Soldering 101 — A Basic Overview

This application note provides a basic understanding of the soldering process to individuals new to the field of soldering. It is not meant to be an exhaustive treatment of the subject, but simply a brief overview.

Metallurgical Bonding Processes

The attachment of one metal to another can be accomplished three basic ways: 1) welding, 2) brazing, and 3) soldering. The most significant difference between these methods is the process temperature.

1) **Welding** typically involves the bonding of high-melting temperature metals such as steel to steel. The process can be performed with or without the addition of a filler metal. Ideally, the filler metal has properties that match the properties of the adjoining pieces. This process requires very high heat, typically provided by an acetylene torch or DC arc welder. Both metallic surfaces being joined are melted locally to effect the bond.

2) **Brazing**, unlike welding, is a lower-temperature process. It does not involve melting of the substrate surfaces, but rather depends on the formation of intermetallics to provide adhesion. The process uses a filler alloy (braze) that has a melting temperature above 350°C but lower than the melting temperature of the metals being bonded. Brazing fluxes are required to remove oxides from the filler material and mating pieces, and to promote good flow of the molten filler. Typically, brazing fluxes contain borates and fluorides and are considered corrosive for electronics use.

3) **Soldering,** like brazing, uses a filler metal, and in most cases, an appropriate flux. The filler metals are typically alloys (there are some pure metal solders) that have liquidus temperatures below 350°C. The elemental metals typically alloyed in the filler metals or solders are: tin, lead, antimony, bismuth, indium, gold, silver, cadmium, zinc, and copper. The 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.

The Physical Forms of Solder

The common forms of solder are: 1) paste, 2) preforms, 3) spheres, 4) wire, 5) ribbon and foil, and 6) shot and ingot (bar).

1) **Solder paste** is a mixture of a pre-alloyed solder powder and a flux vehicle that has a creamy peanut butter-like consistency. The flux vehicle portion of the paste is made with rosin or resin, activators, viscosity control additives, flux chemicals, stabilizers, and solvents. The ratio of powder to flux (referred to as "metal load %") will vary slightly with different alloys and different applications. Solder pastes are commonly used in electronics industry for PCB assembly in surface mount technology applications. An example of a typical use would be in the assembly of PCBs used in computers and cellular (mobile) phones. Pastes can be "printed" through a stencil onto the circuitry. After printing, components are placed onto the bonding pad areas of the printed circuit and are held temporarily by the tackiness of the paste. Boards are then sent through a reflow oven where a specific temperature profile is used to evaporate the solvent, activate the flux, and melt the solder alloy. The type of flux used is dependent on the desired activity and whether or not cleaning is an option.

   The three basic flux formulations are: a) no-clean, b) RMA, and c) water-washable

   a) **No-clean** fluxes are mild activity fluxes that produce post-soldering residue which is both non-conductive and non-corrosive. Therefore, the residue can be safely left on the assembly with no corrosion concern, and cleaning is not required. No-clean flux residues can be removed after soldering if desired. Cleaning procedures are generally similar to RMA flux residue removal.

   b) **RMA** fluxes (Rosin Mildly Activated) are also mild activity fluxes. RMA fluxes were the precursor to no-clean formulations. However, the RMA flux residues may be conductive and/or corrosive after soldering. Removal of the flux residue is recommended. RMA flux residues, being rosin-based and organic in nature, are generally removed with a solvent/saponifier.

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www.indium.com askus@indium.com

ASIA: Singapore, Cheongju, Malaysia: +65 6268 8678
CHINA: Suzhou, Shenzhen: +86 (0)512 628 34900
EUROPE: Milton Keynes, Torino: +44 (0) 1908 580400
USA: Utica, Clinton, Chicago, Rome: +1 315 853 4900

c) **Water-Washable (Soluble)** fluxes are higher activity fluxes designed for removal after soldering. The flux residue is cleanable using water. The water is typically heated and used in a pressurized spray. Water-washable flux residues are corrosive and conductive after soldering, therefore removal is mandatory.

Note: Specific flux residue cleaning procedures and products (saponifiers and solvents) can be recommended by the solder provider.

2) **Preforms** are generally flat, manufactured solder shapes. Solder preforms come in standard shapes such as squares, rectangles, washers, frames, and discs manufactured to custom geometries. Preforms can be coated with a flux (by the solder provider) to eliminate an assembly step, or a liquid or paste flux can be applied separately during assembly. In certain circumstances, flux is not required (this can be said of other solder forms as well, except paste). However, certain parameters must be met for fluxless soldering. (For more information read Indium Corporation's application note on "Fluxless Soldering.")

3) **Spheres** are precise spherical shapes of solder with diameters ranging from .004″ to .095″ (100µ to 2375µ). The most frequently used diameters fall between .010″ and .040″. The most common use of spheres is for BGA (Ball Grid Array) package and flip-chip assembly. Spheres are typically used with a tacky flux which holds the spheres in place until soldering occurs. Spheres can be placed manually or, more commonly, using commercially available automated equipment. Like solder paste, the flux can be stencil printed onto an assembly substrate, and spheres can be manually or automatically placed on the flux-coated bonding pad.

4) **Wire solder** can be solid or, in the case of commonly used solder alloys, cored with a flux. Typical diameters are 0.010″ and up. Solder wire is typically used in manual soldering operations but, with the appropriate equipment, can be automated. In the case of solid core wire, a liquid or paste flux can be applied separately.

5) **Ribbon and foil** are long strips (typically spooled) and sheets, respectively. Ribbon widths range from .010″ to 2+″. Ribbon thicknesses range from .0005″ and up. Foil is similar to ribbon, with both the X and Y dimensions being greater than 2.375″ (maximum limit of the X or Y dimensions is less than or equal to 12″. Examples: 12″ x 12″, 11″ x 18″, 6″ x 6″, 4″ x 8″ and 4″ x 16″). The dimensions available (particularly the thickness) will be heavily dependent on the alloy. Ribbon and foil are used in any application where a somewhat large, flat piece of solder is needed. Simple preforms can be manually cut from both. Liquid fluxes are applied in a separate operation.

6) **Shot and Ingot (Bar)** are the most basic forms of solder available. Shot is teardrop-shaped solder that allows for convenient weighing. Ingot or bar, a simple three-dimensional block of solder, is cast in a mold. These forms are generally used to fill solder pots for manual lead pre-tinning or to fill the solder-holding reservoir of conveyorized wave soldering machines. Parts to be pre-tinned are first dipped in a liquid flux then dipped into a heated pot containing molten solder. Wave soldering is a printed circuit assembly process that utilizes PCBs with plated through-holes for attaching leaded components. The process is less costly than the surface mount assembly described above, but can only be used for PCBs with substantially less circuit density. In this process, components are inserted into the holes in the center of the bonding pads of the boards and placed on the wave-soldering conveyor. The conveyor passes through a flux sprayer where liquid flux is applied to the bottom side of the board. The board continues through a molten wave of solder which bonds the component leads to the PCB metallization pads.

Basic Solder Metallurgy

As heat is gradually applied to solder, the temperature rises until the alloy's solidus is reached. The solidus is the highest temperature at which an alloy is completely solid. At temperatures just above the solidus, the solder is a mixture of liquid and solid component (analogous to snow mixed with water). As the temperature is further increased, the liquidus is reached. The liquidus is 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. Upon removal of the heat source, the cycle is reversed, i.e., the solder's physical form changes from completely liquid to liquid+solid to completely solid. Graphs that plot temperature vs. composition are known as phase diagrams

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ASIA: Singapore, Cheongju, Malaysia: +65 6268 8678
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and are widely used to determine the phases and intermetallic compositions of solder at a given temperature.

The range between the solidus and liquidus is known as the plastic region or zone of the solder. If the solder joint is mechanically disturbed while the assembly is cooling through the 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 "cold solder joints" and are undesirable. To avoid this problem, it is best to select a solder that has a narrow plastic range, one with less than 10°C.

There are some solder alloys that have no plastic region (liquidus = solidus). These solder alloys 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 Sn63/Pb37 to strengthen the alloy somewhat or to prevent excessive silver dissolution from silver-plated circuitry. This alloy, Sn62/Pb36/Ag2 has a eutectic melting point of 179°C.

While tin-lead is the most common solder alloy, Indium Corporation produces over 220 specialty solders to match particular applications. There are Pb-free compositions, gold-containing compositions, indium-containing solders for soldering to gold, thermal fatigue resistant solders, solder with higher or lower melting points than tin-lead eutectic, and a multitude of solders with specific physical properties to match specific design requirements.

Fluxes

The purpose of a flux is to remove surface oxides on the substrate metallization (such as pads on a PCB), component leads, and the solder itself, to allow adequate wetting. The choice of flux 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. Similar to solder paste fluxes, liquid fluxes can be no-clean, solvent cleanable (RMA) or water-washable. Fluxes are an integral part of the soldering process. In order for a good solder bond to form, 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.

Flux performs have 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, thereby displacing air, and protecting 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. Therefore, this function of preventing re-oxidation during soldering can be just as important as removing the initial oxides. 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 un-waxed automobile finish, the water easily flows.

Substrate Metallizations

Most component leads and pads, and PCB bonding pads, are copper. Copper is an excellent electrical conductor but is prone to oxidation. To preserve solderablity and ensure that the flux will function properly, copper is usually coated with another metal, alloy, or organic coating. The most common coatings in PCB assembly are: 1) HASL (Hot Air Solder Leveling), 2) ENIG (Electroless Nickel/Immersion Gold),
3) Immersion Tin and Immersion Silver, and 4) OSP (Organic Solder Preservative).

1) **HASL** is the most common PCB metallization. The PCB is fluxed and subsequently immersed in molten Sn63 (Sn63/Pb37) solder, with the excess blown off using hot air. It leaves a thin layer of Sn63 solder on the copper pads. The HASL finish protects the underlying copper from oxidizing, thereby ensuring a solderable surface. One drawback is that the resultant layer is often dome-shaped. This presents co-planarity issues that may produce defects when using fine-leaded components.

2) **ENIG** is a surface finish scheme in which the copper is first plated with nickel [typical thickness ranges from 50 – 250 microinches (1.2 – 6μ)] as a diffusion barrier, then immersion-plated with gold [<15 microinches (0.38μ)] to preserve the solderability (prevent oxidation) of the nickel. ENIG finishes have better co-planarity than HASL finishes.

APPLICATION NOTE

3) **Immersion Sn/Immersion Ag** are similar processes. The copper pads are immersion-plated with either tin or silver. The plated layer is thin (<15 microinches) and protects the underlying copper from oxidation to preserve solderability.

4) **OSP** is a thin copper-organic layer that is applied directly onto the copper. This layer temporarily protects the copper from oxidation. The OSP burns off during reflow.

There are several other metallizations used in soldering. The propensity of the metallizations to oxidize has a bearing on which flux needs to be used. Solder paste fluxes, being relatively mild, are somewhat limited to the metallizations mentioned above.

Gold is the most solderable material due to its resistance to oxidation. In fluxless applications, thick gold (50+ microinches) is usually required. Tin-bearing solder alloys will readily dissolve gold and form brittle intermetallic gold-tin compounds. These intermetallic compounds can cause joint cracking and failures if the assembly is subjected to thermal cycling. The degree of intermetallic formation is a function of available gold on the substrate, soldering temperature, and time at liquidus.

Similar to tin and gold, indium-bearing alloys should be avoided when soldering directly to copper. Indium will diffuse into the copper and form a brittle intermetallic. Nickel can be plated (50 microinches minimum) onto the copper to prevent the diffusion.

Hydrogen (forming gas) can be used as a reducing gas flux in soldering applications over 350°C.

More information is available on gold-tin and indium-copper interactions in their respective application notes (“Soldering to Gold – Alloy Choice and Limitations” and “Indium/Copper Intermetallics”).

Soldering Temperature

As a rule of thumb, the soldering temperature should be 30°C to 50°C higher than the liquidus temperature of the alloy. This ensures that there is enough heat energy available to form a good metallurgical bond between the solder and substrate. With lower temperature solders, it is ideal to lean toward the 50°C end of that range. Since the process is taking place at a lower temperature, there is not much energy inherently present. This extra energy will help make up for an already low energy situation.

The time that the solder is molten should be kept to the minimum required to get a good bond. Excessive time and temperature will proliferate intermetallic formation within the joint. This typically leads to embrittlement of the solder bond. Depending on the process, the time above the liquidus temperature of the solder will typically range from a few seconds (hand soldering with wire) to a minute or more (solder paste).

When performing multiple soldering steps (step soldering), it is advisable that the first solder alloy have a solidus temperature 50°C higher than the liquidus of the solder alloy used in the next step, and so on. (For additional information, see the application note on Step Soldering).

Soldering Heat Sources

Heat sources for soldering range from low tech, hand- held soldering irons to high tech lasers. Typical heat sources include soldering irons, hot plates, static convection ovens, belt furnaces (both convection and IR), induction heating apparatus, resistance heating and lasers. The heat source can be dependent on the form of solder used. For example, solder pastes used 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 ramp.

Summary

This application note gives a basic overview for those new to the world of soldering. It is impossible to address every facet of soldering in such a short document. Additional information can found in product data sheets, application notes, technical papers, the technical database, and other information sources on www.indium.com. Alternatively, if you have a specific question, you can contact the technical support group at Indium Corporation at techservice@indium.com, or by telephone at 1-800-4INDIUM.

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