

## METHOD AND APPARATUS FOR FILLING A BALL GRID ARRAY

### FIELD OF THE INVENTION

This invention relates to ball grid arrays and more particularly to the placement of solder balls in such arrays.

### 5 BACKGROUND OF THE INVENTION

Ball grid arrays are well known in the art and available commercially. Such an array comprises a plastic film with an array of recesses, each recess providing a receptacle for a solder ball. The arrays are available in strips and the individual segments of the strip (i.e. array) can be detached from the strip.

10 The task of populating the recesses reliably is a difficult one and a number of procedures to accomplish reliable solder ball placement have been devised. One such procedure developed by Motorola, employs a vacuum chuck with a number of holes corresponding to the recesses in a ball grid array. The holes are defined in a shift plate which moves to release the ball  
15 into the ball grid array, properly positioned, when the vacuum is removed. Another method employs a "dip strip" which captures the balls and then mates the ball grid array to the "dip strip" to transfer the balls.

### BRIEF DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS OF THE INVENTION

20 In accordance with the principles of this invention, a cylindrical gantry, rotatable about a central axis much like a Ferris Wheel, is employed for filling the ball grid array with solder balls. A ball grid array strip is secured to the

inner face of the gantry and a tooling fixture is secured to the outer face of the gantry in a position corresponding to that of the ball grid array. A reservoir is positioned at the bottom of the gantry and is filled with solder balls. The gantry is rotated to move the tooling fixture through the reservoir of solder balls to fill recesses in the tooling fixture with solder balls. The gantry is rotated further upwards to a position where solder balls not positioned in recesses of the tooling fixture fall back into the reservoir. Gravity also ensures that the solder balls captured in the recesses of the tooling fixture always move to the same position in the recesses thus providing predictable positions for the solder balls even though the recesses are larger than the solder balls.

The tooling fixture is coupled to an associated ball grid array, illustratively, by means of a rail and solenoid arrangement which pushes the tooling fixture into juxtaposition with the associated ball grid array at a point in the operation where gravity operates to move the solder balls, captured by the tooling fixture, into the corresponding recesses of the Ball Grid Array.

In accordance with another embodiment of this invention, gravity again is employed to transfer solder balls from a tooling plate to a closely positioned ball grid array. Further, the tooling plate is moved with respect to a reservoir of solder balls for populating the tooling plate with solder balls for later transfer to the ball grid array. But in this second embodiment herein, the reservoir geometry is such as to capture loose solder balls during a one hundred and eighty degrees rotation of the reservoir and both the reservoir and the fixture carrying the tooling plate and the ball grid array actually rotate through about one hundred and eighty degrees.

The balls in the reservoir spread across the tooling plate at one range

of positions during the rotation sequence to populate the tooling plate. As the gantry, to which the reservoir, the tooling plate and the ball grid array are attached, rotates further, a riser cylinder is activated to move the ball grid array into close proximity to the tooling plate. As further rotation occurs, the tooling plate moves above the ball grid array for gravity transfer. The gantry oscillates over about a one hundred and eighty to two hundred degree angle so that solder balls do not escape the reservoir.

### BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a top view of a representative, commercially available, ball grid array strip; and

Fig.2 is a schematic view of a Ferris Wheel apparatus for filling ball grid arrays in accordance with the principles of this invention;

Figs. 3, 4, 5, and 6 are schematic representations of a representative ball grid array strip and associated tooling fixture affixed to a Ferris Wheel apparatus of figure 2 as the wheel moves to consecutive positions during the operation;

Figs. 7, 8, and 9 are side, top and front views of an implementations of the Ferris Wheel apparatus in accordance with the principles of this invention; and

Fig. 10 is a flow diagram of the method of populating a ball grid array with the apparatus of figure 2.

Figures 11 through 22 are schematic side views of a solder ball

placement work cell in accordance with the principles of this invention showing the orientation of the various components therein during operation;

Figures 23, 24 and 25 are schematic end, side and top views of a practical embodiment in accordance with the principle of this invention; and

5           Figures 26 through 28 are enlarged schematic representations of portions of the embodiment of figures 23, 24 and 25.

#### DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS OF THIS INVENTION

10           Figure 1 shows a top view of a ball grid array strip 10 which is available, for example, from AMKOR/ANAM, Korea. The strip is comprised of a plurality of individual ball grid arrays 11. The individual array can be separated from one another along lines indicated by the broken line at 12. The ball grid array recesses are shown as an 11x11 array at 14 in the figure resulting in an array of 121 solder ball recesses, each 0.63 thousandths in  
15           diameter on 1.27 thousandths centers.

          Figure 2 shows, schematically, a "Ferris Wheel" type apparatus for filling a ball grid array in accordance with the principles of this invention. The wheel comprises a circular gantry 20 having an inner face 21, an outer face 22 and a thickness of about one inch. A tooling fixture 23 is attached to  
20           the outer face of the wheel and a ball grid array 24 is attached to the inner face of the wheel in a position corresponding to that of the tooling fixture. A reservoir 25 of solder balls is positioned at the bottom of the wheel.

In operation, the wheel is rotated about axis 26 so that the tooling

fixture 23 moves through the reservoir while the ball grid array does not engage the solder balls in the reservoir. the thickness of the wheel thus can be seen to be arbitrary, but is related to the depth of the reservoir and the necessity for rigidity.

5           Figures 3, 4, 5, and 6 illustrate, schematically, the sequential positions of a ball grid array and the associated tooling fixture as the wheel of figure 2 rotates in a manner to move the tooling fixture through the reservoir of solder balls. Specifically, figure 3 is a schematic side view of an illustrative  
10           ball grid array 31 and associated tooling fixture 32. The components (31 and 32) are moving downwards and to the right as indicated by the curved arrows 33 and 34 in figure 3.

          As the wheel rotates further, tooling fixture 32 enters the reservoir while the associated ball grid array remains above the reservoir. The positions of the components at this juncture of the operation are illustrated  
15           in figure 4. It is to be noted that ball grid array 31 has an array of recesses (37 in figure 4) which are facing downwards, as viewed in figure 4. The tooling fixture, 32, has recesses facing upwards, as viewed in figure 4. The recesses in the tooling fixture are dimensioned to hold only a single solder ball. Since the tooling fixture become occupied.

20           The wheel continues to rotate as illustrated in figure 5. Gravity acts to return excess solder balls (38) to the reservoir as the components (31 and 32) move upwards and to the right as indicated by the curved arrows 39 and 40 in figure 5. Wheel 20 is grounded electrically to ensure that static electricity does not act to retain excess solder balls on the surface of the  
25           tooling fixture. The now filled tooling fixture is positioned to transfer the solder balls to the associated solder ball array.

5 The transfer of the solder balls is accomplished by moving the tooling fixture and the associated ball grid array into juxtaposition and then moving the juxtaposed components upwards as the wheel continues to rotate counterclockwise. As the components pass the forty five degree position, with  
10 respect to a vertical reference axis 42 of figure 5, gravity begins to act to move the solder balls from the tooling fixture to the ball grid array. It should be clear that the continued rotation of the wheel positions the ball grid array beneath the tooling fixture whereas in figures 4 and 5 the tooling fixture was beneath the ball grid array. Moreover, as shown in figure 6, the recesses of the ball grid array are directed upwards and the recesses of the tooling fixture are directed downwards. The recesses of the tooling fixture are dimensioned so that a solder ball is free to move in a recess and the recesses in a ball grid array are more closely dimensioned to fix the position of a solder ball therein.

15 The movement of a tooling fixture and an associated ball grid array into juxtaposition is accomplished, illustratively, by moving the tooling fixture along a track arranged between the associated components. The movement along a track is provided by a solenoid activated when the components are in the optimum angular position for such movement and before the wheel rotates to a position where gravity acts to transfer the solder balls.

20 Figure 7 illustrates the "dropping" of the solder balls from the recesses in the tooling fixture to the corresponding recesses of the associated ball grid array. Note that the recesses in the ball grid array are relatively shallow to position the captured solder balls so that they protrude from the recesses as is the case with populated ball grid arrays.

25 In principle, apparatus, in accordance with the principles of this invention, employs gravity to transfer solder balls from a populated,

juxtaposed tooling fixture and includes a mechanism to space the tooling fixture and the associated ball grid array to permit movement of only the tooling fixture into a reservoir of solder balls for temporarily capturing the solder balls for transfer at a later time to the ball grid array when the components are repositioned for gravity to effectuate the transfer.

Figures 8 and 9 are front and end views of an implementation of the apparatus of figure 2.

The apparatus 80 of figure 8 is operative to rotate Ferris Wheel 81 illustratively counterclockwise about axis 82 in response to the energization of motor 84. As viewed in figure 8, the ball grid array strip 85 and the tooling fixture 86 move downward towards the solder ball reservoir. The tooling fixture and the ball grid array are spaced apart a distance to ensure that only the tooling fixture actually contacts the solder balls in the reservoir. As the tooling fixture moves through the reservoir, solder balls in the reservoir occupy the recesses with an excess of solder balls accumulating on the surface of the strip. Moreover, the solder balls which do occupy recesses are moved downwards in those recesses under the force of gravity to move to consistent and predictable positions within the recesses.

Figure 8 also shown a positioning arrangement 90 for positioning the tooling fixtures and the ball grid array on the outer and inner faces of the wheel. The arrangement includes a support 91 from which manipulating arms 92 and 93 are suspended. Manipulating arm 92 is operative to place the ball grid arrays in position and the manipulating arm 93 is operative to position the tooling fixture. Figure 8 also shows engagement mechanism 95 operative to move the tooling fixture and the associated ball grid array together once the tooling fixture has moved through the reservoir or bin of solder balls.

Figure 8 shows the tooling fixture and ball grid array in position at the reservoir at the bottom of the figure. Operation is counterclockwise having moved the tooling fixture and the ball grid array into the reservoir as indicated by curved arrow 98. When the components move further to a position indicated by axis 99, engagement mechanism 95 is activated to move the tooling fixture into juxtaposition with the ball grid array. The mechanism includes a clutch to retain the components in a position while they are moved upwards and to the left as viewed in figure 8.

Figure 9 shows an automatic solder ball or sphere loader 100. the solder ball loader is controlled by a controller 101 operative also under operator command to rotate the wheel, move the components into juxtaposition, and also fill the reservoir. Controller 101 is shown in figure 9 and comprises a process computer as is well understood in the art.

It should be apparent to those skilled in the art that more than one ball grid array strip may be populated in a continuous operation so long as the apparatus ensures that the solder balls remain in the recesses once they are in position in those recesses.

Although dimensions vary according to the intended use of the ball grid arrays populated in accordance with this invention, typically the outer diameter of a wheel is from twelve to fifteen inches and the inner diameter in one inch less. Such dimensions ensure that the ball grid array does not enter the reservoir of solder balls while the tooling fixture is being populated.

Further, it should be clear that more than one ball grid array or strip along with an associated tooling fixture can be positioned on the wheel for increasing the throughput of the apparatus. This is clear from figure 8 where

associated ball grid array and fixture are shown in two positions. Two different associated ball grid arrays and fixtures could be so positioned.

Figure 10 is a flow diagram of the method of operation of the apparatus of figure 2. The first block 120 of figure 10 indicates that the ball grid array and the tooling fixture are secured to the inner and the outer faces of the wheel of the apparatus with the recesses facing one another. The second block 121 indicates that the wheel is rotated through first and second positions at which the fixture is beneath the array and at which the array is beneath the fixture respectively. The third block 122 indicates that a reservoir of solder balls is located at the first position so that only the fixture enters the reservoir. Block 123 indicates that the spacing between the fixture and the array is reduced before the wheel moves to the second position at which gravity causes the solder balls to drop from the fixture into the recesses in the array. The array now is fully populated and can be removed at the position identified by the numeral 85 in figure 8.

Figure 11 shows a schematic side view of a work cell 210 in accordance with the second embodiment of this invention. The work cell includes a gantry 211 rotatable about on axis 213. The gantry includes a reservoir 215 to the top of which (as viewed in the figure) a tooling plate 216 and a backing plate 217 are secured.

A ball grid array 218 is spaced apart from but aligned with the tooling plate. The ball grid array is positioned on riser cylinder 219 operative like a solenoid to move the ball grid array into juxtaposition with the tooling plate controllably. The riser cylinder, the ball grid array, the tooling plate and the reservoir are all affixed to the gantry and rotatable through first, second and third stages of orientations as the gantry moves through about one hundred

and eighty to two hundred degrees of rotation.

5       The rotation of the gantry and the operation of the various components herein are described in connection with figures 12 through 22. The rotation initially is counterclockwise as indicated by arrows 220 in the figures. The solder balls, 221, can be seen to assume different profiles as the gantry rotates to a 45 degree orientation as shown in figure 12, and to a 90 degree, a 135 degree, a 180 degree to 200 degree orientation as shown in figures 13, 14, 15 and 16 respectively. The operation as shown in figures 11 through 16, spreads the solder balls in the reservoir across the tooling plate as shown in figures 15 and 16.

10       The direction of rotation now reverses as shown by arrows 220 in figures 17 through 21. Specifically, the gantry now moves clockwise collecting loose solder balls in the reservoir as the gantry moves to the 160 degree orientation as shown in figure 17. The populated tooling plate moves to an orientation where all loose solder balls have fallen free of the tooling plate as shown in figure 18.

15       The gantry now is entering a range of orientations where riser cylinder 219 is operative to move the ball grid array into juxtaposition with the tooling plate as shown in figure 19. Further rotation occurs, as shown in figure 20, where gravity begins to become operative. Figure 21 shows the gantry rotated into the range where gravity is operative to drop solder balls from the tooling plate to the awaiting (and aligned) ball grid array.

20       Figure 22 shows the rotation (or oscillation) cycle to be completed and the gantry is returned to the position shown for it in figure 11.

The operation depicted in figures 11 through 22 can be seen to be divided into several operations: The first is the solder ball spill operation to populate the tooling plate. This operation occurs during a first range of gantry orientations depicted in figures 11 through 16. The second operation is the movement of the ball grid array into close proximity to the now populated tooling plate. This operation occurs when the gantry is reoriented through a second range of orientations depicted in figures 17 through 20. The third operation occurs when the gantry is rotated through a third range of orientations depicted in figures 21 and 22 where gravity is operative to transfer the solder balls from the tooling plate to the ball grid array.

Figures 23 and 24 show schematic side and top views of apparatus for implementing the invention shown in figures 11 through 22. Figure 23 shows a gantry 313 rotatable about axis 314 via motor 315. First and second work cells 316 and 317 are secured to the gantry at the top and at the bottom as viewed in figure 23. Each of the work cells is as depicted in figures 11 through 22. In operating, the work cells are rotated, as described hereinbefore, along a circular path designated 319 in figure 24. The use of two work cells permits a doubling of the throughput of the apparatus, one of the work cells always being readied for ball placement while the solder balls are being transferred to the ball grid array in the other work cell.

Figure 25 shows a top view of work cell 316 of figure 23. The figure shows an array pattern of holes in the tooling plate receiving solder balls during the operation depicted in figures 11 through 22. Figure 26 shows the pattern enlarged. The tooling plate is designated 350 in figures 25 and 26 and the hole pattern is designated 351.

Figure 27 shows enlarged, the tooling plate 370 and backing plate 371.

The tooling plate has an array of solder ball pockets 373 for receiving the solder ball during the operation of figures 14 through 17.

Figure 28 shows enlarged the area of figure 24 encircled by broken line 380. The figure shows the tooling plate 381 and the backing plate 382 where the tooling plate has an array pattern as shown in figure 26. The tooling plate also has a number of alignment pins 383 shown also in figure 26.

The ball grid array is mounted on the riser cylinder as discussed hereinbefore. The ball grid array is designated 385 and is positioned in a nesting plate, in practice, for handling and alignment. The nesting plate mates with the riser cylinder mounting plate 386. The riser cylinder 387 moves the mounting plate and thus the ball grid array into juxtaposition with the tooling plate. Such juxtaposition is shown schematically in figure 19.

As is common practice with ball grid arrays, the arrays are coated with a flux which is an adhesive to retain the solder balls in place. The adhesive is coated onto ball grid array strips in a silk screening process prior to positioning the ball grid array in the work cell. One adhesive used in practice is, illustratively, a Chester Corporation - SP291 which is a resin based material with actuators which is heated to between 100 and 120 degrees Fahrenheit before application.

The apparatus may be any size so long as it accepts ball grid array strips and in the prototype stage had dimensions of about one by one and one half feet.

The operation is controlled by controller 390, as shown in figure 23, responsive to user input. Outputs of the controller are connected to inputs

to motor 315 and to riser cylinder 387 (219 of figure 11 through 22) for providing timing control and power from a power source 395. When first and second work cells are affixed to opposite ends of the gantry as shown in figure 23, the controller is operative to activate the riser cylinder in each work cell at the appropriate time in the third range of orientations for that work cell.

While embodiments of the invention have been described in detail it will be evident to those skilled in the art that the invention may be embodied otherwise without departing from its spirit.

**WHAT IS CLAIMED IS:**

1. Apparatus for placing solder balls in a ball grid array, said apparatus comprising a wheel rotatable about a horizontal axis, means for attaching a ball grid array to the inner face of said enclosure, means for attaching a tooling fixture to the outer face of said wheel in a position corresponding to that of said ball grid array, means for forming a reservoir of solder balls in the bottom of said wheel, means for controllably rotating said wheel to move said tooling fixture through said reservoir in a manner to fill recesses in said fixture with solder balls and to remove from the surface of said array any excess solder balls which are not occupying recesses, said inner and outer faces being separated a distance sufficient to permit said tooling fixture to engage solder balls in said reservoir while said ball grid array does not engage said solder balls.

2. Apparatus as in claim 1 wherein said means for attaching comprises means for attaching a ball grid array strip.

3. Apparatus as in claim 2 wherein said apparatus is cylindrical in geometry and is rotatable along the central axis of the cylinder.

4. Apparatus as in claim 2 wherein said means for attaching comprises means for attaching more than one ball grid array strip to said inner surface of said wheel at spaced apart positions on said surface.

5. A method for filling a ball grid array with solder balls, said method comprising the steps of placing a ball grid array on the inner face of a wheel rotatable about a horizontal axis, placing a tooling fixture in a corresponding



position on the outer face of said wheel, filling the bottom of said enclosure with a reservoir of solder balls, and rotating said wheel to move said wheel through said reservoir in a manner to avoid the movement of said ball grid array through said reservoir.

5           6. Apparatus for filling a ball grid array with solder balls, said apparatus comprising a reservoir for solder balls and means for moving a tooling fixture through said reservoir in a manner to populate recesses in said tooling fixture with said solder balls, said apparatus also including means for  
10           securing a ball grid array in a position corresponding to that of said tooling fixture, said ball grid array also including recesses therein, the recesses in said tooling fixture and in said ball grid array facing each other, said apparatus including means for dropping solder balls in recesses in said tooling fixture into corresponding recesses in said ball grid array under the force of gravity.

15           7. Apparatus as in claim 6 wherein said apparatus includes a wheel having an inner and an outer face, said fixture being attached to said outer face and said ball grid array being attached to said inner face, said means for moving comprising means for rotating said wheel.

20           8. Apparatus as in claim 7 wherein said wheel rotates through first and second positions at which said fixture is beneath said ball grid array and at which said ball grid array is beneath said fixture, said reservoir being located at said first position.

          9. Apparatus as in claim 8 also including means for moving said fixture and said ball grid array into juxtaposition before said second position is reached and after said first position is reached.

25           10. A method for filling the recesses in a ball grid array with solder



5 balls located in an array of recesses in a tooling fixture, said method comprising the steps of placing said ball grid array and said fixture in closely spaced apart positions, recesses facing, moving said array and said fixture about a circular path through first and second positions at which said fixture is beneath said array and at which said array is beneath said fixture, respectively, moving said array and said fixture into said first position such that only said fixture enters said reservoir, moving said array and said fixture to said second position at which gravity acts to transfer solder balls in recesses in said fixture into recesses in said array, and moving said array and said  
10 fixture into juxtaposition before said second position is reached.

11. Apparatus for filling a ball grid array, said apparatus comprising a reservoir for solder balls and a tooling plate with an array of holes for receiving solder balls, said apparatus including a gantry rotatable about an axis, said tooling plate and said reservoir being attached to said gantry and  
15 rotatable with the gantry about said axis, said reservoir being of a geometry to hold loose solder balls during said rotation and to spill said solder balls across said tooling plate during a first range of orientations of said gantry, said apparatus also including a fixture for securing a ball grid array to said gantry, said fixture being aligned with said tooling plate rotatable therewith, said  
20 fixture including a riser cylinder for moving said ball grid array into juxtaposition with said tooling plate during a second range of orientations of said gantry for later transfer of said solder balls from said tooling plate to said juxtaposed ball grid array when said gantry later moves through a third range of orientation.

25 12. A work cell for transferring solder balls from a reservoir of solder balls to a ball grid array, said work cell comprising a gantry rotatable about an axis, a solder ball reservoir said reservoir being adapted for holding loose



5 solder balls and also being affixed to said gantry and rotatable therewith through first, second, and third ranges of orientations of said gantry, said work cell also including a tooling plate also affixed to said gantry and rotatable therewith, said apparatus also including a ball grid array also affixed to said gantry, said ball grid array being spaced apart from and aligned with said tooling plate and rotatable with said gantry, said tooling plate and said reservoir being positioned for spreading solder balls from said reservoir onto said tooling plate during said first range of orientations, said apparatus also including a riser cylinder for moving said ball grid array into juxtaposition with  
10 said tooling plate during said second range of orientations, said ball grid array and said tooling plate bring positioned for gravity transfer of solder balls to said ball grid array during said third range of orientations of said gantry.

15 13. A method of filling a ball grid array with solder balls in a first work cell including a tooling plate, a ball grid array, a riser cylinder and reservoir, said method comprising the steps of aligning said ball grid array with said tooling plate, said tooling plate having an array of holes for receiving solder balls, rotating said ball grid array, said tooling plate and a reservoir of solder balls through a first range of orientations such that loose solder balls spread over said tooling plate for populating said array of holes  
20 therein, activating said riser cylinder for moving said ball grid array into juxtaposition with said tooling plate during a second range of orientations in which loose solder balls are recaptured in said reservoir and rotating said ball grid array and said tooling plate through a third range of orientations during which gravity is operative to transfer the solder balls to a like array of holes  
25 in said ball grid array.

14. Apparatus is in claim 11 wherein said reservoir has a geometry to contain said solder balls over about a 200 degree rotation of said gantry.



15. Apparatus as in claim 11 wherein said tooling plate is affixed to said reservoir in a position exposed to the movement of solder balls in said reservoir during said 200 degree rotating of said gantry.

5 16. Apparatus as in claim 15 including a controller for rotating said gantry from a reference orientation to between 185 degrees and 200 degrees in a first direction and back to said reference orientation.

17. Apparatus as in claim 16 wherein said controller is operative to activate said riser cylinder during said third range of orientations when said gantry is being rotating back to said reference position.

10 18. Apparatus as in claim 17 including first and second work cells affixed to said gantry, each of said work cells including a reservoir, a ball grid array and a tooling plate, said first and second work cell also including first and second riser cylinders respectively, said controller being operative to activate said first and second riser cylinders during a third range for each of  
15 said first and second work cells.

19. Apparatus as in claim 18 wherein said tooling plate for each of said work cells is nested into the bottom of the reservoir of the respective work cell.

20 20. Apparatus as in claim 19 wherein said reservoir of each of said work cell includes an aperture for receiving and positioning a tooling plate.

21. A method as in claim 13, said method including the steps of attaching said first work cell and a like second work cell to opposite ends of a gantry, rotating said gantry such that said first and second work cell reorient



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through first, second, and third ranges of orientations at different times, activating the riser cylinder of said first and second work cells during the associated and different second ranges for affecting gravity transfer of solder balls from each tooling plate to the associated ball grid array during the associated and different third range of orientations.