Detection of Defects of BGA by Tomography Imaging

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ABSTRACT

To improve a cost performance and the reliability of PC boards, an inspection of BGA is required in the surface mount process. Types of defects at BGA solder joints are solder bridges, missing connections, solder voids, open connections and miss-registrations of parts. As we can find mostly solder bridges in these defects, we pick up this to detect solder bridge in a production line. The problems of image analysis for the detection of defects at BGA solder joints are the detection accuracy and image processing time according to a line speed of production. To get design data for the development of the inspection system, which can be used easily in the surface mount process, it is important to develop image analysis techniques based on the X-ray image data. We attempt to detect the characteristics of the defects of BGA based on an image analysis. Using the X-ray penetration equipment, we have captured images of an IC package to search an abnormal BGA. Besides, in order to get information in detail of an abnormal BGA, we tried to capture the tomographic images utilizing the latest imaging techniques.

Keywords: Image Analysis, X-ray, BGA (Ball Grid Array), Tomography.

1. INTRODUCTION

In a conventional IC package, the lead pin of it is set on the outside of the IC package and the defects of the solder joints of lead pin to the PC board have been done by the visual inspection [1]. Recently according to the high density surface mount, Ball Grid Arrays (BGA) and Chip Scale Packages (CSP) are used in PC boards, because they are easily mounted to the surface of PC boards [2, 3]. However, we can't inspect directly the solder joints of BGA, because these are hidden under IC packages. In a production line, many companies that product the PC board with BGA have done the inspection of BGA in the function test of electric circuits in the final process. To improve the cost of performance in manufacturing IC packages, it is required to detect defects at BGA solder joints in the process of surface mount. Therefore, it is important to develop image analysis techniques for the inspection system in a production line. In actual production line, we can find mostly the solder bridges (short of two balls). In order to prevent a bad package is sent to the next process, it is required to detect solder bridges in the surface mount process. We pay attention to detecting solder bridges in a production line.

In this paper, we propose to develop image analysis techniques for the detection of defects at BGA solder joints by the X-ray imaging. The problems of image analysis for the detection of defects of BGA are summarized in the following, one is the detection accuracy, that is, BGA is very small and we must inspect many BGAs according to a production line speed. The solder ball diameter is 0.76 mm and one IC package has three hundred solder balls. The other is the processing speed, that is, huge image data must be analyzed in the real time manner. At the first step of our study, it is important to develop image analysis techniques for the detection of defects at BGA solder joints. We attempt to detect BGA bridges by the X-ray penetration equipment and try to analyze the vertical cross-section images using the tomographic techniques.

2. TEST IC PACKAGE

It is very difficult to process directly the image data of BGA, because of a small ball and huge image data. Therefore, we need the fundamental experiment with the test IC package. We can find the test IC package based on the final electrical circuit test in the production line. BGA is an important technology for utilizing higher pin counts, without the attendant handling and processing problems of the peripheral leaded packages. They are used in manufacturing PC boards, because of their higher ball pitch (1.27 mm pitch), better lead rigidity, and self-alignment characteristics during re-flow processing. Fig. 1 shows the flow of a surface mount process with BGA. PC board comes into this process.

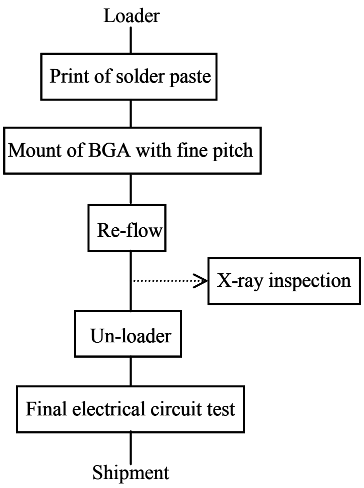

Fig. 1 Flowchart of surface mount.

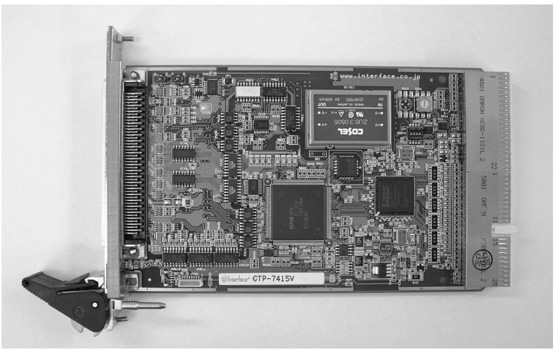

Fig. 2 Photograph of one example of test board.

At the first step, solder paste is printed in the circuit and next BGA with fine pitch are mounted and solder joints between IC package and the surface of printed circuit are made by the re-flow process. BGA solder joints could not been inspected and reworked using the conventional methods. In Chip Size Packages (CSP), Mondou et al. have proposed to measure precisely the surface structure by using the co focal optics before the re-flowing [4, 5]. In BGA, the ability to inspect visually the solder joints is desired in a production line to provide confidence in solder joint reliability.
In the most case of defects at BGA solder joint, the solder bridges between two balls are founded in a production line. These result from excess solder or misplaced solder, because dirty solder paste stencils are often founded in a production line. In manufacturing PC boards, IC package used with BGA is CPU for main function in an electronics circuit. In the actual production line, we can find the test IC packages based on the final electrical circuit test. Fig.2 shows a photograph of one example of a test IC board. The thickness of PC board is 2 mm and it has six layers. IC package is mounted with BGA to the surface of the PC board. The solder ball diameter is 0.76 mm and the ball pitch is 1.27 mm and the number of BGA is two hundred and fifty six. The size of IC

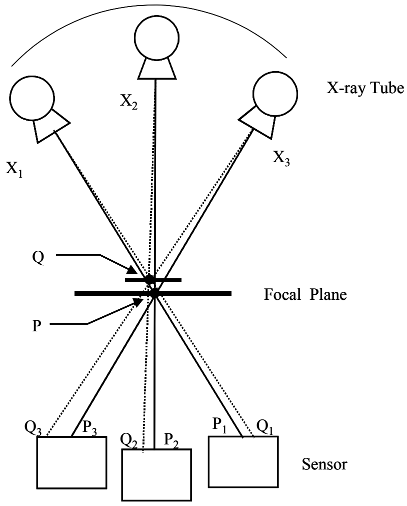

Fig. 3 Principle of tomographic imaging.

package is 27 × 27 mm. This test package does not pass the electrical function test. We consider that this package has defects at BGA solder joints.

3. CAPTURE OF X-RAY IMAGE DATA

At the first step, we have captured image of an IC package to search an abnormal BGA using the X-ray penetration equipment. Two dimensions image is convenient in capturing speed and processing time, comparing to the tomographic image. We have captured two kinds of im ages with inclination angle of 90 degrees and 45 degrees. Besides, in order to get information in detail of an abnormal BGA, we tried to capture the tomographic image utilizing the latest imaging techniques [6].
The essential components of tomographic equipment are an X-ray tube, an X-ray sensor and a rigid concerning rod that rotates about a fixed fulcrum [7]. Fig. 3 shows the principle of this equipment. Both the X-ray tube and the sensor move along an arc. When the tube moves in one direction, the sensor moves in the opposite direction. The sensor is placed in a tray so that it is free to move without disturbing the test sample. The fulcrum is the only point in the system that remains stationary. The X-ray tube and the sensor move along an arc in the same plane. As the distance of the focus and the sensor from the fulcrum is constant, the geometric enlargement and the exposed X-ray are constant in the every position of the X-ray tube and the sensor. The amplitude of tube travel is measured in degrees and is called the tomographic angle. The plane of interest within the sample is positioned at the level of the fulcrum in sharp focus and it is the only plane that remains in sharp focus. All points above and below this plane are blurred.
Tomographic techniques blur all points that are outside (above and below) the focal plane. In Fig. 3, by synchronizing in the operation of the X-ray tube and the imaging sensor, the position which is in focus (cutaway layer image) is always received at the same point P in the imaging sensor and the images coincide, but since the imaging positions of the areas which are not in focus (indicated by the dotted lines) are moving, they do not coincide. Point Q is above the focal plane. As the x-ray tube moves, only the image of point P, which is on the focal plane, remains in sharp focus, because it is the only image that moves exactly with the same distance as the sensor. The image of point Q moves more

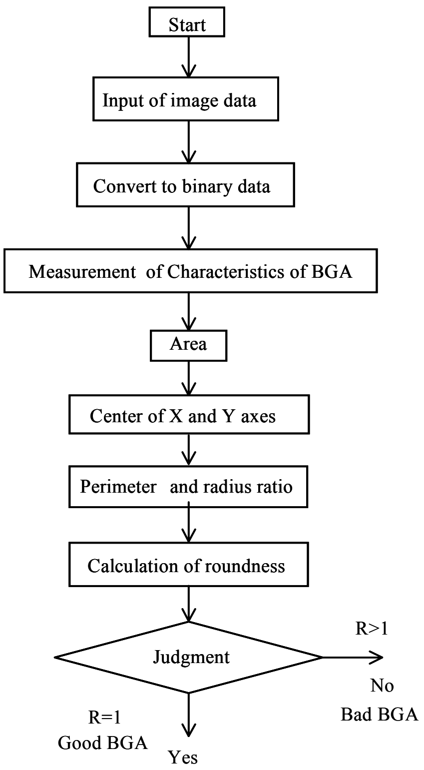

Fig. 4 Flowchart of image analysis.

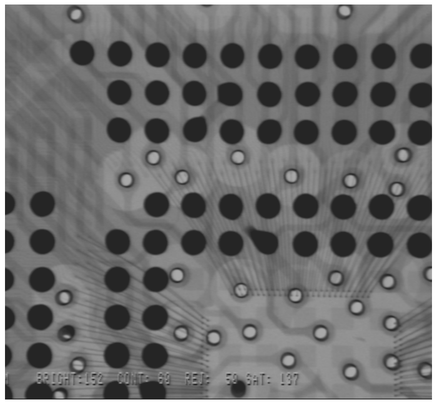

Fig. 5 Original image data (inclination angle: 90 degrees).

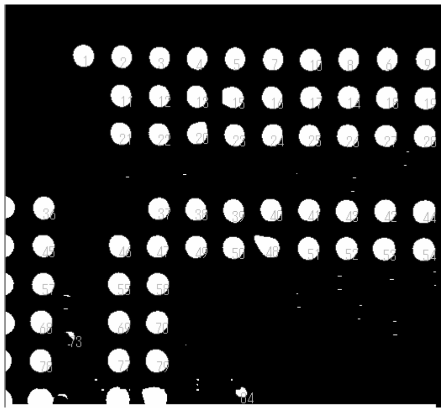

Fig. 6 Binary image data (inclination angle: 90 degrees).

than the sensor, so it is blurred. The further an object is from the plane of the fulcrum, the more its image is blurred. The X-ray focus is 5 μm and the sensor is the image intensifier. The condition for capturing image data is as follows. The X-ray tube voltage: 100 kV, the X-ray tube current: 100 mA.

4. ANALYSIS OF X-RAY IMAGE DATA

In the actual X-ray image data in PC boards, the image data of each solder ball is very small and we must process huge data. It is very difficult to process directly the image data of BGA. Therefore, at the first step, we need image analysis of BGA to get fundamental data for the development of an inspection system used easily in a production line. We propose the following image process techniques. Fig. 4 shows a flowchart of an image processing for the X-ray image data obtained by the above equipments. Image data is an input data to the personal computer for analysis. It is converted to the binary data to detect accurately the counter of a solder ball. Threshold levels are determined based on the histogram of the image data and the signal profile on horizontal line [7]. We selected 60 counts gray levels as the threshold level and converted to black and white image data to measure accurately the following factors of BGA. After labeling, first we measure the area of each solder ball and center of X axis and Y axis. Next we measure the perimeter and the radius ratio of each solder ball. A normal pattern of a solder ball is a circle. If a solder ball has defects such as bridge, the shape of the object separate from a true circle. In the case of solder bridges, two solder balls are shorted with the narrow path and we can observe the different pattern such as connected with the bridge.

In order to judge whether the solder joints are connected normally to the base pad in a surface mount process or not, we pay attention to the radius ratio and the roundness of a solder ball. Roundness R is calculated by the following equation.

$$R=L^2/4\pi S \qquad (1)$$

Where L (m) is the perimeter of a solder ball, S (m^2) is the area of a solder ball. If the object is a true circle, the radius ratio and the roundness equal to 1.

According as the shape of the object separate from a true circle, the radius ratio and the roundness become lager than 1. The judgment whether BGA is good or not is determined by the radius ratio and the roundness. If the value of these terms equals to 1, we judge BGA is normal. Then, if the values of these terms overrun equal to 1, we judge BGA is abnormal.

5. RESURUTS AND DISCUSSIONS

Fig. 5 shows an example of the original image data captured by the X-ray penetration equipment with inclination angle of 90 degrees. We analyzed this image data based on the above method. Fig. 6 shows the binary image data after labeling. Fig. 7 shows the radius ratio of each solder ball, and Fig. 8 shows the roundness. The roundness is one for the

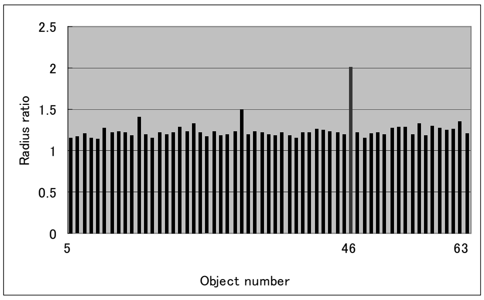

Fig. 7 Radius ratio.

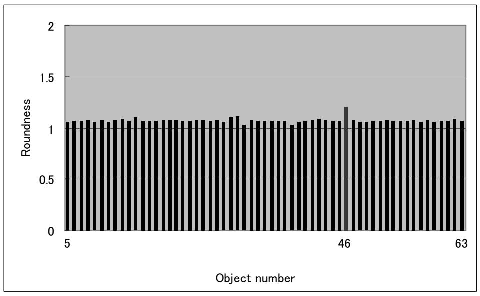

Fig. 8 Roundness.

Table 1 Example of result of image analysis.

No.	Area	Center-X	Center-Y	Perimeter	Radius Ratio	Roundness
17	584	362.5120	110.1849	84.3357	1.11814	1.05711
18	609	453.1133	110.4056	85.0368	1.14909	1.05006
19	610	498.9803	111.2492	85.5557	1.21782	1.06421
20	580	227.9724	152.5259	84.6696	1.36039	1.08543
21	579	136.4646	153.3143	83.0337	1.22294	1.05148
22	574	181.9983	154.0732	83.3519	1.18354	1.05108
45	603	44.5141	287.0746	83.8250	1.1271	1.01573
46	598	134.8863	287.3228	83.7240	1.2134	1.01964
47	591	180.0592	287.9222	84.3355	1.1435	1.05563
48	633	311.1375	286.9968	92.6165	1.9302	1.18018
49	594	226.0505	288.1650	84.5265	1.1536	1.04906
50	601	270.5291	289.2479	85.0132	1.1246	1.04242
51	612	359.9003	290.1111	85.5632	1.1370	1.04790

Fig. 9 Tomography imaging of one abnormal BGA in number 48.

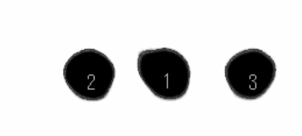

Fig. 10 Binary image data of above picture.

Fig. 11 Tomography imaging of one abnormal BGA in number 20.

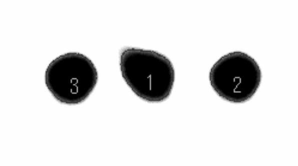

Fig. 12 Binary image data of above picture.

Table 2 Result of image analysis in number 48.

No.	Area	Center-X	Center-Y	Perimeter	Radius Ratio	Roundness
1	5990	315.5963	240.4758	279.9102	1.415142	1.04088
2	5725	186.3759	243.3128	270.6553	1.156723	1.018234
3	5533	463.0219	241.687	266.8342	1.151995	1.02403

Table 3 Result of image analysis in number 20.

No.	Area	Center-X	Center-Y	Perimeter	Radius Ratio	Roundness
1	5763	301.6868	230.3153	279.8832	1.52986	1.081671
2	5140	448.5663	235.4383	256.9989	1.122507	1.022562
3	5376	174.1557	236.9115	262.2167	1.120992	1.017775

true circle by Eq. (1). The actual radius ratio and the roundness of a solder ball are a little over one as shown in Table 1. This table shows an example of the result of the image analysis.

When the radius ratio is below 1.3 and the roundness is below 1.1, we judge BGA is normal and if two terms overrun these values, we judge BGA is abnormal. In this table, we can find one abnormal solder ball as shown in the data number 48. The radius ratio is over 1.5 and the roundness is over 1.1, namely, 1.9302 and 1.18018 respectively. Therefore, we can warn this solder ball is abnormal. This abnormal image data is shown as number 48 in Fig.6. In number 20, the radius ratio is over 1.3, namely 1.3603 and the roundness is below 1.1, namely 1.0854, as shown in Table 1. We pay attention to these BGA. This test package is inspected in the function test of the electrical circuit and is determined as an abnormal board.

In order to get more information on these BGA, we tried to capture the tomographic images of these BGA. Fig. 9 shows the tomography imaging of one abnormal BGA in Fig. 6. This image data provides image of one vertical cross-section in the center of the abnormal BGA, as shown with number 48 in Fig. 6. Fig. 10 shows the binary image data. Fig. 11 shows the tomographic image of the BGA in number 20, and Fig. 12 shows the binary image data. We measured the radius ratio and the roundness in these tomographic images. Table 2 and table 3 show the data of the vertical cross-section in number 48 and 20 respectively. The radius ratio of the abnormal BGA is over 1.5. On the other hand, the roundness is not over 1.1. We consider these vertical cross-sections to be

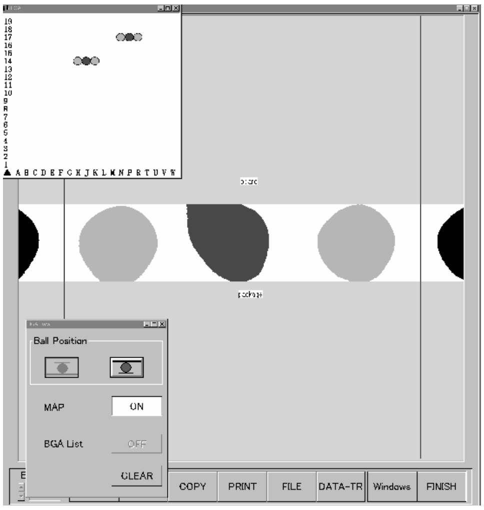

Fig. 13 Vertical cross-section in number 48.

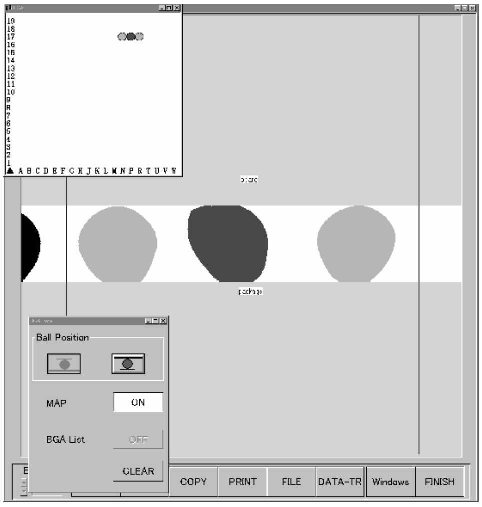

Fig. 14 Vertical cross-section of number 20.

relatively circle, because we captured only one vertical cross-section image of BGA.

To get information of the open connection of BGA, we drew the tangential line along the BGA, as shown in Fig. 13 and Fig. 14. In these figures, upper part is PC board and lower part is IC package. In Fig. 14, we can observe slightly open connection of BGA on the right side of the abnormal BGA.

Processing speed of penetration images is fast and the cost of the inspection equipment is low, compared to tomography imaging. And then, we consider that two dimensions inspection is effective for the detection of defect of the bridges, because of capturing and processing speed and cost of the equipment. On the other hand, tomographic imaging is effective to get information on open connection of BGA.

In the actual production line, we founded some abnormal PC boards based on the functional test of electrical circuit. Each board has only one or two solder bridges. In the X-ray image, we could not find obviously two balls short but can find a ball having tail. We wonder if every joint on every board needs inspection. We hope to inspect everything to provide higher confidence of reliability of PC boards. But members of a company that pro ducts PC boards say that they need to inspect every BGA, when the condition of a production is changed. Once a process runs well, a manufacturer could inspect only a test sample of PC boards.

6. CONCLUSIONS

For a practical purpose of developing the inspection system to detect defects at BGA solder joints in a production line, we have proposed the image analysis techniques, in order to carry out the inspection of the IC package having BGA. We deal with an image analysis of the test package, and significant results are obtained as follows.

1) To analyze BGA defects, the radius ratio and the roundness of a solder ball are effective. For a normal solder ball, we can get these values equal to 1. On the other hand, for an abnormal solder ball, it is cleared that the radius ratio and the roundness overrun 1.

2) To analyze minutely defects of BGA, it is effective to get tomography imaging. It offers us information on the joint with the base pad and the IC package.

To realize the inspection system of BGA in a production line, further studies are desired such as the construction of control system of the X-ray focus for covering all BGA in one IC package and image analysis algorithm according to a line speed of production.

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