Lead-Free Connectors - An Overview

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Introduction

For more than 50 years, lead-bearing solders have been used almost exclusively throughout the electronics industry for attaching components to printed wiring boards (PWBs). However, such solders are now coming under close scrutiny following concerns over lead ending up in landfills, eventually contaminating ground water sources.[1] Despite scientific evidence that indicates the environmental impact of lead from electronics is extremely low (if not immeasurable)[2] , a movement to ban lead from electronics has still emerged.

In October 2002, legislation was approved in Europe banning lead from most electrical and electronic products starting 1 July 2006. Additional legislation targeting lead usage in the European Automotive industry went into effect on 1 July 2003. Although the legislation only directly covers the European community, anyone that supplies companies in Europe will also have to comply with the legislation. Molex is committed to supporting our customers in their transition to lead-free products by providing timely and effective solutions in line with their requirements. The transition to lead-free products within Molex began in 2000 and is expected to be complete in 2006, in line with the European legislation.

[1] B. Richards, “The Reality of Lead-free Soldering,” National Physics Laboratory
[2] B. R. Allenby et al., “An Assessment of the Use of Lead in Electronic Assembly,” Proc. Surface Mount Int., San Jose, CA, 1992, pp. 1-28.

Lead In Electronics

There are three primary sources of lead in electrical and electronic assemblies: the solder alloy, the printed wiring board (PWB) finish, and the component lead finish. In a typical solder joint, the solder alloy accounts for the largest contribution of lead. The PWB finish and the component lead finish contribute significantly less lead to the assembly. As a result, the initial focus of the industry has been to eliminate lead from the solder alloy. The solder alloy is supplied to the assembly through a number of methods. In a surface mount process, the solder alloy is applied as a paste through a stencil printing operation. For through-hole applications, the predominant method of delivery is through wave soldering. Lastly, repair processes commonly use solder in a wire form applied via a handheld soldering iron.
Results of numerous investigations over the last few years have led the industry to converge on the tin-silver-copper (SnAgCu) “family” of alloys as the primary replacement for the lead-bearing solders used today. For surface mount applications, a SnAgCu alloy composition close to the eutectic appears to be the most popular choice. Perhaps the biggest challenge facing the industry in adoption of this alloy is the need to accommodate its higher melting temperature (e.g. near-eutectic SnAgCu melts at approximately 217^{o}C vs. Sn37Pb at 183^{o}C). In order to accommodate the higher melting temperature, increased processing temperatures will likely be required. These process temperatures could range from 240^{o}C – 260^{o}C.

Legislation

The primary driving force behind the movement to remove lead from electrical and electronic equipment can be traced to legislation originating in Europe. In late 2002 the European Parliament approved two directives related to the reduction of electrical and electronic waste. As part of that legislation, the use of lead in most electrical and electronic equipment will be banned or severely restricted. The Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substances (RoHS) Directives call for the elimination of lead from most electronic equipment starting 1 July 2006.

In addition to these two directives, the EC has also passed a Directive on End-of-Life Vehicles (ELV) which targets lead used in automotive applications. Although lead in solders for automotive applications have a temporary exemption from the lead ban, certain uses of lead for connectors will not fall under the exemption and will have to comply with the 1 July 2003 implementation date.

In Japan, there is no legislation specifically banning the use of lead in electronics. However, there are two laws which when combined indicate that such a ban may be forthcoming. The first law, the Japanese Home Electronics Recycling Law, calls for OEMs to be prepared to collect and recycle four major products (TV's, refrigerators, washing machines and air conditioning units) by April 2001. The second law forbids these OEMs from putting any kind of waste leaching toxic elements into the environment.

There is no comprehensive legislation (either existing or pending) in the United States that requires the elimination or restriction of lead in electrical or electronic equipment.

Impact on Connectors

The connector industry has been actively engaged in investigations concerning the impact that the lead-free initiative will have on connector products. In general, the elimination of lead will affect products in two areas – the terminal plating finish and the plastic housing.

The predominant source of lead in connector products can be found in the terminal plating finish. Because many terminals are currently plated with tin-lead, a finish without the lead content will need to be adopted for future products. Tin-lead is currently used for connector applications as a solderable surface, as a contact interface and as a solderless interface (e.g. press-fit application, crimp, wire wrap). The requirements of these applications must be considered in the selection of an appropriate lead-free finish. As a solderable coating, the selected lead-free finish must provide acceptable solderability and reliability. For contact interface and solderless applications, the lead-free plating must provide an acceptable level of electrical performance (contact resistance) without undue degradation due to mating/unmating wear, fretting wear or fretting corrosion. The contact interface coating (and some specific solderless applications) must also exhibit a coefficient of friction that is sufficiently low to permit mating forces similar to tin-lead finishes. In all cases, the selected lead-free finish must also provide an acceptable level of resistance to tin whisker formation. Tin whiskers are pure tin filaments that can grow spontaneously out of tin-rich coatings. There is a concern that in certain situations, the whisker can be long enough to cause a short between adjacent conductors. Because the lead in tin-lead materials is effective in suppressing tin whisker formation, this phenomenon has received considerable attention in recent years due to the requirement to eliminate lead from electrical and electronic assemblies.

Although the plastic housing materials used in connector products do not contain lead they will still be impacted by the lead-free initiative. Significantly higher soldering process temperatures (240^oC – 260^oC) are expected for lead-free soldering processes and the plastic housing must be able to withstand those exposures. Many thermoplastic materials are used for surface mount connector products, but their ability to survive the lead-free soldering process can only be determined on a part-by-part basis. A "blanket" qualification of plastic housing materials is not possible because a product's size, shape and configuration (e.g. wall thickness) greatly influence its ability to withstand the higher temperatures without blistering, deforming or discoloring.

Lead-free Solutions

Terminal Finish

The best candidate for a replacement finish for connector terminals is pure tin. The connector industry has been reliably using pure tin finishes on connector products for over twenty years. In addition, recent internal and external studies have validated the reliable performance of pure tin for connector applications.

In the search to find a replacement for tin-lead plating for connectors, a number of candidates have been identified. They include tin (Sn), tin-bismuth (SnBi), tin-copper (SnCu), tin-silver (SnAg), gold flashed palladium-nickel (Au flash/PdNi) and gold flashed palladium (Au flash/Pd). The evaluation of these candidates require comparing them to tin-lead with respect to various criteria including:

- Solderability
- Solder Joint Reliability
- Tin Whisker Susceptibility
- Tin-Lead and Lead-free Process Compatibility
- Contact Resistance
- Fretting Resistance
- Coefficient of Friction
- Plating Process
- Scrap Value
- Cost

Most connectors currently utilize a 90% tin, 10% lead or 93% tin, 7 % lead (nominally, by weight) composition as the predominant solderable plating finish. The following Table compares each of the lead-free candidates to 90/10 or 93/7 SnPb with respect to the criteria listed above:

Criteria	Sn	SnBi	SnCu	SnAg	Au flash/PdNi	Au flash/Pd
Solderability	OK	OK	OK	OK	OK	OK
Solder Joint Reliability	OK	SnPbBi reliability[3]	OK	Not tested	OK	OK
Tin Whisker Susceptibility	Slightly higher risk[1]	Slightly higher risk[1]	Significant Risk[2]	Slightly higher risk[1]	No whisker risk	No whisker risk
SnPb and Pb-free Process	OK	SnPbBi reliability[3]	OK	Not tested	OK	OK
Contact Resistance	OK	OK	OK	Not tested	OK	OK
Fretting Resistance	OK	OK	OK	Not tested	Better than SnPb	Better than SnPb
Coefficient of Friction	OK	OK	OK	Not tested	OK	OK
Plating Process	Easier than SnPb	Difficult[4]	Difficult[4]	Very Difficult[5]	OK	OK
Scrap Value	OK	Bism uth content[6]	OK	OK	OK	OK
Cost	OK	OK	OK	Expensive	Very Expensive	Very Expensive

Footnotes:

1. Pure tin, tin-bismuth and tin-silver have all shown a slightly higher susceptibility to tin whiskering than tin-lead in published studies. The use of a nickel barrier layer has been found to minimize the risk of whisker formation. Most connector products typical use a 1.25 micron (minimum) thick coating of nickel as a barrier layer.
2. Investigations have indicated that tin-copper finishes grow tin whiskers more readily than pure tin.
3. When tin-bismuth finishes are used in conjunction with tin-lead solders, a ternary alloy of tin, lead and bismuth can form that melts at 96ºC. This ternary alloy can collect in the solder joint and cause decreased reliability in applications that approach or exceed the melting temperature.
4. For both tin-bismuth and tin-copper plating, it is very difficult to control the composition of the alloy. In the case of tin-bismuth plating, the bismuth content can drop rapidly, causing significant composition control issues.
5. Tin-silver plating chemistries require complexing agents that allow the tin and silver to deposit simultaneously. Process control for the chemistry is very difficult and the complexing agents cause significant problems for waste treatment systems.
6. The scrap value of terminals plated with tin-bismuth is substantially less than tin-lead, tin and tin-copper. The scrap material is often recycled by copper alloy producers. Bismuth is a severe contaminant in the copper alloy production process and therefore is restricted from their operations.

As can be seen from the Table above, the best candidate for replacing tin-lead as a plating finish is pure tin.

<u>Plastic Housing</u>

There are a number of engineering thermoplastic materials used for connector housings. Some have demonstrated resilience to surface mount hot air reflow processes using traditional tin-lead solders. However, the predominant lead-free solder alloy candidates require significantly higher temperatures in order to ensure proper soldering. In general, it is expected that the lead-free solder alloys will require peak soldering temperatures of approximately 260°C. A typical lead-free soldering profile may require surface mount components to be able to withstand a temperature exposure between 255°C and 260°C for up to 120 seconds.

Two of the thermoplastic materials' properties can provide an indication as to the ability to withstand the expected increase in lead-free soldering temperatures - melting point and heat deflection temperature (HDT). The melting point is the temperature at which the plastic changes from liquid to solid and is important because the material must be liquid for use in the molding process. The heat deflection temperature is the relative measure of a plastic material's ability to perform for a short period of time at elevated temperatures while supporting a load. In general, for a material to perform adequately in a lead-free surface mount connector application, it first must have a melting point above the expected 260°C peak temperature. To be reasonably assured of compatibility with lead-free surface mount soldering, its HDT should also exceed 260°C. However, there is a "gray area" in which a material may have a melting point above 260°C, but a HDT at or just below 260°C. In these cases, the particular product application must be considered and specific engineering tests may be requiredThe following chart shows melting points and heat deflection temperatures for common plastic materials used in connectors today.

Material	Heat Deflection Temperature	Melting Point
PBT	205°C	220°C
SPS	245°C	300°C
PA 6/6	250°C	255°C
PCT	255°C	310°C
PPS	265°C	320°C
PPA	285°C	330°C
PA 46	290°C	300°C
LCP	270°C	335°C

As can be seen, there are materials currently used today that will withstand the higher lead-free surface mount soldering process temperatures (PPA, PA46 and LCP) and some that will need to be evaluated according to their specific application (PCT and PPS). In general, the materials with higher temperature compatibility are also more costly. As a result, any products that require material replacement for higher temperature compatibility will also have a concurrent cost increase.

Summary

As the electronics industry moves towards lead-free products, connectors must meet the requirements associated with the change. Viable terminal plating finishes and plastic housing materials are available to meet the needs of the electronics industry, but the transition will be lengthy and complicated as electrical and electronic equipment manufacturers appear to have varying timelines for the conversion to lead-free. Close coordination and communication will be required for a smooth transition.