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Seeing Is Believing

The principles of x-ray inspection

SAC and Non-SAC Pb-Free Solders, Compared

Packaging and SMT Assembly Converge

对于无法以光学检测的产品（如BGA和CSP），X光检测是以无损方式检查焊点和位置的一个方法。它也可以用来检查半导体装置封装和某些贴装元件中的线路附着质量。近来，X光技术更被用于生产质量和过程控制，其中自动光学检测(AOI)的使用有限，因为存在着隐藏的焊点。X光检测系统分几个不同类型，包括分层成像和断层成像(CT)。本文重点讨论最常用的类型，即二维X光检测。

An A-to-Z Guide to X-Ray Inspection

Dr. David Bernard

Understanding x-ray inspection theory is essential when selecting a system.

Ed: This is the first of a two-part article.

X-ray inspection systems offer PCB manufacturers a way to inspect solder joints and locations in a non-destructive manner with products that cannot be inspected optically. For example, x-ray inspection permits examination of the solder joint quality of area array packages such as BGAs and CSPs. It can also be used to investigate the wire attachment quality within semiconductor device packages and very fine pitch SMT components. Inspection applications are almost endless with a high quality x-ray machine. Without x-ray inspection, the only alternative method would be destructive removal of the part in question with subsequent optical investigation. However, the optical approach renders the product and device useless and can destroy the area that needs to be investigated, potentially eradicating vital analytical clues that can indicate the cause of process defects or failures.

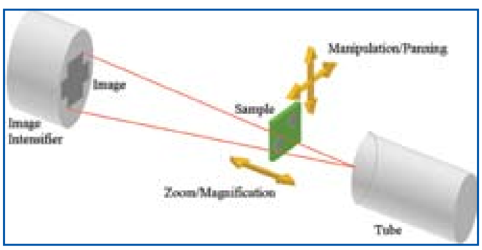

Figure 1. Basic layout of x-ray inspection system.

X-ray inspection has conventionally been used for development and field-failure analysis. More recently, x-ray's advantages have become more important for both production quality and production process control applications. Increased use of area array packages, chip scale packages and flip chips demands it. AOI is ineffective on these devices because their solder joints are hidden from view.

Several different types of x-ray inspection systems include laminography and computerized tomography (CT). This article will focus on the most common type: two-dimensional x-ray inspection.

2-D x-ray inspection systems are essentially x-ray microscopes. X-rays are produced from a tube, passing through the sample and then into an x-ray image-capture device (**Figure 1**). The image-capture device converts the x-rays it receives into visible images typically displayed on a PC monitor. Any object, or material, within the sample that is of higher density than the surroundings will absorb more of the x-rays in that location. As a result, fewer x-rays will pass through the sample at that location, so fewer will hit the capture device at that point, thus casting a darker shadow on the detector. A typical x-ray image produced by an x-ray inspection system has solder locations, device terminations and copper tracks appearing dark compared with the laminated circuit board in a PCB. The greater the density difference between the materials, the more clearly the contrast will appear on the x-ray image. For example, voids, or air bubbles, within BGA solder balls are much less dense than the surrounding solder, and as such can be easily distinguished (Figure 1).

Sample manipulation in the x, y and z directions within the x-ray inspection system is necessary to permit movement to different locations on the test sample (x and y-plane movements) and to change the height of the sample relative to the x-ray tube position (z-direction). Sample movement in the z-direction changes the magnification achieved by the system. For example, moving the sample closer to the x-ray tube increases the magnification (**Figure 2**).

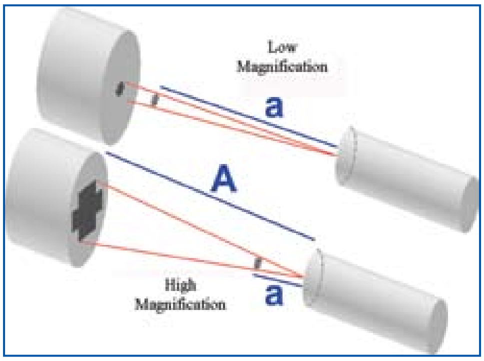

Figure 2. Geometric magnification in x-ray inspection system.

Magnification and Image Quality

The magnification level a particular x-ray inspection system can provide is called the geometric magnification. This is a ratio of

$$\frac{\text{Distance between the x-ray tube focal spot and the detector}}{\text{Distance between the x-ray tube focal spot and the sample}} = \frac{A}{a}$$

Historically there have been two main tube types used in 2-D x-ray inspection systems. These tubes are called closed or sealed tubes, and open or demountable tubes. Further information on the various types of x-ray tubes used for inspection, and the effects different tubes have on the inspection capabilities such as on magnification and resolution, can be found within numerous literature.

In some x-ray machine specifications, the term "system magnification" or "total magnification" is used in place of geometric magnification to indicate the systems capability. This term indicates the ratio of the sample size as presented on the operator's viewing screen compared to its actual size. Therefore, if a substantially larger monitor or flat panel display was used on an existing x-ray system, its system magnification would be substantially increased as the x-ray image would appear larger on-screen, but the geometric magnification and image quality of that system would be unchanged (**Figure 3**).

The geometric magnification values used in x-ray system specifications always assume the test sample is extremely thin, permitting its placement as close as possible to the x-ray tube. However, as the sample grows in thickness, and its proximity to the x-ray tube reduced, then the actual geometric magnification for a specific sample may be substantially less. The best approach to confirm acceptable magnification for a particular application is to try real samples within different x-ray systems.

Determining which additional capabilities and functions an x-ray system needs to optimize inspection for a particular application requires answers to a number of questions. Whatever the answers generated to define and satisfy an x-ray inspection system suitable for a particular application, it is strongly recommended that the system provide a top-down view and oblique angle views. The system should also provide a substantially high level of grayscale sensitivity in the image capture device.

Oblique angle viewing. When limited to inspection of solder bumps from directly above the sample, the main mass of the solder ball will mask the observation of subtle variations that might occur in the interfacial areas between the solder ball and device on one side, and the pad on the other. These interfacial areas will indicate if the joint quality is acceptable. By viewing the joint at an oblique (slanted) angle, and equally important at several different angles, the interference from the solder ball bulk can be reduced or eliminated. This permits the solder ball shape and any interfacial variations, including voids, to be clearly visualized.

Imagine a good BGA solder ball joint as a soccer ball sandwiched between two flat pieces of wood. Compared with the oblique angle view, a top down view limits the information that can be obtained. The larger the oblique angle, the better the separation between the bulk of the ball and the interface.

In a 2-D x-ray system, all layers within the board are shown at the same time. Ideally, oblique angle views should be available without any loss of available geometric magnification. If oblique angle views are not available, then the bulk of the feature or a device or component on the second side of a board may obscure the object under investigation. Consequently, as devices continue to shrink, any lack of magnification will again compromise the analytical value.

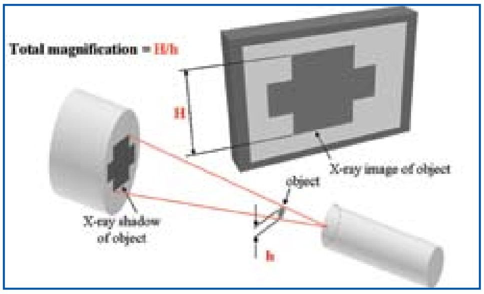

Figure 3. Total or system magnification of x-ray inspection system.

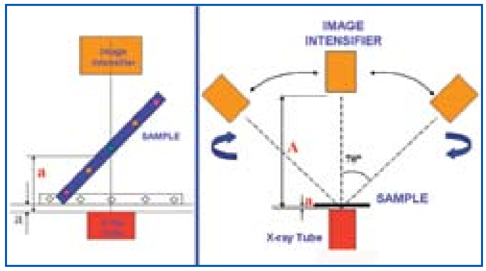

Figure 4. Tilting sample to achieve oblique viewing versus moving detector.

Oblique viewing capability can be achieved by moving the system image-capture device, in some way, into an oblique angle relative to the plane of the x-ray tube and sample. This replaces the traditional method of tilting the sample relative to the plane of the x-ray tube and image capture device. By moving the image-capture device for oblique views, the sample need not be moved away from the x-ray tube to prevent collisions, as would be required in the traditional method. Therefore, there will be no loss in available geometric magnification when an oblique view is needed, unlike with traditional methods (**Figure 4**).

Enhanced grayscale sensitivity of the image-capture device is required so that in smaller and less dense objects, the x-ray system has better capacity to visually separate and very small density differences in the samples. This permits detection of more subtle variations and faults. The images use this enhanced sensitivity to highlight faults within the samples. ■

Ed.: Part two will be published in January.

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