COVER ARTICLE

欧洲的环境立法，如RoHS和WEEE动议，连同市场力量，正在推动走向无铅焊料的转化。结果是焊接过程会发生显著变化。这些过程变化所带来的其中一个后果是在焊接点内存在气泡，使用新的焊接合金使这个问题更为严重。过多的气泡会导致焊接点质量差、烘乾过程或热循环中发生开路故障，以及现场失效。因此，需要尽量减少气泡，以保持过程质量并降低次品率和退货率。

Investigating Voids

Keith Bryant

Does a connection exist between pad finish and voiding in lead-free assemblies?

Along with market forces, European environmental legislation, such as the Restriction of Hazardous Substances (RoHS) in Electrical and Electronic Equipment and the Waste Electrical and Electronic Equipment (WEEE) initiatives, is driving the move to lead-free solders. As a result, significant changes will occur to the soldering process. The presence of voids within the joint is one of the consequences of these process changes and is exaggerated by the use of the new soldering alloys. An excess of voids can lead to poor quality joints, open circuit failures during burn-in or thermal cycling and field failures. Therefore, voiding needs to be minimized to retain process quality and to reduce rejects and returns.

Quite a lot of information has been published about changes in the level of voiding as the industry moves from a lead-based assembly process to a lead-free process. This technology shift will generally result in an increase of voids within the formed joints. Many theories exist about the cause, and a lot of research has been performed. After an extensive review, certain facts appear irrefutable:

- Voiding increases with the use of higher melting point tin/silver/copper alloys.
- The increased surface tension of these materials adds to this phenomenon.
- Moisture trapped within printed circuit boards (PCBs) and components becomes more of an issue with steeper temperature gradients and higher melting point materials.
- Many lead-free solder pastes contain more aggressive flux chemistries than lead-containing materials, which often means higher volumes of gas vent during joint formation.
- Reflow profiles and cooling rates have a significant influence on voiding and the position of the voids.

To date, much conjecture still exists on voids formed within tin-lead solder joints: the "safe" level of total voiding, the largest single void allowed and the safe position of voids within a joint. This conjecture is further complicated by the introduction of the new lead-free alloys. While this article does not enter into this debate, it will report on the findings of a controlled lead-free study and draw comparisons to current knowledge.

Background

This article is based in part on results from industry research. The SMART Group (High Wycombe, Bucks, UK; www.smartgroup.org) is a European technical trade association representing the electronics manufacturing industry. It hosted a Lead-Free Experience conference in 2003, in which PCBs with different surface finishes were assembled using the same solder materials, components and process conditions. Two different reflow systems were used during the study: convection and vapor phase. Only the results from the convection process are revealed in this article to allow accurate comparisons; the exclusion of the vapor phase results is not a comment on the use of vapor phase technology.

The PCBs were manufactured by the same company and stored under the same conditions; in short, everything possible was done to allow a level playing field. Once assembly was completed, the array packages were inspected with a high quality digital x-ray system with automated ball grid array (BGA) inspection routines and void calculating software (Figure 1).

In addition to the SMART Group's study, this article also discloses the results of several companies who have conducted similar studies but have asked to remain confidential.

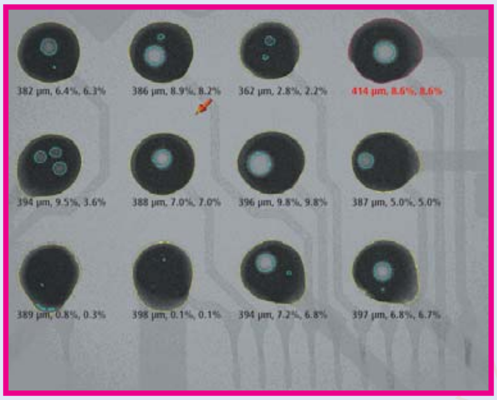

FIGURE 1: This screen capture shows automated void calculation. The first number is ball diameter; the second is total percentage of voids and the third is the largest single void.

Pad Surface Finishes

A myriad of finishes are available in the market, and many are differentiated only by brand name. The most popular categories of surface finishes were chosen for evaluation, and, as will be seen, some are more suited to lead free than others.

The five finishes listed below represent a cross section of currently available technologies and will form a solid basis on which to evaluate the findings.

OSPs

Organic surface preservatives (OSPs) are a surface treatment applied over clean copper pads to prevent oxidation. The material burns-off during reflow, providing solderable copper surface. Post-assembly characteristics include:

- exposed copper due to the poor wetting ability of lead-free pastes
- unsuitability for repeated thermal excursions, which is a characteristic exhibited by many, but not all, OSPs
- finish damage that is easy to repair
- least expensive of surface finishes.

Immersion Tin

After removal of oxides from the copper pads and processing the boards using this chemistry, a layer of electroless tin was deposited over the pads. As tin is the major part of lead-free solder, the metallurgy is well suited. However, some manufacturers fear tin whiskers, which are thought to form when the tin is under stress and could cause shorts on the board. Many debates on this subject are currently ongoing.

Immersion Silver

Immersion silver is an electroless deposit of silver. It is being heavily promoted due to the issue of tin whiskers, and its cost is similar to immersion tin.

Electroless Nickel/Immersion Gold

With electroless nickel/immersion gold (ENIG), the mechanism is slightly different. The gold provides a barrier stopping the nickel from oxidizing in air. When it is soldered, the joint is formed at the nickel interface, not the copper pad. ENIG is the highest cost surface finish, but it provides a flat, easy-to-solder surface. However, one major drawback is that the chemistry has to be well controlled or defects like black pad can result.

Lead-Free Hot Air Solder Level

Hot air solder level (HASL) was the preferred PCB surface finish for years. It fell out of favor as component pitch decreased with the use of quad flat packs (QFPs) and other high I/O devices. PCB manufacturers could not give the assemblers the consistently flat surface needed to assemble these devices. Today, the process is much improved and gives a much more consistent surface finish. However, due to the increased temperature requirements of lead-free alloys, the move from leaded HASL to lead-free HASL could put more stress on the PCB. This additional stress could lead to increased warpage or, in severe cases, material delamination. Having said this, HASL is a low cost option without any metallurgy mismatch issues.

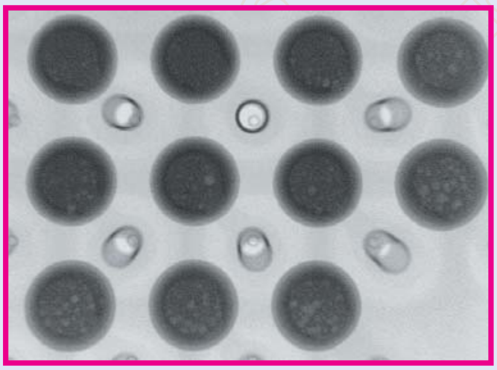

FIGURE 2: Note the large number of voids, all in the smaller area of the balls. This finding suggests that all the voids are in the pad-to-void interface. Oblique views confirm this theory to be correct.

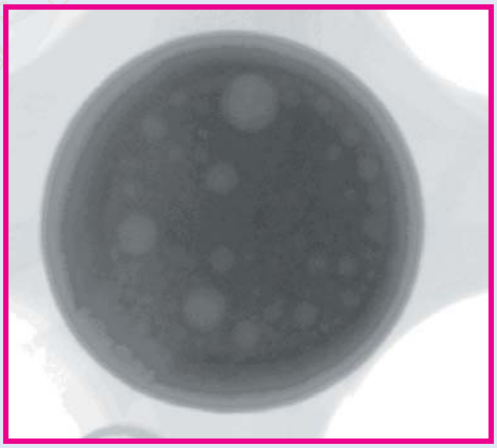

FIGURE 3: An excellent example of the new voiding phenomenon, this image shows the voiding in the pad area and on the circuit, which is clearly seen in the lower left-hand side of the image.

Void Measurement and Calculation

The location, size and frequency of voiding were determined by x-ray inspection. The use of a fully digital system with 65,000 levels of grayscale allowed voids to be located and measured accurately. The inspection algorithms gave accurate, reproducible numbers for void percentage and largest single void size (Figure 1).

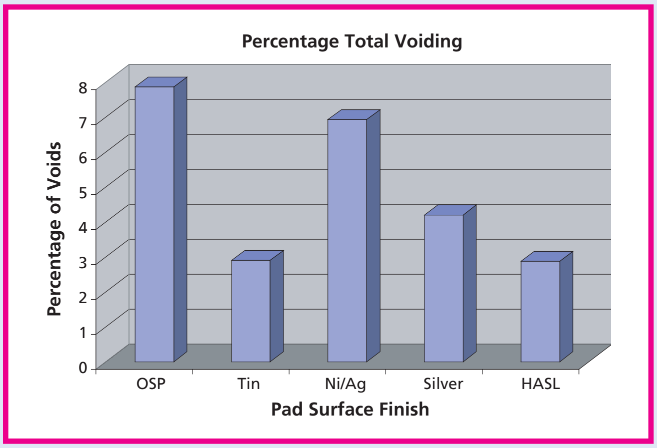

TABLE 1: Findings indicate that the surface finishes exhibiting the lowest percentage of voids are immersion tin and lead-free HASL.

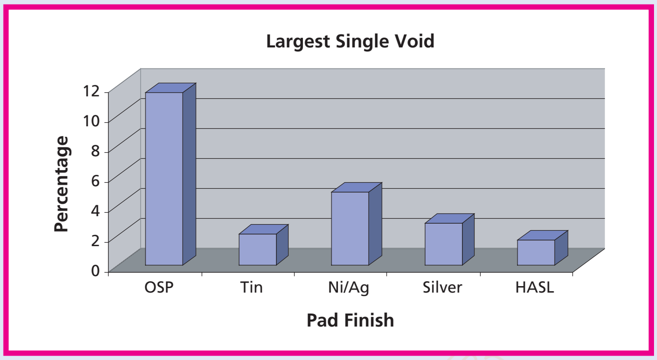

TABLE 2: The results here show that the voids in OSP joints tend to be much larger. Combining these results with the results shown in Table 1, this finish may produce or trap the most gas in the lead-free joint.

In addition, the ability to view the balls from oblique angles through 360° allowed the position of the voiding to be confirmed. At the start of this study, void position was not considered to be significant, but the findings changed the significance dramatically.

Summary

Tables 1 and 2 show the total percentage void results in graphical form as a mean value of all measurements taken on each surface finish. Any result that varied more than two standard deviations from the norm was not included, as it would point toward an issue with the process, component or board finish.

The largest single void results display the average size of the five largest individual voids for each type of pad surface finish.

Average Percentage Total Voiding

Table 1 indicates that the surface finishes exhibiting the lowest percentage of voids are immersion tin and lead-free HASL. This finding could be due to the affinity of the pad finish to that of the component termination and the solder paste.

The two pad finishes with the highest percentage of voids may be the ones that are likely to produce the most gas from the action of removing oxide (flux activity) from the surface prior to soldering taking place.

More conclusions may be able to be drawn from these results; however, many influences can affect the levels of voiding and looking any deeper into these numbers may be misleading.

Current IPC Class 1 allows 30% of the ball area to be devoid of solid material; as a result, all of these results could be considered acceptable.

Largest Single Void

The results in Table 2 show that the voids in OSP joints tend to be much larger. Combining these results with the results shown in Table 1, this finish may produce or trap the most gas in the lead-free joint.

Small voids are potentially less of an issue than large voids, but opinions conflict as to whether or not any voiding is detrimental.

Additional Findings

This work has highlighted variances in voiding that have been noted during digital x-ray inspection. While conducting this research, another voiding phenomenon was seen for the first time, and it has the potential to become a severe failure mechanism. The phenomenon is not easy to locate and cannot be seen on many x-ray systems.

As seen in Figure 2, it consists of a large number of very small voids formed at the pad-to-ball interface. Due to its position and the fact that all the voids lie in the same plane, the failure mechanism could easily lead to an open circuit or high resistance joint after thermal cycling, burn in or, worse, a failure in service. Potential causes of this finding are oxidation of the pad finish, issues within PCB manufacture or some form of intermetallic reaction. Figure 3 illustrates very clearly the problem and its location.

This voiding phenomenon has been found on PCBs with OSP, ENIG and immersion silver finishes. It is seen infrequently and does not exhibit a defined pattern, which points to a random failure mode, not simply a material mismatch. Needless to say, additional evaluation is ongoing, with additional findings hopefully reported soon.

Table 2 also points to the fact that the ENIG finish produced a very high percentage of voids that tend to be small in diameter. This finding could be due to the fact that the gas produced is of different composition or takes longer to produce and is frozen in the solder before it joins together to form larger voids.

Further analysis shows that these voids are more central or close to the joint face, whereas the OSP voids are often close to the joint open edge.

The void profile of tin, silver and HASL is much smaller, and, therefore, the conclusion may be offered that these pad finishes are more suitable for lead-free assembly.

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