The Critical Role of Robotic Hot Solder Dip Processing of Components for High-Reliability and Mission-Critical Applications

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Abstract

Many mission-critical applications including military, defense, security, aerospace, and commercial avionics products, as well as medical device manufacturing, telecom infrastructure systems, plus BEV, PHEV and non-EV electronic vehicle power systems, and advanced driver assistance automotive systems all require stringent protocols to ensure robust solder interconnections. These critical protocols include robotic hot solder dip processing to minimize the adverse effects of gold embrittlement, tin whisker formation, impending ball grid device re-purposing, and conversion of lead-free components to tin-lead for defense or aerospace applications.

Key Terms: Robotic hot solder dip process, gold embrittlement, gold removal, tin whisker mitigation, BGA de-balling, BGA re-balling, tin-lead and lead-free component re-conditioning, component solderability testing

Gold Embrittlement

Since gold plating dissolves rapidly during the soldering process the remaining gold within a solder joint can weaken the integrity of the interconnection. If this gold dissolution is excessive during the solder alloy's liquidous phase formation the composition and mechanical properties of the resulting solder joint can potentially change. Gold embrittlement within tin-lead (SnPb) solder joints is a well-known failure mechanism. Commonly used lead-free solder alloys including tin-silver-copper (SAC305) and tin-nickel-copper (SN100C), are more capable of maintaining their mechanical properties when combined with gold partially due to the greater tin content. However lead-free solder joints will also degrade with increased gold inclusion.

Gold embrittlement can be a significant reliability issue. The risk of embrittlement is dependent upon several factors including, the amount of gold expected to be leached from the plated surfaces, the volume of the resulting solder joint, and whether the solder is from an infinite source such as a wave or selective soldering process, or from reflowed solder paste. In most cases the source of excessive gold dissolution is from gold-plated component leads rather than gold contribution from the printed circuit board finish such as electroless nickel immersion gold (ENIG) or electroless nickel electroless palladium immersion gold (ENIPIG). These types of board finishes are typically too thin to contribute to gold embrittlement since their average thickness is below the threshold considered as minimal contribution to gold embrittlement.

Gold Removal

Removal of gold plating from component leads is typically performed by a pre-tinning process which removes the gold as it is solubilized in the molten solder during a component re-tinning process. A double tinning process or dynamic solder wave should be used for gold removal prior to soldering the components into a board assembly, improper removal of gold on component leads and terminations prior to board level assembly can potentially result in solder cracks and/or field failures.

Beginning with the IPC J-STD-001 Rev F requirements implemented in 2014, and continuing to the current Rev H requirements it is stated that gold shall be removed from all Class 2 and Class 3 products for the following conditions: 1) 95% of through-hole component lead surfaces with 2.54µm or more of gold thickness, 2) 95% of surface mount component leads regardless of gold thickness, and 3) from surfaces of solder terminals plated with 2.54µm or more of gold thickness.

With this criterion, gold removal is therefore required for all high-reliability Class 2 and Class 3 electronic products, and it affects almost everyone in the electronics manufacturing industry meaning gold removal is no longer limited solely to aerospace and military applications.

The ideal method to facilitate the removal of gold plating from SMT and through-hole components is to use the robotic hot solder dipping (RHSD) process. It is recommended that this re-tinning operation be carried out using a lead tinning machine utilizing controlled flux application, preheating, single or dual solder pots, nitrogen inert atmosphere, as well as defined process control. A defined process of this type is highly recommended in lieu of manually dipping components into a standalone static solder pot to reduce solder contamination, minimize non-wetting issues and to enhance solderability.

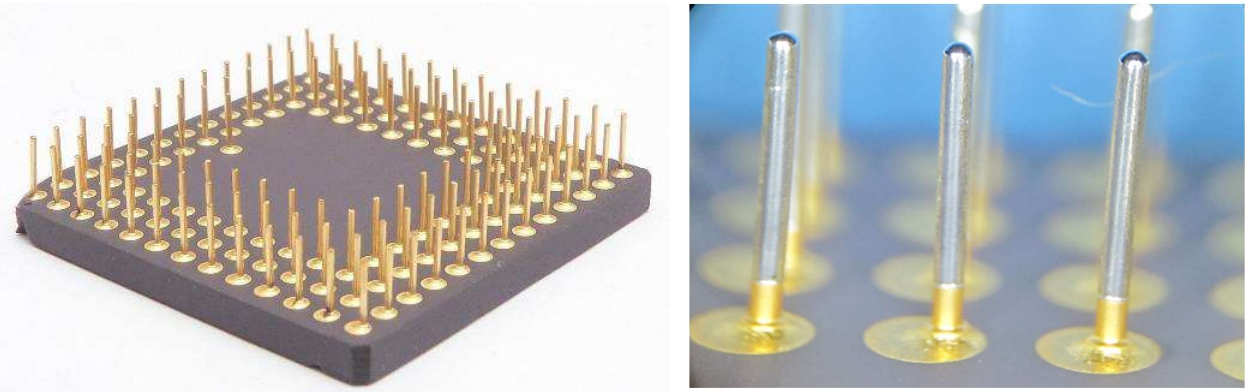

Figure 1. High thermal mass ceramic pin grid array (left), and re-tinned pins after gold removal (right)

Robotic hot solder dip (RHSD) machines can use either single or dual static or dynamic solder pots. The first pot is used to remove gold plating, oxidation, or other residues, and the second pot is used for precise control over solder depth. A nitrogen inert atmosphere helps the appearance of the resulting solder finish while mitigating icicles, bridging and dross buildup. Immersion of the component lead or termination into the flux and solder should be controlled to allow the flux and solder to flow up the lead or termination to a controlled depth. A defined withdrawal or extraction speed should be used in the second solder pot to control the re-tinning solder thickness. Solder pots should be tested regularly for gold, copper, nickel, and other contaminants.

Tin Whisker Reliability Concerns

The phenomenon of tin whiskers in printed circuit board assembly is a failure mechanism associated with electronic devices that utilize various solder alloys containing low melting point elements such as tin (Sn), cadmium (Cd) or indium (In). However, this phenomenon most commonly occurs with tin. Historically the issue of tin whiskers was avoided by adding lead (Pb) to the solder alloy used for component leads or pads, as well as circuit boards with HASL (hot air solder leveled) finish. However, since lead has been identified as a hazardous substance and has been banned this process or practice is no longer widely used.

Tin whiskers are a reliability concern since tin whiskers are conductive and can carry a high current. Without lead, the material utilized for the past 50 years to limit whisker growth this failure mechanism issue can affect most current electronic applications.

Whiskers will grow from several surfaces of copper electronic device leads, pads, or from copper substrates, finished with low melting point solder alloys containing tin (Sn), cadmium (Cd), indium (In), zinc (Zn) or antimony (Sb). Research has shown that whiskers will even grow from tin-lead (SnPb) surfaces under certain conditions, but the length of these whiskers will typically be shorter due to the presence of lead.

Figure 2. Tin whisker growth from plated leads (left), and electrical short resulting from tin whisker (right)

Unlike tin pest, a failure mode that occurs solely in extremely low temperature environments such as high-altitude aerospace applications, tin whiskers can occur at ambient temperatures. Tin whiskers have been found to grow to a length of 0.025” (0.635mm) on 100% bright tin-plated connector leads stored for approximately 4 months at ambient conditions.

An often-asked question is if a conformal coating will prevent the growth of tin whiskers. There is no known conformal coating that will prevent a tin whisker from emanating from tin-plated surfaces. However, a properly applied conformal coating can avoid electrical shorts associated with tin whiskers. It has been determined that Parylene C and silicone coatings are the most effective at suppressing tin whisker growth while acrylics are typically the least effective. The difference being the hardness of the coating as harder coatings tend to perform better at stopping tin whisker propagation due to the greater force needed to penetrate these harder coatings by a tin whisker.

There are certain conditions that promote tin whisker growth including, but not limited to, a thin tin plating, residual stresses during the tin plating process, or insufficient intermetallic compound formation during plating. All tin-plated copper alloys experience the formation of copper-tin intermetallic compounds, either Cu_6Sn_5 or Cu_3Sn, at the interface of the tin and the base metal. Thin tin plating is more susceptible to whisker growth since thin plating develops greater compressive stresses than does a thick tin plating.

Tin Whisker Mitigation

Based on iNEMI research, it is recommended to use printed circuit boards with a board finish of either nickel palladium gold (NiPdAu), nickel palladium (NiPd), electroless nickel immersion gold (ENIG) or nickel gold (NiAu) to reduce the risk of tin whiskers originating from the copper surfaces of the circuit board itself. Alternatively, a matte tin finish on printed circuit boards can be used providing the plating has a minimum thickness of 6µm (microns).

A more reliable method to mitigate tin whiskers is robotic hot solder dip processing of components prior to circuit board assembly that removes 100% of the pure tin plating from the leads or terminations and replaces it with tin-lead thereby preventing tin whisker formation. Robotic hot solder dip processing can be performed on all through-hole and surface mount components including axial, radial, SIPs, DIPs, SOICs, SOTs, QFPs, plus through-hole and SMT connectors as well as discreet electronic devices.

BGA Component Reballing

Some ball grid array (BGA) devices need to be converted from a lead-free finish, predominantly SAC305 (Sn96.5/Ag3.0/Cu0.5) to a tin-lead (Sn63Pb37) finish to meet the requirements of various defense or high reliability applications. The first step in this conversion process is deballing where the original lead-free solder balls are removed from the underside of the BGA device exposing the pads of the interposer. The Hentec/RPS Odyssey component lead tinning system is ideal for performing automated BGA deballing. This deballing process is followed by either manual or automated reballing consisting of fluxing, alignment, and attachment of new solder spheres of the replacement alloy, reflowing, inspection, cleaning (more on this subject later), and repackaging.

BGA deballing is best accomplished using a robotic hot solder dip (RHSD) machine equipped with a dynamic solder wave and Sn63Pb37 solder. Robotic hot solder dip machines are available with either a single solder wave or dual solder waves. A single wave stripping process is adequate providing the solder wave has sufficient scrubbing action to completely remove the original SAC solder balls. It is typically not recommended to use a dual solder wave for BGA deballing since the additional thermal cycle can have a negative impact on the BGA device itself and any residual silver or copper from the original SAC305 interconnections would be negligible.

Even though SAC305 overwhelming consists of tin, routine analysis of the stripping pot should be carried out to ensure the contamination level for silver remains below the J-STD-001 allowable maximum of 0.10% and copper remains below 0.02%. The only concern is if the alloy in the stripping pot becomes contaminated with lead-free solder the remaining solder could also potentially become contaminated.

Figure 3. Ball grid array device before de-balling (left), and ball grid array being de-balled (right)

There are various methods for solder sphere attachment when reballing BGAs and other area array devices such as land grid array (LGA) and quad flat pack, no leads (QFN) devices including solder paste deposition or using tacky flux and solder spheres. Laser-based BGA component reballing services are available for BGA devices with a pitch as fine as 0.4 mm pitch. Ball count, device pitch, sphere diameter, solder alloy and package size are all considerations for which method is appropriate for a particular application. The use of tacky flux is the most common approach since variability in solder paste volume will contribute to variability in the final sphere volume, and therefore in sphere size and the paste can create additional voiding by incorporating flux volatiles into the final sphere.

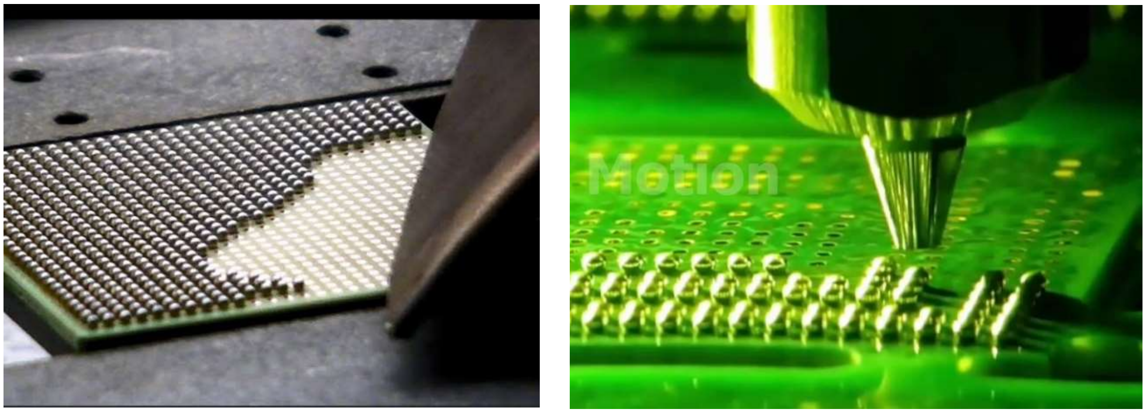

Figure 4. BGA reballing via custom fixture (left), and fixture-less 0.4mm pitch laser BGA reballing (right)

Following the deballing and reballing processes, post reballing process inspection should be carried out including Z-height measurement of solder balls to the bottom interposer surface verifying device coplanarity, missing solder balls, solder ball volume, oversized solder ball volume, shorts between adjacent solder balls, and detection of any foreign object debris.

Component Lead Tinning

The primary motivation behind component lead tinning is to either: 1) facilitate the removal of gold plating to eliminate the risk of gold embrittlement, 2) mitigate tin whisker growth, or 3) processing of components for applications that require refinishing with lead-free solder for RoHS compliance. The component lead tinning process produces a homogeneous intermetallic layer with the base metal of the component leads or terminations increasing the overall solderability thus facilitating improved reliability of printed circuit board assemblies.

All types of leaded through-hole components such as axial, radial, dual-inline package (DIP), or single in-line package (SIP) devices can be successfully re-tinned using a Hentec/RPS Odyssey component lead tinning system. Surface mount components that have terminations or pads without leads, such as chip components, SOTs, SOICs, leaded chip carriers (LCC), or plastic leaded chip carriers (PLCC) can be re-tinned using the solder drag process. In many cases fixturing may be required when automatically re-tinning surface mount components to ensure parallelism is maintained during the re-tinning process.

Formed multi-side components such as flat pack (FP) and quad flat pack (QFP) devices have very delicate leads that can be easily damaged are typically re-tinned using a side wave process with the components held in position by a multi-axis articulated robot equipped with a rotary vacuum head.

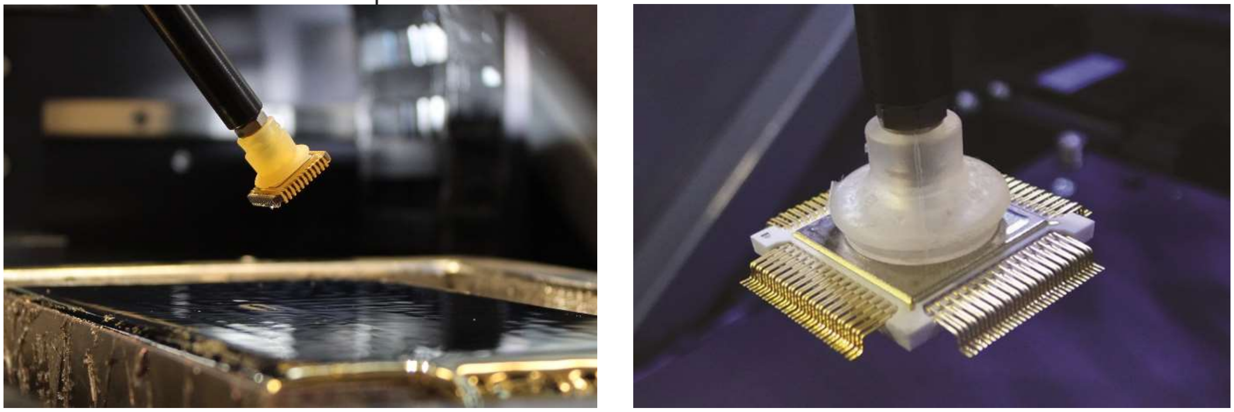

Figure 5. Quad flat pack (QFP) device during re-tinning (left), and QFP held with vacuum nozzle (right)

A key issue when re-tinning fine-pitch surface mount devices such as QFPs and quad flat pack, no lead (QFNs) is to maintain coplanarity across all leads while assuring bridge free results at the same time. Fine-pitch QFPs as small as 6mm x 6mm with a lead pitch as small as 0.012” and up to 50mm x 50mm can be re-tinned with bridge free results. Device coplanarity as well as solder thickness from the re-tinning process can be verified using X-ray fluorescence (XRF) testing to verify the alloy composition.

Following robotic hot solder dip processing all re-tinned or reballed devices should be cleaned in a batch wash, or cleaning, system using the appropriate solvent or aqueous cleaning agent to remove any residual flux residues, as well as dry baking for the applicable component moisture sensitivity level (MSL). This should be followed by solderability testing per J-STD-002. Ultrasonic cleaning should be used cautiously since semiconductor devices can be potentially damaged by cavitation resulting from certain frequencies in some ultrasonic cleaners that are not designed for cleaning electronic components. Ultrasonic cleaners meant for other applications such as cleaning of small mechanical parts, etc. should not be used. If an ultrasonic cleaner is used, it should be a constantly variable frequency (CVF) type designed specifically for cleaning of electronics.

Solderability Testing

Solderability testing determines how well molten solder will wet on solderable surfaces of electronic components. The most common solderability test methods being the dip-and-look method and the wetting balance method. The dip-and-look method is a qualitative type test performed by comparative analysis after specimens are dipped in a bath of flux and molten solder. The wetting balance method is a quantitative type test based upon the interpretation of a wetting curve measuring the buoyancy of a specimen using a load cell. There are several solderability test standards, but the most common standards are MIL-STD-883 Method 2003, IPC J-STD-002 and MIL-STD-202 Method 208.

While the wetting balance test method is precise and measures the wetting forces between molten solder and a test specimen as a function of time, it requires the interpretation of a wetting curve by skilled personnel in a laboratory environment. Another disadvantage is that wetting curves can be easily distorted if the system is not properly calibrated or performed incorrectly by unskilled personnel.

There are, however, no established industry standard pass/fail criteria for wetting balance analysis. This is why wetting balance testing is used primarily as an engineering tool and not as a production monitor. In order to establish a pass/fail wetting force, a dip-and-look test must be performed since even though an acceptable wetting force is established, it must be based on a visual test.

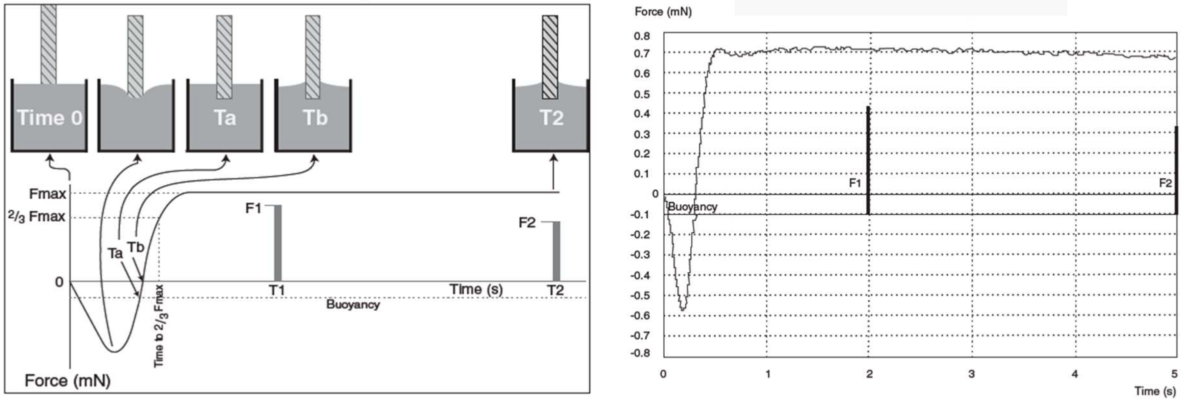

Figure 6. Wetting balance solderability test method (left), and wetting curve of highly solderable lead (right)

An advantage of the dip-and-look method is it is based on comparative analysis and can be performed rapidly by shop floor personnel with minimal training as well as requiring significantly lower capital investment than a wetting balance test system.

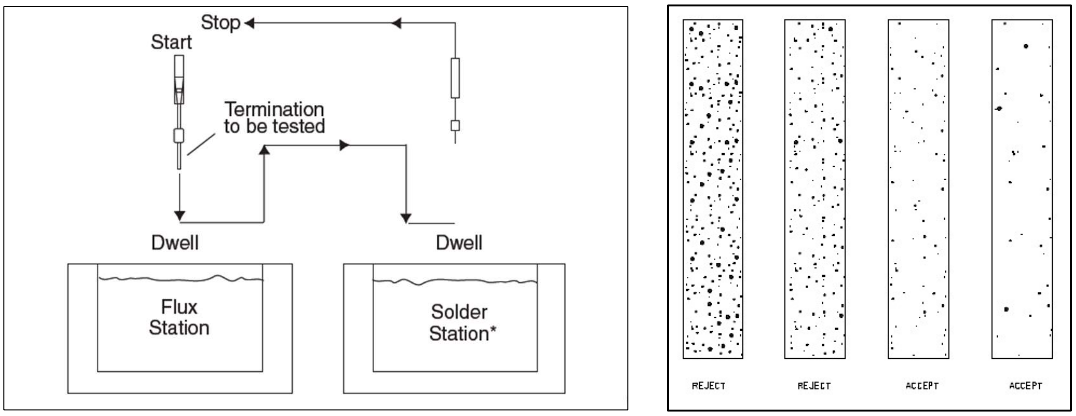

Figure 7: Dip-and-look solderability test method, (left), and dip-and-look specimens at 10X magnification (right)

The Hentec/RPS Pulsar dip-and-look test system can also be configured for low-volume lead tinning of component terminations that exhibit poor solderability due to oxidation or prolonged storage.

Figure 8: Dip-and-look solderability test equipment (left), and component steam aging system (right)

For certain high-reliability applications additional solderability testing may be required and can include steam aging which is used for accelerated life testing to simulate elongated storage conditions.

Summary

Robotic hot solder dip processing is an essential protocol for minimizing the adverse effects of gold embrittlement, tin whisker formation, ball grid device re-purposing and conversion of tin-lead and lead-free electronic components for high-reliability and mission critical applications. The use of robotic hot solder dip processing equipment is gaining increasingly effective use within the defense, aerospace, medical, telecom and automotive industries.

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