

CHAPTER

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MITIGATING TIN WHISKERS IN ELECTRONICS VIA ELECTROLESS DEPOSITION

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2.1 INTRODUCTION

Lead has long been widely used in electronic components owing to its excellent performance and favorable chemical properties. However, growing environmental and health concerns led to its prohibition in many electronics applications because exposure to lead, whether by ingestion or inhalation, can adversely affect the brain and nervous system. Consequently, manufacturers of Printed Circuit Boards (PCBs) were compelled to shift toward lead-free soldering solutions. In response, the European Union's Restriction of Hazardous Substances Directive (RoHS) established regulations effective 1st July 2006, mandating that certain products cannot contain restricted substances, such as lead and its compounds, beyond 0.1 % by weight.

Alongside lead, other toxic substances such as mercury, hexavalent chromium, cadmium, Polybrominated Biphenyls (PBBs), and Polybrominated Diphenyl Ethers (PBDEs) are also restricted under RoHS. The ban on lead triggered major changes within the electronics

industry and drove the transition from lead-based surface finishes to lead-free alternatives (Cheng et al., 2017).

Surface finishes on PCBs, which are applied over bare copper lands, are a critical part of the manufacturing process. Common metallurgies include Hot-air Solder-levelled (HASL), Organic Solderability Preservatives (OSP), Electroless Nickel Immersion Gold (ENIG), Electroless Nickel Electroless Palladium Immersion Gold (ENEPIG), Immersion Silver (IAg), and Immersion Tin (ISn). HASL, which historically relied on Sn-Pb alloys, was once the predominant finish. With the shift to lead-free soldering, pure tin-based plating emerged as a cost-effective choice offering good solderability (Cenci et al., 2022). Nevertheless, replacing Sn-Pb finishes with tin-only surface finishes introduces reliability risks, most notably tin whisker formation. These slender conductive filaments can bridge electrical contacts and cause short circuits, posing serious threats to device reliability (Illes et al., 2025).

The phenomenon of tin whiskering has been documented since the 1950s, including cases compiled by NASA spanning from 1946 to 2005 (Brusse et al., 2002). Whisker-related failures have occurred in settings ranging from nuclear plants and aerospace to automotive electronics, underscoring the risk associated with tin-based finishes (Jiang et al., 2019). Research indicates that tin whisker growth is influenced by multiple factors such as environmental temperature, residual stress, mechanical loading, Intermetallic Compound (IMC) formation, and the presence of oxide layers. For example, the formation of IMCs such as Cu_6Sn_5 and Cu_3Sn at the interface between a tin finish and a copper base introduces compressive stresses into the tin layer, which in turn can trigger whisker growth as a stress-relief mechanism (Jagtap et al., 2018).

Although extensive investigation has been carried out, the detailed mechanisms governing tin whisker nucleation and growth (including grain-boundary diffusion, dislocation movement, recrystallization, and interface flow) remain incompletely understood. Further study to explore more on the reliability of the tin surface finish is needed, and the established method of study has been developed in order to produce consistent results.

2.2 ELECTROLESS DEPOSITION

Recent studies have reaffirmed the value of electroless copper (Cu) deposition as a competitive and efficient method for metallization in electronic packaging, particularly surface finish. As microelectronic devices continue to scale down, challenges such as void-free filling, barrier layer formation, and electromigration resistance have led researchers to explore electroless techniques more rigorously (Bath, 2007; Fadil et al., 2015).

Electroless deposition is a chemical reduction process whereby metal ions in a solution are reduced onto a catalytically active surface using a reducing agent without requiring external current. These reducing agents, such as hypophosphite or formaldehyde, transfer electrons to metal ions in solution, causing metallic Cu to deposit uniformly across the substrate. This deposition occurs regardless of the substrate geometry, which gives electroless plating a significant advantage over conventional electrodeposition.

Furthermore, insights from tin whisker research (Susan et al., 2013) have contributed to understanding the mechanical stress behavior in plated films, especially where microstructural control of Cu is critical to avoid failure modes such as protrusions, delamination, or stress migration. These reliability concerns become more pressing as the interconnect density increases, reinforcing the need for refined, stress-minimized deposition strategies. Several theories have been developed to understand the growth mechanism of whiskers such as grain boundary diffusion, oxidation, recrystallization theories.

2.3 THEORIES OF TIN WHISKER GROWTH

Over the decades, various mechanisms have been proposed to explain the spontaneous and hazardous growth of tin whiskers, the metallic filaments that pose reliability risks in microelectronics. These theories aim to relate atomic migration and microstructural transformation to environmental and mechanical stresses. Among the most widely