The Basics of Soldering

IN SUMMARY

In this article, I will present a basic overview of soldering for those who are new to the world of soldering and for those who could use a refresher. I will discuss the definition of soldering, the basics of metallurgy, how to choose the proper alloy, the purpose of a flux, soldering temperatures, and typical heating sources for soldering operations.

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Throughout history, as society has evolved, so has the need for bonding metals to metals. Whether the need for bonding metals is mechanical, electrical, or thermal, it can be accomplished by using solder.

Metallurgical Bonding Processes

Attachment of one metal to another can be accomplished in three ways: welding, brazing, and soldering. The most significant difference between these methods is the processing temperature and melting temperatures of the metal. Welding is the highest temperature process, often performed at temperatures above 1500°C. While brazing is accomplished at temperatures above 450°C, only soldering can be performed at low enough temperatures to take place in the presence of organic materials, such as printed wiring boards (PWBs) and the plastics in electronic component packages. Thus, soldering is a fundamental technology that enables electronic assembly. Without soldering, we would not have an electronics industry.

Soldering uses a filler metal and, in most cases, an appropriate flux. The filler metals are typically alloys (although there are some pure metal solders) that have liquidus temperatures below 350°C. Elemental metals commonly alloyed in the filler metals or solders are tin, lead, antimony, bismuth, indium, gold, silver, cadmium, zinc, and copper. By far, the most common solders are based on tin. Fluxes often contain rosin, acids (organic or mineral), and/or halides, depending on the desired flux strength. These ingredients reduce the oxides on the solder and mating pieces.

Basic Solder Metallurgy

As heat is gradually applied to solder, the temperature rises until the alloy's solidus point is reached. The solidus point is the highest temperature at which an alloy is completely solid. At temperatures just above solidus, the solder is a mixture of liquid and solid phases (analogous to ice mixed with water). Further temperature increases bring the liquidus point, the lowest temperature at which the alloy is completely molten. The solder remains in the fully liquid or molten state at temperatures above the liquidus point. Upon removal of the heat source, the cycle is reversed, i.e. the solder's physical form changes from completely liquid to liquid and solid to completely solid. Graphs that plot temperature vs. composition are known as phase diagrams and are widely used to determine the phases and intermetallic compositions of solder at a given temperature.

Figure 1. Cross-section of an acceptable solder joint with surface graping.

Soldering 101 — A Basic Overview

The temperature range between the solidus and liquidus is known as the plastic zone of the solder. If the solder joint is mechanically disturbed while the assembly is cooling through its plastic region, the solder crystal structure can be disrupted, resulting in a high electrical resistance. Such solder joints with high electrical resistance are referred to as cold solder joints and are undesirable. To avoid this problem, it is best to select a solder that has a narrow plastic range, typically less than 10°C. There are some solder alloys that have no plastic region (liquidus = solidus). These are known as eutectic alloys. As heat is applied to a eutectic alloy, the solder passes directly from solid to liquid instantaneously at the eutectic melting point of the solder.

Alloy Selection

The most common solder is tin/lead-based. The eutectic version, Sn63/Pb37, has a melting point of 183°C; the Sn60/Pb40 variation has a melting range of 183°–188°C (183°C is the solidus; 188°C is the liquidus). Higher lead versions of this alloy system have higher melting ranges. Often, 2% silver is added to the 63/37 mix to strengthen the alloy or prevent excessive silver dissolution from silver-plated circuitry. This alloy, Sn62/Pb36/Ag2 has a melting range of 179°–188°C. Alloy compositions can accommodate various needs: lead-free, gold-containing, indium-containing for soldering to gold, thermal fatigue resistant, or specific (high or low) melting points. A multitude of solders with specific physical properties are available to match specific design requirements.

Figure 2. An example of good solder wetting (A) and poor wetting (B).

Fluxes

The purpose of a flux is to remove surface oxides on substrate metallizations, component leads, and the solder itself to allow adequate wetting. Flux selection is based on the substrate/component metallization to be soldered and/or the desired cleaning procedure. Metallizations that are prone to forming tenacious oxides will require a stronger flux. Fluxes can be no-clean (i.e. the PCB assemblies do not require cleaning after soldering), solvent cleanable, such as RMA (resin mildly activated) fluxes, or water-washable.

To form a good solder bond, the solder alloy must wet adequately to the substrate metal. This means that no surface oxides can be present. Because most non-precious metals and alloys oxidize to some degree, the oxides must be removed. Fluxes provide three basic functions:

1) Reducing (chemically dissolving) oxides on the surface of the substrate metallization and the solder alloy itself,

2) Coating the solder joint location. Fluxes displace the air and protect the surface so that oxides do not reform during the soldering process. Since soldering requires elevated temperatures, there is more energy for oxides to form. Preventing re-oxidation during soldering can be just as important as removing the initial oxides, and

3) Promoting the flow of the solder. Molten solder alloys are subject to surface tension physics just like any other liquid. Using an automobile finish as an example, flux can be thought of as an anti-wax. On a freshly waxed automobile, water will bead up, while on an unwaxed automobile finish, the water easily flows.

Figure 3. Cross-section of a large-crystalline grain structure solder joint.

Soldering Temperature

As a rule of thumb, the soldering temperature should be 30°–50°C higher than the liquidus temperature of the alloy. This ensures that enough heat energy is available to form a good metallurgical bond between solder and substrate. With lower temperature solders, it is better to gravitate toward the 50°C end of this range. In a lower temperature process, there is not much energy inherently present to form a good solder joint.

The time that the solder is molten should be kept to the minimum required to acheive a good bond. Excessive time and temperature will cause intermetallic formation within the joint to proliferate. This typically leads to a brittle solder bond. Depending on the process, the time above liquidus (TAL) of the solder will typically range from a few seconds (for hand soldering with wire) to a minute or more (as with solder paste in a reflow oven). When performing multiple soldering steps (step soldering), it is advisable that the first solder alloy have a solidus temperature of 50°C higher than the liquidus of the solder alloy used in the next step, and so on.

Soldering Heat Sources

Heat sources for soldering range from low-tech handheld soldering irons to high-tech lasers. Typical equipments include soldering irons, hot plates, static convection ovens, belt furnaces (both convection and IR), induction heating apparatuses, resistance heating devices, and lasers. The heat source can be dependent on the form of solder used; for example, solder pastes for PCB assembly are commonly used with multi-zone belt furnaces. This is because solder pastes are best used with a temperature profile that incorporates a specific temperature ramp-up and cool-down.

Summary

Creating a metallurgical solder bond can be very easy if the appropriate metallizations, alloys, fluxes, and processes are used. Although soldering has a wide variety of applications, because of its ability to form a solder joint at low temperatures that circuit boards and electronic components can tolerate, it is a foundation technology for the electronics industry. Without the marvel of soldering, we would not have mobile phones, personal computers, televisions, and all of the many electronic devices that we take for granted. SMT

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