Article #19: Solder Mounting Technologies for Electronic Packaging

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Soldering provides a cost-effective means for attaching electronic packages to circuit boards using both small scale and large scale manufacturing processes. Soldering processes accommodate through-hole leaded components as well as surface mount packages, including the newer area array packages such as the Ball Grid Arrays (BGA), Chip Scale Packages (CSP), and Flip Chip Technology. The versatility of soldering is attributed to the variety of available solder alloy compositions, substrate material methodologies, and different manufacturing processes. For example, low melting temperature solders are used with temperature sensitive materials and components. On the other hand, higher melting temperature solders provide reliable interconnects for electronics used in high temperature service. Automated soldering techniques can support large-volume manufacturing processes, while providing high reliability electronic products at a reasonable cost.

The technology of solder mounting components onto a circuit board will be outlined. The term, "circuit board," refers to any one of several substrate materials, including organic laminates such as FR-4 and Teflon™, as well as inorganic substrates such as alumina and engineered ceramics used for hybrid microcircuit (HMC) and multi-chip module (MCM) products. The general topics of solderability, solder compositions, substrate materials (device package I/Os as well as board materials) and fluxes will be discussed. An overview of soldering processes will discuss schedule preheat, reflow, and
I. Solderability

Solder joint formation is governed by wetting and spreading processes of molten solder metal on the substrate surfaces. Wetting refers to the formation of a metallurgical bond between the solder and substrate. Spreading describes the spontaneous flow of molten solder over a substrate surface (with the help of a flux). Wetting and spreading action together constitute the solderability of the solder-substrate-flux system.

The molten solder profiles for open geometries of horizontal and vertical surfaces are described by Young's equation (1) and illustrated in Figs. 1a and 1b, respectively (Young 1805):

\[ \gamma_{SF} - \gamma_{SL} = \gamma_{LF} \cos \theta_c \]  

(1)

The contact angle, \( \theta_c \), provides the generalized solderability metric. It represents an equilibrium balance between the three interfacial tensions: \( \gamma_{SF} \) (substrate-flux), \( \gamma_{SL} \) (substrate-liquid solder), and \( \gamma_{LF} \) (molten solder-flux). The smaller the contact angle, better is the solderability. The value of \( \theta_c \) is minimized by maximizing \( \gamma_{SF} \) and minimizing both \( \gamma_{SL} \) and \( \gamma_{LF} \). A high value of \( \gamma_{SF} \) is realized by removing surface contaminants and oxides, primarily by means of the flux. Reducing the solder-flux interfacial tension (\( \gamma_{LF} \)) is also an important role of the flux. The value of \( \gamma_{SL} \) is predetermined by the substrate (or coating) and the solder compositions.
Solder joints may require wetting and spreading by molten solder within a confined geometry such as a cylindrical hole. In these cases, capillary action assists the movement of the molten solder (Fig. 1c). Generally, as the hole diameter decreases, greater is the capillary force. However, too small of a gap will mechanically force a higher contact angle on the molten solder, causing a loss of capillary action. Reducing the value of $\gamma_{L,F}$ through the use of a flux allows $\theta_c$ to decrease, thereby improving capillary flow.

2. Solder joint technologies

There are two general types of solder joint technologies used in electronics today. They are through-hole technology and the surface mount technology. Through-hole solder joints date back to the first electronic devices fabricated in the early part of the twentieth century. Although still a cost-effective means for assembling many types of electronic hardware, through-hole technology is being replaced in many applications with surface mount technology. Smaller package footprints and denser signal traces allow surface mount technology to realize significant weight and size reductions over comparably functional, through-hole product. However, the size and geometric attributes of surface mount circuit boards cause it to be more susceptible to soldering defects, thereby requiring greater attention to process control issues.

2.1 Through-hole technology
Through-hole technology refers to the use of electronic devices having leads that pass through a hole in the circuit board. An example of a through-hole circuit board is shown in Fig. 2. Device leads come in a wide range of diameters and materials (Cu, steel, Fe-Ni-Co alloy, etc.). The circuit board holes can be mechanically drilled or laser drilled. The hole wall or "barrel" is coated with Cu to allow electrical continuity between conductive layers of the circuit board.

The three general types of through-hole circuit boards are: (1) single-sided circuit boards, (2) double-sided circuit boards, and (3) multilayer circuit boards. Single-sided circuit boards have conductor features and solder joints on only one surface. Double-sided circuit boards have conductor features on both surfaces and within the board holes. The multilayer circuit board is similar to the double-sided board, except that it is typically thicker to accommodate internal layers of circuitry.

From a strength standpoint, through-hole solder joints are particularly robust. Therefore, through-hole joints are often used to attach larger devices such as inductor coils, relays, connectors, switches, and fuse holders to the circuit board.

Electric irons are used in manual soldering processes to assemble through-hole circuit boards. Automated techniques for through-hole joints include drag soldering and the more widely used wave soldering process. So-called, paste-in-hole processes are being developed whereby solder paste (a mixture of solder metal, flux, and organic binders) is deposited in each of the circuit board holes. The device leads are placed into their
The past 15-20 years have seen a significant growth in the use of surface mount technology for electronics assembly. An example of a surface mount circuit board is shown in Fig. 3. The advantages of surface mount include reduced board size through denser circuitry, lower product weight through device miniaturization, simplified circuit board fabrication with the absence of holes, and faster circuitry because package leads and long signal traces have been eliminated. Also, large-volume, surface mount assembly processes can produce high-quality consumer and military electronics in a cost-effective manner.

As the term implies, surface mount technology uses electronic devices that are soldered only to the surface of the circuit board. Packages may have leads along two or all four sides of their periphery. Lead configurations include the gull-wing lead, J-lead, and S-lead geometries. Some packages have no leads at all. So-called leadless discreet devices include discrete resistors, capacitors, and inductors. The solder connection is made to a conductive surface or termination made from a fired-on metal film (typically Ag-based with a Ni or Cu barrier layer). Silicon chips are mounted in larger, leadless packages termed leadless ceramic chip carriers (or LCCC). The solder connection is made to a conductive surface referred to as the castellation which is also comprised of a fired-on
Area array I/Os are an increasingly popular, surface mount package configuration; the most widely used is the ball-grid array (BGA). The advantage of BGA packages is the larger number of signal I/Os (upwards to several 1000s). Smaller, finer pitched versions of the BGA have been marketed under the trade names of mini-BGA™ and µBGA™. Further miniaturization of the area array package has been achieved with the chip scale package (CSP) where by the lineal dimensions of the package are less than, or equal to, 1.2 times those of the Si chip. The ultimate step in chip packaging is directly mounting the silicon chip to the circuit board, using an area array of solder bumps located directly on the chip; this approach is referred to as flip-chip technology. The metallurgy of a flip-chip solder joint (or "bump") on ceramic substrate is shown in Fig. 5. A high temperature, Pb-Sn solder (90Pb-10Sn or 95Pb-5Sn) is used to prevent re-melting during subsequent solder assembly operations.

The solder fillet provides both the electrical continuity and mechanical fastening for surface mount interconnects. Thermal expansion mismatch across the joint structure and subsequent aging-related failures has caused an increased emphasis on understanding the thermal mechanical fatigue (TMF) properties of surface mount solder joints, and solder materials in general. These efforts were not required for the more robust through-hole
technology. Like lead and hole diameters in through-hole circuits, design rules have been
developed that specify package and I/O configurations, pad sizes, shapes, and location on
surface mount boards in order to optimize solder joint reliability (IPC-D-330 1992).

Although surface mount devices do not require holes, holes are still used in the circuit
boards to transmit signals between internal layers and surface traces or pads. In this
application, the hole is referred to as a via. Because the sole function of the via is to
transmit electrical signals, it can be very small to save space. Currently, mechanical
drilling technology provides holes as small as 0.20 mm diameter (Coombs 1995). Non-
drilled vias made by plasma etching and so-called built-up laminate technologies can
produce via diameters as small as 0.025-0.150 mm diameter.

There are four general types of surface mount product. There is the single-sided circuit
board in which components are present on one side of the laminate; the double-sided
circuit board having components on both sides, and the multi-layer circuit board that is
based upon the double-sided case, but with internal conducting layers. The fourth type of
surface mount product is the mixed technology circuit board which has both surface
mount and through hole components. The assembly processes for mixed technology
product are more complicated than if a single technology was in place.

The traditional assembly process for surface mount circuit boards has been furnace
reflow. Solder paste (85-90 wt.% metal powder) is deposited on the circuit board lands;
the package is placed on the board so that the leads or terminations are located on top of
the paste deposit; then, the assembly is passed through a furnace to melt the solder and form the joints. Surface mount boards have also been assembled by wave soldering, by hand soldering with an iron and solder wire, as well as by thermal conduction using the "hot bar" technique. In addition, laser techniques have shown promise for soldering surface mount interconnects.

3. Solder joint materials

Three materials participate in the fabrication of a solder joint: the molten solder alloy, the liquid flux, and the solid substrate. Substrates can also include metal coatings that are applied over the substrate material to provide adequate solderability. The molten solder, the flux, and the substrate all impact the soldering process. After soldering, joint performance is determined by the solid solder and the substrate materials (including coatings). The flux affects the fabricated joint through potential corrosion by its residues.

3.1 Solder alloys

Solder alloys can be elemental metals such as Sn and In; binary alloys such as 63Sn-37Pb (wt.%) and 96.5Sn-3.5Ag; or more complex ternary and quaternary compositions. The attributes relevant to assembly processes are the melting properties and the solder surface tension (which is modified by the flux). The melting properties of interest are the solidus temperature, at which melting begins, and the liquidus temperature at and above which, the alloy is fully liquid. The temperature range between the solidus and liquidus
Development of a soldering process is based primarily upon the liquidus temperature of the solder. Solder spreading is usually optimized when the alloy is fully liquid. The processing temperature of the solder is typically 20-40°C above the liquidus point. This temperature margin allows for heat sink effects caused by the substrate materials and/or changes to the solder composition as it dissolves substrate materials and coatings during wetting and spreading.

The solder surface tension impacts solderability. A low surface tension value improves the spreadability of the molten alloy on open surfaces (both horizontal and vertical), resulting in thin, uniform solder films and concave fillet profiles. A reduced surface tension also facilitates the flow of molten solder into confined geometries such as gaps and holes. The surface tension of common (molten) solders range from 400 to 700 dynes/cm (Muir 1975). Alloys containing Pb and Bi tend to have lower surface tensions while solders containing Ag and Sb will have increased surface tension values. Recall that the surface tension of the solder is modified in the presence of a flux coating, typically lowering the value, thus improving solderability.
The just-solidified solder must withstand residual stresses generated by the thermal expansion mismatch between lead materials (metals and alloys) and circuit board material during cooling. Large axial stresses develop in through-hole joints by thermal expansion mismatches: Cu lead, 17.3 x 10^-6 /°C; FR-4 laminate (thickness or "z" direction), 100-200 x 10^-6 /°C; and 60Sn-40Pb solder, 25 x 10^-6 /°C (Prasad 1989, Klein-Wassink 1989).Residual stresses can be reduced by slower cooling rates that allow the solder and other materials to deform during cool-down.

2.2 Substrate materials

The substrate materials comprising the solder joint are predetermined by circuit board design and device I/O configuration. The prevalent metallic material for device leads and laminate features is copper (Cu). Other metallic substrate materials include Ni, Fe-based alloys, and noble metals such as Au, Ag, and Pt. The different substrate materials have a wide range of solderabilities. The noble metals can be soldered using the very weakest of fluxes (once organic contaminants have been removed). A similar case can be made for Cu, although slightly stronger fluxes are often required to remove the nascent oxide. The solderability of circuit board Cu features can be maintained with organic solderability preservatives (OSPs). On the other hand, Be alloys, Ni, Ni-based and Fe-based alloys require strong precleaning agents and/or very aggressive fluxes to allow solder wetting and spreading.
Electronic components may also utilize "unsolderable" materials for which no cleaning process or flux will provide adequate solderability within the constraints of the soldering process steps. Inherently unsolderable materials include ceramics, glasses, and organic substrates (e.g., printed wiring board laminates). Metals and alloys may be so difficult to solder as to be designated as unsolderable; those metals include Al as well as the refractory metals such as Cr, W, and Mo. Coatings deposited on the substrate surface(s) can be used to achieve solderability for difficult-to-solder metals and alloys. One such coating stack is Ni-Au. The Ni is deposited directly onto the substrate material and provides the solderable coating. It is the surface of the Ni layer to which the solder will ultimately wet and adhere in the completed joint. The Au layer is deposited on top of the Ni layer and is referred to as the protective coating because it protects the solderability of the Ni surface. Typical layer thicknesses are: Ni solderable layer, 3.8-7.6 μm and Au protective finish, 1.3-2.5 μm. The minimum thickness of the Ni layer must not allow its full consumption so that molten solder contacts the non-solderable substrate surface. The protective layer must be sufficiently thick to exclude air from the underlying solderable coating surface, but not so thick as to overly contaminate the solder.

Thick film coatings and thin film coatings provide solderable pads and conductive traces on ceramic and ceramic/glass substrate materials used in hybrid microcircuit (HMC) products (Harper 1982, Holland 1963, Holmes and Loasby 1976). An HMC circuit board is shown in Fig.6. Thick film coatings are derived from a paste comprised of a metal component (Cu, Ag, Au-Pd, Au-Pd, Au-Pt-Pd), a glass agent, and an organic binder. The paste is screen printed onto the substrate with the desired circuit pattern; the substrate is
Coatings can support soldering assembly through two other scenarios. (1) It may be preferred to solder to a particular coating rather than to the actual base metal surface to prevent excessive dissolution of the latter. For example, the dissolution of a Ni coating is significantly slower than is that of Au or Cu in Sn-based solders (Bader 1969, Bader 1975). (2) A coating can serve as a barrier layer between the solder and substrate material (or coating) to prevent solid-state interactions (intermetallic compound layer growth) between them during service.

2.3 Fluxes

The flux serves three roles during the soldering process: (1) The flux removes the oxide layers from the substrate surfaces and the surface of the molten solder. (2) The flux protects the newly cleaned substrate surface from further oxidation under the process cycle. (3) The flux reduces the surface tension of the molten solder by intrinsic interface reactions and elimination of the latter's oxide skin. The capacity for a flux to remove the
The process temperature must equal or exceed the flux activation temperature. Failure to exceed the activation temperature during soldering results in poor solderability of the joint. Overly high temperatures cause the flux to break down chemically, causing a loss of surface tension modification as well as oxide removal capabilities.

There are four general categories of flux materials used in electronic assembly (ANSI 1996). From weakest to strongest, they are: rosin-based fluxes, resin-based fluxes, organic (acid) fluxes, and the inorganic (acid) fluxes. In each of those categories are sub-classifications that describe the further breakdown the activity levels.

The rosin-based fluxes are the predominant flux used in electronics assembly. The flux formulations are a combination of pine rosins extract (containing primiric and abietic acids), an alcohol vehicle, and wetting agents. Until recently, rosin flux strengths were designated as "R," rosin-based flux with no activator; "RMA," rosin-based, mildly activated; and "RA," rosin-based, fully activated. The stronger the flux, greater is the need to remove their residues to prevent latent corrosion. Two current approaches toward eliminating residue removal are the no-clean fluxes, in which corrosive components are encapsulated to prevent their release on the circuit board, and the low-solids fluxes which simply minimize the amount of residues retained from the flux. Rosin-based fluxes
The resin based fluxes are synthetic formulations rather than plant extracts. The formulations can be made with varying levels of aggressiveness equivalent to RMA and RA activity levels. A particular attribute of these fluxes is stability at higher temperatures (350-375°C).

The organic (acid) fluxes are comprised of one or more organic acids (e.g., lactic acid, glutamic acid, citric acid, etc.) in a vehicle of water, alcohol, or polyglycol and wetting agents. Halide-based activators are added to increase flux activity. Residue removal can be performed with water or water-based detergents. Activation and maximum stability temperatures are similar to those of the rosin-based fluxes.

The inorganic acid fluxes are the strongest corrosives. These fluxes are comprised of chloride-based acids generated from additions such as ZnCl₂, NH₄Cl, and HCl and are active at room temperature to 300-400°C. The inorganic acid fluxes are used to prepare heavily oxidized lead surfaces for applying hot solder dipped coatings ("pretinned" layer). They are not used in circuit board assembly due to their high activity and very corrosive residues.

3. Soldering processes
A number of techniques are available for soldering electronic assemblies. Traditional hand soldering using an iron, torch, or hot-air source is cost-effective for many applications. On the other hand, large-volume automated soldering processes such as furnace reflow, wave soldering, or laser soldering may be preferred. Irrespective of the specific process, a proper assembly process includes five steps: (1) pre-cleaning procedures, (2) the preheat step, (3) the reflow or soldering step, (4) the cool down step, and (5) the post-assembly cleaning step.

The pre-cleaning step removes organic contamination and heavy oxide scales from the component or circuit board surfaces that cannot be eliminated by the flux. Organic contaminants, such as process chemicals (from plating solutions), lead forming lubricants, and fingerprints are removed by solvents. Inorganic contaminants, such as heavy oxide layers, are removed with chemical etchants or brighteners. The solderability of circuit board surfaces can be preserved with organic solderability preservatives (OSP) or metal layers (conversion coatings, electroless or electroplated coatings) that include Sn, Ni-Au, Cu, or Ag.

The preheat step has the following roles. The temperature of the components and circuit board are gradually increased to minimize thermal shock when exposed to the high-temperature solder reflow step. The preheat temperature initiates "activation" of the oxide removal function of the flux. The preheat stage consists of a temperature ramp (typically 1-10°C/s) and then short hold time (1-3 min) at a temperature 10-20°C below
During the reflow or soldering step, the now molten solder wets and spreads over the base material surfaces to create the solder joint. Typically, the soldering temperature is 20-40°C above the liquidus temperature of the solder alloy; time durations for the reflow step can range from a few seconds in hand soldering to 30-45 s for furnace processes. The soldering time is minimized to prevent excessive substrate metal dissolution and limit degradation to the flux.

The cool-down stage includes solidification of the solder. Movement of the joint due to handling or vibration must be minimized to prevent solder cracking ("disturbed joint"). Slow cooling rates reduce temperature gradients in the solder joint materials that can generate high residual stresses which can damage device packages, crack the solder joint, or cause warpage to the circuit board.

The post-assembly cleaning procedure is implemented to remove flux residues and other process contaminants from the product. The use of no-clean and low-solids flux products eliminate the need for the post-assembly cleaning step. Otherwise, organic solvents (that comply with the Montreal Protocols prohibiting the use of CFC compounds) or semi-aqueous cleaning processes are available for organic flux residues; aqueous-based processes can be used for water-based, organic acid fluxes.
3.1 Hand soldering

Hand, or "manual," soldering refers to the use of a soldering iron, torch, or hot air source to make solder joints one-at-a-time. Although time consuming in comparison to automated processes, hand soldering can be a cost-effective approach for limited product runs that do not warrant the capital investment of automated equipment. Also, hand soldering is preferred for high-reliability assemblies by utilizing the operators "in-situ inspection" capabilities to immediately identify and correct defects.

Hand soldering is used primarily on through-hole circuit board products. It is used to a lesser extent on surface mount circuit boards and primarily, only as a repair and rework activity. Soldering a through-hole joint with flux, solder wire (cored with flux or solid), and an iron is a routine task. After the surfaces have been coated with a flux, the soldering iron tip and solder wire are contacted to opposite sides of the lead. As the solder wire melts, it fills the gap and completes the fillets. Solder joints on two-sided circuit boards are always soldered from one side, never both sides. Oxide removal from the substrate surfaces can be augmented with an ultrasonic soldering iron for solder joints that cannot tolerate the presence of a flux and/or its residues.

3.2 Automated soldering processes

Automated soldering has several attributes. First and foremost, it can provide high volume rates of production because a large number of solder joints can be made at a
given time and with fewer operators. A second attribute is consistency of solder joint quality. Through the proper selection of processing parameters (temperatures, time, flux application, etc.) and maintaining process control, defect rates as low as a few parts-per-million can be realized for most circuit board products. Several automated soldering processes are described below.

The drag soldering process is the movement of a circuit board across the surface of a molten solder bath. The molten solder contacts the bottom of the board, forming the joints of surface mount devices glued into place there, or completing through-hole joints for leaded components by capillary action. A modification of the drag soldering process in widespread use today, is wave soldering (Fig. 7). The circuit board is attached to a conveyor belt and passed through a flux coating system followed by exposure to the preheat zone. The circuit board then passes along the top of the solder wave at the "take-off" angle, \( \alpha \). Surface mount devices glued to the bottom side are soldered into place while molten solder fills through-hole joints via capillary action. The soldering process may be performed in air or in an inert gas environment (\( \text{N}_2 \)). Wave soldering is used primarily on through-hole circuit boards.

The predominant assembly process for surface mount circuit boards is the furnace reflow technique. The in-line furnace is preferred to batch furnaces to achieve the maximum production through-put rates. The two types of in-line furnaces utilize convection and/or infrared (IR) heat transfer mode(s) or use thermal conduction from the conveyor to transfer heat to the substrate. The convection/IR furnaces use circulated hot gas and
infrared radiation to heat the circuit board and components. The conduction furnace are
used largely with hybrid microcircuit electronics built with ceramic substrates that can
withstand the high temperatures of the underlying conveyor surface. Both types of in-
line systems can operate in air or under an inert gas environment (N₂ at 10-20 ppm
residual O₂). In-line furnaces (convection/IR and conduction) have several heating zones
which are individually set to precisely control the preheat, reflow, and cool-down
conditions.

The solder is used in paste form for furnace reflow processes. The solder paste is
comprised of solder metal in the form of powder particles (85-90 wt.%); a flux; and a
vehicle that includes wetting and thixotropic agents to optimize printing operations. In
special cases, the use of preforms or solid-solder deposits (SSD) may provide an
alternative approach to solder placement. The SSD technology is particularly suited for
fine-pitch, surface mount packages.

The processing sequence of a circuit board is as follows: (1) The solder paste is screen or
stencil printed on to the circuit board. A screen or stencil delivers the precise paste
thickness and footprint dimensions onto the solder pads. (2) The components are placed
at their appropriate location, on top of the solder paste deposit, using a pick-and-place
machine. (3) The "populated" circuit board is passed through the furnace for solder
reflow. Proper cleaning processes are then performed to remove flux residues.
The current approaches to soldering mixed technology boards are limited to (1) the two-step procedure of wave soldering plus furnace reflow or (2) wave soldering both families of components that requires the gluing down of surface mount devices. Having the capability to furnace solder through-hole solder joints would allow mixed technology circuit boards to be assembled in a single process. Today, paste-in-hole techniques are being developed that precisely dispense solder paste, and locate the package leads, into the hole for furnace soldering.

Vapor phase soldering equipment has been manufactured as both batch and in-line formats. The physical basis of vapor phase soldering is that when a vapor transforms into a liquid, it releases its latent heat of vaporization; this heat is used to effect the soldering process. An attribute of vapor phase soldering is that the condensation process occurs only at the vaporization temperature (e.g., 100°C for water) thereby preventing overheating of the circuit board.

A schematic diagram of a vapor phase reflow system is shown in Fig. 8. The circuit boards with solder paste and components in place, are lowered into the chamber. In some systems, preheating of the part is provided by a lower temperature, secondary vapor envelope located above the primary fluid vapor. Or, a separate preheat chamber may be installed on the equipment. Then, the circuit boards are lowered into the vapor of the primary fluid. The primary vapor is created by boiling the primary fluid in the base of the chamber; the liquid and its vapor cloud are at the vaporization temperature (and no higher than that). The vapor condenses on the part surfaces, releasing its heat of vaporization.
Once a very popular technique for assembling surface mount circuit boards, vapor phase soldering lost its appeal after international regulations banned the production of several CFC compounds that were used as the fluid media (e.g., Freon). A resurgence of the technique has now occurred as substitute, ozone-safe fluids have been developed. The newer fluids also offer a wider range of vaporization temperatures, thus improving the flexibility of this technique.

The last technique is laser soldering. Lasers produce a small, coherent beam of radiant energy. The "light" emission used for laser soldering is in the infrared (or heat) region of the electromagnetic spectrum, at a typical wavelength of 1.06 μm; therefore, it is actually not visible. An important attribute of laser soldering is that heat energy is concentrated in the immediate joint structure. The temperature of the components and circuit board laminate are unaffected. Therefore, laser soldering is particularly well suited for solder joints that include temperature-sensitive materials.

The foremost challenge facing the widespread application of laser soldering is a low rate of solder joint production when compared to furnace reflow and wave soldering. Sophisticated mirror set-ups have been used to multiply and raster the beam in order for it
4. Defects, inspection, and repair/ rework procedures

Maintaining proper control of the soldering process will assure that solder joint defects are kept to acceptable levels. It is important to recognize defects in solder joints and their potential impact, if any, on solder joint reliability. Several inspection techniques are used to identify defects, including visual observations, low-magnification stereo microscopy, x-ray imaging, and metallographic cross sections. Defects should always be quantified as part of a Statistical Process Control (SPC) program. Repair/rework procedures can be implemented to remedy defective solder joints on high valued, high reliability circuit boards.

Poor solderability of component I/O surfaces (leads and terminations) and circuit board lands or holes is a leading circuit board defect. Low processing temperatures, contaminated surfaces, or inadequate flux strength result in solderability defects such as non-wetting and dewetting conditions. Poor solderability in holes is often indicated by void formation. Inadequate solderability results in an incomplete joint which can degrade
Void formation in solder fillets and holes is a defect that often signifies process difficulties. Voids may appear as "blow holes" on the solder fillet; however, void propensity is more accurately determined by metallographic cross sections. A leading source of voids is volatilization of the flux vehicle while molten solder is forming the joint. An important role of the preheat stage is to volatilize most or all of the flux vehicle prior to the soldering operation. Voids may also be created by organic chemicals or water vapor that has been absorbed by the substrate surfaces, particularly electroless or electroplated coatings which entrap plating bath chemicals in them. The absorbed contaminants quickly volatilize upon contact with the molten solder, leaving voids in the solder.

Several other defects in electronic interconnects are mentioned. They include deformation (warpage) or damage (cracking) to component packages and/or circuit board materials, or cracking of the solder joint. These symptoms are usually indicative of overheating of the circuit board or excessive movement during solder solidification. Of particular concern with surface mount circuit boards is misregistration of the device I/Os over the circuit board lands. Poor handling practices or excessive conveyor vibration are likely sources of this defect. Although compensated somewhat by the molten solder surface tension, misregistration can cause shorts or opens to develop or degrade the reliability of the solder joint. Finally, the incomplete removal of flux residues after
soldering can lead to corrosion in the presence of water vapor from the air that degrades both structural integrity and electrical function of solder interconnects.

Soldering processes provide the means to manufacture reliable electronic products. Defect-free solder joints is a goal that requires the manufacturing engineer to have a thorough understanding of substrate materials, solder alloys, and fluxes as well as their mutual interactions in particular assembly techniques.

Bibliography


Bader W 1969 Dissolution of Au, Ag, Pd, Pt, Cu, and Ni in a molten tin-lead solder. *Welding Journal* 48, 551-s - 557-s


Holland L 1963 *Vacuum Deposition of Thin Films* Chapman and Hall, London, UK

*Handbook of Thick Film Technology* 1976 ed. by Holmes P, Loasby R Electrochem. Pub., Ltd. Ayr, Scotland

*IPC-D-330 Design Guide* 1992 The Institute for Interconnecting and Packaging Electric Circuits, Lincolnwood, IL


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### Table 1
Solidus and liquidus temperatures of commonly used electronic solder compositions - ranked by liquidus temperature.

<table>
<thead>
<tr>
<th>Solder Composition (wt.%)</th>
<th>Solidus Temperature (°C)</th>
<th>Liquidus Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>52In-48Sn</td>
<td>118</td>
<td>118</td>
</tr>
<tr>
<td>40In-40Sn-20Pb</td>
<td>121</td>
<td>130</td>
</tr>
<tr>
<td>58Bi-42Sn</td>
<td>138</td>
<td>138</td>
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<tr>
<td>100In</td>
<td>157</td>
<td>157</td>
</tr>
<tr>
<td>70Sn-18Pb-12In</td>
<td>162</td>
<td>162</td>
</tr>
<tr>
<td>62.5Sn-36.1Pb-1.4Ag</td>
<td>179</td>
<td>179</td>
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<tr>
<td>63Sn-37Pb</td>
<td>183</td>
<td>183</td>
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<tr>
<td>60Sn-40Pb</td>
<td>183</td>
<td>188</td>
</tr>
<tr>
<td>50In-50Pb</td>
<td>178</td>
<td>210</td>
</tr>
<tr>
<td>96.5Sn-3.5Ag</td>
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<td>221</td>
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<tr>
<td>100Sn</td>
<td>232</td>
<td>232</td>
</tr>
<tr>
<td>90Pb-10Sn</td>
<td>275</td>
<td>302</td>
</tr>
<tr>
<td>95Pb-5Sn</td>
<td>308</td>
<td>312</td>
</tr>
</tbody>
</table>
Figure 1
Equilibrium configuration of molten solder wetting (a) a horizontal surface, (b) a vertical surface, and (c) a confined geometry (hole).

Figure 2
Example of a through-hole circuit board.

Figure 3
Example of a single-sided surface mount circuit board.

Figure 4
The materials systems for tape-automated bonding (TAB). The chip is bonded to the Cu lead-frame; the lead-frame is then soldered to the circuit board.

Figure 5
The metallurgy of flip-chip solder joints, in this case, on a ceramic substrate. The 90Pb-10Sn or 95Pb-5Sn solders are typically used.

Figure 6
Example of a hybrid microcircuit (HMC) product.

Figure 7
Schematic diagram of wave soldering a mixed technology circuit board.

Figure 8
Schematic diagram of a vapor phase reflow system.
Figure 1

(a) Substrate (S) and Solder (L) with Flux (F) interaction

(b) Close-up view of Substrate (S) and Solder (L) showing the contact angle $\theta_c$

(c) Flux (F) penetrating the Solder (L) with $\theta_c$ angle
Substrate

Inner Lead Bond

Copper Lead

Outer Lead Bond

Silicon I.C.

Metallization

Au (20μm)

Au_xSn_{1-x} Solder (Au + Sn)

Sn (0.5μm)

Copper Lead (50-75μm)

Substrate

63Sn-37Pb Solder

Land

Substrate

Fig. 4

Vianco
Sect. 6.10 Art. 19
Fig. 5

Vianco
sect. 6.10
Art. 19
Fig. 8
Vranco Sect 6.10
Art. 19