# THROUGH HOLE BUMP CONTACT

## Background

The disclosures herein relate generally to solder ball electronic interconnections and more particularly to a via plug adapter for strengthening a solder ball connection in a beveled via.

Vertical interconnects between circuit layers is well known. U.S. Patent 3,541,222 discloses a connector screen for interconnecting aligned electrodes of adjacent circuit boards or modules. The connector screen comprises a matrix of spaced conductive connector elements embedded in a supporting non-conducting material with the conductive connector elements protruding from both sides thereof. The size and spacing of the connector elements are chosen so that the connector screen can be disposed between the circuit boards or modules to provide the required interconnections between the electrodes without requiring alignment of the connector screen with respect to the boards or modules. A preferred method of making the connector screen involves forming a conductive mold having a grid pattern of ridges in a non-conductive base. Conductive material is then cast between the ridges of the mold, following which selected portions of the mold are removed to form a web of non-conductive material supporting a matrix of spaced conducting elements protruding from both sides of the web.

U.S. Patent 4,830,264 describes a method of forming solder terminals for a pinless module, preferably for a pinless metallized ceramic module. The method is comprised of the following steps: forming a substrate having a pattern of conductors formed onto its top surface and preformed via-holes extending from the top to bottom surface; applying a droplet of flux at at least one of the preformed via-hole openings of the bottom surface of the substrate to fill the via-holes with flux by capillarity and form a glob of flux at the bottom openings; applying a solder preform, i.e. solder balls on each glob of flux to which it will adhere, the volume of the preform being substantially equal to the inner volume of the via-hole plus the volume of the bump to be formed; heating to cause solder reflow of the solder preform to fill the via-hole and the inner volume of the eyelet with solder; and, cooling below the melting point of the solder so that the molten solder solidifies to form solder terminals at the via-hole locations while forming solder columns in the via-holes. The resultant pinless

metallized ceramic module has connections between the I/O's of the module interfacing with the next level of packaging (i.e., printed circuit boards), that consist of integral solder terminals. Each integral solder terminal comprises a column in the vias of the metallized ceramic substrate, a mound of solder at the top surface of the substrate and spherical solder bumps on the bottom level for making interconnections with the next level of packaging.

In U.S. Patent 5,401,913, a multi-layer circuit board includes electrical interconnections between adjacent circuit board layers of the multi-layer board. A via hole is provided through a circuit board layer. The via hole is filled with a via metal. The via metal is plated with a low melting point metal. An adhesive film is deposited over the circuit board layer. Adjacent layers of the multi-layer circuit board are stacked and aligned together. The layers are laminated under heat and pressure. The low melting point metal provides an electrical interconnection between adjacent layers.

U.S. Patent 5,491,303 discloses an interposer for connecting two or more printed circuit boards comprising a circuit-carrying substrate with two or more solder pads on each of two sides. Each of the solder pads are connected to an electrically conductive via in the substrate, providing electrical interconnection from one side to the other side. Each solder pad has a solder bump on it. A circuit assembly is made by soldering the solder bumps on one side of the interposer to corresponding solder pads on a printed circuit board. The solder bumps on the other side of the interposer are likewise soldered to the corresponding solder pads of a second printed circuit board.

U.S. Patent 5,600,884 describes an electrical connecting member, one surface of which is connected to a connecting section of a first electrical circuit member and another surface of which is connected to a connecting section of a second electrical circuit member. The electrical connecting member includes a holding member formed of an electrically insulative member. The holding member has a plurality of recess holes. The connecting member also includes a plurality of electrically conductive members provided in the electrically insulative member, insulated from each other. One end of the electrically conductive members is exposed on one surface of the holding member to be connected to the connecting section of the first electrical circuit member. Another end of the electrically conductive members is exposed on

another surface of the holding member to be connected to the connecting section of the second electrical circuit member.

U.S. Patent 5,726,497 discloses a method of manufacture of a semiconductor device on a silicon semiconductor substrate which comprises formation of a first stress layer on the semiconductor substrate, formation of an interconnect layer over the first stress layer, formation of a second stress layer on the interconnect layer, formation of an inter-metal dielectric (IMD) layer over the second stress layer, patterning and etching a via opening through the inter-metal dielectric layer and the second stress layer, exposing a contact area on the surface of the metal interconnect layer, and heating the device at a temperature sufficient to squeeze the metal interconnect layer up into the via.

U.S. Patent 5,757,078 discloses a semiconductor device including a semiconductor chip having electrode pads, a package composed of a plurality of insulating films and adhered to the semiconductor chip by an adhesive agent. The package includes wiring patterns interposed between the plurality of insulating films. The wiring patterns are selectively connected to the electrode pads at one end, and to the plurality of electrically conductive protrusions at the other end, by means of via-holes. The semiconductor device further includes a plurality of electrically conductive protrusions extending from the outermost wiring patterns by way of the via-holes provided in the outermost insulating film.

Japanese Application JP 10-41356 discloses a tape carrier that is used as the bonding medium when semiconductor elements are bonded to the outer part of a substrate board for a BGA application. An insulating film includes vias having straight or non-tapered walls. A conductive land is formed in the vias and solder balls have one side engaged with the lands inside of the vias. The remainder of each solder ball protrudes from the insulating film.

The use of flexible circuitry in IC packaging has been a growing trend for many years where the use of via connections through the flexible circuit dielectric have been employed in Tape Ball Grid Array (TBGA) IC packaging applications and recently, into Chip Scale Packaging (CSP) applications. In Ball Grid Array (BGA) applications, the via interconnection traditionally uses a solder ball reflowed first to connect to the flexible circuitry through the via, then second, reflowed onto the printed circuit board with conventional surface mount assembly practices.

This solder ball connection must make a reliable electronic interconnect from the flexible circuitry to the printed circuit board. This reliability is often directly related to the area of the solder connection to the flexible circuitry, as a common failure mode of this interconnection is the solder ball shearing through the solder material at the point of the minimum cross sectional area. Therefore, larger vias are desirable to increase the area in which shear stress is distributed to meet minimum solder ball interconnection reliability requirements.

Conversely, the demand for smaller electronic packages and higher input/output (I/O's) requires increased routing density, including smaller via sizes to allow electronic traces to route between solder ball via areas. Smaller vias require smaller via capture pads, thus, allowing more space to route electronic traces between printed circuit board interconnection vias.

Traditionally, vias in the dielectric are made by punching, leaving a via through the dielectric with straight walls. Other methods include chemically dissolving the dielectric and laser drilling to expose the metal conductor of the flexible circuitry. Direct solder ball attachment to any of these via methods controls the solder ball interconnection reliability by means of the via size, such that, vias typically have to be larger than 0.200 mm in diameter to meet minimum reliability requirements for the electronic package.

Therefore, what is needed is an apparatus and a method for providing a strong and reliable solder ball connection to flexible circuitry with small diameter vias and via capture pads so as to permit more space in which to route more electronic traces.

## Summary

One embodiment, accordingly, provides a strength enhanced solder ball connection to flexible circuitry with small diameter vias which improves the routability of the flexible circuit to address higher I/O and finer pitch flex based BGA packaging applications. To this end, a circuit comprises a substrate including a dielectric layer having a first surface and a second surface. A conductive layer is on the first surface. A beveled via is formed in the dielectric layer and has a first opening of a first width in the first surface, and a second opening of a second width in the second surface, greater than the first width. A conductive plug is formed in the via, connected to the conductive layer, and extends from adjacent the first opening toward

the second opening. The plug terminates adjacent the second opening at a plug interface surface. A conductive solder ball is connected to the plug interface surface and extends to protrude from the second surface.

A principal advantage of this embodiment is that the via adapter plug enables a reliable solder ball connection to flexible circuitry with small (less than 0.200 mm diameter) vias. Using the via plug adapter concept, solder ball interconnection reliability does not have to be compromised to accommodate the routing requirements of high I/O, fine pitch flex based IC packaging applications. Using common design rules for flexible circuitry, a smaller via allows for a smaller via capture pad, thus, more space between via capture pads in which to route electronic traces.

## Brief Description of the Drawings

Fig. 1 is a side view illustrating an embodiment of a substrate interconnected to a circuit board by a plurality of solder balls.

Fig. 1A is a top view illustrating a circular via opening.

Fig. 1B is a top view illustrating an oblong via opening.

Fig. 2 is a side view illustrating an embodiment of a plug in a tapered via.

Fig. 3 is another side view illustrating an embodiment of a plug in a tapered via.

Fig. 4 is another side view illustrating an embodiment of a plug in a tapered via.

Fig. 5 is a side view illustrating an embodiment of a substrate interconnected to a circuit board by a solder ball.

Fig. 6 is a side view illustrating an embodiment of a two-layered substrate interconnected to a circuit board by solder ball.

Fig. 7 is a side view illustrating an embodiment of a chip scale package including an IC chip connected to a substrate.

Fig. 8 is a view of the substrate taken along line 8-8 of Fig. 7.

## Detailed Description

According to one embodiment, Fig. 1, a flexible circuit **10** comprises a substrate **12** formed of a flexible dielectric material. The substrate **12** is of a polymer or other suitable material having a thickness T1 of from 12 micrometers to 25 micrometers. The polymer may be a polyimide, a polyester, or other known polymers

for electronic applications. Substrate **12** also includes a first surface **14** and a second opposite surface **16**. A conductive layer **18**, of copper, gold plated copper, gold or other suitable material, is formed on first surface **14** and includes a plurality of conductive capture pads **20** and a plurality of conductive traces **22** routed between the capture pads **20**.

A plurality of beveled vias **24** are formed in substrate **12**. Each via **24** has a first opening **26** of a first width W1, in first surface 14, and a second opening **28** of a second width W2, in the second surface **16**. Second width W2 is greater than first width W1. Beveled via **24** includes a sidewall **30** which is sloped away from first surface **14** at an angle $\alpha$ of from 20 degrees to 80 degrees, and preferably at an angle of from 20 degrees to 45 degrees. First opening **26** is circular, Fig. 1A, or oblong, Fig. 1B or may be of another suitable shape and first width W1 is from 0.05 mm to 0.5 mm.

A conductive plug **32**, Figs 1 and 2 is formed in beveled via **24**, and extends from a first plug interface surface **34**, adjacent first opening **26**, toward the second opening **28**. Plug **32** terminates adjacent the second opening **28** at a second plug interface surface **36**. The first plug interface surface **34** is connected to conductive capture pad **20**. The second plug interface surface **36** is of a dome shape. Second plug interface surface **36** may be formed to terminate between first surface **14** and second surface **16**, may be formed such that a portion of the dome extends outwardly from the second surface **16**, Fig. 3, or may be formed such that the entire dome-like surface extends outwardly from the second surface **16**, Fig. 4. Thus, a range of plug thickness or height T2 extending from first plug interface surface **34** to second plug interface surface **36** may vary, but is at least 5 microns, Fig. 2.

A conductive solder ball **38**, Fig. 5, is connected to second plug interface surface **36** at a first solder ball surface **40**, and protrudes from second substrate surface **16**. Solder ball **38** terminates at a second solder ball surface **42** which may engage a printed circuit board **44**. Plug **32** and solder ball **38** may be formed of various suitable materials. For example, plug **32** may be formed of a high temperature tin-lead solder engaged with solder ball **38** formed of a eutectic tin-lead solder. Also, plug **32** may be formed of copper engaged with solder ball **38** formed of a tin-lead solder. Other combinations may be used which meet the conductivity requirement and meet the condition that they provide the plug material of a stronger

shear strength than the solder ball material. As a further example, plug **32** may be formed of nickel engaged with solder ball **38** formed of a tin-lead solder. In addition, for improved bonding, an interface coating **46** may be provided between capture pads **20** and first plug interface surface **34**. Coating **46** may be formed of a suitable material selected from gold, paladium and nickel-gold. Furthermore, bonding between plug **32** and solder ball **38** may be improved by another interface coating **48** therebetween. Coating **48** may be formed of a suitable material also selected from gold, paladium and nickel-gold.

Beveled vias **24**, Fig. 1, are spaced apart in a side-by-side configuration. Capture pads **20** are formed at each first opening **26**. Therefore, capture pads **20** are also spaced apart in a side-by-side configuration. Spacing between vias **24** is of a center-to-center distance D of from 0.25 mm to about 1.27 mm. This spacing permits at least three traces **22** to pass between side-by-side capture pads **20**.

In Fig. 6, circuit **10** includes a substrate including a first dielectric layer **12a** and a second dielectric layer **13**. First dielectric layer **12a** includes a first surface **14a** and a second surface **16a**. A conductive layer **18a** is provided on first surface **14a** between first dielectric layer **12a** and second dielectric layer **13**. A beveled via **24** is formed in first dielectric layer **12a** as described and referred to above. Also, the second dielectric layer **13** may be formed of a polymer material as described above. One of the layers **12a** and **13** may be provided as a cover coat for the other layer.

Well known tape ball grid array (TBGA) package typically includes a substrate having an integrated circuit (IC) mounted in a cavity that is surrounded by an array of vias. Leads from the IC interconnect to the vias. One embodiment herein, Figs. 7 and 8, discloses a substantial improvement such that the substrate is substantially of the same surface area as the IC. This is possible due to the reduced size openings of the tapered vias as described above. Thus, the advantages provided by the reduced size openings permits increased trace routing between the vias. Also, the opposite or larger via openings provide increased surface contact to improve solder ball shear strength. The chip scale package **100**, Fig. 7, includes a substrate **112** having a first surface **114** and a second surface **116**. A surface area A1 of first surface **114** is substantially the same as a second surface area A2 of an IC **150** mounted on substrate **112**. A conductive layer **118** on portions of first surface **114** area is connected to IC **150** by leads **152**. An adhesive layer **155** on surface **114** of

substrate **112**, and an adhesive layer **157** on IC **150** are interconnected by an interposer layer **154** therebetween. The interposer layer **154** may, for example, be a compliant material such as a foam or elastomeric material, or a non-compliant material such as a ceramic or a copper sheet. Substrate **112** includes a plurality of beveled vias **124**, as described above. Each via includes a first opening **126** in first surface **114** and a second opening **128** in second surface **116**. The second width being greater than the first width as herein described. A plug **132** is provided in each via to extend from adjacent the first opening **126** to adjacent the second opening **128** and terminating at a plug interface surface **136**. A conductive solder ball **138** is connected to the plug interface surface **136** and extends to protrude from second surface **116** for connection to a printed circuit board **144**. Thus, a plurality of solder balls **138** provide an array which is uniform across second surface **116** of substrate **112**, without interruption by a commonly heretofore known space required for mounting an IC package on opposite surface **114**.

As it can be seen, the principal advantages of these embodiments are that the via plug adapter enables a reliable solder ball connection to flexible circuitry with small (less than 0.200 mm diameter) vias. Using the via plug adapter concept, solder ball interconnection reliability does not have to be compromised to accommodate the routing requirements of high I/O, fine pitch flex based IC packaging applications. Using common design rules for flexible circuitry, a smaller via allows for a smaller via capture pad, thus, more space between via capture pads in which to route electronic traces. As an example, using a via plug adapter in a 0.085 mm diameter beveled via, 4 traces can be routed between capture pads with similar solder ball interconnection reliability as with 0.300 mm diameter vias that only allow routing of a single trace.

The foregoing describes a flexible circuit with a z-axis via interconnection between fine feature flexible circuitry and gross feature printed circuit board solder ball pads using traditional solder balls with the novel use of a via plug adapter. One such application of this via plug adapter is the flexible circuit application in IC packaging for BGA to printed circuit board interconnection.

The via plug adapter is a metal plug additively plated into a beveled via. In addition to forming the plug using an additive plating process, a process such as solder reflow could be used to form the via plug. This via plug adapter is a frustum

(the solid of a cone between two parallel planes) shaped metal feature with a slight dome shape at the second interface surface. As the z-direction thickness of the frustum grows within the beveled via, the surface area for traditional solder ball attachment grows dramatically creating a mechanical adapter allowing small vias to have similar solder ball interconnection reliability as with large via applications.

Allowing small vias in the flexible circuit improves the routability of the flexible circuit to address higher I/O and finer pitch flex based BGA packaging applications.

As a result, one embodiment provides a circuit comprising a substrate including a dielectric layer having a first surface and a second surface. A conductive layer is on the first surface. A beveled via is formed in the dielectric layer. The via has a first opening of a first width in the first surface and a second opening of a second width, in the second surface, greater than the first width. A conductive plug is connected to the conductive layer and is formed in the via and extends from adjacent the first opening toward the second opening. The plug terminates adjacent the second opening at a plug interface surface. A conductive solder ball is connected to the plug interface surface, and extends to protrude from the second surface.

Another embodiment provides a circuit comprising a substrate including a dielectric layer having a first surface and a second surface. A conducted layer is on the first surface. A beveled via is formed in the dielectric layer. The via has a first opening of a first width in the first surface and a second opening of a second width in the second surface, greater than the first width. A conductive plug is connected to the conductive layer and is formed in the via and extends from adjacent the first opening toward the second opening. The plug terminates adjacent the second opening at a plug interface surface. A conductive solder ball has a first solder ball surface connected to the plug interface surface. The solder ball extends to protrude from the second surface and terminates at a second solder ball surface. A printed circuit board is engaged with the second solder ball surface.

In still another embodiment, a circuit comprises a substrate including a dielectric layer having a first surface and a second surface. A pair of side-by-side beveled vias are formed in the dielectric layer. Each via has a first opening of a first width in the first surface, and a second opening of a second width in the second surface, greater than the first width. Each via includes a conductive plug having a

first plug interface surface adjacent the first opening. Each plug extends from adjacent the first plug interface surface toward the second opening. Each plug terminates adjacent the second opening at a second plug interface surface. A conductive solder ball is formed at each via and has a first solder ball surface engaged with its respective second plug interface surface, and extends to protrude from the second surface. Each solder ball terminates at a second solder ball surface. A printed circuit board is engaged with the second solder ball surface. A conductive capture pad layer is engaged with the first interface surface of each plug to form side-by-side, spaced apart, capture pad layers. A plurality of conductive traces extend between the side-by-side capture pad layers.

A further embodiment provides a method of attaching a solder ball to a via in a flexible circuit substrate. This is accomplished by forming a beveled via in the flexible circuit substrate having a first surface and a second surface. A first via opening is formed in the first surface and has a first width. A second via opening is formed in the second surface and has a second width, greater than the first width. A conductive layer is formed at the first opening. A conductive plug is formed in the beveled via connected to the conductive layer so that the plug extends from adjacent the first surface toward the second surface. The plug terminates at a plug interface surface adjacent the second surface. A conductive solder ball is engaged with the plug interface surface. The solder ball extends to protrude from the second surface.

Although illustrative embodiments have been shown and described, a wide range of modifications, change and substitution is contemplated in the foregoing disclosure and in some instances, some features of the embodiments may be employed without a corresponding use of other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the embodiments disclosed herein.

What is claimed is:

1. A circuit comprising:

a substrate including a dielectric layer having a first surface and a second surface;

a conductive layer on the first surface,

wherein the dielectric layer and conductive layer form a flexible circuit;

a beveled via formed in the dielectric layer, the via having a first opening of a first width in the first surface, and a second opening of a second width in the second surface, the second width being greater than the first width;

a conductive plug connected to the conductive layer, the plug being formed in the via, and extending from adjacent the first opening toward the second opening, and terminating adjacent the second opening at a plug interface surface; and

a conductive solder ball connected to the plug interface surface and extending to protrude from the second surface.

2. The circuit as defined in claim 1, wherein the dielectric layer is formed of a polymer material selected from polyimide and polyester, such material having a thickness of from 12 micrometers to 125 micrometers.

3. The circuit as defined in claim 1 wherein the beveled via has a sidewall sloped away from the first surface at an angle of from 20 degrees to 80 degrees.

4. The circuit as defined in claim 1 wherein the plug interface surface forms a dome.

5. The circuit as defined in claim 4 wherein the dome is between the first surface and the second surface.

6. The circuit as defined in claim 4 wherein a portion of the dome extends outwardly from the second surface.

7. The circuit as defined in claim 1 wherein the plug has a thickness dimension extending from the first surface to the dome, the thickness dimension being at least 5 microns.

8. The circuit as defined in claim 1 wherein the ball is formed of a tin-lead solder and the plug is formed of a conductive material and has a stronger shear strength than the tin-lead solder.

9. The circuit as defined in claim 1 wherein the conductive layer is formed of copper or gold.

10. The circuit as defined in claim 9 further comprising:

an interface coating between the conductive layer and the plug, the coating being selected from the group consisting of gold, paladium and nickel-gold.

11. The circuit as defined in claim 9 further comprising:

an interface coating between the interface surface of the plug and the ball, the coating being selected from the group consisting of gold, paladium and nickel-gold.

12. A circuit comprising:

a substrate including a dielectric layer having a first surface and a second surface;

a pair of side-by-side beveled vias formed in the dielectric layer, each via having a first opening of a first width in the first surface and a second opening of a second width in the second surface, the second width being greater than the first width;

each via including a conductive plug having a first plug interface surface adjacent the first opening, each plug extending from adjacent the first plug interface toward the second opening, each plug terminating adjacent the second opening at a second plug interface surface;

a conductive solder ball formed at each via, each solder ball having a first solder ball surface engaged with its respective second plug interface surface, and extending to protrude from the second surface, each solder ball terminating at a second solder ball surface;

a printed circuit board engaged with the second solder ball surface;

a conductive capture pad layer engaged with the first interface surface of each plug to form side-by-side, spaced apart capture pad layers; and





a plurality of conductive traces extending between the side-by-side capture pad layers.

13. The circuit as defined in claim 12 wherein the plurality of conductive traces includes at least three traces.

