Tin Whiskering on PCBA Capacitors in Storage (Inside ESD Bag, Inside a Sealed Cardboard Box)

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ABSRACT

The tin whisker failures investigated in this paper were found on functional RoHS-compliant hardware. The samples were not conformal coated. This paper will document the conditions associated with the whisker formation under the following conditions; tin plated components, RoHS-compliant assembly, stored in an ESD bag (not sealed), placed inside a box (taped shut) with power from a 3.3 volt battery on components that are in direct contact with the ESD bag. We will address the issue of microenvironments responsible for the formation of tin whiskers.

Keywords: tin whiskers, ionic contamination, ion chromatography, localized cleanliness, residues, ESD bag, microenvironments and lead-free.

INTRODUCTION

The concerns of when will a conductive tin whisker form and how does it form are questions that the high reliability industry, military, and avionics manufacturers are still struggling with. This is well documented at NASA (http://nepp.nasa.gov/whisker/) and addressed weekly by the Tin Whisker Alert Group (an ad hoc collection of engineers and companies discussing and addressing the issues of tin whiskers). Military and industry consortium groups such as PERM are gathering data from iNEMI, IPC, JEDEC and IEC to look at the issues that deal with the RoHS-compliant soldering conditions and materials for lead-free manufacturing. The amount of time that has been allocated to understanding tin whiskers over the last 50 years is mind numbing, because of the time, money and brain power put into it with only minimal results with regards to control, predication and elimination.

Solderability or circuit cleanliness are definable and controllable properties with full understanding of the processing variables. Solderability of the PCB or component can be directly correlated to the amount of oxide on a properly-plated surface to form a good intermetallic and wetting of the pad, hole and lead surfaces to create the best joint. Cleanliness of electronics is similar to solderability due to the fact that the surface between two pads, holes, or traces is well defined in terms of circuit design performance. The unknown variables are the amount of porosity in mask and laminate, the amount of flux applied that spreads between the critical spaces, and the approach to processing (cleaning or no cleaning). With tin whiskers we know if we have lead in the alloy we do not get whiskers, we know that stress is a critical factor, but beyond that we do not know the other variables that can turn whisker formation on or off.

If we look at other whisker and crystal formations we find interesting issues. Copper sulfide corrosion (creep corrosion) requires the galvanic cell of silver and copper in a sulfur-rich microenvironment. This is the same with exposed copper and a sulfur cloud in a controlled environment. Zinc whiskers form in a stress condition with the presence of soapy water (high in chloride, sulfate and ammonium ions). But with each of these conditions, a microenvironment is present and required.

Microenvironment

The environment of a very small, specific area, distinguished from its immediate surroundings by such factors as the amount of incident light, the degree of moisture, and the range of temperatures. The side of a tree that is shaded from sunlight is a microenvironment that typically supports a somewhat different community of organisms than is found on the side that receives regular light. (Source: Wikipedia)

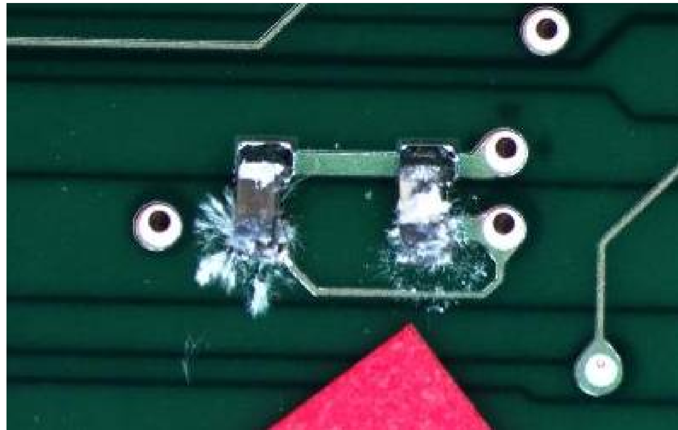


Figure 1 – Capacitors with tin whiskers growing on surface of tin plating.

CASE STUDY #1

Tin whiskers were found on a PCBA within an ESD bag, growing on the tin plated surface. The variables causing the microenvironment conditions were as follows:

1. Time – (Storage of the hardware) <3 months;
2. Temperature – +35-42°C;
3. Humidity inside ESD bag – Unknown, no desiccant present;
4. Location – Malaysia (standard storage facility);
5. Enclosure – ESD bag, not sealed, inside corrugated box with foam. Box sealed with tape;
6. Electrical conditions – Biased (caps only) with 3.3 volts;
7. Bare board finish – Immersion silver;
8. Assembly flux – 2-sided SMT/selective wave, no clean flux, soldering process with SAC 305 solder;
9. Conformal coating – no coating was present on the surface of the PCBA.

The subject PCBA experienced a large growth of whiskers in a short period of time – what, if any, residues were associated with the whisker growth?

The assembly was a no clean flux with RoHS compliant solder (SAC 305) and components on an immersion silver bare board - no visible whiskers were produced anywhere but on the capacitors on the bottom of the PCBA with a battery circuit.

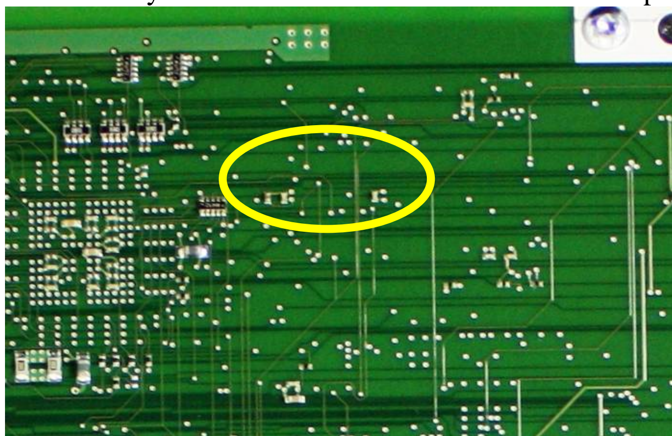


Figure 2 - Bottom side of PCBA (area of interest)

An interesting fact was that these three capacitors were inside the ESD bag inside a box with foam pressing the bag across the surface of the capacitors. This apparently caused a short circuit across the surface of the capacitors, causing the power side of the capacitor to heat up. This did not cause dendrite growth indicating that the moisture inside the bag was low.

Figure 3 – Capacitor #1 with tin whiskers on power input side

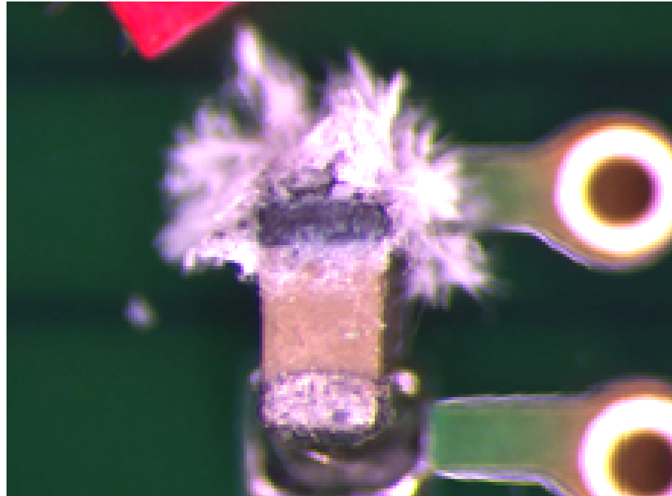


Figure 4 – Capacitor #2 with tin whiskers on input side only

The thermal image shows that with the three volts shorting across the component surface at a temperature of xx.x C was enough to soften and release the dissipative residues inside the ESD bag to create a localized chemical soup. This microenvironment around the capacitor created the conditions that accelerated the formation of the thousands of tin whiskers that formed - only on the power input side of the component. If the component would have been dirty from fabrication both sides of the exposed tin metallization would have reacted similarly. The photo above (Figure 4) shows one of the capacitors with all of the exposed tin consumed to form the whiskers.

Figure 4 shows only crystal formation on the impure side of capacitor #2. There was no visible corrosion on the vias of the immersion silver or on the output side metallization.

Figure 5 – Inside ESD bag surface above capacitor #2

Figure 6 – Inside ESD 1inch away from capacitor #2

Inside the ESD bag we see surface differences only above the direct contact points of the capacitor. It appears that the inside waxy chemical dissipation material was heated and cooled only over the capacitor.

Inside the same ESD bag 1 inch from capacitor #2 we see no evidence of melting or change to the surface of the ESD dissipative material.

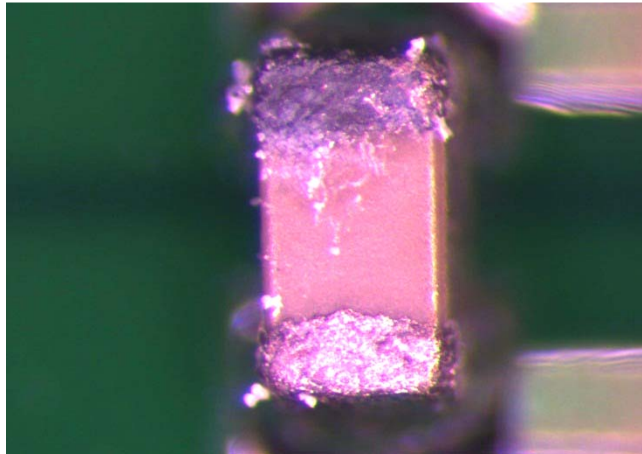


Figure 7 – Capacitor # 8 showing tin corrosion and small whiskers forming on surface

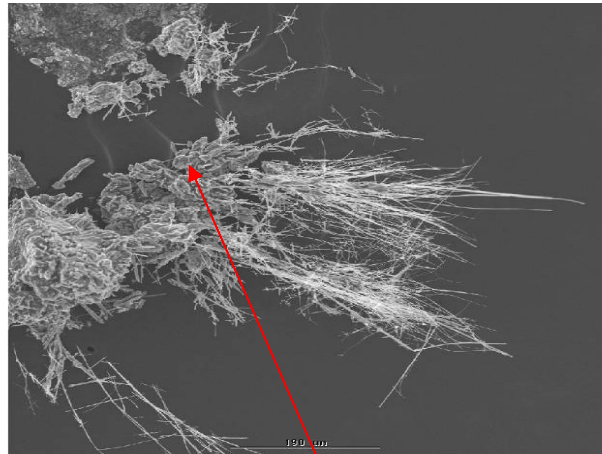
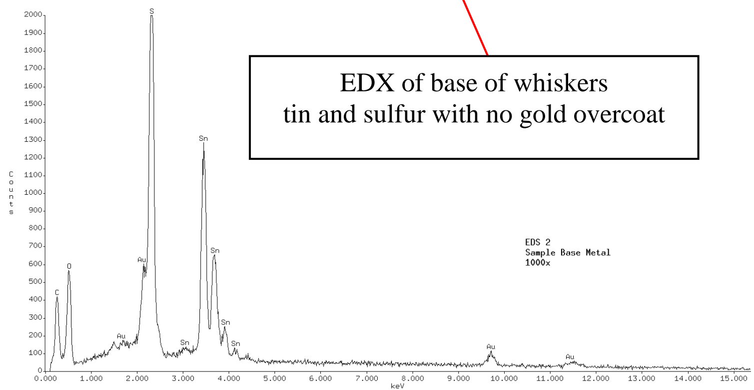


Figure 8 – SEM of whiskers removed from capacitor

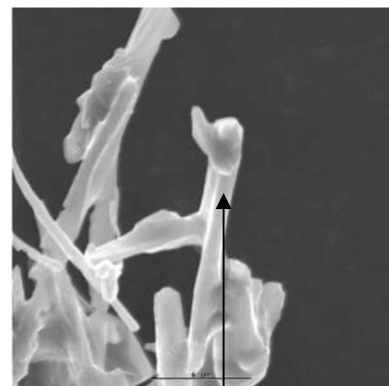


EDX of base of whiskers
tin and sulfur with no gold overcoat

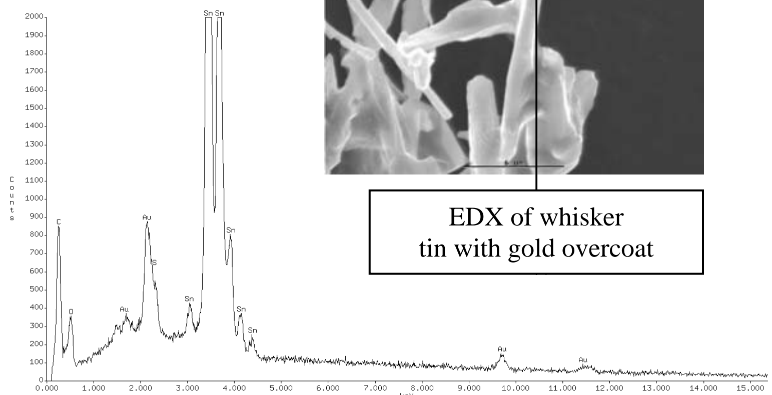
The image of the whisker shows the formation of the single crystal tin structure from the base of the tin plating.

To expound upon ionic cleanliness, it can be defined as a result, or signature, of the assembly process, materials and secondary processes required to create a finished assembly.

Ionic residue types and levels are the product of the assembly process; how these residues react pad to pad and hole to hole determines the quality of electrical performance. Through correlation analysis, it has been found that circuit board field performance, good or bad, is directly proportional to the specific amount of visible and invisible residues between pads and holes in all areas of active circuitry.



EDX of whisker
tin with gold overcoat



The whisker found on the capacitor growing from the corner of the capacitor where the stresses can be the highest grew to more than 5 mm long.

This is a group of tin whiskers that grew in three months – no other area of the entire assembly has any corrosion or tin whisker formations. The assemblies built at the same time, that were put into the field, show

no performance problems or signs of corrosion, tin whiskers or electrical leakage.

Figure 9 – SEM of whiskers removed from capacitor

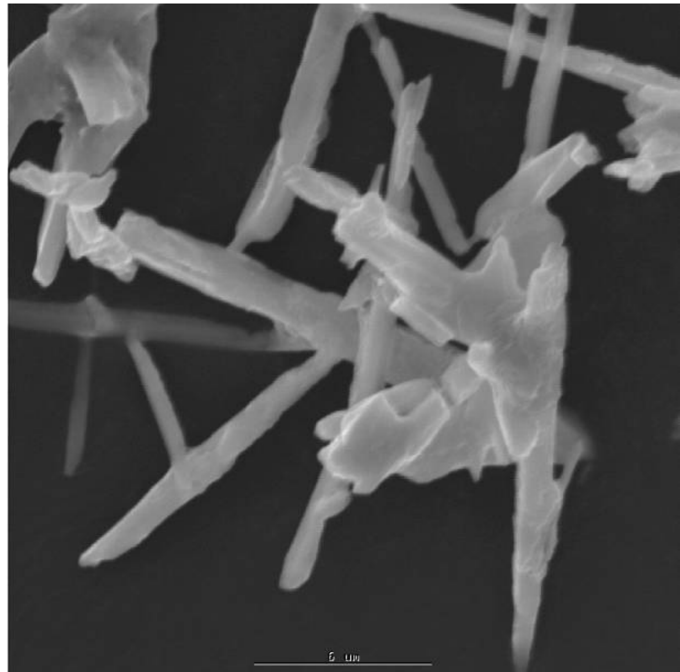
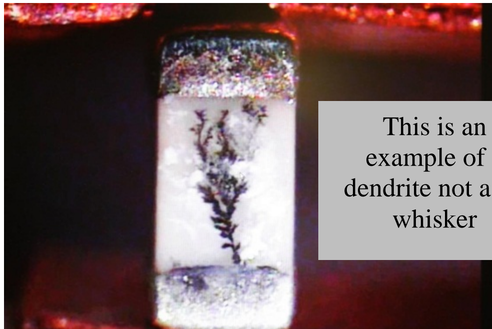


Figure 10 – SEM of whiskers removed from capacitor



The cleanliness of the microenvironment was determined using the C3 and Ion Chromatography with interesting results. As has been seen previously the surface cleanliness associated with specific areas creates the condition that is capable of corrosion, leakage and even whisker growth. The residues at a specific area can be extracted using controlled microbursts of DI steam.

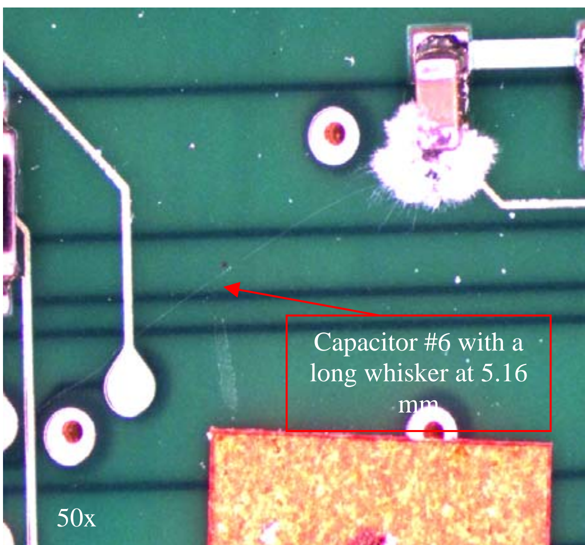


Figure 11 – SEM of whiskers removed from capacitor

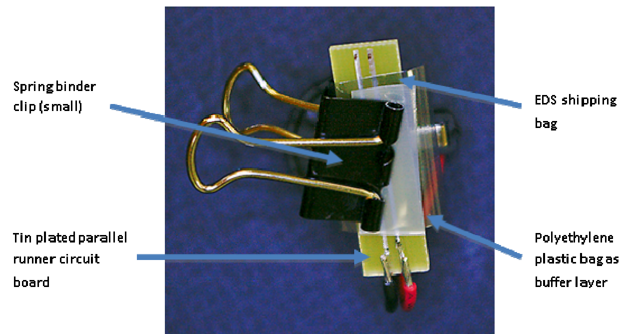
Figure 12 – C3 test system for localized extractions

The analysis areas of the assembly include the following areas;

3 assemblies with whisker growth

1. Capacitor area with whisker growth
2. Capacitor area without whisker growth - direct contact with ESD bag
3. Capacitor area without whisker growth - no direct ESD bag contact during storage
4. ESD bag above whisker growth
5. ESD bag - 1 inch away with no whisker growth

To isolate the areas of the circuit board and ESD bag we used the C3 extraction and test system to determine the specific area cleanliness and electrical effect on the test electrode in solution after the extraction. Due to the small area configuration of the 0402 components we choose the smaller C3 test cell (the extraction area is the size of an 0805 chip component) which extracts a 0.02 in^2 area of the board surface and has an extraction volume of 2.0 mls of extraction solution.

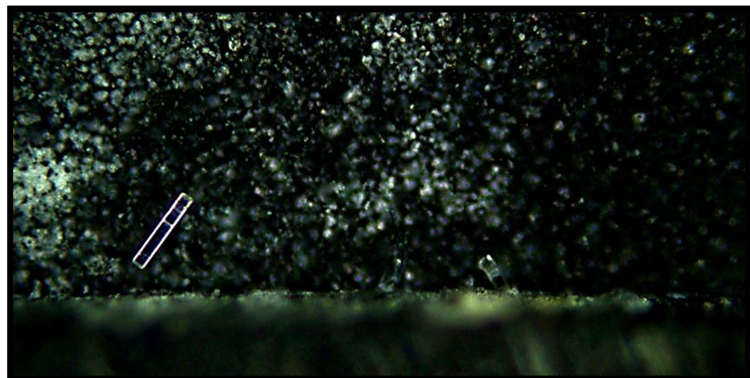


Results in the table below show high chloride, sulfate and ammonium by ion chromatography on the whiskered locations but not on the reference areas.

CONCLUSION

The whiskers that formed on the powered side of the capacitor were not the result of electro-migration, but localized heating of the capacitor power side, which released contaminants from the ESD-dissipative bag waxy surface. This contamination was the driving force of the formation of the tin whiskers. No other areas of the PCBA showed any sign of tin whiskers or creep corrosion (or even dendrite corrosion). The surface of the capacitor that grew the whiskers shows high chloride, sulfate, and ammonium which also were present inside the ESD bag (these are the dissipative elements inside the bag). The residues are not transferable to the board surface unless there is heating or steam extraction.

Under similar conditions, Foresite was able to grow tin whiskers on the surface of the tin plated electrode with the ESD bag and the 3.3 volt battery in a sealed bag in 5 days, which indicates that the mechanism is reproducible.



Foresite sample grown in 5 days at 1000x under ESD bag

	all values in µg/in2	C3 localized Extraction and Ion Chromatography				
Board #	**Location**	**Chloride**	**Sulfate**	**WOA**	**Sodium**	**Ammonium**
Brd #1	1. Cap with whiskers and ESD Bag	15.98	9.85	18.05	3.23	22.36
Brd #1	2. Cap without whiskers and ESD Bag	1.36	0.33	19.34	1.26	2.04
Brd #1	3. Cap without whiskers / no ESD Bag	1.59	0.54	18.47	2.05	1.69
Brd #1	4. ESD Bag above whiskered cap	44.84	17.95	0	0	36.96
Brd #1	5. ESD Bag 1 inch away from cap	41.05	16.36	0	0	51.27
Brd #2	1. Cap with whiskers and ESD Bag	18.95	8.04	15.24	1.69	16.11
Brd #2	2. Cap without whiskers and ESD Bag	1.05	0.61	16.94	2.66	1.25
Brd #2	3. Cap without whiskers / no ESD Bag	0.95	0.52	15.47	1.65	1.05
Brd #2	4. ESD Bag above whiskered cap	29.44	12.33	0	0	22.96
Brd #2	5. ESD Bag 1 inch away from cap	31.05	14.26	0	0	35.05
Brd #3	1. Cap with whiskers and ESD Bag	16.69	8.24	16.55	2.36	9.65
Brd #3	2. Cap without whiskers and ESD Bag	1.14	1.22	17.41	2.15	1.69
Brd #3	3. Cap without whiskers / no ESD Bag	1.62	1.06	16.53	2.63	1.52
Brd #3	4. ESD Bag above whiskered cap	35.98	15.36	0	0	16.96
Brd #3	5. ESD Bag 1 inch away from cap	38.54	16.27	0	0	21.25