

Although various regions and structures shown in the drawings are depicted as having very precise, sharp configurations and profiles, those skilled in the art recognize that, in reality, these regions and structures are not as precise as indicated in the drawings. Additionally, the relative sizes of the various features and doped regions depicted in the drawings may be exaggerated or reduced as compared to the size of those features or regions on fabricated devices. Nevertheless, the attached drawings are included to describe and explain illustrative examples of the subject matter disclosed herein.

Figures 1A-1B depict an illustrative embodiment of a device 10 in accordance with one aspect of the present subject matter. The device 10 comprises a die 12 that is attached to an interposer or substrate 14, *e.g.*, a printed circuit board. The terms "substrate" and "interposer" will be used interchangeably herein and they shall be understood to refer to any type of structure to which an integrated circuit die may be mounted. The die 12 comprises a plurality of schematically depicted solder balls 16 that are conductively coupled to conductive pads 17. The solder balls 16 have an illustrative oxide layer 20, *e.g.*, tin oxide, formed on the outer surface thereof due to the manufacturing processes performed to form the solder balls 16. A plurality of piercing bond structures 22 are formed on the substrate 14. The piercing bond structures 22 are conductively coupled to illustrative wire traces or lines 24 that extend through vias 26 formed in the substrate 14. The wiring traces 24 are conductively coupled to illustrative contact pads 28 formed on the substrate 14. A layer of dielectric material 30 is also provided to electrically isolate various electrical components on the substrate 14. At least one anti-oxidation film 23 (see Figure 1C) is provided on the piercing bond structures 22.

Figure 1A depicts the situation wherein the die 12 is positioned proximate the substrate 14 prior to attachment. The die 12 may be coupled to the substrate 14 using a variety of known techniques, *e.g.*, adhesives, epoxies, etc. In the depicted example, an amount of non-conductive paste 32 is positioned on the substrate 14. A non-conductive film may, in some applications, be applied in lieu of the non-conductive paste 32.

Figure 1B depicts the device 10 at the point of fabrication wherein the die 12 has been conductively coupled to the substrate 14 by virtue of the conductive engagement between the piercing bond structures 22 and the solder balls 16. The piercing bond structures 22 pierce the oxide layer 20 and the solder ball 16 to thereby establish this conductive connection. Also note that Figure 1B depicts an illustrative standoff structure 34 that may be employed if

desired or needed to ensure that the die 12 is positioned a fixed distance from the substrate 14.

In attaching the die 12 to the substrate 14, the device 10 is heated and an illustrative downforce 40 is applied. The magnitude of the downforce 40 may vary depending upon the particular application. In one illustrative embodiment, the downforce 40 may range from approximately 2-12 kg. In some specific applications, a downforce 40 of approximately 8 kg may be employed. The device 10 is heated to a temperature above the melting point of the material of the solder ball 16, *e.g.*, to a temperature ranging from approximately 190-210°C. The downforce 40 may be applied for a duration of 0.5-2 seconds, depending on the particular application. The article entitled "Instantaneous Fluxless Bonding of Au with Pb-Sn Solder in Ambient Atmosphere," *Journal of Applied Physics*, Vol. 98, 034904 (2005) is hereby incorporated by reference in its entirety.

Figures 1C-1D are enlarged views of an illustrative solder ball 16 and piercing bond structure 22 prior to engagement (Figure 1C) and after engagement (Figure 1D). As mentioned previously, the piercing bond structure 22 has one or more anti-oxidation layers 23 formed on the structure 22 to prevent an oxide film from forming on the piercing bond structure 22. In the illustrative example depicted in Figures 1C-1D, the anti-oxidation layer 23 comprises a layer of gold 23A and a layer of nickel 23B. Of course, other materials may be employed. The layer of gold 23A may have a thickness of approximately 2.5 μm , while the layer of nickel 23B may have a thickness of approximately 0.3 μm .

Figures 2A-2B schematically depict the reduced pitch between adjacent conductive structures that may result by use of the piercing bond structures 22 disclosed herein. Figure 2A schematically depicts an illustrative conductive bond structures 90 that are commonly formed using known techniques. The conventional bond structures 90 have a substantially planar upper or contact surface 92. In Figure 2A, the width of the contact surface 92 is designated "A," the width of the sloped sidewalls 94, due to the isotropic nature of the etching process used to form the structures 90, is designated as "B" and the spacing between the structures 90 is designated as "C." Thus, the pitch "P" for the conductive structure 90 would be $A + 2B + C$. In contrast, the pitch ("P1") between the piercing bond structures 22 shown in Figure 2B would be equal to $2B + C$. In short, using the techniques and piercing bond structures 22 disclosed herein, the pitch between conductive bonding structures (like the piercing bond structures 22 disclosed herein) may be substantially less as compared to prior

CLAIMS

WHAT IS CLAIMED:

1. A method, comprising:
providing an integrated circuit die having a plurality of solder balls, each of which have a layer of oxide on an outer surface of the ball;
performing a heating process to heat at least the solder balls; and
applying a force that causes each of a plurality of piercing bond structures on a substrate to pierce one of the solder balls and its associated oxide layer to thereby establish a conductive connection between the solder ball and the piercing bond structure.
2. The method of claim 1, wherein the steps recited in claim 1 are performed in an ambient, oxygen-containing environment.
3. The method of claim 1, wherein performing the heating process comprises heating at least the solder balls to a temperature that is above a melting point of a material of the solder balls.
4. The method of claim 1, wherein applying the force comprises applying a force ranging from 5-12 Kg for a duration ranging from 0.5-2 seconds.
5. The method of claim 2, wherein the steps recited in claim 1 are performed without applying a flux to the plurality of solder balls.
6. The method of claim 3, wherein the substrate comprises a printed circuit board.
7. The method of claim 4, wherein each of the plurality of piercing bond structures has a substantially triangular cross-sectional configuration.

8. The method of claim 1, further comprising forming a standoff structure between the integrated circuit die and the substrate.

9. The method of claim 1, further comprising forming an anti-oxidation layer on at least one of the plurality of piercing bond structures.

10. The method of claim 9, wherein the anti-oxidation layer includes a first layer with a first thickness of about 2.5 μm and a second layer with a second thickness of about 0.3 μm .

11. The method of claim 9, wherein the anti-oxidation layer includes a first layer of gold and a second layer of nickel.

12. The method of claim 1, further comprising determining a distance between the integrated circuit and the substrate at least by controlling the heating process.

13. The method of claim 1, further comprising controlling a distance between the integrated circuit and the substrate at least by adjusting the force.

14. The method of claim 1, wherein the plurality of piercing bond structures includes a first piercing bond structure and a second piercing bond structure, wherein the first piercing bond structure has a first size different from a second size of the second piercing bond structure.

15. A method, comprising:

forming a plurality of solder balls on a microelectronic component, wherein the individual solder ball includes an oxide layer;

forming a plurality of piercing bond structures on a substrate, wherein the individual piercing bond structure includes an anti-oxidation layer;

heating at least the solder balls; and

moving the piercing bond structures and/or the microelectronic component to pierce the solder balls and the associated oxide layers;

establishing a conductive connection between the microelectronic component and the piercing bond structures.

16. The method of claim 15, further comprising forming a standoff structure between the microelectronic component and the substrate.

17. The method of claim 15, wherein the anti-oxidation layer includes a first layer of gold and a second layer of nickel, and wherein the first layer has a first thickness of about 2.5 μm and the second layer has a second thickness of about 0.3 μm .

18. The method of claim 15, wherein the plurality of piercing bond structures includes a first piercing bond structure and a second piercing bond structure, wherein the first piercing bond structure has a first size different from a second size of the second piercing bond structure.

19. The method of claim 15, wherein heating at least the solder balls comprises heating the solder balls to a temperature that is above a melting point of a material of the solder balls.

20. A device, comprising:
a microelectronic component having a plurality of solder balls conductively coupled to bond pads on the microelectronic component, each of the solder balls having an oxide layer on its outer surface;
a substrate having a plurality of piercing bond structures, each of the piercing bond structures penetrating the corresponding oxide layer and extending partially into the corresponding solder ball to establish a conductive connection; and
a standoff structure positioned between the microelectronic component and the substrate, wherein the standoff structure spaces the microelectronic device apart from the substrate by a desired distance.

21. A device, comprising:

an integrated circuit die having a plurality of solder balls that are conductively coupled to bond pads on the die, each of the solder balls having a layer of oxide on an outer surface thereof; and

a substrate comprising a plurality of piercing bond structures, each of the piercing bond structures penetrating and extending at least partially into a corresponding solder ball to thereby establish a conductive connection between the solder ball and the piercing bond structure, the piercing bond structure penetrating the layer of oxide.

22. The device of claim 21, wherein the piercing bond structures have a non-flat end.

23. The device of claim 21, wherein each of the piercing bond structures comprises at least one anti-oxidation layer formed on an outer surface of the piercing bond structure.

24. The device of claim 23, wherein the at least one anti-oxidation layer comprises a plurality of layers of material.

25. The device of claim 24, wherein the plurality of layers comprises a layer comprising gold formed on an exposed surface of the piercing bond structure and a layer comprising nickel formed on the layer comprising gold.

26. The device of claim 21, wherein the plurality of piercing bond structures has a substantially triangular cross-sectional configuration.

27. An integrated circuit device, comprising:

a first component configured to be conductively coupled to a first solder ball and a second solder ball, the first solder ball having a first layer of oxide, the second solder ball having a second layer of oxide, wherein the first solder ball is larger than the second solder ball; and

a second component configured to have a first piercing bond structure and a second piercing bond structure,

wherein the first piercing bond structure penetrates the first layer of oxide and extends at least partially into the first solder ball to establish a first conductive connection, and

wherein the second piercing bond structure penetrates the second layer of oxide and extends at least partially into the second solder ball to establish a second conductive connection.

28. The device of claim 27, wherein the first piercing bond structure includes a non-flat end, and wherein at least one anti-oxidation layer is formed on an outer surface of the first piercing bond structure.

29. The device of claim 27, wherein the second piercing bond structure includes a non-flat end, and wherein at least one anti-oxidation layer is formed on an outer surface of the second piercing bond structure.

30. The device of claim 28, wherein the at least one anti-oxidation layer comprises a plurality of layers of material, and wherein the plurality of layers comprises a layer comprising gold formed on an exposed surface of the first piercing bond structure and a layer comprising nickel formed on the layer comprising gold.

31. The device of claim 29, wherein the at least one anti-oxidation layer comprises a plurality of layers of material, and wherein the plurality of layers comprises a layer comprising gold formed on an exposed surface of the second piercing bond structure and a layer comprising nickel formed on the layer comprising gold.

32. The device of claim 27, wherein the first piercing bond structure and the second piercing bond structure respectively have a substantially triangular cross-sectional configuration.

33. The device of claim 27, wherein the first piercing bond structure and the second piercing bond structure respectively have a substantially pointed end.

34. The device of claim 27, wherein the first piercing bond structure and the second piercing bond structure respectively have a substantially rounded end.

35. The device of claim 27, wherein the first piercing bond structure and the second piercing bond structure respectively have an end with multiple peaks.

36. An electronic device including a semiconductor structure, the semiconductor structure comprising:

an integrated circuit component having a plurality of solder balls that are conductively coupled to the integrated circuit, each of the solder balls having a layer of oxide on an outer surface thereof; and

a plurality of piercing bond structures conductively coupled to a plurality of bond pads, each of the piercing bond structures penetrating and extending at least partially into a corresponding solder ball to establish a conductive connection between the integrated circuit and the plurality of bond pads.

37. The device of claim 36, wherein the plurality of piercing bond structures are positioned on a substrate.

38. The device of claim 36, wherein each of the plurality of piercing bond structures includes a non-flat end, and wherein at least one anti-oxidation layer is formed on an outer surface of the second piercing bond structure.

39. The device of claim 38, wherein the at least one anti-oxidation layer comprises a plurality of layers of material, and wherein the plurality of layers comprises a layer comprising gold formed on an exposed surface of the piercing bond structure and a layer comprising nickel formed on the layer comprising gold.

40. The device of claim 36, wherein the plurality of piercing bond structures respectively have a substantially triangular cross-sectional configuration.

Although various regions and structures shown in the drawings are depicted as having very precise, sharp configurations and profiles, those skilled in the art recognize that, in reality, these regions and structures are not as precise as indicated in the drawings. Additionally, the relative sizes of the various features and doped regions depicted in the drawings may be exaggerated or reduced as compared to the size of those features or regions on fabricated devices. Nevertheless, the attached drawings are included to describe and explain illustrative examples of the subject matter disclosed herein.

Figures 1A-1B depict an illustrative embodiment of a device 10 in accordance with one aspect of the present subject matter. The device 10 comprises a die 12 that is attached to an interposer or substrate 14, *e.g.*, a printed circuit board. The terms "substrate" and "interposer" will be used interchangeably herein and they shall be understood to refer to any type of structure to which an integrated circuit die may be mounted. The die 12 comprises a plurality of schematically depicted solder balls 16 that are conductively coupled to conductive pads 17. The solder balls 16 have an illustrative oxide layer 20, *e.g.*, tin oxide, formed on the outer surface thereof due to the manufacturing processes performed to form the solder balls 16. A plurality of piercing bond structures 22 are formed on the substrate 14. The piercing bond structures 22 are conductively coupled to illustrative wire traces or lines 24 that extend through vias 26 formed in the substrate 14. The wiring traces 24 are conductively coupled to illustrative contact pads 28 formed on the substrate 14. A layer of dielectric material 30 is also provided to electrically isolate various electrical components on the substrate 14. At least one anti-oxidation film 23 (see Figure 1C) is provided on the piercing bond structures 22.

Figure 1A depicts the situation wherein the die 12 is positioned proximate the substrate 14 prior to attachment. The die 12 may be coupled to the substrate 14 using a variety of known techniques, *e.g.*, adhesives, epoxies, etc. In the depicted example, an amount of non-conductive paste 32 is positioned on the substrate 14. A non-conductive film may, in some applications, be applied in lieu of the non-conductive paste 32.

Figure 1B depicts the device 10 at the point of fabrication wherein the die 12 has been conductively coupled to the substrate 14 by virtue of the conductive engagement between the piercing bond structures 22 and the solder balls 16. The piercing bond structures 22 pierce the oxide layer 20 and the solder ball 16 to thereby establish this conductive connection. Also note that Figure 1B depicts an illustrative standoff structure 34 that may be employed if

desired or needed to ensure that the die 12 is positioned a fixed distance from the substrate 14.

In attaching the die 12 to the substrate 14, the device 10 is heated and an illustrative downforce 40 is applied. The magnitude of the downforce 40 may vary depending upon the particular application. In one illustrative embodiment, the downforce 40 may range from approximately 2-12 kp. In some specific applications, a downforce 40 of approximately 8 kp may be employed. The device 10 is heated to a temperature above the melting point of the material of the solder ball 16, *e.g.*, to a temperature ranging from approximately 190-210°C. The downforce 40 may be applied for a duration of 0.5-2 seconds, depending on the particular application. The article entitled "Instantaneous Fluxless Bonding of Au with Pb-Sn Solder in Ambient Atmosphere," *Journal of Applied Physics*, Vol. 98, 034904 (2005) is hereby incorporated by reference in its entirety.

Figures 1C-1D are enlarged views of an illustrative solder ball 16 and piercing bond structure 22 prior to engagement (Figure 1C) and after engagement (Figure 1D). As mentioned previously, the piercing bond structure 22 has one or more anti-oxidation layers 23 formed on the structure 22 to prevent an oxide film from forming on the piercing bond structure 22. In the illustrative example depicted in Figures 1C-1D, the anti-oxidation layer 23 comprises a layer of gold 23A and a layer of nickel 23B. Of course, other materials may be employed. The layer of gold 23A may have a thickness of approximately 2.5 μm , while the layer of nickel 23B may have a thickness of approximately 0.3 μm .

Figures 2A-2B schematically depict the reduced pitch between adjacent conductive structures that may result by use of the piercing bond structures 22 disclosed herein. Figure 2A schematically depicts an illustrative conductive bond structures 90 that are commonly formed using known techniques. The conventional bond structures 90 have a substantially planar upper or contact surface 92. In Figure 2A, the width of the contact surface 92 is designated "A," the width of the sloped sidewalls 94, due to the isotropic nature of the etching process used to form the structures 90, is designated as "B" and the spacing between the structures 90 is designated as "C." Thus, the pitch "P" for the conductive structure 90 would be $A + 2B + C$. In contrast, the pitch ("P1") between the piercing bond structures 22 shown in Figure 2B would be equal to $2B + C$. In short, using the techniques and piercing bond structures 22 disclosed herein, the pitch between conductive bonding structures (like the piercing bond structures 22 disclosed herein) may be substantially less as compared to prior

CLAIMS

WHAT IS CLAIMED:

1. A method, comprising:
providing an integrated circuit die having a plurality of solder balls, each of which have a layer of oxide on an outer surface of the ball;
performing a heating process to heat at least the solder balls; and
applying a force that causes each of a plurality of piercing bond structures on a substrate to pierce one of the solder balls and its associated oxide layer to thereby establish a conductive connection between the solder ball and the piercing bond structure.
2. The method of claim 1, wherein the steps recited in claim 1 are performed in an ambient, oxygen-containing environment.
3. The method of claim 1, wherein performing the heating process comprises heating at least the solder balls to a temperature that is above a melting point of a material of the solder balls.
4. The method of claim 1, wherein applying the force comprises applying a force ranging from 5-12 kp for a duration ranging from 0.5-2 seconds.
5. The method of claim 2, wherein the steps recited in claim 1 are performed without applying a flux to the plurality of solder balls.
6. The method of claim 3, wherein the substrate comprises a printed circuit board.
7. The method of claim 4, wherein each of the plurality of piercing bond structures has a substantially triangular cross-sectional configuration.

8. The method of claim 1, further comprising forming a standoff structure between the integrated circuit die and the substrate.

9. The method of claim 1, further comprising forming an anti-oxidation layer on at least one of the plurality of piercing bond structures.

10. The method of claim 9, wherein the anti-oxidation layer includes a first layer with a first thickness of about 2.5 μm and a second layer with a second thickness of about 0.3 μm .

11. The method of claim 9, wherein the anti-oxidation layer includes a first layer of gold and a second layer of nickel.

12. The method of claim 1, further comprising determining a distance between the integrated circuit and the substrate at least by controlling the heating process.

13. The method of claim 1, further comprising controlling a distance between the integrated circuit and the substrate at least by adjusting the force.

14. A method, comprising:
forming a plurality of solder balls on a microelectronic component, wherein the individual solder ball includes an oxide layer;
forming a plurality of piercing bond structures on a substrate, wherein the individual piercing bond structure includes an anti-oxidation layer;
heating at least the solder balls; and
moving the piercing bond structures and/or the microelectronic component to pierce the solder balls and the associated oxide layers;
establishing a conductive connection between the microelectronic component and the piercing bond structures.

15. The method of claim 14, further comprising forming a standoff structure between the microelectronic component and the substrate.

16. The method of claim 14, wherein the anti-oxidation layer includes a first layer of gold and a second layer of nickel, and wherein the first layer has a first thickness of about 2.5 μm and the second layer has a second thickness of about 0.3 μm .

17. The method of claim 14, wherein heating at least the "solder balls" comprises heating the solder balls to a temperature that is above a melting point of a material of the solder balls.

18. A device, comprising:

- a microelectronic component having a plurality of solder balls conductively coupled to bond pads on the microelectronic component, each of the solder balls having an oxide layer on its outer surface;
- a substrate having a plurality of piercing bond structures, each of the piercing bond structures penetrating the corresponding oxide layer and extending partially into the corresponding solder ball to establish a conductive connection; and
- a standoff structure positioned between the microelectronic component and the substrate, wherein the standoff structure spaces the microelectronic device apart from the substrate by a desired distance.

19. A device, comprising:

- an integrated circuit die having a plurality of solder balls that are conductively coupled to bond pads on the die, each of the solder balls having a layer of oxide on an outer surface thereof; and
- a substrate comprising a plurality of piercing bond structures, each of the piercing bond structures penetrating and extending at least partially into a corresponding solder ball to thereby establish a conductive connection between the solder ball and the piercing bond structure, the piercing bond structure penetrating the layer of oxide, wherein the at least one anti-oxidation layer comprises a plurality of layers of material, and wherein the plurality of layers comprises a layer comprising gold formed on an exposed surface of the piercing bond structure and a layer comprising nickel formed on the layer comprising gold.

20. The device of claim 19, wherein the piercing bond structures have a non-flat end.

21. The device of claim 19, wherein each of the piercing bond structures comprises at least one anti-oxidation layer formed on an outer surface of the piercing bond structure.

22. The device of claim 19, wherein the plurality of piercing bond structures has a substantially triangular cross-sectional configuration.

23. An integrated circuit device, comprising:

a first component configured to be conductively coupled to a first solder ball and a second solder ball, the first solder ball having a first layer of oxide, the second solder ball having a second layer of oxide, wherein the first solder ball is larger than the second solder ball; and

a second component configured to have a first piercing bond structure and a second piercing bond structure,

wherein the first piercing bond structure penetrates the first layer of oxide and extends at least partially into the first solder ball to establish a first conductive connection, and

wherein the second piercing bond structure penetrates the second layer of oxide and extends at least partially into the second solder ball to establish a second conductive connection.

24. The device of claim 23, wherein the first piercing bond structure includes a non-flat end, and wherein at least one anti-oxidation layer is formed on an outer surface of the first piercing bond structure.

25. The device of claim 23, wherein the second piercing bond structure includes a non-flat end, and wherein at least one anti-oxidation layer is formed on an outer surface of the second piercing bond structure.

26. The device of claim 24, wherein the at least one anti-oxidation layer comprises a plurality of layers of material, and wherein the plurality of layers comprises a layer comprising gold formed on an exposed surface of the first piercing bond structure and a layer comprising nickel formed on the layer comprising gold.

27. The device of claim 25, wherein the at least one anti-oxidation layer comprises a plurality of layers of material, and wherein the plurality of layers comprises a layer comprising gold formed on an exposed surface of the second piercing bond structure and a layer comprising nickel formed on the layer comprising gold.

28. The device of claim 23, wherein the first piercing bond structure and the second piercing bond structure respectively have a substantially triangular cross-sectional configuration.

29. The device of claim 23, wherein the first piercing bond structure and the second piercing bond structure respectively have a substantially pointed end.

30. The device of claim 23, wherein the first piercing bond structure and the second piercing bond structure respectively have a substantially rounded end.

31. The device of claim 23, wherein the first piercing bond structure and the second piercing bond structure respectively have an end with multiple peaks.

32. An electronic device including a semiconductor structure, the semiconductor structure comprising:

an integrated circuit component having a plurality of solder balls that are conductively coupled to the integrated circuit, each of the solder balls having a layer of oxide on an outer surface thereof;

a substrate carrying a plurality of piercing bond structures positioned on a substrate and conductively coupled to a plurality of bond pads, each of the piercing bond structures penetrating and extending at least partially into a corresponding solder ball to establish a conductive connection between the integrated circuit and the plurality of bond pads; and

a standoff structure positioned between the integrated circuit component and the substrate, wherein the standoff structure spaces the integrated circuit component apart from the substrate by a desired distance.

33. The device of claim 32, wherein each of the plurality of piercing bond structures includes a non-flat end, and wherein at least one anti-oxidation layer is formed on an outer surface of the second piercing bond structure.

34. The device of claim 33, wherein the at least one anti-oxidation layer comprises a plurality of layers of material, and wherein the plurality of layers comprises a layer comprising gold formed on an exposed surface of the piercing bond structure and a layer comprising nickel formed on the layer comprising gold.

35. The device of claim 33, wherein the plurality of piercing bond structures respectively have a substantially triangular cross-sectional configuration.