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Tin Whisker Mitigation Methods

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Joseph Aragon, Richard Wavrik, Paul Vianco, John Witham, Jimmy Bou

Sandia National Laboratories
P.O. Box 5800, MS 1076
Albuquerque, NM 87185-1076
josarag@sandia.gov Phone: 505-844-6726

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Introduction
Tin Whiskers - Example

Examples of Components with Tin Whiskers

200 microns

Ceramic Chip Capacitor
(Pure Tin-Plate Over Nickel Terminations)
Observed in 2001

Conductive Epoxy Mounted
Inside Hermetically Sealed Hybrid

Whiskers appeared AFTER
Thermal Cycle -40°C / +90°C
(~200 Cycles Shown Here)

Ref: Qss Group, Inc. @ NASA Goddard

What are Tin Whiskers?

Hair-like structures of tin that may grow spontaneously from tin finishes.

- The fundamental mechanisms of tin whisker growth are not fully understood.

Tin whiskers are highly suspected in the costly failure of a number of electronic systems: Military Aircraft, Missiles, Satellites, Heart Pacemakers, etc.…

The drive to eliminate lead (Pb) from electronics has resulted in the use of pure tin (Sn) finishes as a lead-free plating option.

Purpose

Component engineers receive components with pure tin plating. Whisker growth and mitigation studies are performed on these components. By evaluating proven mitigation measures, one can assess the risk of whisker propensity, growth rates and lengths to the given application. From the results of these experiments, recommendations on the mitigation methods and risk assessment for use “as-Is” on the parts are made.

Methods used at SNL to evaluate Tin Whisker Mitigation

- **SOLDER WICKING** – Normal reflow process for mounting parts on boards
- **FUSING** 230 C for one minute

  Heat treat in the range of 232 C where the tin fully melts
- **ANNEALING** 150 C for 1 hour

  Heat treat at a lower Temp than fusing but longer
- **Hot Solder Dip (HSD)**

  Dip termination ends into hot tin/lead solder bath
- **AEM Plating***

  Plating with subsequent lead mixing process performed by AEM, Inc., San Diego, CA

* Reference to a commercial product implies neither an endorsement by Sandia National Laboratories nor a lack of suitable substitutions

Conditions used in these Experiments to promote Whisker Growth

iNEMI Test Conditions

Temperature Cycling (TC)

- 40C to 85C at 10 minute dwell time

Whisker inspections performed at intervals of 500, 1000 and 2000 cycles

Temperature & Humidity (HAST)

60 C at 93% RH

Whisker inspections performed at 800 hrs and 1500 hrs.

Storage

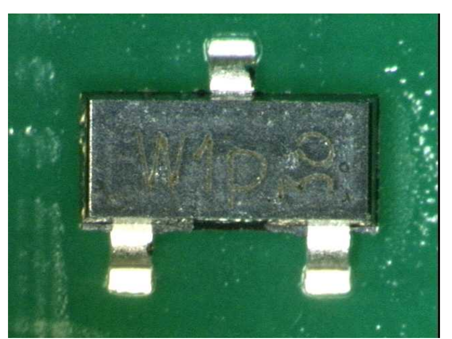
Long Term Storage (LTS)

Parts stored in a container at continuous ambient rooftop conditions at SNL.
Ref: CMSE Paper “Long Term Dormant Storage Experiment…” by John Lopez

Whisker inspections performed at 4, 8, 12, 18 and 24 months

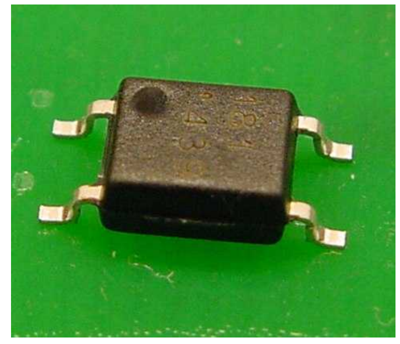
Note: Parts not biased in tests

Parts used in these Experiments



Transistor

Package size (mm)
= 3.0x 1.4w x 1.0h
Case Type: SOT23
Three leaded package
Tin plated matte finish lead
Fe60%, Ni40% base material
Mitigation Methods
Solder Wicking
Fusing
Annealing

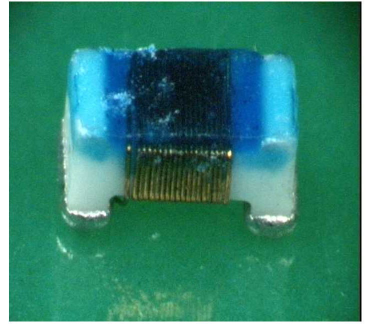


OPTO Coupler

Package size (mm)
= 4.40L x 3.75w x 2.00h
Case Type: SO4
Four leaded package
Tin Plated Matte Finish lead
Cu97%, Fe3% base material
Mitigation Methods
Solder Wicking
Fusing
Annealing

Capacitor

Package size (mm)
= 3.3L x 2.6W x 2.0H
Chip Component with
5-sided Tin plated Termination Ends with middle Ni barrier and an interior Cu termination
Mitigation Methods
Solder Wicking
AEM Plating
HSD

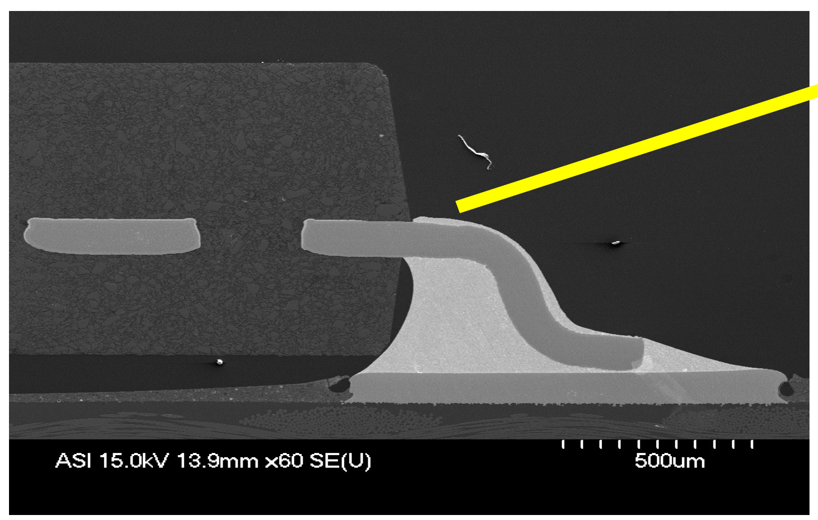


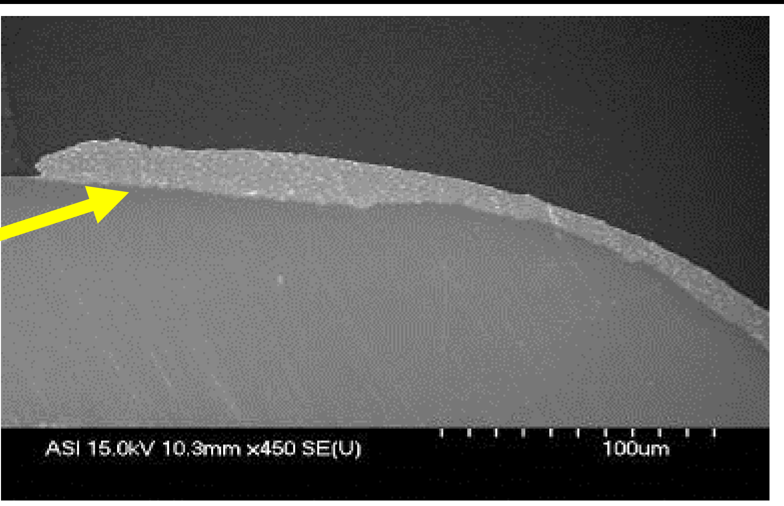
Coli Inductor

Package size (mm)
= 1.6L x .80w x .80h
Chip Component with
5-sided Tin plated Termination Ends with middle Ni barrier and an interior Ag termination
Mitigation Methods
Solder Wicking
AEM Plating
Fusing

Tin Whisker Mitigation – Solder Wicking SOT23 Transistor

Cross Section Shows Pb/Sn Solder Wicking Coverage to Package Entry





Wicking results in an average of 19% Pb in top region (27 part sample)

Concerns:

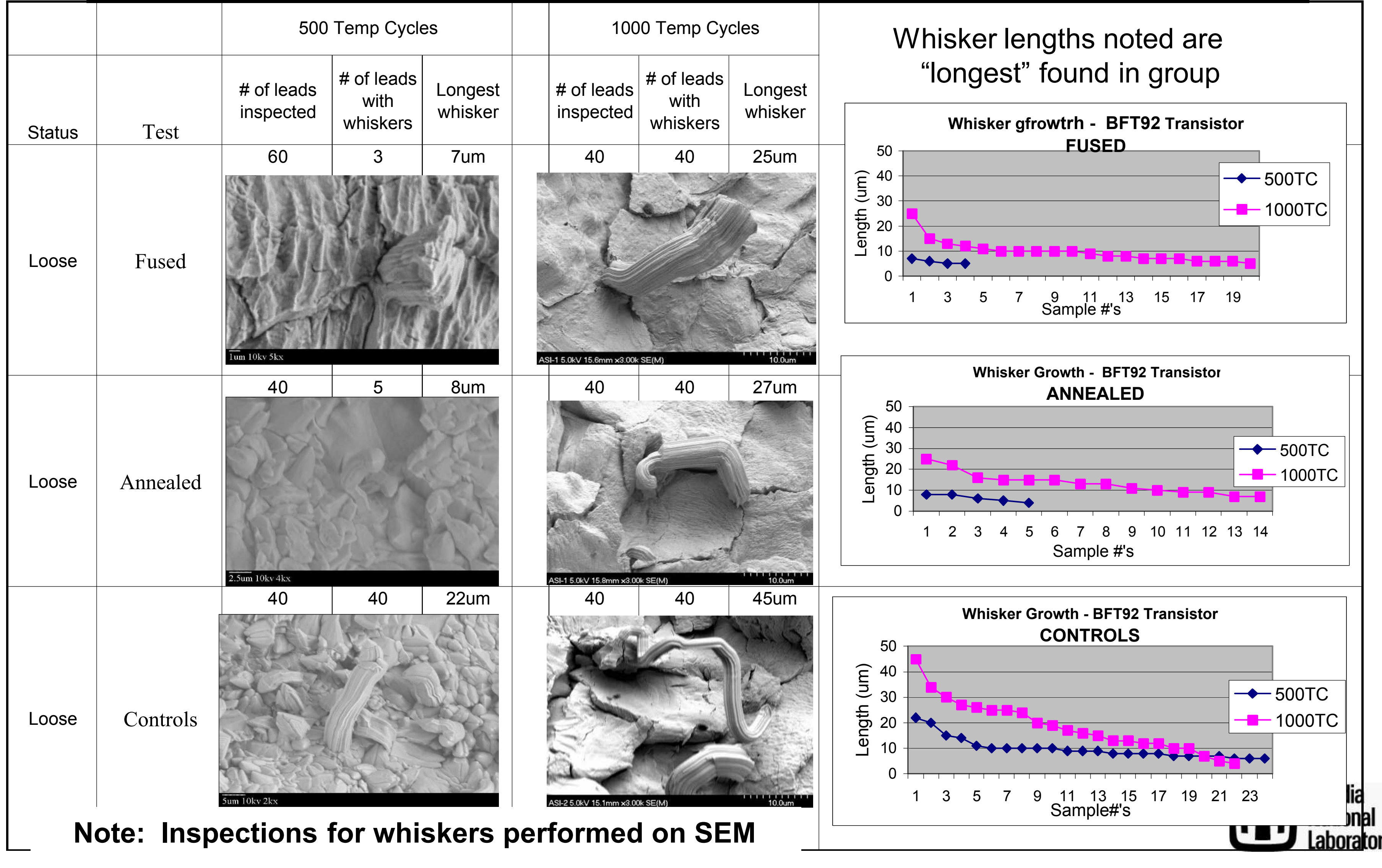
May only be true for short, stubby leads like SOT23.

Is it consistent for all SOT23 parts?

Will this happen with other types of leads?

3% Pb coverage suggested to eliminate tin whisker growth

Solder Wicking Results at 1000 Temperature Cycles SOT23 Transistor - Loose



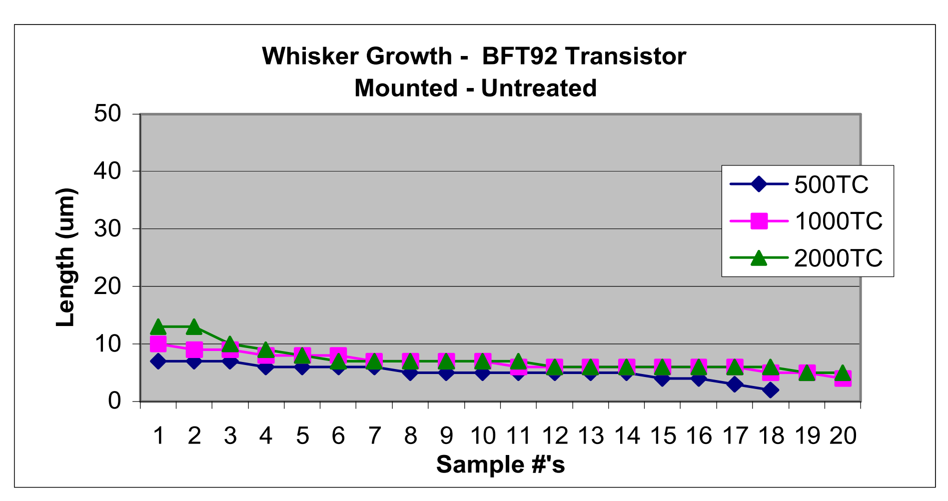
Status	Test	500 Temp Cycles			1000 Temp Cycles		
		# of leads inspected	# of leads with whiskers	Longest whisker	# of leads inspected	# of leads with whiskers	Longest whisker
Loose	Fused	60	3	7um	40	40	25um
Loose	Annealed	40	5	8um	40	40	27um
Loose	Controls	40	40	22um	40	40	45um

Whisker lengths noted are “longest” found in group

Note: Inspections for whiskers performed on SEM

Solder Wicking Results at 2000 Temperature Cycles
SOT23 Transistor - Mounted

Status	Test	500 Temp Cycles			1000 Temp Cycles			2000 Temp Cycles		
		# of leads inspected	# of leads with whiskers	Longest whisker	# of leads inspected	# of leads with whiskers	Longest whisker	# of leads inspected	# of leads with whiskers	Longest whisker
Mounted	As is	20	20	7um	36	36	10um	30	30	13um



Whisker Growth Summary for SOT23 Temperature Cycling

Capability Analysis for different mitigation methods at 1000TC

Note: 45um used as upper limit. Per JESD201 acceptance criteria for maximum allowable whisker length for Temperature cycling.

Controls- Loose

-3s Mean +3s

LSL USL

0 10 20 30 40 50

Mean	18.59
Std Dev	10.130
N	22

Annealed- Loose

-3s Mean +3s

LSL USL

Mean	13.35
Std Dev	5.271
N	14

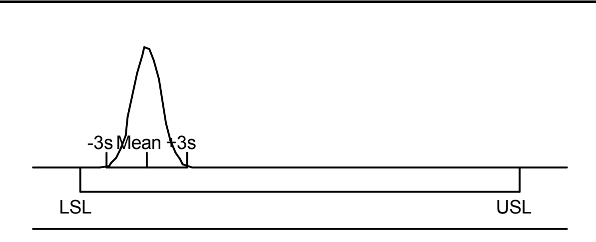
Fused- Loose

-3s Mean +3s

LSL USL

Mean	9.75
Std Dev	4.423
N	20

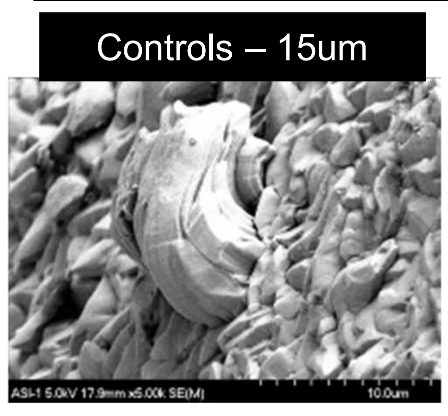
Solder Wicking
As-is - Mounted



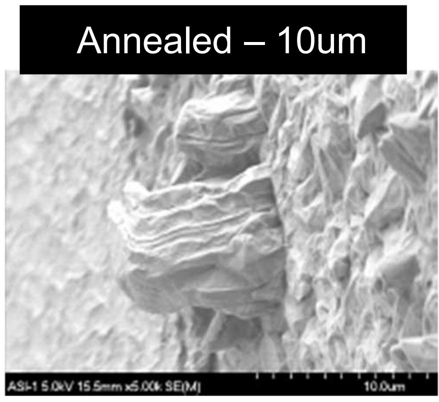
Mean	6.75
Std Dev	1.409
N	20

HAST (Temp & Humidity) at 1500 hours SOT23 Transistor – Loose parts

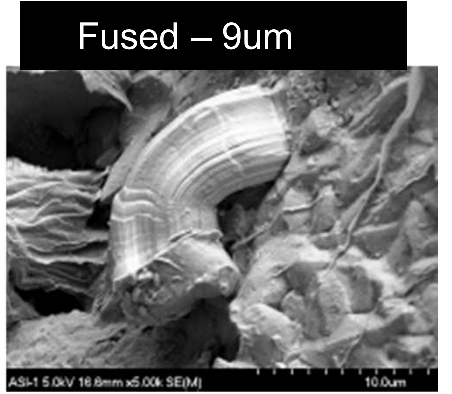
Controls – 15um



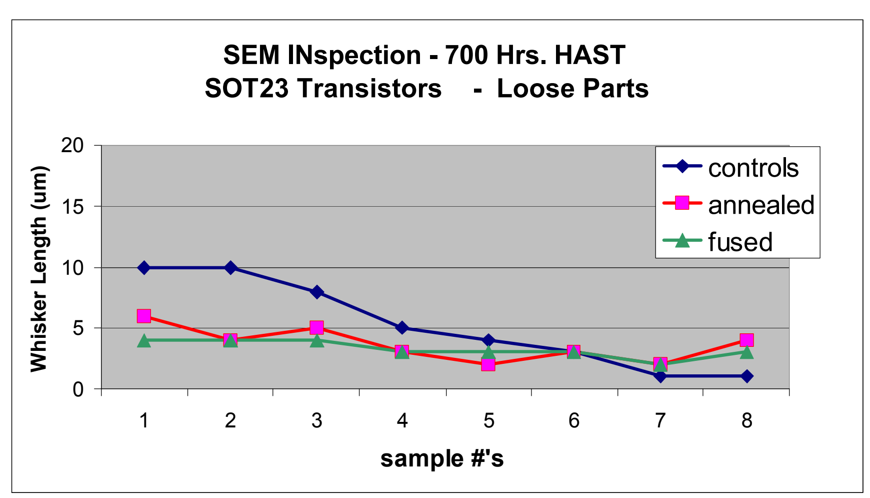
Annealed – 10um

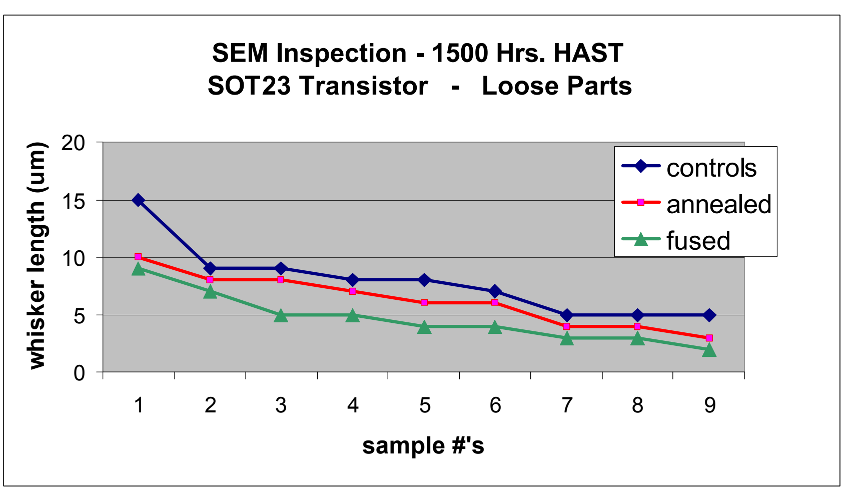


Fused – 9um



Photos taken at 1500 hrs.





Note: 1500 hrs. in process for mounted parts

Tin Whisker Mitigation – SOT23 Transistors Fusing (Loose) / Long Term Storage - Results

Inspection at 2 and 4 months: **No whiskers**

Inspection at 8, 12, 18 and 24 months:

220 C for 1 minute - WHISKERS! (5/5)

230 C for 1 minute - No Whiskers (0/5)

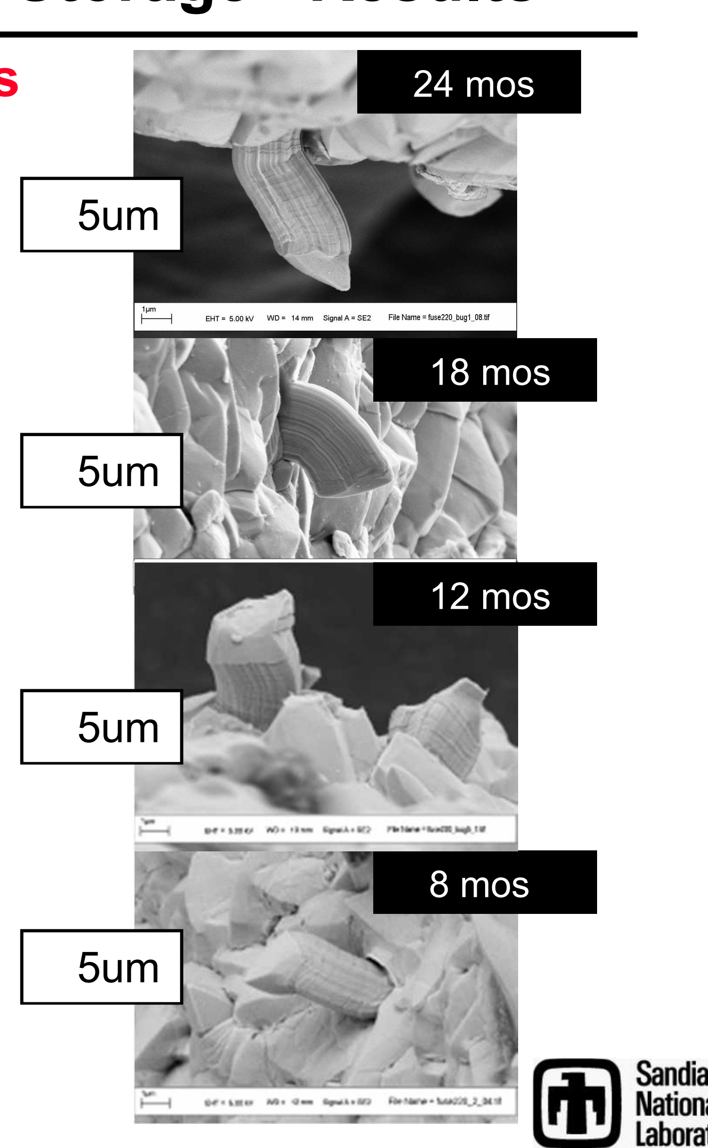
240 C for 1 minute - No Whiskers (0/5)

240 C for 30 minutes - No whiskers (0/5)

No continuous growth (5um) noted on whiskers from 8 to 24 months for parts fused at 220 C – See photos

No whiskers found at 24 months on parts fused at 230 C or above.

Testing is on-going for Long Term Storage evaluation



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Long Term Storage Whisker Growth results at 24 months – SOT 23 Transistor

SOT23 Transistor parts inspected for whisker growth at 2, 4, 8, 12, 18 and 24 months.

These are control parts – untreated /as-is loose parts.

LTS - Whisker growth

Whisker Length (um)

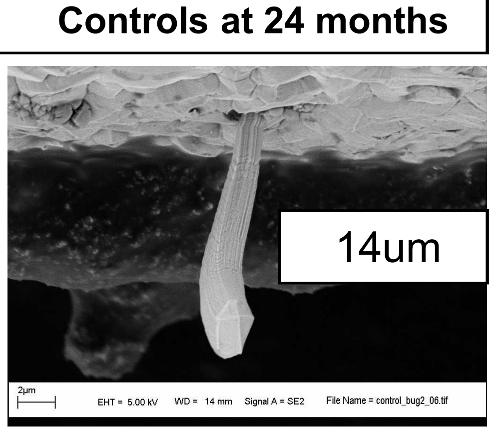
16
14
12
10
8
6
4
2
0

2 4 8 12 18 24

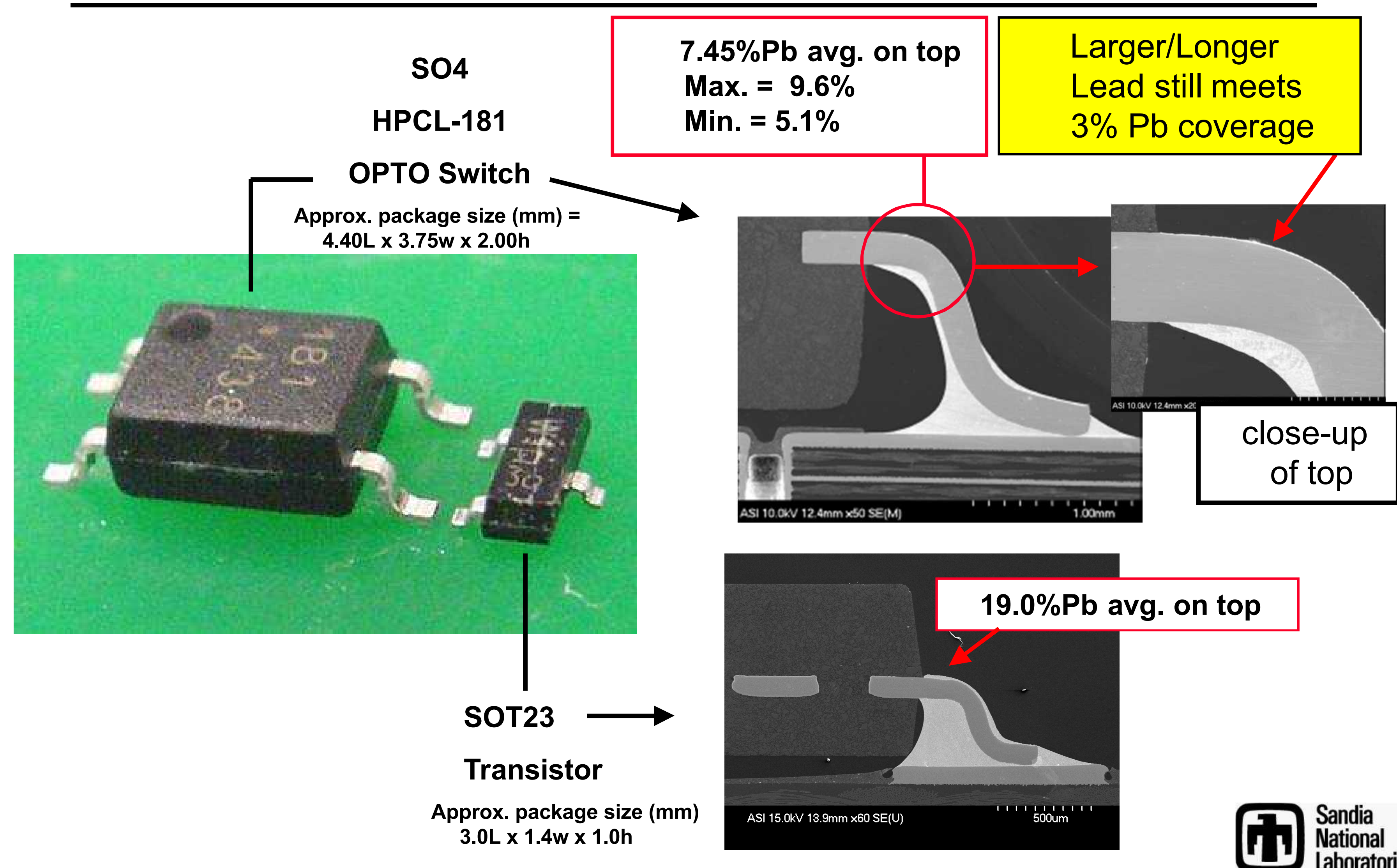
Months

Avg
Max

Controls at 24 months



Tin Whisker Mitigation - S04
Solder Wicking - Lead Comparison



Heat Treat Results at 1000 Temperature Cycles
SO4 OPTO Coupler - Loose

Status	Test	500 Temp Cycles: # of Leads inspected	500 Temp Cycles: # of Leads with whiskers	500 Temp Cycles: Longest whisker	1000 Temp Cycles: # of Leads inspected	1000 Temp Cycles: # of Leads with whiskers	1000 Temp Cycles: Longest whisker
Loose	Fused	50	0	0	25	13	16um
Loose	Annealed	40	0	0	20	18	11um
Loose	Controls	40	40	35um	20	20	44um

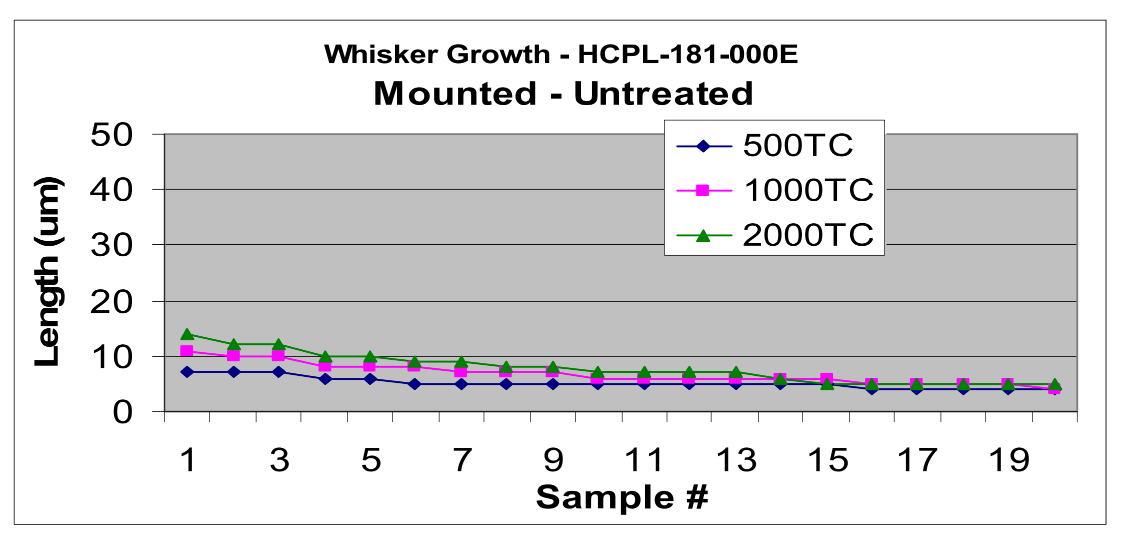
No whiskers (Fused, 500 Temp Cycles)

No whiskers (Annealed, 500 Temp Cycles)

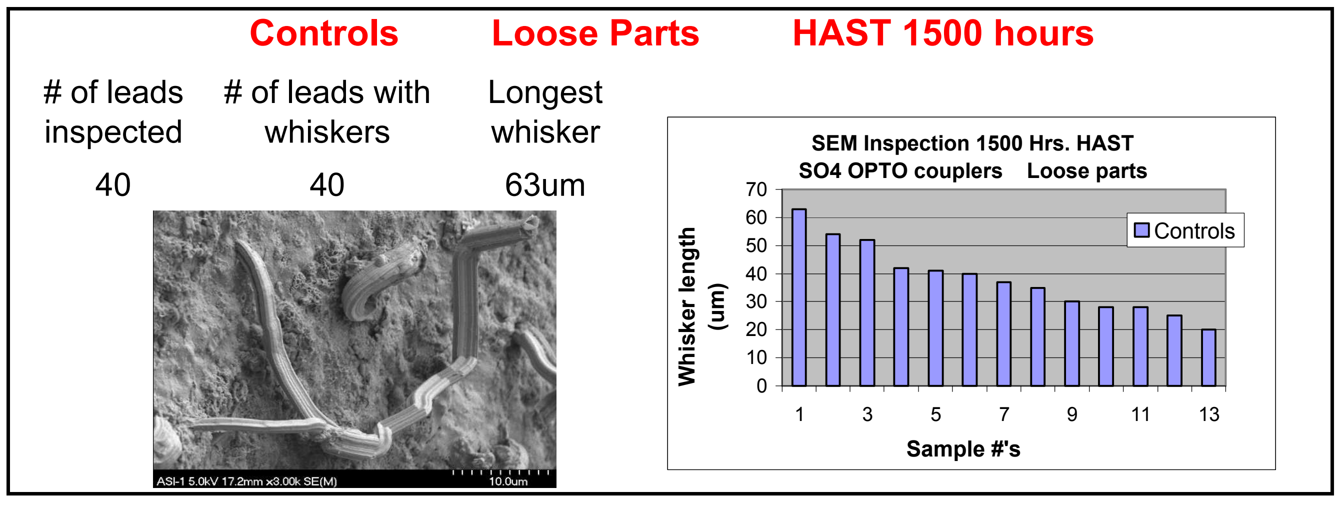
Note: For both leaded parts (SOT23 & S04), no whisker growth or very minimal growth found at 500TC for the treated loose parts. Growth is more evident and defined at 1000TC. Will continue to 2000TC.

Heat Treat Results at 2000 Temperature Cycles
SO4 OPTO Coupler - Mounted

		500 Temp Cycles			1000 Temp Cycles			2000 Temp Cycles		
Status	Test	# of Leads inspected	# of Leads with whiskers	Longest whisker	# of Leads inspected	# of Leads with whiskers	Longest whisker	# of Leads inspected	# of Leads with whiskers	Longest whisker
Mounted	As is	50	50	7um	72	72	11um	40	40	14um



HAST (Temp & Humidity) Results SO4 OPTO Coupler



Solder wicking **Mounted Parts** **HAST 800 hours**

# of leads inspected	# of leads with whiskers	Longest whisker	
40	0	N/A	No whisker growth found at 800 hrs.

Solder wicking appears to be effective in eliminating tin whisker growth for the SO4 package under iNEMI Temperature and Humidity recommended conditions at 800 hours. Will re-inspect at 1500 hrs.

Tin Whisker Mitigation – Capacitor Solder Wicking on Termination Ends

Cross sections were made on the end termination solder joints in the X and Y direction.

Y - direction

ASI-1 10.0kV 12.9mm x30 SE(M) 1.00mm

ASI-1 10.0kV 12.9mm x150 SE(M) 300um

ASI-1 10.0kV 12.9mm x150 SE(M) 300um

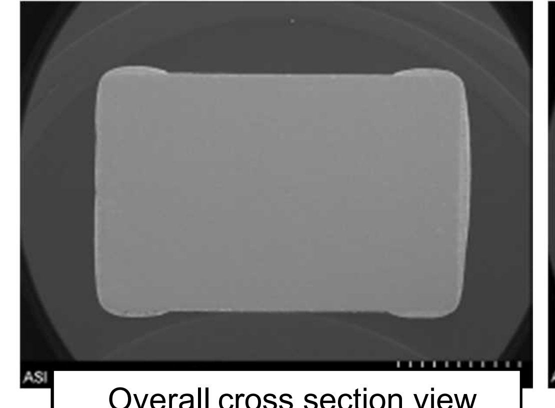
Further close-up view on questionable corners.

EDS revealed 100% Sn still on top after soldering

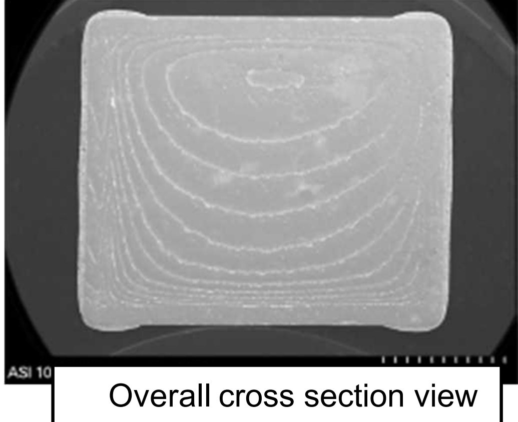
Tin Whisker Mitigation - Capacitors AEM Plating

Cross-sectioned in two directions to assure complete solder coverage

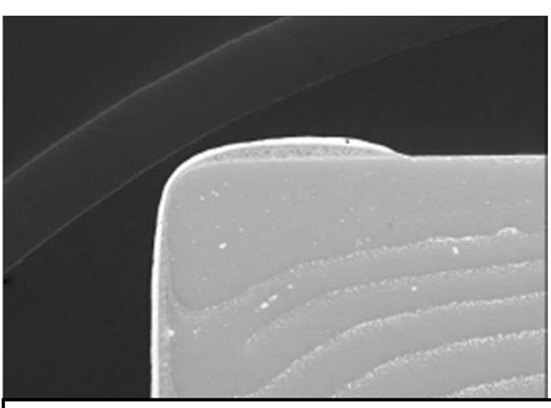
Note: Electrical tests performed after plating to assure parts still functional



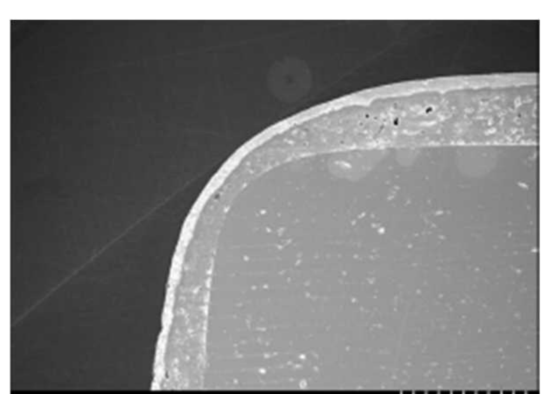
Overall cross section view in the Z-direction.



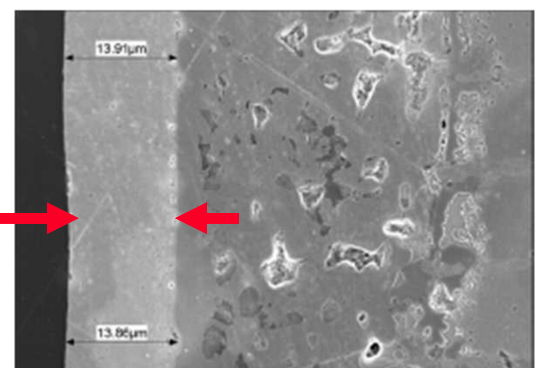
Overall cross section view in the Y-direction.



Close-up view showing the plating coverage beyond the tin surface



Detail view showing the plating coverage around the corner of the capacitor.



Typical close-up view showing the plating on the termination side. Thickness Approx. 13um

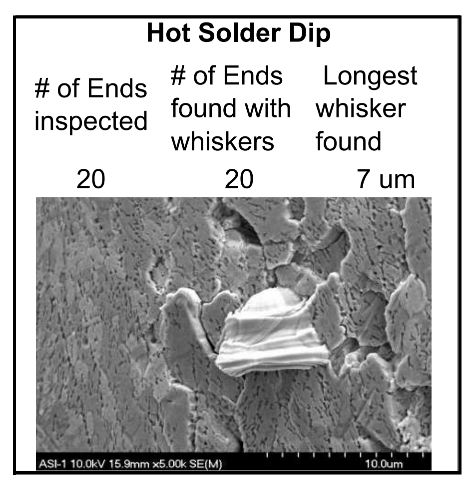
Results

Hot Solder Dip (HSD), AEM Plated and Controls Capacitors - Temperature Cycling – Loose parts

Parts exposed to 1000 Temperature Cycles

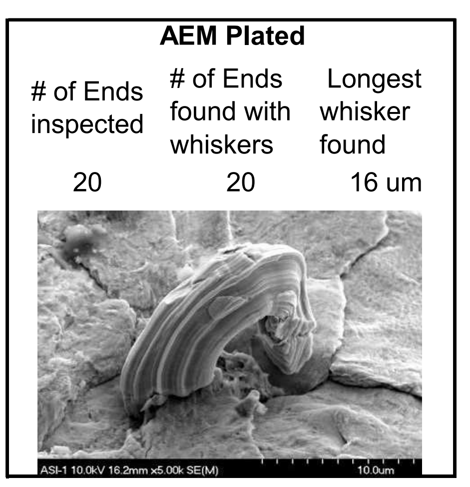
Hot Solder Dip

# of Ends inspected	# of Ends found with whiskers	Longest whisker found
20	20	7 um



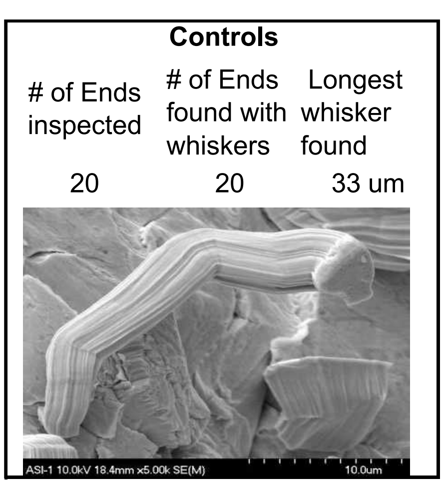
AEM Plated

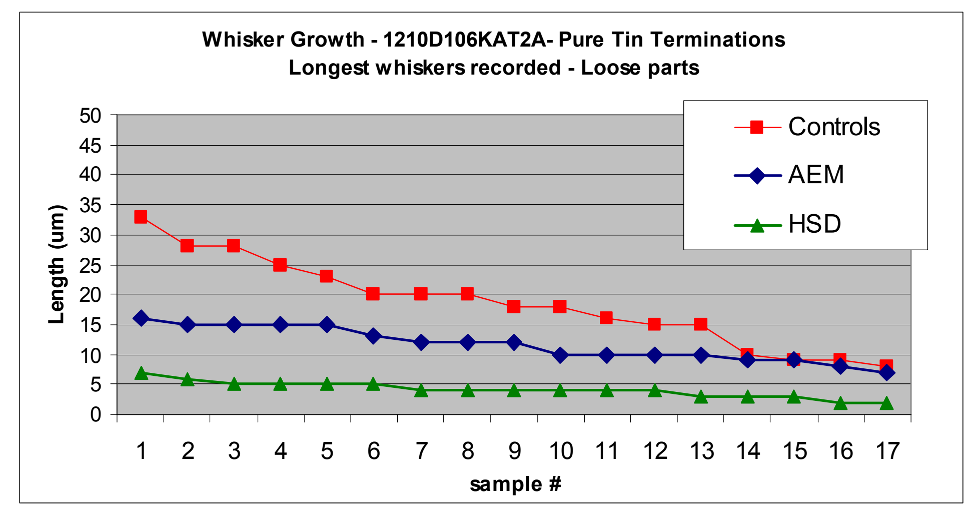
# of Ends inspected	# of Ends found with whiskers	Longest whisker found
20	20	16 um



Controls

# of Ends inspected	# of Ends found with whiskers	Longest whisker found
20	20	33 um

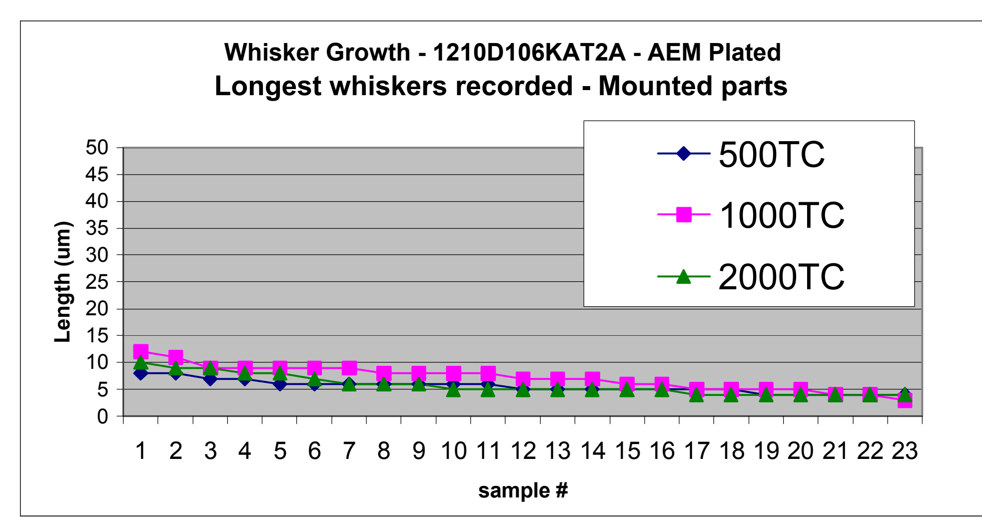




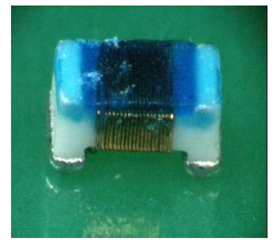
Plating and HSD seems to stunt the growth. Whiskers are short and not very well defined. Will continue to 2000TC and re-inspect.

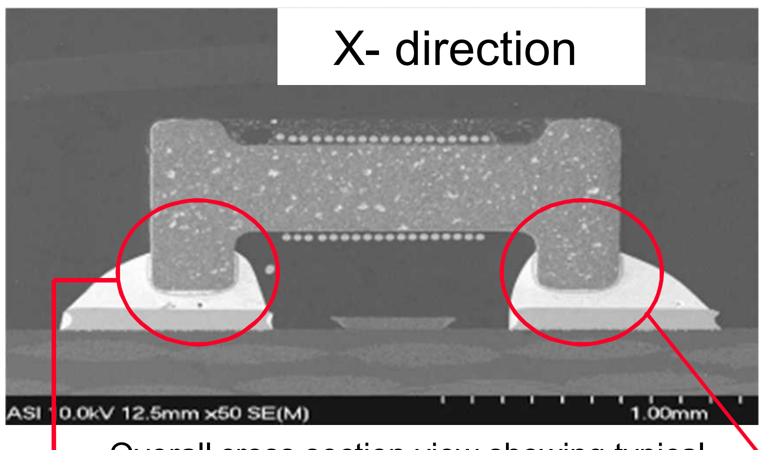
Results - AEM Plated Mounted Capacitors Temperature Cycling

		500 Temp Cycles			1000 Temp Cycles			2000 Temp Cycles		
Status	Test	# of End Terminations inspected	# of Ends with whiskers	Longest whisker	# of End Terminations inspected	# of Ends with whiskers	Longest whisker	Terminations inspected	# of Ends with whiskers	Longest whisker
Mounted	12103D106 AEM Plated	30	30	8um	26	26	11um	20	20	10um

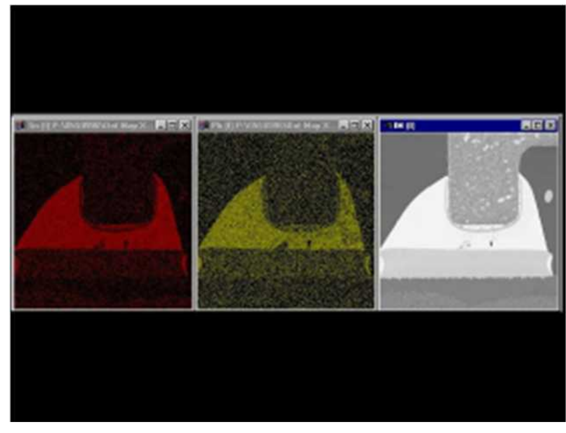


Tin Whisker Mitigation – Coil Inductor Solder Wicking on Termination Ends

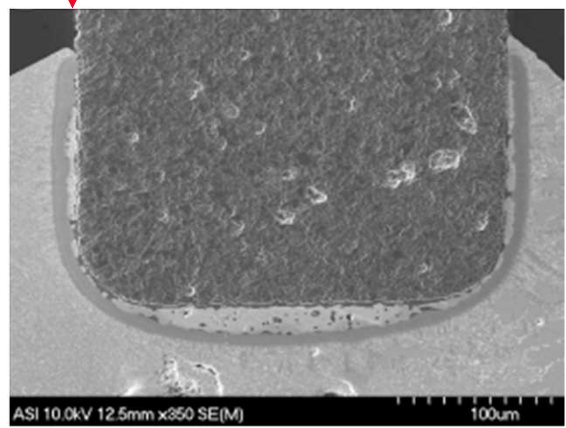




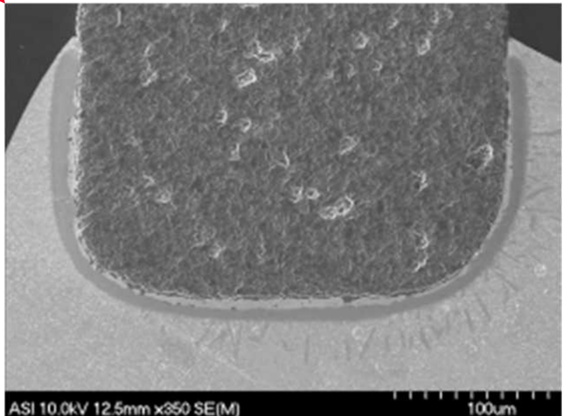
Overall cross section view showing typical inductor in the X-view.



X-ray dot map view showing typical cross sectioned solder connection; good intermixture between Sn and Pb was observed.



Detailed SEM view showing the **LEFT** end termination, covered entirely by the solder joint.



Detailed SEM view showing the **RIGHT** end termination, again covered entirely by the solder joint.

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Results at 1000 & 2000 Temperature Cycles
Coil Inductor

		500 Temp Cycles			1000 Temp Cycles			2000 Temp Cycles (mounted only)		
Status	Test	# of End Terminations inspected	# of Ends with whiskers	Longest whisker	# of End Terminations inspected	# of Ends with whiskers	Longest whisker	# of End Terminations inspected	# of Ends with whiskers	Longest whisker
Loose	Fused	20	20	12um	15	15	15um			
Loose	AEM Plated	20	20	10um	15	15	12um			
Loose	Controls	20	20	14um	15	15	15um			
Mounted	Un-treated Solder Wicking	36	36	9um	26	26	10um	20	20	9um

Very minimal growth regardless of test including controls.

In all conditions, growth still in the stubble length stage.

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HAST (Temp & Humidity) SEM Whisker Inspection Results of Chip Components Coil Inductor and Capacitor

Capacitor

1500 Hours HAST

Inspected 40 loose – AEM Plated parts - No whiskers found

800 Hours HAST

Inspected 10 Mounted – AEM Plated parts - No whiskers found

Coil Inductor

1500 Hours HAST - All Loose parts

AEM Plated – 15 parts inspected - No whiskers found

Fused – 15 parts inspected - No whiskers found

Controls– 15 parts inspected - No whiskers found

Exposure to HAST conditions for 1500 hours produced no whisker growth on Chip Components with Termination Ends

Conclusion

The best mitigation practice from these experiments showed that solder wicking from reflow works for both parts with leads and end terminations. For all mounted part types, there was no significant whisker growth noted from 500TC to 2000TC. Whisker growth stayed in the stubble stage length exhibiting a low level of reliability risk

Per JESD201 acceptance criteria for maximum allowable tin whisker length is 45um for TC and 20um for HAST. SNL mitigation methods are all within for both the loose and mounted parts.

The best indicator for whisker growth is Temperature Cycling to 1000 cycles. Why?

- Temp. Cycling is more of an indicator of whisker growth than HAST. HAST showed no evidence of whisker growth on parts with termination ends including control parts.
- Advantage of TC vs. HAST: 1000TC (19 days) vs. 1500 hrs. (63 days).
- For both leaded parts, no whisker growth or very minimal growth found at 500TC for the treated loose parts. Growth was more evident and defined at 1000TC.

Conclusion - continued

Solder wicking, though not 100% throughout the termination ends, combined with AEM plating proved to be an effective mitigation method on the capacitors.

On the coil Inductors whose termination contains a Ag interior layer, parts are not prone to significant growth regardless of test conditions. This includes control parts.

The potential risk of system failure from components plated with 100% tin varies from part to part and therefore each part must be tested individually.

Will proceed to 2000 Temp. cycles & 1500 HAST Hrs. for all parts (loose and mounted) and re-inspect.

Long Term Storage is continuous. A total of two years under field conditions have been completed.