Lead free production & problems when changing the processes

Dr. Dongkai Shangguan, VP - Advanced Technology at EMS-provider Flextronics, is discussing a lead free production and the problems that might occur when changing the processes.

EMS

1) Lead free alloys

In general, different variations of the Sn-Ag-Cu alloy (SAC), with silver content from 3.0% to 4.0%, are all acceptable compositions for lead-free soldering (including reflow and wave soldering). Studies using SMT test vehicles, by IPC in collaboration with solder suppliers and EMS companies (such as Flextronics), have concluded that there is no significant difference in the process performance and thermal cycling performance among these different variations of the alloy composition.

However, when the silver content is much lower (such as SAC105), the thermomechanical reliability performance is adversely affected, due to the reduced amount of Ag3Sn intermetallic compound in the solder microstructure. SAC105 is more suitable for BGA/CSP balls for handheld products where drop test reliability is more critical than thermal cycling reliability.

The tin-copper alloy is a viable alternative for wave soldering of cost sensitive products where reliability is less critical. Several variants of the Sn-Cu alloy have also been considered by the industry, including silver (Ag), nickel (Ni), and other elements as alloying additions. In addition to cost, reliability, hole-fill, and copper dissolution (especially for PTH rework) are important considerations when selecting an alloy for wave soldering.

Introducing and qualifying a new solder alloy for volume production is a significant undertaking which demands an industry-wide effort. Flextronics is working with several industry consortia to study various alternative lead-free alloys, for solder paste, bar, BGA solder balls, etc., with the hope of finding a common alloy that is suitable for across-the-board applications.

2) Compatibility issues

As the industry transitions to lead-free using SAC alloys for the BGA/CSP balls, tin-lead soldering still exists for several product categories. The SAC alloy (with melting temperature 217oC) will not always completely melt during reflow with the tin-lead solder (typically at peak temperatures between 205-215oC).

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, lack of mixing leads to grossly segregated microstructures, causing concerns about solder joint metallurgical uniformity and reliability, in addition to increased voiding.

Detailed studies have been carried out at Flextronics to investigate what process conditions are needed in order to minimize the risk. The complete mixing of tin-lead solder with the SAC ball is critical to forming uniform and homogeneous microstructures. Our study has shown that the mass of the tin-lead solder relative to the mass of the SAC ball, as well as the temperature, determine the degree of dissolution and mixing.

For reliability performance, the loading conditions must be considered. Solder joints fail mostly within the solder during thermal cycling but more at the interface under dynamic mechanical loading. Our studies have indicated that the thermomechanical reliability is more sensitive to the homogeneity of the microstructure than dynamic mechanical reliability (such as mechanical shock and drop).

More recently, the proliferation of various SAC compositions for the solder paste and BGA balls adds to the variety of "compatibility" issues which are the subject of active studies.

3) Board layout design changes

For SMT, no major changes in footprint design rules have been found necessary when switching to lead-free soldering. For example, our study has indicated that the "rule of thumb" for pad design to prevent component fall-off during second reflow still applies to lead-free. Our design rules have been established based on extensive DOE's and all of our design rules today are written for lead-free.

For wave soldering of through-hole components, some changes in the design rules are necessary to accommodate the difference in the physical properties between lead-free and tin-lead solder alloys, especially to fulfill the hole-fill requirements for thick boards. The general guidelines, such as component orientation relative to the soldering direction, thieving pads, etc, still apply to lead-free wave soldering.

Generally, it is important to optimize board layout, component distribution and Cu distribution in the PCB in order to minimize the temperature delta across the board. For wave soldering in particular, the thermal effect of Cu planes on hole-fill for thick boards need to be carefully considered.

4) PCB pad cratering

The PCB laminate material must be qualified to meet lead-free requirements. In lead-free applications, increased incidences of PCB pad cratering has been encountered by the industry, with several failure modes such as: interfacial cracking, pad cracking, lifted pads, and prepreg cracking.

Our investigation has indicated that the occurrence of pad cratering can be affected by several factors, including solder alloy properties, solder mask, BGA size, PCB brittleness, as well as the reflow condition and of course, the mechanical loading condition.

To mitigate the pad cratering concern, the issue of solder mask defined (SMD) pads versus non solder mask defined (NSMD) pads is being re-visited, for different loading conditions (stress concentration for thermomechanical conditions versus pad cratering for dynamic mechanical conditions).

5) Process challenges: wave solder hole fill, copper dissolution, Head-in-Pillow (HIP) defects

Due to the surface tension of the lead-free alloys, PTH hole-filling becomes more difficult as compared with tin-lead, especially with OSP PCB finishes and for thick boards with inner layers (when connected to ground planes, for example) which sucks the heat away, and/or with high thermal mass components.

Hole size, flux, inerting, and wave soldering profile, all need to be optimized in order to promote hole-filling. Recent Telecordia and IPC standards activities have recognized this phenomenon and provided guidance accordingly for OEM and EMS companies. Flextronics has performed detailed studies on how the PTH hole fill may affect reliability, and presented our findings to various industry bodies.

Cu erosion/dissolution is a metallurgical reaction where the Cu on the PCB dissolves into a Sn-rich molten solder. The higher Sn content in the SAC alloy, higher wave soldering temperature, and the long dwell time for PTH rework, have led to serious Cu dissolution for lead-free.

PCB surface finish, wave solder alloy, wave soldering and rework parameters (such as temperature, time, flow rate and direction), are the key factors to control in order to minimize Cu dissolution. The result of our investigation has been presented at several conferences.

The "head-in-pillow" defect occurs when the BGA solder ball does not mix and metallurgically bond with the solder paste on the PCB, with the BGA ball "resting" on the solder on the PCB . This creates a "latent defect" as the board may pass all of the production testing but fail early in the field. Our research has revealed that this defect is related to a number of factors, often in combination.

The stack-up of PCB warpage, BGA warpage, BGA co-planarity, and solder paste height variations, may lead to a "gap" between the BGA ball and the solder paste on the PCB during reflow. Poor BGA ball solderability, loss of flux activity in the solder paste (due to low flux thermal stability and/or low solder paste volume) further adds to the difficulties.

A non-uniform temperature profile may aggravate the situation if the BGA ball and the solder paste are not in sync in reaching the soldering temperature. The HIP defect presents challenges in its detection, mitigation, specification, as well as in solder paste evaluation. Flextronics has performed detailed studies on this subject and accumulated considerable know-how in addressing this important issue.

6) Lead free solder reliability

The industry has gained a great deal of knowledge on lead-free solder reliability, through fundamental studies, accelerated testing, and field applications, including components, PCB, and the solder joints of various alloys.

We have learned that lead-free solder reliability is a rather complex issue, when we consider various loading conditions (thermomechanical, dynamic mechanical, electrochemical, etc.), and even different loading levels (such as low/high stress levels for thermal cycling). As such, the design and interpretation of accelerated testing becomes very complicated and must be handled methodically and with great caution. A comprehensive review can be found in my book "Lead-Free Solder Interconnect Reliability".

Process control when dealing with latest technologies

Miniaturization and functional densification and integration, along with environmental compliance, fast time to market, low cost and high reliability, continue to represent leading trends for electronics products. The demand for smaller and lighter products (or greater functionality within the same real estate) is driving the implementation of 01005, 0201, finer pitch (0.3-0.4mm) QFPs and SMT connectors, finer pitch (0.3-0.4mm) CSPs, flip chips and COBs, as well as tighter spacings (<8mil) between components, all the while using lead-free solder. These, along with embedded PCB, are important capabilities at various stages of development and deployment at Flextronics to provide competitive solutions to our customers.

Inline Package-on-Package (PoP) is a technology developed at Flextronics in 2002 and implemented in volume production in Flextronics China in 2003. PoP offers a new avenue for further miniaturization and densification of PCBA, fully utilizing the space within the product envelop. It also enables configurable assemblies and provides greater flexibility in the supply chain, with faster time to market and better management of compounded yield issues. This technology has since gained great popularity in the industry and enabled the proliferation of 3G handheld products.

Moving forward, miniaturization technologies will be leveraged for large form factor boards as well, for "local density" on the PCB as well as electrical performance considerations. At the same time, we have also been working on technical capabilities for large form factor boards (with large, high pin count area array components and connectors) and backplanes, for telecom and computing applications.

The complete assembly capability for these new technologies demands methodical optimization for PCB footprint design, stencil technology and aperture design, solder alloy and solder paste evaluation, printing process, component specification, pick-place machine evaluation and parameters, reflow profile and atmosphere, AOI machine evaluation, rework process, reliability testing, etc. A detailed "factory qualification program" has also been in place at Flextronics for many years now to ensure that advanced capabilities are established at our global volume production sites.

Author: Dr. Dongkai Shangguan, VP - Advanced Technology, Flextronics

ANKE SCHRÖTER
info@evertiq.com