Tin Whisker Observations on Pure Tin-Plated Ceramic Chip Capacitors

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Tin whiskers pose a risk of intermittent short circuits in terrestrial applications and potentially catastrophic metal vapor arcs in space (vacuum) environments. Research on whiskering and mitigation practices has historically produced highly variable results. These variations and recurring observations of whisker-induced failures are central to the high reliability community's reluctance to adopt lead-free finish alternatives, especially pure tin, until clear evidence exists that the factors affecting whisker growth are understood and can be controlled. This paper highlights the variability of previous claims using recent observations of greater than 200-µm-long whiskers on pure tin-plated ceramic chip capacitors as a classic example of the confounding nature of this phenomenon.

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Introduction

Electroplated tin (Sn) and tin alloy finishes are used extensively in the electronic components industry to enhance solderability and corrosion resistance of electrical conductors made from metals such as copper, phosphor bronze and alloy 42 (iron-nickel alloy). Additional benefits of tin finishes include excellent control and uniformity of plating thickness (especially critical in miniaturized, fine-pitched components), good electrical conductivity, and non-toxicity[1]. "Bright" finishes (those using organic additives in the plating bath to produce fine grain finishes) are also commonly used because they maintain an aesthetically pleasing shiny surface. For all of these purposes, a wide assortment of pure tin and tin-lead (2% to 50% Pb) based electroplated finishes have been used with much success[2]. Since the mid-1990's, the United States (U.S.) military and other high reliability users have preferred tin-lead based finishes (minimum 3% Pb) over pure tin due to documented failures resulting from whisker growths on tin-plated components. These failures will be briefly described later.

Legislative pressures in recent years (particularly in Japan and Europe) have pushed the electronics industry to consider methods of eliminating Pb from their products and manufacturing processes[3]. Generally speaking, these rules are being developed in response to potential environmental and health hazards that may result from the manufacturing and disposal of consumer products bearing Pb and other hazardous materials. Although the U.S. is lagging Japan and Europe in introducing similar legislative restrictions, changes made by the U.S. Environmental Protection Agency (EPA) in 2001 now require industries to formally report any manufacture, use and/or disposal of Pb or Pb compounds in excess of 100 pounds per year[4]. Previously, the EPA reporting limit was as high as 25,000 pounds per year. These EPA rule changes and the desire to remain competitive in a world economy have prompted many U.S. electronic component manufacturers to explore alternatives to tin-lead based plating systems.

Recently, significant attention has been given to pure tin plating (especially “matte” finishes) as a candidate to replace widely used tin-lead finishes. With several factors in its favor, such as ease of converting existing tin-lead plating systems, ease of manufacture and compatibility with existing assembly methods, in addition to years of successful commercial use, pure tin plating is seen by many in the industry as a potentially simple and cost effective alternative[5].

Despite the benefits, there remains one major impediment to the simple adoption of pure tin for use in high reliability applications: *many pure tin electroplates develop potentially damaging growths known as tin whiskers.* Assured methods for predicting if or when such growths may occur do not currently exist.

Hazards of Tin Whiskers

Figure 1 shows examples of tin whiskers on various types of pure tin-plated electronic components. As the name implies, tin whiskers are hair-like growths of near-perfect single-crystalline structures of tin that grow outward from some electroplated tin surfaces. Typical tin whiskers have diameters of only a few microns (µm) and have been reported to grow to lengths of several millimeters (mm), though lengths of less than 1-mm are typically reported[1,6,7]. Their tiny dimensions make them extremely difficult to see unless proper illumination and/or high power inspection techniques are used such as scanning electron microscopy (SEM). In addition, troubleshooting of system problems may sometimes obscure whiskers as the root cause of failure if handling or probing is used which results in removal of the offending whisker.

Predicting if or when a particular tin-plated product will form whiskers has perplexed researchers and users alike for decades. Perhaps the most insidious traits of tin whiskers are the seemingly unpredictable nature of their growth initiation and subsequent growth rate. Although several researchers have reported whisker incubation periods as short as a few days from the time of electroplating, others have documented incubation periods that have lasted many years[8,9]. Growth rates as high as 9mm/year have been reported, but slower rates are much more common[10]. These attributes of whisker growth are particularly challenging because of the lengthy experiments (years) needed to establish meaningful results. Formally accepted test methods (environments) to accelerate whisker growth have not been established. Various industry groups in the U.S., Japan and Europe are presently working to develop such effective screening practices[11].

The primary concern with tin whiskers is that they are electrically conductive and can lead to short circuits in electronic assemblies. It is tempting to expect these tiny conductive filaments will fuse open at the instant they grow long enough to cause a short creating perhaps an unnoticeable "glitch" to the circuit performance. However, documented experiences have shown tin whisker failures also include permanent low current (few milliamps or less) shorts as well as catastrophic metal vapor arcs in vacuum capable of sustaining HUNDREDS of AMPERES[12]. Table 1 categorizes the common failure modes attributed to tin whiskers while table 2 lists some notable examples of tin whisker induced failures in medical, military and space applications.

In previous work performed at the NASA Goddard Space Flight Center (GSFC), it has been demonstrated that tin whiskers (especially the longer, filament types) will bend in response to forces of electrostatic attraction (see Figure 2)[13]. Therefore, a tin whisker growing from a surface at one electrical potential will be attracted towards an adjacent conductor with a different potential. This behavior is highlighted to show that the probability of a tin whisker shorting event is greater than a "random" occurrence dependent solely on the whisker's direction of growth.

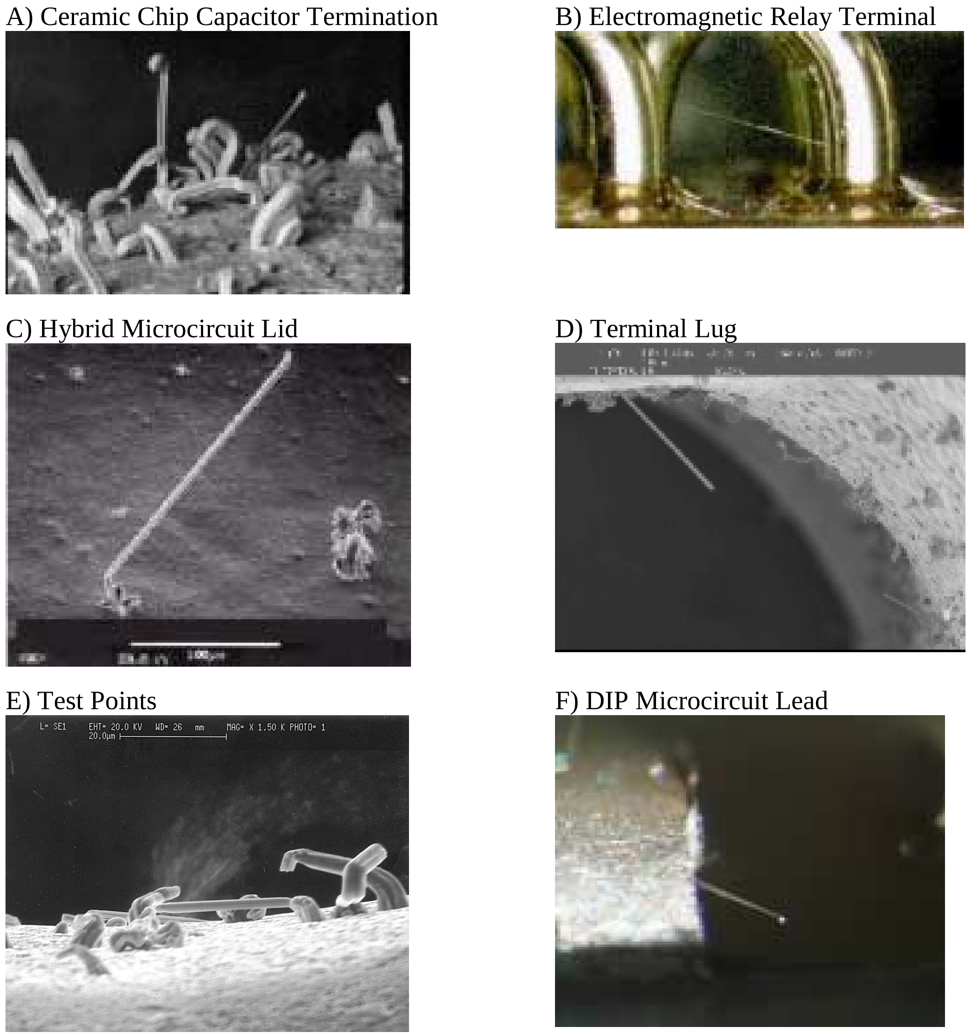

Figure 1: Examples of Electronic Components with Tin Whiskers (All are Pure Tin-Plated)

Table 1: Equipment Failure Modes Induced by Tin Whiskers

Failure Mode	Description
Permanent Short Circuits	In low voltage, high impedance circuits there may be insufficient current available to fuse the whisker open. Fusing currents between 30 mA and 75 mA have been reported[8, 24].
Transient Short Circuits	If the available current exceeds the fusing current of the whisker, the circuit may only experience a transient glitch as the whisker fuses open.
Metal Vapor (Plasma) Arcing In Vacuum[12]	In vacuum (reduced atmospheric pressure) a much more destructive short circuit phenomenon can occur. If currents of above a few amps are available and the supply voltage is above approximately 18V, the whisker may vaporize creating a plasma of tin ions that can conduct **Hundreds of Amperes**. An adequate supply of tin from the surrounding plated surface can help to sustain the arc until the available tin is consumed or the supply current is interrupted such as occurs when a protective fuse or circuit breaker interrupts the current flow.
Debris/Contamination	Mechanical shock, vibration or handling may cause whiskers to break loose from the plated surface. Once free to move about, these conductive particles may then interfere with sensitive optical surfaces or the movement of microelectromechanical systems (MEMS). This debris may also lead to short circuits as noted above[25].

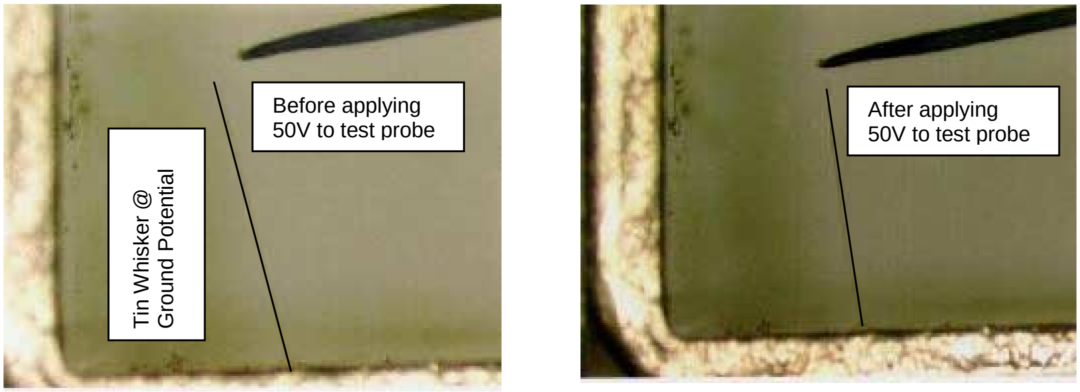

Figure 2. Tin Whisker "Bending" in Response to Electrostatic Attraction.
(Note: Photo has Been Enhanced to Aid in Observation of the Tin Whisker which is Difficult to See in this Optical Photograph)

Table 2: Reported Field Problems Induced by Tin Whiskers

Application	**Problem**
	Medical
Heart Pacemaker[26]	Class I Product Recall: Tin whisker shorts from pure tin-plated housing of crystal causes complete loss of pacemaker output.
	Military
F-15 Radar[25]	Tin whisker from pure tin-plated hybrid microcircuit lids.
U.S. Missile Program[27]	Tin whisker from pure tin-plated relays
U.S. Missile Program[28,29]	Tin whisker growing from pure tin-plated TO-3 transistor can shorts collector to case.
Phoenix Air to Air Missile[30]	Tin whisker shorts inside hybrid microcircuit.
Patriot Missile II[31]	Tin whiskers from pure tin-plated terminals
	Space (Satellite)
GALAXY IV[32,33]	Complete loss of satellite operations. Tin whisker short (metal vapor arc in vacuum) from pure tin-plated relays
GALAXY VII[33]	Complete loss of satellite operations. Tin whisker short (metal vapor arc in vacuum) from pure tin-plated relays
SOLIDARIDAD I[33]	Complete loss of satellite operations. Tin whisker short (metal vapor arc in vacuum) from pure tin-plated relays
Additional Satellites[32,33]	Three additional satellites of the same general design as above have lost one of two redundant satellite control processors due to tin whisker shorts

Compressive Stress Theory of Whisker Growth

Although tin whiskers were first reported in the 1940's [14], researchers still have not reached consensus to explain the mechanism(s) that drives whisker formation. However, most experts concur that whisker formation is the result of a mechanical stress-relief process. More precisely, it has been postulated that the development of "compressive" stress in the tin layer provides the fundamental driving force for whisker growth[2,15,16]. The following factors have been cited in the literature as potential contributors to compressive stress in the tin layer[17]:

- Substrate Element Diffusion (e.g., copper, zinc) into Tin Layer
- Intermetallic Compound (IMC) Formation between Tin and Substrate (e.g., Cu_6Sn_5)
- Plating Chemistry (e.g., Organic additives termed "brighteners" may increase the "as-plated" residual stress)
- Plating Process Parameters (e.g., higher current density may produce high residual stress)
- Contamination (organic and inorganic)
- Substrate Stress (e.g., stamping, cold working, swaging)
- Environmental Stresses (temperature, humidity)
- Externally Applied Mechanical Stress (e.g., torquing of a fastener, scratches from handling)

Lee and Lee[15] have described one plausible model for whisker growth that is heavily reliant upon the processes of diffusion and intermetallic compound (IMC) formation occurring between the tin layer and the underlying substrate. In this model atoms with high diffusivity in tin (e.g., copper or zinc) migrate from the substrate material (phosphor bronze in their study) into the tin layer preferentially along the tin grain boundaries. The diffusing elements and the resulting IMCs (e.g., Cu_6Sn_5) occupy space within the tin crystallographic structure producing a resultant compressive stress in the tin layer. As the stress increases with time, the thin, brittle tin oxide layer that forms over the electroplated tin can rupture. Once the oxide layer has ruptured, tin grains (whiskers) may then be extruded in a continuous fashion through the oxide layer as a means of relaxing compressive stresses. As growth proceeds, the localized compressive stress tends to reduce until the stress level is no longer sufficient to support further growth (equilibrium).

Based upon "compressive" stress theories such as this one, the majority of whisker mitigation practices being explored today involve attempts to minimize or eliminate those factors which encourage the development of compressive stresses within the tin electroplate. Multilayer ceramic capacitors (MLCCs) are one example of tin-plated components where whisker mitigation practices used in their manufacture have been studied and reported.

Multilayer Ceramic Capacitor Construction

Today, MLCCs are utilized in almost every electronics application. Annual production of MLCCs exceeds several billion capacitors worldwide. MLCCs come in a wide range of capacitance/voltage ratings and package configurations (leaded and surface mount). Surface mount chip MLCCs are by far the most popular package configuration and are currently available with footprints as small as 0.5-mm x 0.25-mm (0.02-in. x 0.01-in.). Figure 3 illustrates the typical construction of a ceramic chip capacitor designed for installation by soldering methods.

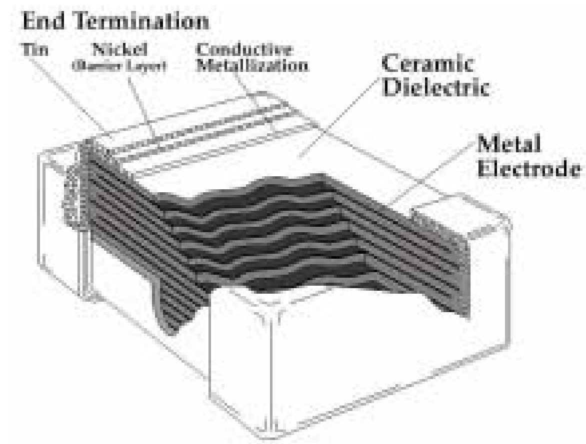

Figure 3. Typical Cutaway View of a Tin-Plated Multilayer Ceramic Chip Capacitor (Kemet Electronics Corp Data Sheet)

The capacitor element consists of layers of a ceramic-based dielectric material (e.g., barium titanate) with metal electrodes (e.g., palladium-silver [Pd-Ag]) interleaved. The ceramic-electrode structure is sintered at high temperature to form a homogenous block. Conductive terminations are applied to the ends of this ceramic block to provide electrical contact points for this surface mountable device. The end termination structure typically consists of three distinct layers as follows:

1. ***Silver Frit:*** Silver paste (with some glass frit mixed in) fired onto the ceramic to make electrical connection to the electrode layers. The glass facilitates mechanical adhesion to the ceramic.
2. ***Nickel:*** Typically electroplated ~5-µm thick applied over the silver frit to minimize diffusion of silver into the final solderable finish.
3. ***Tin or Tin-Lead Alloy:*** Typically electroplated ~5-µm to 10-µm thick over the nickel barrier layer to provide a solderable final finish.

Note: For wire bonding or conductive adhesive (e.g., silver epoxy) attachment applications, MLCCs with gold or Pd-Ag final finishes are also available instead of tin or tin-lead.

Previous Whisker Research on MLCCs

In the vast research conducted to date on tin whiskers, there are only a few studies that directly discuss tin whisker growth in passive electronic components such as MLCCs[18-21]. These papers generally proclaim MLCCs to be immune to tin whisker formation based on a number of characteristics of the MLCC termination structure. Selcuker[18] and Endo[19] have categorized the following attributes of the typical MLCC construction and manufacturing processes as factors that reduce their propensity to form whiskers:

1. "Large" (>5-µm) and well-polygonized tin grain structure
2. "Thick" tin-plated layer (~5 - 10-µm)
3. Electroplated Nickel barrier layer (at least 2-µm thick) limits silver diffusion into tin and itself has very low diffusivity into tin.
4. Post-electroplate annealing processes help reduce residual stress in the tin layer and stimulate tin grain growth

Recent research employing pure tin finishes over nickel barrier layers over copper substrates has postulated that the nickel layer may also impart a "tensile" (rather than a compressive) stress to the tin layer[22]. If this is true, then theoretically such tensile stresses tend to discourage whisker extrusion.

In 1997 Endo[19] reported 18 years worth of whisker-free observation of MLCCs stored continuously at 50°C. This storage condition was chosen because of previous whisker research citing 50°C as the optimal temperature for whisker formation to occur.

In 2001, the author of this present work surveyed five major domestic manufacturers of MLCCs to solicit their experience with tin whiskers[23]. All of those surveyed indicated they knew of no formal reports of tin whiskers on any of their MLCC products.

Recent Experimental Observations of Tin Whiskers on MLCCs after Temperature Cycling

To illustrate the confounding nature of the tin whisker phenomenon, several recent examples of profuse tin whisker formation (some approaching 250-µm long) on pure tin-plated MLCCs (Figure 4) are described. The construction of these MLCCs is typical of the MLCC manufacturing industry and is comparable to MLCCs previously studied. Despite having most of the "whisker reducing" attributes described in previous studies[18,19], it will be shown that these capacitors formed tin whiskers when exposed to environmental test conditions different from those used in prior research.

Figure 4. Pure Tin-Plated MLCC from Manufacturer "A" with Tin Whiskers (Max. Whisker Length ~100-µm in this Image)

The following examples of tin whiskers on pure tin-plated MLCCs were collected from formal and informal exchanges of information with Original electronic Equipment Manufacturers (OEMs) who reported their observations to engineers at the NASA Goddard Space Flight Center (GSFC). As noted, some of the work has been augmented by examination at GSFC and independent experiments performed by The Aerospace Corporation[17] to confirm the effects of environment reported by other researchers. In all cases, these examples are presented with due concern for the confidentiality of the OEMs involved.

Example #1: Pure Tin-Plated MLCCs from Manufacturer "A" in Hybrid Microcircuit

In 2000 an OEM ordered Pd-Ag terminated MLCCs from a major manufacturer (Manufacturer "A"). The MLCC manufacturer mistakenly supplied pure tin-plated capacitors due to a logistical error. The OEM's intent was to mount Pd-Ag terminated MLCCs onto gold plated mounting pads of a substrate inside a hermetically sealed hybrid microcircuit. The OEM's mounting process employs a widely used silver-loaded conductive epoxy to accomplish the bond between the substrate pads and the MLCC terminations (Figure 5). Once assembled, the hybrids are hermetically sealed in a Nitrogen atmosphere. These assembly practices are commonly used in the manufacture of complex hybrid modules. However, the use of pure tin MLCCs with conductive epoxy is not a recommended practice due to potential mechanical and electrical integrity concerns when bonding epoxies to tin or tin-lead.

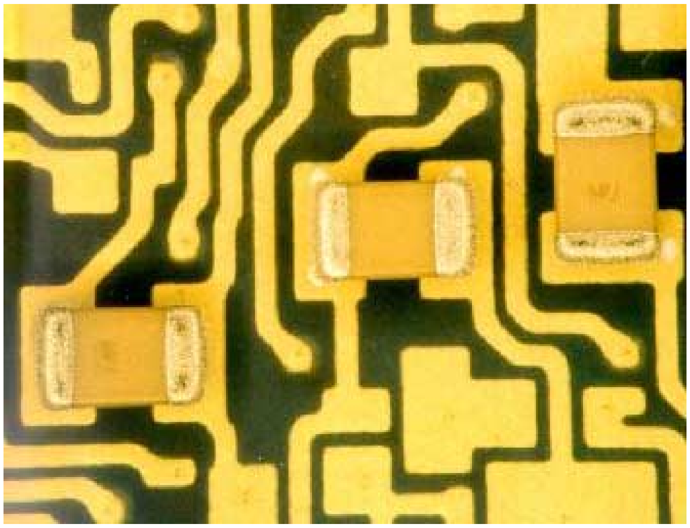

Figure 5: Optical View of Hybrid Package Substrate with Epoxy Mounted Pure Tin-Plated MLCCs (MLCC dimensions 2.03 mm x 1.27 mm)

Example #1: Description of Experiment

In the present example, the OEM was fortunate to catch the MLCC manufacturer's mistaken shipment of pure tin prior to issuing the MLCCs to the production floor. Rather than return the erroneous shipment for replacement, the OEM opted to conduct an evaluation to determine if the pure tin MLCCs may still meet the performance requirements of their application even when mounted using conductive epoxy. Therefore, the OEM manufactured and sealed several representative hybrid packages utilizing the pure tin-plated MLCCs and conductive epoxy mounting methods as described above. The hybrids were divided into two groups for the following environmental test conditions designed to evaluate the electrical and mechanical integrity of this bonding technique:

Condition 1: Thermal Cycle
-40°C to +90°C up to 500 cycles

Condition 2: High Temperature Storage
+90°C for 400 hours

The OEM removed representative hybrid packages from test at discrete intervals of time for inspection. The inspection test protocol consisted of delidding the hybrid to enable optical and scanning electron microscope (SEM) inspection of the capacitors, electrical conductivity measurements of the epoxy joints and mechanical strength measurements of the bond via die shear testing.

Example #1: Experimental Results

One representative hybrid package was removed from test Condition 1 (temperature cycling) after 300+ cycles. During visual inspection the user was completely surprised to find the entire termination surface of every

MLCC in the package was covered with a dense forest of “moss-like” tin whiskers with some approaching 100-μm long (Figure 4).

Additional packages were inspected after 500 thermal cycles. The OEM reported whisker growths on the MLCCs were longer than those observed at the 300-cycle inspection point. At this point in the evaluation the OEM determined that the size and density of the tin whiskers observed were unacceptable for their densely packaged circuitry.

Hybrid packages subjected to test Condition 2 (high temperature storage) were inspected after 400 hours of test. Interestingly, there was no evidence of tin whiskers for specimens stored under this condition.

Incidentally, the user’s analysis of the bond integrity after Conditions 1 and 2 revealed less than desirable adhesion strength and electrical conductivity. These results also show that it is not advisable to use conductive epoxy mounting practices with pure tin-plated MLCCs. However, OEMs that do not have safeguards in place to protect against incorrect shipment of pure tin-plated MLCCs when Pd-Ag MLCCs are ordered may be prone to problems such as observed in Example #1.

Example #1: Effects of Additional Ambient Storage on MLCCs with Tin Whiskers
Component engineers at the NASA Goddard Space Flight Center (GSFC) learned of this OEM's dilemma through a technical email discussion forum catering to topics in electronics assembly. Intrigued by the OEM's experimental observations, GSFC engineers petitioned the user for representative MLCCs with tin whiskers to further document the whisker formations and analyze the MLCC termination construction. One hybrid package containing six epoxy mounted MLCCs was supplied for this analysis.

The OEM reported that the representative hybrid had been subjected to 200+ thermal cycles of test Condition 1. As received by GSFC, the hybrid package had already been delidded by the OEM for optical inspection only (i.e., the MLCCs were still epoxied to the substrate). Upon receipt of the hybrid, GSFC parts analysts performed SEM inspection. Figure 6 shows the profuse density of growths (as high as 800 per mm^2) and maximum whisker lengths on the order of 100-μm thus confirming the OEM's previous reports.

Figure 6: NASA GSFC SEM Inspection of Pure Tin-Plated MLCC from Manufacturer "A" with Tin Whiskers

The hybrid package with MLCCs still attached was placed in a protective enclosure to minimize exposure to dust and handling contamination. Ongoing storage conditions consist of a room ambient environment which for this GSFC facility is nominally 20°C - 25°C, 30% - 60% relative humidity.

After approximately six months of additional storage time under the GSFC ambient conditions, another SEM inspection was conducted. Surprisingly, this inspection (Figure 7) revealed several whiskers had grown in excess of 200-µm long (max. of ~250- µm). This finding suggests that the rapid whisker growth process initiated by thermal cycling has continued despite the removal of the initiating environment.

Figure 7. NASA GSFC SEM Inspection of MLCCs after ~ 6 Months of Additional Ambient Storage After Original Thermal Cycle Exposure.

Example #1: Cross Section Analysis of MLCCs with Tin Whiskers

During the initial receiving inspection at GSFC, one MLCC was mechanically removed from the hybrid substrate (using a die shear tester) for cross section analysis. The purpose of this analysis was to document possible construction differences between these whisker-laden MLCCs from the MLCCs described in previous research on tin whiskers.

Figure 8 shows the cross section of the MLCC that was removed from the hybrid. SEM inspection and Electron Dispersive Spectroscopy (EDS) were performed to measure the various termination layer thicknesses and composition. The analysis showed the termination structure as follows:

1. Silver Frit: 17-µm thick
2. Nickel Barrier: 6.5-µm thick
3. Pure Tin: 6.5-µm thick

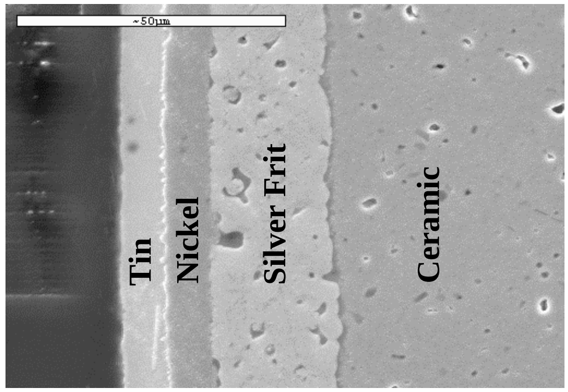

Figure 8: Cross-Section of MLCC Indicating the Thickness and Composition of the Various Layers

The bulk ceramic dielectric was observed to be of a commonly used barium titanate formulation.

The cross-sectioned MLCC was next chemically etched to highlight the grain structure of the tin electroplate. Though difficult to see in Figure 9, this analysis showed that the tin grains were polygonal structures ranging from 5 to 15-µm in size.

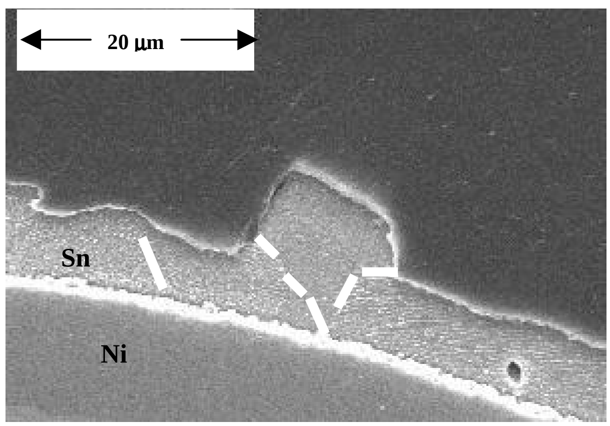

Figure 9. Tin Etch of Cross Section of MLCC Termination Structure with Grain Boundaries Highlighted

The results of the cross section analysis show that the attributes of this MLCC are essentially identical to those of the MLCCs reported to be whisker-free after 18 years in the earlier studies.

The most obvious difference between the experiments of the different researchers is the environmental test conditions chosen for judging whisker propensity. The more recent OEM's experiments described in Example #1 suggest that exposure to thermal cycle environments more actively excites the necessary stresses to spawn whisker formation in devices with a construction like MLCCs. Coefficient of thermal expansion mismatches among the various materials in the MLCC construction or possible IMC formation between nickel and tin are suspected to be potential factors contributing to whisker formation in this study. However, the exact mechanisms involved in these growths have not been determined.

Example #2: Thermal Cycle Evaluation of Pure Tin-Plated MLCCs from Manufacturers "B" and "C"
Having heard the reports of MLCCs with tin whiskers described by Example #1, The Aerospace Corporation performed experiments designed to validate these previous observations. Despite the fact that the OEM application would utilize reflow soldering of the pure tin MLCCs using Sn/Pb solder paste, the OEM was

concerned that portions of the capacitor terminations may remain unreflowed or tin-rich as some soldering processes do not guarantee complete wetting of the MLCC termination with Sn/Pb solder.
In a study to assess the risk of tin whisker formation, The Aerospace Corporation obtained pure tin-plated MLCCs from two different manufacturers ("B" and "C"). The MLCCs from Manufacturer "B" are typical commercial grade capacitors whose cross section is shown in Figure 10. Note that this lot of MLCCs contains a nickel barrier layer ~ 6-µm thick with a pure tin final finish ~10-µm thick

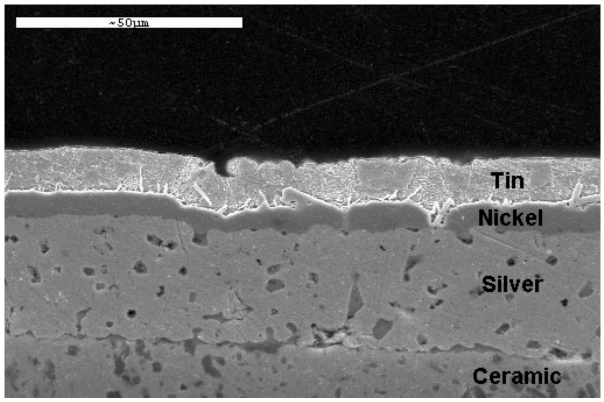

Figure 10. Cross-Section of Pure Tin-Plated MLCC from Manufacturer "B"
("Typical" MLCC Construction with Nickel Barrier Layer)

The production lot of MLCCs from Manufacturer "C" was also of similar construction; however, this lot was manufactured in accordance with U.S. Military specification requirements (MIL-PRF-55681).

To simulate the effects of reflow temperature exposure that might be expected from typical installation methods, several parts from Manufacturer "B" were exposed to temperatures of 215°C for 5 seconds without actual solder present. Additional samples from Manufacturer "B" and all of the samples from Manufacturer "C" were not subjected to this simulated reflow.

All of the capacitors were then subjected to the same environmental test described by Condition #1 of Example #1 (thermal cycle). Capacitors from Manufacturer "B" were examined after 500+ cycles and densely populated regions of tin whiskers up to ~25-µm in length were observed (Figure 11) even for those parts exposed to simulated reflow. The MLCCs from Manufacturer "C" were examined after 100 cycles and also showed evidence of whiskers ~25 to 30-µm long (Figure 12).

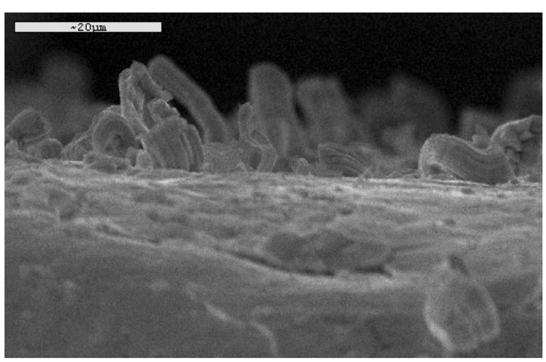

Figure 11. Tin Whiskers on Pure Tin-Plated MLCCs from Manufacturer "B" After Thermal Cycle

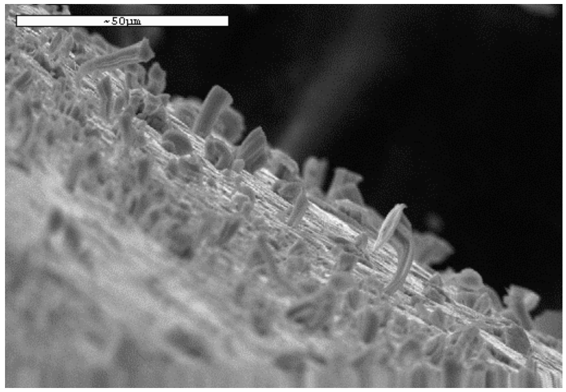

Figure 12. Tin Whiskers on Pure Tin-Plated MLCCs from Manufacturer "C" After Thermal Cycle

The results of these experiments confirmed most of the observations from Example #1. However, the maximum length of the whiskers found in Example #1 were from 3 to 10 times longer than those observed in Example #2. It will be interesting to see if the whiskers from Example #2 continue to grow under ambient storage as reported in Example #1.

Example #3: Tin Whiskers on Pure Tin-Plated MLCCs from Manufacturer "B" After Vapor Phase Installation and Thermal Cycle Testing

Many who have heard of the intriguing observations described in Examples #1 and #2 have suggested that these capacitors would not have whiskered if they had been installed using soldering techniques for which tin-plated MLCCs are designed. They cite references in the tin whisker literature that suggest the heat of the reflow process will relax residual stresses in the plating thought to be key contributors to whisker formation. They also cite references that suggest the introduction of Pb from the Sn-Pb solders commonly used to mount this type of capacitor would cover most of, if not the entire, MLCC termination surface thus introducing an alloying element (Pb) that is widely considered to have whisker inhibiting properties.

Circa 1997, a different OEM conducted experiments to determine the whiskering propensity of MLCCs after vapor phase installation at 217°C using Sn63/Pb37 solder paste. Pure tin-plated MLCCs of four different chip sizes all from Manufacturer "B" were assembled onto FR4 printed wiring boards using the OEMs standard vapor phase process.

Some of the assembled boards were then subjected to thermal cycle testing from -55°C to +100°C for several hundred cycles. SEM inspection was performed at discrete intervals to examine for evidence of tin whiskers.

Upon examination after 50 cycles, the two larger MLCC chip sizes showed evidence of tin whiskers (~10-µm long) growing from the tin-rich areas which were not wetted by Sn/Pb solder during installation. Additional cycling to 400 cycles showed evidence of tin whiskers approaching 30-µm long.

Example #4: Tin Whiskers on Pure Tin-Plated MLCCs from Ambient Storage

In 2000, the author heard anecdotal reports of pure tin-plated MLCCs from a fourth manufacturer (Manufacturer "D") that showed "moss-like" growths on the terminations of parts taken from stock. The OEM who made these observations reportedly had ordered Pd-Ag terminated capacitors for their hybrid epoxy mount application, but was supplied with pure tin-plated MLCCs by mistake (similar to the scenario described by Example #1). Unfortunately, formal documentation of this example has not been made available.

Conclusions

The observations and circumstances surrounding tin whisker formation on multilayer ceramic capacitors (MLCC) from four different manufacturers have been described. All of these observations provide a contrasting view of previously held beliefs that MLCCs are immune to tin whisker formation.

1. Surface mount multilayer ceramic capacitors (MLCCs) with electroplated pure tin finishes are not immune to tin whisker formation. Thermal cycling has been demonstrated to excite tin whisker formation in MLCCs with some documented growths approaching 250-μm.

2. Electrical shorting due to tin whiskers remains a significant problem. The incidence of tin whisker induced failures will increase in frequency with increased use of pure tin-plated electronic components and assemblies unless significant discoveries are made regarding effective mitigation practices.

3. Even when prohibited by system design and procurement requirements, components manufactured with pure tin finishes continue to appear in electronic equipment.

4. The factors that affect tin whisker formation are not fully understood. The author believes that there are also interactions amongst the various factors involved in whisker growth that makes research of this phenomenon difficult to control. Despite efforts to perform controlled experiments to judge whisker propensity, many subsequent experiments show “other” factors that can change previously held beliefs.

Recommendations

There are literally hundreds of published papers that discuss general and specific aspects of the tin whisker phenomenon. Reliance on simply a few of the more prominent publications on the subject could prove to be dangerous to manufacturers and users of electronic components and assemblies requiring the utmost in long-term reliable performance of their products. Despite the fact that this phenomenon has been known for more than 50 years, all must be aware of its confounding and sometimes conflicting nature.

1. The electronics manufacturing industry must strive to achieve and verify through direct investigation a consensus understanding of the fundamental mechanism(s) of whisker formation.

2. "Accelerated" test method(s) to judge a product or process's propensity to grow tin whiskers need to be developed. Methods must be tailorable to assess a wide variety of electronic component constructions and user application conditions including factors such as temperature, temperature change, humidity, and pressure.

3. Experiences with tin (and other metal) whiskers need to be shared more openly in order to create an environment conducive to resolution of this dilemma.

4. OEMs and electronic component manufacturers should adopt practices to assess and mitigate the risk of tin whisker induced failures in their products.

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