Tin Plating at Tyco Electronics

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Abstract:
This document reviews the tin plating processes in use at Tyco Electronics. In particular we examine the thicknesses of tin plating and typical applications. Included in the review is a discussion about the use of nickel plating as a barrier layer and its role in whisker mitigation. Key performance metrics for tin plating are considered with references to more detailed information and test reports. Lastly, Tyco Electronics’ qualification process for tin plating is described with an emphasis on control for tin whisker mitigation.
Introduction:

Lead free electronic manufacturing has been mandated by several directives from the European Union. The impact of conversions required to meet these directives has been far reaching and has real impacts on the process yields, availability and performance of these products. At Tyco Electronics, we manufacture an enormous variety of passive electronics components. Previously, many of these products had used tin/lead plating as a contact interface material or in the solderable interface. In previous publications we reviewed the reasons for selecting pure tin as the replacement for tin/lead and the general issue of tin whiskers. This document provides information about the use of tin plating at Tyco Electronics, our qualification process, performance of tin platings and our strategy for conversions.

Typical Tin Platings at Tyco Electronics:

For passive electronic components, the biggest challenge for RoHS compliance is the elimination of lead from the plating process. In the past we plated tin/lead alloys, typically with a lead content of 7% by weight. The platings were either bright or matte finishes. Bright finishes have a submicron grain size and are generally reflective. Matte finishes have grain sizes in excess of 1 μm and are dull or non-reflective in appearance.

Connector products typically include multiple regions which have different functional requirements. Table 1 shows the common regions in connector products and the plating finishes that are normally used in those regions.

<table>
<thead>
<tr>
<th>Contact Element</th>
<th>Underplating</th>
<th>Traditional finish platings</th>
<th>RoHS compliant finish platings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separable interface</td>
<td>Nickel (1.3μm)</td>
<td>Gold, gold flashed palladium nickel, silver, tin/lead (bright and matte), tin (bright and matte), hot tin dip</td>
<td>Gold, gold flashed palladium nickel, silver, tin (bright and matte), hot tin dip</td>
</tr>
<tr>
<td>Crimp</td>
<td>Nickel (1.3μm)</td>
<td>Typically tin/lead or tin, hot tin dip</td>
<td>Typically tin, hot tin dip</td>
</tr>
<tr>
<td>Insulation displacement</td>
<td>Nickel (1.3μm)</td>
<td>Typically tin/lead or tin</td>
<td>Typically tin</td>
</tr>
<tr>
<td>Press-fit contact</td>
<td>Nickel (1.3μm)</td>
<td>Typically tin/lead or tin, limited use of gold</td>
<td>Typically tin; tin/lead still offered as a RoHS compliant finish</td>
</tr>
<tr>
<td>Solder tail</td>
<td>Nickel (1.3μm)</td>
<td>Typically tin/lead or tin</td>
<td>Typically tin</td>
</tr>
</tbody>
</table>

A key observation from Table 1 is that nickel underplating is used on most products. Examples of connector products are shown in Figure 1. These products are
Examples of components which utilize duplex plating processes; these are processes where the final surface finish is dependent upon the location on the connector. In many cases, these products are tin plated on the solder tail and gold plated on the separable interface. Gold plating requires a barrier layer between the gold and the copper base metals in order to reduce the diffusion rates of copper through to the gold surface. A nickel barrier of 1.3 microns substantially reduces copper diffusion rates. The nickel barrier is also beneficial under tin plating to reduce copper diffusion which can lead to the formation of copper-tin intermetallics. Copper-tin intermetallics can reduce solderability and induce compressive stress in the tin deposit, a significant contributor to tin whisker formation.

Figure 1. Examples of connector products which utilize duplex plating and employ a nickel barrier layer under the tin and gold plating.

Figure 2. Example of a FASTON® quick interconnect product. These products are tin plated and do not typically utilize a nickel barrier. This product has performed reliably in this form for 50 years.

Bright tin and matte tin each have engineering advantages and disadvantages in passive electronic components. Depending on the application, a product engineer may specify bright tin. Bright tin provides a shiny, aesthetically pleasing surface finish. It
also provides a somewhat lower coefficient of friction when compared to matte tin.

Figure 3 shows some examples of applications which may benefit from bright tin plating. Press-fit interconnects can use bright tin plating to reduce the required insertion forces; excessive forces can lead to damage of the plated through hole in the PCB.

Matte tin is preferred by some customers. Matte tin is typically less difficult to control in a plating manufacturing setting than bright tin. Matte tin also has some differences in the solderability performance compared to bright tin (more on that subject later in this document).

A key difference between matte and bright tin is the visual appearance of these two finishes. Bright tin has a smaller grain size and products made with bright tin have a smooth reflective surface. The degree of brightness, i.e., how reflective the surface is, can vary from part to part. This is a result of differences in the plating conditions used to make the parts as well as some difference in the metallurgy of the tin plating. Matte tin plating offers a dull, non-reflective surface that varies in color from ash-white to mid grey. Again, plating process parameters affect the color and uniformity of the appearance. Since the surface of a matte tin plated part is non-reflective, superficial damage to the plating is easily seen with the naked eye. Matte tin is inherently softer than bright tin and is more susceptible to handling damage. Some parts are packaged loose which will cause them to contact each other during transport. This can lead to superficial damage to the tin plating. Figure 4 shows an example of RF connector housings finished with bright tin and matte tin. The bright tin plating better resists...
localized deformation from handling than the matte tin plating. Also, matte tin is more likely to show fingerprint marks than bright tin. These are all aesthetic issues and do not generally relate to the technical performance of the product.

Figure 4. RF connector plated with bright (left) and matte (right) tin finishes.

Tin plating can also come in the form of hot tin dip and electroplated/reflowed tin. In the former case, the tin is applied similar to soldering – the copper alloy strip is drawn through a molten tin tank and a thin layer of tin is coated on the surface. This process produces a coating of tin on top of a thin copper-tin intermetallic layer on top of the copper alloy. A nickel barrier is not used. The intermetallic layer and the very large grain size of these deposits prevent the formation of tin whiskers. The same approach is true for electroplated/reflowed tin. In this case the tin plating is applied, typically directly on copper, then immediately reflowed in a convection oven. These products have been used reliably for decades without whisker growth. These coatings are also endorsed by the iNEMI Users group as a tin whisker mitigated finish.

The plating thicknesses for tin plating used at Tyco Electronics vary as a function of the product application. Table 2 shows typical plating thicknesses for tin plating. In general, tin thicknesses are lower than the 10 μm thick coatings used in the leadframe industry. Thicker coatings would be problematic to process and handle for connector applications and could lead to higher mating forces for separable contacts.
Table 2. Typical Tin Plating Thicknesses in Connector Products.

<table>
<thead>
<tr>
<th>Application</th>
<th>Tin thickness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solder tail</td>
<td>3 to 5</td>
</tr>
<tr>
<td>Separable contact</td>
<td>1.5 to 3.5</td>
</tr>
<tr>
<td>Crimp</td>
<td>3</td>
</tr>
<tr>
<td>IDC</td>
<td>2 to 3</td>
</tr>
<tr>
<td>Press-fit contact</td>
<td>0.8 to 1.5</td>
</tr>
</tbody>
</table>

**Performance of Tin Platings:**

In connector applications, there are a number of key performance factors which are critical to ensure reliability of the devices. Several of these will be reviewed here with additional information available elsewhere.7

For many connector applications, tin serves as a terminal finish for a separable contact interface. Typically, the mating interfaces are both tin plated. In order to measure the electrical performance of the interface, AMP pioneered the development of the electrical contact resistance probe.8,9 This is a four wire electrical measurement of the two mating interfaces under dry circuit test conditions (50mV maximum voltage, 50mA maximum current) with variable applied load and wipe. The test uses a 6mm sphere mated against a flat coupon.

Figure 5 below shows the performance of matte tin plating mated to matte tin plating. Three curves are shown, each of which represent the median performance of 18 replicate datasets. The data represent the as-plated state and the performance after 50 and 500 hours of heat aging at 125°C. The thermal aging process increases the oxidation of the tin; it also promotes the formation of tin intermetallic compounds which can oxidize to form deleterious electrically insulating compounds on the surface of the tin. Figure 5 shows that the heat aging has an initial impact on the resistance at low normal forces (below 100g). The difference in performance does not change as the contacts are aged for longer periods of time. This demonstrates that the tin plating encourages a low and stable electrical contact resistance.
Surface corrosion and oxidation of tin can contribute to degradation of the contact resistance of some plating finishes. Electrical contact to a tin plating layer is made by providing sufficient normal force to fracture surface oxides and corrosion products and produce a metal-to-metal interface. Tin oxide forms quickly on the surface after plating and proves to be a chemically robust and tenacious barrier. This barrier virtually eliminates corrosion from typical corrosion media, such as industrial mixed flowing gas. Several tests were run to examine the role of industrial mixed flowing gas on tin plating contact resistance. The results show no effect on performance; i.e., parts exposed to mixed flowing gas performed the same as parts which were fresh plated.

The formation of tin oxide prevents corrosion yet is deleterious in aspect – fretting corrosion. Fretting corrosion is the excessive buildup of tin oxide due to repeated exposure of nascent tin to air. Figure 6 shows a schematic of how this occurs in a separable contact interface. Fretting corrosion tests on tin and tin/lead platings have shown that the performance is equivalent for both finishes.  

Figure 5. Contact resistance performance of matte tin plating, as plated and after 50 and 500 hours of heat aging at 125 C.
Some electrical connectors use crimp technology to join a contact to a wire or cable. Changing the terminal finish of the crimp has no effect on the electrical performance of these interconnects. A series of crimps were made in tin and tin/lead finishes then exposed to severe environmental test conditions used in the automotive industry. The results shown in Figure 7 show the equivalence of the tin and tin/lead surface finishes in crimp contacts.\[11\]
The most common use of tin plating is for promoting and preserving solderability. Tin platings of 1 to 6 um provide a solderable finish, comparable to tin/lead finishes. There are several methods used to predict and measure solderability of a terminal finish. Two of the most common are the so-called “dip and look” method and the wetting beam balance test.  

The dip and look test is performed according to JEDEC J-STD002A and a similar test using lead free solder. Parts are dipped in flux for 5 seconds then immersed in the solder for 5 seconds. The parts is examined for the extent of solder wetting on the surface. A part with greater than 95% coverage of solder is deemed acceptable. Tin plated parts were examined using this method and submerged in tin/lead solder and tin-silver-copper solder for lead free applications. Prior to testing, 1/3 of the parts were heat aged and 1/3 of the parts were steam aged (8 hours) to simulate product aging before soldering. Each of the parts passed this solderability test with either tin/lead solder or lead free solder and thus are both forward and backwards compatible. This is the test most commonly performed in the manufacturing environment to ensure on-going product solderability. 

The second test method used for solderability is the wetting beam balance test. In this test, the part is fluxed then partially submerged into a solder pot. During the submersion process, the force required to submerge the part is measured using a delicate balance. The insertion process produces a characteristic diagram of force versus displacement with several key features which relate to solderability. During insertion, the surface tension of the solder initially resists insertion by the terminal. This appears as a downward dip in the curve. At some point, the solder begins to wet the surface of the
terminal, drawing the terminal into the solder pot. The wetting force produces an upswing in the force curve.

The first key metric is the zero-cross time. This indicates the time required for the wetting force to overcome the surface tension of the solder. Acceptability conditions vary, but generally times of less than 1 second are desired. Figure 8 shows two sets of wetting beam balance curves for products tested at low tin/lead solder temperatures (simulated tin/lead reflow conditions). The data show that the matte tin has a zero cross time of about 1 second, while bright tin is slightly faster.

As the insertion continues, wetting forces reaches a maximum. Another key metric is the maximum wetting force achieved at 5 seconds of immersion when compared to the maximum theoretical value. For the data in Figure 8, both finishes show a similar maximum wetting force of 300 micronewtons. Figure 9 shows the performance of matte tin and tin/lead when submerged in lead free solder at 260 °C. The wetting speed for both finishes is slightly slower than tin/lead soldering. The curves show that the tin plating has a slightly higher maximum wetting force, but in general the responses are similar and acceptable.
Solderability shelf life is preserved by ensuring that the tin plating remains available at the solderable interface. Over time, the tin plating can convert to intermetallic materials or oxidize, which can reduce solderability. Intermetallic formation is the greatest concern for solderability shelf life. As tin plating ages, it reacts with the metals it contacts. If tin is in contact with copper, for example, copper-tin intermetallics will form readily and can grow to reach the surface of the tin plating. To reduce this effect, a nickel barrier layer is used between the tin and the copper. Nickel is a highly effective barrier against copper diffusion and significantly extends the solderability shelf life of tin plated terminal finishes. While tin-nickel intermetallics can form and reduce solderability, the growth rate of tin nickel is very slow.

Solderability shelf life is not significantly impacted by a move from tin/lead to pure tin. Tin/lead plating is nominally 93% tin, thus the small fraction of the layer that contains lead only slightly reduced the intermetallic growth rate. Figure 10 shows the intermetallic growth rates of tin on nickel and tin on copper during various storage conditions.

![Figure 10. Intermetallic growth rates for tin on nickel and tin on copper.](image)

Tin Whiskers:
Tin whiskers are single crystal growths of tin which can develop in tin and tin alloy platings after storage. Tin whisker growth is generally attributed to stress in the tin plating. Likelihood for growth of tin whiskers is related to many factors including the plating processes used to create the tin plating. A good overview of tin whiskers and their causes can be found in JEDEC JP002. Tyco Electronics has also published related scientific papers on: assessing product reliability with whisker growth, bright tin for
whisker mitigation,\textsuperscript{16} the role of electrostatic fields on tin whisker growth,\textsuperscript{17} and on zinc whiskers.\textsuperscript{18}

It is important to note here that tin whiskers are not a concern for every electronic product. Some product are intended to operate in high power applications or are fully enclosed in plastic and thus do not require whisker mitigation to perform reliably. Other products are fully encapsulated by sealants or have excessively large spacing between contacts. These products can operate safely with tin whiskers present and in many cases have operated that way for decades.

JEDEC recently published a test\textsuperscript{19} and acceptance method\textsuperscript{20} for examining tin whisker growth. The qualification requirements are similar to those previously developed by the iNEMI Tin Whisker User’s Group Acceptance Document.\textsuperscript{21} As one of the co-authors of these documents, we understand the requirements well and have created a qualification procedure for tin plating that meets the requirements of the industry standard with only minor exceptions.\textsuperscript{22} Details on the overall tin plating qualification process are provided in the section below.

For tin whisker testing, plating processes used to make our lead free tin plating must pass tin whisker testing. Since Tyco Electronics sells about 500,000 unique part numbers; we cannot test every product we sell. Our test methods have been designed to test the worst case scenarios for tin plating – these qualifications are then used to qualify other products by similarity. Quality control methods employed at each tin plating plant ensure that the plating processes are similar and produce similar tin platings.

Tyco Electronics has a broad portfolio of electronic products and the plating processes required to make them can vary depending on product geometry and plating needs. When the plating processes must differ, a new tin whisker test is completed. Tin whisker test reports that are available at the time of this writing are referenced here.\textsuperscript{23} Each of these provides details and test data on the plating process and their relative performance in tin whisker testing. In each case, the plating processes meet the acceptability requirements of the JEDEC standard.

\textbf{Qualifying Tin Plating Processes:}

The qualification process for lead free tin plating at Tyco Electronics can be shown schematically in Figure 11. Detailed procedures for this process are used to document the process and ensure compliance.\textsuperscript{24} While whisker performance is a key metric, additional performance criteria are used to assess the performance of the tin deposit.
Once a plating process has been approved, the same plating process may be used at other locations within Tyco Electronics and at our suppliers. The plating process is documented, including the chemistry of the plating process and all process control parameters. These specifications are shared (under confidentiality agreement) with our suppliers. Each plating plant that provides lead free tin plating to Tyco must adhere to these practices. For initial installations, the plant must provide a sample of plated product to Tyco Electronics for inspection and analysis. X-ray diffraction is used to characterize the crystallographic morphology of the plating and compare the orientation to known good samples on file. Known good samples are those samples that have already successfully passed the JEDEC tin whisker test. Since the crystal orientation can change if the process parameters are not followed, this test provides assurance that the process is operating according to specification. Audits of the plating plants further ensure compliance to the specification.

Once a plating process is in production, the plating plant must retain one sample per line per week for ongoing whisker inspection. The products are retained in the plating plant and inspected at 3 and 6 month intervals for evidence of whisker growth.

Lead can be found in the tin plating anodes used to provide tin metal to the plating bath. As the anodes dissolve, lead can leach into the plating bath. To ensure our products do not exceed the maximum concentration limits for lead, as per the RoHS document, the plating bath is monitored for lead content. The maximum lead level allowable for each plating process is specified in the plating process control data sheets.

Figure 11. Schematic of plating qualification testing.
Conclusions

1. Tin plating is a viable replacement for tin/lead plating in RoHS compliant applications.
2. Nickel barrier platings are typically applied to Tyco Electronics products as a barrier to copper diffusion and as a whisker mitigation process.
3. A qualification process is described which is used to provide manufacturing uniformity throughout internal manufacturing operations and the external supply base.

References:

1. See for example European Union Directives 2002/95/EC and 2000/53/EC.
5. For example, see Hilty, R., “Tin Whisker Qualification Testing – Plating Process A”, Tyco Electronics document 503-1000.
7. Please see our RoHS support center website at: http://www.tycoelectronics.com/customersupport/rohssupportcenter/TechnicalData.asp


The exceptions to our qualification are typically the elimination of preconditioning requirements that are called out in JESD201 for solder simulation. There is no evidence to support the need for this when a nickel barrier is present. In order to stress the tin plating, products are formed after tin plating to induce compressive stress in the tin plating. Forming occurs prior to environmental exposure.

Tin whisker test reports available on our internet website are:

