SAND2008-7346C

Tin Whisker Mitigation Methods

Defense Manufacturing Conference

December 1- 4, 2008

Orlando, FL.

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Acknowledgements: SEM photos from ASI (Analytical Solutions, Inc.), Albuquerque, NM and Mounted parts from NNSA's Kansas City Plant Operated by Honeywell FM&T

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

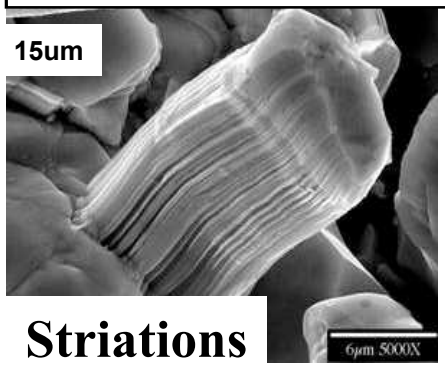
SAND number 2008-XXX-XX

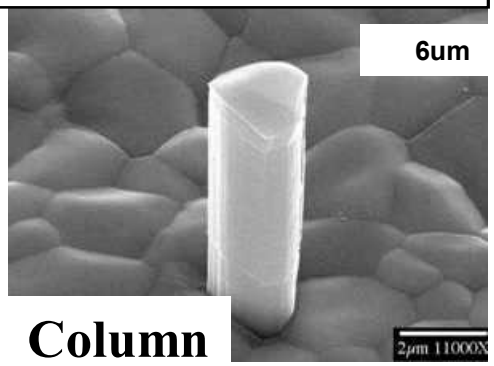
Introduction
Tin Whiskers - Examples

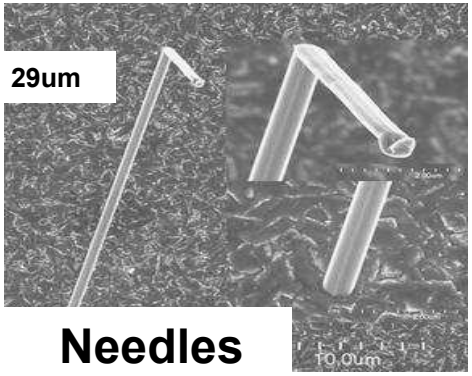
What are Tin Whiskers? Hair-like structures of tin that may grow spontaneously from tin finishes.

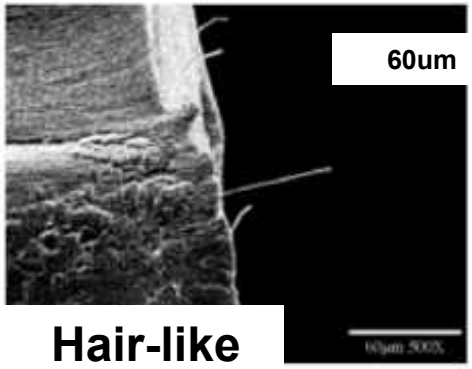
The fundamental mechanisms of tin whisker growth are not fully understood.

Initial growth stages – various types

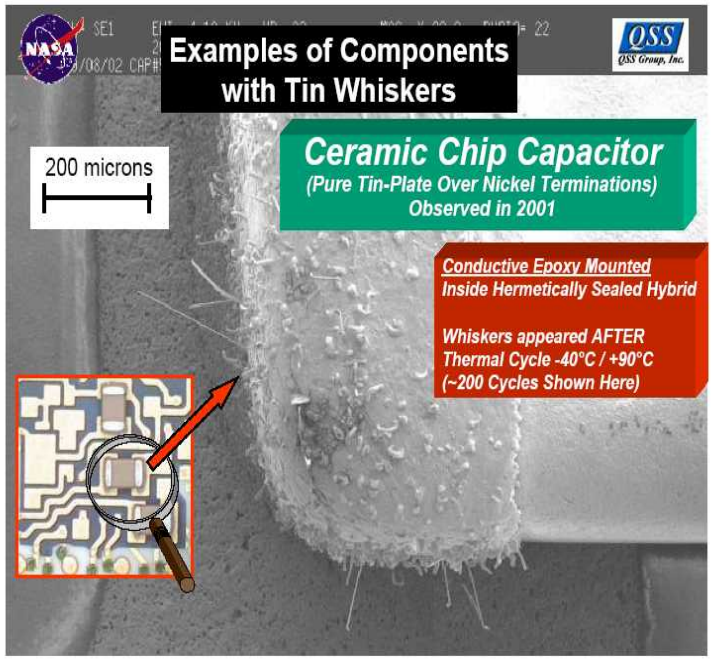








Ref: NEMI Tin Whisker Test Project



Ref: Qss Group, Inc. @ NASA Goddard

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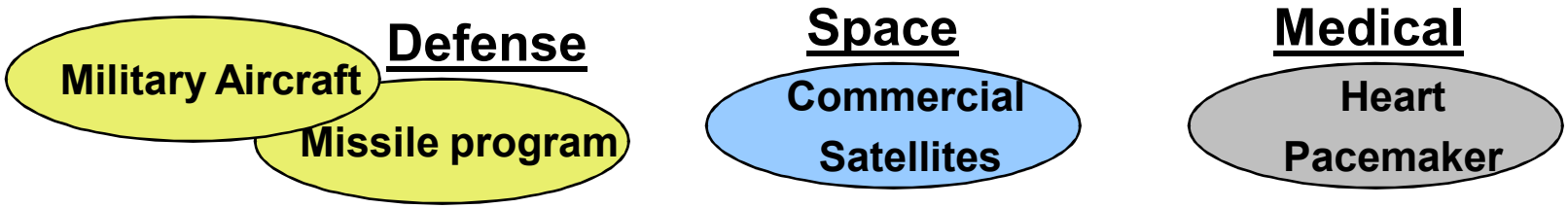
Whisker Problems
Purpose of Experiments

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

Tin whiskers are highly suspected in the costly failure of a number of electronic systems.



SNL has started an experimental test program to evaluate ways to mitigate tin whiskering

Purpose

Component engineers receive components with pure tin plating. Whisker growth and mitigation studies are performed on these components. 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 mitigate Tin Whiskers

- **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
- **Conformal Coating –** Protection barrier

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

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Conditions used in these Experiments to promote Whisker Growth

iNEMI Test Conditions

Temperature Cycling (TC)

- 40°C to 85°C 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 rooftop container at continuous ambient conditions at SNL
Whisker inspections performed at 4, 8, 12, 18, 24 months & 4 yrs. and continuous

Note: Parts not biased in tests

Parts tested both Loose (free sate) and Mounted (soldered to board)

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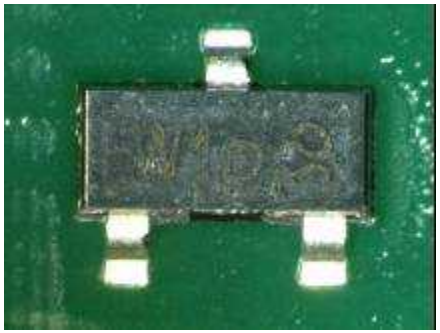
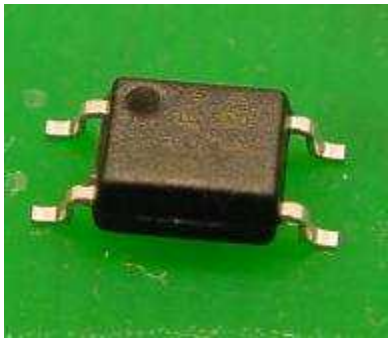
Parts Evaluated

Photos not to scale



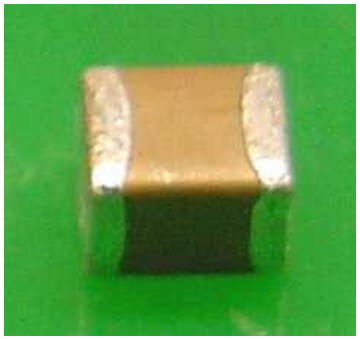
Transistor

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



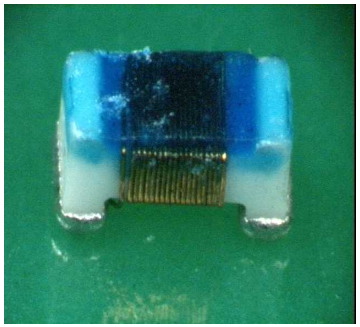
OPTO Coupler

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
1210 Chip Component with
5-sided Tin plated
Termination Ends with
middle Ni barrier and an interior Cu termination
Mitigation Methods
Solder Wicking
AEM Plating
Conformal Coating
HSD



Coil Inductor

Package size (mm)
= 1.6L x .80w x .80h
0603 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

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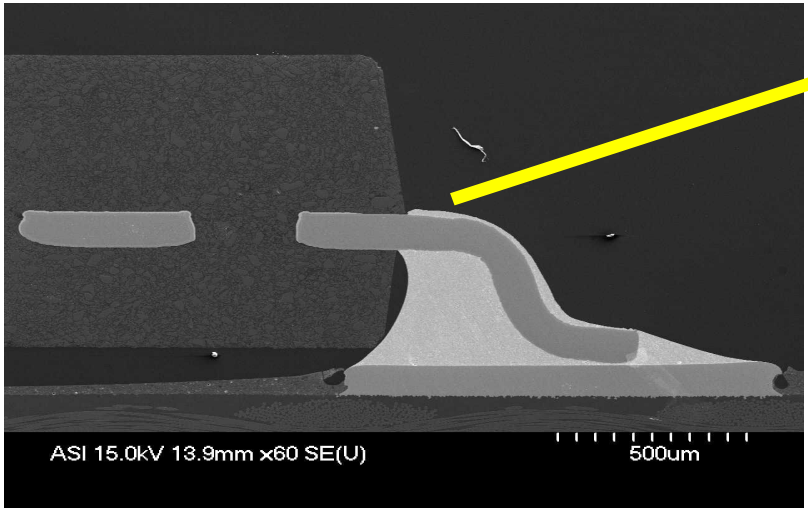
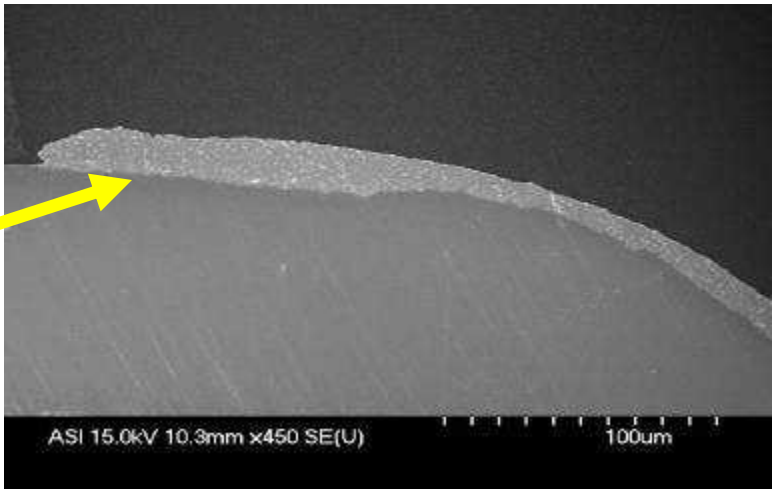
Tin Whisker Mitigation – Solder Wicking SOT23 Transistor

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

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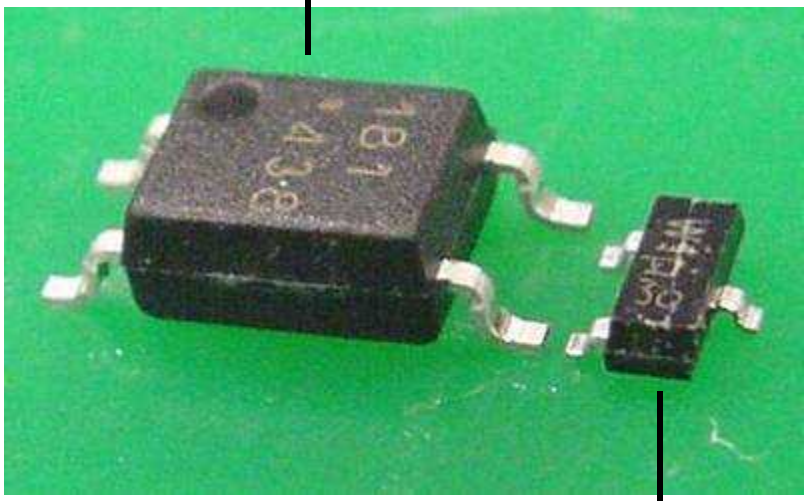
Tin Whisker Mitigation - Solder Wicking
SOT23/S04 Lead Comparison

SO4

HPCL-181

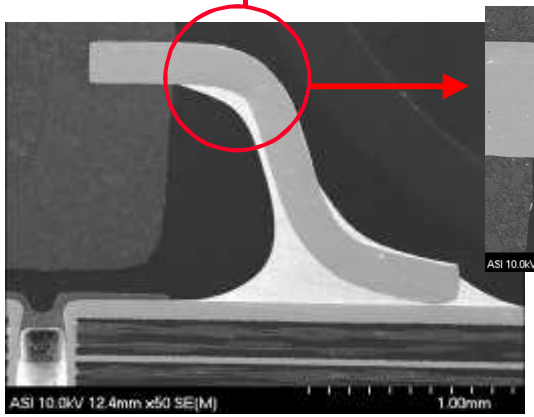
OPTO Switch

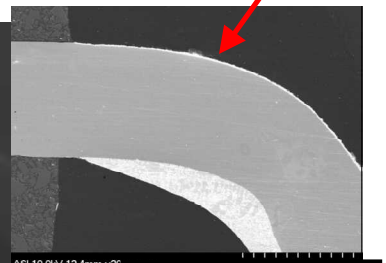
Approx. package size (mm) =
4.40L x 3.75w x 2.00h



7.45%Pb avg. on top
Max. = 9.6%
Min. = 5.1%

Larger/Longer
Lead still meets
3% Pb coverage



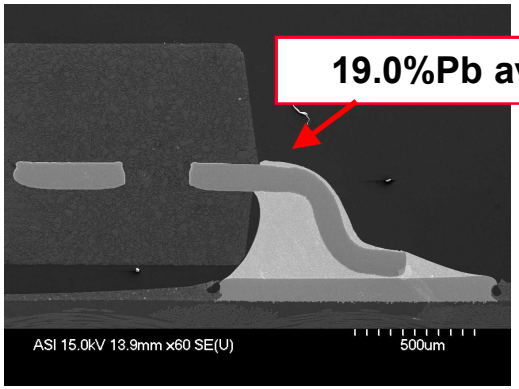


close-up
of top

SOT23

Transistor

Approx. package size (mm)
3.0L x 1.4w x 1.0h



19.0%Pb avg. on top

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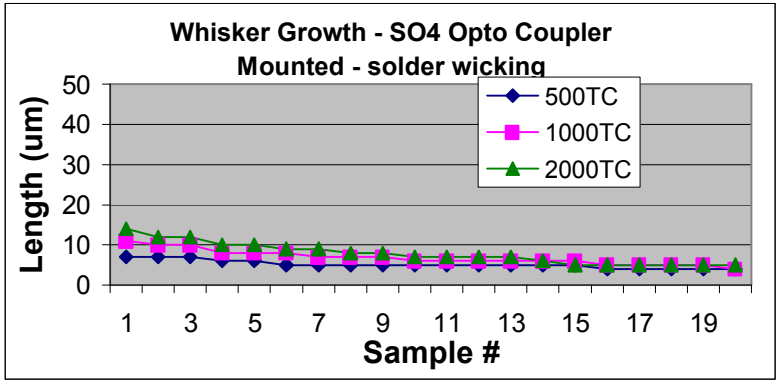
Results – Solder Wicking on SO4 & SOT23 After 2000 Temperature Cycles

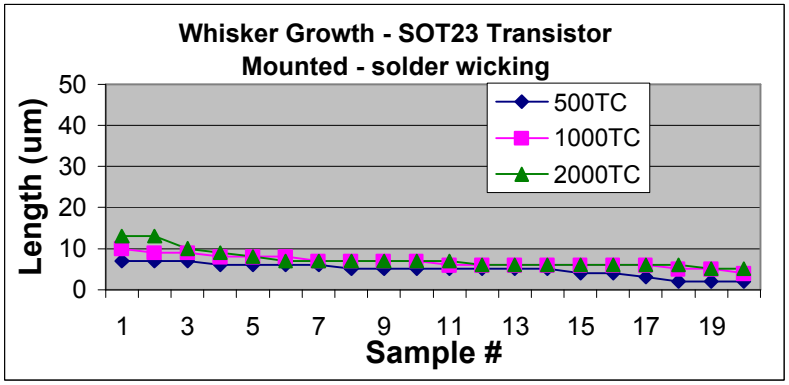
Parts exposed to Temperature Cycling using iNEMI Test Conditions (-40C/+80C, Dwell = 10 minutes)

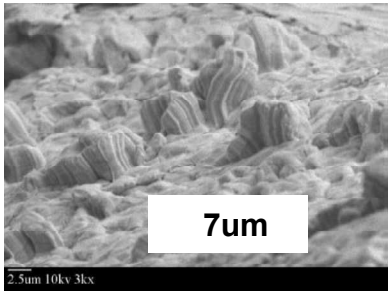
Summary of whisker growth for parts Mounted and exposed to 2000 Temp Cycles.

	Temp Cycles	# of Leads inspected	Longest whisker
SOT23 Transistor	500	20	7um
	1000	36	10um
	2000	30	13um

	Temp Cycles	# of Leads inspected	Longest whisker
SO4 OPTO Coupler	500	50	7um
	1000	72	11um
	2000	40	14um

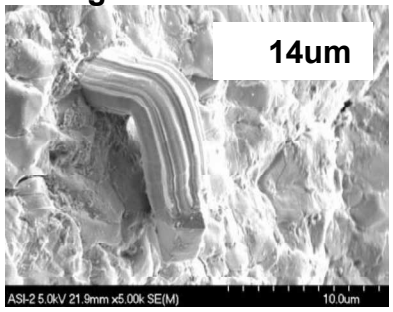






Typical whiskers found

Longest whisker found



Suggested maximum whisker length occurs at 1500TC. At 2000TC all growth is still in the "Stubble" stage. Risk level is very low

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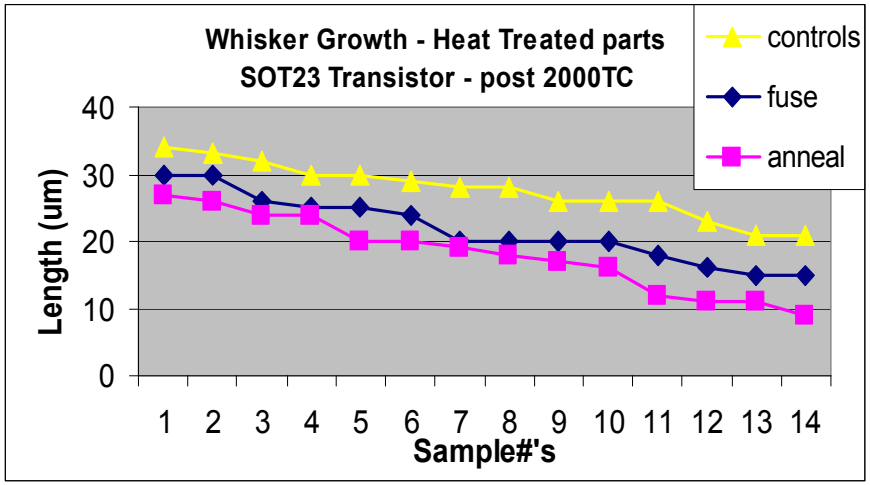
Heat Treat Results - Loose SOT23 Transistor After 2000 Temperature Cycles

Parts exposed to Temperature Cycling using iNEMI Test Conditions (-40C/+80C, Dwell = 10 minutes)										
Summary of whisker Growth for Loose parts exposed to 2000 Temp Cycles.										
		500 Temp Cycles			1000 Temp Cycles			2000 Temp Cycles		
Part 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
Loose	Fused	60	3	7um	40	40	25um	40	40	30um
Loose	Annealed	40	5	8um	40	40	27um	40	40	28um
Loose	Controls	40	40	22um	40	40	45um	40	40	35um



For leaded parts very minimal growth found at 500TC for the heat treated parts. Growth is more evident and defined at 1000TC.

Fusing and annealing have some effect on mitigating growth.

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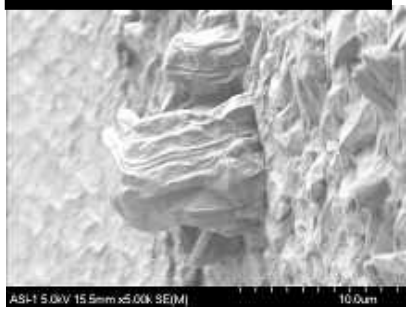
Results – Solder Wicking
SOT23 Transistor
1500 hrs. HAST

Loose Parts **HAST 1500 hours**

Controls – 15um

40 / 40 / 15um

Annealed – 10um



40 / 40 / 10um

Fused – 9um

13 / 40 / 9um

Longest whisker

# of leads with whiskers

# of leads inspected

Photos taken at 1500 hrs.

Solder wicking	Mounted Parts	HAST 1500 hours	
# of leads inspected	# of leads with whiskers	Longest whisker	No whisker growth found at 1500 hrs.
40	0	N/A	

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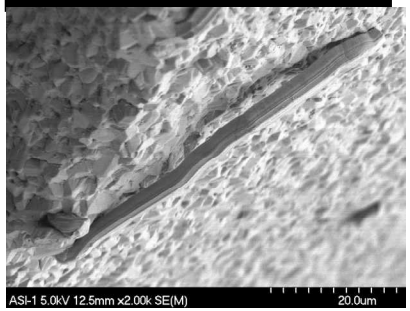
Results – Solder Wicking
SO4 OPTO Coupler
1500 Hrs. HAST

Loose Parts **HAST 1500 hours**

Controls – 63um	Annealed – 64um	Fused – 38um
		
40 / 40 / 63um	**40 / 40 / 64um**	**21 / 48 / 38um**

Longest whisker
# of leads with whiskers
# of leads inspected

Photos taken at 1500 hrs.

Solder wicking **Mounted Parts** **HAST 1500 hours**

# of leads inspected	# of leads with whiskers	Longest whisker	No whisker growth found at 1500 hrs.
40	0	N/A	

Solder wicking appears to be effective in eliminating tin whisker growth on the SO4 and SOT23 package under HAST conditions at 1500 hours.

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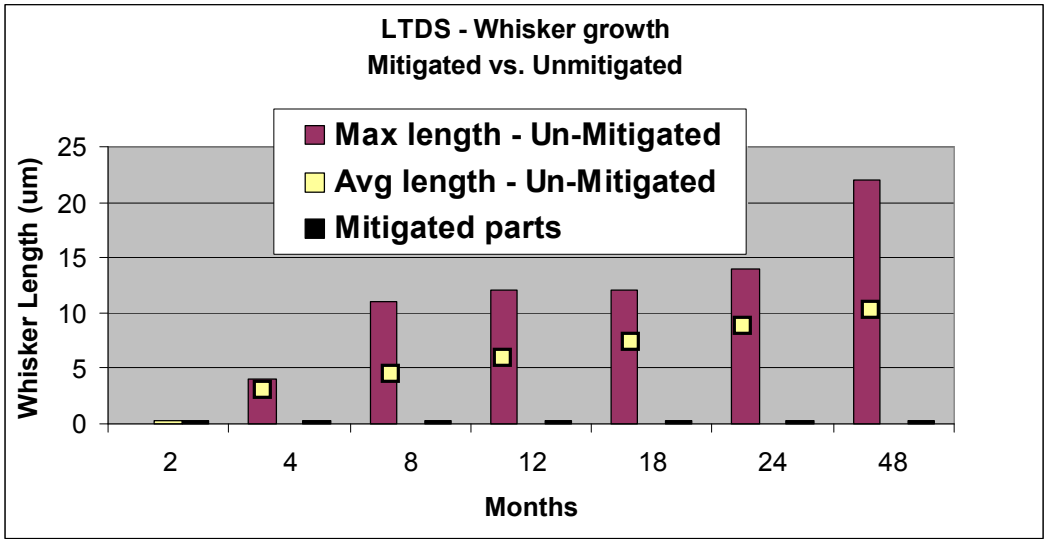
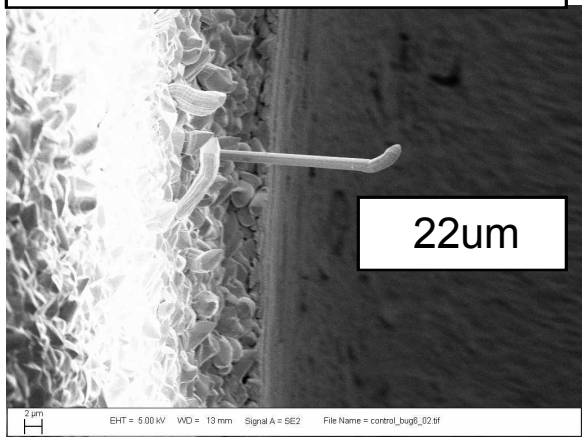
Results - SOT23 Transistor
48 months Long Term Dormant Storage
Solder Wicked Mitigated and Un-Mitigated Parts

Un-Mitigated Parts

SOT23 Transistor parts inspected for whisker growth at 2, 4, 8, 12, 18, 24 and 48 months.



Un-Mitigated at 48 months



Mitigated Solder Wicked Parts

@ 4 year inspection

Results – "No Whiskers".

Mitigated technique still valid after 4 years

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Results - SOT23 Transistors
Fusing (Loose) / Long Term Storage

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

Inspection at 8, 12, 18, 24 and 48 months:

220° C for 1 minute - WHISKERS! (5/5)

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

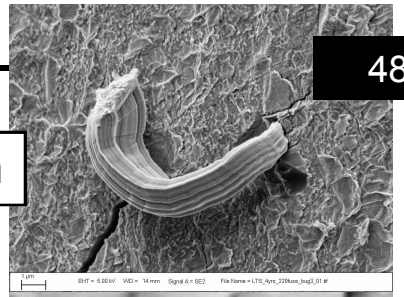
240° C for 1 minute - No Whiskers (0/5)

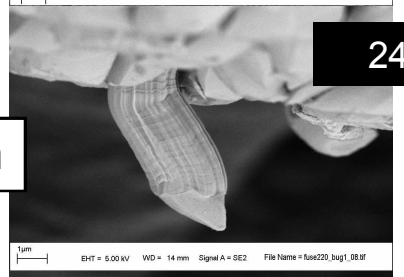
240° C for 30 minutes - No whiskers (0/5)

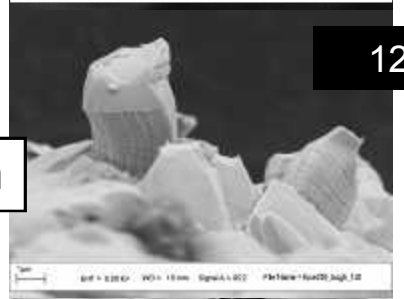
Minimal growth (5um-8um) noted on whiskers from 8 to 48 months for parts fused at 220° C – See photos

No whiskers found at 48 months on parts fused at 230° C or above.

Testing is on-going for Long Term Storage evaluation







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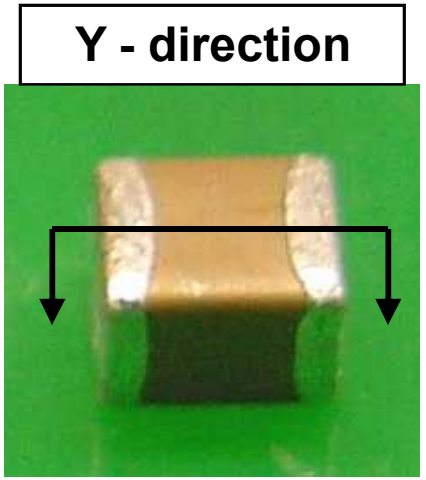
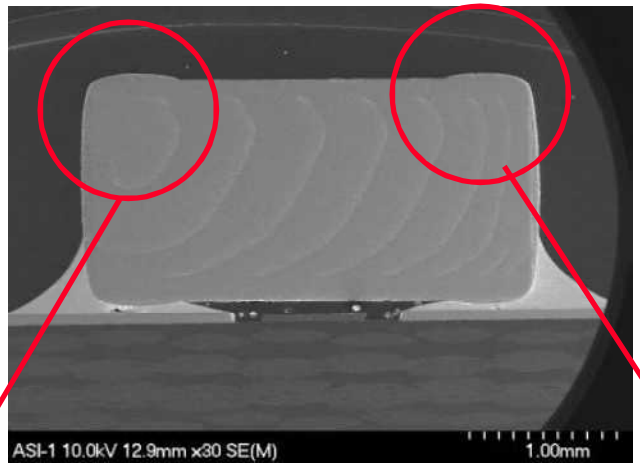
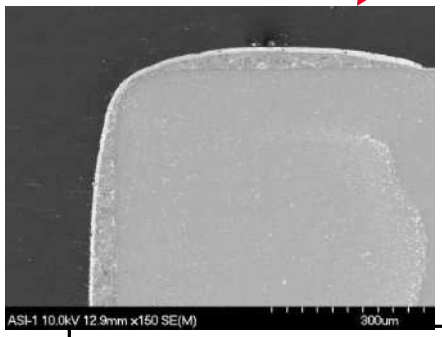
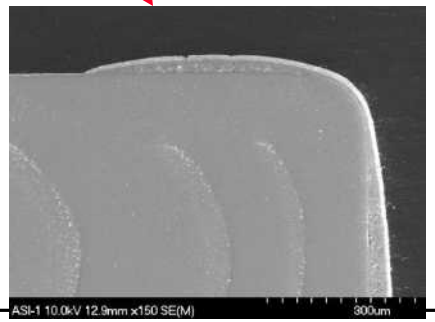
Tin Whisker Mitigation – 1210 Capacitor Solder Wicking on Termination Ends

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









Further close-up view on questionable corners.

EDS revealed 100% Sn still on top after soldering

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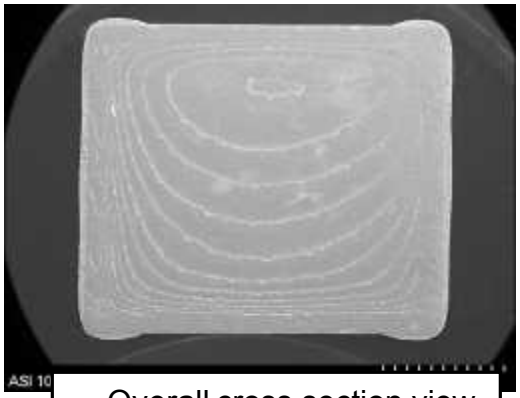
Tin Whisker Mitigation – 1210 Capacitors
AEM Plating

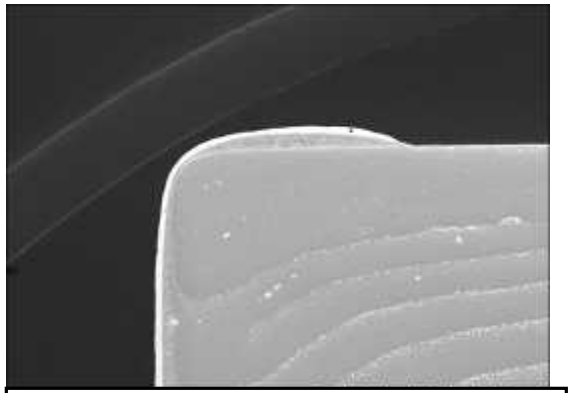
Cross-sectioned in two directions to assure complete solder coverage

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

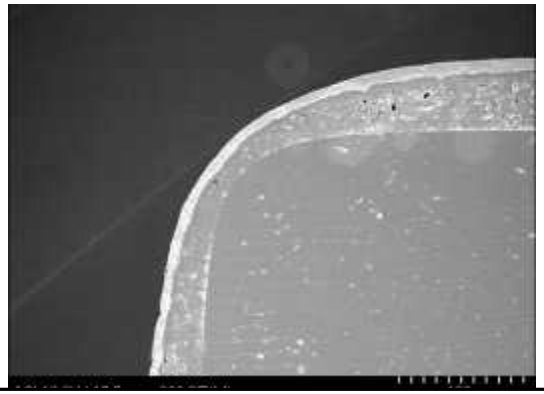
Overall cross section view in the Z-direction.



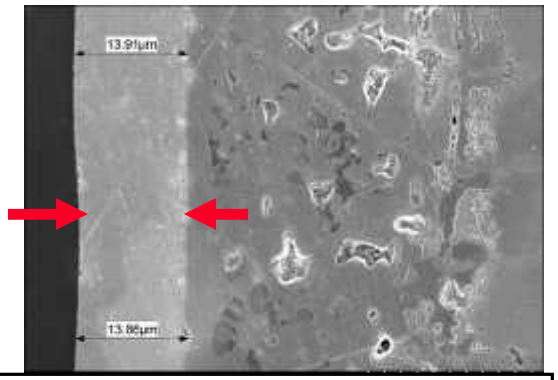
Overall cross section view in the Y-direction.



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

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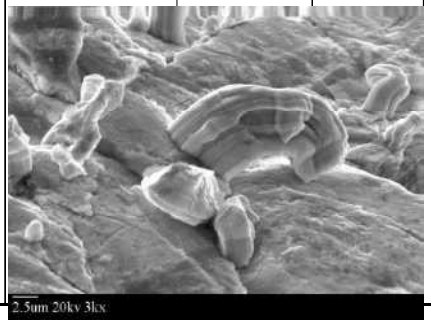
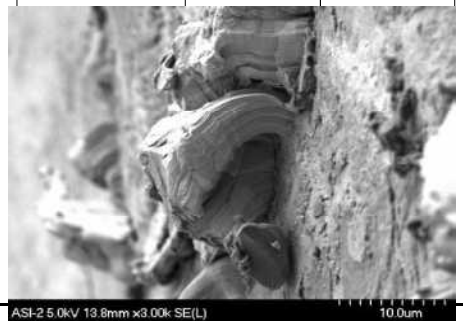
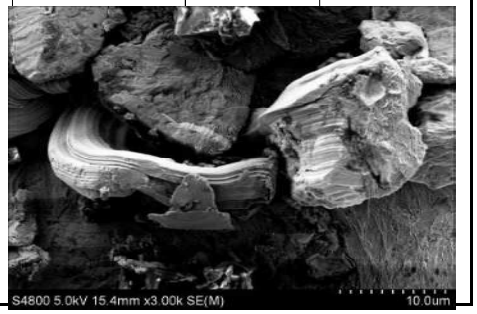
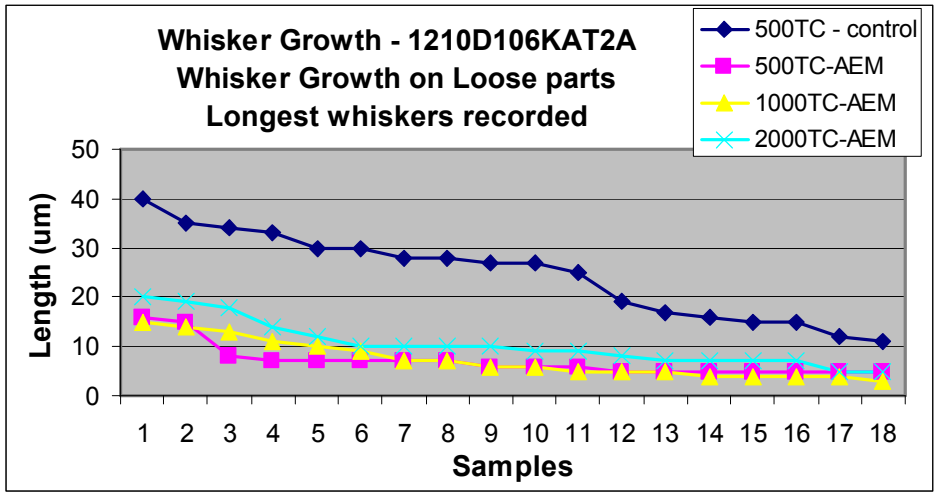
Results - AEM Plated Loose Capacitors After 2000 Temperature Cycles

		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	# of End Terminations inspected	# of Ends with whiskers	Longest whisker
Loose parts	12103D106 AEM Plated	20	20	16um	20	20	16um	40	40	20um









At 500TC the whisker growth is significant on the controls.

The AEM plating process stunts the growth at 500TC.

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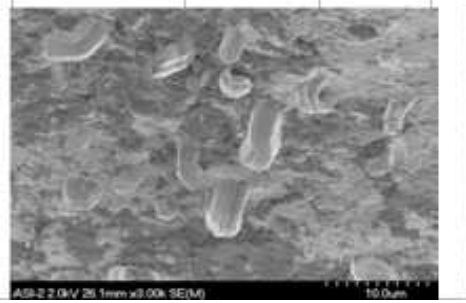
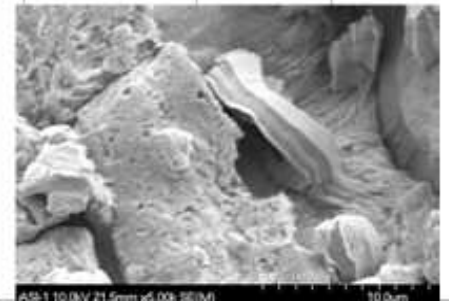
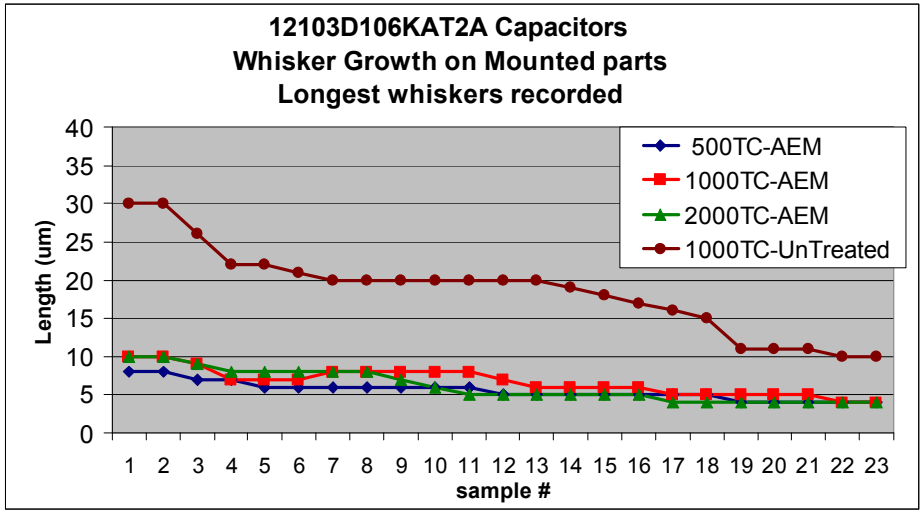
Results - AEM Plated Mounted Capacitors After 2000 Temperature Cycles

		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	# of End Terminations inspected	# of Ends with whiskers	Longest whisker
Mounted	12103D106 AEM Plated	30	30	8um	26	26	10um	20	20	10um







No additional growth after 500TC for AEM plated parts. All growth is still in the "Stubble" stage.

Very low risk level of whiskers growth using AEM plating

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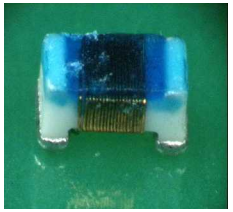
Results – Loose and Mounted Coil Inductor After 2000 Temperature Cycles



		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	10um

Very minimal growth regardless of test including controls

In all conditions growth still in the stubble stage

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Results of Chip Components Coil Inductor and Capacitor 1500 Hours HAST (Temp & Humidity)

Capacitor

Inspected 40 parts loose – AEM Plated parts - No whiskers found

Inspected 15 parts Mounted – AEM Plated parts - No whiskers found

Coil Inductor

<u>All Loose parts</u>

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 the two Chip Components with Termination Ends

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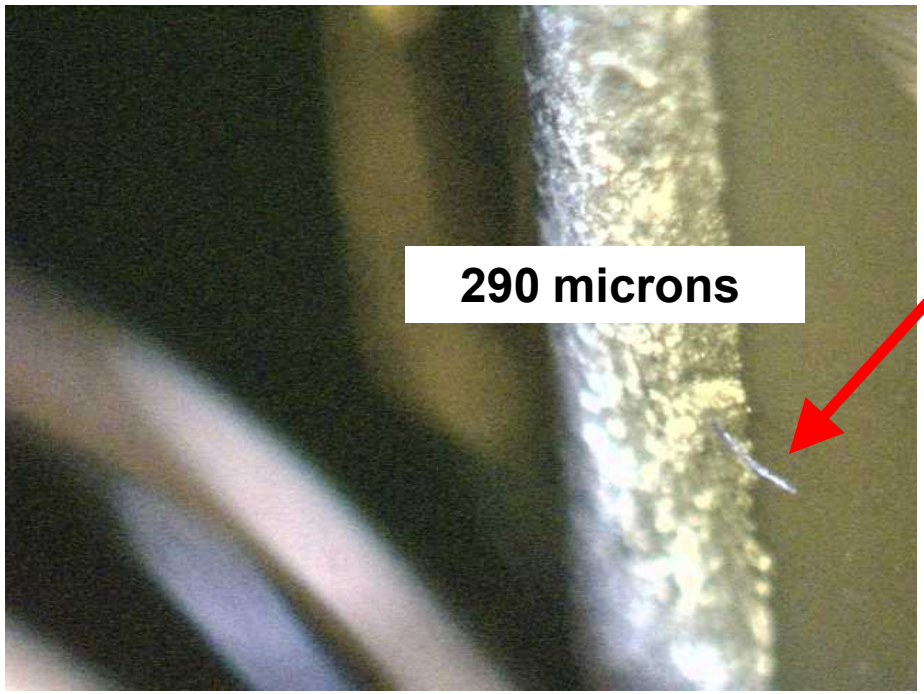
Conformal Coating – 1210 Capacitor Long Term Dormant Storage



- 2 year Long Term Dormant storage
- 1210 Capacitor soldered to board
- Conformal coated

  Removable coating

  Thickness of .01” to .03”

Component returned to storage site. Will look again in a year to see if it has grown.

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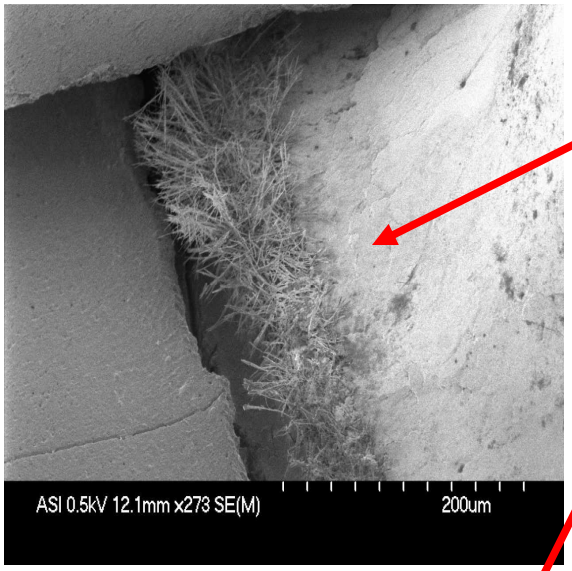
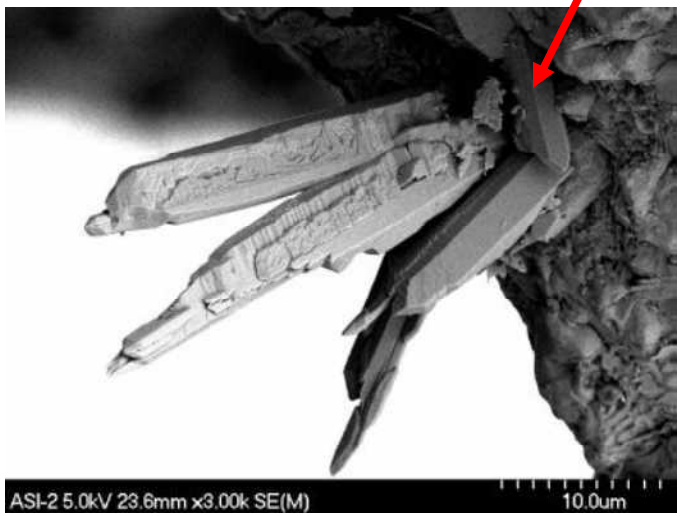
Other Growth Can Be Confused for Whiskers





Growth found at the base of the lead on SOT23. EDS indications suggests a copper mineral.

Other growth found on SO4. EDS analysis shows they contain Pb, S and O which suggest they are likely lead sulfate crystals.

<u>Note difference-whiskers exhibit</u>:

Low density

Uniformly spread – like a bed of nails

Long / straight – do not branch/cross

Striated texture

Note: Dendrites can also be mistaken as whiskers.

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Conclusion

From these experiments, Solder wicking from reflow is the most effective mitigation practice. Whisker growth, if any, stays in the stubble stage length exhibiting a low level of reliability risk.

Potential risk of system failure due to whisker growth varies from part to part. Factors: Sn thickness, base material, plating (Ni) barriers, termination type, plating inconsistencies and grain structure.

Other mitigation methods show potential Fusing, Annealing, Hot solder Dip and AEM plating.

Future Work

Will proceed to 4000 HAST Hrs. for all parts (loose and mounted) and re-inspect.

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