Global Preparations For Pb-Free Solders

Electronics Bulletin Nov 2004 Issue
Hong Kong Productivity Council Publications

By the year 2010 the worldwide transition from Pb solder to Pb-free solders will have been completed for some time, and users of electronics systems will take for granted the fact that most systems contain no Pb. There will probably be some applications where Pb solder is still used, but these are likely to be military and other specialized applications where products are not exported or where an exemption has been granted.

Anyone looking back from 2010 to today will see a somewhat confused picture. European electronics manufacturers are working under a deadline: on July 1,2006, the provisions of RoHS (Restriction of Hazardous Substances) directive will go into effect across the European Union, and Pb solder will effectively be prohibited. Actually, RoHS will permit very small amounts of Pb and other toxic substances such as cadmium to be incorporated into electronics systems, but the legislation has created its won confusion because the wording of the legislation is unclear. Does the small percentage of Pb that is allowed refer to the weight of the whole appliance, or only to the weight of the board? The laws are currently being written to make the percentages clear.

Electronics manufacturers in Europe are already producing and marketing Pb-free, or “green” products, and consumers are accustomed to seeing them in stores. At the same time, manufacturers are continuing the expensive research needed to bring all components and all boards in compliance with the Pb-free requirements.

The situation in the U.S. is quite different. The U.S. has no national legislation affecting Pb solders, but manufacturers in the

U.S. have begun the necessary research in order to be prepared for selling into global markets. There are a few Pb-free products on sale in the U.S., but far fewer than in Europe. It is not clear how U.S. consumers will react to the change.

Some Agreement on Solder Types

International agreement of a sort is emerging concerning which of the numerous available Pb-free movement had its origins in Japan, which has successfully used alloys such as tin-bismuth and tin-zinc. Some of these alloys had melting points that were actually lower than the melting point to conventional SnPb solder. Increasingly, though, the global electronics manufacturing community is turning to two types of alloys, SnAg and SnAgCu. These are the two most widely used alloy types in Europe, in the U.S., and even in Japan. Recommendations from advisory groups vary slightly from region to region. In Europe, for example, manufacturers can select SnAgCu solders that fit the formula Sn/3.4-4.1Ag/0.5-0.9Cu.

Differences in Reflow Temperatures

When a manufacturer begins the change from Pb-solder to Pb-free solder, there are several significant considerations. Pb-free solder itself is more expensive than Pb-solder. The reflow temperatures for Pb-free solder are considerably higher than the reflow temperatures for Pb-solder, and are very close to the temperature at which damage to components and to the board is likely to occur. For this reason, new molding compounds for IC packages must be used-and they are more expensive than conventional molding compounds. Other materials, such as the plate finish on the lead frame in a component, must also be changed. The manufacturer is faced not only with higher material costs, but also with the need to do the engineering that will make all of these materials work together without creating defects.

A great deal of attention is given to plastic packages, and to the boards themselves where the conventional FR4 material may have to be replaced by a newer material more tolerant of heat. But other components are affected as well, and sometimes in unexpected ways. Ceramic chip capacitors, for example, tend to delaminate when they are exposed to the higher heat of Pb-free reflow. During temperature ramp-up in the early part of reflow, the ceramic plates and the solder terminations on the capacitor expand at different rates, but the solder terminations eventually melt, thus avoiding stress. During cooling however, the solder terminations solidify while the ceramic plates are still very hot. This places stress on the plates and can cause them to delaminate from each other.

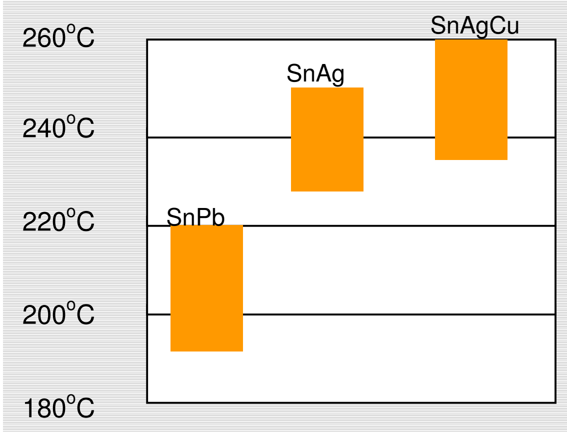
The Four Reflow Zones

For both Pb-solder and Pb-free solder, the reflow process has four stages or zones. These four zones are:

1. The pre-heat zone, where the temperature is increased from room temperature at 3°C to 5 °C per second.
2. The pre-reflow dwell zone, where temperatures are held nearly stable in order to permit all parts of the board to heat evenly.
3. The reflow zone, where temperature is raised to the highest level in order to melt the solder and permit reflow to occur.
4. The cool-down zone.

The most critical zone is zone 3, because this is where the highest temperatures occur. It is desirable to avoid temperatures of 260o and higher, because at these temperatures damage to the board and to components is very likely. In this respect, conventional Pb-solder was a very safe material because the highest temperature reached during reflow in any part of the board was about 225°C – well below the 260°C danger point. For SnAg, the highest temperature on the board is about 250°C, and for SnAgCu about 260°C [Figure 1]. These very high maximum temperatures are the primary reason that the engineering of Pb-free processes is both difficult and expensive. Much of the preparation for Pb-free solder reflow concerns potential damage to plastic-packaged ICs. There are two ways in which the high reflow temperatures can damage these components.

THE REFLOW ZONES BETWEEN PB AND PB-FREE-SOLDER MATERIAL



Differences in Coefficient of Thermal Expansion

Each of the various materials in a plastic IC package – the epoxy, the silicon, the metals – has its own coefficient of thermal expansion. When temperatures increase during reflow, each material expands at its own rate and in three dimensions. The higher the temperature, the greater the expansion. Heating components to near 260° can cause internal stresses that may be relieved by cracking inside the component.

A crack caused by differences in the coefficient of thermal expansion may be in a location where it causes an electrical failure – it may break a wire, for example, or crack the die. Electrical tests after reflow will probably find this electrical failure. The component can then be identified, and the board can be sent to rework, where the component will be replaced.

But some cracks do not cause and electrical failure immediately. In this case, there is nothing for electrical testing to find. But when the component undergoes the heating and cooling that are part of normal use of the appliance, the crack is likely to come larger. Eventually it may reach a wire, the die or another critical element, and cause an unexpected field failure.

Moisture within the Package

Plastic IC packages generally contain a small amount of moisture. The volume of moisture may be very small, but the high temperature of reflow can cause the moisture to turn into steam and increase greatly in volume. The resulting pressure can cause various kinds of damage to the package. Damage from moisture occurs with conventional Pb solder, but the significantly higher temperatures of Pb-free solder make this kind of damage even more of a threat.

On form is the infamous “popcorn crack”, so called because its formation sounds much like a single kernel of corn popping. Popcorn cracks generally originate below the die and form a circular crack around the die and extending upward or downward, often reaching the surface of the package.

But moisture can also cause delaminations between various elements in the IC package. For example, the molding compound may be separate from the face of the die. Like a crack, this delamination can expand during service until it breaks wire bonds and causes an electrical failure.

Delaminations caused by moisture expansion can also be sites where corrosion can occur inside the IC package. Moisture and ionic contaminants tend to collect in delaminations. Even very small amounts can then become a miniature electrolytic cell that begins the process of corrosion.

To provide guidelines for engineers, IPC/JEDEC in July of this year issued maximum temperature classifications for both Pb and Pb-free solders. The classifications are designed to help prevent damage from overheating, and are based on both the thickness and the volume of the component. The basic concept behind the classifications is that, during reflow, thinner and smaller packages heat up more quickly than larger, thicker packages. The new IPC/JEDEC classifications for Pb-free solders are shown below:

IPC/JEDEC classifications for Pb-free solders

Package Thickness	Volume mm^3 <350	Volume mm^3 <350-2000	Volume mm^3 >2000
<1.6mm	260 + 0^oC*	260 + 0^oC*	260 + 0^oC*
1.6mm – 2.5mm	260 + 0^oC*	260 + 0^oC*	245 + 0^oC*
>2.5mm	250 + 0^oC*	245 + 0^oC*	245 + 0^oC*

Tolerance: The device manufacturer/supplier shall assure process compatibility up to and including the stated classification temperature (this means Peak reflow temperature (this means Peak reflow temperature +0oC. For example, 260^oC +0^oC)

Source: IPC/JEDEC J-STD-020C, July 2004

This article is contributed by Keith Gurnett and Tom Adams. Tom Adams, a professional writer based in the USA, has written extensively on semiconductors and microelectronics subjects for many years.