JEDEC/IPC
JOINT PUBLICATION

Current Tin Whiskers Theory and Mitigation Practices Guideline

JP002

MARCH 2006

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION
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The material in this joint standard was developed by the
JEDEC JC-14.1 Committee on Reliability Test Methods for Packaged Devices
and the IPC Tin Whiskers Guideline Task Group (5-23e).

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CURRENT TIN WHISKER THEORY AND MITIGATION PRACTICES GUIDELINE

Foreword

This publication provides guidance in understanding the prevalent tin whisker formation theories, driving forces and mitigation practices used to minimize tin whisker formation. This publication serves as a source of background information for JESD22-A121, *Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes* and JESD201, *Environmental Acceptance Requirements For Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes*.

Introduction

Sn whiskers have been an industrial concern and interesting problem for many years. They are known to cause short circuits in fine-pitch pretinned electrical components [1]. Sn whiskers grow by the addition of material at their base not at their tip (i.e., they grow out of the substrate) [2]. They can grow from as-formed electrodeposits, vapor deposited material [3], and intentionally deformed coatings of Sn [4]. Similar whiskers are observed in Cd, In, and Zn [5]. Whiskers appear to be a local response to the existence of residual stress. Compressive residual or external stress is usually considered a precondition for whisker growth [4]. Annealing or melting (reflow in solder terminology) may mitigate the growth for an undetermined period of time. In 1959, Pb additions of a few percent to Sn electroplate were found to greatly reduce the tendency to form whiskers [6] and interest in the subject waned. Legislation that will restrict the use of lead in electronic products sold in the European Union, due to be in effect on July 1, 2006, has led many electronic component suppliers to propose the removal of Pb from tin-lead plating, leaving essentially pure Sn. This approach is the most convenient and the least costly lead-elimination strategy for the majority of component manufacturers. However, for the high-reliability user community, the pure tin strategy presents reliability risks due to the whisker forming tendencies of pure tin and tin alloy plating.

This publication discusses the current tin whisker history, theories and driving forces behind tin whisker formation and potential mitigation practices for various applications. It should be noted that for certain applications with special needs (e.g., military or aerospace), the Sn mitigation methods contained in this document may not be sufficient due to additional performance requirements [7].

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CURRENT TIN WHISKER THEORY AND MITIGATION PRACTICES GUIDELINE

(From JEDEC Board Ballot JCB-05-143, Formulated under the cognizance of the JC-14.1 Subcommittee on Reliability Test methods for packaged Devices in conjunction with the IPC Tin Whiskers Guideline Task Group (5-23e).)

1 Scope

This document will provide insight into the theory behind tin whisker formation as it is known today and, based on this knowledge, potential mitigation practices that may delay the onset of, or prevent tin whisker formation. The potential effectiveness of various mitigation practices will also be briefly discussed. References behind each of the theories and mitigation practices are provided.

2 Terms and definitions

For the purposes of this publication, the following terms and definitions apply.

whisker: A spontaneous columnar or cylindrical filament, usually of monocrystalline metal, emanating from the surface of a finish. (See Annex C for example pictures of tin whiskers.)

whisker growth: Measurable changes in whisker length and/ or whisker density.

tin whisker mitigation practice: Process(es) performed during the manufacture of a component to reduce the propensity for tin whisker growth by minimizing the surface finish internal compressive stress.

matte tin: A tin film with lower internal stresses and larger grain sizes typically of 1µm or greater and carbon content less than 0.050% [8].

bright tin: A tin film with higher internal stresses and smaller grain size of 0.5 µm to 0.8 µm and carbon content of 0.2% to 1.0% [8].

Underlay: A plated barrier layers between the base metal and the tin finish.

3 History of tin whiskers

A metallic whisker is generally a single crystalline filamentary surface eruption from a metal surface, though polycrystalline filamentary surface eruptions have been observed [9,10]. Whiskers are usually found on relatively thin, 0.5 µm to 50 µm, metal films that have been deposited onto a substrate material. A typical whisker is one to five µm in diameter and between 1 µm and 500 µm long [8]. Whiskers can be straight, kinked, or even curved, see Annex C. Metallic film deposits have also shown other types of eruptions that are quite different in appearance from the whisker eruption. These eruptions are referred to in the literature as flowers, extrusions, and volcanoes. They have not been of as much general interest as the much-longer whisker eruptions.

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3 History of tin whiskers (cont'd)

Metallic whisker formation first became of widespread interest to the scientific community immediately after WWII. In 1948, the Bell Telephone Corporation experienced failures on channel filters used to maintain frequency bands in multi-channel telephone transmission lines. Bell Laboratories quickly initiated a series of long-term investigations into the general topic of whisker formation, the results of which were first reported in 1951 by K.G. Compton, A. Mendizza, and S.M. Arnold [11]. This Bell Laboratories work established that whisker formation occurred spontaneously, on cadmium (Cd), zinc (Zn), and tin (Sn) electroplating. The Bell Lab experiments studied a variety of substrate materials including copper (Cu), copper alloys, steels, and nonmetallic substrates.

An excellent annotated bibliography of tin whisker history and references is provided [8] that include a comprehensive listing of articles published through Dec. 31, 2004.

One reason that the problem of tin whiskers has not been solved is the lack of appropriate analytical tools to study the basic structure of the Sn film. Only in recent years have tools like Focused Ion Beam (FIB), Synchrotron X-Ray Diffraction, and Electron Back Scattering Beam (EBSD) become available for researchers to use in investigating this problem. As data from these tools becomes available, the industry may get a better understanding of tin whisker formation and the reasons they occur [12].

Other reasons that the whisker problem has not been solved are: 1) all of the variables that effect whisker growth are not known, 2) variables known or suspected of affecting whisker growth are not always reported when data is published, 3) Pb has been used as a mitigation method for whisker growth for decades, 4) current test methods cannot correlate whisker growth in test conditions to field conditions, and 5) as such, test results cannot be used to predict whisker growth in other environments or longer durations.

4 Discussion of and theory behind whisker formation

The following information represents the generally accepted knowledge on the prevailing theory of tin whisker formation available at this time. It is intended to aid suppliers in understanding whisker formation and how tin whiskers formation might be minimized or delayed on products. Many of the mitigation methods described in this document are based on interrupting the development of compressive stress in the tin layer.

The lead-frame material or substrate has a major impact on whisker formation, and as such, has been one of the factors causing confusion and inhibiting consistent conclusions from being formed. It should be noted that the information provided in this publication refers to 100% Sn plating on a copper-based lead frame materials, unless otherwise specified.

Another area for confusion in interpreting results has been the use of matte versus bright tin. In general, matte tin films are less prone to whisker formation and growth than so-called bright tin films. Many current suppliers claim that a proprietary version of matte tin is whisker-free, but these claims may be premature and should be considered carefully before use. This document refers only to matte tin finishes unless otherwise noted.

In reporting and analyzing results, all pertinent information should be noted including, but not limited to, type of tin used, lead frame material, and any underlay material.

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4 Discussion of and theory behind whisker formation (cont'd)

4.1 Primary cause of whisker formation

The driving force behind tin whisker formation is stress in the Sn film [13]. Stress may come from the as-plated film with its associated texture [14,15], intermetallic formation or mechanical means, such as bending, forming, thermo-mechanical stresses (CTE mismatch induced), or possibly oxygen diffusion and/or oxide formation on the surface. The corrosion of Sn is another possible source for the stress in the Sn finish [9,16]. Compressive stresses are fundamental to all whisker formation and provide a driving force for the creation of whiskers.

In many cases the driving force behind a reaction, such as a compressive stress, is eliminated or reduced by diffusion-based relaxation mechanisms. These mechanisms can slow or stop the reaction. However, there are some cases where the driving force is not relieved by diffusion or other solid state mechanisms. In addition, it is possible that the driving force can be continuously regenerated or renewed. In these cases the driving force remains active. Intermetallic formation, oxide reactions at the film surface, temperature cycling, and certain kinds of constant mechanical clamping forces are all examples of conditions where the compressive stress is continually regenerated or is undiminished by solid state mechanisms. However, stress is a necessary but not solely sufficient condition for whisker formation. It appears that there has to be a specific type of crystalline microstructure required that is favorable to a localized surface eruption or whisker [16, 17]. The variation in whisker "incubation times", which range from minutes to decades, is believed to be due to the mechanisms involved in nucleating these specialized crystalline microstructures and/or the time required to build up sufficient compressive stress in the Sn films to start whisker formation [18]. If the film stress levels are maintained at a high enough compressive level for a long enough period of time, there will be a very high likelihood of a whisker growth event as a means of further relaxing the stress levels within the film beyond the extent affected by simple diffusion.

It is believed that one of the prime causes of stress that may result in whisker formation, as seen in testing, is the irregular growth of the Cu_6Sn_5 intermetallic, when Sn is plated on Cu based substrates, which occurs rather quickly under room ambient conditions [19]. The irregular growth of intermetallic compounds is also referred to as a chemical reaction.

Another source of stress in electronic components is CTE mismatch induced stresses [20]. These are particularly significant when the substrate material has a low CTE, such as Alloy 42.

In addition to stress associated with component material mismatches, any mechanical stresses associated with the product may play a role in whisker formation. This could include stress in the Sn layer due to the assembly loading conditions associated with specific product. More research is needed in this area to better understand the interaction of other mechanical stresses and whisker formation.

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