Analysis of Identifying Specific Position of Voids in Multiple Solder Layers of Power Module by 2D X-ray inspection device

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It is very important to identify the voids position in the solder layers of power module because it improves the reliability of modules in the manufacturing process. This paper proposes an inspection method of voids with specifying the voids position in the solder layers of power module using 2-dimensional X-ray inspection. The inspection introduced here, will not cause any damages to the module during inspection (nondestructive method) and can also reduce inspection process time, which implies it could be a better solution for solder joint void inspection.

Key word: Power module, Solder layer, Solder joint, Void inspection, X-ray,

1. Purpose

In the recent development of high efficiency power modules in the semiconductor industry, one of the major problems is how to prevent heat generation and let the heat dissipate out of the module. Figures 1 and 2 show an example picture of a double-sided cooling module and a schematic of its cross-section structure, respectively. If voids are accidentally formed in the solder joints during the manufacturing process, the heat dissipation performance of the module will be deteriorated. Therefore, it is essential for us to examine voids in the module to improve the module properties.

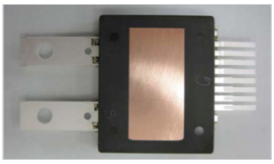

Fig. 1 Double-sided cooling module.

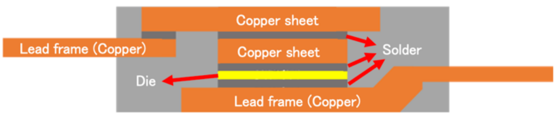

Fig. 2 Cross-section structure of double-sided cooling module.

This paper presents an inspection method of voids in the solder layers of power module with specifying the voids position, which is a 2-dimensional X-ray inspection method. In order to investigate such voids, there are several common methods including: (i) Cross section observation, (ii) Scanning acoustic tomography: SAT, and (iii) 3-dimensional CT scanning: 3D-CT. Methods (ii) and (iii) are nondestructive whereas Method (i) is a destructive test. In Method (ii), however, the module needs to be soaked, which sometimes causes damages to the module during the tests and Method (iii) usually requires a substantially longer time for inspection, which is not suitable for inline inspection.

The characteristics of 2D X-ray inspection is as follows:

(1) Nondestructive method

(2) Shorter inspection time (compare to 3D-CT)

Accordingly, the authors have adopted this inspection method. The details are in the following description.

2. Experimental

2-1. Material

For this experiment, the authors made a simple module which the configuration is similar to an actual double-sided power module. Figure 3 represents the cross-section construction of simple module. Two pieces of copper sheets (thickness: 1.5mm) on the top and bottom of module. Between the copper sheets, there are three layers of solder joints (t: 0.1mm), one silicon die (t: 0.087mm) and a piece of copper sheet (t: 1.5mm) as a spacer.

In addition, voids are put in every layer of solder joint on purpose by using red resin during the soldering process. The size of void is around 550 µm diameter. Figure 4 shows the layout of voids and also the inspection result of SAT (Scanning Acoustic Tomograph) on the right side.

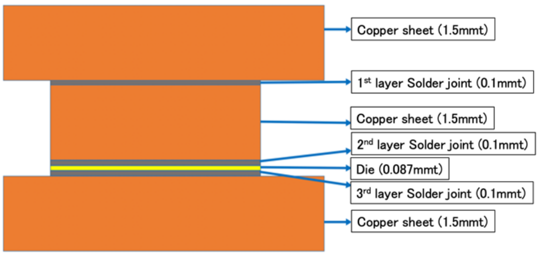

Fig.3 Cross-section of simple double-sided cooling module.

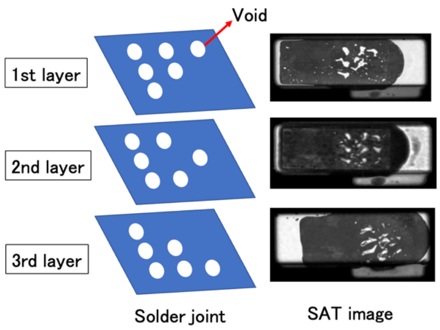

Fig.4 Layout of voids and inspection result of SAT.

2-2. Apparatus

(i) The X-ray inspection machine, X200, which is a cutting-edge tool designed by SVXR.[1)]

The feature of X200 is as follows:

(1) Hight power (Max 70kV x 14mA)

(2) High resolution(2.8µm/pixel) with large FOV (field of view)

(3) 16-bit CCD camera

(4) Automatic inspection for solder joint by original algorism.

High power X-ray can help us to see through thick copper without taking long imaging time. In addition, high resolution and 16-bit CCD camera provide clear images with 65,536 levels of gray scale. Therefore, we can see more details from the image by changing the contrast.

(ii) For analyzing the position of voids, we use an open-sourced software, ImageJ Fiji.[2)] It can display, edit, analyze, process, save, and print 8-bit color and grayscale, 16-bit integer, and 32-bit floating point images.[3)]

2-3. Inspection procedure

The procedure of experiment is as follows:

Step 1: Take a top-down image and a tilted image at the same location of module under the same imaging condition.

Step 2: Use ImageJ to measure the coordinate value (x-axis and y-axis) of voids on top-down X-ray image and tilted X-ray image.

Step 3: Compare the coordinate value of voids with top-down X-ray image and tilted X-ray image. Calculate how much the value changed on every void.

Step 4: Find correlation between the coordinate value and the void position by analyzing the result which we got from step 3.

A kind of stereo radiography is utilized in the image analysis where a pair of X-ray photographs taken at 0 degree and 15 degrees of source angle are compared.

Misalignment of voids can be seen with comparison between two photographs, which is then measured in x-y coordinates using the image analysis software.

Fig. 4 shows an example. The precise positioning of each voids in the cross section of the sample can be accomplished using the measured coordinates and X-ray incident angles.

3. Results & Discussion

3-1. X-ray images

X-ray photographs were taken twice for a module with the X-ray source angles 0 and 15 degrees for a imaging time 5 minutes as can be seen in Fig. 5.

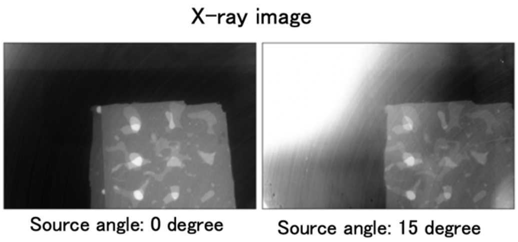

Fig.5 X-ray images at two X-ray source angles: 0 and 15 degrees.

In Fig. 6, the target voids A, B and C are shown. It is seen that, for void A, the image shifted its location to A' at 15 degrees X-ray source angle. Similar changes in the image happened for voids B and C as well. The graphic overlay shows a clear shifting between the two images. From these images, the location change of the voids can be measured.

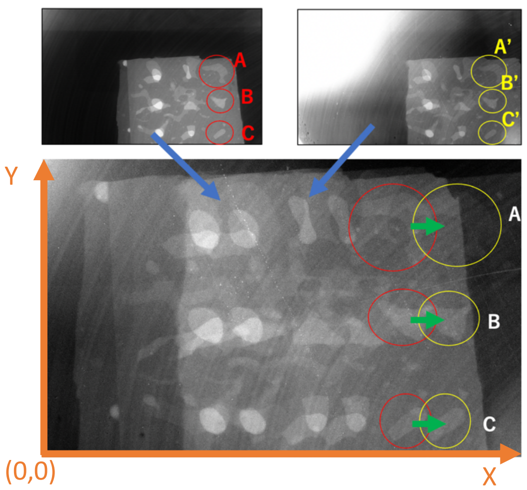

Fig. 6 Overlaid images of 0 and 15 degrees of X-ray source angle.

3-2. The calculation of the void level

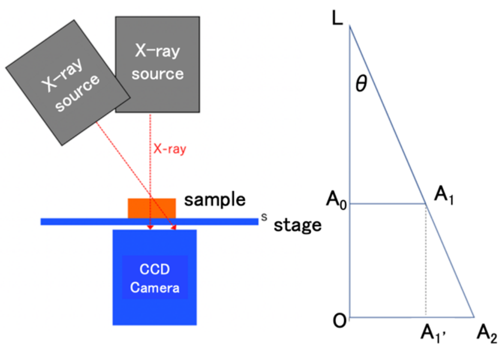

Fig. 7 Configuration of shifting shadow of voids.

In the X-ray filming, the following method can be applied. The configuration in X-ray radiation is shown in Fig. 7. It may be possible to assume that the X-ray beam is ejected as parallel rays because of the very small size of the target module. In the right of Fig. 7, a straight X-ray beam from point L reaches at point O on the bottom plane OA_2, where the light detective elements are placed. In case the width of a void, say Void A, extends from A_0 to A_1 on the corresponding plane where Void A is laid, its shadow should be detected as $OA_{1'}$ on the bottom plane. In case where the X-ray beam is tilted in an angle of θ (nominally, 15 degrees), the shadow of A_0A_1 (Void A) should be horizontally shifted to the right on the bottom plane. According to triangle similarity,

$$\overline{A_{1'}A_2} = \overline{OA_0}\tan\theta \qquad \text{(i)}$$

where the distance $A_{1'}A_2$ is a horizontal position aberration between A_1 and A_2. Similarly, if there are voids expanding from B_0 to B_1 and from C_0 to C_1, the corresponding shadows will be appeared with satisfying the following relationships.

$$\overline{B_{1'}B_2} = \overline{OB_0}\tan\theta \qquad \text{(ii)}$$

$$\overline{C_{1'}C_2} = \overline{OC_0}\tan\theta \qquad \text{(iii)}$$

As can be seen in the bottom picture of Fig. 6, the horizontal position aberration differs, and the aberration should increase with decreasing the distance between the X-ray source and the plane where the void is placed. Therefore, if the void is the closer to the X-ray source, the position aberration becomes larger, and vice versa.

Table 1 The void level of voids A, B and C

Target void	Location	Distance (layer to CCD)	Shifted distance of void			Relative ratio
			max 0	min 0.1	average (min+max)/2	
A	1st layer	$\overline{OA_0}$	$\overline{A_{1'}A_2} = \overline{OA_0}\tan\theta$			1.49296552
		5.462mm	1.4635385	1.4367436	1.4501410	
B	2nd layer	$\overline{OB_0}$	$\overline{B_{1'}B_2} = \overline{OB_0}\tan\theta$			1.05158621
		3.862mm	1.0348198	1.0080249	1.0214223	
C	3rd layer	$\overline{OC_0}$	$\overline{C_{1'}C_2} = \overline{OC_0}\tan\theta$			1
		3.675mm	0.9847133	0.9579184	0.9713158	

3-3. Data

Table 2 Measurement of voids A, B and C

Target void	Imaging angle of X-ray source	coordinate of Y-axis	① Shifted distance of Y-axis	coordinate of X-axis	② Shifted distance of X-axis	Relative ratio of ②
A	0 degree	2005	8	5258	534	1.49770637
	15 degree	1997		5792		
B	0 degree	3019	1	5315	375	1.05233288
	15 degree	3018		5690		
C	0 degree	4048	4	5320	357	1
	15 degree	4052		5676		

From the result shown in Table 2, it is found that the readings in Y-axis coordinate of each target voids did not shift much. The reason is that the X-ray source angle was changed in a single direction, i.e., in the direction parallel to X-axis. On the other hand, the larger changes in X-axis coordinates are observed. Therefore, it is reasonable for one to understand that larger shifting of a void corresponds to the upper layer of the solder joint. As a matter of fact, void A is located in the 1st layer (at the top), void B in the 2nd layer and void C in the 3rd layer (at the bottom) of the solder joint. The relative ratio shown in Table 2 sufficiently matched the result of relative ratio in Table 1.

In order to demonstrate that the result is reliable enough, the other voids D-1, D-2 and D-3 were selected, as seen in Fig. 8, to confirm if the reproduction of the data can be obtained in the same manner. These three voids are overlapped as they are in the different layers of solder joint. From the result of SAT, it is found that the void D-1 is located in 1st layer and void D-3 is in the 3rd layer.

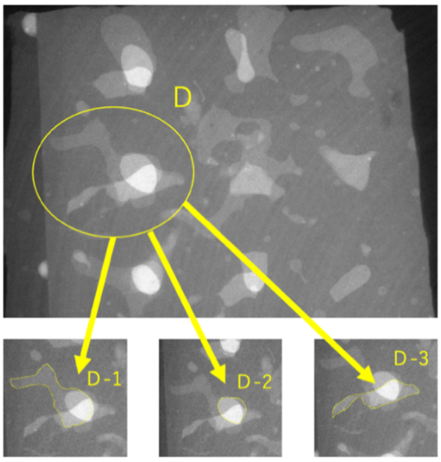

Fig.8 Detail photographs of void D (D-1, D-2 and D-3).

The measurement results are summarized in Table 3. It is shown that void D-1 should be located in 1st layer for

Table 3 Measurement result of void D-1, D-2 and D-3

Target void	Void location (verified by SAT)	Imaging angle of X-ray source	coordinate of X-axis	Shifted distance of X-axis	Void location (identified by change value)
D-1	1st layer	0 degree	3242	518	1st layer
		15 degree	3760		
D-2	2nd layer	0 degree	3460	361	2nd layer
		15 degree	3821		
D-3	3rd layer	0 degree	3398	343	3rd layer
		15 degree	3741		

the largest shifting value. It perfectly corresponds to the result of SAT. The same results can be applied to the locations of void D-2 and void D-3.

4. Conclusion

It is clearly shown in this study, that the solder layer in which voids are formed, can be successfully specified. In this experiment, the structure and configuration of the test specimen is precisely known. Under these circumstances, the measurement of the void shadow shifting will give the solution in which layer the voids are detected. The importance of the result is that levels of voids can be obtained from a 2-dimensional X-ray photograph in a simple calculation. An accurate size and extent of the void can also be determined with the measurement of its cross section from the photograph.

5. Acknowledgment

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6. References

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