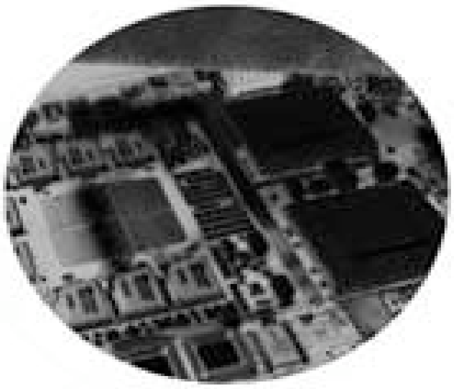
Quality Verification with Real-time X-ray

By Richard Amtower

One can look at trends in packaging and assembly and predict that geometries will continue to shrink and PCBs will become more complex. As a process and quality-control tool, real-time X-ray can respond by providing accurate, repeatable measurements.



The expanding application of ball grid arrays (BGA) and other components with hidden solder joints has resulted in the increased use of real-time X-ray inspection systems to verify the quality of assembled printed circuit boards (PCB). Whereas the relatively large dimensions of the first BGAs meant it was possible to use standard X-ray systems to check quality, increased I/O counts have driven bump and pitch size down while package sizes have both grown and shrunk. At one extreme, microprocessor modules such as the Pentium III and K6-2 are highly complex, compact assemblies; at another, PCB manufacturers are turning to direct-chip-attach (DCA) devices with tightly matrixed solder bumps to meet cost/performance goals.

Real-time X-ray Parameters

Because of large variations among real-time X-ray systems, it is helpful to discuss some key performance issues. Because BGA, chip scale package (CSP) and flip chip inspection requires high-quality X-ray images and the appropriate image analysis/measurement tools, a system with insufficient resolution, magnification or image clarity may be of little more use than the naked eye.

Image quality in an X-ray system depends on: image sharpness, a direct function of the X-ray focal spot size; magnification (which is actually of little help without adequate image sharpness); and contrast/brightness/noise, generally a function of X-ray energy (kev), radiant flux, detector performance and the absorption characteristics of the object inspected.

Image sharpness and magnification depend on the geometry of the X-ray focal spot, or the area from which the X-radiation is generated. As shown in Figure 1, large focal spots project a fuzzy X-ray shadow, with larger spots causing larger fuzz. The term "microfocus" generally describes small focal spots generating sharp images. Because measurement of small spot sizes is difficult at best, this term is somewhat problematic, but in general, an X-ray focal spot having a diameter of 20 É m or less at the 80 percent power points can be called microfocus. Typical minimum focal spots for commercially available sources are 5 to 10 É m for sealed tubes and 0.5 to 10 É m for demountable (pump-down) tubes.

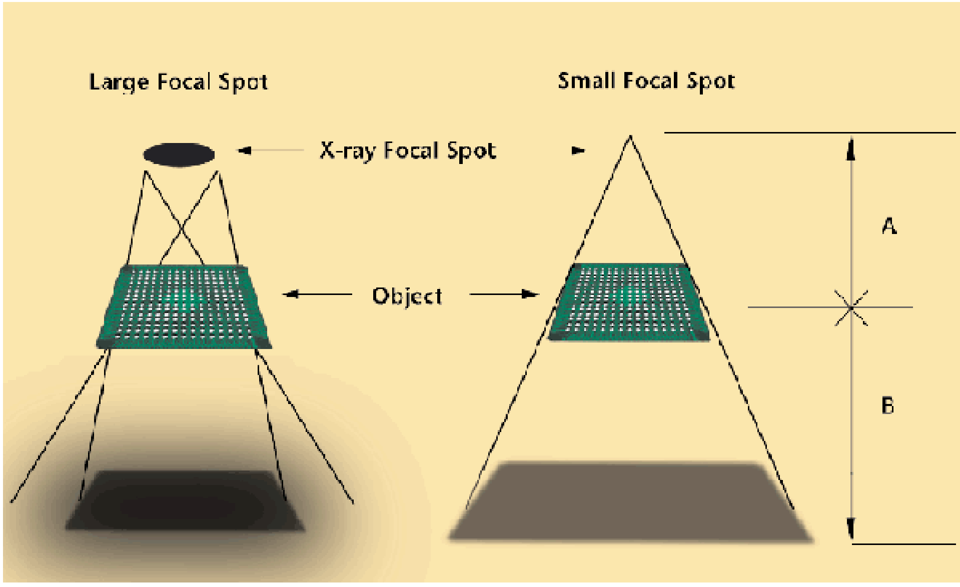


Figure 1. Geometric magnification and sharpness — magnification = (A + B) / A. Large focal spots project fuzzy shadows.

Geometric magnification is the first and most important step in obtaining useful magnification. As Figure 1 shows, the closer the part is to the X-ray source, the higher the geometric magnification. Suppliers usually quote their maximum geometric magnification based on the source-to-window distance of the X-ray source itself. However, magnification is usually limited by the physical size of the object inspected including the thickness of the PCB itself, the thickness of the package or other features on the board, which prevent the feature of interest from reaching maximum magnification. The magni-fication required depends, of course, on the application.

BGA X-ray Inspection

The most routine inspections of BGA devices involve sample checking for common defects such as shorts, bridges, foreign objects, missing solder bumps and undersized or deformed bumps. Figure 2 shows examples of common BGA defects viewed at 10X magnification. Another surprisingly common defect may be a chip capacitor dropped between the BGA and the PCB substrate by the chipshooter. The chip may induce a solder bridge.

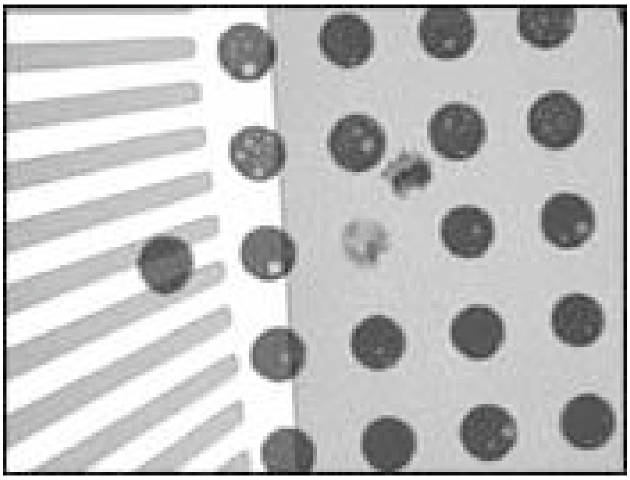


Figure 2. Common defects — shorts, bridges, foreign objects and missing bumps — as viewed at 10X.

At these low magnifications, it is both fast and practical to automatically inspect BGA devices for shorts/bridges, misshapen solder (which indicates excess or inadequate solder), missing or extra bumps, and foreign objects. Defects are flagged in red and data are logged to a file. Typical inspection time is 0.025 seconds.

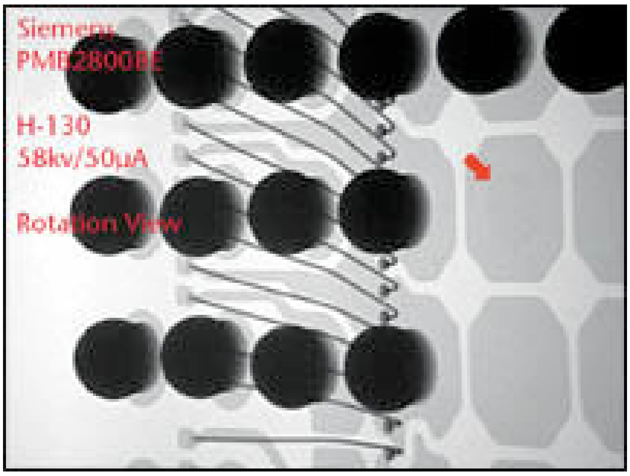


Figure 3. A good BGA with bond wires viewed at 60°. By tilting the source object between the source and the image detector, a clear view of hidden features is obtained.

Rotation, Magnification and BGA Connections

The advantages of microfocus X-ray sources with geometric sharpness are clearly evident when viewing an object at an angle. By rotating or tilting a PCB between the source and the image detector, one can view features otherwise hidden by an overlaying object from a side that permits a clear view. This includes viewing components on double-sided boards as well as examining solder-joint fillets under BGA solder bumps. Figure 3 shows a good BGA with its related bond wires at an angle of approximately 60°. All features are in sharp focus because of the geometric sharpness of the X-ray source.

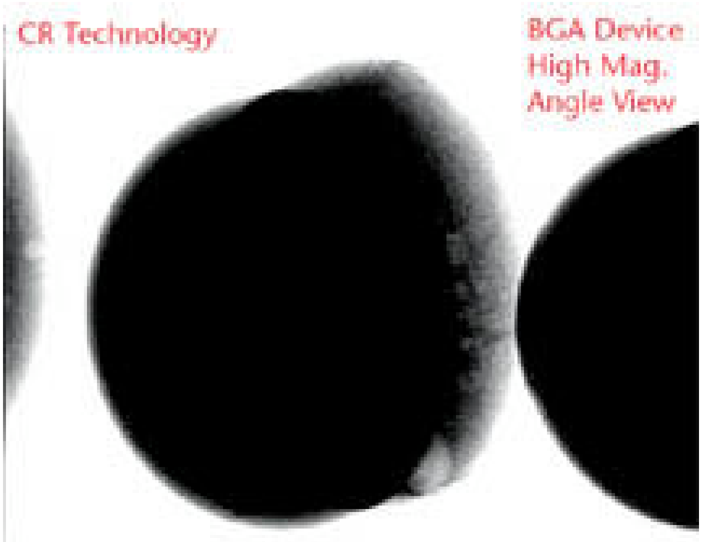


Figure 4. A nonreflowed solder joint revealed beneath a BGA bump (50X). Note the fine structure but also the voids between the bump and the pad.

Figure 4 reveals the presence of a nonreflowed solder joint beneath a BGA bump magnified to 50X. The voids in the joint are located at the interface between the bump and the PCB pad. Studies have concluded that BGA voids result from vapor formation at the solder/substrate interface and that they are spherical in shape due to the tendency to form a minimum liquid surface area in the void bubble.

BGA Measurements: Voidings and Offsets

In the simplest form of X-ray inspection, an initial visual check of the X-ray image will spot obvious defects such as missing solder bumps, bridges, etc. In more critical applications, precise measurements are needed to control process setup and to monitor critical tolerances during production, among them the measurement of voiding in BGA devices and the positioning of BGA bumps relative to solder pads.

Offset measurements are generally performed for more demanding applications, such as CSPs. To measure offset of the center of a solder bump from its pad requires locating the geometric center of the bump, seeing the pad through the bump, locating the pad's center and measuring the relatively small offsets of these overlapping objects. One can use several steps to visualize and measure the features:

1. Capture and enhance the image with sufficient magnification for accurate measurement (e.g., 50X).
2. Enhance feature outlines with synthetic contour relief.
3. Locate the outlines of the solder bump and pad.
4. Locate the centers of the bump and pad and measure the offset.

The same technique is used to measure flip chip pad/bump offsets. Higher geometric magnifications of 100X to 150X are needed for these smaller features.

Voiding measurement. Although the definition of acceptable vs. unacceptable voiding in BGA solder joints is under continual review, there is agreement that overly large voids are unacceptable and that having a large number of voids is undesirable. BGA voiding is an indicator of the effects of process variables in the assembly/reflow process. Its occurrence is affected by parameters such as reflow temperature, solder paste, flux and even pad dimensions. Accurate measurement and analysis of BGA voiding is therefore a useful tool for process setup and verification.

Voids are typically spherical and located at or near the bump/pad interface. X-rays are strongly attenuated by the lead in solder bumps and are selectively less attenuated when they pass through a solder void, resulting in a lighter X-ray shadow where the void is found. The image will be brightest at the center of the void (where the X-ray passes through the least amount of absorbing material), and will gradually darken as it moves to the edge of the void. This effect will be clearly visible in an image with sufficient magnification and resolution. The increased X-ray absorption at the outer edge of the void is clearly visible and is measured on this image with a line profile tool, which gauges the intensity levels of the image along its length and shows the data as a graph in the lower right corner. A void-free solder bump appears along the line as a drop in intensity to approximately 100 gray level, while the voided bump appears as a brightening to 200 gray level. Even the presence of the copper trace in the PCB can be seen as a slight flattening of the void's maximum intensity.

Because all of this information is presented in digital form, precise analysis can be performed by saving the data as a report file and importing it to a spreadsheet for analysis. Once in Excel, it is easy to generate other graphs, statistics and fine-tuned information for specific requirements.

Automated Void Measurement

The key elements of an automated voids measurement X-ray tool include:

1. A high-resolution X-ray source with software programmable voltage and current settings.
2. A programmable manipulator to index the X-ray sample at high magnification.
3. Software.

To ensure reliable and repeatable results, the systems must be easy to program and use. The data must also be available in an easy-to-use format. Accurate measurement is complicated by the variation of intensity levels over the solder bump and void images. Hence, special image processing algorithms must be employed.

For example, consider a BGA void measurement wherein the area of each void in an individual solder bump is measured separately and reported. The system locates the bump in its field of view, finds and measures the area of each void, and compares their sizes to that of the overall solder bump. A pass/fail parameter is set for both the maximum total percent voiding allowed and for the largest single void as a percent of the solder bump. Voids are highlighted in color for the benefit of the operator and all data are stored in a report file.

The Future: More of the Same

The future requirements for inspecting BGA devices are clear because the future is already here in the form of flip chip and DCA. The issues associated with flip chip are more demanding versions of BGA issues, i.e., at higher magnifications and resolutions. Where 10 É m resolution performs admirably for detailed BGA inspection and for routine flip chip screening, higher resolutions are needed for inspection of flip chip-bump voidings and offsets.

The need for high-resolution/magni-fication X-ray systems with an array of sophisticated image processing and analysis tools will continue to increase. As with the advent of BGA devices, the introduction of even a few flip chip or similar devices into production will drive the need for more capable inspection tools. Manufacturers of PCBs should bear these requirements in mind as they plan their X-ray inspection resources.