1. Baseline visual inspection, SEM/EDX on as-received parts to verify pure tin; 2. Tin mitigation process; 3. Post mitigation visual inspection, SEM/EDX, cross section; 4. Installation on CCA; 5. Temp cycle, temp/humidity tests; 6. Post test visual inspection, SEM/EDX/ Xray/functional test.

The tests were intended to foster growth of tin whiskers and also stress the solder joints. Test guidelines were taken from JEDEC standards JESD22A121 and JESD201 (see Table 1). Note that the durations of thermal cycling (1000 cycles) and temperature/humidity storage tests (3000 hours) performed in this study were based on JESD22A121; since then, new guidelines were released in JESD201calling for 1500 cycles and 4000 hours of test.

There is considerable uncertainty in any study of tin whisker growth. The driving forces and mechanisms for tin whisker growth are not fully understood; there are numerous variables affecting whisker growth; and it is not currently possible to accurately correlate the JESD tests to a service life duration or hardware life cycle. Assuming that tin whisker growth is an Arrhenius type process with activation energy 0.5 eV, 3000 hours of test at 60°C and 87% RH corresponds to approximately 26 years of storage at 25°C and 50% RH. In terms of solder fatigue, 1000 cycles between -40 and 85°C may be similar in scope to one accelerated life for some types of high-reliability, long-life hardware, such as military or space applications. However, as stated in JESD201, "*the testing described in this document does not guarantee that whiskers will or will not grow under field life conditions.*"

The test vehicle was a small circuit card assembly (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 were included in the study. The PWB was 3"x4" in size and 0.032" thick with 2 layers. The following variables were included:

- Component finish: lead-free (pure tin, SnBi, NiPdAu, flash gold) vs. tin mitigated (SnPb)

- Three tin mitigation process suppliers and processes: solder dip to component body vs. Pb addition
- PWB material: epoxy glass laminate vs. ceramic-filled PTFE laminate
- PWB pad finish: immersion silver vs. electroless nickel-immersion gold (ENIG)
- Solder reflow environment: air vs. nitrogen
- Urethane conformal coating vs. no conformal coating

PWB material and pad finish were incorporated into the study since they affect solder joint quality and reliability. Different solder reflow conditions (nitrogen purged vs. air purged) were used because nitrogen-purged ovens can reduce the amount of oxidation and increase solder wetting during solder reflow. Thirty CCAs were assembled and subjected to JESD-recommended tests. Temperature cycling was done in a calibrated single-chamber oven with ramp rates >10°C/minute and 15 minute dwell times.

**Table 1. Guidelines for Tin Whisker Growth Tests**

| **Category Description** | **Details** | **Reference** |
|---|---|---|
| Test Conditions and Duration:<br>1. Temperature cycling<br>2. Ambient temp/humidity storage<br>3. High temp/humidity storage | <br>Low dwell: -55 to -40°C, high 85°C, 1000 cycles<br>30°C, 60% RH for 3000 hours<br>60°C, 87% RH for 3000 hours | JESD 22A121 |
| Sample Size | • Leaded parts: min 96 terminations from 6 components<br>• Leadless parts: min 18 terminations from 9 components. | JESD201 |
| Inspection magnification | Minimum 50X for optical inspection, 250X for SEM. | JESD 22A121 |
| Whisker density classification | Low: < 10 whiskers/lead<br>Medium: 10-45 whiskers/lead<br>High: > 45 whiskers/lead | JESD 22A121 |
| Maximum allowable whisker length | For Class 3 products (mission/life critical applications such as military…), “pure tin alloys are typically not allowed.” For Class 2 products (business critical applications), 40 µm for temp/humidity storage tests, 45 µm for temp cycle tests. | JESD201 |

**Results**

**Pre Test Analysis.** Prior to installation onto the PWBs, 6 component types were analyzed to confirm that the “control group” had pure tin lead finishes and to determine if tin mitigated parts had incurred any damage during the mitigation process. All baselined PLCC, TSSOP, SOT23, and chip parts showed pure tin on the terminations. Tin whiskers were observed on PLCC and TSSOP parts before the tin mitigation process, the largest about 40 µm long.

Tin mitigation by solder dipping carries serious risks that can adversely affect component reliability. To protect components, IPC J-STD-002, MIL-STD-2000 and other standards on high reliability electronics manufacturing recommend solder dipping close to, but not contacting, the component body. To completely mitigate pure tin coated leads, the components must be dipped in solder up to the component body, in violation of most standards. Hence it is critical that the solder dipping processes be well-controlled, including repeatable dwell time and immersion angles, consistent fluxing action, solder pot composition and temperature. Improper or uncontrolled solder dipping may have several consequences. The risks from solder dipping include

- Damaged components. Excessive dwell time and/or thermal shock due to lack of preheating can crack glass seals or melt plastic encapsulation, cause delamination, blistering, cracked die, lifted bonds or loss of metalization adhesion.
- Insufficient dwell time may result in poor solderability and inferior solder joints on circuit card assemblies.
- Inconsistent component cleaning processes may lead to poor solderability or inadequate removal of pure tin coating.
- Incomplete coverage may result in exposed pure tin surfaces and whisker growth

An effective solder dip completely dissolves the tin plating, replacing it with the SnPb solder. The dissolution rate of tin into Sn63Pb37 is about 35 microinches per second at eutectic liquidus temperatures, so most solder dipping processes (with residences times of a few seconds in molten solder) will effectively dissolve tin from the component leads.

Figure 1 shows a component lead, originally plated with pure tin, that has been properly mitigated. The SnPb plating is uniform all the way up to the component body and there are no signs of damage to the component. Figure 2 shows a component lead that was not dipped all the way to the component body, with whiskers growing from the residual exposed area of pure tin.

Cross sections of PLCC, TSSOP, SOT23 and chip parts mitigated by solder dipping showed no visual evidence of residual pure tin plating. No mechanical damage such as internal cracks, discoloration or delamination, was observed on the tin-mitigated parts. Solder dipping did not completely remove pure tin from leads of “low profile” (L-leaded) components and connectors. Some parts showed excessive solder on the leads after the solder dipping process.

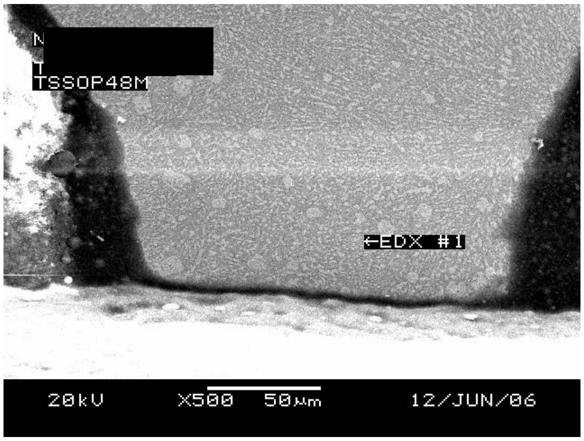



Figure 1. SEM image of TSSOP lead after solder dip. Solder coverage was good and the molding compound did not appear to be disturbed by the solder dip process. EDX analysis showed uniform distribution of SnPb, even at component body.

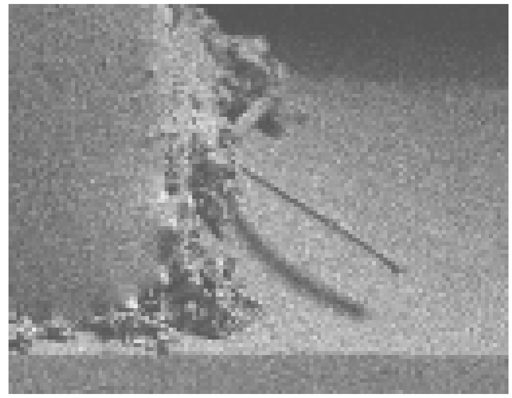


**Figure 2. SEM image of component whose leads had been dipped in solder but not quite to the component body. Several whiskers are visible growing from the small area of pure tin still exposed near the component body. This photo illustrates the importance of a well-controlled tin mitigation process with solder dipping all the way to the component body.**

**Figure 3. Cross section of ceramic chip capacitor after tin mitigation. Pure tin finish appeared to be completely removed and replaced with SnPb. No mechanical damage such as cracks in the dielectric was observed on any of the parts after tin mitigation. Plating was thin at/near corners.**

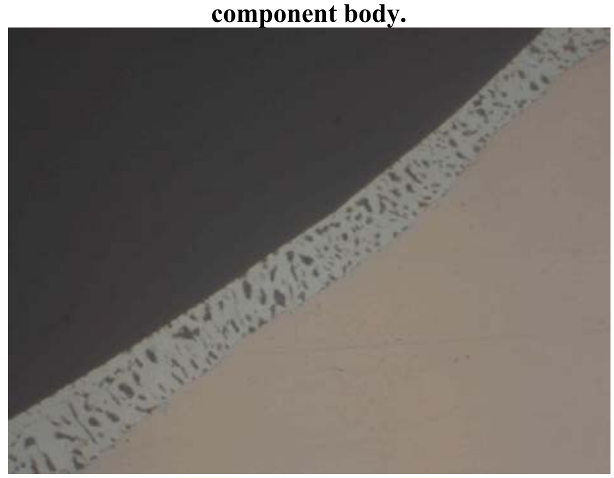


**Figure 4. Cross section of a PLCC lead after tin mitigation. From cross section images, pure tin finish appeared to be completely removed and replaced with SnPb. No mechanical damage was observed on any of the parts after tin mitigation.**

**Post-Test Analysis.** The components were inspected during and after the temperature cycling and temperature/ humidity storage tests at 50 to 500X magnification. The degree of uncertainty in the whisker measurements by visual inspection was estimated to be ±20% and was attributed to the difficulties in detection and measurement, such as resolving of small whiskers and nodules (down to 5 µm), distinguishing whiskers from contamination and solder peaks, distortion and glare caused by conformal coating, and limitations in microscope depth of field. Confirmation by SEM/EDX, with its superior resolution and elemental analysis, was completed on as many parts as possible. Table 2 summarizes the compliance matrix for the part types included in this study.

**Table 2. Compliance Matrix for Components Tested for Tin Whisker Growth based on JESD201 Pass/Fail Criteria**

| Component lead finish | Parts Compliant with Margin (tin whisker < 20 µm) | Parts Marginally Compliant (20 µm > tin whisker > 40 µm) | Parts Not Compliant (tin whisker > 40 µm) |
|---|---|---|---|
| Pure tin | Encapsulated module | QFN64, SOT23 | TSSOP, PLCC, DFN8, 0402 & 1206 chips, connectors |
| Tin Mitigated (SnPb) | DFN8, QFN64 | TSSOP, PLCC, 0402 & 1206 chips, SOT23, connectors | |

Visual inspection/SEM results are summarized in Table 3 (whisker densities) and Figure 5 (whisker lengths). Photos of the components before and after the testing are shown in Figures 1 through 4. The data showed that

- Whisker densities and lengths were higher after the testing; temperature cycling and temperature/humidity storage induced whisker growth.
- Whiskers grew on all pure tin parts, including 0402 chips and small leaded parts, even though significant portions of their lead areas were covered with SnPb after CCA installation.
- No whiskers were observed to “short” between leads; the largest percentage of lead separation spanned by a tin whisker was about 30%.
- Whiskers grew even on tin mitigated parts.
- 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 3 different suppliers.
- 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.

The overall conclusion was that tin mitigation processes severely limited whisker size and density but were not completely effective in eliminating tin whisker formation. All of the tin-mitigated parts were compliant to the JESD201 requirements on whisker size after tin whisker growth tests. Six out of the eight types of control group parts (un-mitigated pure tin components) grew whiskers longer than 40µm and did not meet the JESD guidelines.

**Table 3. Summary of Whisker Densities Before and After Mitigation and Tests**

| | | **Whisker Density** | | | |
|---|---|---|---|---|---|
| **Part type ↓** | **Finish** | **Baseline** | **Post-Temp cycle** | **Post-30°C, 60% RH** | **Post-60°C, 87% RH** |
| 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 |
| SMT connector | Pure tin | Medium | High | Medium | Low |
| | SnPb /2 | Medium | Medium | High | Low |

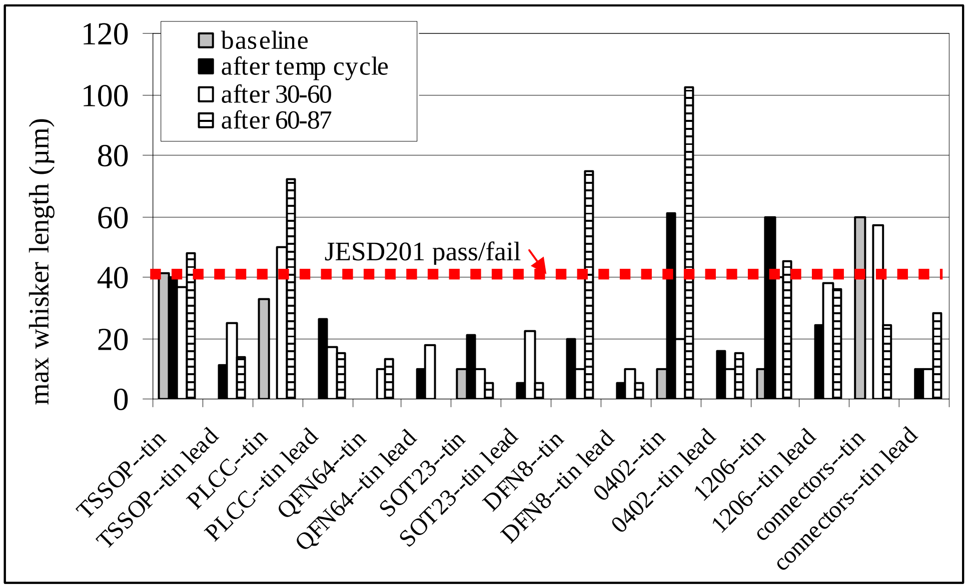



**Figure 5. Maximum measured tin whisker lengths observed on different part types before and after temperature cycle and temp/humidity tests. Lengths were measured by visual inspection at 50-100X and by Scanning Electron Microscopy.**

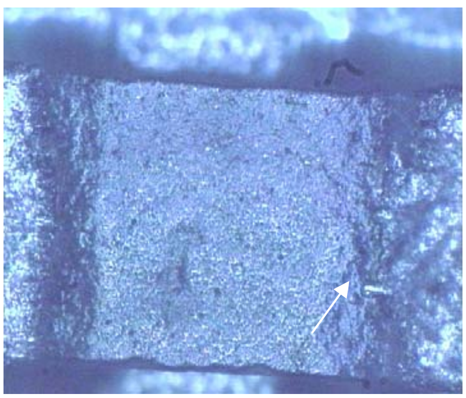


**Figure 6. 0402 resistor (pure tin, soldered with SnPb) after temp cycle. High densities of nodules and whiskers were observed on these parts, up to 60 µm long. Areas of pure tin were detected on the termination near the component body. The results shows that solder wicking during oven reflow cannot be relied upon to mitigate pure tin surfaces and tin whisker growth.**

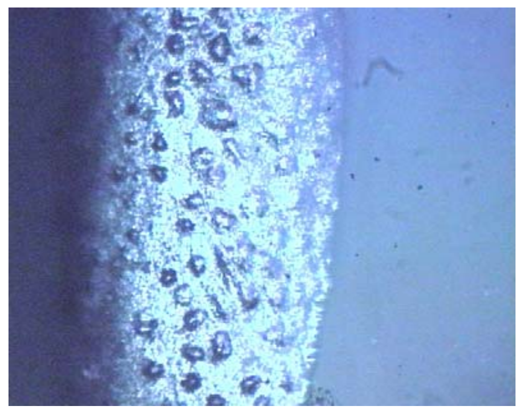


**Figure 6. Photo of 1206 chip capacitor (tin mitigated, soldered with SnPb) termination after completion of temp cycling test. High densities of wide but short nodules or bumps were observed on these parts as evidences by the "measled" appearance of the SnPb finish. These bumps were not considered as high risk for growth to significant lengths.**

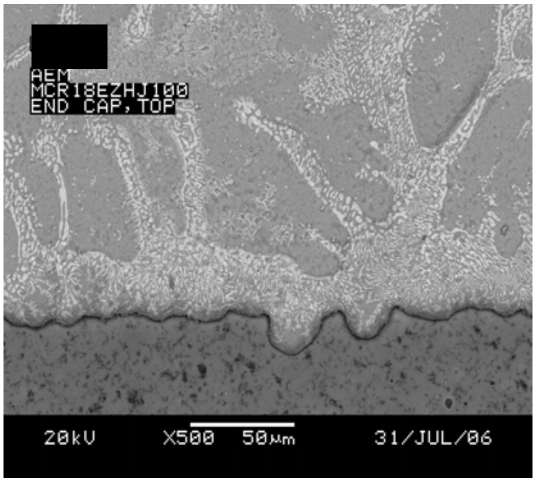



**Figure 8. SEM image of chip resistor termination at interface with component body, after tin mitigation. At high magnification, Pb (darker) and Sn-rich (lighter) pockets are visible on the SnPb surface. This segregation may account for some whiskers observed to grow from SnPb surfaces on tin mitigated parts.**

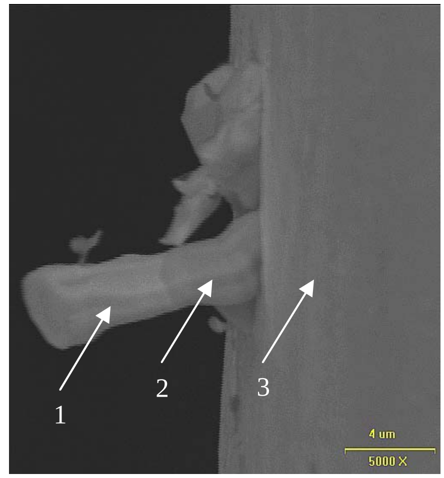



**Figure 9. SEM image of "hybrid" 10 µm whisker growing from TSSOP part after temp cycling tests. EDX analysis showed that tip of whisker was nearly pure Pb (region 1), base of whisker was composed of nearly pure Sn (region 2), whereas the bulk surface was coated with SnPb (region 3).**

Hybrid modules pose a special challenge for tin whisker detection if their tin-plated sub-components are encapsulated and not accessible for visual or SEM inspections. De-potting, X-ray analysis and/or functional electrical test can be performed to evaluate these types of components. In this study, X-ray was attempted to discern any whisker growth, with resolution down to approximately 10 µm. No whiskers were detected, even though many of the passive components inside the modules are pure tin plated. It is possible that harder plastic encapsulation materials inhibit tin whisker growth more than softer conformal coatings.

Several BGA components with lead-free (SnAgCu) balls were reballed with SnPb balls at a third-party supper. The parts were then soldered to PWBs and subjected to temperature cycling and 30°C, 60% RH testing. The BGA balls looked acceptable in Xray and visual inspection. A complete evaluation of the BGA solder joint quality would require electrical test, cross section analysis, and possibly ultrasound, but these tasks were beyond the scope of the study.

Some piece parts and CCAs were subjected to high-power inspection by Scanning Electron Microscopy (SEM) and elemental analysis by Energy Dispersive Xray (EDX), as shown in Figures 1,2,8 and 9. In most cases, SEM confirmed the whisker density and length measurements made by visual inspection. Leads with sharp edges and bends tended to have higher whisker densities. This is consistent with the belief that tin whiskers are a stress relief mechanism, since edges often correspond to higher plating stresses.

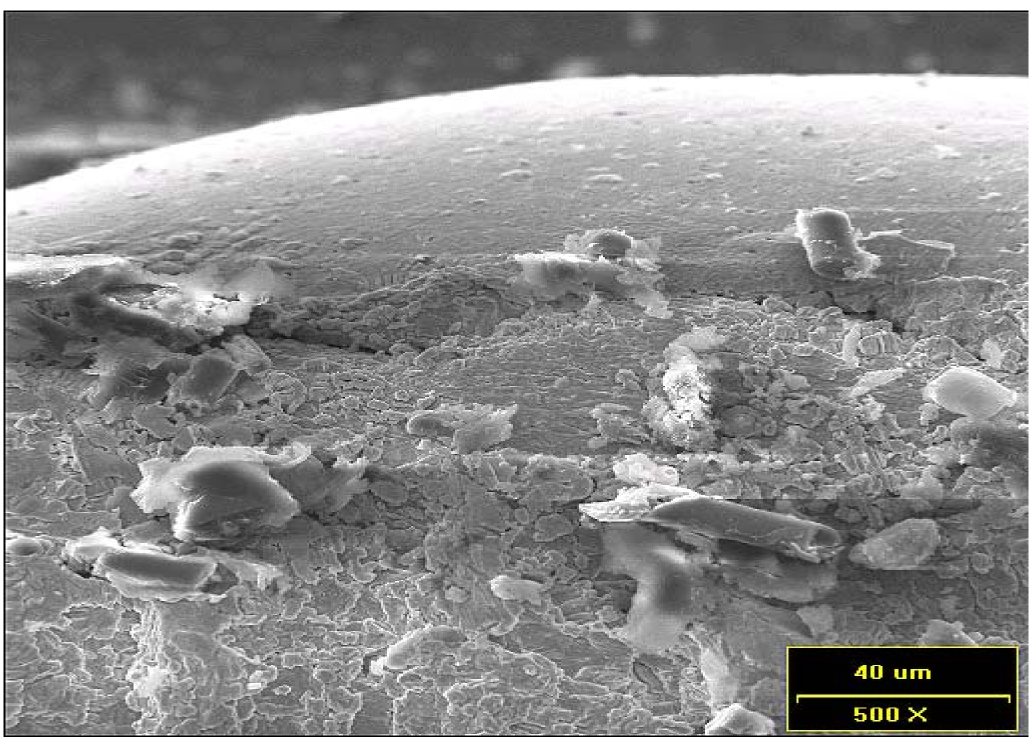
Some unexpected observations were made on the tin-mitigated components. First, whiskers and nodules appeared to grow from tin-lead terminations, at high densities in some cases. Three different compositions of whiskers were observed: pure Sn, pure Pb and "mixed" SnPb. At least 3 instances of lead (Pb) whiskers, and one "mixed" SnPb whisker, were confirmed by analysis; see Figure 9. It is possible that the "mixed" SnPb whisker was an artifact of an incompletely mitigated tin finish, as shown in Figure 8. If tin is covered over but not completely removed, it becomes an underlayer that can grow whiskers. One explanation of the "mixed" SnPb whisker is that a pure tin whisker growing in a locally Pb-rich region attached itself to the Pb material as it emerged to the surface.

**Solder Joint Evaluation.** Besides tin whisker growth and component damage, the third focus area of the study was the effects of tin mitigation processes on the component solder joints. Visual inspections showed that with some exceptions, the solder joints were acceptable per J-STD-001 Class 3 workmanship criteria with good wetting and solder volume. Excessive solder was observed on some SOT23 and 0402 chip parts. In small samples sizes, Pb-free parts with non pure-tin lead-free finishes (including SnBi, NiPDAu and AgPd) showed similar solder joint quality as tin mitigated components with SnPb.

About half of the part types showed at least one partially cracked solder joint after 1000 thermal cycles, but no catastrophic damage, such as large cracks on 100% of the leads, was noted on any of the part types. Damage was more widespread on solder joints of larger components than smaller ones. These results were not unexpected since the solder joints experienced significant fatigue during the 1000 temperature cycles. No cracks or other anomalies were observed on the component bodies. Solder joints on PLCCs installed on epoxy-glass PWBs with silver finish reflowed in air showed more cracks than on the ceramic filled PTFE boards. These findings support the conclusion that robust solder joints can be made with components that have been through tin mitigation processes.

**Summary and Recommendations**

- Tin mitigation processes performed by 3 different suppliers were effective at replacing pure tin coatings with SnPb on exposed component lead surfaces.
- Tin mitigation processes did not induce detectable damage on the components.
- No catastrophic solder joint failures were observed on tin mitigated parts or lead-free parts after 1000 temperature cycles. Partially cracked solder joints were observed on about ½ of the parts.
- Visual inspection showed that whiskers grew on almost all of the parts, even from SnPb surfaces on parts that had been through tin mitigation by solder dipping.
- Six of the 9 component types with pure tin finishes in the “control group” (no tin mitigation) did not meet the JESD201 guidelines since they grew tin whiskers larger than 40-45 µm after temperature cycling and temperature/humidity tests.
- The act of soldering components to a PWB in some cases resulted in decreased whisker density and size on installed pure tin parts, but there were still more and larger whiskers than on SnPb parts.
- Among 7 part types tested in significant numbers, the decrease in maximum whisker length affected by tin mitigation was 30 to 70% relative to the pure tin components.
- SEM/EDX analysis showed that the whiskers originating from SnPb surfaces were Pb whiskers and “mixed” SnPb whiskers.
- Small whiskers and nodules grew beneath and through conformal coatings.
- Differences in tin mitigation supplier, PWB material, pad pattern or solder reflow condition did not have significant effects on tin whisker growth or solder joint cracking after temperature cycling.
- Pure tin terminations on certain part types, such as encapsulated modules, hermetic parts, connectors and low profile “L” leaded parts, cannot be fully mitigated by solder dipping and 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 included in this study and should be evaluated on a case-by-case basis.
- The use of pure tin parts is not recommended for use on hardware requiring long-lifetimes and high reliability.



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# 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,<br>underlayers:  Ni = 5-10µm,<br>Au = 0.5µm min Cu = 35µm</td><td>Reballed with SnPb</td></tr>
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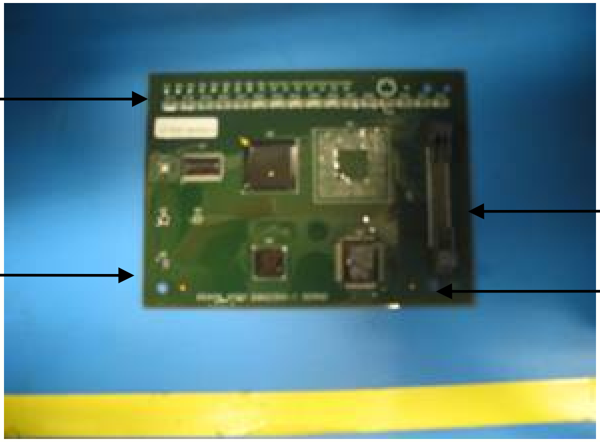
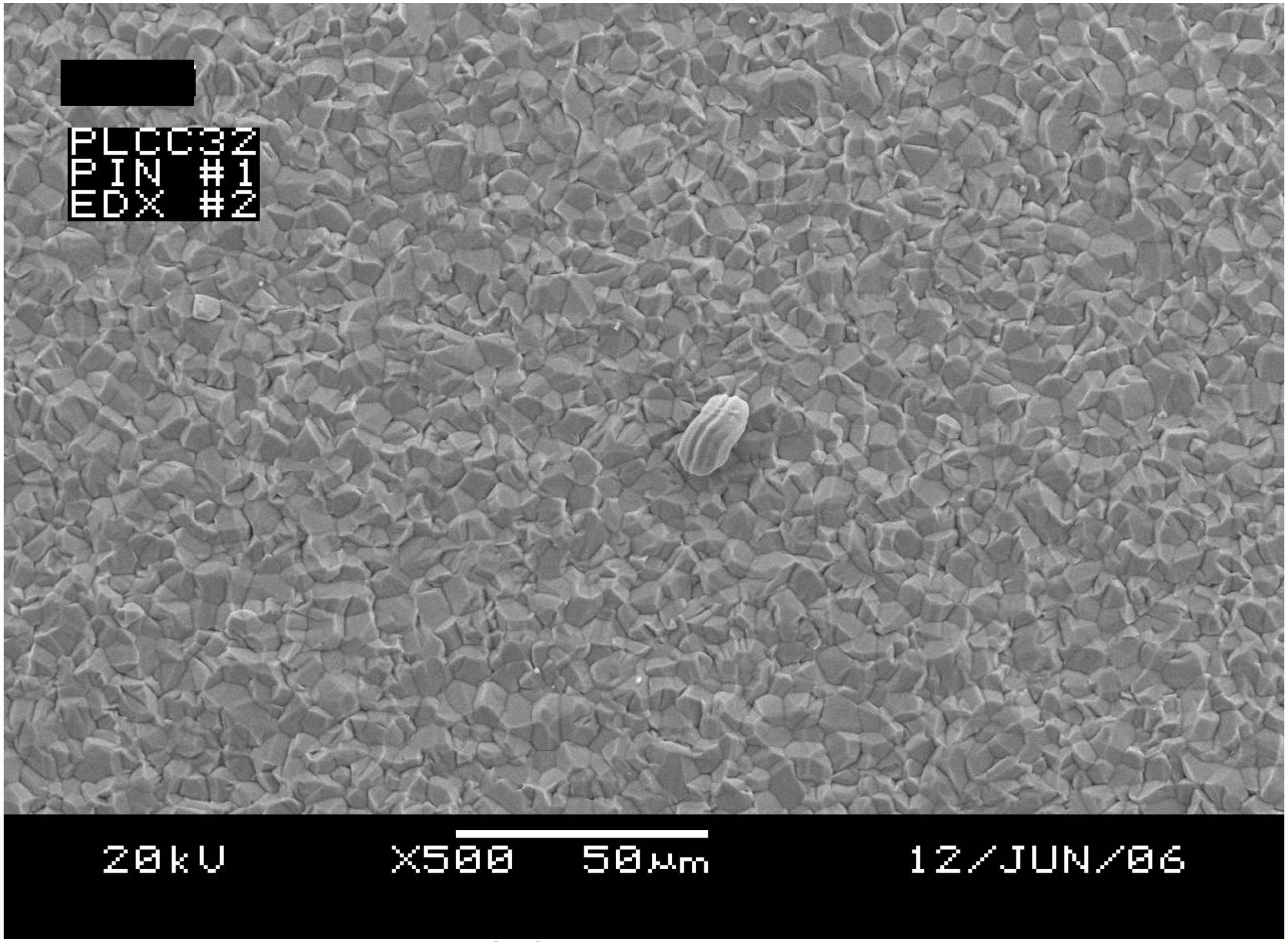
# Test article




- 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

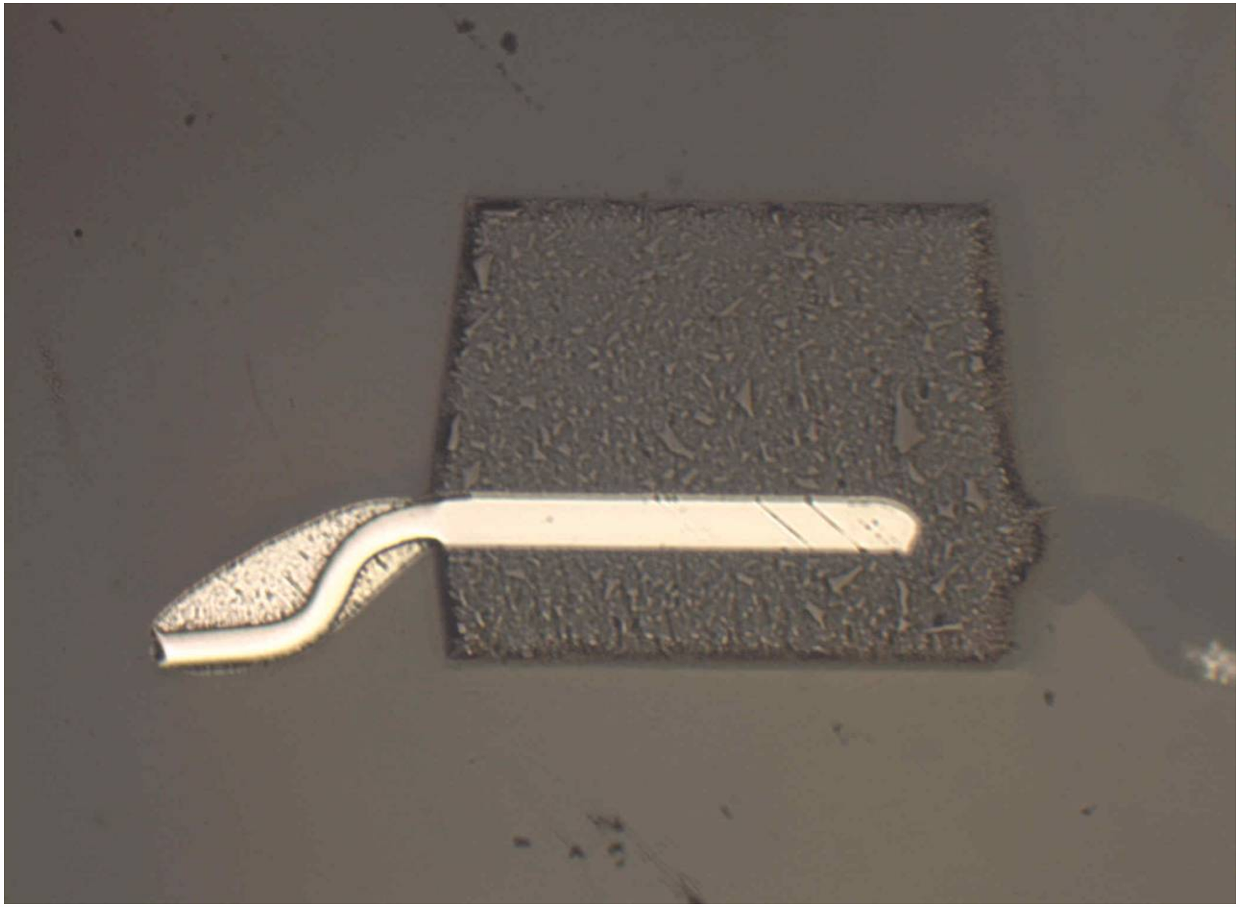
# Evaluation of Parts before & after solder dip

# Pre-test evaluation



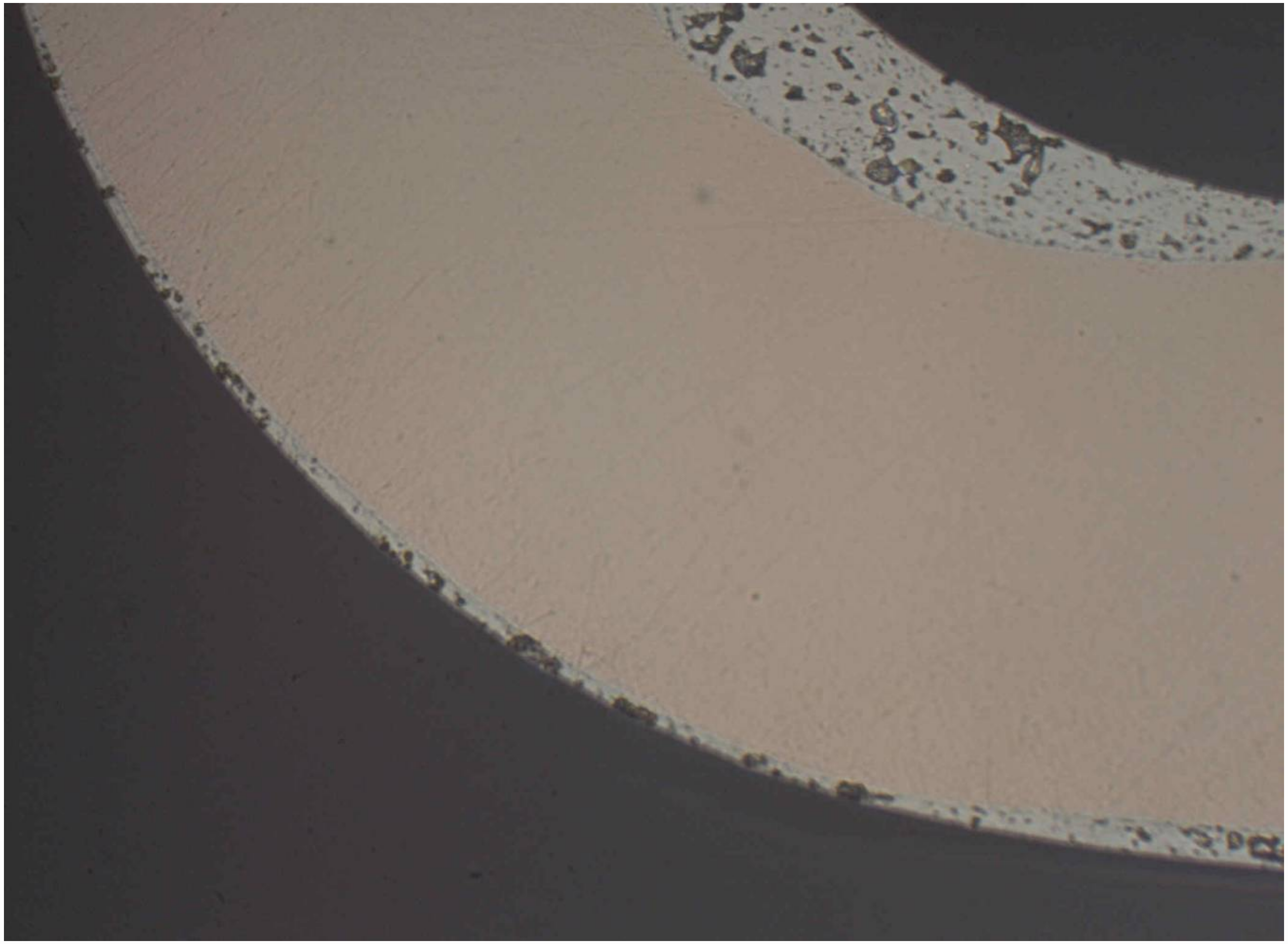

**Tin whisker on PLCC component prior to solder dip**

# Post solder dip, pre-test evaluation



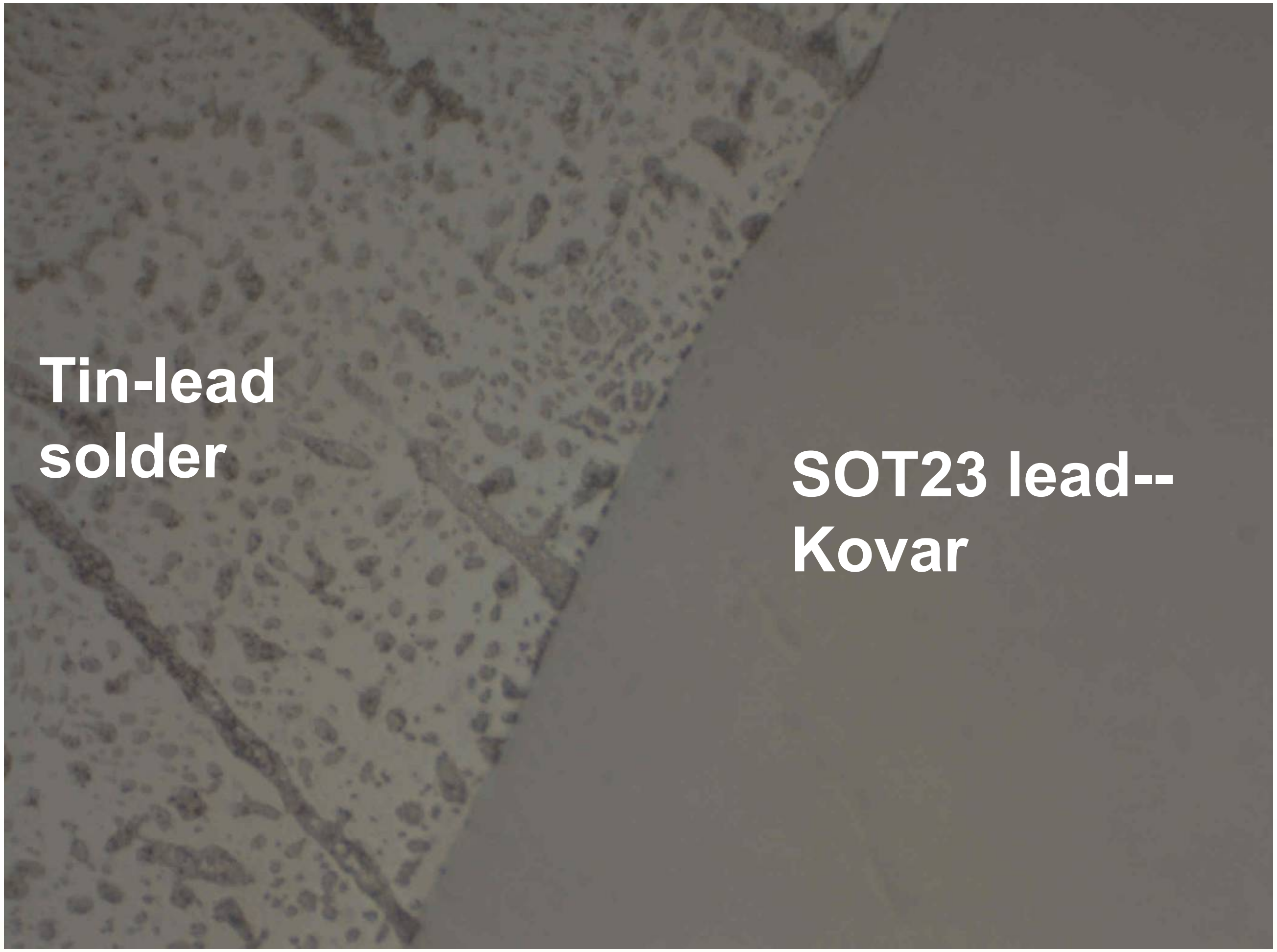
**Cross section of SOT23 component after solder dip—excessive solder**

# Post solder dip, pre-test evaluation



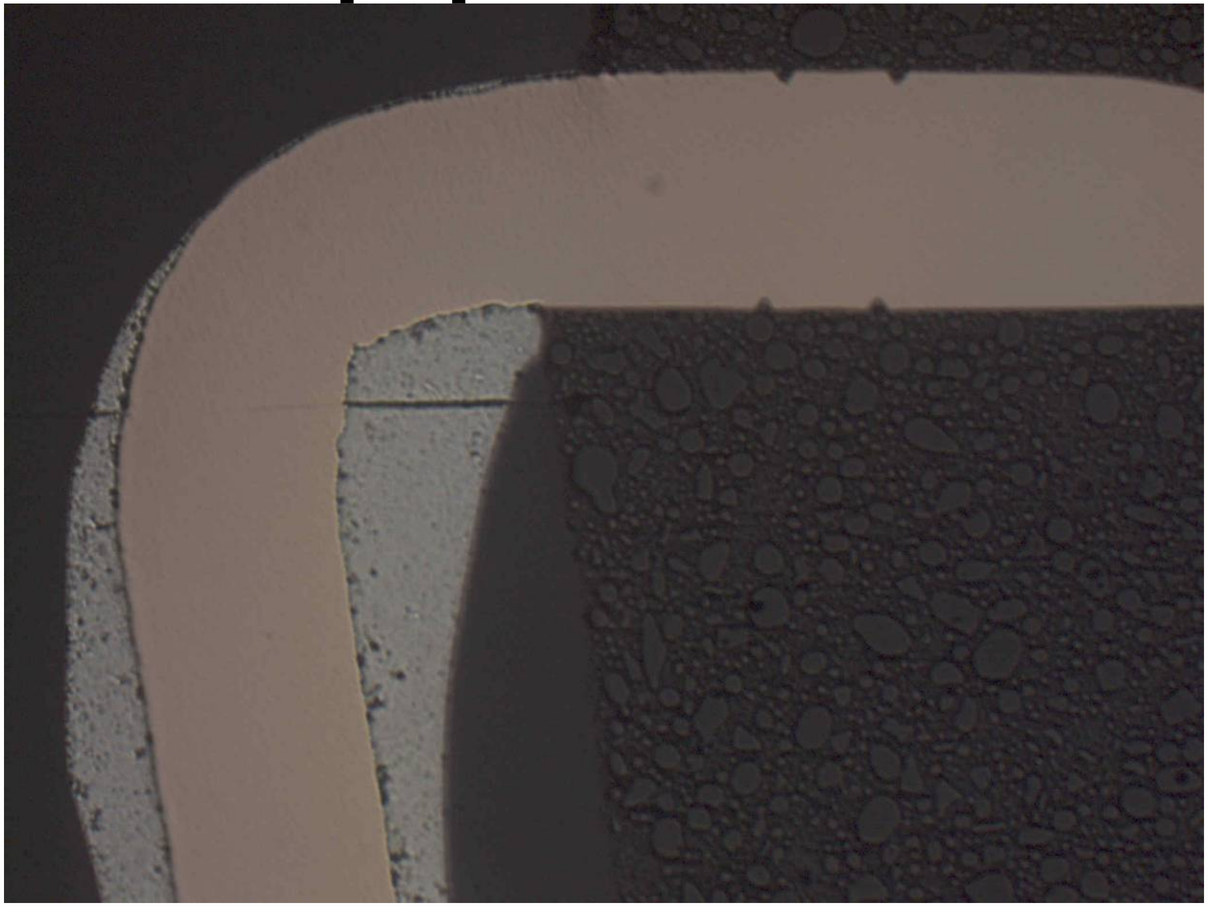
Cross section of TSSOP lead after solder dip—no residual tin

# Post solder dip, pre-test evaluation



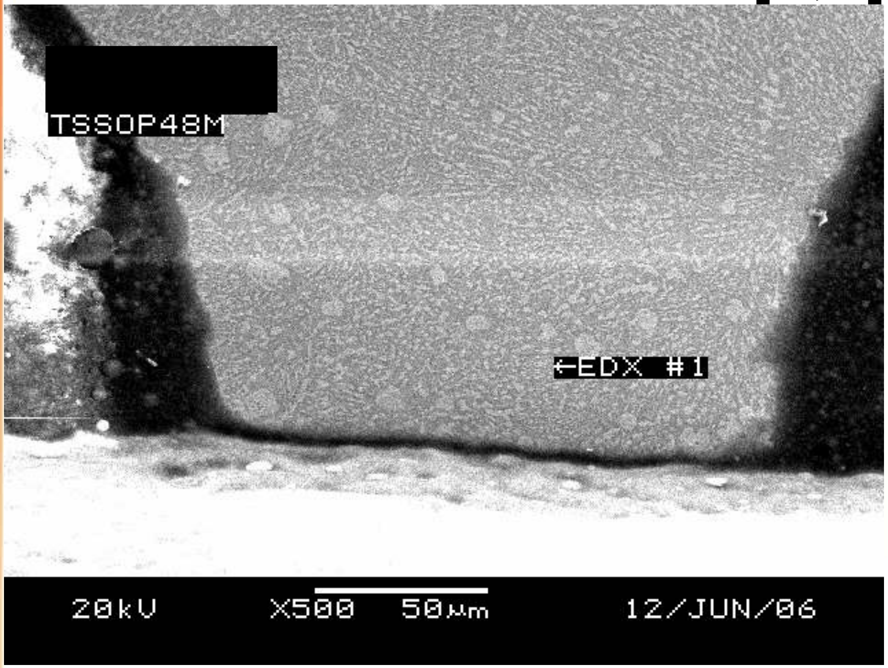

**Cross section of SOT23 lead after solder dip—no perceptible residual tin**

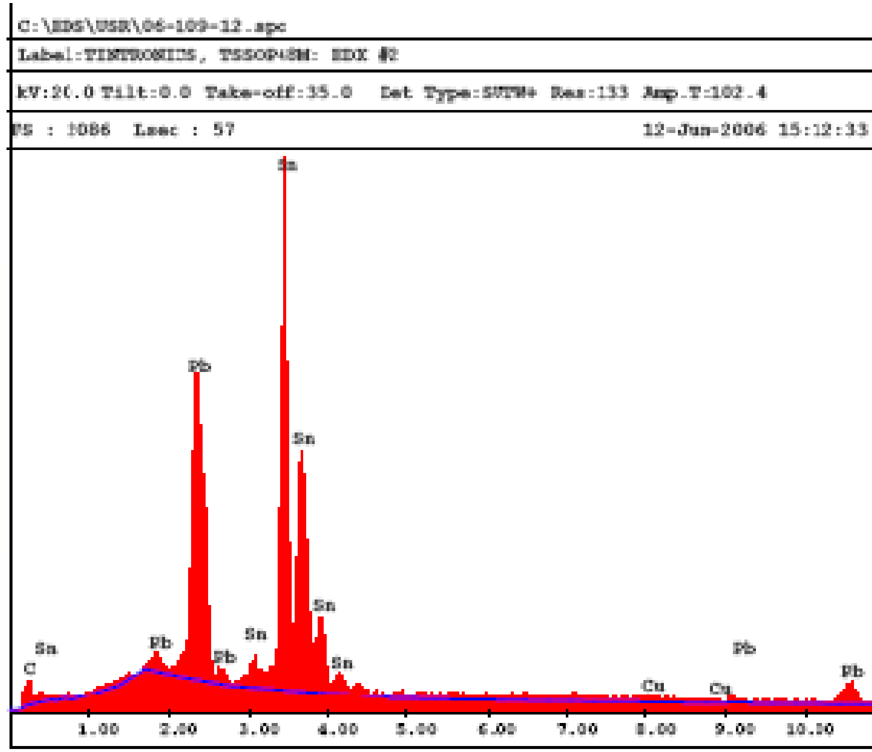
# Post solder dip, pre-test evaluation



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

# Post solder dip, pre-test evaluation



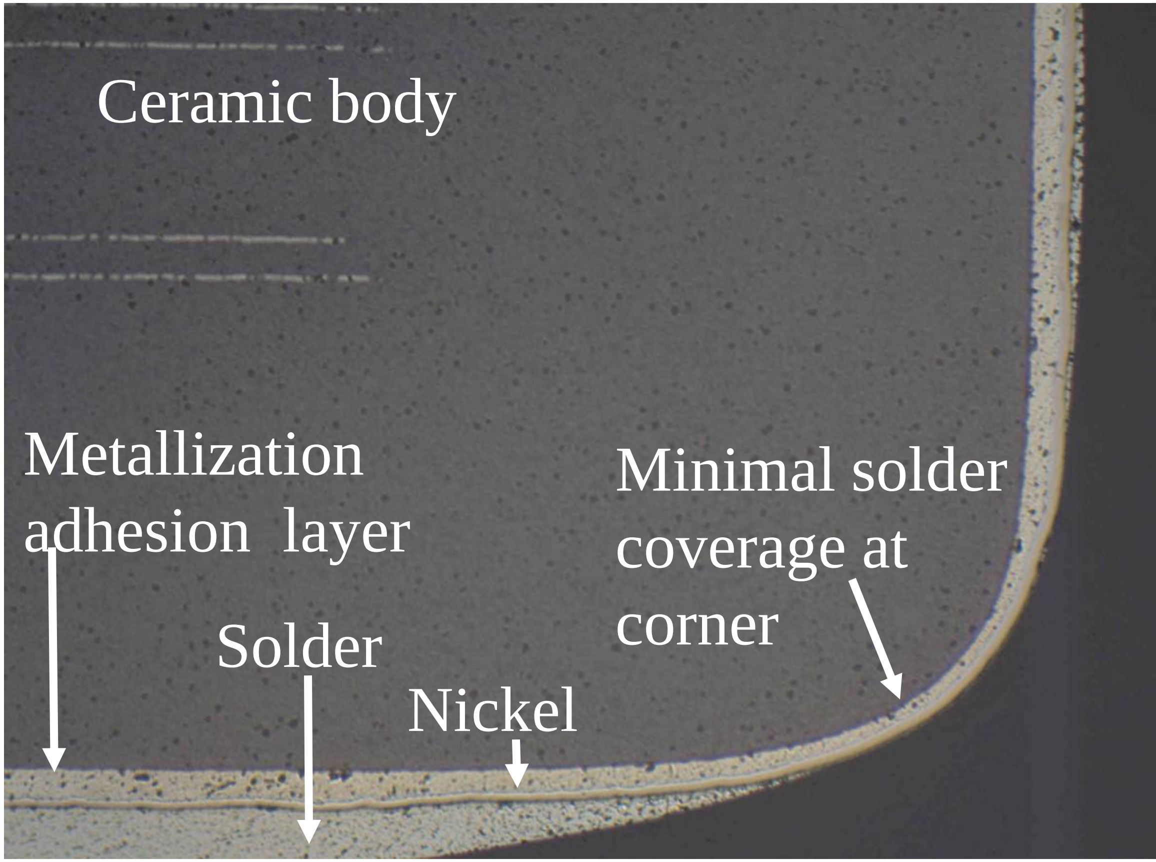

EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

| 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 |

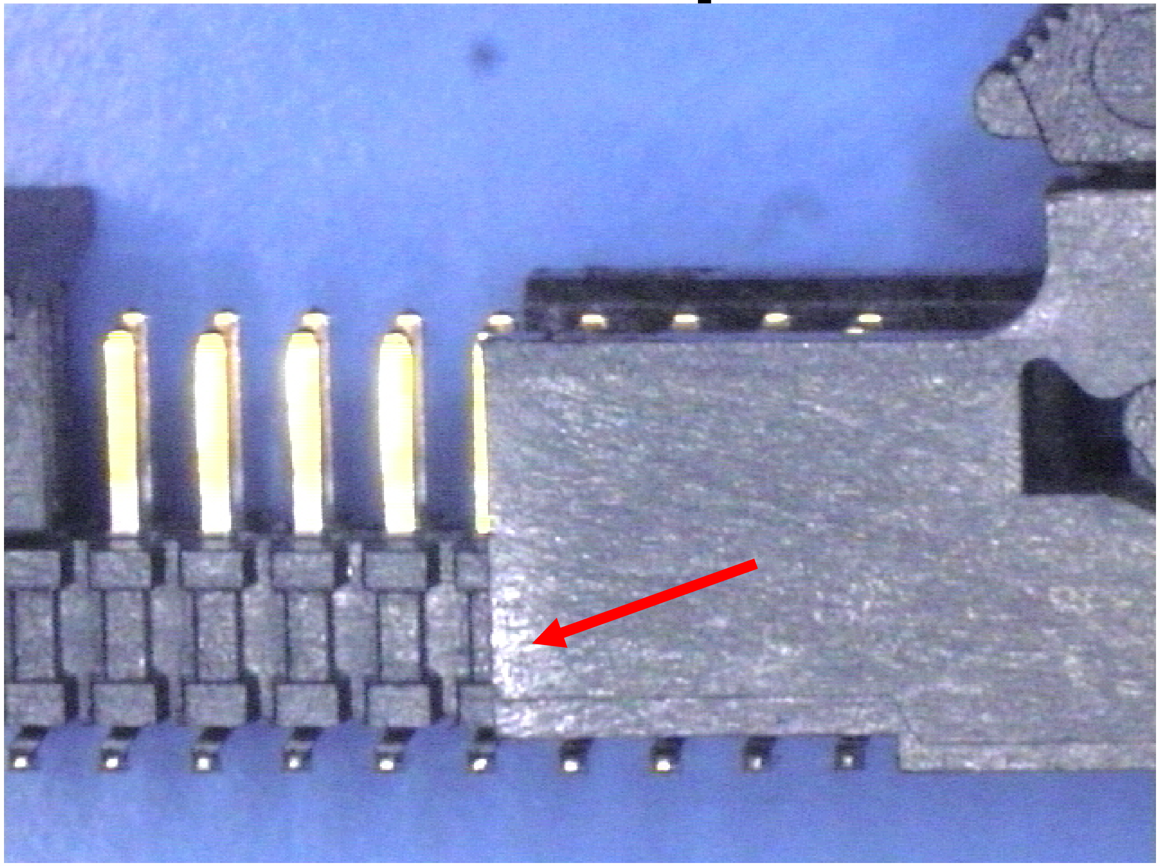
**SEM examination of TSSOP showed no damage at lead egress. EDX was consistent with Sn63.**

# 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

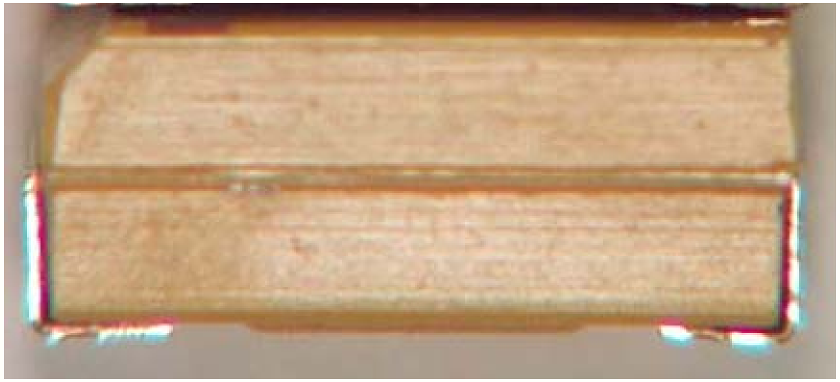


Area where connector leads are housed in plastic—very difficult to replace tin coating with SnPb after connector has been built

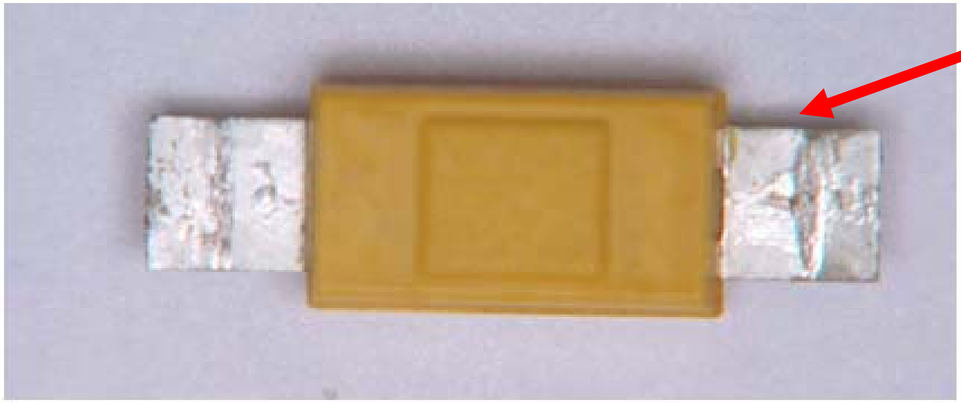
Pure tin surfaces on connector leads were not fully mitigated due to lead/body configuration.

Another concern: solder may wick up onto contact surfaces

# Post solder dip, Pre-test evaluation



Tantalum capacitor with "wrap-around lead configuration

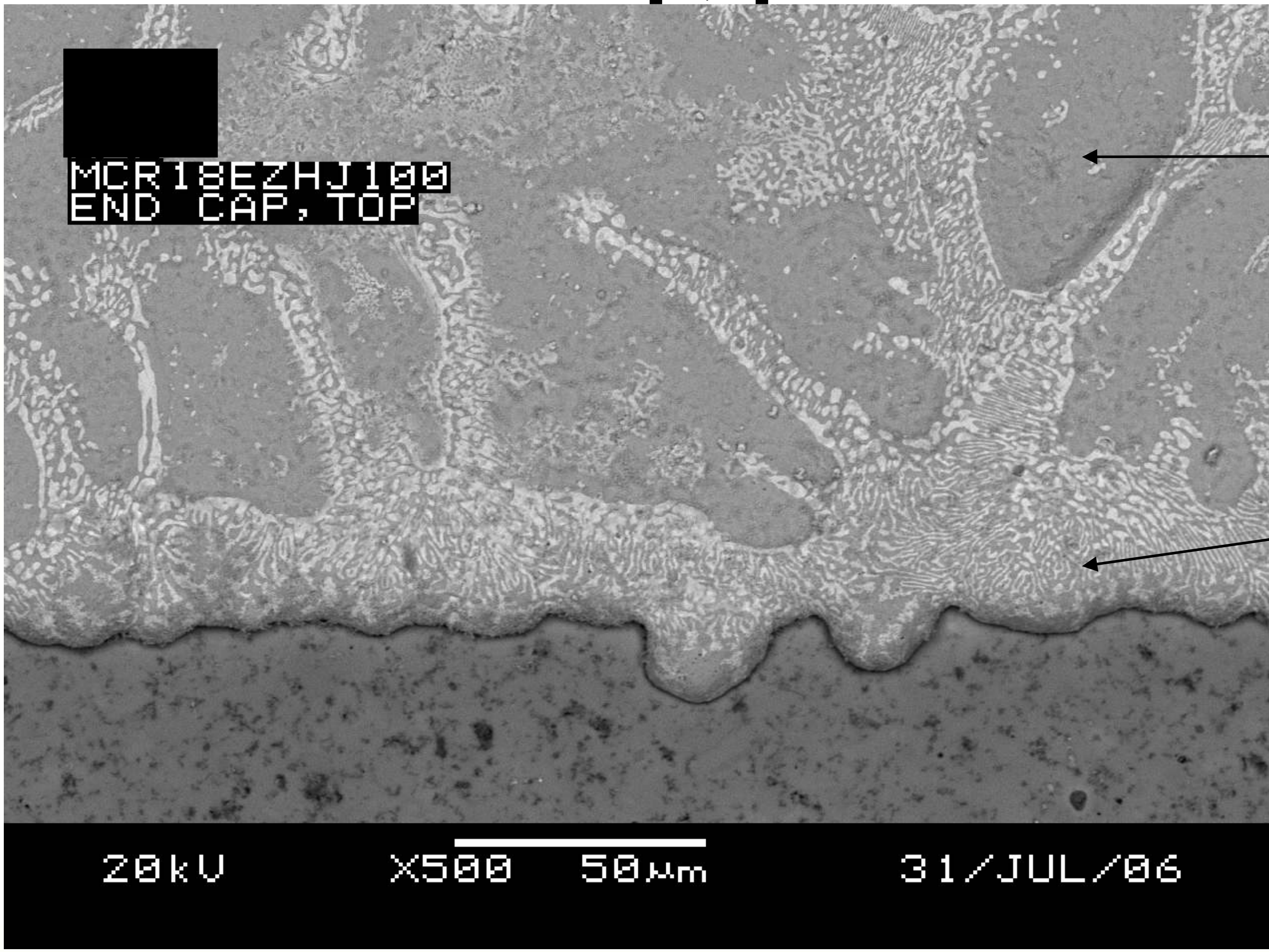


EDX analysis of pulled back leads revealed that solder dipped part had incomplete solder coverage

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 |

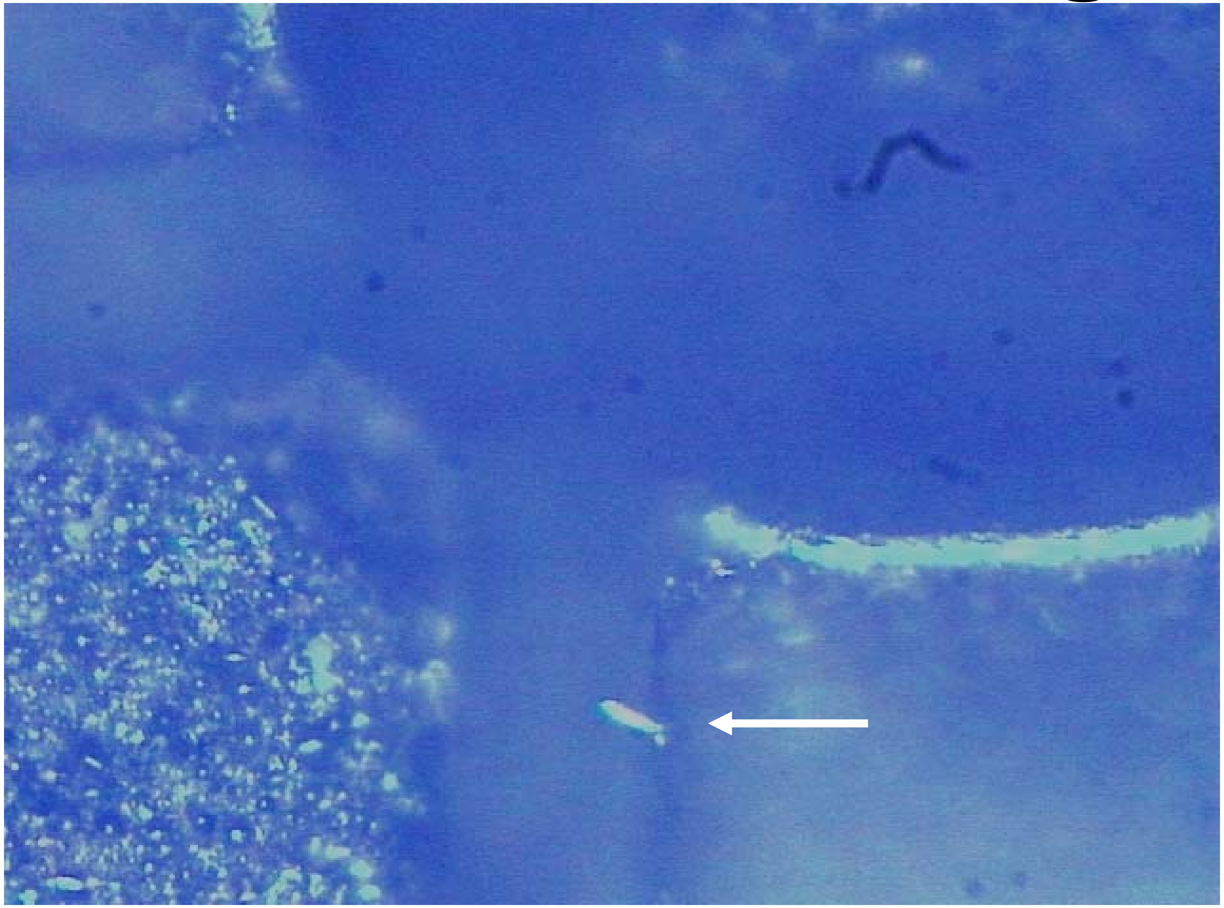
# Test & Inspection Conditions

<table>
<tr><th>Category Description</th><th>Details</th><th>Reference</th></tr>
<tr><td>Test Conditions & Duration:<br>1.Temperature cycling<br>2.Ambient temperature/ humidity storage<br>3.High temperature/humidity storage</td><td>-40°C to 85°C, 1000 cycles<br>30°C, 60% RH, 3000 hours<br><br>60°C, 87% RH, 3000 hours</td><td>JESD 22A121</td></tr>
<tr><td>Sample Size</td><td>•Multi-leaded components: minimum of 96 terminations/6 components<br>•Leadless components: minimum of 18 terminations/9 components</td><td>JESD201</td></tr>
<tr><td>Inspection magnification</td><td>Minimum 50X for optical inspection, 250X for SEM.</td><td>JESD 22A121</td></tr>
<tr><td>Whisker density classification</td><td><table>
<tr><th>Whisker Density</th><th># Whiskers per lead</th></tr>
<tr><td>Low</td><td>< 10</td></tr>
<tr><td>Medium</td><td>10-45</td></tr>
<tr><td>High</td><td>> 45</td></tr>
</table></td><td>JESD 22A121</td></tr>
</table>

# Results—tin whisker growth

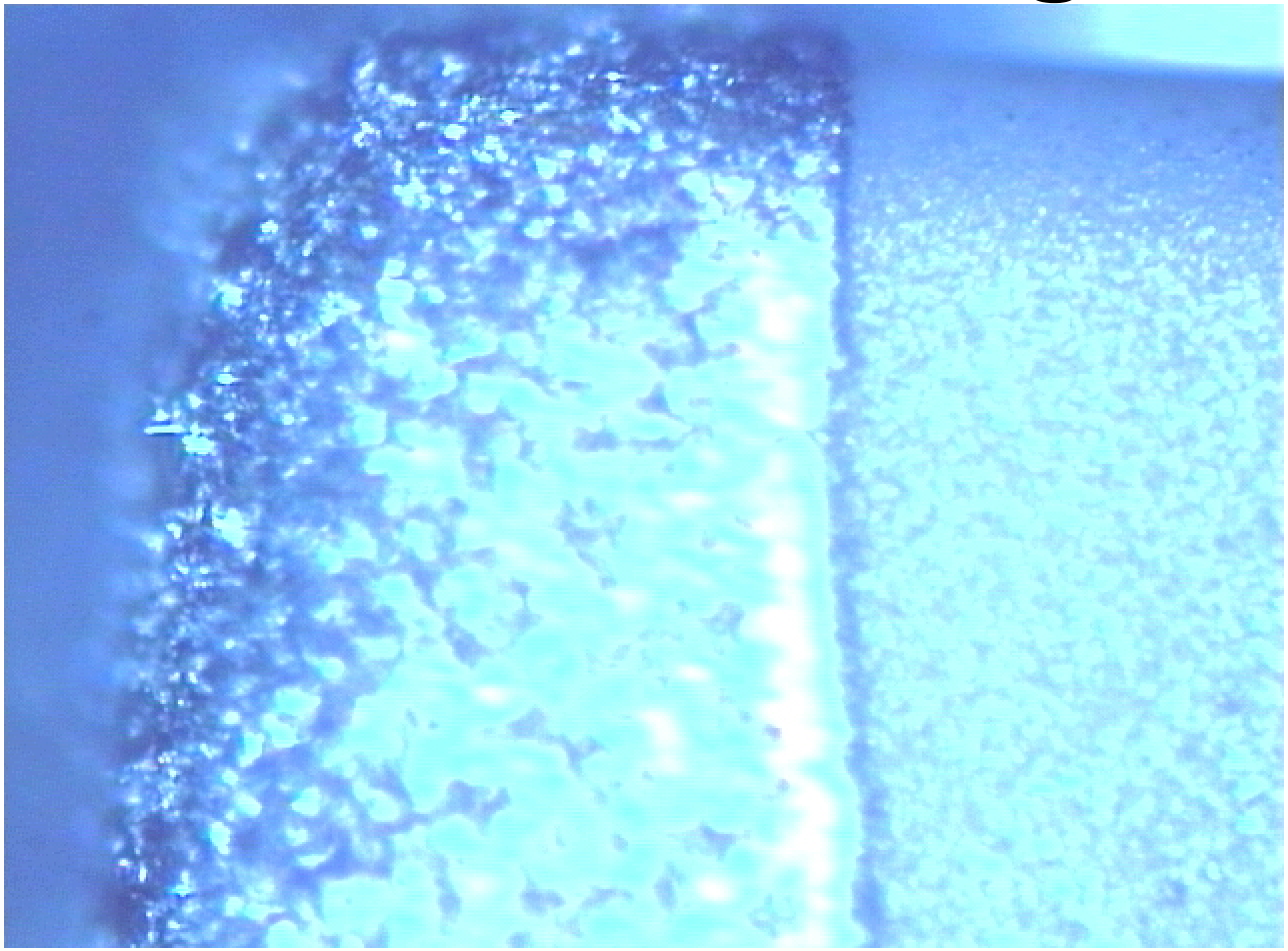
Tin whiskers on connector lead prior to solder dip

# Results—tin whisker growth



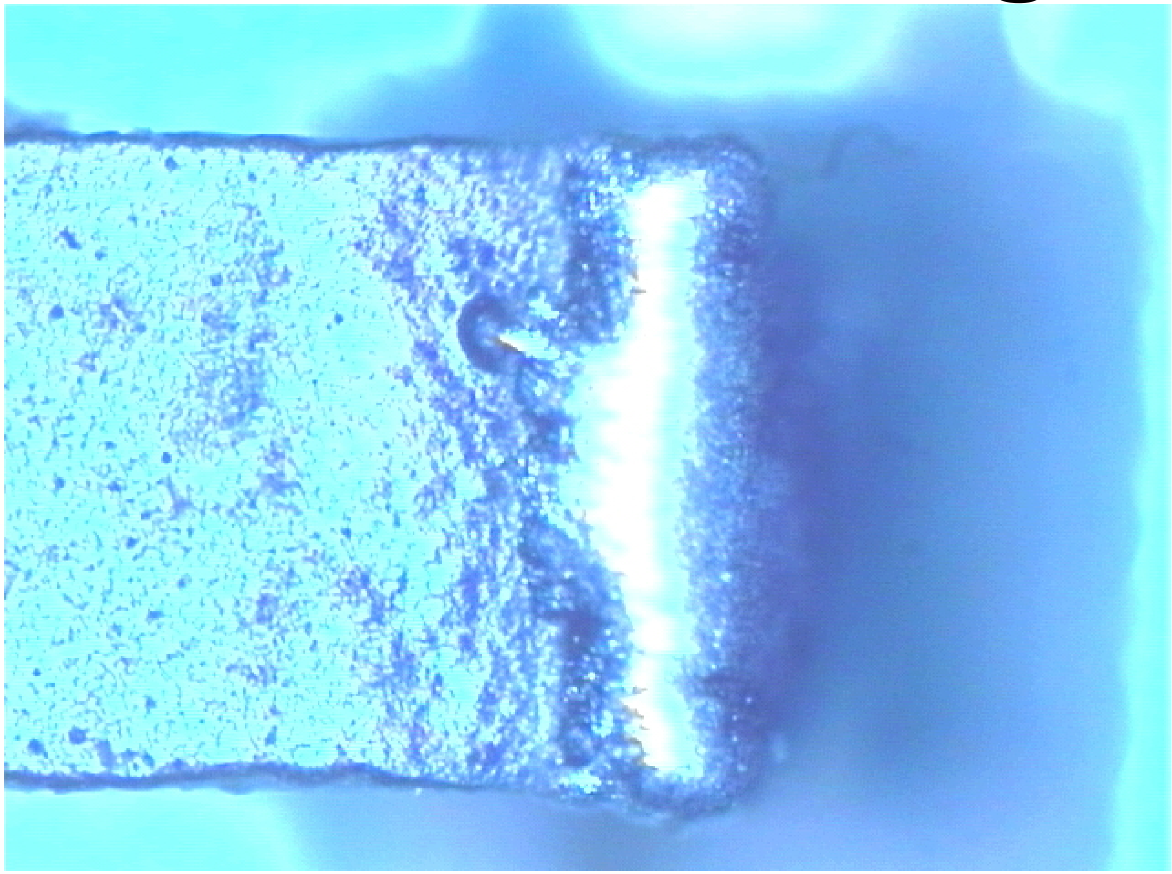
**25 µm whisker on pure tin PLCC piece part during 60° C, 87% RH test.**

# Results—tin whisker growth



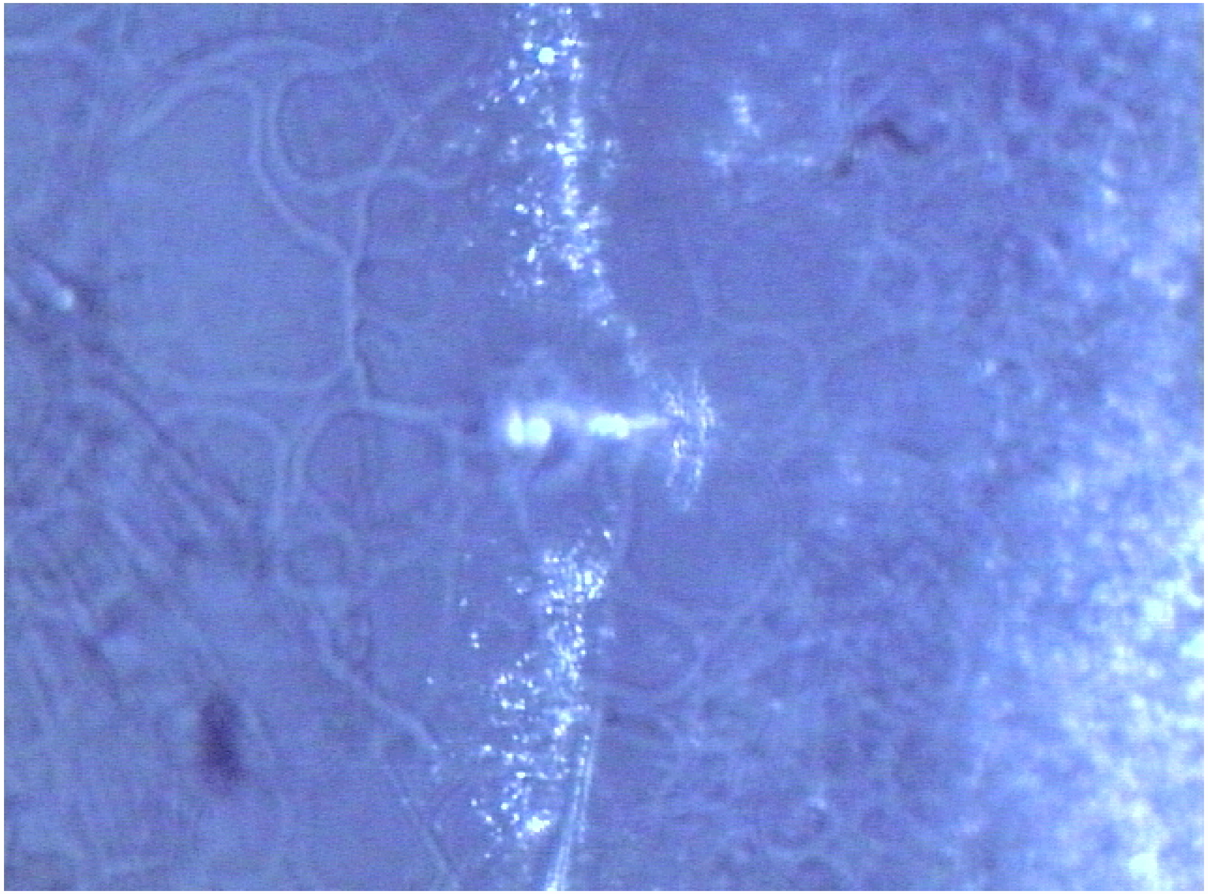
**Whiskers and nodules on tin plated control part--1206 capacitor--after 1000 temp cycles.**

# 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**

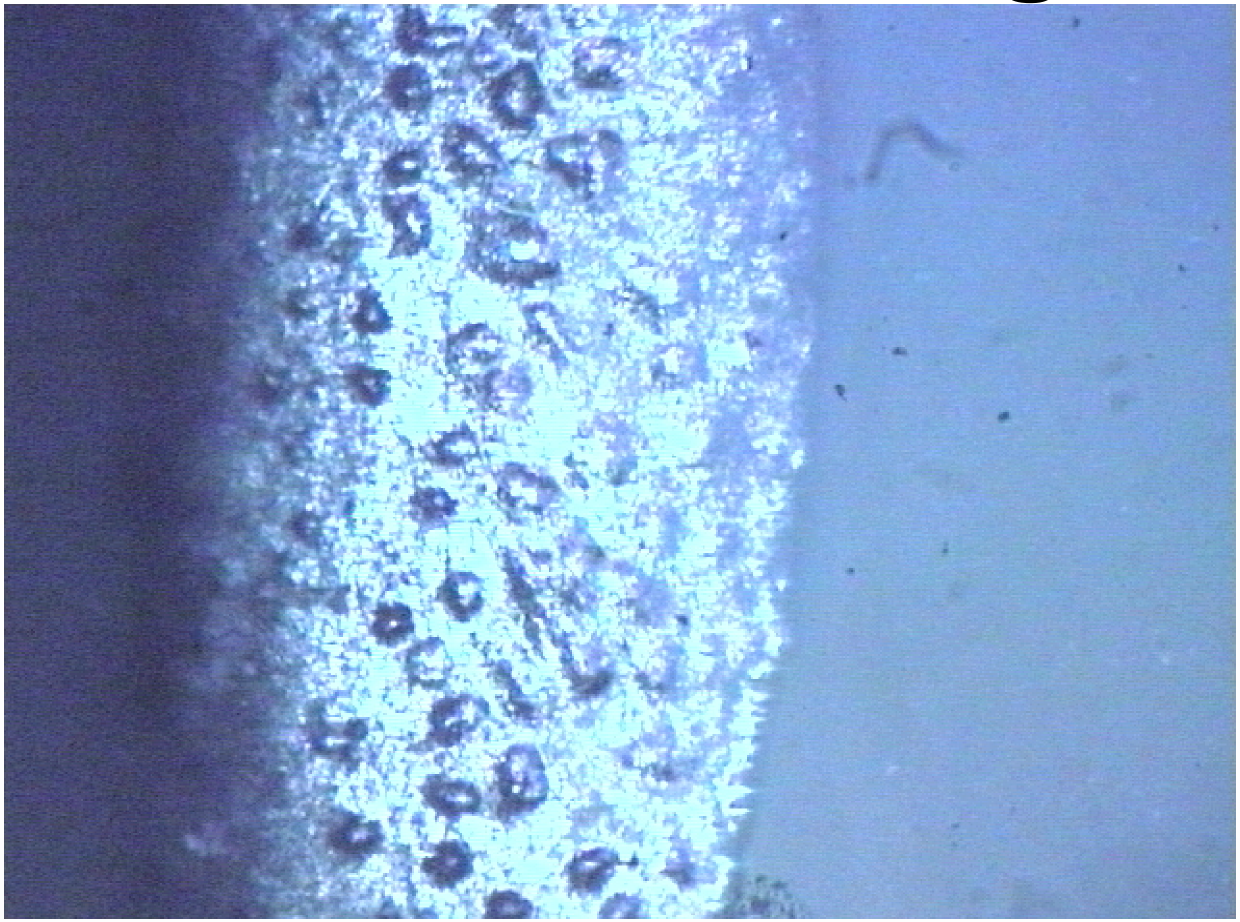
# Results—tin whisker growth



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

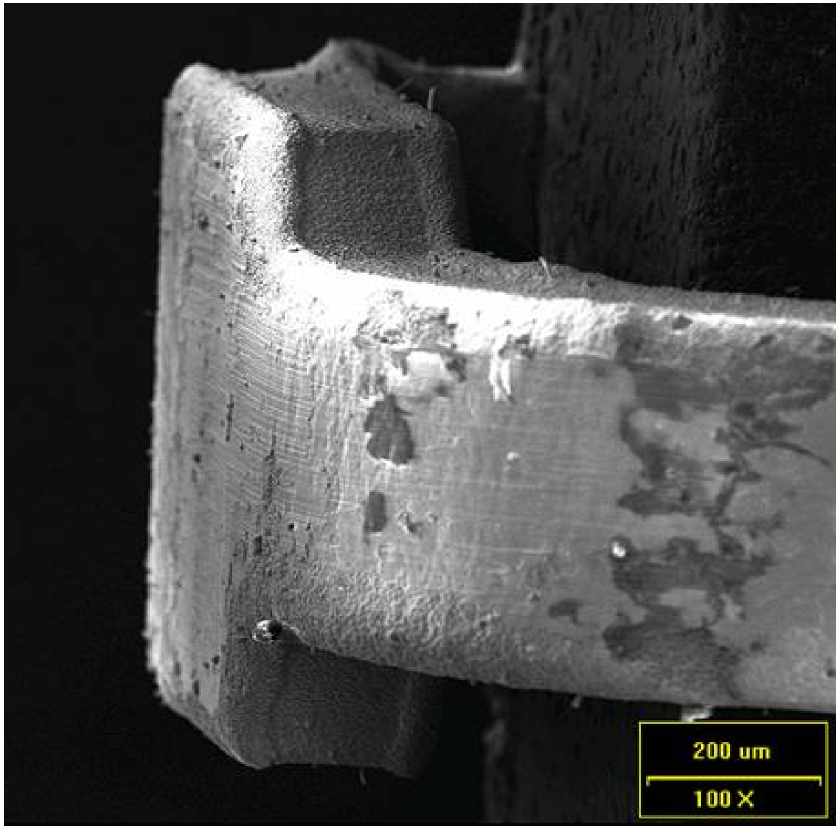
Presence or absence of urethane conformal coating did not significantly affect whisker length or density

# Results—tin whisker growth



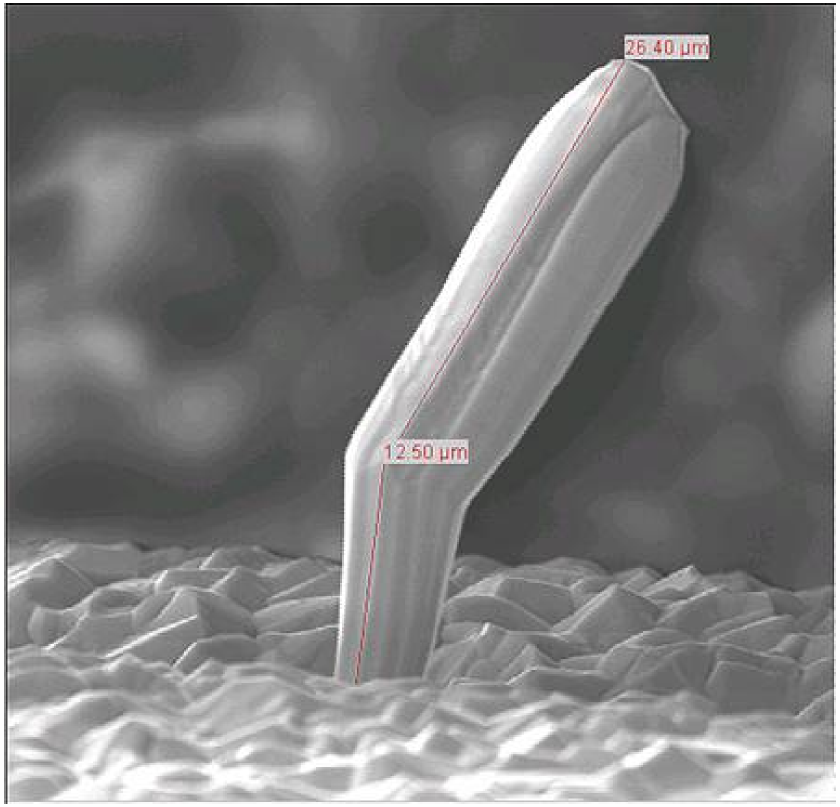
“Hillocks” on tin mitigated 1206 part after 1000 temp cycles

# Results—tin whisker growth



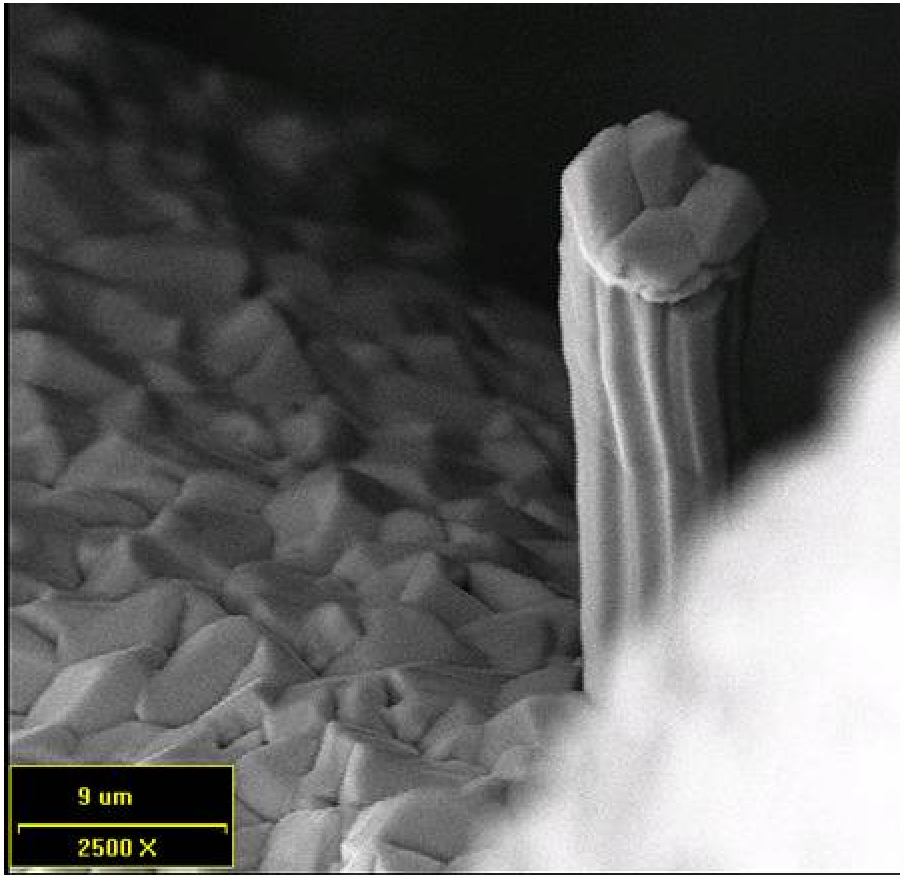

**Whiskers and nodules on pure tin PLCC after 3000 hours 30C, 60% RH**

# Results—tin whisker growth



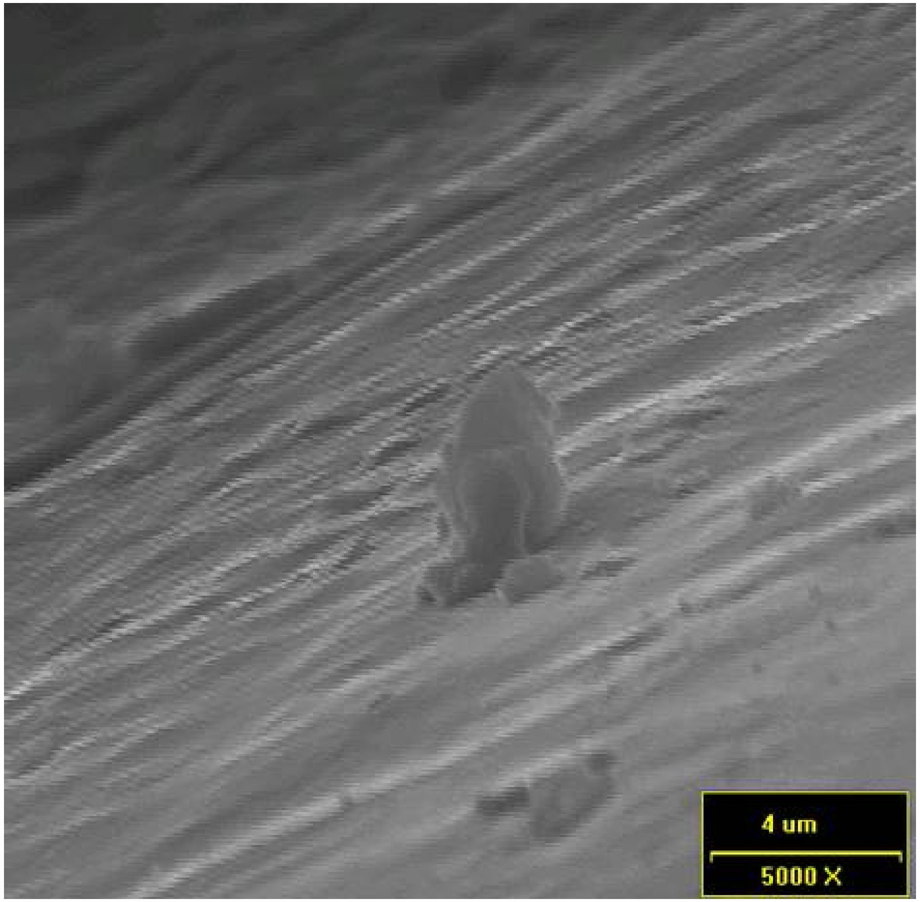

**39 µm tin whisker growing from PLCC piece part after 3000 hours 30C, 60% RH**

# 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

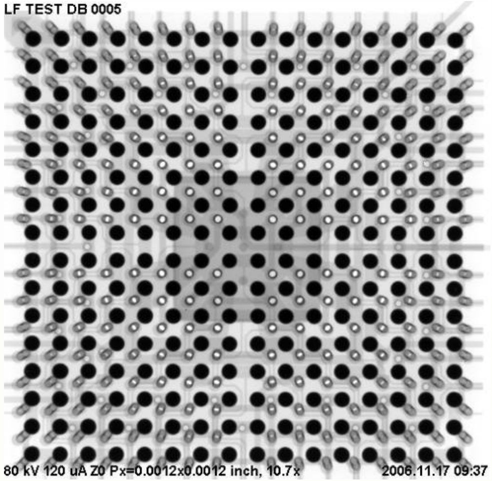
Area 1 = Pb

Area 2 = Sn

Area 3 = SnPb

# Results—Xray evaluation

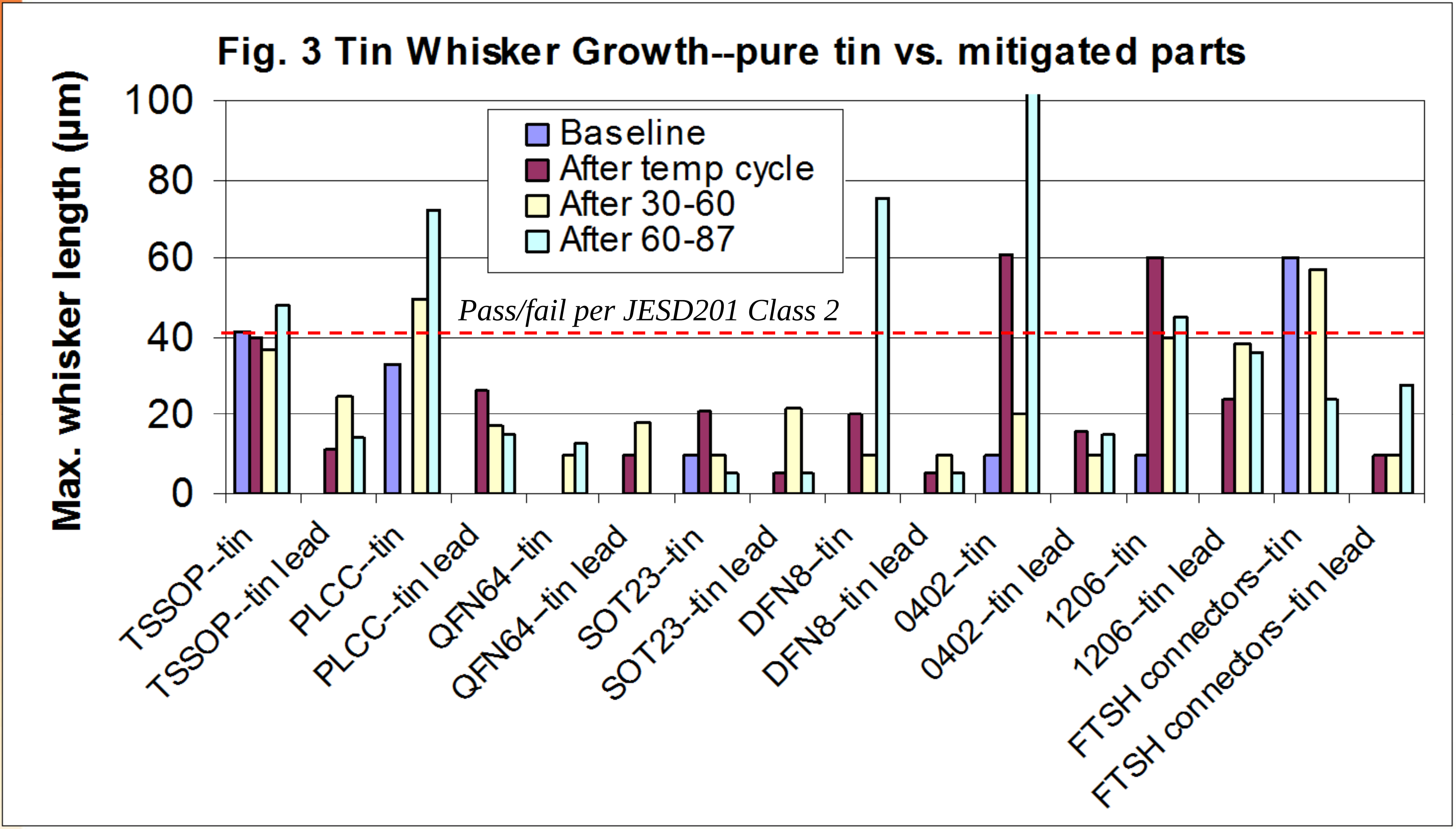
- Encapsulated modules and reballed BGAs could not be visually or SEM inspected
- X-ray analysis was attempted to discern whisker growth, with resolution down to approximately 10 µm.
- No whiskers were detected; BGA solder balls looked OK
- Encapsulated modules passed electrical test.
- Ceramic-filled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

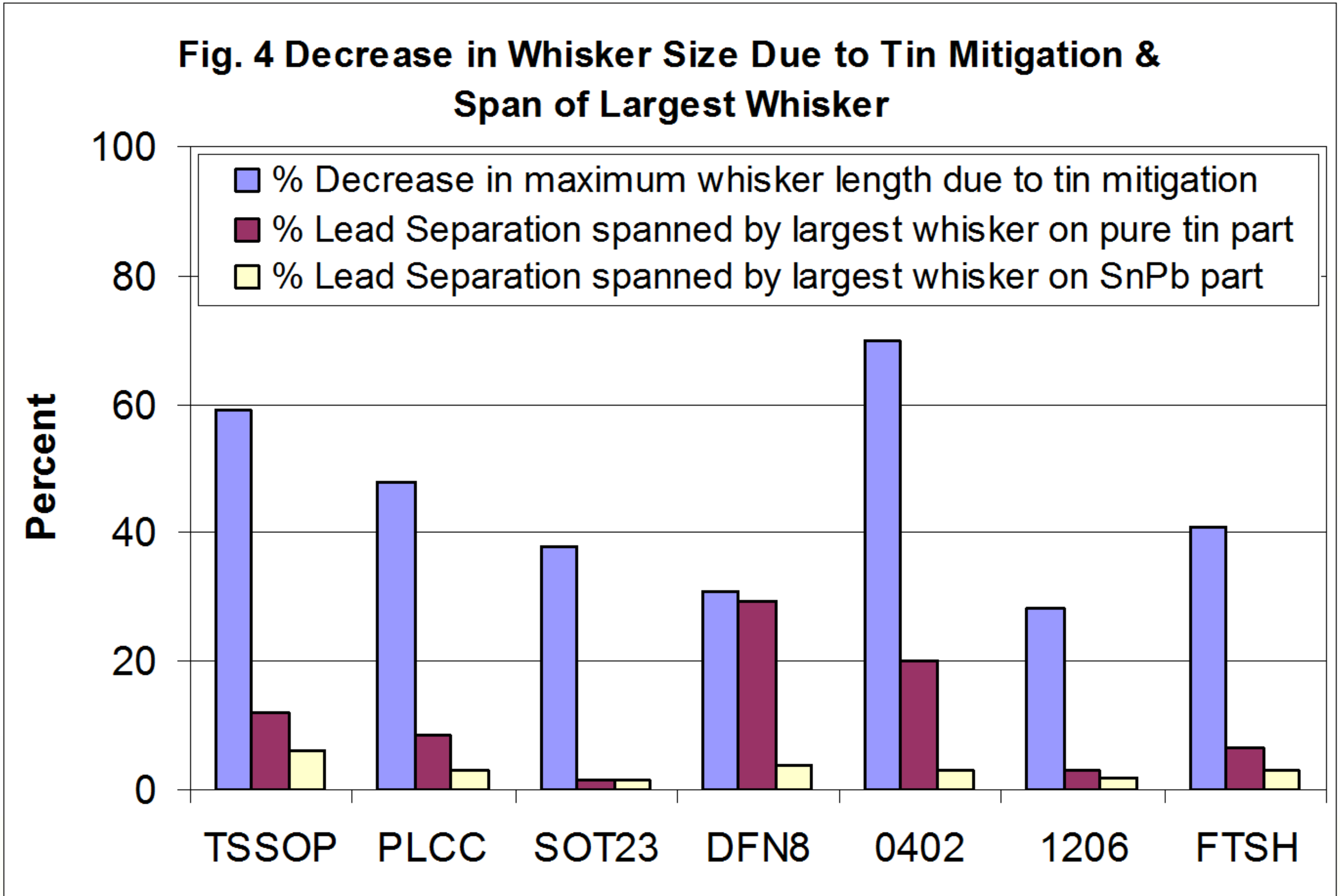
# Summary of Whisker Density Data

| | | 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.**

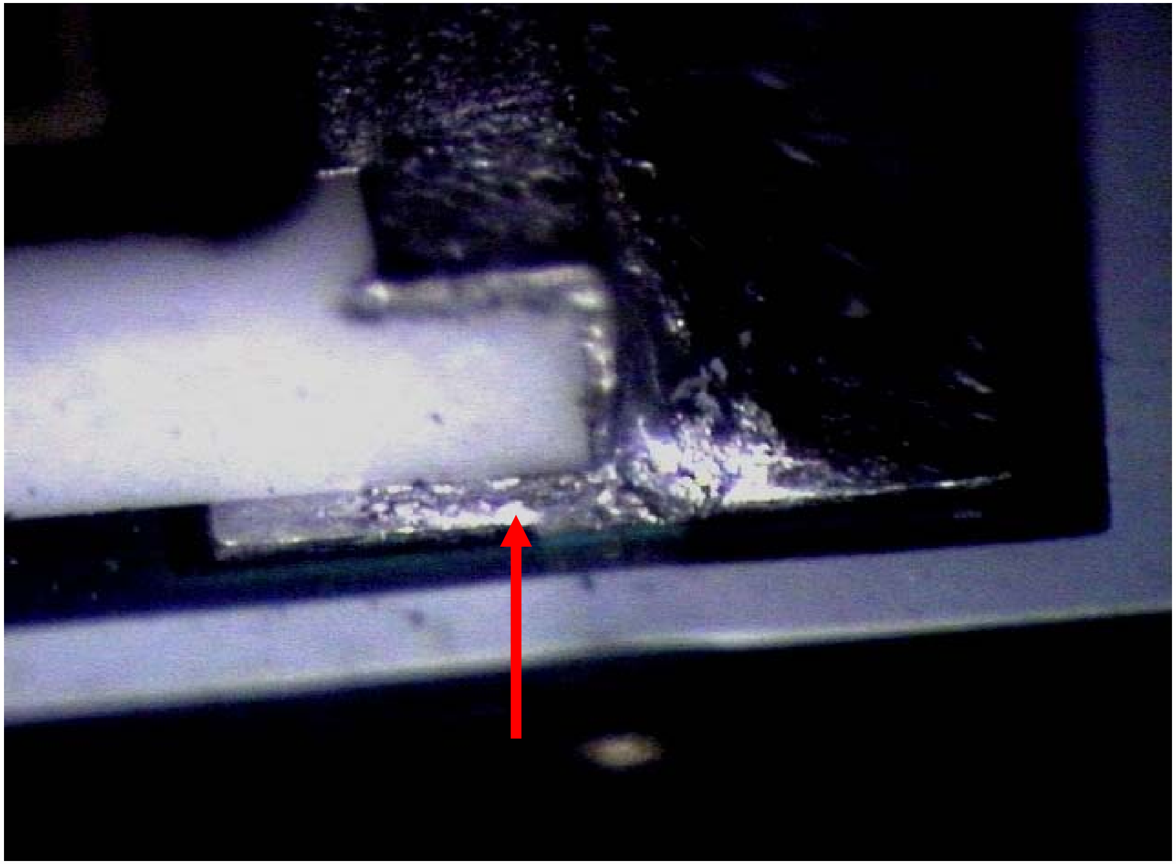
# Test results: tin whisker growth

- 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**

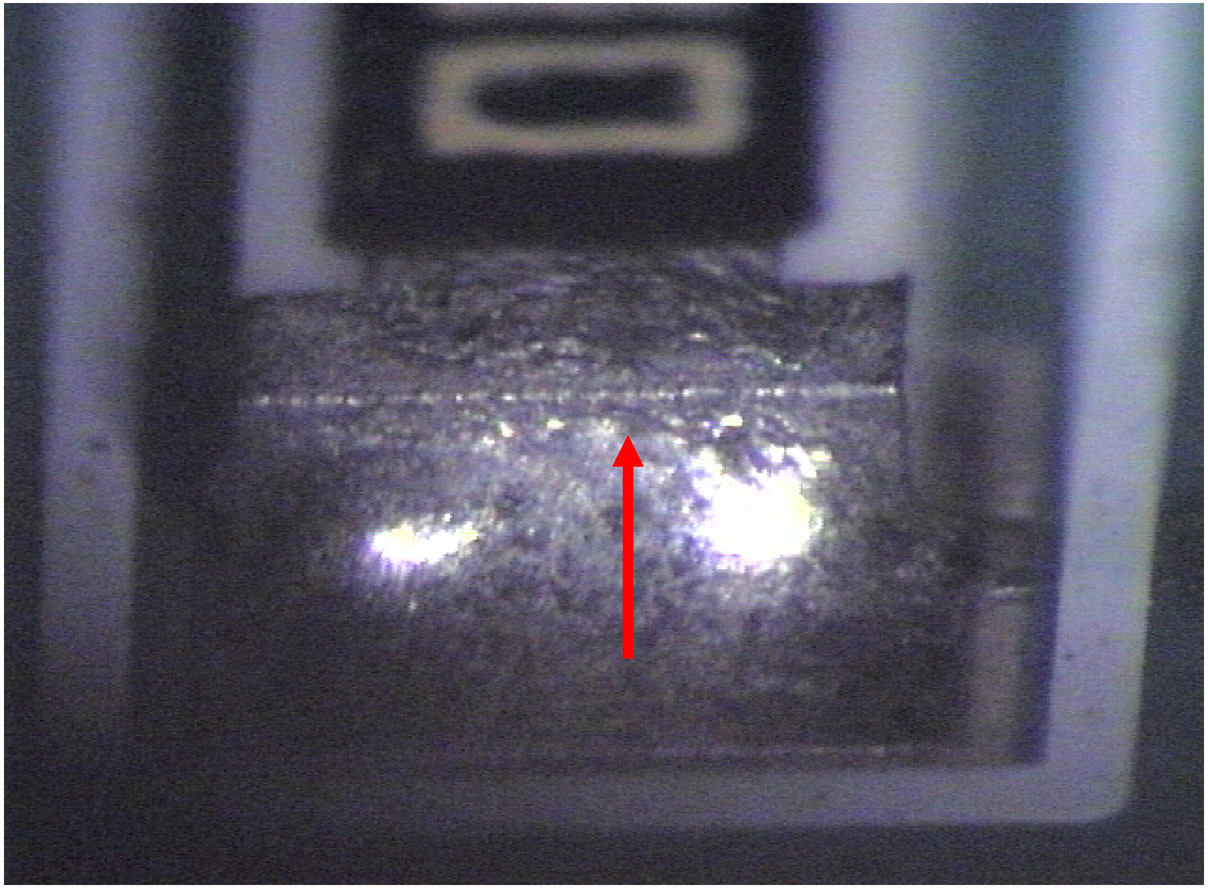
# Evaluation of solder joint reliability after temperature cycling

# Results--Solder joint evaluation



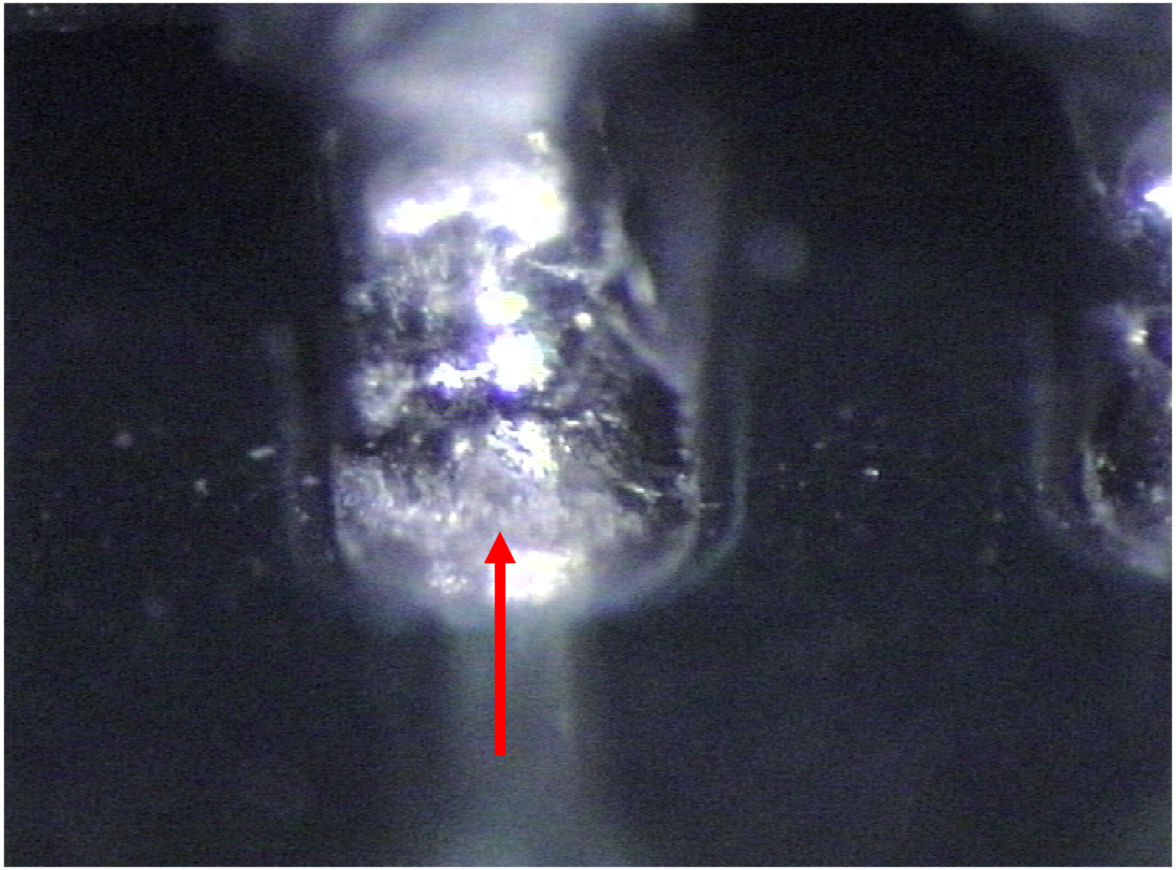
**Cracked solder joint on 1206 chip resistor after 1000 temp cycles**

# 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**<br>**Accurate forecast may not be possible** |
| **Redesign** | **Can change parts** | **Cost, schedule** |
| **Mitigation** | **Avoid redesign & last time buys** | **Extra handling, processing & cost**<br>**May not eliminate all risks** |
| **Qualify new parts/finishes** | **Avoid redesign & last time buys** | **May not be offered by suppliers**<br>**Extensive cost & technical obstacles** |