A New Stencil Rulebook for Wafer Level Solder Ball Placement using High Accuracy Screen Printing

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Printer-hosted processes for solder ball placement are now widely used for package technologies ranging from BGAs using ball diameters above 750µm to the latest WL-CSPs demanding 250µm diameter. This broadening spectrum of applications brings more choices in terms of stencil design rules and production methodologies.

The State of the Art

As the package technology of choice for portable consumer electronic products, Wafer-Level Chip Scale Packages are swelling global production of devices that incorporate area array interconnects. According to TechSearch International, annual capacity for WL-CSP production is set to break through the 10 billion units mark within the next year. At the same time these packages are moving to ever finer solder ball diameter and interconnect pitch specifications. Across all applications for area grid array packages, from standard BGA through WL-CSP, assemblers need solder ball attachment processes for ball diameters ranging from over 750µm to 250µm. Looking ahead, processes for attaching 200µm balls are now proven under laboratory conditions and ready to enter advanced production facilities.

Semiconductor OEMs, wafer processing houses and back-end packaging specialists need processes for solder ball attachment that are fast, robust, and cost-effective. To keep pace with other packaging processes performed either side solder of solder ball attachment, wafer bumping specialists are typically able to accept a cycle time of between 60 seconds and four minutes. The cycle time depends on the size of the wafer, the number of interconnects required, and the type of IC being assembled. In other processes, such as those where substrates are bumped in strips, a cycle time of around 10 seconds may be required.

One solution to meeting these demands is to host substrate fluxing and solder ball placement on equipment derived from inline surface-mount screen printing platforms. The fundamental accuracy of high-end screen printers is more than adequate to place solder balls at pitch dimensions significantly below 200µm. In practice, today, many BGA and Micro-BGA packages are being assembled using solder ball attachment processes hosted on mid-range screen printer platforms.

Solder Ball Attachment

The solder ball attachment process has two elements, comprising a fluxing phase followed by solder ball placement. Current processes are compatible with wafers in standard diameters up to 300mm, and will also accept substrates presented as strips or in a standard carrier such as an Auer boat. Singulated substrates may be processed one at a time. Alternatively, a number of units may be aligned simultaneously for fluxing and solder ball attachment using a virtual-panel substrate support technology that aligns each substrate individually.

Two precision screen printing platforms are used. This delivers equal accuracy and repeatability for fluxing and ball placement. A precision emulsion screen is used to deposit flux at uniform thickness and volume. Emulsion screen technology is used to maintain a tightly gasketed seal against the surface of the wafer or substrate, preventing smearing of the flux even after many hundreds of cycles without cleaning the screen. The resulting high beat rate and low usage of cleaning consumables help to boost effective productivity. Fluxing is followed by solder ball placement, using a metal stencil that combines a laminated stand-off layer.

The solder ball placement machine is fitted with purpose-designed solder ball transfer head. The width of the transfer head exceeds the active area of the stencil. Internally-machined channels provide a low-friction solution to continuously direct solder balls to the surface of the stencil apertures. The transfer head is driven at a constant speed across the active area of the printer. As the transfer head moves over the stencil, in direct contact with its surface, a positive placement force is exerted to push the solder balls through the apertures and thereby populate each fluxed interconnect site. The linear speed of the transfer head is adjusted to optimize yield and throughput. The total instances of defects, such as unpopulated sites or damaged balls, is typically less than 0.01% of placed solder balls, in a well-adjusted process.

The solder ball storage capacity of the transfer head is usually sufficient to sustain at least one hour of continuous operation. Upon completion of the solder ball placement stage the wafer or substrate is unloaded from the screen printer, and may then be inspected and stored for subsequent reflowing of the solder balls to complete the attachment process.

Screen and Stencil Design

While the capabilities of the printer platform define the fundamental alignment accuracy and repeatability of the process, successful solder ball placement depends heavily upon the quality of the screen and stencil set used for flux deposition and solder ball placement.

The gasketing properties of precision emulsion screens make these the preferred medium for flux deposition. The screen is created using a polyester or stainless steel mesh. The specification of the screen is determined to ensure the optimum volume of flux in relation to the ball diameter. This ratio is constant for all ball diameters, and is controlled by selecting the correct pitch and wire diameter of the mesh and adjusting the emulsion aperture size according to the intended ball diameter. Standard screen coating and developing processes are applied. Clean-room conditions meeting at least Class 10,000, systems to closely control temperature and humidity, and the skills of experienced designers and producers of precision emulsion screens, are necessary to achieve sufficient accuracy and uniformity for wafer-level fluxing for 200µm solder balls to be placed at 300µm pitch.

Provided the screen, as fabricated, meets the intended specification including aperture size, mesh tension, and image stretch/shrinkage, little process-optimization effort is subsequently required. Typically, a print gap of up to 2.0mm, print-speed up to 50mm/s, and print pressure of 2kg per 100mm of squeegee length will result in uniform flux deposits. High fluxing accuracy and uniformity have been achieved using a polyurethane squeegee inclined at 60°.

The process has proved robust and reliable both in production as well as laboratory applications, to the extent that post-fluxing inspection has proved unnecessary. Most assemblers perform inspection after ball placement. Recent experiments at 200µm ball diameter have shown this to be an effective strategy, since no post-placement defects have been found that could be attributed to fluxing problems.

The solder ball placement stencil is a composite structure. The stand-off layer is typically created by depositing a standard PCB photoimageable dry-film resist onto the stencil underside. The resist is applied primarily to prevent the metal stencil coming into contact with the deposited flux, but as a relatively soft material brings the added benefit of protecting the wafer against potential damage. Exposure and development of the photo-resist creates apertures at the interconnect sites. The cross-section of a solder ball placement stencil is shown in figure 1. Typically, the metal stencil is mesh-mounted in a standard aluminum frame, and one row of ball-recovery apertures is created along one edge to minimize wastage and to prevent solder balls from entering the machine.

Techniques for producing the metal stencil layer have included laser-cutting, which is commonly used to produce surface-mount stencils. Chemical etching is also frequently used, particularly in the case of thicker stencils or when the total aperture count is high. The stencil thickness is closely related to the ball diameter, to ensure that the ball will be satisfactorily embedded in the flux and, when placed, will not interfere with the seal of the transfer head against the stencil surface. The stencil thickness required for fine-pitch bumping with solder balls of diameter 200µm and below points toward electro-forming as the most suitable stencil production technology. In particular, the ability of the electro-forming process to deliver a uniform thickness and coplanarity at sub-300µm gauge, especially where the aperture count is also high, is necessary to achieve a high successful placement rate (ball yield). On the other hand, for stencil thickness greater than around 300µm, the electro-forming process cannot guarantee uniform stencil thickness. At this thickness and above, apertures can be laser-cut into stainless steel blanks cost-effectively and with satisfactory results. For thicknesses up to around 500µm, laser cutting may be the most suitable stencil manufacturing technique, provided the aperture count is less than around 15,000. When producing a large number of apertures, as is becoming the norm for fine-pitch WL-CSPs, the energy transferred into the stencil blank during the laser cutting process can be sufficient to warp the stencil, leading to poor coplanarity and a resulting deterioration in ball yield.

A clear understanding of this and other factors that influence the production of ball placement stencils, as well as design expertise acquired over several generations of precision SMT and semiconductor processes, are central to achieving the optimum stencil design.

The graph shown in figure 2 details applicable stencil technologies in terms of application and solder ball diameter, as a guide for stencil designers and end users. The graph shows how aperture-count is an important parameter when selecting the stencil technology.

Key Design Data for Stencil Optimization

From figure 2 it can be seen that the parameters governing selection of the stencil material and manufacturing technology are the intended ball diameter, the minimum interconnect-pitch, and the approximate total number of solder balls to be attached. These also determine the appropriate stencil design rules, which must be applied in combination with the customer’s source CAD data describing the interconnect positions. In the case of a wafer bumping process, for example, this data is readily retrieved from the GDS-II or .dxf file describing the pad metallization sites.

To accelerate stencil design, DEK has created an automatic calculator that computes the complete set of stencil dimensions based on input of four key parameters plus user-selection of two yes/no options. The calculator is used in conjunction with CAD conversion software, which converts the electronic GDS-II, .dxf or .dwg file to gerber format. The data thus generated is used to drive the stencil laser cutting equipment, or to produce a mandrel for the electro-forming process. The stencil design rules embedded in the automatic calculator tool have been developed over several generations of solder ball attachment processes, from early BGA and Micro-BGA packages to today’s advanced WL-CSPs.

Practical Results

The calculator has been used as part of laboratory research to prove printer-based solder ball placement of 200µm balls on a 300µm pitch. Figure 3 shows the results achieved using an electro-formed ball placement stencil designed with the aid of this tool.

The cycle times achieved during these experiments have equaled those of existing, production processes placing 300µm solder balls on 200mm-diameter wafers. These results suggest that a production rate of 60 units per hour is achievable at 200µm ball diameter, when combined with automated wafer handling as part of an inline, production-ready procedure.

Further research is now ongoing to refine other aspects of solder ball placement at the leading edge of WL-CSP technology, including wafer-handling equipment capable of supporting back-ground wafers of sub-100µm gauge for forthcoming package types.