X-RAY INSPECTION APPLICATIONS FOR CHIP SCALE DEVICES

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Abstract

The number of new semiconductor package types has been increasing, being driven by the demand for high I/O pin counts. The goal is to reduce the amount of PCB required for the product using new packaging technology. The packaging world made a tremendous advance with the introduction of surface mount technology and then the introduction of ball grid arrays (BGAs). X-ray technology has shown to be very effective in understanding the performance of BGAs starting with the manufacturing process to final assembly and repair. We can expect the same contribution from x-ray with the introduction of chip-scale packages (CSPs).

INTRODUCTION

The advantages of CSPs include a package not much larger than the die itself,. They are typically robust and are now offered in a number of standard sizes. They also come in a couple of different variations including flex circuit, rigid substrate, custom leadframe and wafer level assembly. The challenges for manufacturing a device using this packaging technology are many. 1998 will see CSP volumes very low as compared to the total market for packaged devices but more companies are ramping up production and coming on line every week. The total number of devices expected to be shipped by the end of the year will be between 400 and 600 hundred million. By the year 2000, this number is supposed to increase by five times.

In order to understand what X-ray technology can offer both the manufacturer and user of CSP devices, we first must review the basics of X-ray inspection systems.

2D VERSUS 3D TECHNOLOGY

There is much confusion surrounding the advantages or disadvantages of the two major approaches of of x-ray imaging. The traditional through transmission, 2 dimension approach can provide a great deal of information about the characteristics of the conductive material used for the connection interface in a chip scale package including location, orientation, and volume, The x-ray signature presented to the user can characterize and differentiate a good connection from a bad one.

At first glance, the desirability of being able to slice the connection and dissect it using tomosynthesis or laminography techniques is tempting, however the additional information gained is typically not commensurate with the expense and effort required to capture the image. In addition, off axis imaging can be achieved using 2D techniques by positioning the sample device or assembly at an angle to the x-ray source. Everyone agrees that bridges between the solder balls are straightforward to detect and the challenge comes with detecting opens. Although 3D technology provides a view between the ball and its connection point, off axis 2D imaging will tell you if there is a problem with that connection. Needless to say, it requires an experienced eye, however, great amount of information concerning the package connections can be obtained using this technique. If it is desired to do high volume inspection, then consideration is made for an automated system.

AUTOMATED SYSTEMS VS MANUAL SYSTEMS

There are two criteria to define the difference between manual and automated systems: How the parts are handled and where the defect decision is made. A manual system will be defined as one where the operator loads and unloads the parts to be inspected from the cabinet x-ray system. These could be individual parts, tubes or trays. In addition, the defect decision is made by the operator by viewing the image. Many times the operator may want to electronically enhance the image or perhaps make a measurement. All manual systems include some sort of image enhancement hardware. Since the defect decision is being made by the operator visually, any tools to aid the human eye will reduce the chance of a false call. The technique of image averaging provides a “smoothing “ effect to the image helping to define the edges and aid in defect detection. In addition, by calibrating the number of pixels for a known distance, the operator can quantify measurements of void areas and diameters of solder bumps and balls.

With automated systems the operator and the machine have different roles. The system may perform the component or assembly handling duties automatically using conveyor feed or the operator may place the inspection samples into a robotic system for feed through the inspection process and even routing the defective units to a rework or reject area. More importantly, the system will make the defect call not relying on the operator’s visual interpretive capabilities. With the image routed to computer processor technology, the image can be examined pixel by pixel and, with the appropriate application of algorithms, will be able to locate and log the defective connections.

With the emphasis on the machine processor making the defect call, visual enhancement tools typical to manual systems will not be needed. The image having been digitized is now examined at megahertz speed with a number of different measurements taken on each of the gray “blobs” within the field-of-view. This measurement data, when compared to a set of measurement rules, is used to make the out of tolerance call. Taking it one step further, if the measurement data can be crunched and formatted, you can now determine what direction your manufacturing process is going. In order to be more useful, the information is available at near real time.

The differences between the manual and automated are distinct. A manual system provides more analytical examination but at the expense of throughput and the addition of operator variability, while the automated provides throughput and repeatability at the expense of the initial set-up plus the measurement details that need to be defined. There is also the expense differential. An automated system will typically cost more to build with the additional mechanical assembly and processing power needed.

THE BUILDING BLOCKS OF THE X-RAY INSPECTION SYSTEM

Now we can break down the x-ray inspection system into four major blocks of functionality in order to see what is needed for each specific application.

The first block is the manipulation or sample handling element. For a manual system, this consists of a stage area for each component or trays of components. The stage area should accommodate a mechanical remote controlled manipulator in order to view the part off axis. If the part is mounted on an assembly such as a printed circuit board, then the stage needs to accommodate the area of this assembly. For a 2D automated system, the part or assembly is positioned via the preprogrammed CAD data, using an X/Y table, in a position to allow passage of the x-rays through the part. For 3D, the part is placed in a fixed position and the x-ray source is passed through at multiple angles to achieve a single image. In addition, there needs to be a conveyor interface to the X/Y table both going in and going out. In some automated systems the part stays on the conveyor and the x-ray source and detector move in tandem around the assembly or part stopping to collect images.

The second block is the image train that consists of the x-ray source and the detector system. These elements will determine the quality of the x-ray image and the ability to resolve defects. In addition, parameters such as magnification and field-of-view are determined by the these elements and their relative position to each other. If you encounter heat sinks or other material difficult for x-ray penetration, then an x-ray with sufficient penetrating capability is needed. As the trend continues for finer pitch packages, the challenge is for the detection system to provide adequate resolution so the image can be useful for the operator viewing the image or for the analysis software used in the automated category. Array detection technology is improving all the time providing for increased resolution. The obvious benefit for automated systems includes a fewer number of views required if the resolution can be increased or maintained along with a field-of-view increase. This will have a direct benefit on the throughput that can be achieved. For manual systems , the image viewed on the video monitor starts out as the output from the detector system. If the quality in the beginning of the enhancement process is the best possible then the resultant image will be that much better. This has obvious implication for failure analysis applications as we will discuss later.

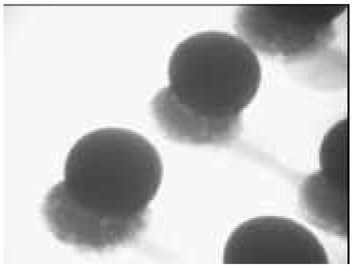
The next building block is the image processor or image analysis element. As we discussed earlier, this takes the raw output from the detector system and enhances it through the use of software manipulation, typically evolved from medical industry applications. For manual systems, it is critical that the quality of the image reaching the operator is the best available. Likewise for an automated system, if the image is less than ideal, then the analysis software will report a high level of false calls and the repeatability needed will be absent. Since we are dealing with a black and white image with nothing but varying levels of gray to work with, any tools to help the human eye are needed. With the ability of the image processor to divide this gray image into 256 distinct levels of gray, we can through the magic of software assign color to a particular bandwidth. Techniques such as “shift and subtract” result in a contour relief map of the image and edge enhancement provides for crisper detail.

For automated systems, the image is pixel mapped using the 256 levels of gray. Each pixel has an expected level of gray that will change if the amount of x-ray sensitive material changes in volume at that location. With the appropriate application of algorithmic software, the amount and location of this material can be determined. If we are dealing with a predefined material reflow process, you can even measure slope and voids to insure that this part of the process was completed to expectation. An adequate amount of processing power becomes necessary due to the enormous amount of data that can be generated with each image. Then this data must be compared to the expected measurements and noted in some defect file. The notation must include enough detail so the operator can locate the problem for process adjustments or rework. It is easy to conclude that the software is key for an automated system with the manipulation system and image train considered the “front end”.

The last element in this group of four, is the display, print, store, and transfer block. This consists of what is needed for an operator interface. For manual systems, there is a video monitor and printer for hard copies. You also need the ability to store the image for later review or additional enhancement. With the ability to transfer the digital image to your own memory device, you can then use all the modern techniques to share it with others around the building or around the world.

With the automated systems, there is typically a large number of images collected with the interest in those with defects. Also, with the large amount of data collected, the emphasis is placed upon software that can provide user friendly summaries of defect trends. It is possible to even network the defect and SPC information to separate work stations for the purpose of rework and process monitoring.

Now we can examine the different applications of x-ray inspection for the new packaging technologies.



DEFINING THE MANUFACTURING PROCESS

One of the driving forces and requirements of new packaging technology is the need for high yield with the ability to produce packages at a low cost. After the package design is completed, a manufacturing process needs to be defined that will produce the package reliably and repeatably. This activity could also be defined as design verification. After the first few parts are produced they need to be analyzed thoroughly. Most semiconductor manufacturers have established a failure analysis lab within their facility. The first test would be electrical that would establish the performance of the die within the new package. This electrical testing does not address the long term reliability of the internal connections of the package. Unfortunately, techniques such as cross sectioning are very time consuming. A failure analysis x-ray inspection system has the advantage of being non-destructive and will provide information about the condition of the part after burn-in and any environmental testing. The failure analysis x-ray system needs to have a multi-axis manipulation system capable of holding one part at a time. The image train needs to provide magnification of at least 200X to provide detailed images of the internal connections whether they are pins, wires or balls. Also, the detection system needs to have resolution to resolve down to the .001” range or less for a complete analysis. This type of system may also require an x-ray source with energy output great enough to penetrate ceramics and possibly heat sink material. This type of system is typically found in a lab environment and is at the high end of the price range of manual systems costing upwards of $200,000.

MONITORING THE MANUFACTURING PROCESS

After the design has been shown to be reliable, the manufacturer needs to monitor the process at least on a sample basis. Since most of the manufacturing process takes place using automated equipment, there is always the risk of a production tool moving out of tolerance quickly resulting in a large quantity of bad parts. If the x-ray system is to be useful, it needs to be located close to the production floor and be easy to use by production personnel. The characteristics of this system also include performance requirements at a lower level than what is found in the lab and at a lower price. What is needed is a quick look to verify the process has not strayed from nominal.

Sometimes, in certain critical situations, it may be required to collect engineering data on a large sample. This would be to characterize the process. In this case, an automated system would provide the repeatability and precision measurements needed for this task.

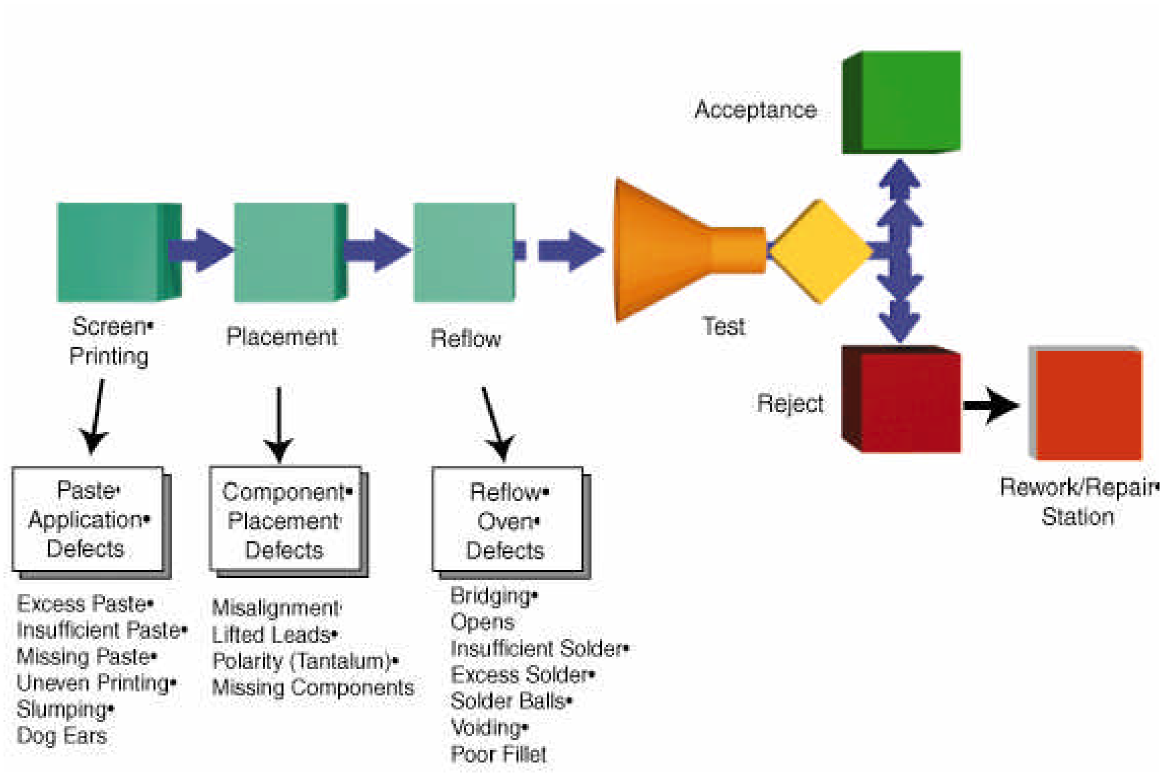
Other applications for an automated system include the need for high reliability in the component and the end product. By verifying each package with 100% inspection, you are providing the user of the part assurance he is not adding value by using your part and then having a failure either later in his manufacturing process or in the field.

INCOMING INSPECTION - SPECIFICATION VERIFICATION

An x-ray system can be used by the customer of CSP components who would like to verify on a sample basis that these parts are meeting specifications.. Positioned in the incoming inspection area, a certain percentage of parts can be checked. The level of performance the of the system will depend upon the accuracy and detail needed. Typically you would want to quantify the measurements to detect trends and to then alert your supplier. Once an acceptance procedure is established, then the required system performance is defined. Every effort should be made to verify the quality of the product before any value is added when it becomes part of an assembly. Eventually, if the assembly fails ICT or functional test, the question that needs to be answered will be, is it a component failure or an assembly process problem?

MONITORING THE ASSEMBLY OF CSPs INTO CIRCUITS

Placement of any of the new packaging technology is a challenge. BGAs are relatively forgiving when it comes to positioning on a printed circuit board but how do verify the performance of your process? It is now common practice to incorporate x-ray technology into the assembly line either



A Typical Automated X-Ray System Placed In-Line

off-line, on a sample basis, or even in-line for 100% inspection of the BGAs and other surface mount solder joints. X-ray technology can not only be used to identify bad solder joints but also can point to the area in the process that created the defect.

For example, when the x-ray system detects insufficient solder, it points to the paste dispense operation as the source of the problem. When the x-ray inspection process shows that the part is skewed, then the placement system should be checked. Voids in the solder reflow indicate a check of the oven profile is in order. More importantly, as the automated x-ray system collects measurement information on each joint, it provides immediate feedback on the performance of the assembly process. For a chip scale package, measurements include:

- excess solder
- insufficient solder
- bridging
- opens- using ball size
- voids
- skewed placement
- missing ball
- no reflow

This SPC information should be available as close to real time as possible and provide a summary of defect type and location.

The manual off line systems will again need to have enough manipulator flexibility to handle different sized assemblies. The performance of the system will be in the mid range with the emphasis on ease of use by the production personnel. These systems are typically found in the high mix contract manufacturing environment.

The automated systems, especially for the in-line category, are best suited for low mix, high volume lines. With the increased amount of overhead necessary for bringing a new application on line, most assemblers do not have the luxury of time to invest in this effort.

REPAIR AND REWORK

Despite the fact that, in high volume, CSP packaging may be inexpensive, however, after adding the cost of the die and the rest of the assembly, finding a defect will then necessitate a repair. After removing the part from the assembly using one of the systems designed for repair and rework, the operator needs verification after completing replacement. A low cost manual x-ray system will verify the work was done properly.

In the automated in-line x-ray environment, the defect information is provided to the rework area via the system network. Here the operator can call up the defect type and location and even look at the actual x-ray image to verify that the it not a false call. As a result, no effort is expended in repairing a good connection. The process control engineer will then have access to a summary of the defects by type and location.

SUMMARY

X-ray technology has a been shown to be a valuable inspection tool for new packaging technology. It is now widely accepted by the BGA industry and providing the x-ray system manufacturers a growth industry. Based on this success and the projected growth of chip scale devices, the opportunities for x-ray inspection systems will continue to increase.

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