System Requirements for Visual BGA Inspection

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Visual BGA inspection devices produce the visual display of the solder balls of an area array package. They provide the viewer with a natural image of the result of a solder process and represent a basic tool for monitoring quality in the SMT solder process.
But what are the prerequisites for successfully employing a BGA inspection system?

First, the system's components should comprise an inspection stand, light source, optical system, image recorder, image processor and image display (Fig. 1). The quality of an inspection system regarding the fault detection rate, user friendliness and flexibility is basically determined by the interplay of these components.

System construction and requirements

A visual BGA inspection system magnifies the smallest structures to a factor of three digits. The optical system must therefore be firmly housed in a mechanically stable structure. Even tiny vibrations of the system can cause enormous vibrations of the inspection image! This fact alone makes hand-guided inspection systems unadvisable, and they will not be discussed in the following. The construction must be suitable for inspecting all PCB sizes, so that even outer lying BGAs on larger boards can be inspected without restriction. Especially with large PCBs, accessibility to all controls at the system is important.
Complete inspection of the component requires moving along the component and viewing the different rows. With dimensions of 50µm at the component, this movement must have the appropriate precision. In addition, the object to be inspected on the board must first be accessible with the inspection optical system. Fast adjustment of the table, coupled with fine adjustment is a good way to meet both requirements.
BGAs represent one area of application. The inspection system will be the more useful, however, the more varied the possible applications.
Viewing solder edges on components, seeing the inside of plugs, inspecting plated-through holes and inner solder meniscuses constitute an incredible variety of applications and require mechanically easy adjustment of the optical system. Turning and tilting the optical system should therefore be a feature of the inspection device.
Flexibility is usually possible only through modularity. Exchanging the inspection optical system or the camera and attaching filters or optical components such as converters are all features that may be necessary for adapting the system to particular requirements.
For example, the inspection camera can be used to turn a triocular microscope into a video microscope, or the BGA optical system can be replaced by a top viewing optical system, or a two-fold converter can be introduced in the system structure. Finally, easy exchangeability is important for servicing.

The inspection optical system - the core of the system

The fundamental task of the inspection optical system is to produce an informative image in a gap with a standoff height of 500µm or less.
For this purpose, the inspection head needs a light or image bending component. This bending component is generally a prism or mirror attached to the head end of the optical system.
Since components on a PCB are being packed more and more closely together, the inspection head must be as small as possible. Figure 3 is a schematic diagram of a BGA with the inspection optical system directly adjacent. Here the „footprint" of the optical head is essential. The depth refers to the theoretically minimum

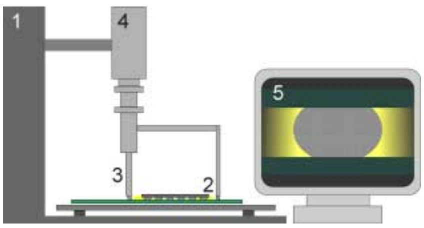

Fig. 1: Visual BGA inspection system
(1) Inspection stand, (2) light, (3) optical system, (4) image recorder, (5) image processing and display

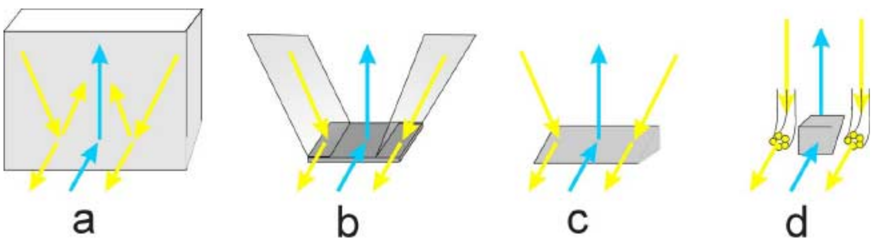

Fig. 2: Inspection head geometries (yellow: light paths, blue: image paths)
a) Prism for integrated image and light bending (with scattered reflection into the image axis), b) bending mirror in plastic holder, c) prism as mirror, d) bending prism and optical fiber bundle

distance between other SMT components and the BGA. The width indicates how far you can move towards the edge of the BGA without bumping into the sides of other components. The farthest row of the BGA should also be accessible. A depth of approximately 1.5 mm and width of approximately 5 - 6 mm are standard for the inspection head. (The depth and width are determined at a height of about 1 mm, the approximate height of most SMT components).

While mechanically the minimum dimensions are clear, optically they are not at all. If the user wants to detect all solder balls under the BGA, then the optical system must provide sharp images from front to back; that is, it must be focused through the depth of the BGA. Figure 4 shows two optical systems. The darker blue color indicates the area that is not focused. Optical system 1 is therefore well positioned at the BGA. Even if it were possible, mechanically bringing the optical system closer to the BGA would bring no benefit. The optical system would not deliver a sharp image of the solder ball. A greater distance from the BGA is not problematic, however, since it would not affect the focus and would even remedy another difficulty: if the optical cone does not have an ideal height that is less than the gap or standoff height of the BGA, then the upper joint of the solder ball cannot be viewed, as shown by the red area in optical system 2. It's easy to see, however, that even at a greater distance, the optical system would flatten the angle to the solder ball and reduce the non-viewable (red) area. Increasing distance improves

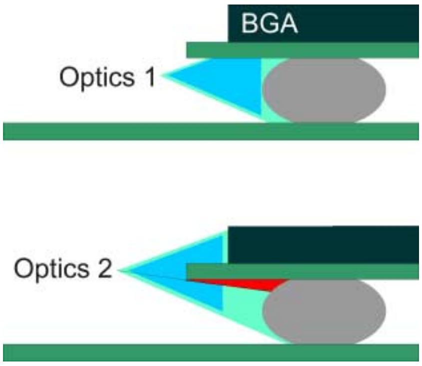

Fig. 4: Height of the optical pupil and related ability to see the ball in full. Dark blue represents the non-focusable area

the image quality. Since space around a BGA is often not available, a good inspection head proves its merit with good images even when placed directly against the BGA.

Image recording needs light

In order to „see“ or visualize an object, light is essential. What is physically possible must serve the inspection goals, for obtaining optimal results. „Physically impossible“ means (e.g.) that a ball covered by another ball cannot be optically viewed, and that the lower a ball lies under the BGA, the less light the ball receives (see Fig. 3).

Despite this problem, the inspection system must be able to supply information for assessing the solder joint quality: the surface structures of the balls, connection to the landing areas, characteristics of the meniscuses, meniscus form, bridges, presence of solder balls, flux residue and other anomalies.
To fulfill these criteria as much as possible, a combination of frontal light and backlight has established itself in the market as the ideal illumination. The frontal light illuminates the outer balls and enables excellent assessment of the surface structure, the joints, the meniscuses and the detection of certain faults, such as micro cracks. Slanting the optical system at an angle to the BGA edge often allows the same evaluation for the nearest, inside rows.
The backlight illuminates the ball from behind during the inspection. The edges and therefore the form of the outer ball „a“ (Fig. 3) become more clearly recognizable. The image has more contrast (Fig. 6). The benefits of the backlight become most evident when the inspection head is used to view between two rows of balls, (see Fig. 3). The backlight immediately indicates whether solder bridges exist and whether the passage is free of any residue. If the optical system has a wide focus range, then you can focus row after row and detect the outline of the inside ball by backlighting (example: light path to the inside ball „i“, Fig. 3; Fig. 5). The form, meniscus and various anomalies can then be evaluated.

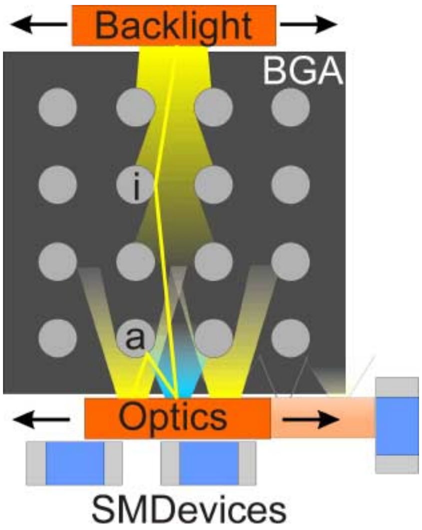

Fig. 3: Movable inspection optical system on the BGA, top view

If you now wish to view all rows of a BGA successively, then you have to move the inspection optical head. As Figure 3 shows, practically only the light incident directly opposite the backlight contributes to the inspection of the inside solder balls. Light coming from the sides is blocked by the intermediate balls. A manageable method for ensuring constant good illumination under the BGA can therefore only lie in guiding the backlight with the inspection head. Coupling within a single system is appropriate in this case.

Image quality

The image quality of a system is specifically determined by the individual quality of the serially connected components in the system. These components are: the inspection head, the design of the optical system for focusing to the middle of the component, the image detail and resolution, and finally adequate and spatially optimized light intensity. The adaptive optical system for the camera, the camera itself with its sensor, the resolution of the video monitor or, alternatively, the Frame grabber and the VGA monitors equally affect the image quality.

In other words, what ultimately interests the user is the system resolution. With the image, what's important is how large the smallest structure on the object must be in order to be visible.

Not essential is that the camera has a correspondingly high resolution, for example – even if such a number is easily determinable and therefore comparable. Rather, the weakest member in the chain determines the quality of the displayed image. Low quality of the optical system cannot be compensated by better camera quality.

The simplest test for determining the system quality is to inspect a structure with the system and to view the display of this structure. Such a structure can be a defined reticule plate. The issue is then how many line pairs can be seen on the monitor.

Here it must be noted that the number of lines decreases as the light conditions become poorer. The image detail must also be considered. For example, if you see 2 balls completely on a BGA with a grid of 1.27 mm, then the image area is 2.54 mm. If you now attain a resolution of 288 line pairs, then structures are still visible along the horizontal direction of size 2.54 mm divided by 288, or barely 9µm. If another optical system allows precise viewing of a ball (= 1.27 mm) and if a resolution of 200 line pairs can be attained, then you will still see structures of about 6µm, i.e. considerably smaller. Of course, you will then also have a different image detail. The image detail should be considered good if the structure in question is completely visible. That is, on a BGA the ball should be completely recognizable with its lower and its upper joints (see Fig. 4, optical system 1; Fig. 6).

Industrial suitability

Visual BGA inspection devices should always be ESD-suitable. Particularly multilayer PCBs have unit prices that come close to the purchase price of a inspection system. Protection of such expensive PCBs should therefore have priority.

Simple, sturdy and easily understandable controls are another must.

The suitability of the inspection head for use in a production environment depends on the protection of the optical head against accidental damage. Some commercially available optical inspection systems require direct contact of the unprotected optical head or glass mirror with the board. The attached prism or mirror edge of such an optical head can be easily damaged, which generally leads to image loss and expensive replacement or repairs. The problem is not remedied by an apparently convenient change of the head.

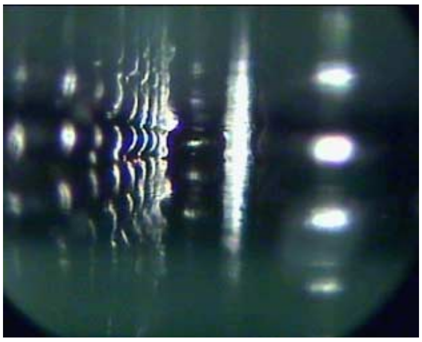

Fig. 5: Focusing the center under a BGA

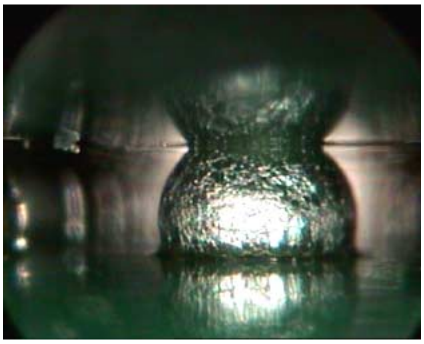

Fig. 6: Outer BGA ball with visible upper and lower joints

The optimal solution lies rather in integrated and sturdy prism protection. The version shown in Figure 2d can of course be more easily protected than that shown in Figure 2c, for example, since the contact surface on the PCB in Figure 2c is clearly larger and the attachment of protective mechanisms would be considerably more difficult and more space-consuming. Well protected heads have the advantage of „near-zero damage": no risk of breakage when handled properly. And since the bottom edge cannot become „frayed" by damage, the optical pupil can be placed very far down. This is very advantageous particularly with the sort of flat columns encountered in CSPs or flip chips.

Costs

The purchase costs of a system are offset by the possible benefits of that system:

- Precise fault detection and related savings potential in the process, so that the investment quickly pays off
- Applicability beyond mere BGA inspection; eg. Maximum flexibility
- Operating costs and service life

An inspection system is economical only if it reveals all possible defects. If the inspection system is to be supplemented by software assisting the user in the analysis and evaluation of inspection results, then the reaction to faults in the process can occur with considerably greater precision.

The prospective buyer's cost-benefit analysis should also consider the waste costs of production and the added value of the knowledge gained by employing the system in research and development.

The amortization costs can be reduced if the system can be used more flexibly and is therefore available for other tasks, such as top view inspections.

An estimate of the operating costs should also consider the inspection head as a fragile component. The purchase of a device with an unprotected inspection head can become a costly venture!

Conclusion

A successful BGA inspection with the aim of process improvement presupposes an efficient inspection system, which basically depends on the layout and coordination of all components. The detailed knowledge of the necessary properties of the individual components, as discussed in this article, coupled with a reliable demonstration performed directly on the object to be inspected forms the rational basis for deciding on the purchase of a visual BGA inspection device.

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