

Evaluation of the Ball Grid Array (BGA) technology with a view to the Space-use application

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Abstract

High-density mounting technique of components is greatly expected as one of the approach to high-speed signal processing and reduction in size and weight of components in the Space field of Japan. We evaluated the reliability of the Ball Grid Array (BGA) technology with a view to the Space-use application. For mounting the BGA package, study of nondestructive inspection procedure in solder, careful selection of boards and mounting materials aimed at improving the process quality, reviewing the countermeasures for the failures such as gap defect and volume defect, as well as vibration test, shock test, and thermal cycling test in mounted circuit board were performed. The study results and the test results for these above will be covered in detail here. We also studied the detection capability of the 4 different types of X-ray devices for the crack defect of mounted BGA and found that the 3 dimension X-ray CT device was the most effective for detecting the cracks. Furthermore, we will show the effectivity of the low thermal expansion underfill materials for shock resistance and vibration resistance.

Key words: BGA mounting, Reliability, X-ray computed Tomography, Space-use

Introduction

We studied a study of nondestructive inspection procedure for the mounted BGA, careful selection of printed circuit boards (PCBs) and mounting materials aimed at improving the process quality and the tests such as vibration, shock and temperature cycling in mounted circuit boards for determining the environmental resistance of spacecrafts. Also we report the study of the detection capability of the 4 different types of X-ray devices for the crack defect of mounted BGA in a review of nondestructive inspection techniques.

We will show a case of 4 μm gap cracks detected by the 3-dimension micro-focus X-ray computed tomography (3D X-ray CT) system. Furthermore, we will show the effectivity of the low thermal expansion underfill materials for ensuring the reliability of the components.

BGA mounting technology issues

The BGA mounting has been widely applied in the field of the consumer electronics and industrial instruments, and the quality of the technique is being improved in the mass production line. However, such technological issues shown in Figure 1 may emerge when the technique is considered being used for the high-reliable electronic devices such as rockets and satellites.

For BGA mounting, the printed circuit boards (PCBs) are required higher density line and space design than ever before, and it is critical to select the mounting materials considering the stress resistance to the structure without a stress relief mechanism in temperature cycling and resistivity to vibration and shock. For inspection technology, since visual inspection for the solder-joints cannot be performed, nondestructive inspection techniques such as X-ray equipment will be necessary instead. For environmental tolerance, the environmental tests for vibration and shock at rocket launch, and the thermal stress test for satellite operation in orbit should be performed and evaluated for reliability.

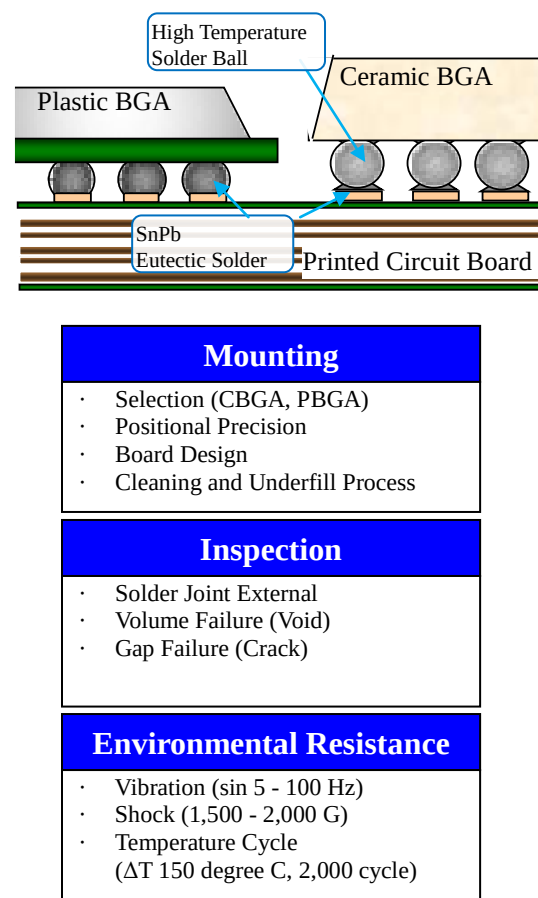


Figure-1. BGA Mounting Technology Issues

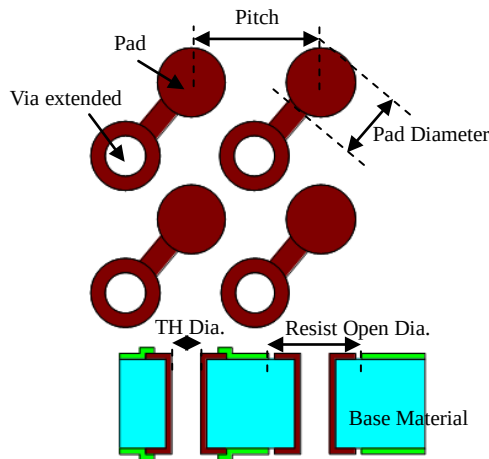
The design for BGA mounting

For BGA package mounting, some well-known standards and guidelines^{[1]~[4]} from space organizations are published. The ball shape is greatly affected by the mounting techniques and controlled by the pad diameter and the solder resist shape, and the solder paste volume on PCBs.

Table-1 Design Parameters (unit: mm)

Pitch	1.27	1.0
Pad Diameter	0.6	0.5
Resist Open Diameter	0.75	0.65
Land Diameter	Inner Layer	0.76
	Outer Layer	0.6
Through Hole Diameter	0.76	0.65
Line Width	0.35	0.3
Space Width	0.13	0.1
Material	0.18	0.125
Number of Layers	Degeneration polyimide	16

(continuing to the next page)

Table-1 Design Parameters (Continued)

In this report, we will show the BGA mounting design with the information above in addition to JAXA's mounting design rules for space-device. Table-1 shows the main mounting design parameters used for the BGA mounting.

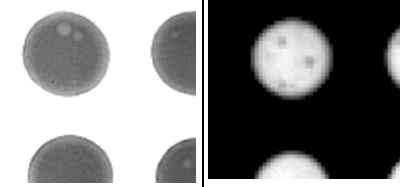
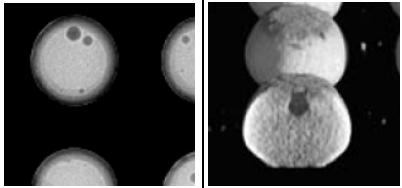
Non-distractive inspection guideline

Because most of the BGA solder joints is hidden under the package, only small number of BGA solder joints which are visible from outside of BGA package can be performed the visual inspection. To check all of the solder joints hidden under the package, non-destructive inspection equipment such as X-ray equipment shall be necessary. We created samples of BGA mounted PCBs in order for us to evaluate the inspection technique and the detection capability. The samples were intentionally made with possible defects in the BGA solder joints such as bridge and misalignment during the mounting process and we forced the samples to make cracks by overloading them. We examined the detect capability for the defects in the joint of these samples with various X-ray inspection equipments. The evaluation of X-ray inspection equipments and two cases of defect detection at BGA solder joint is shown in Table 2.

X-ray generators can be categorized into two types: X-ray device with normal focal spot more than 0.4mm depending upon the focal spot diameter and micro-focus device with focal spot less than 0.1mm in order not to defocus due to X-ray magnification. X-ray generator, detector and scanner can be combined in a best possible combination depend-

ing upon the test object and the specific purpose. It is quite important to get the information of the location and the size for voids and cracks in BGA joints. We found that the micro-focus 3D X-ray CT system, which shows detail information of the defects by 3D image, is most useful for detecting the defects in BGA solder joints.

Table-2 Specification of X-Ray Systems and Image Examples

Technology	Micro-focus X-ray	
X-ray tube	Sealed X-ray tube	Sealed X-ray tube
X-ray detector	Image Intensifier (I.I.)	Imaging Plate (IP)
Focal spot size	7 μ m	7 μ m
Tube voltage	150kV	150kV
Tube current	66 μ A	66 μ A
Image Processing	Digital image processing	Digital image processing
X-ray image (ex.)		
		3D X-ray CT
X-ray tube	Open type X-ray tube	Open type X-ray tube
X-ray detector	Flat Panel (6 megapixels)	Flat Panel (6 megapixels)
Focal spot size	1~4 μ m	1~4 μ m
Tube voltage	100~120kV	100~120kV
Tube current	100~150 μ A	100~150 μ A
Image Processing	Digital image processing	Digital image processing
X-ray image (ex.)		

Gap failure in BGA solder joints

A crack is most known for gap failure in BGA solder joints. A crack is not normally generated in the process of BGA mounting. This is the type of failure which may occur after assembling the BGA mounted PCBs into the device or depending upon the environment of using the products. The crack prevention plan is necessary for the high reliability application such as space equipment. Espe-

cially, a lot of stress concentrated on "Interface of the pad on the BGA package and the ball" and "Interface of the ball and the pad on the PCB" in the BGA solder joint part. Furthermore, there are BGA balls of a lot of different types by the metallic composition and enough tests and checks are necessary to perform in developing phase in order to establish the process. Also the establishment of the inspection method for the flight models is necessary.

Inspection technique (3D X-ray CT)

Figure-2 shows the configuration diagram and the device external views of a 3 dimensional X-ray computed tomography (3D X-ray CT)^[5]. This 3D X-ray CT obtains the X-ray which irradiates the still object (PCB with BGA) from the right under the object with wide range of angle using the FPD detector placed diagonally (inclination angle of about 60°).

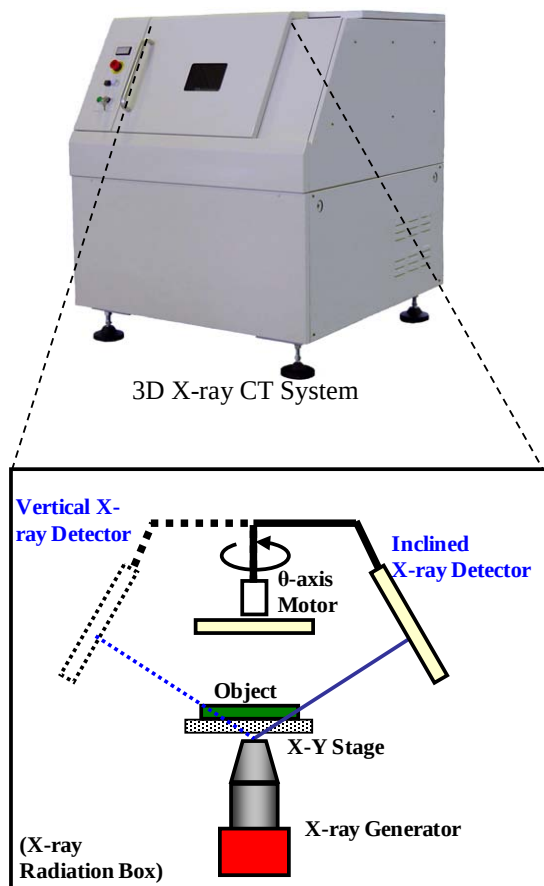


Figure-2. 3D X-ray CT System Structure and Appearance

The detector rotates on a horizontal plane

and then obtains two dimension transmission image data of the cross-section at the height of the object. And 3D X-ray CT obtains three dimension CT image including in the object by taking many of two dimension transmission image data towards the height direction of the object and superimposing the images (reconfiguration) by computer processing. It is important to get higher resolution 3D image that the detector is placed at the angle of about 60° of the object and the adjacent balls are not overlapped when the transmission X-rays are collected. This 3D X-ray CT has two detectors: one is in a vertical direction and another is in a tilted direction. The detector in a vertical direction can obtain the test data for solder thickness, area size, volume and the shape at the same time.

Example of the defects

Figure-3 shows examples of the crack detection. It takes about 20 minutes to get and reconfigure the image on the top.

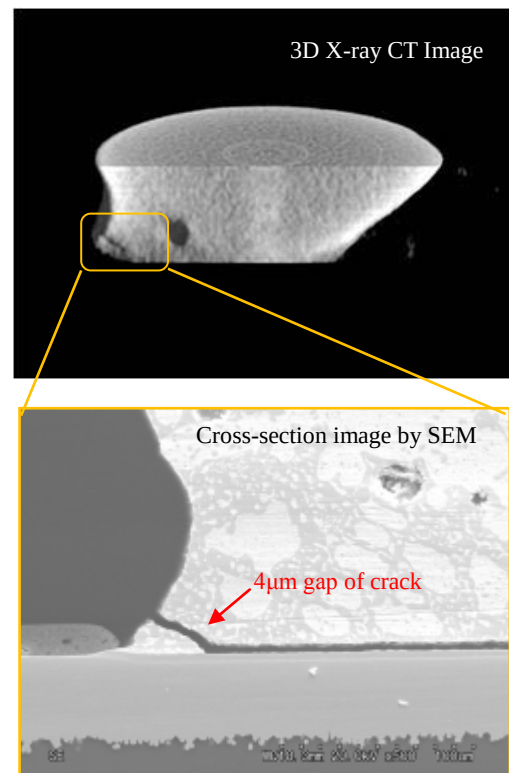


Figure-3. Example of Crack in the BGA solder joint

It is necessary to predict the part where the crack seems to happen from the mounting structure

as described in "Gap failure in BGA solder joints" section. To observe it in detail near the crack, resolution in the direction of height is set to $2\mu\text{m}$, and three dimension image of $200\mu\text{m}$ in thickness of "Interface of the pad on BGA package and the ball" and "Interface of the ball and the pad on PCB" vicinity was obtained. It is required to set the height-direction resolution at around $10\mu\text{m}$ to obtain the images of whole ball while it depends on the ball size.

As a result, a crack was detected at "Interface of the ball and the pad on PCB", and was shown in Figure-3. The cross-sectional observation of the crack point reveals that the size of the crack was approximately $4\mu\text{m}$ gap, and its crack extends between the bottom of ball and the pad surface of PCB.

Mounting and Underfill

It is considered to be useful to underfill between the BGA package and PCB for developing tolerance to the thermal cycle, vibration and shock assuming a space environment. In our tests, filler with less than tens of percent of SiO did not provide sufficient tolerance to the temperature cycle stress. We believe that the low-thermal expansion type underfill which has higher glass-transition point will be effective. However, there is concern that those underfill may generate voids or improper shape after filling as they have high viscosity. Considering the above concern, we select an underfill and improve the filling method.

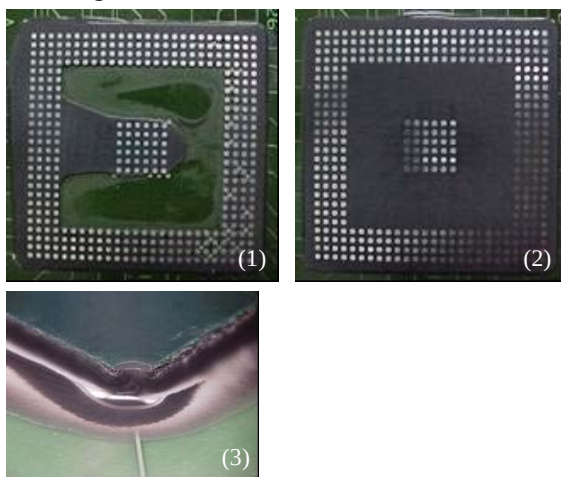


Figure-4. The Transverse Sectional View(1), (2) of Underfill and Underfill Shape(3)

The results in Figure 4. shows the transverse

sectional view obtained by cutting the underfilled BGA mounting PCB at the ball bonding section. The picture No.1 shows large voids where are no-underfill caused by the poor filling method. As a result of improving of the filling method, the picture No.2 shows the underfill is filled properly and no void is observed.

BGA mounting

BGA mounting is performed according to the process flow shown in Table-3.

Table-3 BGA Mounting Process

No.	Process	Control Items	Equipments / Conditions
1	Parts Inspection	Voids	(Micro-focus) X-ray inspection equipment
2	Baking	PBGA, PCB	Oven / 125 degree C, 24 hrs
3	Solder paste printing	Quantity of solder paste Solder finish	Solder paste printer
4	Parts mounting	Ball condition Alignment	Variant type mount device with Ball recognizer
5	Reflow	Reflow condition Solder joint condition Package warpage	reflow furnace / 8 zones, GN2 atmosphere
6	Mounted board cleaning	Flux residue check	Board cleaner / pure water detergent
7	Electrical inspection	Resistant value	Multi-meter / four-terminal method
8	Visual inspection	Solder luster and shape	Prismatic opt micro-scope / for outer side balls
9	Inner transparent inspection	Void Bridge	(Micro-focus) X-ray inspection equipment
10	Filling underfill	Filling method Curing condition	Dispenser Oven
11	Final inspection	Resistant value External view	Multi-meter / four-terminal method Prismatic opt micro-scope / for outer side balls

We have optimized the check points based on the previous experiences. Especially, we have improved the reflow profile focusing on the "void

reduction” and “BGA warpage control”. The close-up picture of BGA (No.1) and the image of BGA solder joints located under the package (No.2) are shown in Figure-5. The picture No.1 was taken with a prismatic microscope at the process No. 8. The picture No.2 is the 3D image generated using the 3D X-ray CT at the process No. 9. The configuration of the object or the BGA package is as follows; plastic package, ball interval: 1.27mm pitch, ball dimension: 0.75mm ϕ , Number of ball: 388.

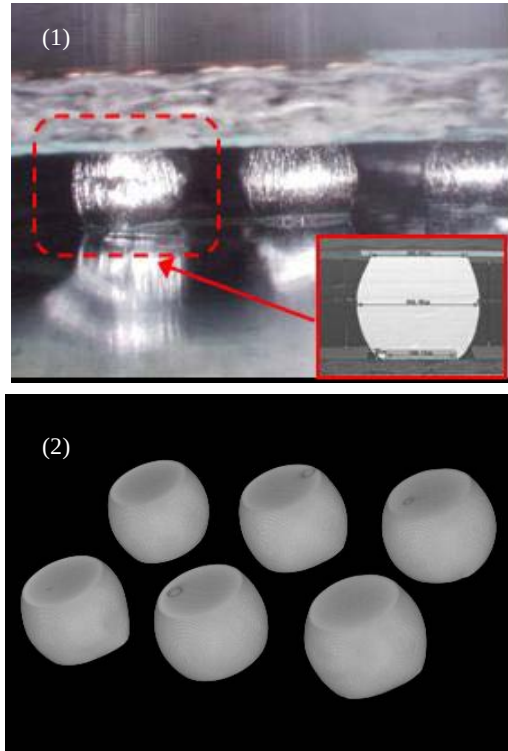


Figure-5. BGA Mounting (1) is external view, (2) is 3D X-ray CT image

Resistance to environment

We have performed three types of test: shock, vibration, and temperature cycling assuming the space environment. Test conditions are shown in Table 4.

The shock test was performed with applying a larger loads assuming the severe environment during the rocket launch. The vibration test was performed by mounting PCB on the vibratory equipment by fixing only four points of corners of PCB to create a harsher condition. The test condition for the temperature cycling was set to keep the largest temperature difference between the high temperature and low temperature as much as possible considering the sol-

dering temperature.

Table 4. Test Conditions

Test	Test condition	Reference
Shock test	2000G, 0.5ms, half sinusoidal wave profile 1 axis, No. of shocks: 3	MIL-STD-202 Method213
Vibration test	34.02rmsG, random wave profile with 3 axis, duration: 4 minutes for each axis	MIL-STD-202 Method214
Temperature cycle test	Range of temperature: -40°C +125°C, 2,000 cycles (target)	IPC-9701

The test results are shown in Table 5. There are three types of BGA packages: ceramic, plastic (large size), and plastic (small size), and three types of underfill: low-thermal expansion type, no-filler type, and no underfill.

Table-5. Environmental Resistance Test Results

BGA	Underfill	Shock	Vibration	Temperature cycle	Results
CBGA (size: 27 x 27mm, ball pitch: 1.27mm, 400pin)					
	None	30	100	100	NG
	Filled	0	0	100	NG
	Filled*	0	0	0	OK
PBGA (size: 35 x 35mm, ball pitch: 1.27mm, 388pin)					
	None	66	0	0	NG
	Filled	0	0	60	NG
	Filled*	0	0	0	OK
PBGA (size: 27 x 27mm, ball pitch: 1.0mm, 388pin)					
	None	0	0	0	OK
	Filled	0	0	0	OK

(*:low-thermal expansion type) (Failure rate %)

The quality judgment is based on the resistance change amount of the daisy chain. The test sample applying the low-thermal expansion type underfill passed the all tests: shock, vibration, and temperature cycling test. Regarding the CBGA, the only sample applying the low-thermal expansion type underfill passed the temperature cycling test, which showed an effect of underfill on easing stress from the difference of thermal expansion between BGA package and PCB. The easing effect of thermal stress by the low-thermal expansion type underfill was also confirmed in the large size PBGA. The BGA mounting samples reject due to the resistance change is subjected the 3D X-ray CT and cross-section analysis. The analysis revealed that

there are cracks on "Interface of the pad on BGA package and the ball" or "Interface of the ball and the pad on PCB". From another point of view, it can be considered that the solder joint did not have any problem withstanding the environmental loads.

Conclusion

We have screened and tested the BGA mounting on the PCB, obtained the technical data on mounting, screening and environmental resistance and performed the fundamental evaluation. We believe the evaluation have objectified the technical issues and problems in applying BGA mounting to the space devices. Though it is necessary to solve those issues or problems and establish the mounting process first, it was indicated that the proper BGA mounting technology can be applied to the space devices. This evaluation also indicated that the evaluation technology is effective to detect a certain gap of cracks and to verify the quality of solder joint. We are planning to study on the mounting evaluation technology of denser BGA (e.g. less than 0.8mm pitch, more than 1,000 balls). In addition, we are planning to add CCGA (Ceramic Colum Grid Array) whose joint-portion is formed by columns instead of balls as a research subject since the number of CCGA to use for the high-density package and for space application is increasing.

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