Comparison of X-ray Inspection Systems for BGA/CCGA Quality Assurance and Crack Detection

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ABSTRACT

The use of x-ray technique now become an additional inspection tool requirement for quality control and unique defect due to manufacturing for implementation of advanced electronic packages such as ball grid array (BGAs) and chip scale packages (CSPs). Recently, four x-ray systems were evaluated for their defect detection capability especially for damage/cracks induced during thermal cycling of ceramic column grid array (CCGA)/BGA assemblies. These systems were:

1. A 2D real time x-ray with a micro-focus source and image intensifier as detector. For this case, relative position of detector to x-ray source was constant.

2. A 2D system with x-ray transmission similar to the case 1 first one with the exception of detector had rotational capability to provide oblique views.

3. A fully digital x-ray system that is capable to combine 3D volumetric imaging and conventional 2D x-ray for a complete inspection.

4. A custom made 3D computed tomography (CT) x-ray system. It utilizes a high power micro-focus source (cone and parallel beam) and glass scintillator detector or flat panel digital detector to obtain cross-sectional 2D x-ray images with preprogrammed angle views. The reconstruction algorithm then provides a 3D volumetric display

This paper discusses limitation of each system and provides representative inspection images for CCGA/BGA assemblies. The assemblies have subjected to various thermal cycle and ranges and have shown different levels of damage/cracking. The x-ray images were compared to optical images taken by a 3D optical microscopy for outer rows of array package assemblies.

Key Words: x-ray, ceramic column grid array, CCGA, CGA, ball grid array, BGA, solder joint, thermal cycle, crack

INTRODUCTION

BGAs and CSPs (chip scale package) are now widely used for many electronic applications including portable and telecommunication products. System in a package (SIP) development is the most recent response to further increasing demand for integration of different functions into one unit to reduce size and cost and improve functionality.

The BGA version has now started to be implemented for high reliability applications with unique requirements. The BGA version of the area array package, introduced in late '80's and implemented with great caution in early '90's was further evolved in the mid '90's to the CSP with a much finer pitch. Now, distinguishing between size and pitches become difficult for the array versions. These are all now categorized as area array packages in order to be able to distinguish them from the flip chip bare die category. Bare dies have been around for a longer time, but their associated issues- including known good die and difficulty in direct attachment to printed wiring boards (PWB)- have limited their wide implementation.

The CSP definition has evolved as the technology has matured and refers to a package with 0.8 mm pitch and lower, now as low as 0.4 mm pitch. Fine pitch packages, especially those with pitches less than 0.8 mm, and having high I/Os may require the use of costly microvia PWB. Also, they may perform poorly when they are assembled onto boards.

Extensive work has been carried out by the JPL consortia in understanding technology implementation issues of area array packages for high reliability applications. These included issues with process optimization, assembly reliability characterization, and use of inspection tools including X-ray and optical microscopy for quality control and damage detection due to environmental exposures. Lessons learned by the team have been continuously published [1-3]. A Book recently published also includes chapters related to this subject[4-6].

Recent approaches in electronic package development have been to increase functionality through SIP technology, i.e., stacking dice/packages in order to avoid reducing the array pitch. This approach will ease stringent board and assembly requirements. The first SIP used CSPs and included two stacks of flash and SRAM die in a single package. Also known as multi chip package (MCP), it has now been recently released in four die format and may include two flash memories, a fast-cycle-RAM (FCRAM), and an SRAM.

The BGA version of advanced electronic packages now started to be more widely implemented for high reliability applications with unique requirements. BGAs are known to have excellent process robustness generating less manufacturing defect when are compared to their leaded counterparts. They are, however, more prone to solder joint failures than QFPs because of the attachment with rigid balls. It is shown that most plastic parts when attached on polymer printed circuit board have sufficient reliability with reduced values for their ceramic versions.

Delay in full implementation of the advanced area array packages for high reliability applications especially space are mainly due to inability to visually inspect for manufacturing quality and lack of defect detectability, e.g., opens by nondestructive X-ray systems. Inability to rework individual balls is another issue for costly parts. This paper will discuss the key advantages/disadvantages of optical and X-ray inspections especially for BGA/CCGA assemblies. It will also provide details on optical and x-ray inspections performed for numerous package assembly with different levels of damage/cracking.

INSPECTION FOR HIGH RELIABILITY APPALICATIONS

For high reliability electronic application, traditionally visual inspection is performed by Quality Assurance Personnel at various levels of package and assembly. Solder joints are inspected and accepted or rejected based on specific sets of requirements. Further assurance is gained by subsequent short-time environmental exposure by thermal cycle, vibration, and mechanical shock, etc. These screening tests also allow detection of anomalies due to workmanship defects or design flaws at system level. For space application, generally 100% visual inspection is performed at prepackage prior to its closure (precap) and after assembly.

For leaded and leadless package solder joints, the author has performed visual inspection at low and high magnifications to correlate damage level results to those revealed by cross-sectioning [7-8]. Numerous leaded and leadless packages were subjected to thermal cycle, removed at intervals, inspected visually and by scanning electron microscopy (SEM), and results were correlated to cross-sectioning images. An example of such correlation for a ceramic leadless package with 28 I/Os is shown in Figure 1. Assemblies were subjected to –55 to 100°C, 4.2 hours per cycle, and stopped at 652 cycles for cross-section evaluation.

Visual inspection and advanced optical microscopy, while it has been very effective for standard electronics, it may become limited for extremely small dense electronics. It also provides some usefulness for area array packages, but no value for ball/column arrays under the package. SEM and other advanced magnification tools can be used for inspection of tiny packages. Sample size and potential damage due electrostatic discharge (ESD) limits the wider usages of such optical techniques.

During manufacturing process, the three-dimensional laser scanning automatic inspection system has been used to determine solder paste characteristics as a process control for BGAs. Laser scanning can inspect solder paste height and volume before package placement. By inspecting these attributes, solder print process characteristics such as slumping, scooping or peaks can be identified and controlled.

The inspection system's ability to identify, measure, and analyze defect data after assembly is also critical. Inspection of solder joint integrity of BGAs are important but cannot be effectively performed by visual inspection. Inspection of fine internal structures of microelectronics assemblies, the alignment of hidden microcircuit interconnect structures, bridge and voids in BGA assemblies can be carried out using real time X-ray techniques. Internal package delamination, however, cannot be detected by x-ray and other tools such as cross section acoustic microscopy (C-SAM) is needed.

X-ray transmission radiography is an inspection technique in which x radiation is passed through a specimen to produce a full size shadow image of its internal structure. Placing the specimen a remote distance from a conditioning x-ray beam enables image magnification, which permits inspection of fine details. Magnifications of greater than 100sX are now obtainable from commercially available equipment. X-ray inspection is an essential inspection required for BGA assembly, but for many companies unaffordable. NASA's research efforts and collaboration with industry in x-ray inspection technology especially benefit smaller corporations who would not otherwise have access to such expensive research results.

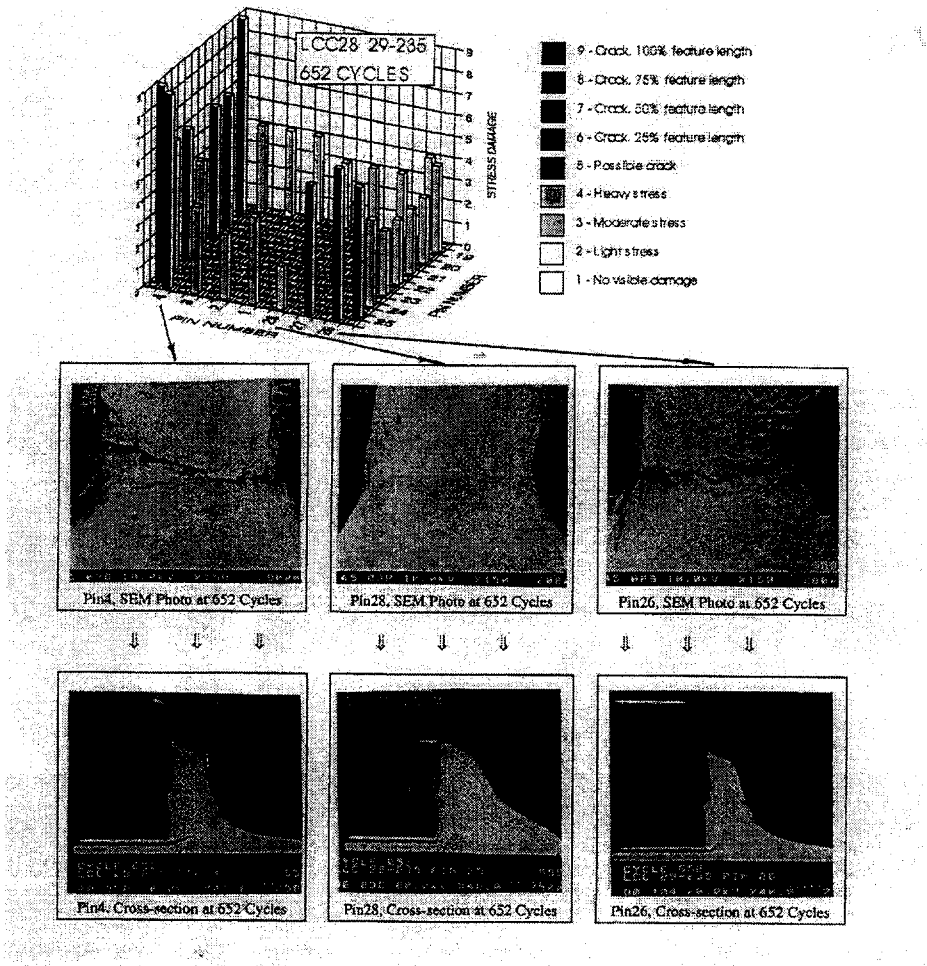

Figure 1 Correlation between visual inspection for damage (crack) progress with thermal cycling and destructive cross-sectional micrographs.

DEFECT DETECTABILITY BY VISUAL AND X-RAY

Table 1, summarizes some general solder joint defects and compares qualitative accuracy of x-ray and visual inspection. X-ray inspection is excellent for detecting hidden features such as void as well as geometric measurement. However, it is apparent that for some of the unique and most critical defect such as dewetting, crack, cold solder, and disturb solder visual inspection is far superior to x-ray detection. For this reason, this investigation was performed to evaluate limitation of x-ray systems for detecting damage/cracking and hidden solder joint. Ideally, a combination of various inspection techniques may be required to be performed in order to assure quality at package and system levels.

Table 1 Key solder defect types and ability to detect visible joints

Visible Features	X-ray Insp	Visual Insp
Stress marks, Cracks	0	+++
Open Contacts	0	++
Cold/Disturb Joint	0	+++
Dull Solder	0	+++
Flux residue/Contamination	0	+++
Porosity and Voids in Solder	+++	0
Solder thickness/volume	+++	0
Heel/Toe Side Fillets	+++	++
Solder balls	+++	++
Solder Bridge	+++	++

+++ Excellent detection
++ Good detection
0 Poor or unacceptable

X-RAY TECHNIQUES

Four different X-ray systems are used for evaluation of various package/assemblies after thermal cycle exposures. Unique features of these systems are:

CASE 1 — A 2D inspection system with a micro-focus source and image intensifier as detector, capable of producing oblique psuedo 3D features [9]. This system was limited to 2D inspections and capability of small sample rotation/tilt. The sample holder was not used since samples were larger than the capability of the sample holder. The transmission x-ray captures everything between the x-ray source and image intensifier. x-rays then emit from the source and travel through the sample. The higher the density of the sample, such as column in CCGA, the fewer x-rays will pass through and be captured by the image intensifier. The x-rays are displayed in a grayscale image, with the lower density, such as voids, areas appearing brighter than the higher density areas. The speed and strength of the x-ray's intensity can be adjusted to x-ray source limitation to reveal features of the most section of sample.

The 2D x-ray systems are very effective in testing single-sided assemblies. With the use of a sample manipulator, oblique view enhances inspection of both single and double-sided assemblies. Experience needed in discerning between bottom-side board elements and actual solder and component defects. This can be very difficult or impossible on extremely dense assemblies. As discussed previously, certain solder-related defects such as voids, misalignment, solder shorts, etc. are easily identified by transmission systems. However, even an experience operator can miss other anomalies such as insufficient solder, open connections, and cold solder.

CASE 2 — The second system that was utilized for evaluation is also a 2D x-ray tool with a similar microfocus source intensity and stationary position, but detector had rotational capability[10]. This feature allows oblique generation of x-ray images with a higher magnification and a better intensity resolution.

CASE 3 — The 3rd system combines the conventional 2D x-ray transmission and 3D volumetric imaging using software control image acquisition, providing fast image reconstruction and image enhancement and analysis[11]. Sample is viewed at multi-angles using x-ray to record coordinates for images. A unique software combines the coordinates for a layer to produce image of a plane. The same coordinates are also could be used to reconstruct the cross-sectional 3D images with minimum out-of-plane interference. This allows to turn-on a special layer for characterization and turn-off the overlying and underlying layers. This is an excellent feature for separating inspection layers in a double-side electronic assembly. Using the vertical view reconstruction, the top and bottom solder joints in a double-sided assembly are detected clearly.

CASE 4 — The 4th system was a 3D x-ray system uses tomosynthesis differ slightly from laminography to generate image slices of sample by moving two of components in an elliptical fashion to generate oblique images. In lminography, the part remains stationary while both x-ray source and detector are rotated. In planar tomography, source remains stationary while both part and detector are rotated. The multiple images from the 3D systems are then reconstructed to create horizontal image slices of the sample, where only the objects in that plane are in focus, and everything above or below the plane can be ignored. Once the plane is defined, software is used to analyze the pixels in the image to determine if they meet acceptable criteria.

A custom made 3D omputed tomography (CT) x-ray system was used to determine its capability. It utilizes a high power micro-focus source (cone and parallel beam) and glass scintillator detector or flat panel digital detector to obtain cross-sectional 2D x-ray images with preprogrammed angle views. The reconstruction algorithm then provides a 3D volumetric display

TEST VEHICLE TEST

Several assemblies that previously were subject to numerous thermal cycles, having different levels of damage/cracking, were characterized. Assemblies that were evaluated included:

1- Plastic BGA, cavity down with heat sink built on the die, 560 I/Os and 352 I/Os
2- PBGA, 256 I/O and 313 I/Os
3- CCGA with 560 I/Os
4- J-lead package with 64 I/Os
5- Fine pitch quad flat package with 256 I/Os

INSPECTION RESULTS

Visual Inspection

Figure 2 shows optical photomicrographs of the CCGA assembly prior to thermal cycling and after cycling when some signs of damage/cracking was observed by visual inspection. As stated previously, 3D optical microscopy and visual inspection are limited to inspection of outer rows of area array assemblies and could be performed only when enough gaps are allowed between the assembled parts. The Assembly after thermal cycles shows signs of damage/cracking.

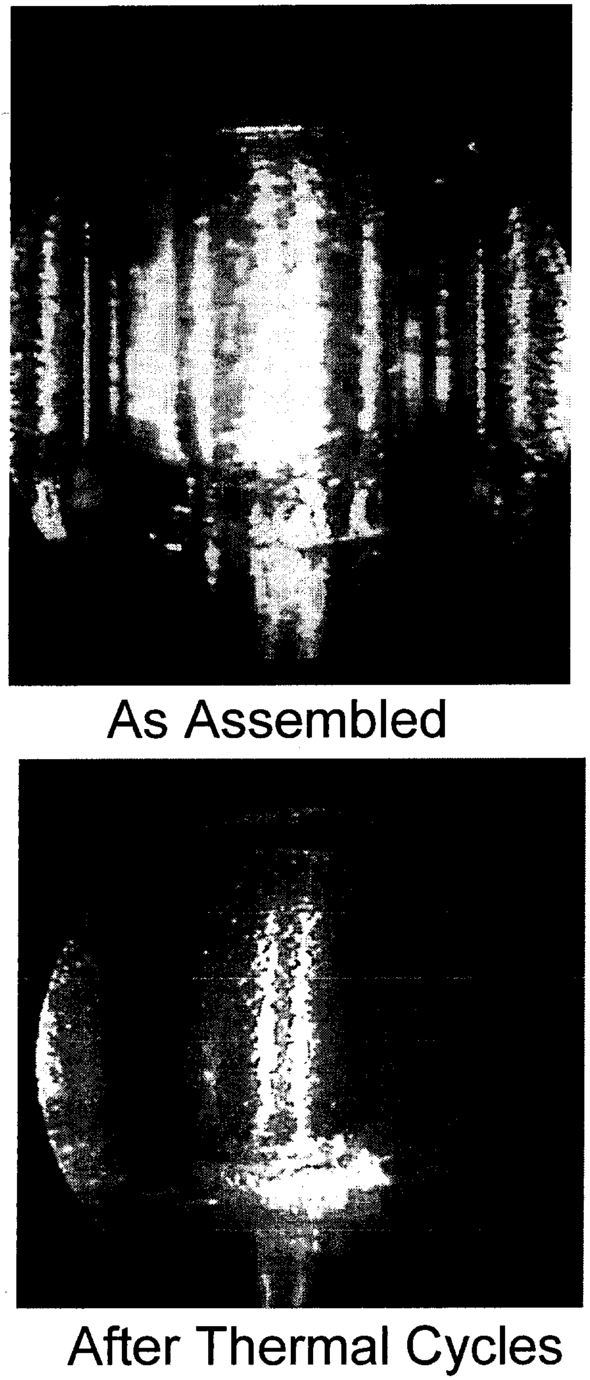

Figure 2 3D optical photomicrographs of CCGA before and after damage/crack observation

CASE 1 — Figure 3 shows X-ray photomicrograph for assembled CCGA after thermal cycle exposure using the 2D X-ray transmission system discussed above for case 1 where parts remained stationary during x-ray exposure. Solder joints could not be detected because of significant x-ray intensity attenuation by CCGA column.

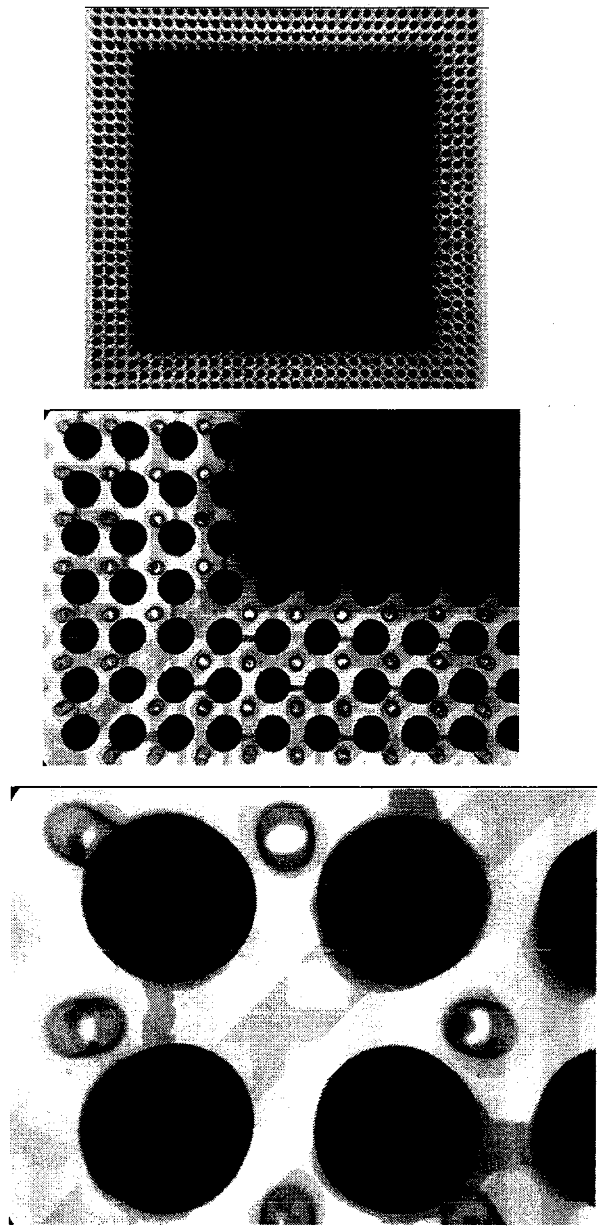

Figure 3 2D X-ray inspection of CCGA assembly after thermal cycles with signs damage/cracking. Damage/cracks are not detectable

CASE 2 — Figure 4 shows x-ray photomicrographs of assembled CCGA after thermal cycle using the case 2 X-ray system with an oblique view capability. X-ray images from two views are included. CCGA columns having high lead composition (90Pb/10Sn) are much darker than eutectic solder (37Pb/63Sn) used for attachment to the board. Within lighter solder joints at lower section of column, other lighter zig zag lines, possibly caused by cracking, are apparent. Non-smoothness of patterns may be an indication of solder graininess generally occurs as thermal cycle progress due to solder grain growth.

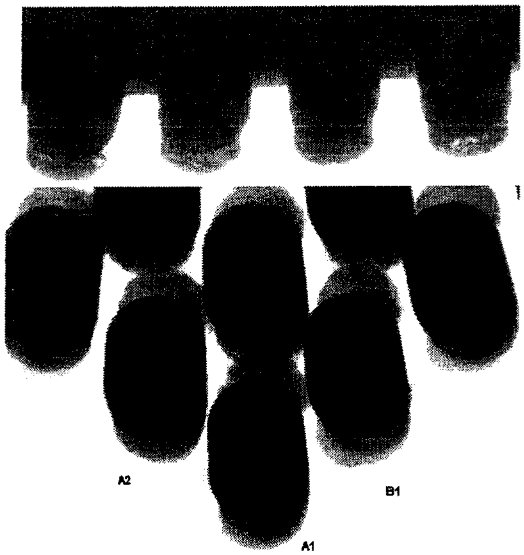

Figure 4 X-ray photmicrographs of CCGA using a 2D X-ray system with oblique detector at two angles

CASE 3 — Figure 5 shows x-ray photomicrographs taken for a cavity down BGA assembly at a specific layer and two 3D cross-sectional images from two locations. Both 2 D image and cross-sectional images provide good information on feature of package and attachment, but lack resolution needed to detect damage/cracks. Further collaborative work is being underway to repeat the test using an x-ray with high resolution capability.

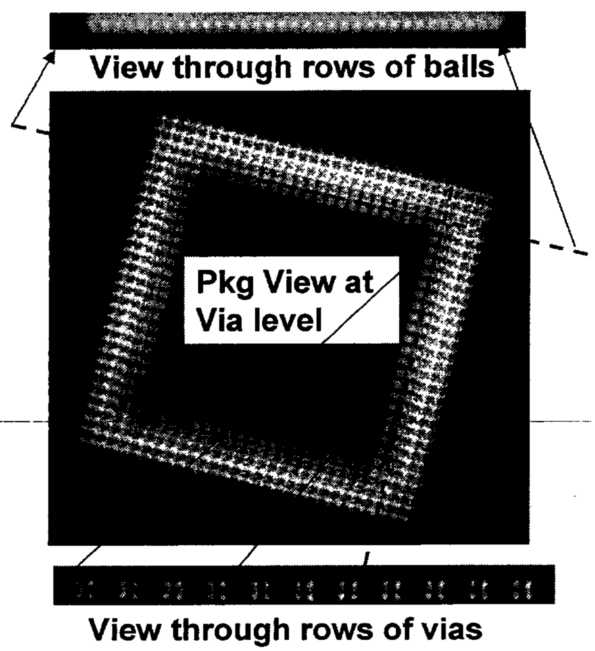

Figure 5 X-ray photmicrographs of SBGA using a 2D/3D volumetric X-ray system

CASE 4 — Preliminary evaluation of the custom made x-ray indicate that there were issues with generating 3D images because of short gap between board/package and also obstruction of x-ray beam by other solder columns.

CONCLUSIONS

Nondestructive systems including x-ray and C-SAM with fine feature detectability become critically important as electronic package/assembly become complex and their feature sizes decrease. X-ray systems are significantly improved since a decade ago, however; still they have their limitation. It is shown that many features of area array package assembly such as shorts and voids could be easily detected by 2D or 3D x-ray systems. Heavy solder joint damage/cracks in CCGA assembly due to thermal cycle could only partially detected by a 2D X-ray system with an oblique view capability. The 3D optical microscopy could easily detect such damages for the outer row solder column. In a recent study[12], cracks in copper traces, averaging 5 μm wide were not detected, either in 3D or 2D x-ray. It was concluded that there would not be confidence in resolving detail of less than 10 μm. Further development in x-ray systems to meet microelectronic needs and investigation in correlation of cracks by optical/SEM and those images observed by x-ray systems are needed.

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