Lead-Free Soldering and Environmental Compliance:

Supply Chain Readiness & Challenges

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Abstract

Supply chain readiness and compatibility are critical to a smooth transition to environmental compliance for the worldwide electronics industry. This paper reviews the status of lead-free soldering and RoHS compliance, supply chain readiness, key compatibility issues and future challenges.

Lead-Free Solutions

Lead-Free Solder Alloy

It has now taken nearly 15 years for the worldwide industry to develop lead-free solder solutions. Naturally, the effort began with the search for lead-free solder alloys. The industry has finally converged on the Sn-Ag-Cu (SAC) alloys; it is not yet clear, however, whether this will be a strong convergence towards a single alloy composition, or a weak convergence with various compositions and modifications. If history can be relied upon to offer any guidance in this regard, more uniformity would be expected in the Western world with more varieties in the Far East. These variations and modifications around SAC are not expected to require significantly different soldering processes and infrastructure among them, due to the overwhelming similarity in their key characteristics.

Knowledge Infrastructure

The industry has made significant progress in building up the knowledge infrastructure to support lead-free solutions, including solder material requirements, component requirements, PCB (printed circuit board) laminate material and surface finish requirements, soldering process know-how including SMT (surface mount technology), wave soldering and rework, for a wide variety of board form factors and complexities. Qualification of lead-free soldering processes has been an effective vehicle for the penetration of lead-free knowledge and capabilities in global factories.

Components

The internal materials for the components must meet the RoHS requirements. In terms of the termination metallurgy, for passive components, matte Sn plating has been used for many years with the Sn-Pb solder and can be used with lead-free solder as well. For leaded components, plating of matte Sn or Sn alloys may be used with lead-free solders ("forward compatible"), as long as the Sn whisker risk can be effectively managed. Ni/Pd has been used with the Sn-Pb solder for many years, and Ni/Pd/Au is currently an alternative for leaded components for lead-free soldering. Area array packages with SAC balls work well with the SAC solder.

For reflow soldering, assuming the minimum peak temperature to be 235°C, the maximum temperature depends on the temperature delta across the board, which, in turn, depends on the board size, thickness, layer count, layout, Cu distribution, component size and thermal mass, thermal capacity of the oven, and certain unavoidable process variations and measurement tolerances. Large thick boards with large complex components (such as CBGA, CCGA, etc.) typically have temperature delta as high as 20-25°C. Rework is another process which contributes to elevated temperature exposure for the components.

When all of the application requirements are taken into consideration, 260°C peak temperature had long been proposed as the temperature required for components for lead-free soldering. The requirements (including soldering peak temperature and tolerances) are captured in the IPC/JEDEC Standard 020, according to the component volume and thickness, and process conditions (such as rework). It is to be noted that the actual component body temperature may be different from the temperature measured on the board, and different components may have different temperatures depending on component thermal characteristics and locations on the board.

PCB

The higher temperature of lead-free soldering presents reliability concerns for the PCB, such as discoloration, warpage, delamination, blistering, pad lifting, CAF (conductive anodic filament), cracking of Cu barrels and foils, and interconnect separation, etc. Some of these issues become apparent immediately after the soldering process, whereas others may cause latent failures.

PTH (plated through hole) reliability can be adversely affected by lead-free soldering depending on the thickness of the PCB, the laminate material, the soldering profile, and the Cu distribution, via geometry, and Cu plating thickness, etc. In terms of the laminate material characteristics, the time-to-delamination and decomposition temperature (Td) reflect the degradation of the resin system, while the Tg (glass transition temperature) and CTE (coefficient of thermal expansion) affect the stress on the Cu, due to temperature excursions. These material properties (Tg, Td, and CTE) can vary independently of one another, and balancing these properties is important in achieving PCB reliability for lead-free soldering, especially for thick boards with high aspect ratio vias.

Much work is still needed, however, to determine under precisely what conditions of PCB layout, thickness and via geometry, alternative laminate materials may be needed for lead-free soldering. This is not to say that lower cost materials cannot be used for lead-free soldering. In fact, a variety of PCB laminate materials (such as CEM3, FR2, FR4, halogen-free, flexible circuits, etc.) have been used with lead-free solder in volume manufacturing, depending on the application.

Since the higher temperature for lead-free soldering can cause delamination, moisture and ionic contamination can permeate and migrate along the gaps between the glass fiber and the epoxy resin, providing an electrochemical pathway for CAF eventually leading to a "short" causing catastrophic field failures. Tests have shown that the higher soldering temperature for lead-free solder can have a significant impact on the occurrence of CAF failures. As the board density increases in miniaturized electronics products, the risk of CAF failures further increases. Moisture absorption, ionic contamination, adhesion between the glass fiber and the epoxy, are some of the key characteristics to be controlled in order to reduce the risk of CAF failures.

Solder Joint Reliability

As we bring more and more lead-free electronic products to the marketplace, lead-free solder interconnect reliability (including the solder joints, components, and the PCB) becomes an ever more important issue. This is a very complex topic, and simply saying that "lead-free is more reliable than Sn-Pb", or vice versa, can be misleading.

The failure modes of lead-free solder joints are similar to those for the Sn-Pb solder. Under typical conditions, the SAC alloy is significantly more creep resistant than the Sn-Pb alloy due to differences in microstructure, and the SAC solder interconnect has been found to be able to withstand a greater number of thermal cycles than the Sn-Pb solder. However, this may not always be the case. Recent studies have shown that below a certain stress threshold, the steady state creep strain rate is much lower for the SAC alloy than for the Sn-Pb alloy; however, above the threshold, the trend is reversed. This is believed to be the reason for the different reliability comparisons between the SAC and Sn-Pb solders under different loading conditions. In most typical use conditions, the SAC solder may be more reliable than the Sn-Pb solder. However, for large components and components with a large CTE mismatch with the substrate, and/or under severe thermal cycling conditions, the SAC alloy may not always be as reliable as Sn-Pb.

With the lead-free solder (which has a higher modulus than the Sn-Pb solder), an increased number of failures may be found during drop tests, due to cracking of the Cu traces and the PCB surface layers.

Backward Compatibility

The "backward compatibility" of CSP and BGA with SAC balls with the Sn-Pb solder is very much questionable. This is primarily due to the fact that the SAC alloy, with a melting temperature of 217°C, will not always completely melt during reflow with the Sn-Pb solder, typically at reflow peak temperatures between 205-225°C (or even as low as 200°C in extreme cases). As such, there will be little or no self-alignment, which is critical especially for finer pitch area array packages, with coplanarity issues further aggravating the situation due to the lack of collapse. Further, very little mixing takes place leading to grossly segregated microstructures. Poor interfacial bonding and increased voids are some of the issues which have been observed leading to poor solder interconnect reliability, which, in combination with the process issues, raise questions about the compatibility of the SAC area array packages with Sn-Pb soldering.

The minimum reflow temperature required for "complete mixing" depends on the ratio of the SAC solder ball volume to the Sn-Pb solder paste volume, and thereby varies with the CSP/BGA type. This is because the liquidus temperature of the "mixed alloy" varies with its composition, which depends on the mass of the Sn-Pb solder paste relative to the mass of the SAC solder ball. The mass ratio (in direct proportion to the volume ratio) in turn is related to the stencil thickness and aperture size, depending on the pitch of the package.

Generally, 225°C (and preferably >235°C) has been considered to be the minimum reflow temperature. When the reflow temperature is high enough and self-alignment does occur, mixing takes place between the SAC balls and the Sn-Pb solder, and the reliability of the interconnect using the Sn-Pb solder paste and SAC balls is generally considered to be no inferior to that using the Sn-Pb solder paste and Sn-Pb balls for area array packages, except that more voids have generally been observed in "mixed alloys". Such a scenario may be technically feasible, but may present significant difficulties for operations and logistics on the factory floor. As such, area array packages with SAC balls are considered to be "backward incompatible" with the Sn-Pb solder.

RoHS Compliance

RoHS compliance, however, is much broader in scope and complexity than lead-free, and as such, needs to be pursued in a holistic and comprehensive manner. For the worldwide electronics industry, the physical infrastructure is not yet complete as certain mechanical components are not yet readily available to meet RoHS compliance requirements. The knowledge infrastructure for RoHS compliance is still emerging, and work is still on-going in areas such as materials declaration and data exchange, operational issues, supply chain management, etc.

The concept of "due diligence" will be driving significant discussions across the industry for some time to come, touching upon issues such as qualification and certification, screening, testing, data retention, etc. It is hoped that environmental compliance assurance management across the industry will be addressed in an effective and efficient manner, in a collaborative effort between various tiers of the industry and relevant governmental elements.

WEEE Compliance

The implementation of the WEEE (and EUP) requirements will have an even greater impact on the industry, over an extended period of time. Design for the environment (DFE), recycling and environmentally responsible end-of-life (EOL) management are considered the ultimate solutions to the environmental concerns posed by the ever increasing volume of waste electrical and electronic equipment (EEE). Increased recognition of the potential economic value of the "cradle to cradle" approach to product EOL management provides additional impetus to accelerate efforts in this important business arena, by fully exploiting the "total economic life cycle" of EEE products. OEMs, EMS companies, recycling companies, along with consumers and national/local governments, all have important roles to play in this effort.

The proactive, intelligent and economical management of the EEE environmental life cycle is a complex and challenging endeavor. It involves environmental considerations at every stage of the product life cycle, including design, manufacturing, use, and EOL. There have been advancements in some of these areas in recent years, particularly in environmentally benign manufacturing. However, it is fair to say that the industry is still in its infancy in the comprehensive management of the total environmental life cycle of EEE.

Summary

It is inevitable that the transition to environmental compliance will have a significant impact on the business landscape in the electronics industry. RoHS compliance capabilities, DFE capabilities and recycling for product end-of-life management, will become key competitive differentiators for firms in the industry.

Reference

D. Shangguan, "**Lead-Free Solder Interconnect Reliability**", Co-published by the Electronic Device Failure Analysis Society and ASM International, 2005 (ISBN 0-87170-816-7).

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