Tin Whisker Mitigation Process for Surface Mount Components

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SUMMARY: Ten years after the EU's lead restrictions took place, electronic components with tin-lead finishes are definitely a thing of the past. Author Scott Sentz explores his company's tin mitigation process which works with both passive and active components.

Abstract

The European RoHS directive to implement lead-free initiatives resulted in obsolescence of commercially available electronic components with tin-lead finishes. Even though all countries have exemptions for special industries requiring lead, the reality is that there are fewer and fewer components available in the tin-lead termination finish.

Lead-free initiatives pose reliability issues due to tin whisker formation, which has resulted in failures due to electrical short circuits.

Applications requiring high-reliability components have to identify solutions to either mitigate RoHS components or consider alternate design approaches with components still available with tin-lead finishes. The latter is not realistic given that substitutes with tin-lead finishes that meet all the critical criteria are not usually available.

This article will explore a tin whisker mitigation process for electronic components applicable to both passive and active components.

Introduction

The European Union (EU) Restriction on Hazardous Substances (RoHS) Directive 2002/95/EC, as well as subsequent EU RoHS 2 Directive 2011/65/EU, which mandate the elimination of lead, essentially moved worldwide electronic components towards lead-free finishes and solder. Even though the U.S. has not adopted a similar green initiative, U.S. electronic component makers have no choice but to follow suit if their products are to be marketed worldwide.

Adoption of lead-free finishes would be a happy event if it were to be accomplished without risks to reliability. Pure tin, defined as tin with less than 0.1% lead, is a high-reliability risk because of its propensity to form tin whiskers. Actually, the consensus in the mil-spec industry is that minimum 3% lead within a tin finish is needed for best practice. Tin whisker growth has been documented since as early as the 1940s. Unfortunately, to date, there is no clear understanding of the mechanism of tin whisker growth, although intermetallic formation and stresses, internal and external, within and on the tin surface are believed to be contributing factors.

Tin whiskers are single-crystal growths which are known to achieve lengths in excess of one centimeter. Tin whiskers grow unpredictably on pure tin surfaces and whiskers can cause catastrophic short circuits due to their conductivity. There are many documented failures where whiskers are believed to be the root cause; the NASA website captures a good number of examples, as does the CALCE website.

Tin Whiskers

Tin whiskers are mono-crystalline strands of tin that grow from pure tin-plated surfaces. The current theory is that diffusion related to intermetallic formation may cause stresses in the tin layer that are relieved with whisker growth; additionally, stresses related to the component's environment may contribute as well. Stresses can also come from the plating conditions, from the substrates or from external scratches/bends on the pure tin surface. Organic brightener additives that give shine to tin plating may exacerbate whisker growth believed to be related to surface stresses; "matte" tin without the additives that cause stress on the surface are less prone to grow whiskers.

It is further theorized that copper substrates are more prone to whisker formation than other metals because of the presence of tin-copper intermetallics, where the volume increase contributes to stress on the tin layer. Additionally, tin-nickel intermetallics are also well known, and AEM has been able to demonstrate growth of whiskers with either precious metal ceramic chip capacitors (silver electrodes, silver termination and nickel barrier below the tin) or base metal ceramic chip capacitors (nickel electrodes, copper termination and nickel barrier below the tin) versions of the same OEM device. Both versions of this pure tin ceramic chip capacitor grew measurable whiskers after 88 temperature cycles from -55°C to +85°C.

Methods for Avoiding Tin Whiskers

Tin whisker risks are foremost in the minds of reliability engineers in industries where reliability is the top priority. Until there is an accepted accelerated test for tin whiskers, pure tin finishes will be prohibited in high-reliability applications such as space, medical implants

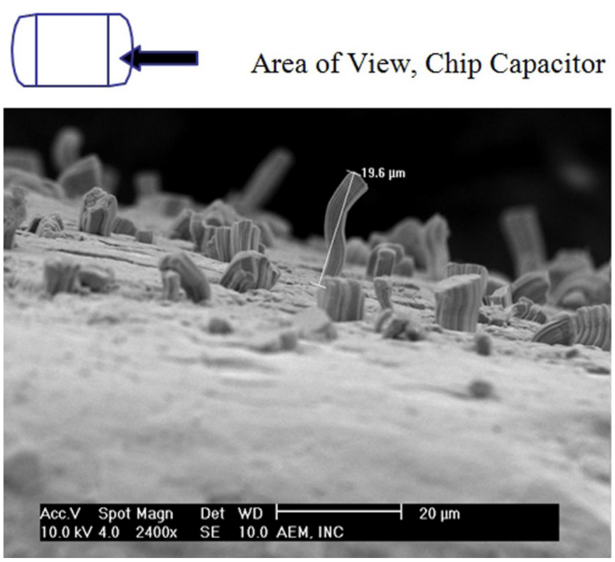

Figure 1: Precious metal construction MLCC (Ag electrodes, Ag termination, Ni and Sn).

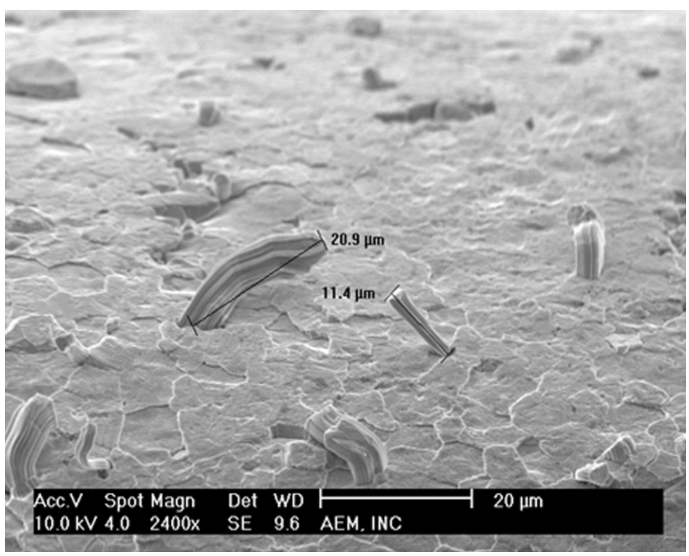

Figure 2: Base metal construction MLCC (Ni electrodes, Cu termination, Ni and Sn).

and other programs where failure within the calculated usage life is not an option. Prohibition of pure tin for high-reliability applications is critical.

Incoming materials inspection to guard against accidental receipt of pure tin products provides a level of assurance, which is why high-reliability industries have implemented incoming material inspection processes. An added tool to protect against pure tin is the X-ray fluorescence (XRF) at the receiving dock. Handheld XRF machines calibrated to detect lead in larger components enable easier analysis on a lot sampling basis. Alternatively, samples from the incoming lot could be sent to in-house analysis laboratories for energy dispersion spectroscopy (EDS), using the same principle as XRF. Inspectors look for a minimum 3% lead content that empirically has shown to mitigate whisker formation in tin-lead surfaces.

Mitigation of RoHS (100% Tin) Components

Electronic components can be divided into two main categories, leaded and un-leaded surface mount technology (SMT) devices.

Leaded Active or Passive Devices

Pure tin-plated active devices can be dipped in standard tin-lead solder. Preheating can prevent thermal shock which can lead to cracking and de-lamination. Robotic handling can improve precise dipping angle and travel. However, it is very difficult to dip inside the meniscus at the lead egress points of leaded devices.

Surface Mount Chip-Size Active or Passive Devices

Pure tin-plated chip-size devices are too small to dip in tin-lead solder and are also susceptible to thermal shock cracking. Solder dipping of these devices is often impractical due to handling of these tiny devices which can be smaller than grains of rice. The ideal mitigation would convert pure tin into the previously universally used "solder plate" tin-lead finish with at least 3% lead content.

AEM Process: Tin Finish to Tin-Lead Finish

The concept behind the AEM process is to treat the pure tin-plated terminal to give it solder plate attributes of minimum 5% lead content for added mitigation assurance. This is achieved by adding lead to the pure tin plating. Furthermore, the lead must be evenly distributed in the entire pure tin-plated area. AEM certifies each lot against the AEM drawing 387070 tin-lead conversion process certifying minimum 5% lead content as measured by EDS and XRF, as well as that solderability has passed per method 208 of MIL-STD-202. Each processed lot will go through pre- (QA1) and post-testing (QA2) as required by AEM drawing 387070 incorporated within the AEM AS9100 quality system.

Following are scanning electronic microscope (SEM) cross-sectional pictures of a typical terminal of a ceramic electronic chip component. Under back-scatter electron scans in the SEM, lead particles are white, and tin is the lightest gray outer-most layer to the right. The dark gray area immediately adjacent to the left is the nickel barrier; see SEM Micrograph 1 below. This termination cross-section is representative of approximately 5% lead, achieved by co-plating tin-lead (typically 60-40) in methane sulfonic acid (MSA) solution. Again, this co-plating is known commonly as "solder plate."

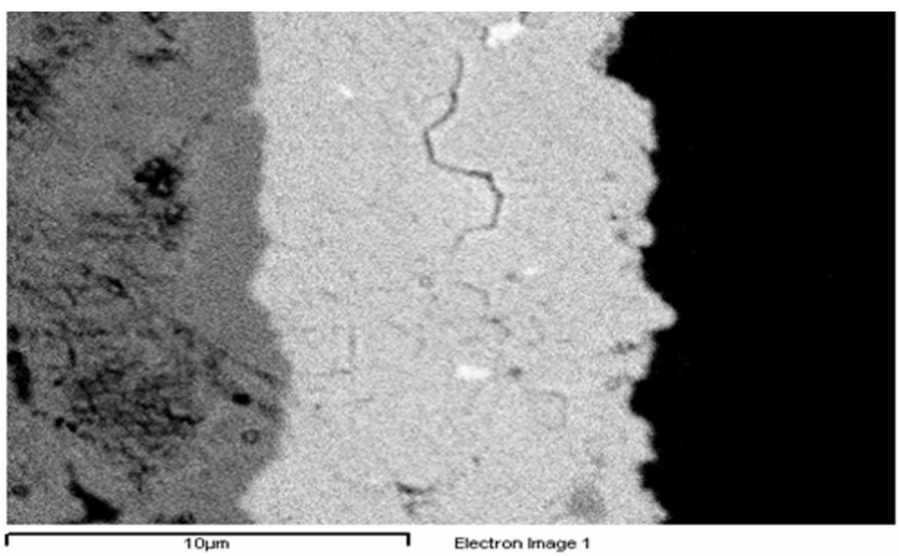

Figure 3: SEM Micrograph 1.

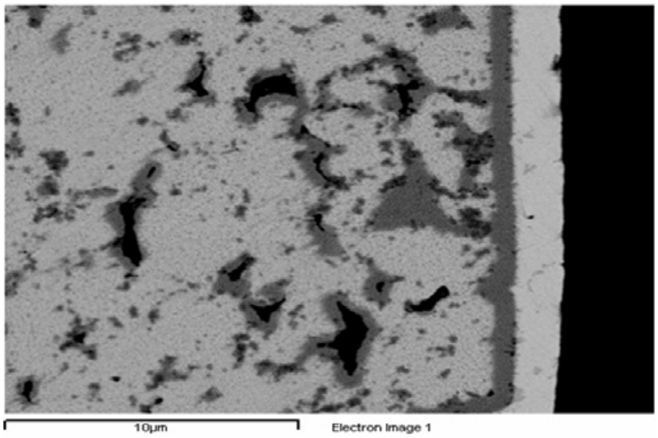

Figure 4: SEM Micrograph 2.

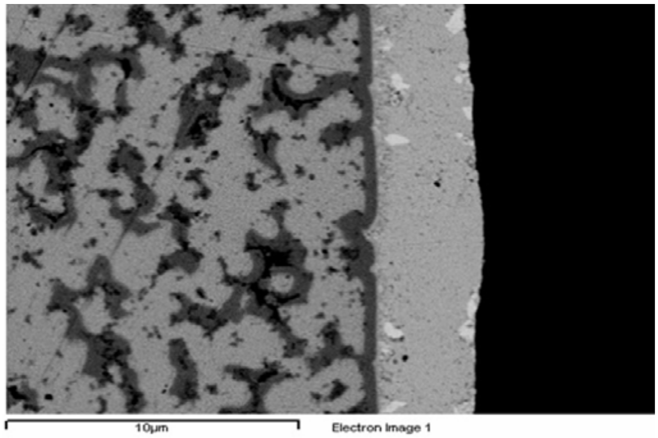

Figure 5: SEM Micrograph 3.

SEM Micrograph 2 shows the cross-section of a typical pure tin version of the same device produced by the same manufacturer. The light gray tin area has no lead indicated by the absence of white particles. SEM Micrograph 3 is the same pure tin Micrograph 2 chip component after AEM re-processing. Notice the distribution of the white lead particles throughout the previously pure tin layer.

Capability of AEM Mitigation

The following are examples of components which have been processed using the AEM tin whisker mitigation (TWM) process. This includes 0201 case sizes and larger with component types such as surface mount capacitors, resistors, inductors, arrays, ferrite chips, varistors, as well as molded MOFETs and diodes, and reverse J-lead packages.

The TWM process can be effective with:

- All passive monolithic chip components where:
  - Tin plating is part of the termination process and
  - Component is intended for solder assembly.
- Some passive surface components where:
  - Pre-tinned leads are molded;
  - Component is intended for solder assembly; and
  - Certain active discrete chip-size, leaded or SMT components.

Conclusions

Tin whisker growth is a high-reliability risk when pure tin is present anywhere in the electronics assembly. The fact is that when there is pure tin, whiskers may form. The onset is unpredictable, but inevitable. There are claims of whisker-free plating, but there is as yet no definitive theory of tin whisker genesis, nor is there an accepted accelerated whisker test method to validate these claims.

For products where no source of tin-lead plated terminations is available, mitigation appears to be the best short-term solution. For SMT chip-size components, the TWM process adds lead to pure tin-plated terminals to convert the pure tin to tin-lead with at least 5% lead. SMT

Scott Sentz began his career at Channel Industries in Santa Barbara, California, where he focused on piezoelectric element formulation and manufacturing in an engineering capacity. He then moved into the world of passive components working at Novacap, Inc. in Valencia, California, and currently AEM, Inc. in San Diego, California, holding various management roles covering operations, engineering, quality, marketing, and sales.