X-ray Inspection "How It Works"

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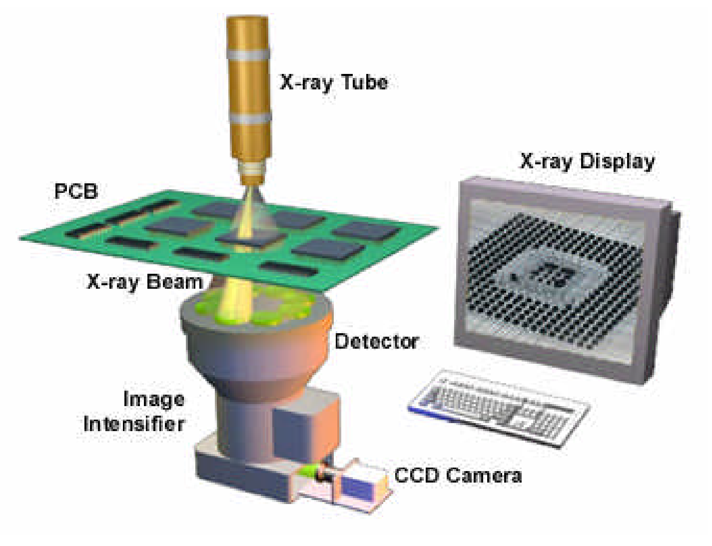
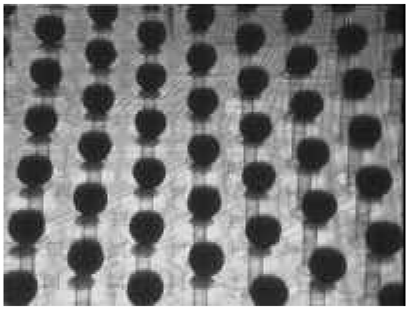
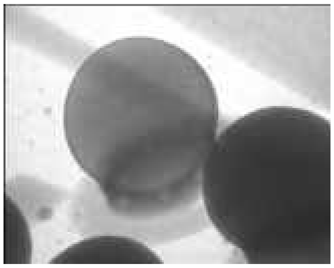
X-Ray Quality Assurance Testing and Process Monitoring

X-ray inspection systems display gray-scale images, which represent variances in the shape and thickness of an object. High-density features produce a darker image than those do with lesser density or thickness. Therefore, it is possible to quantitatively measure these features and develop correlation between acceptable or unacceptable manufacturing process conditions.

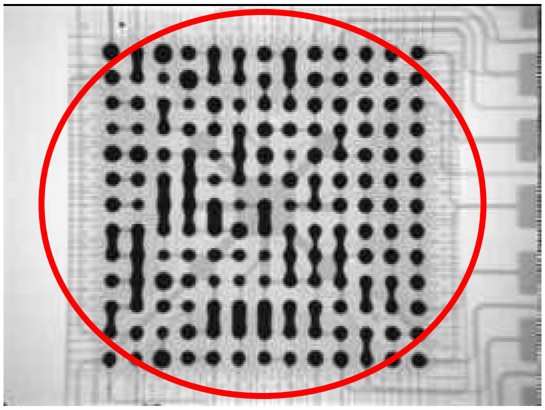




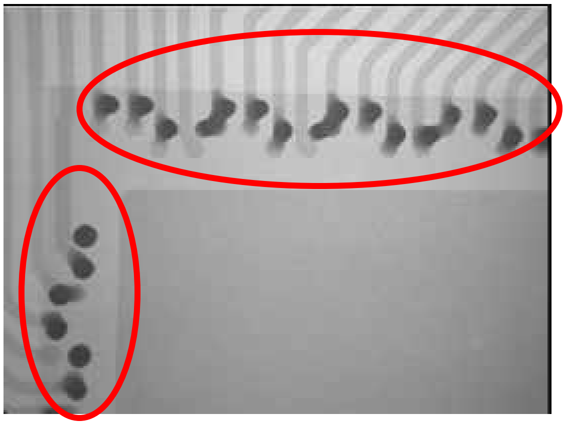


X-Ray Imaging Chain Components

During an inspection, X-rays emitted from the source pass through the circuit board to an Image Intensifier. The images are then directed from the detector through a mirrored assembly to a video camera, where the digitized images are sent to an image processor for display, enhancement, and analysis. Systems are available for manual or fully automatic inspection and defect detection. X-ray inspection can reveal a number of defects, whether hidden or visible, including open or shorted solder joints, lifted leads, component misregistration, chip tombstoning, voiding, and unacceptable size variations in solder bumps (as in BGA components).

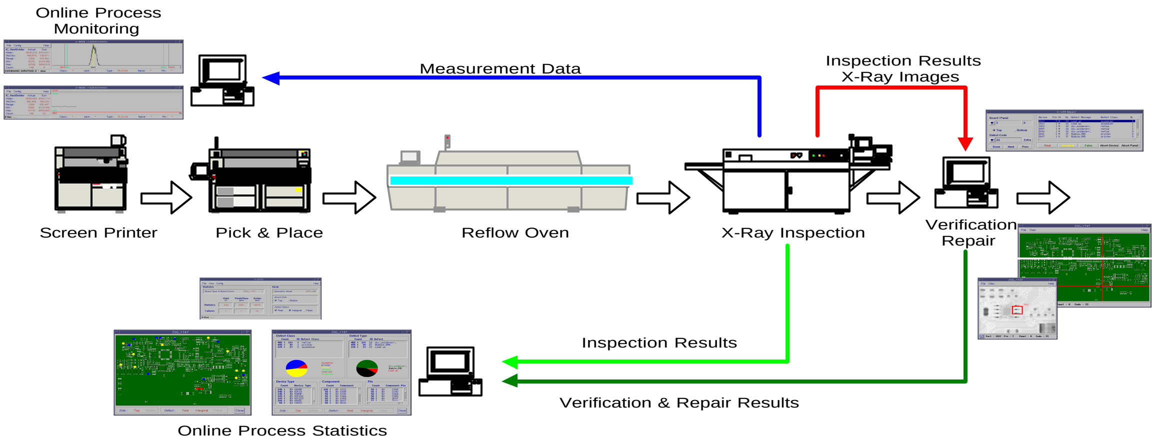


Bridging & Opens



Component Misalignment / Bridging

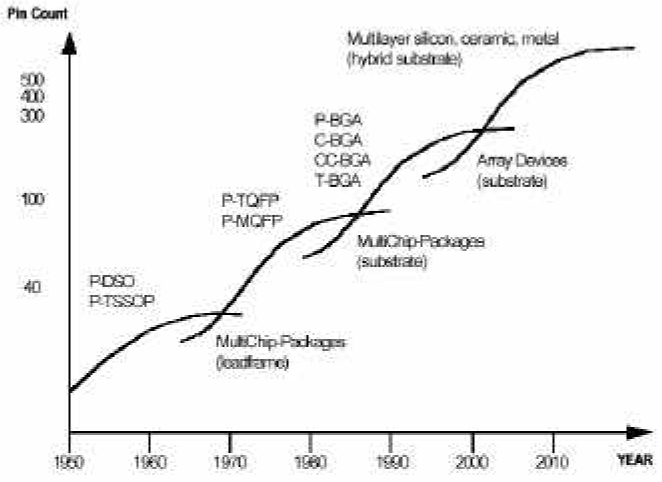
NIS automated industrial X-ray inspection systems operate in-line with Printed Circuit Board Assembly (PCBA) manufacturing equipment. This in-line operation provides real-time monitoring of critical manufacturing variables. By accumulating this detailed measurement data for several of the same assemblies, variations in the manufacturing process can be identified and corrected before out-of-tolerance conditions are able to cause defects. This process is referred to as “Statistical Process Control (SPC)”.



Statistical Process Control (SPC) Block Diagram

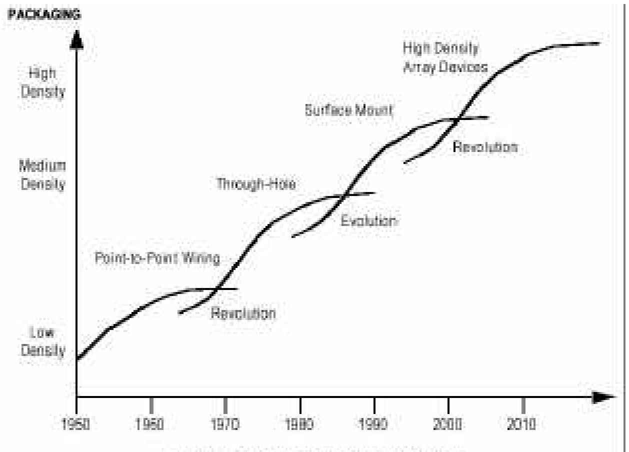
Micro Miniaturized Semiconductor Implementation

Advancements in manufacturing technology and the growing complexity of electronic products will continue to pressure packaging designers into adopting higher lead count devices. Lead pitch on peripherally leaded packages have reach the point where the leads are so small and so delicate, they cannot be assembled at acceptable yields. The area array packaging format aka Ball Grid Array (BGA) was born from this need for increased I/O densities while conserving valuable board real estate.



Device Lead Count Technology Waves

The advantages of CSPs include a package not much larger than the die it's self. 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 ship by the end of the year will be between 400 and 600 hundred million. By the year 2000, this number is expected to increase by five times.



Manufacturing Technology Waves

This push to miniaturize presents new challenges in the areas of process efficiency, testability and repair. These issues translate to assembly process yield and product reliability, the bottom line facing manufacturers of electronic products today. Because some BGA rework is inevitable, it is in the best interest of the assembler to incorporate measures which will enhance the rework operation. Specifically in the areas of process efficiency, fault detection, verification and repair operations. NIS software such as, NIS X-PERT Solutions on-line Process Monitoring, Statistics and Repair Verification software explorer various strategies focused on the inspection of BGA devices.

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 - discussed in the following paragraphs.

2D vs 3D Inspection Technology

There is much confusion surrounding the advantages or disadvantages of the two major approaches 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 Inspection vs Manual Inspection 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.

Characteristics of MANUAL and AUTOMATED Inspection Systems

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.

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 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 an automated system is fewer views (x-ray images) are required if resolution can be maintained in addition to a larger field-of-view. 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 x-ray image processor and analysis engine. As discussed earlier, the output from the detector system is processed and enhanced by the use of digital imaging software which optimizes the output for best resolution using 256 levels of grey. 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 repeatability criteria not be available. 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 to display the images in real time and printer to output hard copies. The ability to store images for review or reporting purpose is a handy feature. With the ability to transfer digital images via network or the internet, this information may then be rapidly shared within your facility or around the world. This is especially convienient for contract manufacturers.

With the automated systems, there are 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 workstations 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 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 for each 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

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 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 midrange 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.

Reworking Defective Boards

Once a particular component has been determined to be defective it must be removed and replaced. When these operations have been executed, the reworked product should possess the same integrity during the first inspection. During the repair process, the assembly will be subjected to at least 3 extra thermal cycles, therefore, it is essential that the processes be well defined and controlled so that the PCB and adjacent components are never subjected to damaging stresses.

Quality rework requires that the following operations be carried out:
- Remove the component
- Dress the site (i.e., remove residual solder and apply solder paste)
- Place and solder a new component

Each of these functions require heating the component to temperatures above the melting point of the solder, typically 183°C, and maintaining the assembly there for some period of time. The rate at which this elevated temperature is reached and the time the assembly is held above 183°C are usually well established, but the ability to create the necessary thermal cycle or temperature profile is not intuitive.

Fortunately, today's automated rework systems are very sophisticated and most of them incorporate software that facilitate rework operations by providing the operator with predefined steps. The parameters for these steps are defined by a Process Engineer, thereby guaranteeing the correct sequence of events, thermal dynamics, and timing. This also allows the process to be fine-tuned and ensures repeatability – the key to successful rework - without damaging surrounding components.

Integrating Manual X-ray Inspection and Rework

When X-ray inspection and rework are integrated, the process of identifying the location of a defective component becomes easy. A PCBA may be identified with a barcode, which may then serve as a traveler (repair ticket) used to associate and communicate captured X-ray images of the failure region of the board to the rework display. This paperless method of initiating rework assists the operator by pinpointing the fault, revealing the precise location of the defect, and eliminating the possibility of reworking the wrong component.

Benefits of integrating X-ray inspection and rework include the following:

- Verify that rework is actually necessary (eliminate false calls)
- After rework the assembly can returned to the X-ray system for inspection to verify that it meets the inspection criteria and solder joint quality standard after rework.
- In addition to validating the rework process, the X-ray system can also be used to monitor the assembly process, detect trends, and provide SPC data for feedback to the production floor.

- The X-ray system can also be used to verify thermocouple location on instrumented boards and provide invaluable information to aid in process development.
- When used together inspection and rework activities provide a strategy for improving yield and validating the quality of PCB assemblies.

Conclusion

When considering the deployment of advanced high-density component technologies such as BGAs, a new set of manufacturing considerations come into play which includes X-ray inspection for failure analysis and process optimization, and advanced rework systems for control and automation of the rework process.

Although X-ray Inspection is not suitable for 100% inline inspection, due to time required to perform testing it is required to test PCB assembles with BGA, µBGA, and flip chip components because:

- **Visual Inspection** - has no visual access.
- **In-Circuit Testing** - Can not identify voids or verify solder quality and, without test points, has no or limited physical access to the component.
- **Functional Test** - Only identifies a board is defective; it can not identify the specific location or cause of the problem.
- **X-Ray Inspection** - Not suitable for 100% inline inspection, due to time required to perform testing.

However, inspection is just one part of the new production methods for Surface Mount Assemblies - automating the rework process has now become economically practical and even necessary. Automated rework stations provide better, faster, and repeatable repairs to damaged boards. From site preparation, which is the removal of residual solder and flux from the pads of a extracted component and the correct application of solder and flux, to the thermal dynamics of the reflow profile, today's automated rework stations are helping to achieve profitable yields.

The best manufacturing practices also include some means of process monitoring, process optimization, quality assessment and rework of failed products. Many companies are realizing the benefits of these practices and are turning to companies such as Nicolet Imaging Systems and Sierra Research & Technology to combine X-ray inspection with reflow and rework technology to provide manufacturers innovative, cost saving solutions.

References:

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