Analysis of a Semiconductor Package Using an X-ray CT Instrument

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Abstract

Conventionally, in order to analyze the inside of a semiconductor device, a method of observation using an X-ray TV projection instrument requiring the package to be cross sectioned, delidded, or subjected to other destructive methods is common. We propose a nondestructive analysis method using a newly developed X-ray CT (computerized tomography). By this method using the X-ray CT instrument, we observed ball joinings of a BGA package and could evaluate the effectiveness and limits of the instrument. The minimum recognition length of the instrument is 4 micrometers, allowing us to observe configurations at stress-concentrated portion and find many kinds of defects. Many voids were observed at reflowed joining potions of BGA and CSP. In the case of BGA or CSP packages, reliability analysis will be needed, considering the existence of voids. However, if there are another parts near the observation point, it is possible to misinterpret the X-ray CT picture. Also, when observing the inner bonding wires of a QFP package, and compositing CT scan data to form a three-dimensional image, we could observe the three-directional configuration of the wire. From this study, we consider this X-ray CT instrument to be very effective for not only research but also production quality control.
Key words
CT, X-ray, Semiconductor Package, BGA, CSP, Solder Ball

1. Introduction
Up until now, it has been necessary to use destructive methods, such as cross sectioning and delidding to perform an analysis inside a semiconductor package. This process requires extensive time and prevents further study of the device. An X-ray projection instrument may be used, but it is very difficult to analyze the three-dimensional location of specific parts within a complex internal structure [1][2].

We propose a new nondestructive method of analyzing the internal structure of electronic components and circuits using an X-ray CT (computerized tomography) instrument. We studied the validity and limitations of this new method under various conditions.

2. Experimental Process

2.1 Instrument
The micro-focus X-ray CT instrument (SMX-225CT) manufactured by Shimadzu Corporation used in this study is shown in Figure 1. (Min focus dimension: 4 micrometers, Max X-ray output: 225W) This instrument was produced for the exclusive use of this industry. In this instrument, the sample rotates, unlike those for medical use, in which the sample is fixed.

2.2 Samples
The samples used for observation were substrates that are used for common electronic devices, such as portable telephones and household electrical appliances. Jointed solder balls were tested by thermal cycling to allow observation of fatigue. The solder balls were jointed between two sheets of FR4 substrates.

2.3 Experimental method
As shown in Figure 2, the sample was rotated on the rotary table and the X-ray permeation quantity (equivalent to the amount of X-rays absorbed by an arbitrary location in the sample) distribution at each location was measured. Figure 3 shows a substrate on the rotary table. In order to compose a three-dimensional image for each fault data, the rotation stage must be moved in the vertical direction, measured, and the image data collected from the multiple locations.

This instrument has a cone beam CT feature. When this feature is used, three-dimensional X-rays absorption quantity distribution data can be obtained from the multiple sets of two-dimensional data. With this we were able to
get a three-dimensional image of the fault and determine its location. The magnification of the sample to be observed depends on the distance from the X-ray source and the sample. In our case, the sample was set as close to the X-ray source as possible.

3. Experimental results

3.1 Observation of BGA package

Figure 4 is the portable telephone substrate used for the observation. Figure 5 is a photograph of a 12 mm × 12 mm FPBGA 116 pin package mounted on this substrate [3]. The solder attachment of the FPBGA to the substrate was observed using the X-ray CT instrument. Figure 6 shows the example observed with a conventional X-ray projection instrument. Though the void inside solder ball can be observed, the vertical location of the void cannot be determined with this method. Figure 7 is an example observed with the X-ray CT instrument. The void inside the solder ball corresponding to the one in Figure 6 can be observed. Figure 8 is a photograph showing a section corresponding to this location. The shape of the solder balls as well as the positioning and shape of the voids

Figure 2. Sample Configuration

Figure 3. Test Setup

Figure 4. Photograph of substrate

Figure 5. Photograph of 12×12 FPBGA 116 pins on substrate

Figure 6. X-ray of solder ball in 12 mm × 12 mm FPBGA (116 pin)
closely match in the results of both the fault image observed with CT and that of the cross-section.

Figure 9 is an example of a 6 mm x 8 mm µBGA 48pin package on the same substrate. Figure 10 is the example observed with the X-ray projection instrument showing the voids inside the solder ball as obscure figures. Figure 11 is the result observed with CT. The voids that were observed with the X-ray instrument are shown more clearly by the CT fault observation. Figure 12 is a photograph of a cross-section cut at the same place showing the same type of voids. It is clear that the voids inside the solder ball that could not be shown clearly with the usual X-ray
300 microns

Figure 12. Cross-section of solder ball in 6 mm x 8 mm µBGA (48pin)

projection instrument from a single direction can be found easily from this result of the CT instrument.

3.2 The influence of the other parts on the package substrate

The CT instrument was used to observe a mounted BGA package in a substrate to be used for household electrical appliances. Figure 13 shows the appearance of the substrate at the arbitrary location using CT imaging. Figure 14 shows magnified images of some of the solder joints. The void that exists in a solder joint can be distinguished clearly. Figure 15 shows a cross-section of the same position, showing that a close match between the CT instrument and visual observation could be obtained. Figure 16 shows a CT image of solder joints. Behind these solder joints are the other parts shown in the cross-sectional image in Figure 17.

When comparing Figures 16 and 17, it is clear that the form of each structure warps greatly at the bonded parts of the substrate in the CT image. The result of the CT scan appears as a ghost image when a large x-ray absorbing object, such as the solder used for the package, exists in the neighborhood of the object to be observed.

Figure 13. CT Photograph of BGA on board

Figure 14. CT photograph of inner voids (arrows) of solder joint

3.3 Observation of fatigue cracks in bonded solder balls

Solder balls were bonded between two sheets of FR4 substrates which had a layer of Si affixed to one side of the front substrate and subjected to 500 temperature cycles from −40 °C to +130 °C. Fatigue cracks were observed in the solder joints after this test.
3.4 The internal structure observation of the Flip Chip BGA package

Figures 20 and 21 are photographs showing a CT fault within the internal structure of the Flip Chip BGA package. Figure 20 is the observational result showing the voids inside the flip-chip bump and Figure 21 is the observational result showing the layer circuitry in the BGA substrate. The observation of formations that were clear in even the X-ray CT image is difficult to make visually for a subject when differences in items such as substrate circuitry, cannot be clearly observed due to contrast.

3.5 Observation of the package internal structure using three-dimensional composite imaging

At present, wiring techniques such as multistage looping, as shown in Figure 22, are standard for the semiconductor package in which wire bonding is to be used. But, when one tries to observe a wire configuration with the usual X-ray projection instrument, they appear to cross each other as shown in Figure 23. In order to observe the actual configuration, it is necessary to have the three-dimensional locational relationships of the wires. These three-dimensional locational relationships can be determined by combining the two-dimensional information obtained using the X-ray CT instrument as shown in Figure 24. It is possible observe this from any given direction. Therefore, the X-ray CT instrument is effective towards analyzing package parts such as semiconductors with such complex internal structures.
Figure 18. X-ray CT image of solder joint including fatigue crack

Figure 19. Cross-section of the solder joint shown in Figure 18

Figure 20. X-ray CT image of solder bump in a Flip Chip BGA

Figure 21. X-ray CT image of Flip Chip BGA bump

Figure 22. SEM image of stagger bonding (QFP package)

Figure 23. X-ray photograph of stagger wire (QFP package)
Figure 25 is a photograph showing the internal structure of a Mold-BGA package by the X-ray projection instrument. The result of the CT image configured to be three-dimensional is shown in Figure 26.

4. Considerations

The X-ray CT method is effective for observation of voids inside molded solder joints and ruptures between a solder ball and the conductor pad. However, when other parts exist in the neighborhood of a sample to be observed, the influence of those parts causes the image to be distorted. It was noted that such limits also existed in observations with the CT instrument. When observing a simple semiconductor substrate, it was found that a three-dimensional image configuration was effective in observing the internal structure. The resolution limit of the X-ray CT instrument used for the observation is 4 mm. As a result, it is possible that the accuracy required to observe a fault that is smaller than the resolution limit cannot be achieved. In addition, the distance between the X-ray source and the sample decides the expansion magnification. However, it has been found that the magnification decreases when that distance is increased in order to allow the sample to be rotated.

Numerous voids were found inside solder ball while observing the BGA package. The existence of voids in BGA solder joints may be detrimental to the reliability of the system. Therefore, the X-ray CT instrument, is very important in locating these voids and in determining their size and number.
5. Conclusions

We confirmed that semiconductor packages could be observed by using the X-ray CT instrument, and also that we can understand the mutual locational relationships of the composed material when the material is visualized three-dimensionally. Furthermore, the validity of this observation result will become more applicable for production control on mass-production lines and for quality control purposes if the operation of the X-ray CT instrument can be further simplified.

References

