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Kenney

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[54] **DIFFUSION PATTERNED C4 BUMP PADS**

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[75] Inventor: **Christopher S. Kenney**, Cedarville, Ill.

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[73] Assignee: **Honeywell Inc.**, Minneapolis, Minn.

Primary Examiner—Patrick Ryan
Assistant Examiner—Jeffrey T. Knapp
Attorney, Agent, or Firm—John G. Shudy; Roland W. Norris

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[57] **ABSTRACT**

[51] **Int. Cl.**⁶ **B23K 31/02**; B23K 1/20

A development process of C4 bump pads is for advanced microelectronic integrated circuit connection technology. This approach involves the laying down of conductor lines on a substrate and an encapsulation over the lines, plus the making of openings for making the bump pads. The bump pads are for situating solder balls for connections with a flip chip or integrated circuit. The openings are made by application of a diffusing material that is patterned on the glass encapsulation to define the areas of the bump pads. After the material is dried and diffused into the encapsulation layer, the diffused material is washed out with water to leave open areas for the bump pads. Then solder balls may be placed on the bump pads and heated to adhere to the conductor lines and form rounded bumps on the respective pads. Flux may then be applied to the solder bumps, and the flip chip is placed with its terminals on the solder bumps which are heated for connection.

[52] **U.S. Cl.** **228/180.22**; 228/254; 427/271; 427/337

[58] **Field of Search** 427/337, 271; 228/254, 180.22

[56] **References Cited**

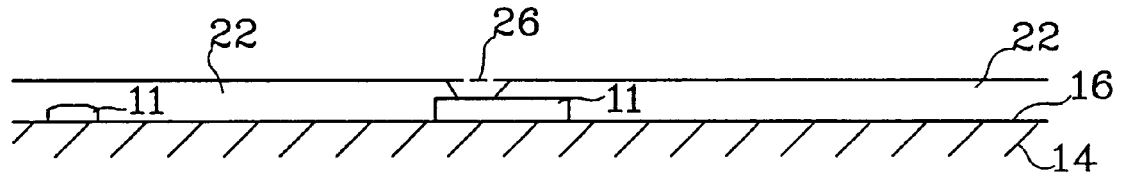
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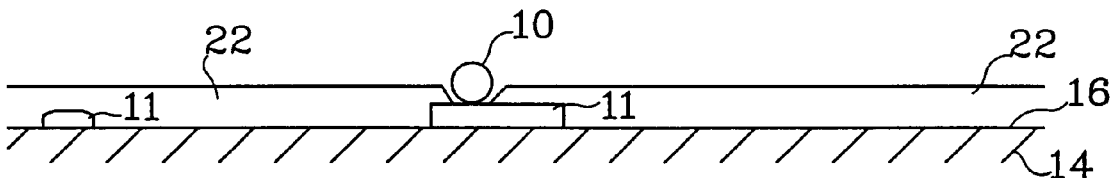
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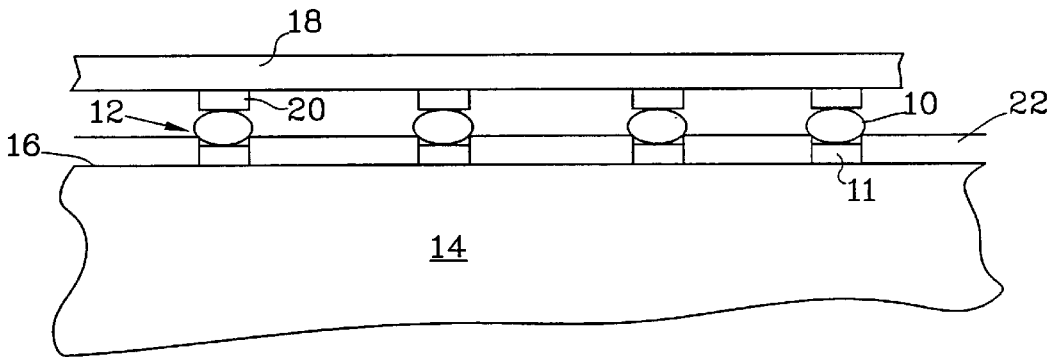
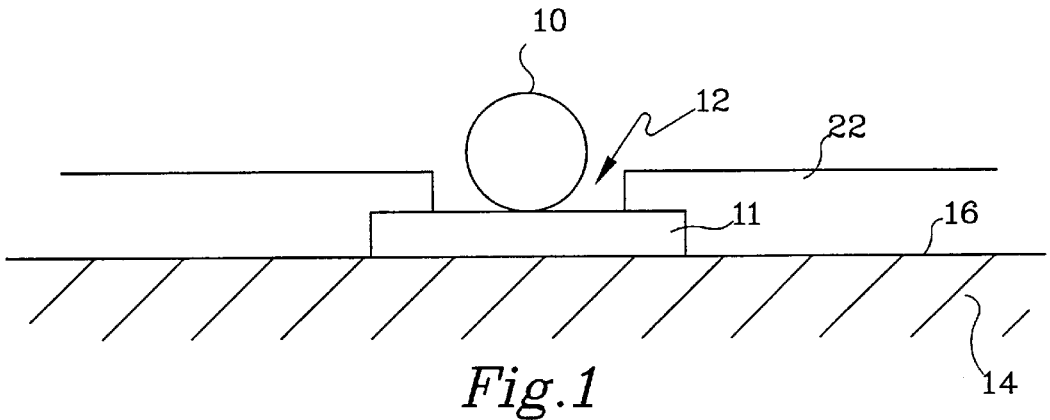
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19 Claims, 4 Drawing Sheets



SECTION A-A





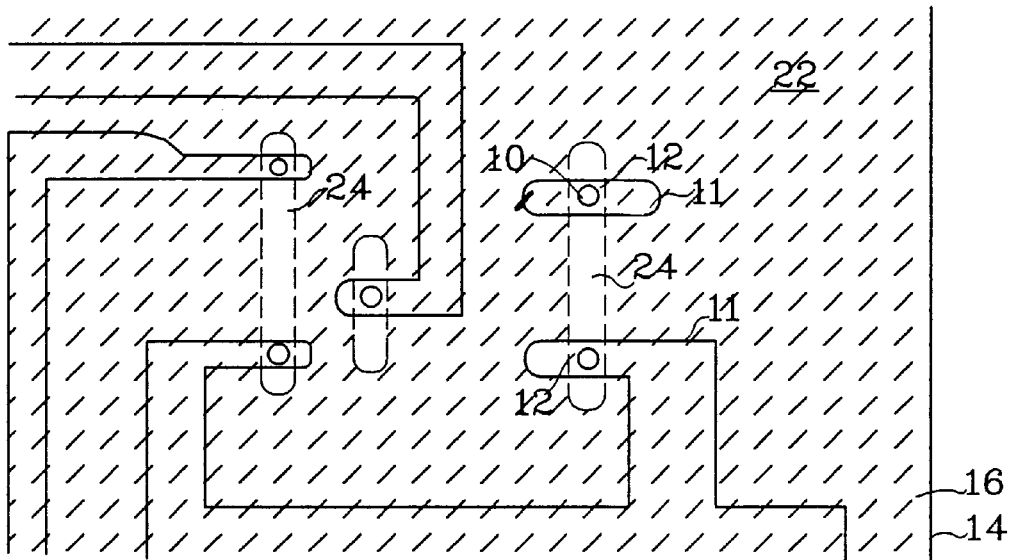


Fig. 3

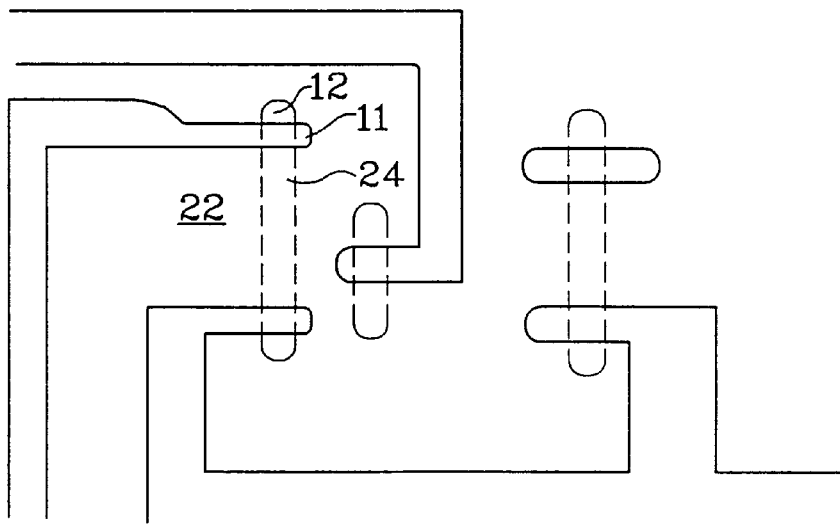


Fig. 4

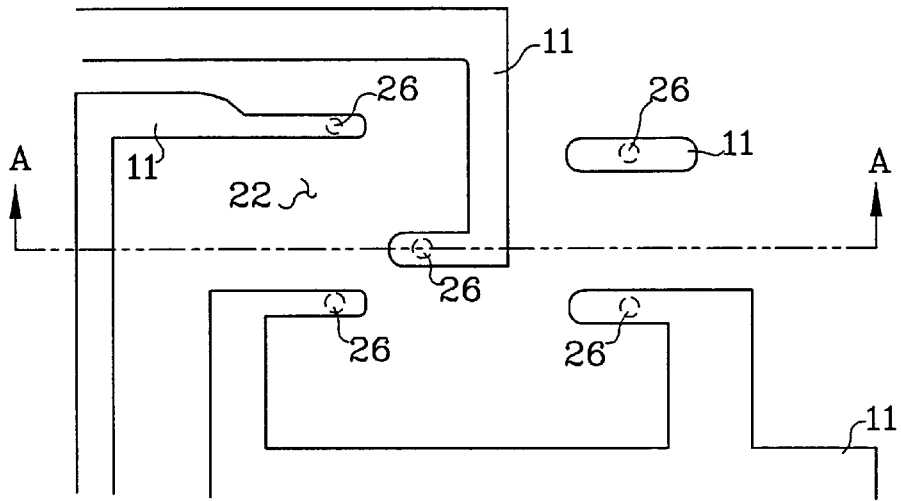
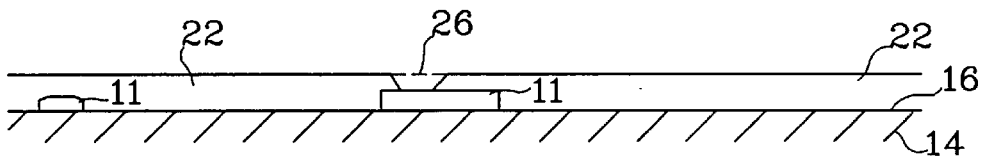


Fig. 5A



SECTION A-A

Fig. 5B

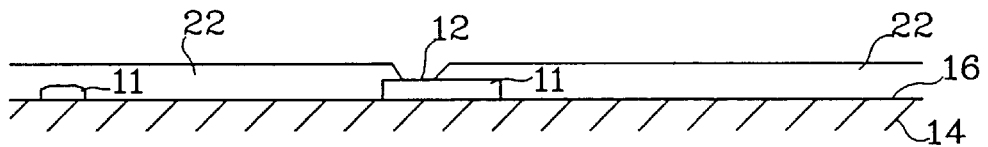


Fig. 5C

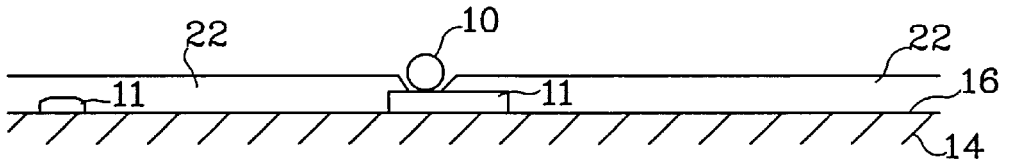


Fig. 5D

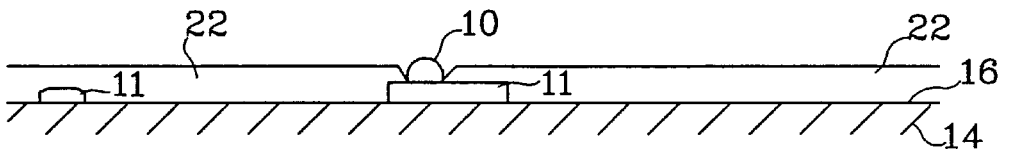


Fig. 5E

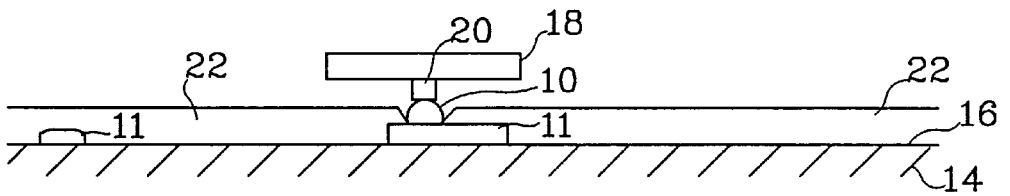


Fig. 5F

DIFFUSION PATTERNED C4 BUMP PADS

BACKGROUND OF THE INVENTION

The present invention pertains to connecting integrated circuits (i.e., "chips") to a substrate for thick film hybrid circuits. It particularly pertains to C4 bump pads for connecting integrated circuits; and, more particularly, the invention pertains to a technique for easier and more reliable laying down solder of bumps on substrate conductors.

C4 is an advanced microelectronic integrated circuit packaging and connection technology. "C4" stands for "Controlled Collapse Chip Connection." C4 relates to the interrelation of "solder bumps" and "flip chips".

The basic idea of C4 is to connect integrated circuits, integrated circuit packages, or other such units to conductor strips or other like connections on substrates or integrated circuits by means of solder bumps partially flattened between two surfaces of the units. The tiny C4 bumps of electrically conductive solder may be arrayed on the surface of one unit and are pressed against metal pads on another unit to make one electrical connection at each solder ball. C4 allows all the connections to be simultaneously made in one step during a reflow operation.

A major application of C4 is in joining semiconductor microchips (integrated circuits) to integrated circuit packages or substrates. The integrated circuits typically are made in repeating rectangular arrays on a mono-crystalline disc of silicon, several inches (or centimeters) across, called a "wafer." Many integrated circuits are formed on each wafer before the integrated circuits are separated into single units. C4 bumps are placed on the metal terminals on the integrated circuits while they are still part of the wafer. Wafers are made as large as possible so as to make the most integrated circuits at once, and the integrated circuits are made as small as possible. The best C4 fabrication system is one that makes very small, closely-spaced solder bumps each precisely placed over a large area. Then the respective integrated circuits may be cut from and isolated from the larger wafer.

C4 is commercially important because it allows a very high density of electrical interconnections. C4 can be used with perimeter connection techniques, similar to tape automated bonding (TAB), but C4 connections can also be arrayed over surfaces. When an area is covered, the number of possible connections for a given size of a unit is roughly squared. C4 bumps are typically about a hundred microns in diameter and the connector density is on the order of several thousand per square inch (6.45 square centimeters).

C4 solder bumps must be and are rugged. A computer or other electronic devices, with dozens of integrated circuits and thousands of C4 solder bump connections, easily can be rendered nonfunctional if only one of the C4 bump connection fails.

One method of fabricating the C4 solder bumps on integrated circuits is by evaporation or vacuum deposition. In this process, terminal metals are first evaporated in a vacuum chamber and these metals are deposited on a wafer through a metal mask. This is followed by evaporation of solder metal, which is deposited through the metal mask on top of the terminal metals. The terminal metals form the ball limiting metallurgy (BLM) and the solder metals constitute the solder bumps.

As shown in FIG. 1, a C4 solder ball **10** (shown as a cross section) is deposited on a metal conductive pad or strip **12** situated on a surface **16** of wafer or substrate **14**. The

substrate might be polyimide, silicon (Si), quartz (SiO₂), ceramic, beryllium oxide (BeO) or other material. In place of the substrate may be a printed circuit board of appropriate material. Ball **10**, approximately ranging between 100 and 200 microns in diameter, is preferably composed of about 97 percent lead (Pb) and 3 percent tin (Sn). Pad or strip **12** may have a composition of one part palladium and two parts silver. Other compositions may be used. The solder may be electro-deposited in the form of a cylinder, and subsequently reflowed into bumps.

While adhesion pulls the molten solder drop outward, an opposing force of cohesion pulls it inward. Cohesion is the molecular attraction of a substance to itself. In a liquid it causes surface tension. The surface tension in the molten solder drop tries to reduce the drop's surface area and make it spherical. If the solder does not wet the conductive pad, layer or strip **12** at all, the solder will ball up into an almost-perfect sphere and barely touch the surface. The force of gravity is negligible for such small droplets because the surface area-to-volume ratio is inversely related to diameter. If the two forces of adhesion and cohesion are equal, the drop will take on the hemispherical shape shown by soap bubbles on a soapy table, where surface tension pulls equally in and out.

FIG. 2 is a schematic partial cross section of a flip chip **18** attached to the top of a chip carrier substrate **14**. A grid array of C4 solder joints **10** mechanically and electrically connect between an array of metal contacts **20** on flip-chip **18** and a mirror image array of metal contacts **12** on top side **16** of substrate **14**.

The related art design involves performing a flip chip **18** attachment on a thick film hybrid circuit of substrate **14** using the C4 solder bump process. This process requires the hybrid circuit design to include C4 solder pads **12** that match the flip chip die **18** solder pads **20**. Solder pads **12** and **20** must maintain specific dimensions (i.e., 8 to 11 mils or 200 to 280 microns in diameter) in order for the C4 process to be properly accomplished. Solder pads that are too large may result in solder from the pad causing a short to an unpassivated edge on die **18**. Solder pads that are too small may cause die placement problems as well as reliability problems for the resultant circuit. C4 pads **12** consist of a thick film conductor material **11** that has been passivated by a dielectric or encapsulant **22** with an opening in it to create a pad **12**. The screen printed encapsulant material is designed to flow and close pin holes or slits caused by the printing processes. This property of the encapsulant material inhibits the forming of small C4 pad openings over the conductor material. To minimize the problems with the encapsulant flow, the C4 pads are located on the circuit by creating a series of square pads out of conductor and glass encapsulant (see FIG. 3).

FIG. 3 reveals the related art C4 solder pad design. By applying an encapsulant **22** with a rectangular opening **24**, the ends are allowed to flow while the area that creates C4 pads **12** is monitored. This reduces the problem of encapsulant flowing, but does not eliminate it. These square pads **12** are designed to be aligned with octagonal pads **20** on flip chip **18**. When solder is applied to pads **20** on flip chip **18**, they take on a round shape. The solder on the thick film circuit has a square shape at the base and a round shape at the top. Proper registration of the bumps relative to one another, as well as size, is critical so that the die can be positioned properly during the C4 bump reflow process.

SUMMARY OF THE INVENTION

The present invention pertains to the using of a diffusion patterning encapsulant to create a C4 bump pad on thick film

hybrid circuits. This invention has particular relevance to the production of automotive and commercial solid state sensors.

Currently, the size of the pads and their location are determined by two thick film printing processes for conductors **11** and glass encapsulant **22**. The conductors are printed first and the width of the lines for the C4 solder pads are measured and preferably maintained between **8** and **11** mils (200 and 280 microns). The extent of this dimension may range from 5 to 15 mils (125 to 380 microns). FIG. **4** illustrates the conductor **11** and encapsulant **22** components for C4 solder pads **12**.

The next step is the applying of a glass encapsulant layer **22**. The encapsulant is applied with a rectangular opening or window **24** that creates a solder pad **12** on conductor **11** (see FIG. **4**). The window should also be held dimensionally between 8 and 11 mils (200 and 280 microns). The extent of this dimension may range from 5 to 15 mils (200 to 280 microns). Holding these dimensions is very difficult since encapsulant material **22** was designed to flow and close small openings. The combination of these two layers (i.e., conductor **11** and encapsulant **22** layers) creates square solder pads **12** for the C4 bumps **10**.

This design relies on controlling two processes which occur at different times with different materials. That is, one has to control the width of conductor strips **11** and control the width of the slits or openings **24** of glass **22** encapsulated over conductors **11** to be soldered, so as to create a specified diameter for a solder bump **10**. Skewed distributions can create solder pads that are rectangular in shape if a conductor **11** print is narrow and an encapsulant **22** print is wide or vice versa.

The answer to this problem is noted in the following description. Instead of relying on two materials and processes that are combined to create the C4 solder pads, one replaces them with a diffusion patterning encapsulant material that is capable of creating an opening between 8 and 11 mils (200 and 280 microns). The first step of printing the conductor **11** material remains the same except that the line width for the C4 pad is not required to be held to a specific dimension. Conductor **11** can be designed at least fifty percent larger than is required for C4 pad **12**. Once the conductor **11** material is in place, a diffusion patterning encapsulant **22** is applied to the circuit. Encapsulant **22** is a continuous glass layer covering the entire circuit. Once the material is dried at about 150 degrees Centigrade, a patterning material **26** is screen printed onto encapsulant **22**. The screen mask for this layer has a round shape for the C4 pads, and provides for their locations and approximate sizes. Once patterning material **26** is applied, the circuit passes through a dryer and material **26** diffuses into encapsulant **22**. After the drying/diffusing process, the resultant diffused portion is water soluble. That portion is rinsed with water and the diffused material washes away. The final step is to fire the remaining encapsulant at approximately 525 degrees Centigrade. What remains on the circuit is an encapsulant with C4 pads **12** having openings between 8 and 11 mils (200 and 280 microns) in diameter. The diffusion process of the present invention enables one to precisely and accurately make an opening or hole having a desired dimension. FIG. **5A** shows diffusion patterning designed C4 solder pads **12** with conductors **11**, encapsulant **22** and patterning **26** components. FIG. **5B** is a cross-sectional view of FIG. **5A**.

The only layer that requires dimensional process control is patterning layer **26** versus controlling dimensions for both the conductor **11** and encapsulant **22** layers of the old

process. Encapsulant **22** creates passivation for all sides of the C4 pad and the round shape of C4 pad **12**. This process creates a better match to flip chip **18** pads **20** than did the square pads from the old conductor/encapsulant process.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross section of a C4 solder ball on a conductor of a substrate.

FIG. **2** shows a C4 solder mounting of a flip chip on a substrate.

FIG. **3** shows the related art C4 solder pad design.

FIG. **4** reveals the conductor and encapsulant components for the C4 solder pads.

FIGS. **5A**, **5B**, **5C**, **5D**, **5E** and **5F** indicate the diffusion patterning, washing out and insertion of solder bumps for the C4 solder pads to connect with a flip chip.

DESCRIPTION OF THE EMBODIMENT

The following lists the diffusion patterning steps for C4 bump pads **12**. Starting with a 96 percent Alumina ceramic substrate **14**, a palladium silver conductor **11** is screen printed, dried, and fired. A DUPONT 6474 Pd/Ag conductor **11** is preferred, but any silver based conductor can be used. Conductor **11** is a paste that is screen printed on ceramic substrate **14**. Paste **11** is dried at 150 degrees C. for 10 minutes and fired at 850 degrees for 10 minutes using a standard 30 minute furnace profile. In the previous process, the width of the printed line **11** in the area of C4 bump pads **12** had to be monitored and controlled between 8 and 11 mils (200 and 280 microns). The new process does not have this requirement, so conductor lines **11** may and are generally designed and printed wider than necessary. This allows for variations in alignment without adversely affecting the reliability of the resultant product.

The next step is to apply an overglaze material **22** (or encapsulant). The previous process, as noted in FIG. **4**, consisted of printing DUPONT 9137 encapsulant **22** over the conductor material **11**. An opening, or window **24**, was created in the pattern to create a C4 bump solder pad **12** using the conductor lines that were previously printed. Window opening **24** in encapsulant **22** was monitored and controlled between 8 and 11 mils (200 and 280 microns). When the part was finished, the conductor line **11** width in combination with the encapsulant window opening **24** had to result in a square C4 bump pad **12** with dimensions between the 8 and 11 mils (200 and 280 microns) in order to be a satisfactory result.

The new process involves an experimental DUPONT encapsulant **22** (E89384-51) that is applied as a continuous layer over the conductor **11** pattern, and then dried at 150 degrees Centigrade for 10 minutes. Next, DUPONT Q95IP is screen-printed on dried encapsulant **22**. The pattern that is applied resembles a series of round dots of material **26**, as shown in FIGS. **5A** and **5B**. The locations of these dots match the locations of the solder bumps on the corresponding flip chip. The next step is to diffuse the Q95IP into the encapsulant **22** with a dryer according to a developed drying time verses temperature curve or table to obtain a particular diameter of the hole for pad **12**. In the present case, one heats the diffusing mixture for 8 minutes at 85 degrees Centigrade (C.). Once the material has diffused, the areas of round deposits **26** of Q95IP are soluble in water. A washout process, with water, is used to rinse away image **26** that was created with the Q95IP. The pattern that is left behind is a hole in the encapsulant that is preferably from 8 to 11 mils

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(200 and 280 microns) in diameter which is located over a conductor line **11** or pad **12**, as shown in FIG. **5C**. The next step is to fire the encapsulant at 525 degrees C. for 30 seconds in a conveyor furnace. Since encapsulant **22** has a round hole, the conductor **11** or pad **12** material is no longer required to be strictly controlled to a specific width. Solder balls **10** may be placed in the holes on bump pads **12**, as indicated by FIG. **5D**, or may be reflowed on to the pads. The solder ball is heated just enough (above its molten temperature) to adhere to conductor **11** and become a bump **10**, as shown in FIG. **5E**. The solder has a composition of 10 percent tin, 88 percent lead and 2 percent silver. Solder bumps **10** are covered with flux. Terminals **20** of flip chip **18** may be brought into contact with solder bumps **10**. Solder bumps **10** and terminals **20** are reflowed at 320 degree C. for 20 seconds so that the terminals are attached securely to the solder bumps, thereby resulting in the attachment of flip chip **18** to substrate **14**, as revealed in FIG. **5F**. Solder balls **10** typically are heated or reflowed into bumps on pads **12** of conductive material **11** prior to the attachment of flip chip **18**.

The old process required both conductor lines **11** and encapsulant windows **24** to be monitored for attaining specific dimensions. If these dimensions were exceeded, solder could result in a short circuit of a conductor **11** or pad **12** to the edge of flip chip **18** placed on pads **12**. The new process only requires encapsulant **22** be monitored since just a round hole is created for each of C4 bump pads **12**.

While the invention has been described in terms of two exemplary embodiments, it is contemplated that it may be practiced as outlined above with modifications within the spirit and scope of the appended claims.

We claim:

1. A C4 bump pad process comprising:
 - situating at least one conductor strip on a substrate surface;
 - laying down an encapsulant on the at least one conductor strip and the substrate surface;
 - applying an imaging paste on the encapsulant situated over a portion of the at least one conductor strip to define a bump pad area;
 - drying the imaging paste, wherein the imaging paste diffuses into the encapsulant resulting in a paste-diffused encapsulant; and
 - washing out the paste-diffused encapsulant from the substrate, which results in an opening through the encapsulant to the at least one conductor strip, resulting in a bump pad formed on the at least one conductor strip.
2. The bump pad process of claim 1, wherein:
 - the substrate is ceramic;
 - the at least one conductor strip is partially composed of silver; and
 - the encapsulant is a glass.
3. The bump pad process of claim 2, wherein the bump pad has a linear dimension from 5 to 15 mils (125 to 380 microns).
4. The bump pad process of claim 2, wherein the at least one conductor strip is made from a Pd/Ag material.
5. The bump pad process of claim 4, wherein a solder ball is placed on the bump pad.

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6. A C4 bump pad process comprising:
 - screen printing a conductor on a substrate;
 - applying an overglaze material on the conductor and substrate;
 - screen printing an imaging paste delineating an area for a bump pad over the conductor on the overglaze material;
 - diffusing the imaging paste into the overglaze material; and
 - washing out the diffuse imaging paste and overglaze material, resulting in a hole through the overglaze material to make a bump pad on the conductor.
7. The bump pad process of claim 6, wherein said substrate comprises beryllium oxide.
8. The bump pad process of claim 6, further comprising placing a solder ball in the hole on the bump pad.
9. The bump pad process of claim 8, wherein:
 - the substrate is ceramic;
 - the conductor is partially composed of silver; and
 - the overglaze material is a glass.
10. The bump pad process of claim 9, wherein the hole has a linear dimension from 5 to 15 mils (125 to 380 microns).
11. The bump pad process of claim 8, wherein the solder ball is partially melted so as to take the shape of a bump on the bump pad.
12. The bump pad process of claim 11, further comprising:
 - attaching a terminal of a flip chip to the solder ball; and
 - heating the solder ball and the terminal of the flip chip to the extent that the terminal attaches to the solder ball.
13. A C4 bump pad process comprising:
 - putting an encapsulant layer on a substrate having conductive areas;
 - designating bump pad areas on the conductive areas by applying an imaging paste on the encapsulant layer;
 - heating the imaging paste so that the imaging paste diffuses into the encapsulant resulting in a water-soluble paste-diffused encapsulant; and
 - washing out the paste-diffused encapsulant over the bump pad areas, resulting in openings through the encapsulant to construct the bump pads on the conductive areas.
14. The bump pad process of claim 13, further comprising placing a solder ball on each of the bump pads.
15. The bump pad process of claim 14, further comprising:
 - situating terminals of a flip chip on the solder balls; and
 - heating the solder balls to the extent that the solder balls attach to the terminals of the flip chip and to the bump pads on the conductive areas.
16. The bump pad process of claim 15, wherein the bump pad has a linear dimension between 5 and 15 mils (i.e., 125 and 380 microns).
17. The bump pad process of claim 16, wherein the conductive areas comprise some silver.
18. The bump pad process of claim 17, wherein the encapsulant is a glass.
19. The bump pad process of claim 18, wherein the substrate is a ceramic.

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