Section 1:
Solder Reflow Basics

Introduction

Electronics assembly is the general term for joining electrical components to printed circuit boards (PCB). Surface mount technology (SMT) is the electronics assembly process where electrical component leads are joined to the PCB via individual pad connections located on the board surface.

The basic SMT process consists of the following steps:

1. Solder paste is applied to the PCB using a screen printer. Stencils designed with holes over individual pads control the solder application to the board.
2. Electronic components are positioned on the PCB using placement equipment (pick-and-place machines, chip shooters, etc.). Component leads are placed in direct contact with the solder-pasted pads.
3. The solder paste is heated until liquidus (reflowed) then cooled until the solder hardens and creates permanent interconnection between the component leads and the PCB. This process is performed in a **SOLDER REFLOW OVEN**.
4. After reflow, the assembled circuit board can be cleaned, tested or assembled into a final product.

High-volume SMT lines use automated equipment to perform these steps. These lines can typically produce a completed circuit board in less than 20 seconds, with placement machines that can position upwards of 40,000 components per hour on the PCB. However, once the solder paste is applied and the components are placed on the board, the only way to create a functioning circuit board is an effective solder reflow process.

A high-volume SMT assembly line.

Reflow Know-How: Prevent and Resolve SMT Process Problems

The reflow oven is the key to the soldering process. Properly working ovens should be "invisible" to line operators. Yet if process problems occur during board production, the reflow oven is often the first place manufacturing engineers look to find answers. Knowing the reflow process and ways the oven effects soldering results is critical to consistent SMT production.

The purpose of the ***Reflow Technology Handbook*** is to explain the reflow process in a way that answers basic soldering questions. The handbook also helps qualify the performance factors you should consider to find a reflow oven to best suit your process needs.

Solder Alloys

The vast majority of electronic interconnections are accomplished with tin-lead alloy solders.

Tin

Pure tin is a soft, shiny metal that is most often found in ore form rather than metallic form. It is easily shaped and molded without breaking.

The essence of the solder process is the ability of molten tin to dissolve nearly any other metal. Copper is one of those metals, and copper is used extensively in the manufacture of printed circuit boards. In the next subsection we will discuss the role of compounds formed when surface copper is dissolved by tin.

Lead

Lead, when exposed to air, has a dull gray appearance. Like tin, lead is an easy metal to work with because it is both soft and flexible.

Lead does very little to aid the bonding of metal to metal during soldering. However, when lead is combined with tin at a ratio of 63% tin to 37% lead, the melting point of the resultant alloy becomes lower than that of either pure tin or pure lead. The abbreviation for tin in chemistry is Sn and for lead is Pb, so this alloy is usually written Sn63Pb37.

This type of alloy is called a eutectic composition. Pure tin melts at 232°C (449°F) and pure lead melts at 327°C (621°F). The melting temperature of Sn63Pb37, however, is 183°C (361°F). At this temperature, the alloy goes from a completely solid to a completely liquid state without going through a “pasty” stage. This is called the eutectic temperature.

When eutectic tin/lead is heated to a temperature higher than 183°C it is said to be in its liquidus stage. The relatively low melting temperature has made eutectic tin/lead the solder alloy of choice for printed circuit board assembly because circuit boards made of FR4 substrate or similar materials can be safely processed at this temperature.

In addition, the low melting temperature means that the equipment that solders the boards does not have to operate at higher temperatures. Finally, a benefit most managers and accountants appreciate is the low cost of tin/lead compared with other alloys.

Intermetallic Compounds

As mentioned above, molten tin dissolves most metals. During the solder process, the primary metals in the solder form compounds with the metals in component leads and circuit board pads at boundaries between the solder and the pad or lead. (Figure 1-1).

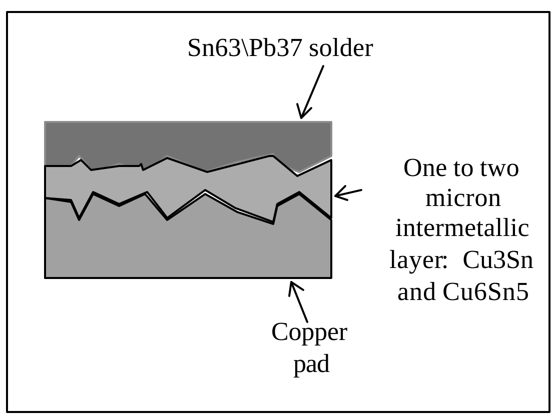

Figure 1-1. The intermetallic layer at the boundary of the solder and copper surfaces.

These intermetallic compounds form a boundary layer that is extremely strong when it is no thicker than one to two microns. At this thickness the natural brittleness of the intermetallic layer is not a problem.

As the intermetallic layer thickens, it becomes more susceptible to cracking. The cracking is caused by expansion and contraction of the circuit board substrate as it heats and cools during normal operation of the electrical device in which it operates. The thickness of the intermetallic layer is controlled primarily by controlling the liquidus time of the solder. Most solder manufacturers recommend a liquidus time between 45 and 60 seconds. *(See Section 3 – Profiling for additional information.)*

Other Solder Compounds

Some special applications require alloys other than eutectic tin/lead solder. A common application for other solder compounds is double sided surface mount assembly. To solder on both sides of the board requires bottom side components be soldered with an alloy that has a melting temperature higher than eutectic tin/lead. Then, the board is flipped over and top side components are soldered with an alloy that has a melting temperature lower than that of eutectic tin/lead. The higher melting temperature allows the solder used for the bottom side components to stay solid during the top side reflow, reducing the risk of intermetallic growth.

Bismuth and Low Temperature Soldering

The addition of bismuth to tin/lead solder reduces the melting temperature significantly without adding serious solderability problems. A typical tin/bismuth/lead alloy is Sn43/Bi14/Pb43. This alloy has a pasty stage from 143°C-163°C (289°F-325°F). The pasty stage means the solder is no longer completely solid at 143°C, but not yet completely liquid until it reaches 163°C.

The lower melting temperature of this and similar alloys means that the flux used in the solder paste must also be different from that used in eutectic tin/lead. This may change the shape of the thermal profile. Consult your solder paste supplier for the recommended thermal profile for the particular low temperature solder you use.

Another matter to consider when you use low temperature solder is that the melting temperature of the solder is affected by any metals dissolved from leads or pads that were plated to prevent oxidation. Usually these contaminant metals raise the melting point of the solder. If this becomes a problem in your process, it might be necessary to strip the plating just prior to the low temperature soldering operation.

Silver

Some printed circuit boards have components with silver plated leads. As noted in the section on tin above, molten tin dissolves most metals, including the silver in silver plated leads.

One way to reduce the amount of plated silver that dissolves in the molten tin/lead is to add a small quantity of silver to the solder itself. The alloy Sn62/Pb36/Ag02 (62% tin, 36% lead, 2% silver) is good for this application.

Another popular silver alloy Sn96/Ag04 melts at 221°C (430°F) and is sometimes used for double sided reflow.

Lead Free Solder

Among the most discussed topics in the late-1990s is the effort to remove lead from electronic products. Concerns about ground water lead contamination are forcing the debate. Many governments are demanding that Tin/Lead alloys be phased out and replaced with lead-free solders. Solder paste manufacturers are working to create new alloys to meet what is likely to become a new regulatory requirement for SMT assemblers.

According to Phil Zarrow of ITM Consulting, the most promising lead-free alloys are in the Tin-Silver family with variations incorporating relatively low amounts of copper of bismuth. (*Circuits Assembly* – August 1999). These alloys cost about the same as Sn63/Pb37, but the 221°C melting temperature means that electronic components must be exposed to reflow temperatures as high as 240°C for effective soldering.

Another reflow alloy being considered is Sn91.8/Ag3.4/Bi4.8. Adding bismuth results in a melting range between 208°C and 215°C (Phil Zarrow: *Circuits Assembly* – August 1999).

Lead-free alloys are being evaluated to verify their performance to standard Tin-Lead compounds. Anyone involved in SMT production should be prepared to convert their lines to lead-free soldering by the mid-2000s.

Flux

Oxygen in the air combines with metal on circuit board pads and surface mount component leads and forms oxides. This oxidation blocks the molecular attraction between the solder and the metal at the surface of the pad or lead.

Flux removes oxides from pad and lead surfaces, as well as from the surfaces of the solder particles themselves. Molten solder then can flow evenly over the surface of pads and leads and form intermetallic bonds with them.

Surface Tension and Wetting

Surface tension is the attraction that molecules at the surface of a drop of liquid have for each other. If that attraction is greater than the attraction for the material which the liquid touches, the liquid will not spread, but will remain in drop form.

Surface tension explains why a drop of rainwater on a waxed car stays in drop form. The wax surface is intended to repel water and keep it from bonding to the car's surface.

The earth's gravity works against surface tension and tries to flatten the raindrop into an oval. If the attraction of the molecules of rainwater for each other is greater than the pull of gravity and the attraction of the car's surface, the drop will remain somewhat round and self contained. If gravity is stronger and the wax is worn down, the drop will disperse.

Wetting is the word used to describe the extent that solder flows over the surfaces to be bonded. Poor wetting is the result of solder particles in the paste bonding to themselves to form a sphere, so the edges of a poorly wetted solder joint are rounded rather than flat.

Wetting is measured by the angle made where the edge of a layer of solder paste meets the pad on a circuit board. Poor wetting leaves a thick edge and a large angle (Figure 1-2).

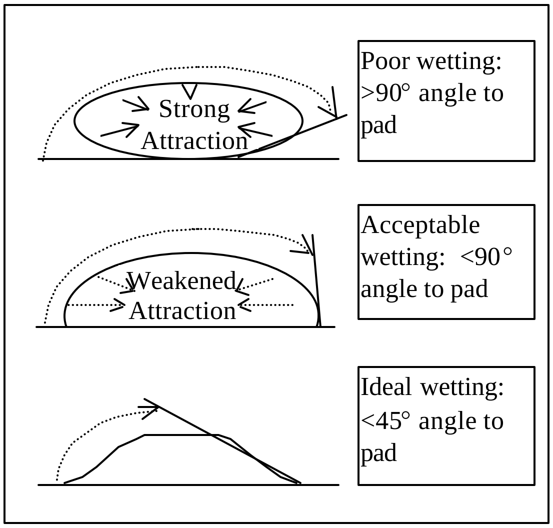

Figure 1-2. The effect of surface tension on wetting.

What Flux Cannot Do

Even the strongest flux does not remove thick layers of oxidation. At most, flux removes the oxide a few molecules thick from a metallic surface.

Flux Chemistry

The basis of flux is usually a solid that has been dissolved by a solvent. The most commonly used solid for many years in PCB assembly was rosin. Rosin is derived from pine trees, and is an inert substance, which does not conduct electricity at room temperature. Rosin becomes liquid between 125°C and 130°C (257°F -266°F).

A substance known as water white flux (abbreviated w/w) is pure rosin dissolved in isopropyl alcohol. Water white is mild and able to remove only the thinnest layers of oxide during soldering.

To make rosin based flux more aggressive when removing oxides, activator substances are added. Many different substances are used as activators, but it is not as important to know exactly what the activator is, as to know:

- at what temperature the activator begins to work, because this affects the thermal profile in the reflow oven, and
- how corrosive the activator is, which determines whether the board needs to be cleaned and what cleaning solution is necessary. Your solder paste supplier can give you this information.

RMA and RA are the most common activator fluxes. RMA is mildly activated rosin based flux, and is much stronger in removing oxidation than water white. RA is activated rosin based flux, and is more aggressive than RMA.

Flux Residue and Cleaning

Water white and RMA fluxes leave a residue after soldering that is not corrosive or electrically conductive at levels high enough to affect the function or life of a circuit board. Residue from these fluxes has often been removed by washing, however, for aesthetic reasons, or because it is non-conductive it interferes with bed of nails testing devices.

The residue from RA fluxes can be more corrosive, and usually needs to be cleaned from the board. RA fluxes require two types of cleaning:

1. A nonpolar solvent to remove the rosin, as well as any oils or waxes that may have contaminated the board during handling. Nonpolar solvents such as chlorofluorocarbons

(CFCs) were used for years, but environmental concerns eliminated them from consideration. Semi-aqueous cleaning systems use a terpene as the nonpolar solvent. The terpene is then removed by a surfactant, which makes the terpene soluble in water.

2. A polar solvent, which is usually very pure water, removes the activator, as well as salts and other water-soluble contaminants that may have gotten onto the circuit board during handling.

A substance called a saponifier can be used to clean PCBs also. One way to understand and remember what a saponifier does is to know that the root word is *sapo*, which is Latin for soap. A saponifier acts like soap in reacting with substances that are not water soluble (oils, for example) so that they become water soluble and can be washed off.

Water Soluble Flux

Water soluble fluxes usually are based on the oxidation removing qualities of an organic acid such as citric or glutamic acid. Organic acid fluxes are more aggressive than RMA, so they provide good cleaning, but they are usually corrosive as well. Because of the corrosiveness of these fluxes, a thorough water wash following solder reflow is necessary. Boards stored without washing for more than an hour after exiting the reflow oven may have serious oxidation buildup.

No Clean Fluxes

Millions of printed circuit boards are manufactured that are never cleaned following solder reflow. This is especially true in consumer product electronic assemblies, primarily to save money. Inert, non-corrosive flux residues are left on the boards and do not cause problems.

By virtue of the fact that the boards are not cleaned, it can be said the fluxes used are no clean fluxes. However, in recent years the term no clean has come to refer to a type of flux specifically designed so flux residues are minimized. No clean fluxes generally have the same aggressiveness as RMA fluxes.

Lower residue is achieved in no clean fluxes by using a lower solids content than in other fluxes. Solids content refers to the ratio of solvent thinner to solid component in the flux. A typical no clean flux now has less than 15% solids, compared with 50% in other types of flux.

Since the solids in a flux are the basis for its effectiveness, reducing the solids content tightens the process window for no clean fluxes. Flux density control thus is more important than with other fluxes.

No clean fluxes can be either rosin or resin based. The most noticeable difference is that rosin based no clean flux produces a thin layer of sticky residue that can be removed if desired. Resin based no clean flux produces a thin residue that is hard and not sticky, but cannot be removed by water or other solvents. This can occasionally be a consideration if rework is necessary.

Nitrogen gas inert atmosphere solder reflow is often helpful when no clean flux is being used, especially when it is used with fine pitch surface mount devices. Nitrogen gas eliminates oxygen from the heat chamber of the reflow oven so that oxidation is minimized. *(See Section 4 – Inert Atmosphere Soldering for additional information.)*