

INDIVIDUAL SELECTIVE REWORK OF DEFECTIVE BGA SOLDER BALLS

TECHNICAL FIELD

5 This invention relates generally to semiconductor device manufacturing. More particularly, the instant invention pertains to methods and apparatus for removal and replacement of individual, defective solder balls on an electronic component.

BACKGROUND

10 Integrated circuit semiconductor devices (IC's) are small electronic circuits formed on the surface of a wafer or other substrate of semiconductor material such as silicon, gallium arsenide or indium phosphide. The IC devices are fabricated simultaneously in large numbers in wafer form in an array over the active surface of the wafer and tested by a probe to determine electronic characteristics applicable to the
15 intended use of the IC's. The wafer is then subdivided or "singulated" into discrete IC chips or dice, and then further tested, assembled with other components and packaged for customer use through various well-known individual die IC testing and packaging techniques, including lead frame packaging (conventional and leads over chip, or LOC), Chip-On-Board (COB) packaging, and flip-chip packaging. Depending upon the
20 relative die and wafer sizes, each wafer is singulated into at least a few dozen dice, as many as several hundred dice or even as many as several thousand discrete dice when large (such as 30 cm) wafers are employed.

 Mechanical and electrical interconnection of discrete semiconductor dice with a carrier substrate such as a printed circuit board (PCB) is often accomplished with an
25 array of solder balls or bumps projecting from the active surface of the semiconductor die, these external interconnection elements usually having a spherical or near-spherical shape, although other shapes are known. Such a package comprises the aforementioned flip-chip package, so called because the semiconductor die, or chip, is mounted active surface down over the carrier substrate, supported by the solder balls or bumps. State
30 of the art flip-chip packages may comprise so called "chip scale" packages, wherein the lateral footprint of the package is the same as, or minimally large than, the lateral dimension of the semiconductor die itself.

Several methods for forming solder balls or bumps on a workpiece are well-known. In the early art, a preformed solder ball was manually placed on a semiconductor die using a forceps or pincer. In later developments, pre-formed balls have been deposited on bond pads on a semiconductor substrate using a single-ball mounting head or full ball grid array (BGA) mounting head, using vacuum to retain the ball(s) on the head prior to placement on the workpiece. Flux is applied either to the pads or the balls prior to ball placement.

Mounting heads configured to simultaneously apply all balls of a BGA for a semiconductor die are preferred because of savings in labor costs. In the current state of the art, ball grid arrays may even be formed on all of the dice of a full wafer prior to semiconductor die singulation therefrom. Thus, upwards of 10,000 balls may be placed on a wafer prior to the singulation process.

Currently, solder balls may be formed on a workpiece by processes of evaporation, electroplating, stencil printing and serial methods. Each of these processes has particular limitations.

In one version, the solder balls are temporarily fastened to the bond pads of a die by heating to a softening temperature and/or by compression during application. The die with the array of balls placed thereon is then subjected to a thermal "reflow" step to return the balls to substantially spherical shape and then cooled to harden the balls.

In another version, a solder paste preform of any shape may be placed on a metallized bond pad and melted to form a globular or "ball" shape fixedly attached to the bond pad. The ball shape is affected by surface tension of the solder and solder-wettable bond pad or cup-shaped receptacle on the semiconductor die. Alternately, other non-solder wettable passivation materials surrounding a bond pad or receptacle may be utilized to assist in preventing undue solder spread or collapse into adjacent balls (resulting in short-circuits) or damage to the die surface surrounding the balls.

Numerous problems may occur in forming a BGA of a large number of balls on a semiconductor die, wafer or other workpiece, and in the subsequent attachment of the BGA to a carrier substrate. The following discussion pertains to merely a few of such problems.

Where a perforated multiple ball vacuum pickup head is used to simultaneously place all of the BGA's solder balls on a workpiece, a common complaint is that one or

more ball-retaining holes is not filled, resulting in workpiece bond pads or other terminal areas devoid of solder balls. In U.S. Patent No. 4,871,110 of Fukasawa et al., a proposed solution is to provide a second perforated plate above the pickup head to retain the balls therein while sweeping extra balls across the surface to ensure that all
5 holes are filled.

U.S. Patent No. 5,284,287 of Wilson et al. denotes two problems, comprising non-pickup of solder balls by a multi-ball pickup tool, and loss of solder balls while contacting them with flux in a flux bath. In the reference, solder balls are only partially submerged in the flux, and never touch the bottom of the flux bath.

10 U.S. Patent No. 5,467,913 of Namekawa et al. discloses a solder ball attachment apparatus in which flux is separately applied to each pad on the semiconductor substrate prior to attaching the solder balls.

U.S. Patent No. 5,680,984 of Sakemi is directed to a solder ball attachment method using a multi-ball head. The solder balls on the head are dipped in flux prior to
15 placement and reflow. The reference notes that when a solder ball is lost in the flux bath, it is recovered in a groove by wiping with a squeegee. No mention is made of what is done to correct the pickup head having an incomplete array of solder balls.

Single-ball pickup heads are known in the art for the purpose of placing solder balls on conductive pads of a workpiece. An example of such is described in U.S.
20 Patent No. 5,506,385 of Murakami et al. in which vacuum is used to hold a solder ball on a tubular pickup head. While sometimes useful where the number of solder balls on the workpiece is few, its use in forming multi-ball BGA's is contraindicated, being generally very slow, labor-intensive, and expensive. In the Murakami et al. reference, the apparatus uses a spring-biased head which holds a single solder ball, picked up from
25 one of a series of containers holding balls of differing sizes. Flux is applied to each pad, followed by application of a solder ball and thermal reflow resulting from a laser beam focused on the ball.

U.S. Patent No. 5,695,667 of Eguchi et al. describes an apparatus for forming a BGA of solder balls on a workpiece. A first multi-ball pickup head is utilized to apply
30 the majority of balls to the workpiece. A camera is used to detect empty pads (i.e. having balls missing therefrom). A second, single-ball pickup head is used to fill in empty spaces, and the workpiece is heated in a furnace to reflow all of the solder balls.

Solder balls installed on the workpiece may be defective in various ways. For example, a ball may be undersize (and thus not be adequately connected to both a die and the carrier substrate during bonding), or the ball may be oversize (and prevent other, adjacent balls from being adequately bonded to the carrier substrate, or spread to contact an adjacent ball). The solder ball may also be irregular in shape, resulting in defective bonding. In addition, a solder ball may contain a surface inclusion which prevents or inhibits proper reflow. A solder ball may also be misaligned with its pad, resulting in defective contact therewith. In the current state of the art, such defects are simply dealt with by removing all of the solder balls on a given workpiece and starting over. The "repair" is thus very time-consuming, material-consuming and expensive. None of the above-indicated references appear to recognize or address such problems.

The current emphasis on increased miniaturization and sophistication of integrated circuits (IC's) has resulted in a continuing reduction in device dimensions, ball diameter and ball spacing (pitch), and increasing numbers of balls in a BGA. As the ball size is decreased, the relative non-uniformity in ball dimensions has been observed to increase. Likewise, as pitch becomes finer a much greater precision in ball placement is required, inasmuch as lateral ball-to-ball contact must be avoided. The increased numbers of balls required to be transferred to each semiconductor die enhances the opportunity for missed solder balls, extra solder balls, and solder balls outside of the acceptable ranges of size or shape. Thus, the problems indicated hereinabove are exacerbated by the ongoing commercial race to further miniaturize and densify semiconductor devices and the like.

The BGA format has been used with discrete conductive elements other than solder balls, such as conductive epoxy bumps, conductor-filled epoxy bumps and the like, each of which presents its own set of problems. However, solder balls such as are formed of tin/lead alloy compositions remain the most widely used conductive elements in BGA constructions. This is primarily because solder is relatively inexpensive and the technologies for ball formation and placement are well developed.

The use of flip-chip technology with solder balls has numerous advantages for interconnection, as compared to conventional leadframe type packages. Flip-chip provides improved electrical performance for high frequency applications such as mainframes and computer workstations. In addition, easier thermal management and

reduced susceptibility to electromagnetic interference (EMI) and radiofrequency interference (RFI) emissions are inherent. Furthermore, small solder balls may be densely packed in a BGA array within the footprint of a semiconductor die, which approach conserves surface area ("real estate") on a carrier substrate and permits a
5 greater number of dice to be placed on a substrate while providing a number of I/O's for each die well in excess of that achievable using lead frames.

Various automation systems have been developed for accurate aligning and joining the solder balls of an installed BGA to the contact sites of a substrate. For example, U.S. Patent No. 4,899,921 of Bendat et al. discloses a slender optical probe
10 which is inserted between a semiconductor die and a substrate to be joined. Superimposed video images of the die and the substrate permit the two members to be accurately aligned while they are narrowly separated. The probe is retracted and the two members brought together and joined.

In another system, disclosed in U.S. Patent No. 5,894,218 of Farnworth et al., an
15 apparatus for aligning and positioning a die on a temporary test package utilizes video representations of the die surface and the test package to which the die is to be joined.

DISCLOSURE OF INVENTION

The present invention provides a method and apparatus for fabricating a reliable
20 interconnect assembly comprising a BGA on a semiconductor die, larger semiconductor substrate, carrier substrate or other electronic component workpiece.

More specifically, the present invention provides a method for extracting and disposing of single defective solder balls placed on or attached to attachment sites (e.g. pad or receptacle) of a BGA on a semiconductor die, larger semiconductor substrate,
25 carrier substrate or other electronic component workpiece.

In this discussion, the term "defective ball" refers to a solder ball which has a high probability of causing difficulties in bonding to a carrier substrate, testing and subsequent use. Thus, a defective solder ball includes one which is outside of the acceptable limits of size, shape, composition, surface finish and included contaminants,
30 is inaccurately placed or misjoined to the attachment site on the workpiece.

The present invention also provides a method for accurately placing a non-defective solder ball on an attachment site vacated by a previously extracted, defective solder ball.

5 The method of the invention is applicable to any BGA irrespective of the type of workpiece and the specific method by which the solder balls were previously attached to the workpiece. In addition, the method is generally applicable to thermally softened solder balls of any size, shape, or composition useful in the semiconductor art.

10 In a method of the invention, a single-ball extractor/placer apparatus with a corrosion resistant capillary tube, heater, and optional vacuum source may be used. A BGA formed on a workpiece is first scanned or otherwise tested to detect and identify the position of any defective solder balls. A capillary tube of the extractor/placer apparatus is then positioned over the defective solder ball and lowered to contact the solder ball and apply heat to soften or melt the solder ball. In one embodiment, capillary action alone may be employed to remove a completely melted solder ball from
15 the workpiece. Optionally, vacuum suction may be applied to the solder ball through the capillary tube and, as heat is applied to soften or melt the ball, assist in releasing it from the attachment site. In either instance, the capillary tube with either the melted ball material therein or a softened defective ball held thereon is then lifted and moved to a location where the ball material or ball is released, such as into a waste solder
20 container.

The single-ball vacuum extractor/placer apparatus may then be used to affix a non-defective replacement solder ball to the vacated attachment site. A fresh, non-defective solder ball is picked up by the capillary tube using a vacuum drawn therethrough. Flux is applied to the vacated site or to the solder ball held by the
25 capillary tube, and the capillary tube lowered to place the ball in the desired site. Heat may be applied by the heater to temporarily or permanently (through reflow) bond the replacement solder ball to the workpiece. Alternatively, the reflow step may be accomplished in a furnace. The result is a workpiece in which defective solder balls are quickly and inexpensively replaced without wasting a large number of non-defective
30 balls, and without reprocessing the entire workpiece.

An extractor/placer apparatus may be operated manually, or may include various degrees of automation in the steps of identifying defective balls as well as extracting and replacing solder balls identified as being defective.

Exemplary apparatus for performing the identification, extraction and placement steps as disclosed herein are also contemplated as within the scope of the present invention, without limiting the present invention to the examples described.

BRIEF DESCRIPTION OF DRAWINGS

The following drawings illustrate various features of the invention, wherein:

FIG. 1 is a schematic isometric view of exemplary apparatus for extracting and replacing a defective solder ball from a ball-grid-array in accordance with a method of the invention;

FIG. 2 is a top view of a workpiece holder with a semiconductor die having a BGA thereon including defective solder balls to be extracted and replaced in accordance with a method of the invention;

FIG. 3 is a cross-sectional side view of a workpiece holder with a semiconductor die having a BGA thereon including defective solder balls to be extracted and replaced in accordance with a method of the invention, as taken along line 3-3 of FIG. 2;

FIG. 4 is a partially sectioned, partially cutaway side view of a ball pickup tool following extraction of a defective solder ball from a BGA on a workpiece, in accordance with the method of the invention;

FIGS. 5 through 16 are schematic side views of a capillary tube illustrating the steps relating to the extraction and replacement of a solder ball in a BGA in accordance with a method of the invention, wherein:

FIG. 5 illustrates the approach of a capillary tube to a defective solder ball;

FIG. 6 illustrates the seating of a defective solder ball on a capillary tube;

FIG. 7 illustrates the softening and extraction of a defective solder ball by a capillary tube;

FIG. 8 illustrates the disposal of a defective solder ball;

FIG. 9 illustrates the attraction of a non-defective solder ball in a ball reservoir by a capillary tube;

FIG. 10 illustrates the removal of a non-defective solder ball from a ball reservoir by a capillary tube;

FIG. 11 illustrates the insertion of a non-defective solder ball into a flux reservoir;

5 FIG. 12 illustrates the removal of a non-defective solder ball with attached flux from a flux reservoir;

FIG. 13 illustrates the alignment of a fluxed solder ball with a vacated attachment site of a BGA;

10 FIG. 14 illustrates the contact of a fluxed non-defective solder ball with a vacated attachment site of a BGA;

FIG. 15 illustrates the thermal reflow of a fluxed non-defective solder ball with a vacated attachment site of a BGA;

FIG. 16 illustrates the retraction of a capillary tube from the reworked attachment site of a BGA;

15 FIG. 17 is a schematic isometric view of exemplary automated apparatus for extracting and replacing a defective solder ball from a ball-grid-array in accordance with a method of the invention; and

FIG. 18 is a schematic chart characterizing control routes between a computer controller and optical devices, positioners, switches and video output of an apparatus
20 useful for extracting, removing and replacing a solder ball in accordance with a method of the invention.

BEST MODES FOR CARRYING OUT THE INVENTION

The invention comprises an improved method and apparatus for reworking a
25 BGA including one or more defective solder balls mounted on conductive sites on a surface of a workpiece. The workpiece may be, for example, a semiconductor die or a carrier substrate bearing circuit traces such as a printed circuit board (PCB). Usually, only a small fraction of semiconductor devices employing BGA's have defective solder balls, and very few devices have more than a few defective balls. The method of this
30 invention permits easy extraction and replacement of only the defective balls, without removal of or adverse effects on the good (non-defective) solder balls.

More specifically, the invention pertains to a method for identifying, extracting and replacing a defective solder ball(s) of a BGA on a workpiece. A defective solder ball is broadly defined as a solder ball which, unless corrected, will probably impair an operable, robust connection through that solder ball to a conductive site when the BGA
5 of the workpiece (semiconductor die or other substrate) is bonded, flip-chip style, to a corresponding pattern of conductive sites on a carrier substrate. Unless removed and replaced with a non-defective solder ball, the defective solder ball may result in short-circuiting, open-circuiting or other problems, rendering useless the assembly of the die and the carrier substrate as well other dice connected to the carrier substrate, such as in
10 the case of a multi-chip module. The current practice of removing all of the solder balls of a BGA when only one or a few are defective, cleaning the workpiece, and then replacing all of the solder balls is time consuming, expensive, and wasteful of materials.

In the method of the invention, each defective solder ball is individually identified, extracted from the workpiece, disposed of, and replaced by a fresh solder
15 ball.

The method of the invention preferably utilizes an apparatus which will be denoted herein as an extractor/placer apparatus 10.

As depicted in FIGS. 1, 2, 3 and 4, an exemplary manually operated solder ball extractor/placer apparatus 10 includes a base 12 and a workpiece holder 30 such as a
20 "precisor" for retaining a workpiece 40 during extraction of one or more defective solder balls 50A, 50B, 50C, etc. and replacement with good or non-defective solder balls 50. The workpiece holder 30 is shown as being attached to positioner 22 through precisor arm 64. Positioner 22 controls the movement of the workpiece holder in X-axis 14 and Y-axis 16. Positioner 22 includes Y-axis positioner 26 mounted on
25 base 12, and X-axis positioner 24 mounted on the Y-axis positioner. The X-axis positioner 24 is moved by rotation of actuator knob 34, and the Y-axis positioner is moved by rotation of actuator knob 36 for alignment of a ball attachment site 62 (see FIGS. 2 and 3) on a workpiece 40 with vertical axis 32 through a pickup head 20, described below. In FIGS. 2 and 3, a workpiece 40, typically a semiconductor device
30 such as a chip scale package, is mounted on a workpiece holder 30. An arrangement or pattern comprising a BGA 70 of solder balls 50 is shown attached to attachment sites 62 on the active surface 72 of the workpiece. Typically, the solder balls 50 are

installed simultaneously with a multi-ball tool. The BGA 70 is depicted for exemplary purposes as having three defective solder balls respectively identified by the numeral 50A, 50B and 50C. Ball 50A represents an undersized ball, which will not make a connection during bonding of the BGA 70 to the bonding sites of a substrate.

- 5 Solder ball 50B represents an unacceptably large or oversized ball, whose height may prevent adjacent solder balls 50 from bonding with the substrate. Solder ball 50C represents a ball which is out of alignment with the attachment site 62C, and has run onto the active surface. During bonding with a substrate, solder ball 50C may become undesirably electrically connected to an adjacent solder ball 50, or it may not make
10 acceptable contact with the carrier substrate.

- As indicated above, and as shown in FIGS. 1 and 4, the extractor/placer apparatus 10 also includes a ball pickup tool or contact head 20, which is attached through tool arm 28 to Z-axis positioner 68. The ball pickup head 20 is controllably movable along vertical Z-axis 18 by rotation of actuator knob 38, and may optionally be
15 controllable in a rotational direction 48 about Z-axis 18. The pickup head 20 includes a hollow capillary tube 42 having an inside diameter 43 which is less than any ball diameter to be encountered, enabling a solder ball 50 to be retained at the lower end 44 of the capillary tube 42. The lower end 44 is configured as a seat for supporting a solder ball or other solder preform 50 by suction force from a vacuum or negative
20 pressure source 46. The capillary tube 42 is preferably formed of a corrosion resistant material such as a stainless steel.

- Also shown in FIG. 1 is a microscope 60 which is useful for inspecting a BGA on workpiece 40 to visually detect defective solder balls 50, for aligning the capillary tube 42 to a defective solder ball 50A, B or C or to a vacant attachment site 62, and for
25 determining the proximity of capillary tube 42 to a solder ball 50. The microscope 60 may include an integral camera 61, not separately visible, and a closed circuit television display (CCTD) with memory (see FIG. 4) for use in inspecting the workpiece 40 to identify and retain the locations of defective solder balls 50A, 50B, 50C, etc. and to permit accurate positioning of the capillary tube 42 relative to any defective solder
30 ball 50 and an attachment site 62. In one embodiment, the microscope 60 may be focused through the capillary tube 42 to align a defective ball with the capillary tube axis 32 and determine proximity of a ball 50 on workpiece 40 to the capillary tube 42.

As shown in FIG. 1, the exemplary extractor/placer apparatus 10 may also include a ball reservoir 80 for supplying a fresh solder ball 50 to the capillary tube 42, a flux reservoir 82 into which a fresh solder ball 50 may be dipped, and a defective ball receptacle 74 for receiving defective solder balls extracted by the capillary tube. As shown, each of the ball reservoir 80, flux reservoir 82 and receptacle 74 may be movable to be more easily accessed by the capillary tube 42. Different apparatus may be used for these purposes, as known in the art.

The exemplary single ball pickup or contact head 20 illustrated in FIG. 4 comprises a body 54 attached to tool arm 28. A hollow capillary tube 42 is attached to body 54, and may be interchangeable with capillary tubes of different sizes for use with different sizes of solder balls 50. The interior 58 of the capillary tube 42 has a diameter 43, and communicates with internal chamber 56, fitting 85 and thereby to conduit 86 leading to vacuum source 46 (see FIG. 1). The lower end 44 of the capillary tube 42 may be configured as a partially spherical seat to more securely hold a solder ball 50 under vacuum. As noted above, a solder ball 50 may be melted by contact with capillary tube 42, and the molten solder material drawn by capillary action alone or with vacuum assist into the interior or bore 58, to be subsequently expelled therefrom as waste material. Alternatively, a gentle vacuum may be applied through capillary tube 42 so that a softened or partially melted solder ball 50A, 50B, or 50C will be held at the end 44 of the capillary tube 42, but molten solder in or on the ball will not generally be sucked through the capillary tube. The capillary tube 42 is formed of a corrosion resistant, highly heat conductive material such as stainless steel. A particulate filter 87 in filter housing 84 is positioned to intercept bits of solder, flux, solder paste, dust, etc. which may be sucked into the capillary tube 42 when vacuum source 46 is placed into communication therewith.

A precision ground, clear glass window 52 provides access for a vertical microscope view into the chamber 56 and through the capillary tube 42 to a solder ball 50 or attachment site 62 below the tube end 44 and along capillary tube axis 32. Microscope 60 preferably includes an integral, focused light source 78 as known in the art, light source 78 being to illuminate workpiece 40, preferably through clear glass window 52 and aligned capillary tube 52 or, optionally, through optical fibers 53 (shown in broken lines) extending from window 52 to locations adjacent capillary

tube 42 and focused adjacent the end 44 thereof. Another approach is to illuminate workpiece 40 using a light source 55 (shown in broken lines) carried by tool arm 28.

Tool arm 28 and attached slider bar 67 are vertically movable relative to Z-axis positioner 68. In addition, tool arm 28 is configured to be spring-biased so that when
5 the capillary tube 42 is lowered onto a solder ball 50, the low resistance to compression of the spring will be absorbed to prevent the ball from being unacceptably deformed. The spring biasing apparatus may be of any workable design, but is shown by way of example as a biasing spring 69 mounted between the tool arm 28 and a slider bar 67 such that upward forces on the capillary tube 42 will be absorbed and cushioned.

10 As illustrated in FIG. 4, a heater 90 surrounds a portion of capillary tube 42 to heat the latter to a temperature which will sufficiently soften, e.g. melt or reflow, a solder ball 50. The heater 90 is shown as having electric resistance elements 91 and power cords 88 leading to a controllable power supply and/or temperature display output, not shown in FIG. 4.

15 In an alternative method of heating a solder ball to soften, reflow or melt it, a laser device (not shown) may be oriented to direct a laser beam along axis 32 through the interior 58 of the capillary tube 42, to project on a solder ball 50 at the end 44 of the capillary tube 42.

In FIG. 4, an example of a workpiece 40 is shown with an array of solder ball 50
20 mounted on attachment sites 62. The workpiece 40 is mounted on workpiece holder 30. A capillary tube 42 is depicted having extracted and lifted a defective solder ball 50C from an attachment site 62C.

FIGS. 5 through 16 illustrate exemplary steps used to perform the extraction and replacement of a defective solder ball 50A in a BGA of a workpiece 40. FIGS. 5
25 through 16 presume that a defective solder ball 50A is not reduced to a completely molten state and drawn into capillary tube 42. However, if a defective solder ball 50A is completely melted and drawn into bore 58 of capillary tube 42 either by capillary action or application of a vacuum, the steps illustrated by FIGS. 7 and 8 are modified only in that the molten solder material is drawn into capillary tube 42 in FIG. 7 and then
30 expelled therefrom into a defective ball receptacle 74 under positive air pressure while still in a molten state. The steps illustrated by FIGS. 5, 6 and 9 through 16 remain the same.

In FIG. 5, a particular solder ball 50A has been identified as being undersized. The central axis 32 of a capillary tube 42 of a ball pickup head 20 is aligned with the ball 50A. With the vacuum on, the capillary tube 42 is lowered to place the capillary tube end 44 on the defective ball 50A, where the ball is attracted to the capillary tube end 44. The heater 90 (see FIG. 4) is activated to soften (e.g. melt) and detach the defective ball 50A from attachment site 62A, as shown in FIG. 6. In one embodiment, a slight upward biasing force may be applied to the capillary tube 42 away from the attachment site 62A to facilitate release of a heat-softened solder ball 50A from the attachment site 62A, the capillary tube 42 and vacuum-held softened solder ball 50A then retracting slightly from attachment site 62A. Such a retraction mechanism may be in the form of a spring-loaded solenoid of which capillary tube 42 forms a part, the solenoid being powered to overcome the retractive force of the spring until retraction of a solder ball 50A is desired. Alternatively, a spring may be used to extend the capillary tube 42 until it is desired to retract same, when the solenoid is powered.

FIG. 7 depicts the defective solder ball 50A being lifted and transported to a disposal site, such as defective ball receptacle 74, shown in FIG. 8. The defective solder ball 50A is discarded by interrupting the vacuum provided to capillary tube 42. Another option, not shown, is to reverse the pressure in capillary tube 42 and use a brief puff of air from a positive pressure source to dislodge the solder ball 50A.

A non-defective (i.e. "good") solder ball 50 is then attracted by vacuum in the capillary tube 42 from a solder ball reservoir 80 (FIG. 9) and picked up from the reservoir (FIG. 10).

As depicted in FIG. 11, the capillary tube 42 then submerses a portion of the carried good solder ball 50 into flux 83 within a flux reservoir 82. When the good solder ball 50 is lifted from the flux reservoir 82 (FIG. 12), a coating of flux 83 (exaggerated for clarity) will cover a portion of the good solder ball 50, enabling effective attachment of the good solder ball 50 to a vacated attachment site 62A. Alternatively, flux may be placed on the vacated attachment site 62A prior to placement of good solder ball 50 thereon.

The fluxed, good solder ball 50 is then aligned and positioned directly over the vacated attachment site 62A, as shown in FIG. 13. The capillary tube 42 is then lowered to place the good, fluxed solder ball 50 on the attachment site 62A (FIG. 14)

without placing undue compressive force on the good, fluxed solder ball 50. The biasing spring 69 serves to limit any force on the good solder ball 50 due to inadvertent overrun of the capillary tube end 44. The capillary tube 42 is heated to soften, or optionally reflow or completely melt the solder ball 50, joining it to the attachment
5 site 62A (FIG. 15), and the capillary tube 42 is retracted to seek another defective solder ball 50 (for example, oversized solder ball 50B) or for use with another workpiece 40.

The process of locating, extracting and replacing defective solder balls 50A, 50B, 50C, etc. on a workpiece 40 may be automated to effectively accelerate the process. Various steps of the method may be automated, and an example of such
10 method and apparatus follows.

As shown in FIG. 17, an extractor/placer apparatus 10A includes features of the apparatus 10 depicted in FIG. 1 and described with respect thereto, with certain additional automated features. The various components of the apparatus 10A are controlled by a computer control board 92 including at least one microprocessor, in
15 conjunction with appropriate programs and data in associated memory storage 94. A video display 98 provides an enlarged visual output which enables easy detection of defective solder balls 50A, 50B, 50C, etc., and precise alignment of the capillary tube 42 of the ball pickup head 20.

FIG. 18 schematically depicts the control lines 110 linking the control board 92,
20 memory 94, keyboard 96, video 98 and the various controlled components of apparatus 10A.

A workpiece 40 is mounted in a workpiece carrier or holder 30. The holder 30 is mounted on a workpiece positioner 22 comprising an X-axis positioner 24 and a Y-axis positioner 26, both of which are controlled by integral electric drive assemblies,
25 which may comprise, for example, linear steppers or fine-pitch screw drives. The positioner 22 is controlled by a program stored in memory in the control board 92 and/or in memory storage 94.

A microscope 60 with an associated camera 100 is positionally controlled from control board 92. Although defective solder balls may have been found in a previous
30 inspection operation, the microscope 60 may be manually used with eyepieces 76 to verify solder ball faults. However, a video display 98 of the output of camera 100 makes the task much easier. Automated analysis using conventional "machine vision"

methods may be employed in a comparison of real-time video or still photographs of the active surface of workpiece 40 with a stored digital image of a model BGA 70 to detect unacceptable variations in size and placement of solder balls 50. Digital imaging may also be employed to rapidly compare individual solder balls 50 of workpiece 40 with design specifications, or for coincidence with visually perceptible defects, images of which are stored in memory storage 94. An auxiliary camera 100A may be positioned to view the workpiece 40 from an oblique angle 114, i.e. along sloping line 112. Combining the views from both cameras may enable more accurate determination of defective solder balls 50A, 50B, 50C, etc. Of course, more than one auxiliary camera may be employed, to enable multiple perspective views. Microscope 60 with camera 100 is shown as laterally extendable in direction 104 and horizontally rotatable in direction 106 about a vertical axis. In addition, the microscope/camera combination may be rotated about a horizontal axis as shown by arrow 108. It may be noted that in a fully automated system, a camera without visual microscope capability may be employed as desired.

A self-contained machine vision system available from a commercial vendor of such equipment may be employed. For example, and without limitation, such systems are available from Cognex Corporation of Natick, Massachusetts. For example, the apparatus of the Cognex BGA Inspection Package™ or the SMD Placement Guidance Package™ may be adapted to the present invention, although it is believed that the MVS-8000™ product family and the Checkpoint® product line, the latter employed in combination with Cognex PatMax™ software, may be especially suitable for use in the present invention.

It is noted that a variety of machine vision systems are in existence, examples of which and their various structures and uses are described, without limitation, in U.S. Patents 4,526,646; 4,543,659; 4,736,437; 4,899,921; 5,059,559; 5,113,565; 5,145,099; 5,238,174; 5,463,227; 5,288,698; 5,471,310; 5,506,684; 5,516,023; 5,516,026; and 5,644,245. The disclosure of each of the immediately foregoing patents is hereby incorporated by this reference.

Vertical movement of the single-ball pickup head 20 through Z-axis positioner is controlled from the control board 92. The Z-axis positioner may also be controllably rotatable about a vertical axis as shown in FIG. 1. The capillary tube heater 90 is

controllable (ON/OFF) from the control board 92, as is an ON/OFF valve 102 controlling vacuum from a vacuum source 46. In addition, movements of the defective ball receptacle 74, ball reservoir 80 and flux reservoir 82 are all controllable from the control board 92. Thus, precise positioning of the capillary tube's end 44 above any of
5 a defective ball 50A, 50B, 50C, an attachment site 62, a defective ball receptacle 74, a good ball reservoir 80, and a flux reservoir 82 is achieved.

The method of the invention may be used simply to remove solder balls from a BGA for any purpose, whether the ball is defective or good but mislocated or extraneous.

10 It should be noted that various terms are used herein in their broad sense. For example, the term "flux" refers to any substance used in conjunction with a solder ball at the time it is reflowed. The term "solder ball" includes not only preformed balls of solder, but also solder paste pellets or other preforms used to replace a defective solder ball 50.

15 Use of this method results in rapid and accurate rework of a BGA 70 having defective solder balls 50A, 50B, 50C, etc. The inventive method also avoids the wastage of a large number of good solder balls 50 which occurs when an entire BGA is removed. It avoids excess use of flux from repeated attachment of the solder balls of an entire BGA. The method also avoids repeated heating of the workpiece to reflow an
20 entire BGA for removal and then again for ball replacement, which operations may, if the heat budget for a device is exceeded, result in irreparable damage.

The methods /and apparatus described herein present many advantages in reworking a BGA workpiece, including higher reliability, lower cost, reduced ball wastage, etc. As used herein, the term "BGA" means and includes any array or pattern
25 comprising a plurality of solder balls on an electronic component workpiece, and is not limited to an array comprising rows and columns of balls, or any other specific pattern.

The embodiments of the invention as described herein are intended to be illustrative and not restrictive, and the scope of the invention is defined by the appended claims rather than the preceding description. Those of ordinary skill in the art will
30 recognize and appreciate that additions, deletions and modifications to the disclosed embodiments, and combinations of features from different embodiments, are possible and easily effected without departing from the scope of the invention. All variations

that fall within the metes and bounds of the subject matter claimed, or which are equivalent thereto, are therefore intended to be embraced by the following claims.

CLAIMS

What is claimed is:

1. A method for correcting a defective ball grid array on an electronic component workpiece, the method comprising:
 - 5 identifying at least one defective solder ball associated with a corresponding attachment site of a ball grid array on a workpiece; and
 - extracting the at least one defective solder ball with a capillary tube to vacate the corresponding attachment site and replacing the at least one defective solder ball with a non-defective solder ball placed on the vacated corresponding attachment site with the capillary tube while maintaining other solder balls of
 - 10 the ball grid array in undisturbed arrayed attachment to the workpiece.
2. The method of claim 1, wherein identifying at least one defective solder ball and extracting the at least one defective solder ball comprises identifying and
- 15 extracting a plurality of defective solder balls, and further comprising extracting and replacing each defective solder ball of the plurality of defective solder balls while maintaining other solder balls of the ball grid array in undisturbed arrayed attachment to the workpiece.
- 20 3. The method of claim 1, wherein the at least one defective solder ball is extracted by individually heating the at least one defective solder ball to effectuate release thereof from the corresponding attachment site and lifting the at least one defective solder ball from the corresponding attachment site using a vacuum drawn through the capillary tube.
- 25 4. The method of claim 1, wherein extracting the at least one defective solder ball further comprises individually heating the at least one defective solder ball to a molten state and removing molten solder from the corresponding attachment site into the capillary tube by capillary action.
- 30 5. The method of claim 4, further comprising assisting the capillary action by application of a vacuum.

6. The method of claim 1, further comprising lifting the non-defective solder ball with the capillary tube, positioning the non-defective solder ball on the vacated corresponding attachment site and heating the non-defective solder ball at least to a temperature to cause the non-defective solder ball to bond to the corresponding attachment site.

7. The method of claim 6, further comprising lifting the non-defective solder ball using a vacuum provided through the capillary tube, and heating the non-defective solder ball through the capillary tube.

8. The method of claim 6, further comprising applying flux to the non-defective solder ball prior to the positioning thereof on the vacated corresponding attachment site.

9. The method of claim 6, further comprising applying flux to the vacated corresponding attachment site prior to positioning of the non-defective solder ball thereon.

10. A method for removing and replacing a solder ball from an attachment site of a ball grid array on an electronic component workpiece, the method comprising:
vertically aligning a capillary tube with a solder ball of a ball grid array on an electronic component workpiece;
lowering the capillary tube to contact the solder ball from above;
heating the solder ball with heat conducted from a heat source through the capillary tube to facilitate removal of the solder ball from an attachment site of the electronic component workpiece;
retracting the capillary tube to extract the solder ball from the attachment site;
retrieving a replacement solder ball from a source of replacement solder balls using the capillary tube;
aligning the capillary tube over the attachment site;
lowering the capillary tube to place the replacement solder ball in contact with the attachment site;

heating the replacement solder ball through the capillary tube at least sufficiently to cause the replacement solder ball to bond to the attachment site; and retracting the capillary tube and releasing the replacement solder ball.

5 11. The method of claim 10, further comprising heating the solder ball sufficiently to reduce the solder thereof to a molten state, and drawing the solder in a molten state into the capillary tube.

10 12. The method of claim 11, further comprising drawing a vacuum through the capillary tube to facilitate drawing the solder in a molten state thereinto.

13. The method of claim 10, further comprising heating the solder ball sufficiently to release a bond thereof to the attachment site.

15 14. The method of claim 13, further comprising drawing a vacuum through the capillary tube to retain the solder ball at an end of the capillary tube during the retraction thereof.

20 15. The method of claim 10, wherein removal of the solder ball comprises removal of a defective solder ball.

16. A method for extracting and removing at least one defective solder ball from an attachment site in a ball grid array of an electronic component workpiece, comprising:
25 placing the electronic component workpiece on a support;
viewing the ball grid array of the electronic component workpiece under magnification to identify and locate at least one defective solder ball in the ball grid array;
positioning a ball pickup head comprising a capillary tube over the at least one
30 defective solder ball and extending the capillary tube to contact the at least one defective solder ball;

- applying heat from a heater through the capillary tube to the at least one defective solder ball to at least weaken a bond thereof to an attachment site on the electronic component workpiece;
- removing the at least one defective solder ball from the attachment site with the
- 5 capillary tube;
- retrieving a good solder ball from a source of good solder balls using the capillary tube;
- positioning the capillary tube over the attachment site;
- extending the capillary tube to place the good solder ball in contact with the attachment site;
- 10 heating the good solder ball with the heater through the capillary tube at least sufficiently to cause the good solder ball to bond to the attachment site; and
- retracting the capillary tube to release the solder ball.

17. The method of claim 16, further comprising cooling the at least one
- 15 defective solder ball, moving the capillary tube and the at least one defective solder ball to a location remote from the electronic component workpiece and releasing the at least one defective solder ball from the capillary tube.

18. The method of claim 16, further comprising applying sufficient heat to
- 20 the at least one defective solder ball to reduce it to a molten state, and removing the molten solder material with the capillary tube using at least capillary action.

19. The method of claim 18, further comprising applying a vacuum to the molten solder material through the capillary tube.

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20. The method of claim 16, further comprising applying sufficient heat to the at least one defective solder ball to cause it to release from the attachment site without completely melting and applying a vacuum to the at least one defective solder ball to retain the at least one defective solder ball at an end of the capillary tube prior to
- 30 the removal of the at least one defective solder ball from the attachment site.

21. The method of claim 16, further comprising:
retrieving the good solder ball from the source of good solder balls with the capillary
tube by applying a vacuum through the capillary tube; and
applying flux to at least one of the good solder ball and the attachment site.

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22. The method of claim 16, further comprising performing at least some of
the method for extracting and removing at least one defective solder ball under control
of a programmed microprocessor.

10 23. The method of claim 22, wherein viewing the ball grid array of the
electronic workpiece under magnification is performed using a machine vision system.

24. The method of claim 23, further including using the machine vision
system in combination with the programmed microprocessor and data stored in
15 memory to compare the viewed ball grid array with a model ball grid array and to
locate the at least one defective solder ball in the viewed ball grid array.

25. An apparatus for extracting and replacing an individual solder ball
mounted on an attachment site on an electronic component workpiece, the apparatus
20 comprising:

a support configured to receive an electronic component workpiece thereon;
a solder ball contact head, comprising:

25 a capillary tube configured to remove an individual solder ball from the
electronic component workpiece and to replace the removed individual
solder ball with another solder ball; and
a heating device operably coupled to the capillary tube;
a structure for aligning the capillary tube with the individual solder ball in substantially
transverse orientation to the electronic component workpiece surface; and
an assembly for controllably extending and retracting the capillary tube toward and
30 away from the surface of the electronic component workpiece.

26. The apparatus of claim 25, further including a vacuum source selectively
operably coupled to the capillary tube for drawing a vacuum therethrough.

27. The apparatus of claim 25, further including a structure for effecting alignment of the support in X- and Y-directions.

28. The apparatus of claim 25, further including a viewing apparatus
5 configured for magnification and orientable over the surface of the electronic component workpiece when the electronic component workpiece is received on the support.

29. The apparatus of claim 28, wherein the viewing apparatus includes at
10 least one of an eyepiece for manual viewing and a camera for generating an electronic image.

30. The apparatus of claim 28, further including a light source orientable for illuminating the surface of the electronic component workpiece.

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31. The apparatus of claim 30, wherein the solder ball contact head is configured for transmission of at least a portion of the illumination from the light source therethrough.

20 32. The apparatus of claim 31, wherein the solder ball contact head is configured with a window in alignment with a bore extending through the capillary tube.

25 33. The apparatus of claim 31, wherein the solder ball contact head is configured with at least one optical fiber positioned to receive light from the light source and extending to a location to transmit the received light onto the surface of the electronic component workpiece.

34. The apparatus of claim 25, further comprising a source of non-defective
30 solder balls in proximity to the solder ball contact head.

35. The apparatus of claim 25, wherein the structure for aligning the capillary tube comprises a machine vision apparatus including a camera, magnifying

lens, at least one programmed microprocessor and memory having data stored therein representative of the surface of the electronic component workpiece and topography thereof.

5 36. The apparatus of claim 35, wherein the memory further includes stored data usable by the at least one programmed microprocessor for identifying defective solder balls within the array.

10 37. The apparatus of claim 36, wherein the at least one programmed microprocessor is programmed to control at least some movements of the solder ball contact head and operation of the heating device.

15 38. The apparatus of claim 25, wherein the solder ball contact head is resiliently biased to absorb upward forces from contact of the capillary tube with a solder ball of the array.

 39. The apparatus of claim 25, further including a retraction device for selectively retracting the capillary tube toward the solder ball contact head.