Pure Tin - The Finish of Choice for Connectors

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Abstract
Business conditions in the electronics industry necessitate the reduction and eventual elimination of lead. The tin/lead plating that has been used for decades to promote low cost, solderable, corrosion resistant, and reliable electrical interconnections for connector products will have to be replaced. As lead is eliminated from the plating finish of both current and future products, these properties must be maintained through the proper selection of lead-free plating. This paper will provide the rationale for endorsing pure tin as the finish of choice for connector applications. Tin will be compared to tin/lead with respect to properties and performance. In addition, concerns with the use of pure tin (e.g. tin whiskers) will be addressed.

Introduction
Business conditions in the electronics industry necessitate the reduction and eventual elimination of lead. These reductions are commonly driven by strategies for environmental citizenship, the environmental directives of customers as well as the need to comply with future legislation. The technical strategies used to eliminate lead are converging to a limited number of viable solutions.

Tin/lead coatings are the primary source of lead in the connector industry. Tin/lead plating has been used for decades to promote low cost, solderable, corrosion resistant and reliable electrical interconnections. As lead is eliminated from the plating finish of future products, these properties must be maintained through the proper selection of lead-free plating.

Many candidates are possible replacements for tin/lead plating. These include tin, gold, silver, gold-flashed palladium-nickel, tin/copper, tin/bismuth and tin/silver. The first four of these have been used for many years as lead-free coatings; however most were engineered for other performance requirements and were not selected because they were lead-free. While precious metal deposits can be thin to reduce their inherently high cost, they will still be substantially more expensive than tin/lead coatings. The last three candidates offer competitive cost to tin/lead, but suffer from various shortcomings with respect to their properties or performance. The industry needs a coating that has property, performance and cost parity to tin/lead. That solution is pure tin.

This paper will provide the rationale for endorsing pure tin as the finish of choice for connector applications. Tin will be compared to tin/lead with respect to properties and performance. In addition, concerns with the application of pure tin (e.g., tin whiskers) will be addressed.

History
The connector industry has been plating pure tin for more than 50 years. Beginning with the first quick connect terminals to today's high performance connectors, pure tin has proven itself to be a viable interconnect material. Tin shows good wetting characteristics during soldering, which helps create a reliable solder joint. Tin also has a proven history of stable performance as a separable contact interface material.

Pure Tin versus Other Lead-free Alternatives
Table I summarizes several attributes of alternate finishes to tin/lead.[1] As one can see from the chart, pure tin is the best alternative to tin/lead.

Pure Tin versus Tin/lead as a Contact Finish
A comparison of the properties of tin and tin/lead provides insight into the rationale for recommending tin as the best replacement for tin/lead as an interconnect material for lead-free applications. Table II compares the properties of pure tin with 93/7 tin lead, a commonly used composition for connectors, and 60/40 tin lead solder, a composition finding its main use in other electronic components.[2]

Table I. Tin versus other lead-free alternatives

Item	Pure Sn	Sn/Cu	Sn/Ag	Sn/Bi	Sn/Zn	Au flash over Ni*	Au flash Pd-Ni
Process	Simple	Complex	Complex	Complex	Complex	Easy	Easy
Composition Control	N/A	Hard	Very hard	Hard	Hard	N/A	N/A
Immersion Plate	No	Yes	Yes	Yes	No	No	No
Melting Point (ºC)**	232ºC	227ºC	221ºC	138ºC	199ºC	1063ºC ***	1063ºC ***
Solderability 60/40	OK	OK	OK	OK	OK	OK	OK
Solderability Pb-free	OK	OK	OK	OK	?	OK	OK
Joint Reliability	OK	Stressed	Stressed	Brittle	Brittle	OK	OK
Stress Control	Good	No	No	Unknown	No	N/A	N/A
Corrosion	Minor	Some	More/H_2S	Some	Major	Minor	Minor
Tarnish	Yes	Yes	Yes	Yes	Yes	N/A	N/A
Phase Transformation	Tin Pest < 13°C	N/A	N/A	Retards tin pest	N/A	N/A	N/A
Whiskers	Manageable risk	Risk	Risk	Risk	Large Risk	No	No
Cost	Low	Low	Medium	Medium	Medium	High	High

* Gold flash of proper thickness to avoid oxidation or Intermetallic Compound (IMC) formation in solder joint
****** Melting point of the solder
*** Melting point of gold

Table II. Comparison of Properties of Matte Tin vs. Tin/lead as a Contact Finish

Property	Pure Tin	93/7 Tin/lead	60/40 Tin/lead
Hardness (VHN_5)	9-12	8-10	12
Ductility	20 %	<20 %	< 20 %
Specific Resistance (µohm-cm)	11.4	13	14.5
Frictional Force (gm [3])	<38	38	95
Density (gm/cc)	7.30	7.49	8.52
Melting Point	232 ºC	< 232 ºC	183 ºC
Wear Cycles	<25	<25	<25
Fretting Resistance	Mil-Std 833	Mil-Std 833	Mil-Std 833
Corrosion Resistance	OK*	OK*	OK*

* Some oxidation depending on environmental conditions, e.g. temperature/humidity, which can be managed through product design techniques.

Tin coatings can be applied as a topcoat for engineering applications and serve as low cost option to gold in electrical connectors. These coatings provide a low contact resistance surface, protection from corrosion, excellent solderability and anti-galling properties.

Some important guidelines for employing tin/lead coatings in connectors with acceptable performance also apply to pure tin coatings.[4] They are summarized below:

A) Tin plated contacts require a mechanically stable interface to prevent micro-motion which can lead to fretting corrosion.
B) For a stable and sustained electrical contact, a minimum of 100 grams (1N) of contact normal force is desirable.
C) Tin contacts may be lubricated in order to reduce friction and fretting corrosion susceptibility.
D) Tin coatings are suitable for continuous high temperature applications at up to 125ºC.
E) Mating of tin plated contacts to gold plated contacts is not recommended due to the potential for fretting corrosion, which transfers tin oxide on the gold surface thus causing poor contacts.
F) Tin coated contacts can be employed both in low and high currents and voltages.
G) The tin plated contacts should employ sliding/wiping which improves electrical contact between the interfaces.
H) For solder applications, tin coatings should be at least 2.5 microns (100 micro-inches) thick with a minimum nickel underlayer 1.27 microns (50 microinches) thick in order to reduce IMC formation. If no nickel underlayer is used, using a tin coating at least 3 microns thick can ensure solderability.
I) The electrical performance of various tin coatings such as plated, reflowed, hot dip, hot air leveled are similar.
J) Bright coatings are pleasing to the eye and do not discolor as readily as matte coatings.

<u>Advantages of Pure Tin as a Replacement for Tin/Lead</u>

1. Low cost
2. Ease of application with controllable thickness
3. Compatible with existing processes and equipment
4. No need to redesign terminals and connectors
5. Corrosion resistant compared to dilute tin alloys (e.g. tin/silver)

<u>Disadvantages of Pure Tin as a Replacement for Tin/Lead</u>

1. Tin whisker mechanisms are not fully known. Empirical test methods have been developed to accelerate whisker growth and mitigate risk.

Pure Tin versus Tin/lead as a Termination Finish (Soldering, Compliant, Crimping)

A review of application performance criteria also helps to illustrate why pure tin is the best replacement for tin/lead as a termination finish. Table III lists the typical performance criteria for tin and tin/lead plating as a solderable coating.

Table III. Comparison of Performance Criteria of Tin versus Tin/lead

Performance Criteria	**Tin**	**93/7 Tin/lead**	**60/40 Tin/lead**
Solderability	Meets J-STD-002B	Meets J-STD-002B	Meets J-STD-002B
Shelf Life/ Oxidation	≥ 1 Year	≥ 1 Year	≥ 1 Year
Solder Joint Reliability	Meets IPC-A-9701	Meets IPC-A-9701	Meets IPC-A-9701
Tin Whisker Risk	Low	Low	Rare

Tin Whiskers

Pure tin and high tin content alloy plating finishes have received significant scrutiny due to reliability concerns associated with tin whiskers. Tin whiskers are hair-like crystals that can grow spontaneously from the surface of tin and high tin content alloys and, in some cases, can potentially cause electrical shorts. Proposals for tin whisker mechanisms link whisker growth to the release of stress that has been induced in the plating finish.[5-10] A comprehensive compendium of tin whisker studies provides an overview of the phenomenon.[11]

Despite significant effort within the electronics industry, the fundamental mechanisms that cause whisker formation are not fully understood. In addition, numerous studies have proposed accelerated tests for longer-term validation of the absence of whiskers.[12-17] The predominant accelerated test methods that have evolved from these studies appear to have converged on the application of one or more of the following conditions:

- Stress
- Heat
- Humidity
- Thermal Cycling

Test Protocol

A test method including all of these factors has been developed for validation of lead-free plating finishes for connectors.[18] The criteria set forth in the test method requires that the maximum whisker length is less than 50 microns for a lead-free plating finish subjected to the following test conditions:

- Preconditioning:
  - Bend each sample a minimum of 90^o to a consistent R/t value, with R/t ratio less than or equal to 6

  Or, optional preconditioning:
  - Temperature Cycling (–55^oC to 85^oC; 20 min. cycle, 7 min. dwell; 500 cycles)

- Test Environments (all exposures – 6 month duration)
  - Dry heat at a temperature of 50 +/- 5^oC, uncontrolled humidity;
  - Heat and humidity storage at a temperature of 52 +/- 5^oC and 90% +/- 5% Relative Humidity;
  - Room temperature storage, 23 +/- 5^oC.

Testing completed to date has shown that some pure tin finishes can meet this specification.

Whisker Mitigation

The possibility of whisker formation is always present in high tin content coatings. However, measures can be taken in order to mitigate their formation. The following steps have been effective in reducing the risk of whisker formation:

- Plate nickel as an underlayer (1.27 micron [50 microinch] minimum) over the substrate;[19]
- Use a smooth, annealed substrate with reduced stress;[20]
- Apply a 5-10 micron (200 – 400 microinch) tin coating;[21]
- Reflow or fuse the tin (application dependent);[22]
- Use hot tin dip (application dependent);[23]
- Use a precious metal coating (application dependent);
- Use a conformal coating to contain whisker growth (application dependent).[24]

Research continues into the fundamental causes of whisker formation and as those causes are identified, associated methods to address them will follow.

In addition to the aforementioned mitigation techniques, it is important to employ good practice guidelines (e.g. optimized bath parameters, current density, cleaning, impurity control, and low carbon content) in the plating of pure tin. Not all plating chemistries are equal in their ability to suppress whisker formation. Therefore it is important that they be qualified to a standard test such as the one listed above.

Based on property, performance and cost criteria, tin is the best candidate for replacing tin/lead in lead-free applications. Tin may not be suitable for some applications, but the selection of any lead-free replacement finish should first consider tin. Other coatings should only be considered if pure tin is not capable of providing the necessary performance.

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