USING "SIGNATURE IDENTIFICATION" FOR RAPID AND EFFECTIVE X-RAY INSPECTION OF BALL GRID ARRAYS

Gil Zweig
Glenbrook Technologies, Inc.
Randolph, New Jersey USA
gzweig@glenbrooktech.com

ABSTRACT

Although X-ray inspection of area array packages is prevalent, most users can identify only obvious defects such as bridges, voids and missing balls. Much more information is contained in the X-ray image of the bond shape pattern (the signature). To interpret this information, the stages of reflow must be understood. This paper will discuss the process parameters that influence reflow and show images from actual real-time X-ray movies of BGA reflow as it occurs. The stages of reflow will then be correlated with X-ray image signatures indicating process problems.

Key words: BGA, defect analysis, reflow stages, X-ray inspection.

INTRODUCTION

The use of X-ray inspection for quality control of ball grid array (BGA) bonding has become widespread in surface mount assembly. While the number of equipment suppliers and features has proliferated, the understanding of what the X-ray image of the BGA means has not advanced very far beyond identifying the simple and obvious defects of shorts and missing balls, and raising misplaced concerns over small solder voids. (Figure 1)

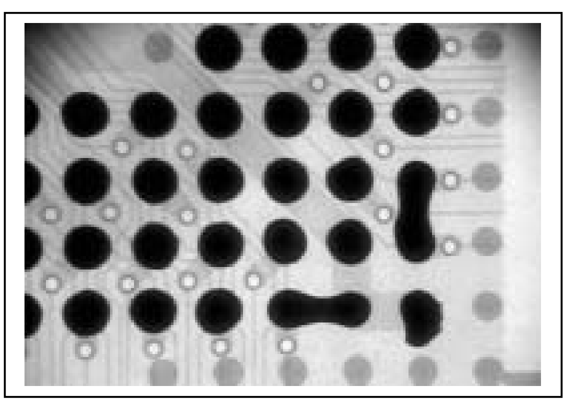


Figure 1A Examples of typical defects in BGA assembly: bridging, missing balls and solder voids:"Bridging"

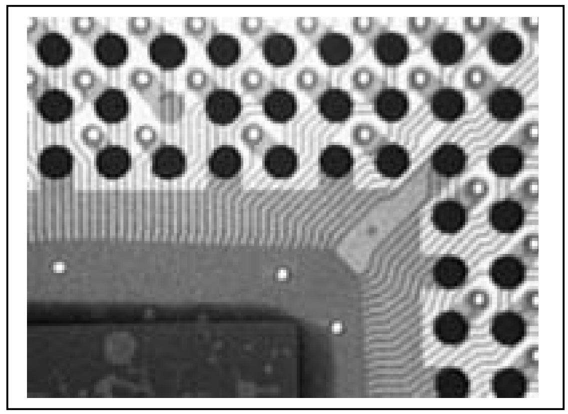


Figure 1B "Missing Balls"

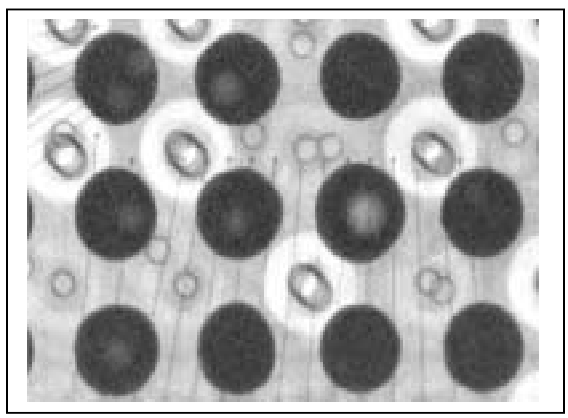


Figure 1C "Solder Void"

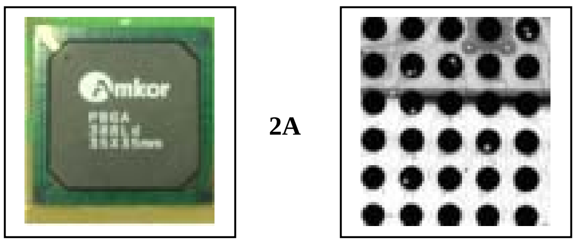
It is the intent of this paper to introduce the concept of X-ray "signature identification" as a means of extending the usefulness of X-ray inspection beyond identifying the obvious defects of shorts and missing balls. A better understanding of how the X-ray image relates to the assembly and reflow processes is needed to achieve this usefulness. In addition, signature identification supports rapid and effective X-ray inspection of BGAs with even the most modest investment in X-ray inspection equipment.

THE ANATOMY OF THE BGA BOND

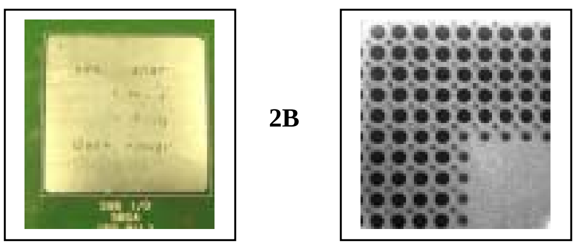
As any radiologist will tell you, before you can start to understand the X-ray image, you first have to understand the anatomy. There are three anatomical features that must be considered before looking at the X-ray image: package type, solder paste and PC board construction.

Package type

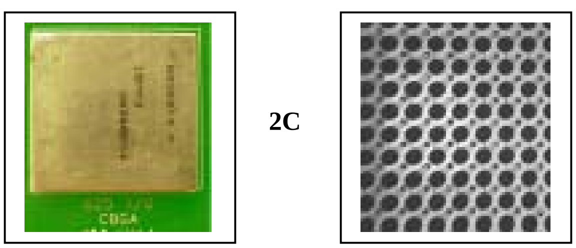
BGA package types include CBGA, PBGA, Super BGA, TAB and others. (Figure 2) The package type provides information on the thermal effects anticipated, such as thermal expansion, heat capacity and tendency to deform. PBGAs in particular have been observed to deform physically during reflow if they have not been properly baked out. Deformation effects can be detected in the X-ray image.



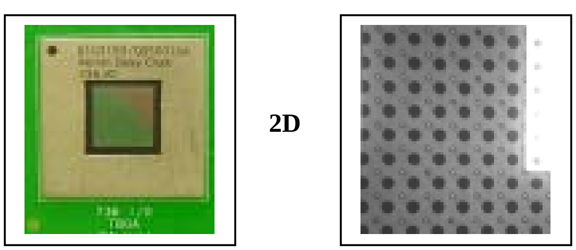
2A



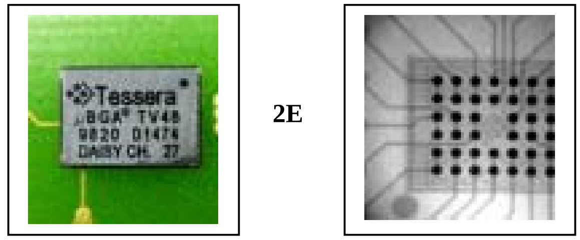
2B



2C



2D



2E

Figure 2 Examples of BGA package types: Plastic BGA (2A), Super BGA (2B), Ceramic BGA (2C), Tab BGA (2D) and Micro BGA (2E)**.**

Solder paste

If solder paste is used, problems can occur from the screen printing of too much or too little paste. This will result in X-ray detectable characteristics.

Construction of the PC board

High-heat capacity boards can affect reflow temperatures and thermal expansions. This too will result in X-ray detectable characteristics.

TYPICAL REFLOW STAGES

By combining real-time X-ray with a rework station, the three stages of reflow have been observed and recorded in real-time X-ray movies as they occurred. They are depicted schematically, and with their corresponding X-ray images, in Figure 3.

In Stage A, the placement of components can result in the BGA being aligned or partially aligned with its corresponding pad.

In Stage B, during initial melting, solder balls start wicking to their pads. The package is pulled into accurate alignment with the pads only when all the balls have melted.

In Stage C, after alignment, a final collapse can be observed wherein the solder wets the pad completely.

How reflow stages affect the X-ray image

In Stage A (pre-heat), the standoff height is equal to the ball height and the diameter of the ball's X-ray image is equal to the nominal ball diameter.

In Stage B (initial collapse), the standoff height drops to approximately 80% of the initial ball height.

In Stage C (final collapse), the standoff height drops to approximately 50% of the initial ball height and the diameter of the ball's X-ray image increases approximately 17%, resulting in an increase in projected area of 37%.

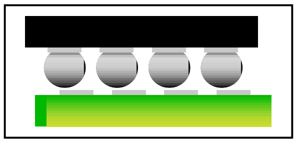
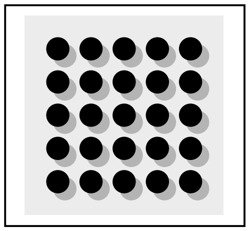


Figure 3A "Misalignment"



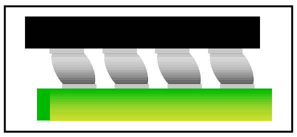
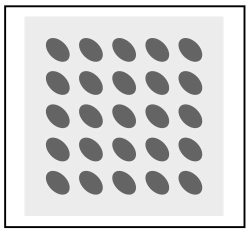


Figure 3B "Wicking"



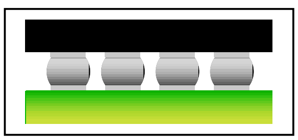


Figure 3C "Alignment"

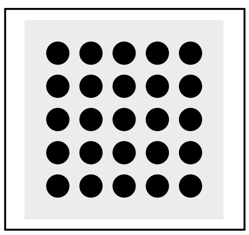


Figure 3 The three stages of reflow. Each action (Stage A, B and C) is shown in schematic form and with its corresponding X-ray image.

The change in size and uniformity of the ball's X-ray image, after reflow, is the key to the intelligent and informed understanding of the meaning of the final X-ray image.

Uniformity

At this stage it can be stated categorically that, if all the ball X-ray images are uniformly circular and equal in area within 10% to 15%, the probability is very good that no defects are present in the ball bonds. This condition may be called "uniformity." (Figure 4) Uniformity provides the first and most important characteristic in the use of X-ray inspection for rapid qualification of the quality of a BGA bond.

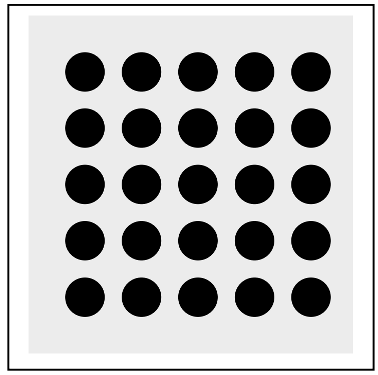


Figure 4 BGA uniformity, the ideal reflow result.

"Signatures" (or non-uniform patterns)

When non-uniformity exists in the BGA X-ray image, it can be observed that the variations can be either random or have some type of pattern. Both random variations and patterned variations provide a clue as to the possible defect or process problem and what may be causing it.

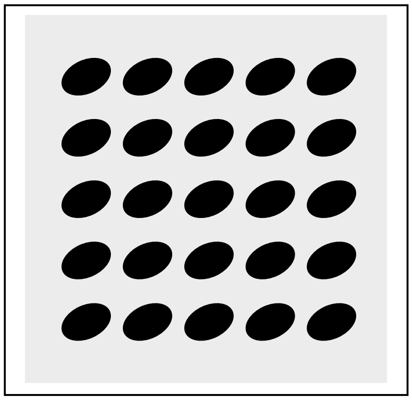
THE MEANING OF SIGNATURES

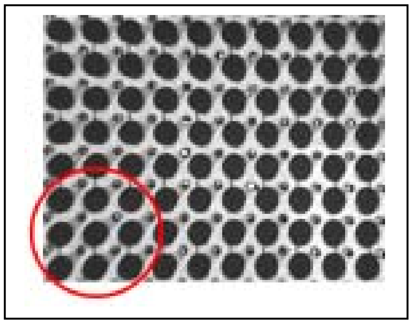
With this understanding, X-ray image signatures can be observed and hypotheses formed as to what may have gone wrong in the assembly process.

Insufficient reflow

When reflow is not sufficient, a number of characteristic signatures can be observed. (Figure 5) Elliptical-appearing bonds can result when the BGA is not registered exactly with the pad at placement. When the initial melting stage occurs, the solder wicks to the pad, creating an elliptical image, until full alignment can take place.

If full reflow is not achieved, full alignment does not occur and some or all of the images appear elliptical. These same elliptical images may also be observed if the pad pitch does not match the BGA pitch.





5A and 5B Elliptical X-ray images, the signature of insufficient reflow.

Cold solder joint

The cold solder signature can appear as one or more bond images having irregular edges around the perimeter. (Figure 6)

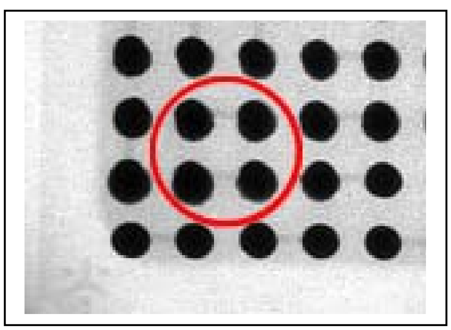


Figure 6 Irregular X-ray images, the signature of cold solder joints.

"Doming" or "dishing" of the BGA package

"Doming" is sometimes referred to as "popcorning" and the opposite effect, "dishing," is referred to as "potato chipping." Both of these defects are caused by the physical deformation of the BGA package. Plastic BGAs are particularly susceptible to this condition if moisture is not baked out prior to placement.

Specific signatures are associated with doming and dishing. (Figure 7) In doming, delamination occurs under the die area, causing the plastic package to dome in the center and resulting in the ball bonds under the die being compressed and enlarged. In dishing, the BGA edges curl upward, causing the bonds on the perimeter to be pulled and become thinner.

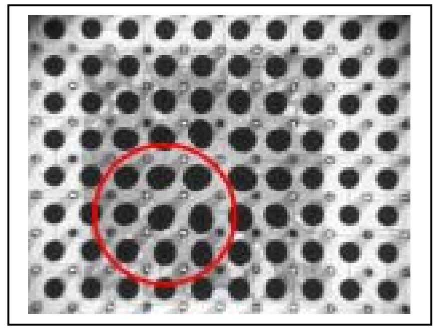


Figure 7A Doming (7A) and dishing (7B), the signatures of BGA package deformation, with (7C) showing a visual microscope image of a ball breaking away from the package.

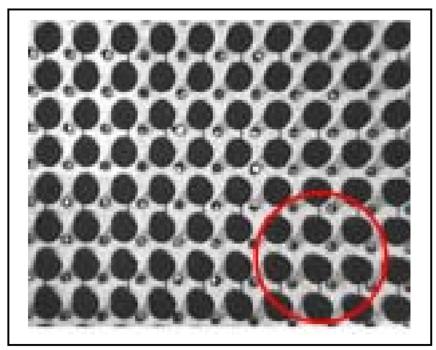


Figure 7B

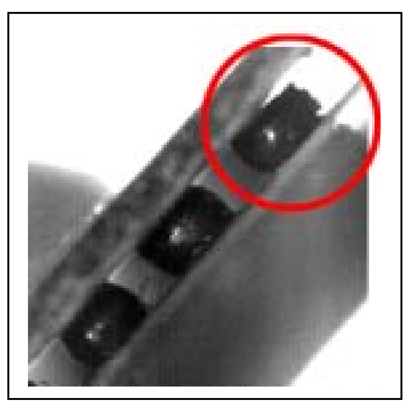


Figure 7C

Random differences in bond areas

When a signature of random differences in ball bond areas is observed (Figure 8), closer observation usually reveals a corresponding random distribution of solder voids. Since solder voids are easily detected with X-ray inspection, they are usually classified, without a clear understanding, as defects.

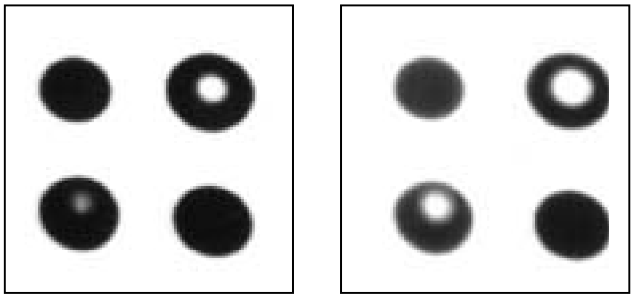


Figure 8 The Voltage Blooming effect, showing the same void appearing to be larger at 60kV than at 50kV.

However, subsequent studies have shown that some solder voids actually improve the reliability of the solder bond. The question then remains as to what level of solder void is acceptable. This issue is addressed in detail in the IPC Standard 7095, “Design and Assembly Process Implementation for BGAs.”

In this standard, there is a cautionary note regarding the tendency of many commercial X-ray inspection systems currently being used to exaggerate or distort the size of the void as the voltage is increased. This type of distortion occurs only if the type of X-ray imaging device used in the particular system suffers from an effect known as “Voltage Blooming.” (Figure 8) Not all X-ray imaging devices exhibit such voltage blooming.

Using BGA signatures effectively

The use of the BGA signature concept can provide rapid and effective X-ray inspection of BGAs with even the most modest investment in X-ray inspection equipment.

X-ray systems are classified as being appropriate for either the production environment and/or the laboratory. When the signature concept is employed in the production environment, image magnifications up to 40 times are usually adequate. In the laboratory environment, where the concern is failure analysis and where rapid inspection is not required, magnifications of 1000 times or more may be utilized.

Using image processing to aid signature analysis

Employing signature identification entails detecting X-ray image variations with greater than 15% deviation from the nominal bond diameter. This difference can be detected by an operator, but computer image processors can highlight and flag deviant signatures more quickly and repeatedly. Some examples of image-processed flagging are shown. (Figure 9)

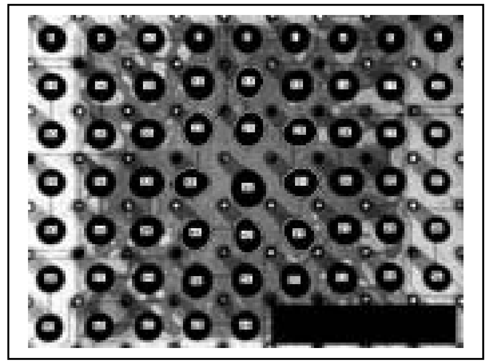


Figure 9 Image processing software can highlight and flag deviant signatures rapidly and repeatedly.

After a signature is identified, then what?

Once a signature is identified, it does not necessarily mean that a defect is present, nor does it precisely determine the cause. However, it does indicate the existence of a process problem that can eventually lead to defects.

Returning to the medical X-ray analogy, if the X-ray looks suspicious, it is time for a second opinion. The most effective technique to identify the problem is to employ a side-viewing optical microscopic probe referred to as an “endoscope.” A number of different, commercially available endoscopic designs may be used to produce a magnified optical, video image of the ball itself. (Figure 10)

Endoscopic inspection as a second opinion

Endoscopic inspection of a BGA bond has proven to be an invaluable adjunct to X-ray inspection. For example, it can positively identify cold solder joints, poor contact, cracks and flux residue.

The one disadvantage of endoscopic inspection is that the procedure is often cumbersome and time-consuming. However, when used in conjunction with real-time X-ray and signature identification, the combination becomes the most effective means of inspecting BGAs, Flip Chips and Chip Scale Packages.

Figure 10A An endoscopic inspection system (10A) and its resulting image (10B).

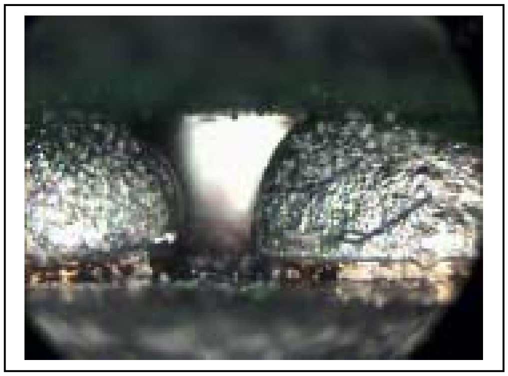


Figure 10B

The reason for this is that X-ray inspection, using signature identification, qualifies the BGA bonds very quickly as being either acceptable or suspicious. If it is desired to determine the exact cause of the solder irregularity, suspicious bonds can be examined off-line, using an endoscope. Knowing the cause can point to the appropriate process correction.

CONCLUSION

Although X-ray inspection is being widely used for quality control of assembled BGA type packages, its full benefits cannot be realized until the use of signature identification is employed. By understanding the meaning of the X-ray signatures, the process becomes more rapid and diagnosis becomes more precise.