X-RAY Inspection for PCB/SMT & Electronics Components Latest Development

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PCB/SMT Nepcon Korea 2004

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Biography:

Mr. Friedhelm W. Maur studied business administration and sales / marketing. He began his career with feinfocus in 1988 as a Sales Administrator and has greatly contributed to expanding the sales territory during his tenure with the organization. He initiated and developed business relationships particularly with the Asian-Pacific region and is currently serving as the Export Sales Manager for this important global sector. Mr. Maur has a profound knowledge of the market and its characteristics as well as microfocus X-ray technology and the importance this inspection modality plays in the industry. He regularly travels throughout the Asian continent, meeting with representatives and customers, attending trade shows and giving papers.

Abstract:

During the past few years, advances have been made in both in X-ray tube and detector technologies. The field of microfocus radioscopy has been established as an important testing process and has expanded into many new industrial applications that require quality control or process optimization. The first nanofocus and multifocus X-ray systems have become available with a focal spot of .5 micron. In the existing range of microfocus X-ray tubes, further improvements have been achieved as well, such as increased long term stability of intensity position constancy. Software, image processing and manipulation techniques have all progressed as well, allowing X-ray to become a formidable non-destructive inspection method for manufacturers in virtually every industry, especially those involved with Electronic Packaging and SMT.

1. Introduction:

This paper will discuss the advancements in X-ray inspection technologies and their importance in the failure analysis and process control of PCBA and semiconductor components. Details about recent X-ray tube and system developments are discussed and beneficial application examples of PCB's, BGA's, Flip Chips and Semiconductor components will be shown.

2. X-ray Tube Technology Developments

X-rays were discovered more than one hundred years ago by Wilhelm Conrad Roentgen in the year 1895. However, this conventional X-ray technology only allows 1:1 views without any magnification and, thus, is insufficient for the inspection of today's sophisticated components. The continuing trend toward miniaturization and more compact construction of electronics devices increases the demand for high-magnification and high-resolution X-ray inspection capabilities.

This is only possible with a very tiny, punctiform X-ray focal spot. Most commonly, this type of X-ray source is known as a microfocus X-ray tube.

Early concepts for microfocus X-ray units were developed in

England in 1950 by physicists V.E. Cosslett and W. Nixon. Despite these early experiments, attempts to develop practical high-resolution X-ray equipment were unsuccessful throughout the 1950's and 1960's. Industrial demand for the technology began to develop in earnest toward the end of the 1970's when the aircraft, automotive and electronics industries sought materials inspection methods for their new technologies, and computer technology began to evolve at a rapid pace.

In the early 1980's, Alf Reinhold saw the developing need for X-ray inspection with improved image quality and detail detection and began researching the technology. In 1982, he designed and assembled the first commercially viable microfocus X-ray tube with a focal spot size of < 5μm.

Since the launch of this first microfocus X-ray tube, the range of applications for high resolution X-ray inspection has developed rapidly. The trend toward increased miniaturization and compactness of components and assemblies is continuing in the electronics and micromechanics industries. New technologies, such as optoelectronics, MEMS (micro-electromechanical systems) and MOEMS (micro-optoelectromechanical systems) have have brought to the industry some of the most challenging new application requirements. With these developments it has become evident that microfocus X-ray inspection does not always suffice for today's inspection tasks. Moreover, some micromechanics industry trends show silica and similar materials with low X-ray absorption being used. This is creating the need for low intensity X-ray with a small focal spot size. There is now a burgeoning demand for ultra-high resolution X-ray inspection in various markets, resulting in the recent development of X-ray sources that emit "soft" X-rays with low intensity and energy and extremely high resolution, allowing for detail detection in the nanometer (sub-micron) range, called nanofocus tubes. Moreover, the need for versatility, ease of use and cost effectiveness have led to the most recent development of multifocus X-ray sources that incorporate microfocus, nanofocus and high-power modes within one unit.

3. X-ray System Properties

In addition to the X-ray source, an X-ray system is made up of several other critical components for optimal operation. A standard 2D X-ray system generally consists of: an X-ray source (sealed or open tube), a fixture for holding and manipulating the part being inspected (sample), a radiation detector, generator, vacuum system, and in some cases, an image processing system as outlined in *figure 1* below.
The basic components of the X-ray system may be arranged in an X-ray room or in a radiation shielded cabinet.

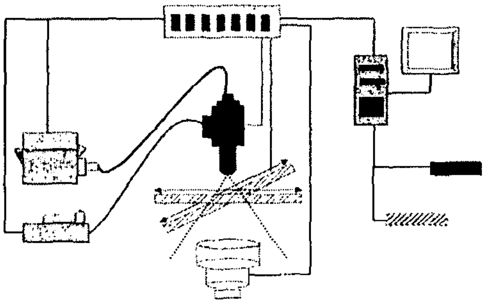

Figure 1. - Illustration of typical X-ray system components.

3.1 X-ray Tube

X-ray captures everything in between an x-ray tube and a detector. X-rays emit from the tube, and travel through the sample. The higher the density of the sample, the fewer X-rays pass through and are captured by the detector. The X-rays are displayed in a grayscale image, with the lower density areas appearing brighter than the higher density areas. The level of image resolution required depends on the analysis being performed.

Typically, there are two types of microfocus X-ray tubes available today. Since X-rays are generated from an electron beam, which requires a vacuum to exist, the distinction lies in when the vacuum is created. In the case of a closed (sealed) tube, the vacuum is sealed within the tube by the manufacturer. Conversely, an open tube is a stainless steel unit that utilizes a vacuum system to create the vacuum each time the unit is powered up.

There are other properties which help to distinguish between the two types of technologies. Closed tubes are generally only available in voltages up to 130kv, whereas open tubes have voltages in upwards of 225kV. The focal spot of a closed tube is in the 5μm range, which results in lower magnifications and resolution than that of open tube technology. Some open tubes have a focal spot as low as 1μm, which results in resolution in the range of .5μm. Subsequently, only open tube types are available for sub-micron (nanofocus) defect detection. Moreover, geometric magnifications of up to 2400x can be achieved by some advanced open tube manufacturers.

Open tube systems are used primarily for high resolution requirements of electronics assembly and packaging.
Closed tube systems are used for lower resolution requirements. Additionally, over time, the vacuum in a closed tube can vary, affecting the stability of the electron beam. While open tubes are generally twice the cost of sealed units, they feature an open construction which allows for the replacement of targets and filaments. Since components can be easily replaced, an open tube basically has an unlimited life. Whereas, because the closed tube is sealed by the manufacturer, it must be replaced completely if any of the internal components fail. The useful life of a sealed X-ray tube is approximately 10,000 hours.

3.2 Detector

The function of the detector is to process the information of the X-ray waves in real-time into an image of visible light that can be observed and assessed by the human eye. While the most common detector is a combination of video camera and image intensifier which converts the X-rays into visible light, other types of detectors recently developed include high-dynamic cameras and flat panel DDDs (direct digital detectors).

3.3 Manipulation System

The manipulator is a device for precise X-Y-Z positioning and rotating/tilting of the sample. The manipulator should be capable of directional and rotational speeds that can be varied for requirements ranging from quick overview searches at low magnification to very low speeds at high magnification. Such speeds, from an X-Y standpoint, may be from less than 10 μm/second to 80 mm/second.

4. Industry Drivers

As the consumer demand increases for portable electronics, manufacturers are faced with several challenges. Competition, smaller stacked packaging, lower power needs and environmental concerns are all important drivers to the semiconductor industry. Moreover, accountability for increased production yields while reducing product costs and increasing quality requirements dictates the necessity for failure analysis and process development throughout.

5. Why X-ray Inspection?

In recent years, inspection has become a vital component of the manufacturing process. While there are several methods available, including wafer probes, scanning electron and acoustic microscopes, and automated optical inspection (AOI), X-ray inspection is the only method that provides a fully non-destructive method for the determination of structural defects and anomalies.

The ability to detect material flaws and component defects and to avoid them in the future results in improved quality output and increased customer satisfaction on one hand, and an increase in efficiency and cost reduction for the manufacturer on the other.

Typical examples of applications include bond wire inspection, as seen in *figure 2a,* and die attach void measurement, as seen in *figure 2b,* as well as inspection of package voids.

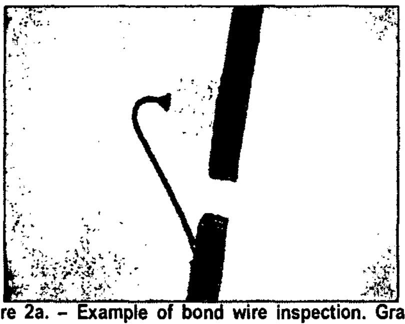

Figure 2a. - Example of bond wire inspection. Gray Scale Densities are converted to color for analysis in this example.

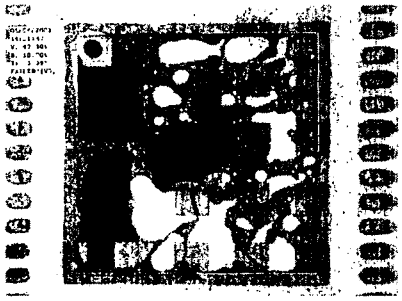

Figure 2b. - Example of die attach void analysis. Yellow and red coloring are used to differentiate void areas & densities in this example.

6. Wafer Bump Inspection

Manufacturers of wafers are benefited by the high resolution, magnification and precise manipulation capabilities of X-ray systems *(See figure 3a).* Whether quality assurance calls for random sample or production lot inspection, X-ray can provide in-depth analysis of wafer bump void and diameter defects *(See figure 3b)* in a timely and efficient manner. Semi or fully automatic inspection routines can be preset and run providing accurate yield reporting of the defects.

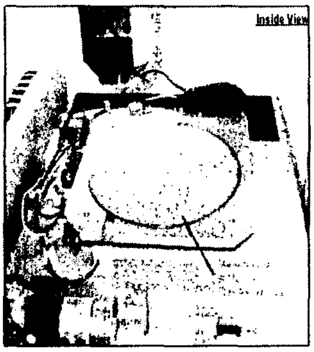

Figure 3a. - Wafer Bump Inspection (WBI) allows for the automatic detection of wafer bumps and voids.

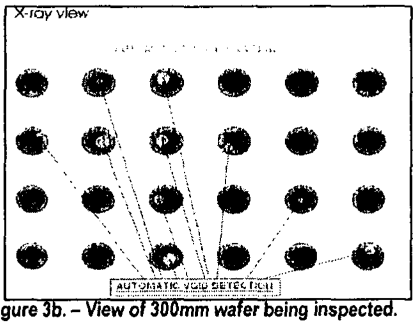

Figure 3b. - View of 300mm wafer being inspected.

7. 2D and 3D X-ray Capabilities

The primary advantage of 2D X-ray inspection is the savings in time in viewing an image, as 3D analysis can take twice as long, or longer. The primary limitations of 2D systems become apparent when imaging double-sided boards. In such instances, since X-rays penetrate through components on both sides of the board, the devices on one side can be partially obscured by devices on the other side. (In the image being viewed, one layer of components can appear to overlay the other.) Oblique angle imaging can lessen, and even eliminate, the problem, depending on the X-ray system and the complexity of the assembly being inspected.

The most notable advantage of 3D X-ray inspection is that it results in a complete picture of the area of concern. For instance, solder balls, on the underside of BGAs can be viewed from all sides, and defects, such as insufficiently wetted or cracked balls, can be easily identified.

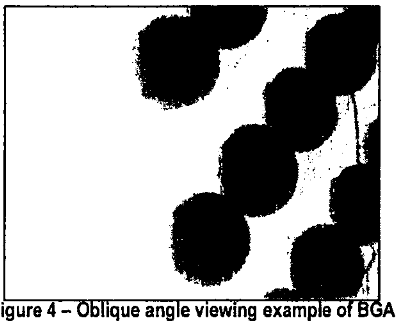

Figure 4 – Oblique angle viewing example of BGA.

2D or 3D? The choice can be difficult; and the requirement may not always be known until the middle of the inspection procedure... or it may change. Actually, an X-ray system that offers both capabilities is likely to be the ideal solution for the majority of applications.

7.1 Combining 2D and 3D in a Single System

Recently, a combined system has been developed by FEINFOCUS, known as the µCT-FOX. *(See Figure 5)* The system incorporates a choice of: a) a standard open microfocus tube, or b) a multifocus tube, which enables the operator to select a microfocus, nanofocus (below 0.3 µm feature recognition), or high-power mode, depending on the requirements of the application. The system offers the ability to perform high-resolution 2D inspection for optimum processing speed, while enabling the operator to switch to 3D for inspection of parts and interconnects that cannot be adequately viewed using 2D. Switching from one to the other is accomplished with a keystroke and by viewing a different screen (one screen is for 2D images, while the second is for 3D) on the same monitor.

Figure 5 - FEINFOCUS µCT FOX X-ray inspection with 2D and 3D capabilities.

7.2 Inspecting with 3D

3D capability is achieved with a process called Axial Computed Tomography, or ACT, with volume rendering software. ACT is a reconstruction technology. By taking multiple 2D views and by calculating the volume data (voxels), a 3D image is constructed, such as the transistor shown in Figure 5. Typically, for 3D inspection, the region of interest (ROI) of the part or interconnect is first located. Then a multitude of images is taken in a 360° circle by rotating the sample, the X-ray beam being projected in a cone, as can be seen in *Figure 6*. The images are subsequently recombined using the software into a 3D visualization model. The manipulator for the 2D/3D X-ray system enables movement around 6 axes, the movement being either programmed by CNC (computer numeric control) or controlled with a joystick. The multiple axes thus provide extreme flexibility in positioning the sample for optimum imaging. The high accuracy of each axis allows precise point-to-point measurements in 2D mode using the so-called central beam method. In 3D mode, wall thickness or void volume measurements can be performed directly from the 3D model due to the known size of the voxel (volume element) data.

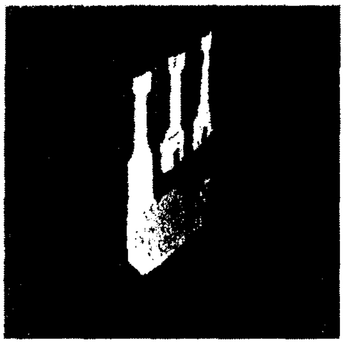

Figure 6 – Image of a transistor sample after the 2D images have been reconstructed and 3D rendering software has been employed.

The combined 2D/3D X-ray inspection system is notable for the ease in which the operator can shift from one mode to the other. Thus, if a stacked memory package or an MCM, for instance, is being viewed using the 2D mode and a 3D image is required to examine for a possible defect, the operator simply punches a certain key on the keyboard and begins the 3D operation. As the multiple images are taken in the 360° circle around the part and the 3D image is constructed by the software, the operator begins to view the image on the second screen. Once viewing is completed, the operator can then shift back to 2D and continue the process.

7.3 Central Beam Method

In 2D mode, point-to-point measurements in the shadow-projected image can be performed using the central beam of the central symmetric cone of the microfocus or nanofocus X-ray source. This method is independent of magnification and allows precise, simultaneous measurements between two points that are not necessarily in the same field of view. Increasing the magnification improves positioning accuracy. A high-precision manipulator with very slow motion (below 10 µm/sec) allows real 2D measurements within a few micrometers without scaling.

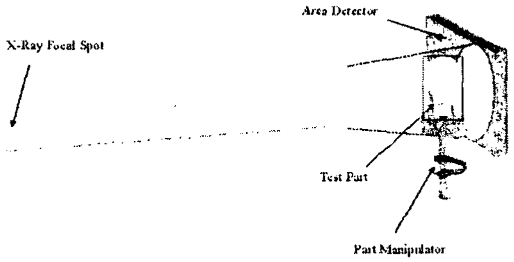

Figure 7 – Cone Beam Method Illustration

7.4 True X-Ray Intensity (TXI)

The performance and accuracy of the 2D/3D X-ray system can be attributed to a unique technology developed by FEINFOCUS called True X-ray Intensity (TXI) control. Unlike systems that attempt to measure and control the *input* level of the high voltage and current to the X-ray tube, TXI is a process that ensures controlled and stable *output* intensity for X-ray emission and, consequently, a constant focal spot size and spatial position. (*See Figure 7a and 7b*) The result is a sharp and consistent 2D image and data that can be reconstructed into an accurate, viable, and complete 3D image. Without precise control over the X-ray intensity, the reconstructed 3D image would be degraded and may not even be possible to achieve. No calibration of the detector is necessary during image acquisition since the intensity is stabilized where it is generated - at the image source (X-ray tube).

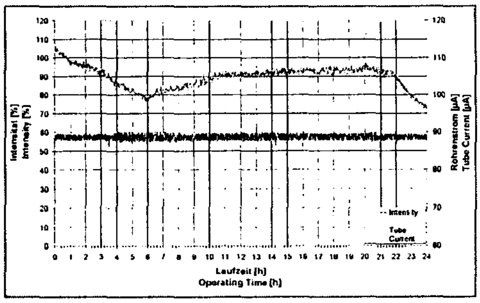

Figure 7a – Without TXI, actual X-ray intensity output fluctuates significantly over a 24-hour period.

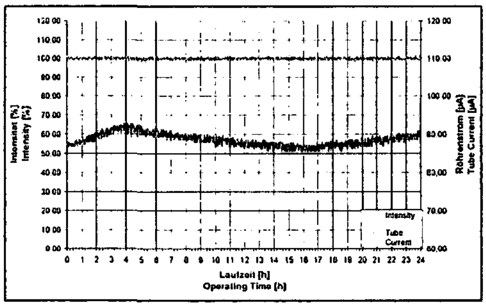

Figure 7b – TXI (True X-ray Intensity) stabilizes the output of X-ray intensity to within one percent over a 24-hour period.

7.5 Flexibility of 2D/3D Inspection Systems

The most important benefit of 2D/3D inspection is flexibility. For instance, several samples can be positioned on a manipulator table, where inspections for failures and 2D real-time measurements can be performed. On the same manipulator, a rotating axis can be affixed, which allows for a 3D scan of one selected sample. In this manner, one can quickly switch from 2D to 3D mode and back without changing the setting. The use of an image intensifier camera chain allows one to generate 3D scans within three minutes, including reconstruction.

7.6 Applications for 2D/3D Inspection Systems

A combined 2D/3D X-ray inspection system can be used for a variety of applications in a multitude of industries. It is, first and foremost, a design, production, and quality control tool. For R&D requirements, a 2D/3D X-ray inspection system can develop and refine the manufacturing process, and is ideal for inspecting prototypes during pre-production, whether electronic assemblies, medical devices, or castings. It can also be used for reverse engineering of existing products.

In terms of electronic assemblies, the system is used off-line to inspect components and packages, such as BGAs, flip chips, CSPs (chip scale packages), etc. Cracks, voids, delamination, and other crucial component anomalies can be observed and measured in either 2D or 3D mode, whichever most easily and accurately depicts the defect. A system like this is particularly useful in the manufacture of sensors and relays, and other MEMS (micro-electromechanical) and MOEMS (micro-optoelectromechanical) devices.

8. Discussion and Conclusion

Wafer and semiconductor component manufacturers are faced with new challenges every day as their technologies advance. With wafers and packaged devices becoming more complex, they also become more expensive to produce. Consequently, inspection methods must meet the critical demands of the industry. X-ray inspection is seemingly the best suited modality for non-destructive inspection and analysis of defects before, during and after production.

The development of sub-micron (nanofocus) and multifocus X-ray technology will undoubtedly meet the demands of the industry in the years to come. With the combined capabilities of 2D and 3D X-ray imaging techniques, manufacturers will see the benefits that inspection brings to their process development and quality assurance.