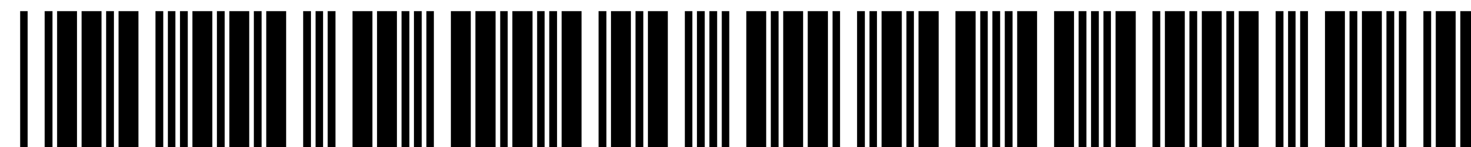

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(54) **LOW-COST CIRCUIT BOARD MATERIALS AND PROCESSES FOR AREA ARRAY ELECTRICAL INTERCONNECTIONS OVER A LARGE AREA BETWEEN A DEVICE AND THE CIRCUIT BOARD**

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(51) **Int. Cl.**
H01L 23/02 (2006.01)

(52) **U.S. Cl.** **257/678**; 257/700; 257/701; 257/690; 257/707; 257/717; 257/724; 257/778; 438/110; 438/112; 438/121; 438/122; 438/113; 438/612

(58) **Field of Classification Search** 361/760; 257/678, 700, 701, 690, 707, 717, 724, 778; 438/112, 110, 121, 122, 113, 612; 345/80, 345/903, 76; 313/506, 503, 498
See application file for complete search history.

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Primary Examiner—Steven J Fulk

(57) **ABSTRACT**

An electronic device and coupled flexible circuit board and method of manufacturing. The electronic device is coupled to the flexible circuit board by a plurality of Z-interconnections. The electronic device includes a substrate with electronic components coupled to it. The substrate also has a plurality of device electrical contacts coupled to its back surface that are electrically coupled to the electronic components. The flexible circuit board includes a flexible substrate having a front surface and a back surface and a plurality of circuit board electrical contacts coupled to the front surface of the flexible substrate. The plurality of circuit board electrical contacts correspond to plurality of device electrical contacts. Each Z-interconnection is electrically and mechanically coupled to one device electrical contact and a corresponding circuit board electrical contact.

47 Claims, 9 Drawing Sheets

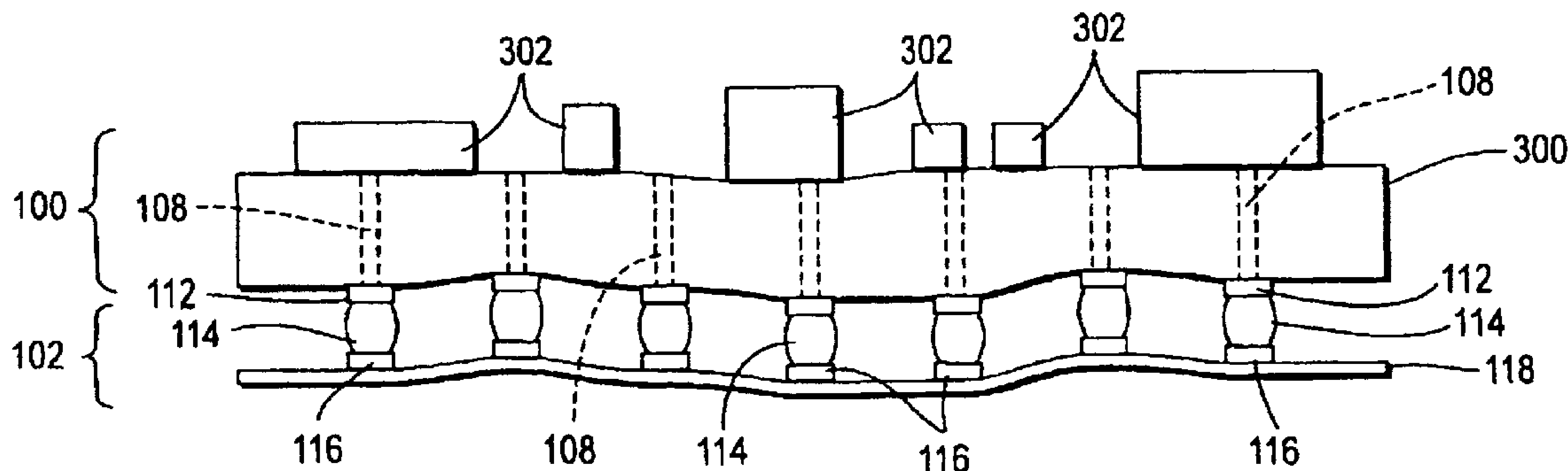

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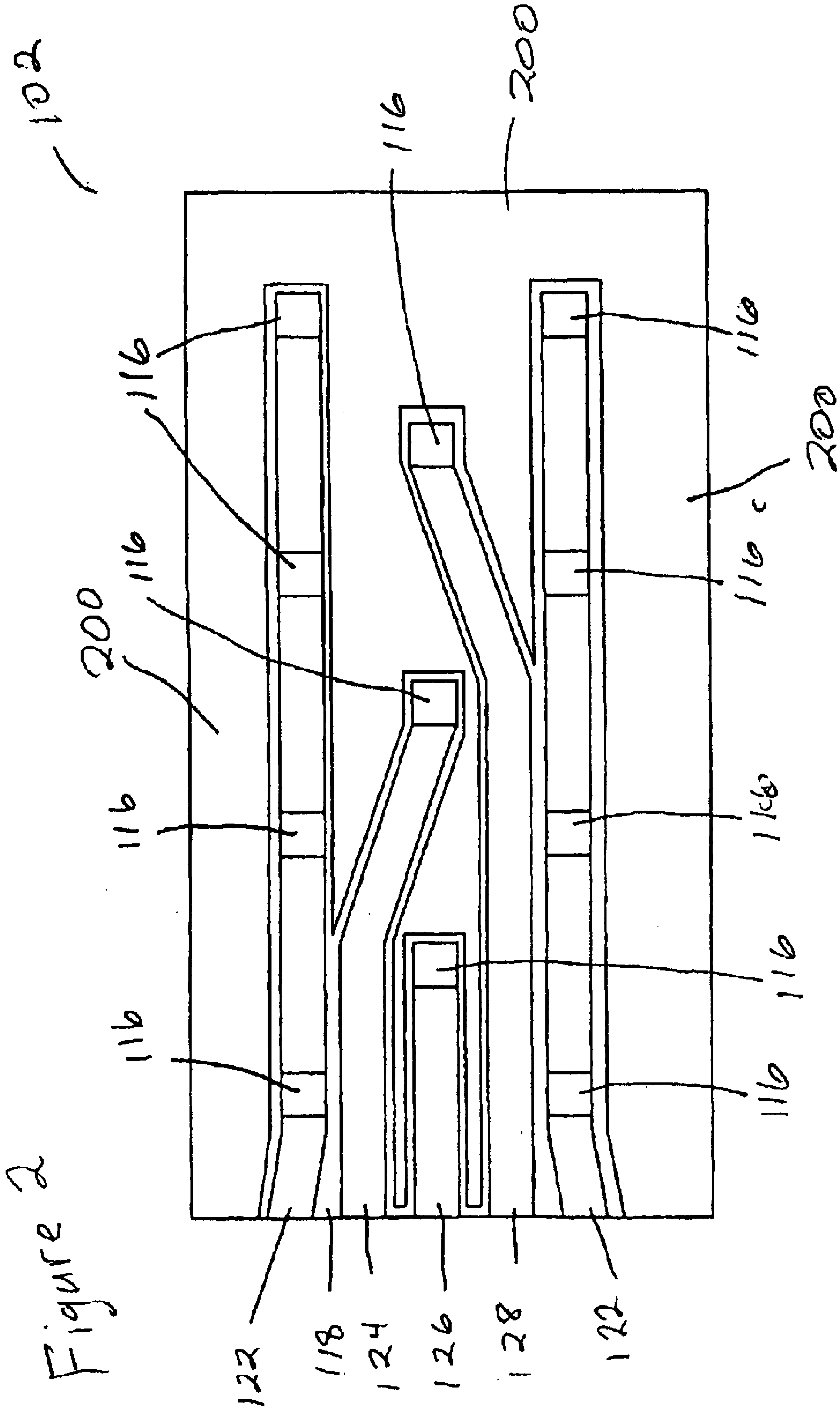
Figure 1A

Figure 1B


102
200
116
200
200
116
116
116
116
116
116
116
116
116
116
122
118
124
126
128
122
Figure 2

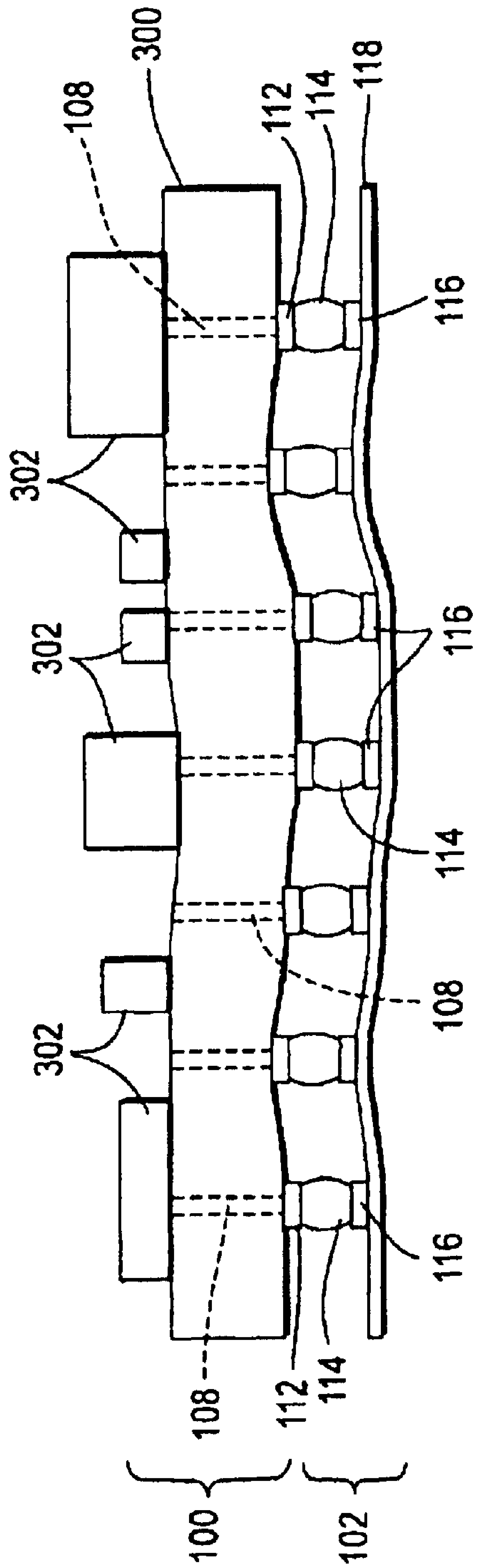


FIG. 3A

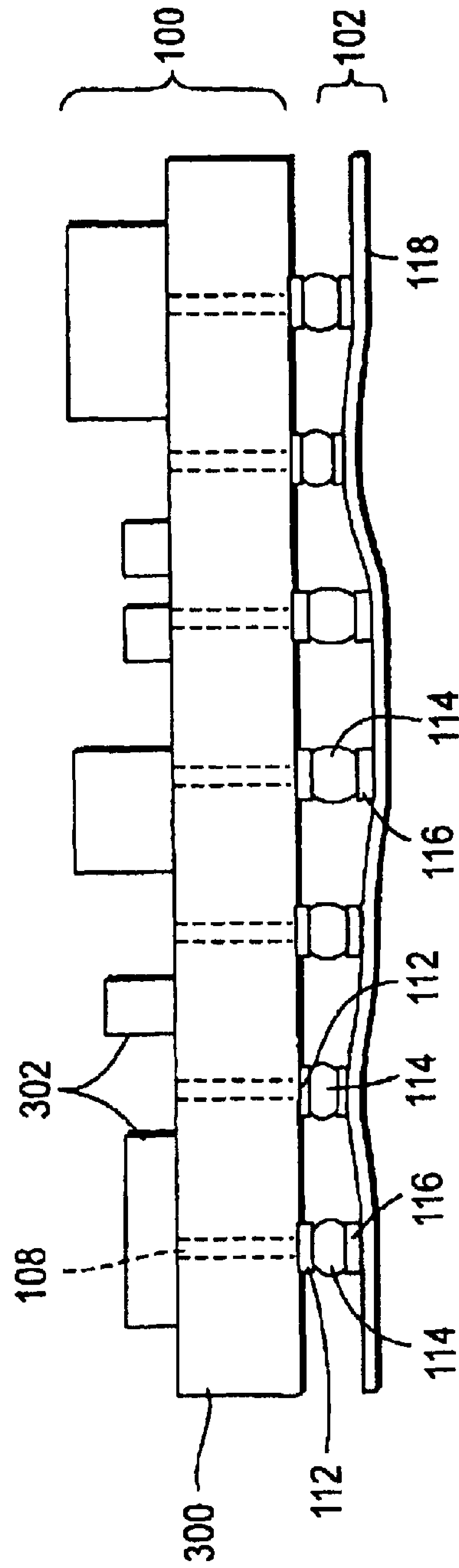


FIG. 3B

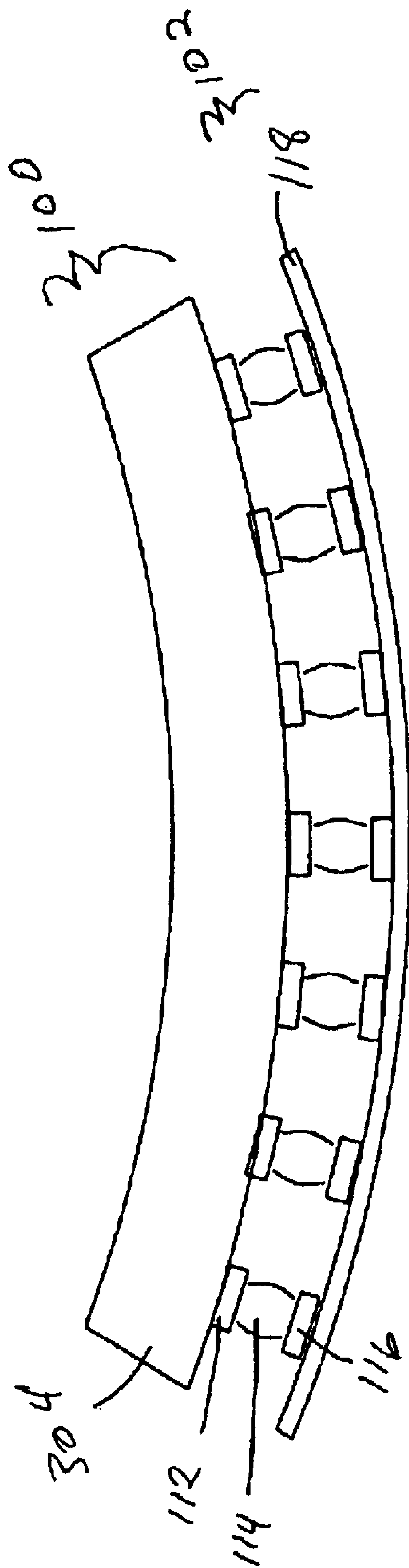


Figure 3C

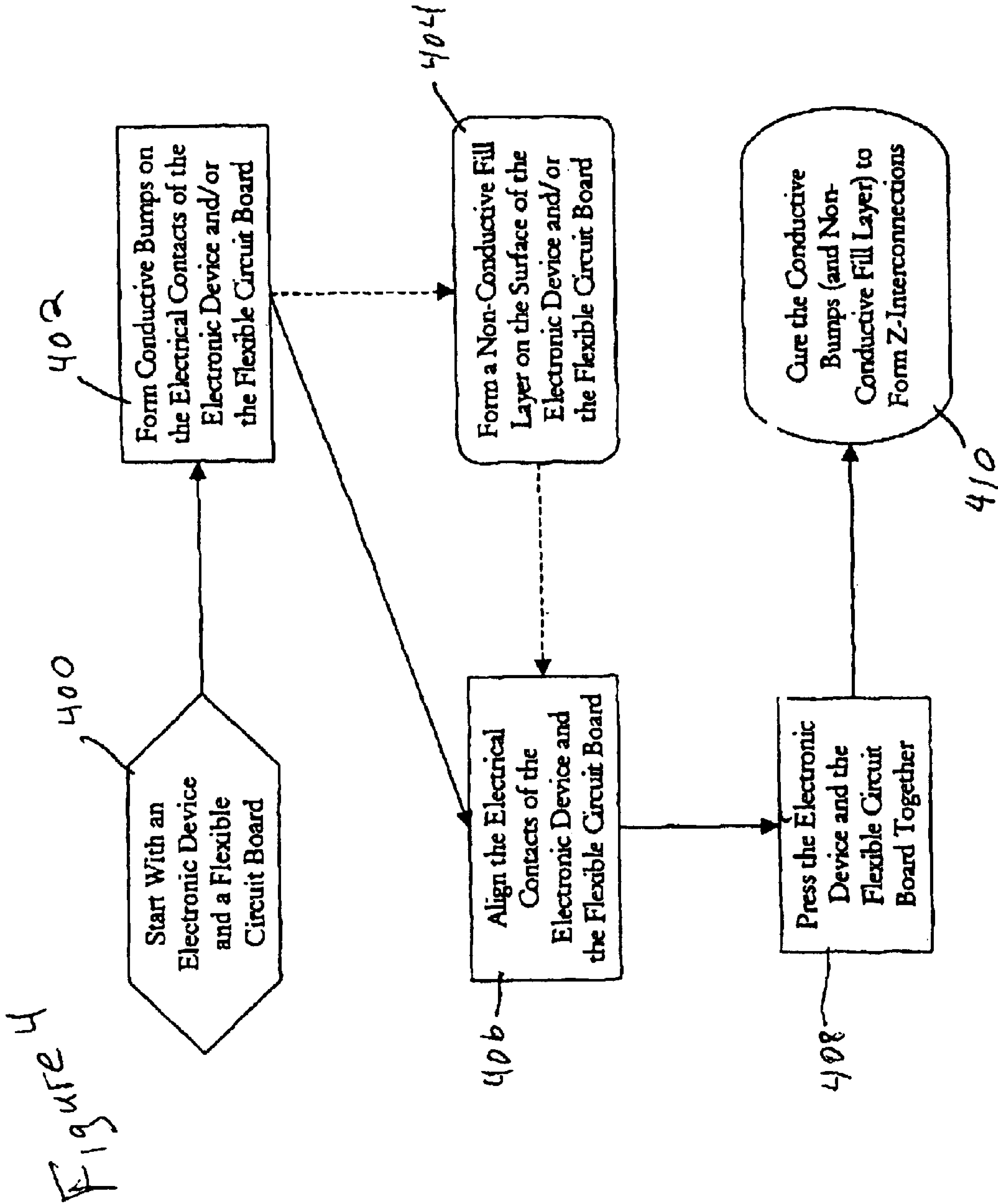


Figure 4
400
Start With an Electronic Device and a Flexible Circuit Board
402
Form Conductive Bumps on the Electrical Contacts of the Electronic Device and/or the Flexible Circuit Board
404
Form a Non-Conductive Fill Layer on the Surface of the Electronic Device and/or the Flexible Circuit Board
406
Align the Electrical Contacts of the Electronic Device and the Flexible Circuit Board
408
Press the Electronic Device and the Flexible Circuit Board Together
410
Cure the Conductive Bumps (and Non-Conductive Fill Layer) to Form Z-Interconnections

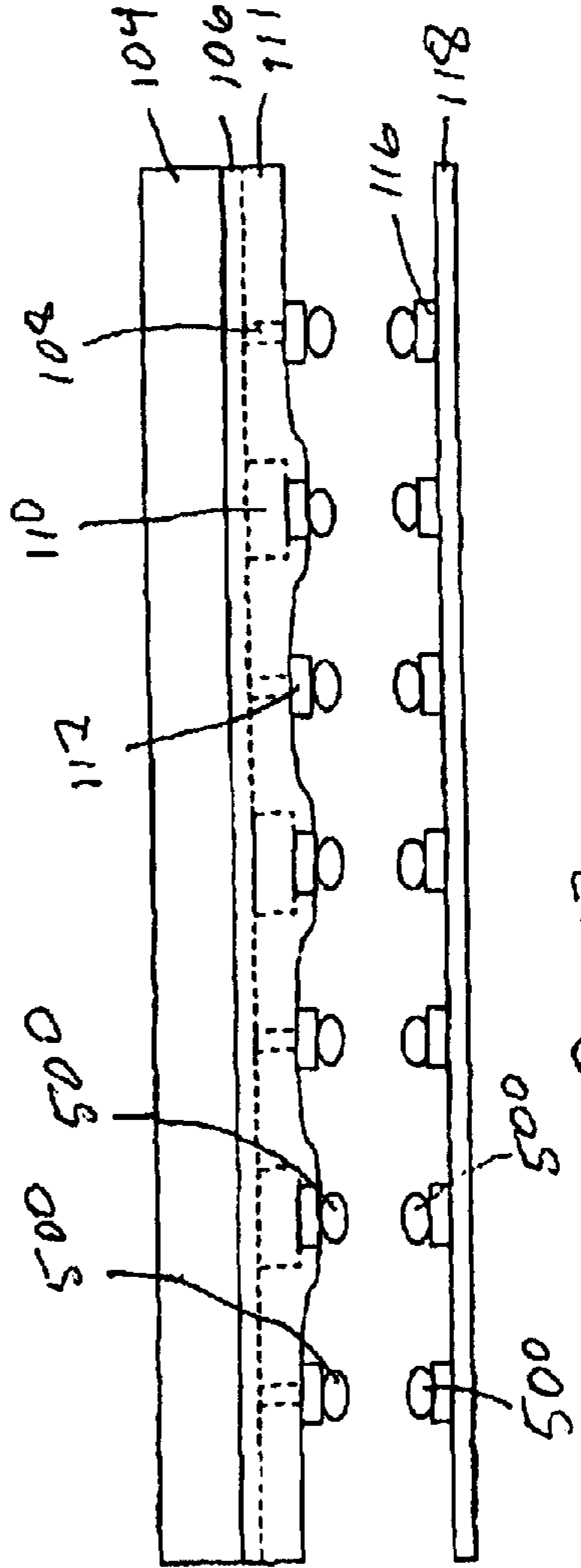


Figure 5A

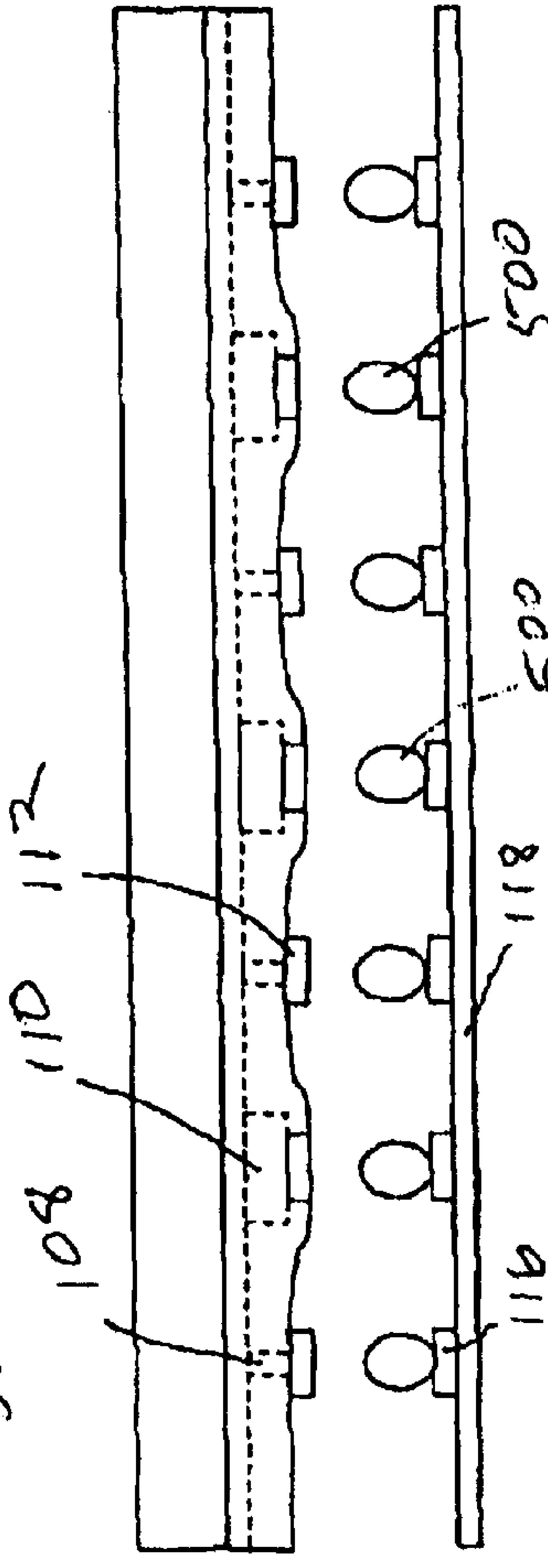


Figure 5B

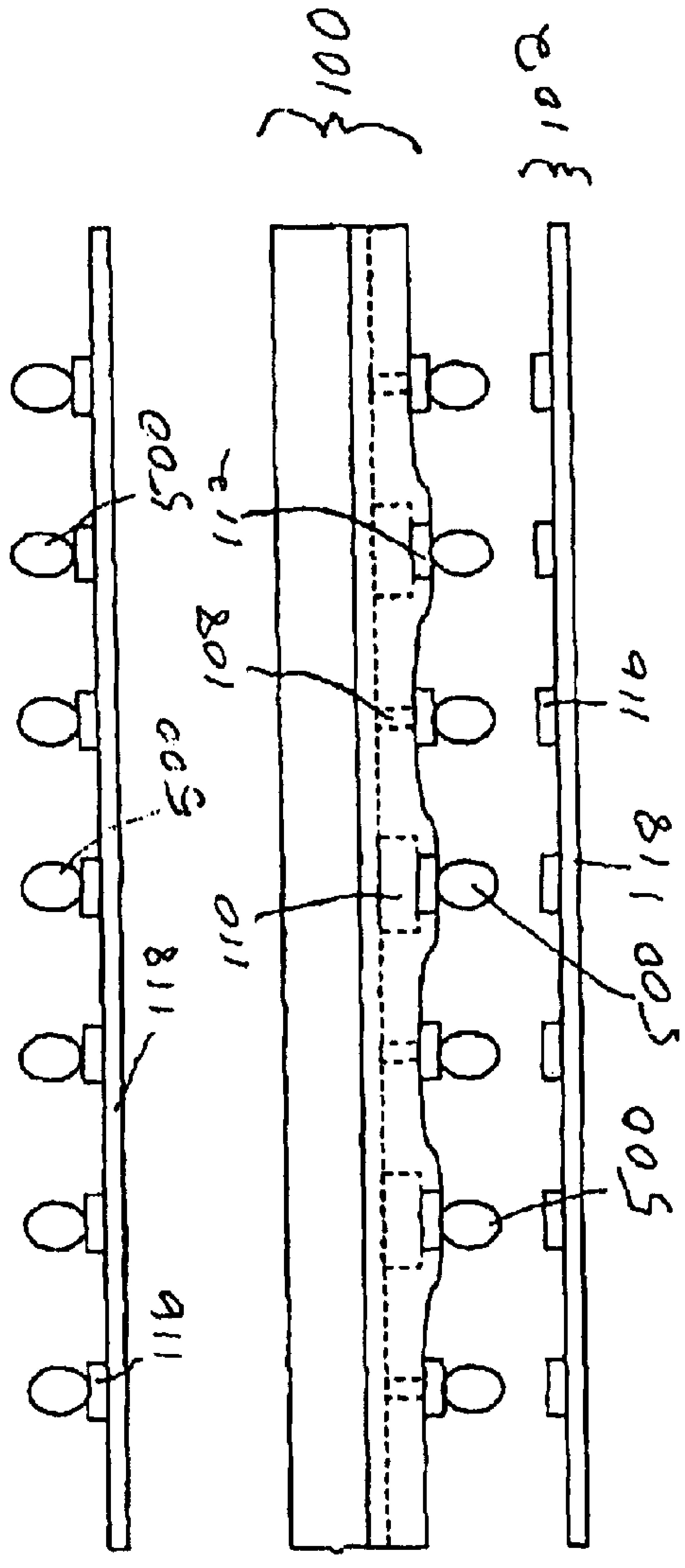


Figure 5C

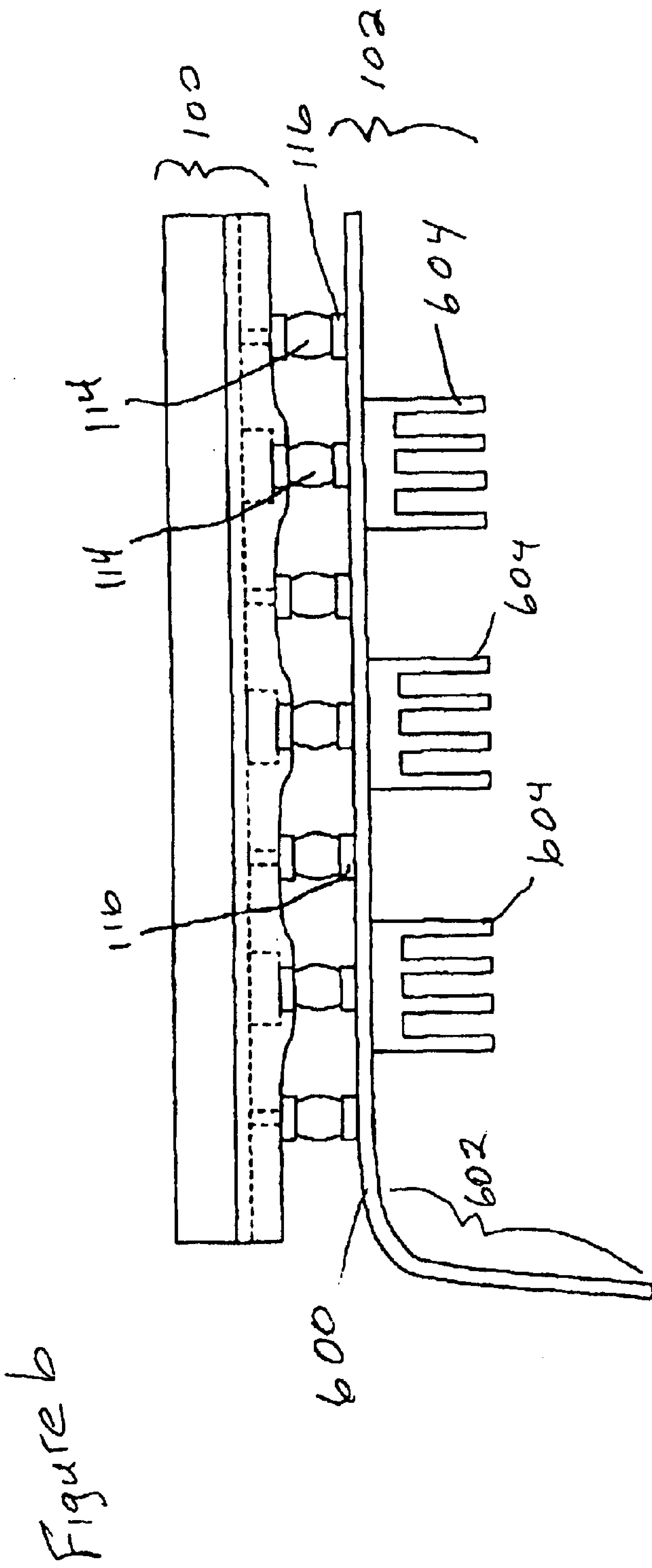


Figure 6
100
102
116
604
114
114
604
604
116
602
600

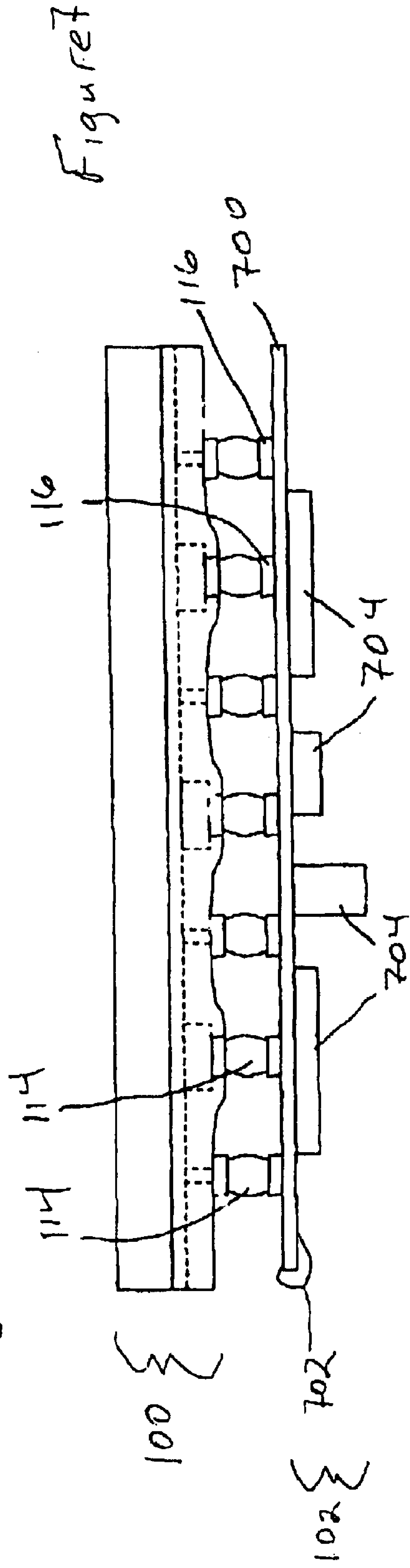


Figure 7
700
116
116
704
704
704
704
114
114
100
702
102

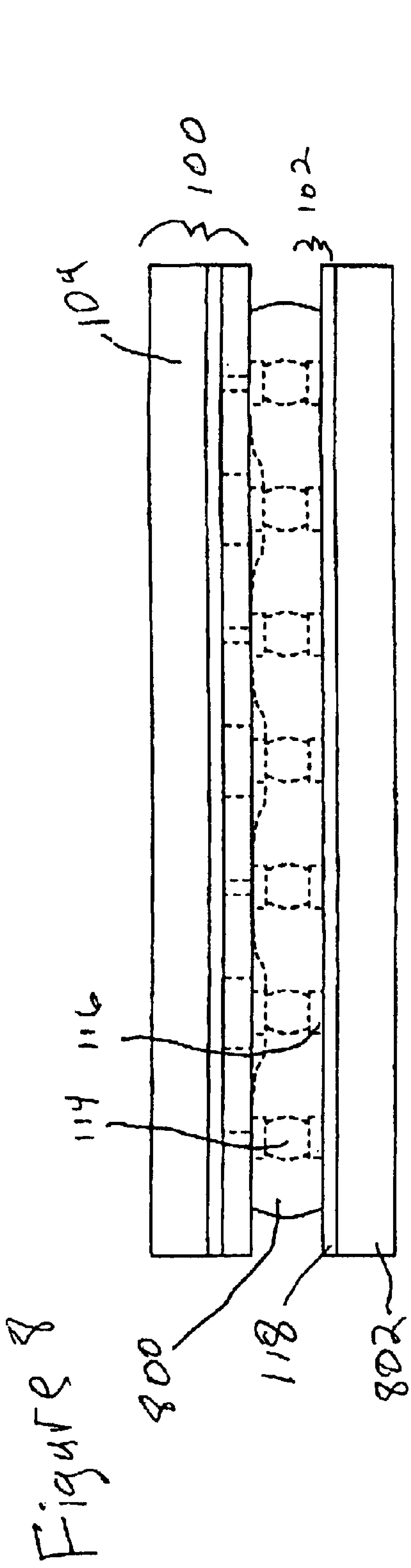


Figure 8
100
102
104
114
116
800
118
802

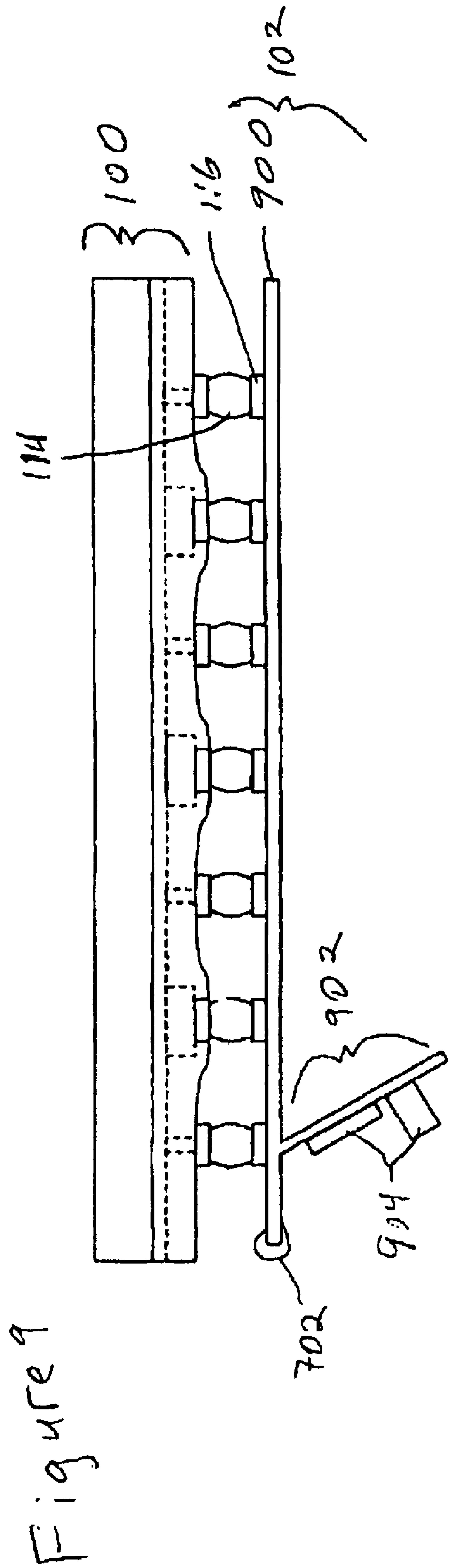


Figure 9
100
116
900
102
114
902
904
702

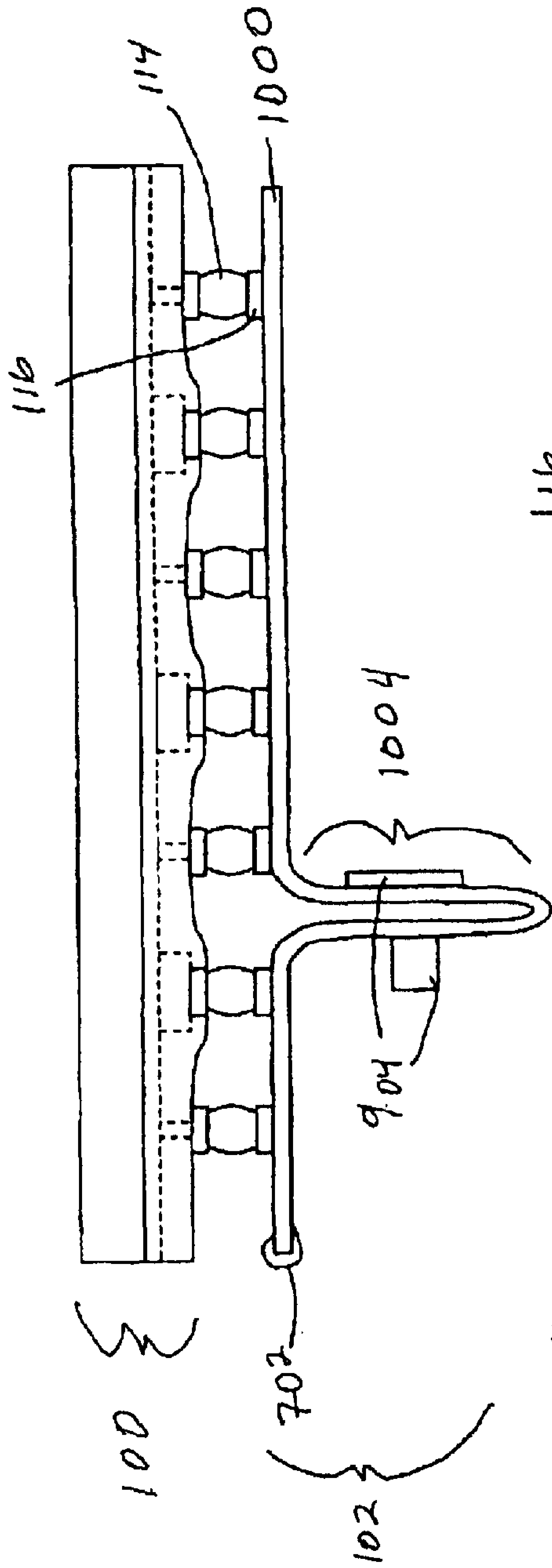


Figure 10A
100
102
702
904
1004
116
114
1000

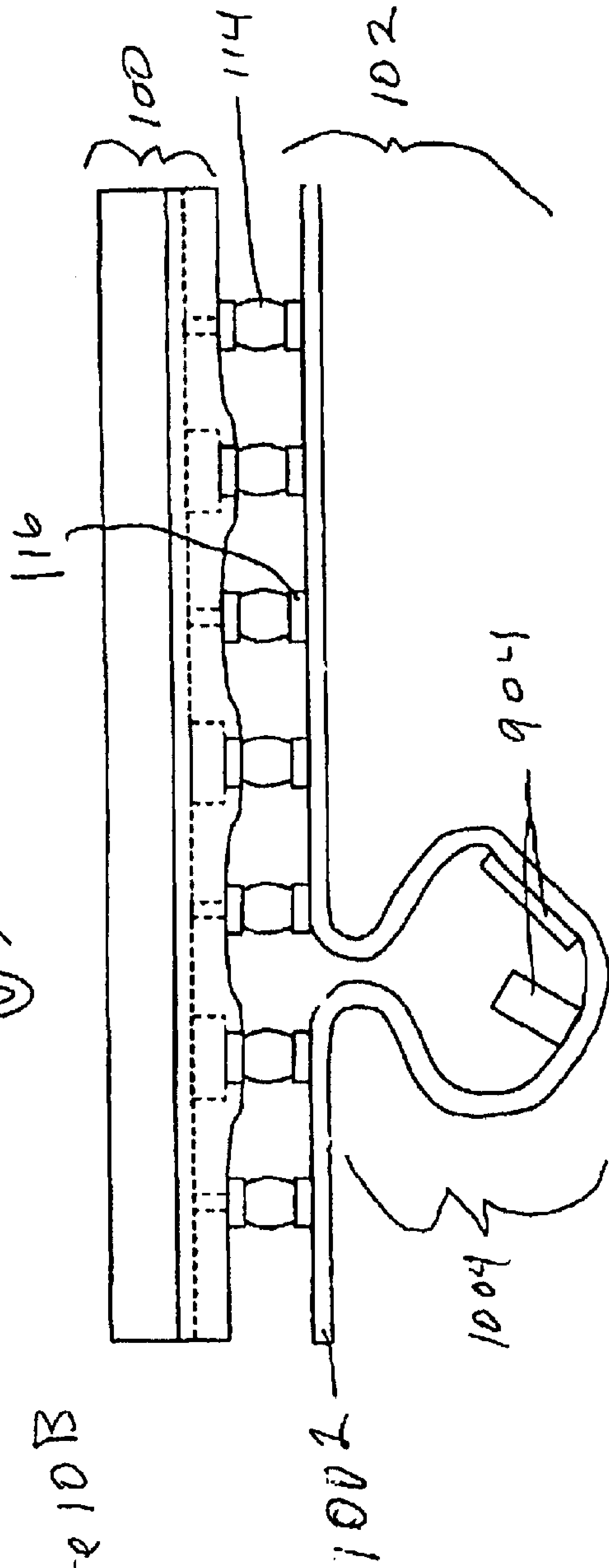


Figure 10B
1002
1004
904
116
100
114
102

LOW-COST CIRCUIT BOARD MATERIALS AND PROCESSES FOR AREA ARRAY ELECTRICAL INTERCONNECTIONS OVER A LARGE AREA BETWEEN A DEVICE AND THE CIRCUIT BOARD

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/379,456, filed May 10, 2002, the contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

This invention is in the field of electronic device circuit boards and interconnections, and specifically relates to the use of Z-interconnections with flexible circuit boards.

BACKGROUND OF THE INVENTION

The use of short interconnection normal to the surfaces of circuit boards (Z-interconnections) is one method to desirably create space saving multi-layer circuit board configurations. For example, in sufficiently complex devices, the number and complexity of the desired interconnections may make the use of a multiple layer circuit board design desirable. Matrix array devices, such as are often found in pixel-based detector and display applications, may also desirably include multiple circuit board configurations coupled using Z-interconnections.

Area array electrical Z-interconnections over relatively large areas (squares of 4 to 6 inches per side) may be particularly desirable to build display modules that could be utilized in the construction of large-area seamless displays, or relatively large area, high-resolution detector arrays. For seamless integration, it is desirable for all electrical connections from the display panel (device in this application) to the circuit board to be made within the space between the device and the circuit board, because the device is covered with display elements almost all the way to the edges. There may be insufficient inactive area at the edges of the device for electrical connections.

Therefore, low cost circuit board materials and processes for forming substantially identical Z-interconnections throughout the large area module are desirable. Achieving high yields and long-term reliability of those interconnections are also desirable.

For example, in the current fabrication of displays based on organic light emitting diode (OLED) as the active element, it is sometimes considered necessary to hermetically seal the circuit board to the device. This is because the primary passivation on the device provided by some device manufacturers are not adequate. Therefore, display module manufacturers use more expensive rigid inorganic circuit board materials such as multi-layer alumina ceramic board that can provide a hermetic cover to the device. A sequential screen printing of conducting (noble metal) layers and insulating layers on a pre-fired, laser-drilled alumina ceramic is used to achieve the circuit precision needed for large area circuits. Due to the relatively lower circuit density of these boards, several layers of metallization may be needed to accomplish the needed circuit routing. These factors result in high materials and production cost in making these circuit boards for back panel applications.

SUMMARY OF THE INVENTION

One embodiment of the present invention is an electronic device and coupled flexible circuit board. The electronic device is coupled to the flexible circuit board by a plurality of Z-interconnections. The electronic device includes a substrate with electronic components coupled to it. The substrate also has a plurality of device electrical contacts coupled to its back surface that are electrically coupled to the electronic components. The flexible circuit board includes a flexible substrate having a front surface and a back surface and a plurality of circuit board electrical contacts coupled to the front surface of the flexible substrate. The plurality of circuit board electrical contacts correspond to plurality of device electrical contacts. Each Z-interconnection is electrically and mechanically coupled to one device electrical contact and a corresponding circuit board electrical contact.

Another embodiment of the present invention is a method of manufacturing the exemplary an electronic device and coupled flexible circuit board. The exemplary method includes providing the electronic device and the flexible circuit board. A plurality of conductive bumps are formed on at least one of the electronic device and the flexible circuit board. For each device electrical contact, a conductive bump is formed on that device electrical contact, the corresponding circuit board electrical contact, or both. The plurality of device electrical contacts of the electronic device and the corresponding plurality of circuit board electrical contacts are aligned and the electronic device and the flexible circuit board are bonded together such that the conductive bumps contact the corresponding conductive bumps or electrical contact. The conductive bumps are then cured to form Z-interconnections, electrically and mechanically coupling the device electrical contacts to the corresponding circuit board electrical contacts.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is best understood from the following detailed description when read in connection with the accompanying drawing. It is emphasized that, according to common practice, the various features of the drawing are not to scale. On the contrary, the dimensions of the various features are arbitrarily expanded or reduced for clarity. Included in the drawing are the following figures:

FIG. **1**A is a side cut-away drawing of an exemplary electronic device and coupled flexible circuit board, cut along line **1**A–**1**A of FIG. **1**B.

FIG. **1**B is a top plan drawing of the exemplary electronic device and coupled flexible circuit board of FIG. **1**A.

FIG. **2** is a top plan drawing of an exemplary flexible circuit board layout for the flexible circuit board of FIGS. **1**A and **1**B.

FIGS. **3**A, **3**B, and **3**C are side cut-away drawings illustrating exemplary advantages of a flexible circuit board, cut along line **1**A—**1**A of FIG. **1**B.

FIG. **4** is a flowchart illustrating an exemplary method of manufacture of the exemplary electronic device and coupled flexible circuit board of FIGS. **1**A and **1**B.

FIGS. **5**A–C are side cut-away drawings of alternative exemplary electronic device and coupled flexible circuit boards during manufacture according to the flowchart of FIG. **4**, cut along line **1**A—**1**A of FIG. **1**B.

FIGS. **6**, **7**, **9**, **10**A and **10**B are side cut-away drawing of alternative exemplary electronic devices and coupled flexible circuit boards, cut along line **1**A—**1**A of FIG. **1**B.

FIG. **8** is a side plan drawing of an additional exemplary electronic device and coupled flexible circuit board.

DETAILED DESCRIPTION OF THE INVENTION

The present invention involves low cost circuit board materials and processes for achieving high yields and long-term reliability of electrical interconnections between a large-area device and a circuit board.

High interest in OLED displays has led to considerable R & D activity in this area. Some of this effort has been directed towards hermetic integral passivations on the front panel. Such a passivation is desirable to allow the use of non-hermetic back panel materials. Among the possible non-hermetic back panel materials low cost organic-based circuit board materials offer a number of advantages, such as improved processes for forming substantially identical interconnections throughout the large area module and achieving high yields and long-term reliability of those interconnections. Flexible circuit boards based on polyimide (for example Kapton from DuPont), polyester (for example Mylar from DuPont), and various laminated structures of these families of materials may be particularly desirable. Laminate materials with built-in gas (moisture, oxygen) barrier layers, such as DuPont Mylar 250 SBL 300, may be used in applications where having this barrier is desirable for the back panel.

FIGS. **1**A and **1**B illustrate an exemplary electronic device **100** and flexible circuit board **102** according the present invention. Substrate **104** of electronic device **100** is not shown in FIG. **1**B for illustration purposes. Although exemplary electronic device **100** shown in these Figures, as well as in FIGS. **5**A–C, **6**, **7**, **8**, **9**, **10**A and **10**B, is shown as an exemplary six pixel electro-optic array, this in merely illustrative of a possible electronic device and should not be construed as a limitation. Other electro-optic arrays or electronic devices, such as those shown in FIGS. **3**A and **3**B including a plurality of electronic components **302** mounted on drilled substrate **300**, may be used as well.

The exemplary electro-optic device shown in FIGS. **1**A, **1**B, **5**A–C, **6**, **7**, **8**, **9**, **10**A, and **10**B includes substrate **104**, column electrode **106**, active material **110**, passivation layer **111**, and row electrodes **120**. Device electrical contacts **112** are arranged on the back surface of the device to allow electrical coupling of the row and column electrodes to the flexible circuit board. These device electrical contacts may be directly coupled to the row electrodes and may be electrically coupled to the column electrodes through passivation layer **111** by vias **108**.

Desirably substrate **104** is formed of a substantially transparent material such as float glass, quartz, sapphire, acrylic, polyester, polyimide or a laminate of these materials. Column electrodes **106** desirably include a substantially transmissive, conductive material such as indium tin oxide, thin gold, polyaniline, or a combination. Row electrodes **120**, device electrical contacts **112**, and vias **108** are desirably formed of a conductive material such as aluminium, aluminum-calcium, gold, silver, copper, nickel, titanium, tungsten, platinum, germanium, polyaniline, polyamide, polysilicon, or a combination thereof. It may be desirable for row electrodes **120**, device electrical contacts **112**, and vias **108** to be formed of the same material. Active material **110** may be formed of semiconductor layers and/or organic polymer layers to form the light emitting or absorbing portion of electro-optic pixel components, such as liquid crystal displays, OLED's, light emitting diodes, and photodetectors.

Flexible circuit board **102** includes flexible substrate **118**, circuit board contacts **116**, and a number of electrical traces formed on the front surface of flexible substrate **118**. These electrical traces include column electrical traces **122** and row electrical traces **124**, **126**, and **128**. In one exemplary embodiment, the row electrical traces **124**, **126**, and **128** may be used to provide operational power for different colors of pixels. For example, row electrical traces **124** may be coupled to red pixels, row electrical traces **126** may be coupled to blue pixels, and row electrical traces **128** may be coupled to green pixels.

Flexible substrate **118** may desirably be formed of a flexible organic substrate material such as polyester, polyimide or a laminate of these materials. Electrical traces **122**, **124**, **126**, and **128** and circuit board electrical contacts **116** are desirably formed of a conductive material such as aluminum, aluminum-calcium, gold, silver, copper, nickel, titanium, tungsten, platinum, germanium, polyaniline, polyamide, polysilicon, or a combination thereof. It may be desirable for electrical traces **122**, **124**, **126**, and **128** and circuit board electrical contacts **116** to be formed of the same material.

In this exemplary embodiment, electronic device **100** and flexible circuit board **102** are electrically and mechanical coupled together by Z-interconnections **114**. These Z-interconnections are desirably formed of an electrically conductive material such as indium, a conductive solder, a conductive thermally-curable epoxy, a conductive radiation-curable epoxy, a conductive thermoplastic, and/or a conductive elastomer.

In addition to electrically and mechanically coupling electronic device **100** and flexible circuit board **102**, Z-interconnections **114** desirably thermally couple electronic device **100** and flexible circuit board **102**. Flexible substrate **118** may desirably be very thin <10 mils, therefore, even though the thermal conductivity of many flexible substrate materials may be low, thermal transfer from the front to back surfaces of the flexible substrate may be quite high, but lateral diffusion of heat may be poor. The relatively high thermal conductivity of the electrical traces may help with lateral diffusion of heat.

FIG. **2** illustrates an alternative exemplary embodiment of flexible circuit board **102**, which includes front side thermal conductivity layer **200** to assist the lateral heat diffusion of the flexible circuit board. This thermal conductivity layer may desirably be formed of the same material as electrical traces **122**, **124**, **126**, and **128**. It is also possible to form a back side thermal conductivity layer on the back surface of flexible substrate **118** to accomplish spreading of heat. This back side thermal conductivity layer may cover the entire back surface of the flexible substrate, or it may be patterned to allow additional electrical traces on this side of flexible circuit board **102** and or to channel heat to certain regions of the flexible circuit board.

FIGS. **3**A–C illustrates some of the advantages that may be derived from the present invention. In the exemplary embodiments of FIGS. **3**A and **3**B, electronic device **100** includes drilled substrate **300** with vias **108** extending from it front surface to its back surface. This substrate may be formed of any standard substrate material such as glass, alumina, epoxy resin, fiberglass, polyester, and polyimide. Electronic components **302** are mounted on the front surface of drilled substrate **300** and electrically coupled to electrical contacts **112** formed on the back surface of drilled substrate **300** through vias **108**. These electronic components may include electrical traces, separate components such as resistors, capacitor, and transistors, or integrated circuitry.

FIG. **3**A illustrates how exemplary flexible circuit board **102** may desirably allow for reliable Z-interconnections **114**

even in the face of camber or unevenness in the back surface of the electronic device. This ability to overcome camber may allow for less restrictive tolerances in selection of substrates for electronic device **100**, possibly lowering the cost of manufacturing and improving yield of these devices.

Also, this relative insensitivity to camber means that Z-interconnections **114** may desirably be smaller. With a rigid circuit board, the Z-interconnections should be large enough to compensate for the anticipated camber. In locations where the camber of both the rigid circuit board and the electronic device lead to large gaps, the Z-interconnection is desirably formed from a material with a sufficient thickness to cross the gap. When the Z-interconnections are made using deformable solder bumps, for example, it is desirable for the deformable bumps from which the Z-interconnections are formed to be at least as large as the largest expected gap, which constrains the minimum separation for the Z-interconnections. In locations where the combined cambers lead to a narrower gap, the deformable bumps may have too much material and expand laterally when deformed, further enlarging the minimum separation of the Z-interconnections. The issue may be further accentuated for large area arrays, as larger substrates tend to have larger cambers.

As FIG. **3**A illustrates, this problem is greatly reduced by using exemplary flexible circuit board **102**. This means that the overall thickness of the Z-interconnections may be reduced and that the density of the Z-interconnections may be greatly increased. Shorter Z-interconnections have less resistance and may lead to a thinner final device. Fine-pitch interconnections are practical with flex circuit back panels because flex circuits offer high density circuitry, and the interconnections can be made very small in cross-section. Minimum separations between the centers of Z-interconnections of <10 mils, or even <2 mils, may be achieved for large area arrays by using a flexible circuit board.

FIG. **3**B illustrates the related problem of unevenly sized Z-interconnections. It may be difficult to precisely control the size of the deformable bumps from which Z-interconnections **114** are formed, but differently sized bumps lead to differently sized Z-interconnections. A rigid substrate may cause particularly large deformable bumps to expand too much laterally, possibly leading to shorts and may not form the Z-interconnections of particularly small deformable bumps. Additionally it is noted that it may be desirable to intentionally vary the size of the Z-interconnections. These issues may be addressed by using exemplary flexible circuit board **102** as shown in FIG. **3**B.

FIG. **3**C illustrate the use of exemplary flexible circuit board **102** when electronic device **100** includes non-planar substrate **304**. It is noted that although non-planar substrate **304** is shown as substantially spherically concave, it could be convex, non-spherically curved, or bent at an angle as well. Such non-planar substrates may be particularly desirable for use in curved displays or detector, or the fit in particular spaces within a larger device. Alignment of the circuit board electrical connections to the device electrical connections to form the Z-interconnections may be significantly easier for a flexible circuit board, as the flexible circuit board may be aligned in stages to maintain the alignment across a large area.

Overall weight reduction of the completed device may also be possible because flex circuit is thinner and weights less than an equivalent ceramic, glass, or rigid organic circuit board.

FIG. **4** illustrates an exemplary method of manufacturing an electronic device and coupled flexible substrate according to the present invention. The method begins with electronic device **100** and flexible circuit board **102**, step **400**. Conductive bumps, or balls, **500** are formed on at least one of the device electrical contact **112** or the circuit board electrical contact **116** associated with each Z-interconnection **114**, step **402**. These conductive bumps may be formed of indium, a conductive solder, a conductive thermally-curable epoxy, a conductive radiation-curable epoxy, a conductive thermoplastic, and/or a conductive elastomer. Conductive bumps **500** may be formed on each device electrical contact **112** and each circuit board electrical contact **116** as shown in FIG. **5**A, each circuit board electrical contact **116** as shown in FIG. **5**B, each device electrical contact **112** as shown in FIG. **5**C, or some device electrical contacts **112** and some circuit board electrical contacts **116** (not shown) as long as at least one conductive bump is formed for each Z-interconnection to be formed. Conductive bumps **500** may be formed using standard deposition or screen printing techniques, including sputtering, vaporization, and ink jet methods. It may be desirable to apply flux to conductive bumps formed of conductive solder.

It may be desirable to form the solder bumps on one side of each Z-interconnection and an organic conductor, such as a conductive thermally-curable epoxy, a conductive radiation-curable epoxy, a conductive thermoplastic, or a conductive elastomer, on the other side. This method may provide better yield than organic conductor bumps alone. It may also be desirable to use the exemplary embodiment of FIG. **5**A with conductive bumps **500** on all of the electrical contacts when forming indium or other cold welded Z-interconnections.

As an alternative embodiment, a non-conductive fill layer may also be formed on the back surface of electronic device **100**, the front surface of flexible circuit board **102**, or both, alternative step **404**. The non-conductive fill layer is desirably formed on a portion of the facing surfaces on which there are no Z-interconnections. This non-conductive fill layer may desirably be formed of a non-conductive (electrically) organic material such as a non-conductive epoxy, a non-conductive thermoplastic, and a non-conductive elastomer. Electrically conductive organic materials such as conductive epoxies, conductive thermoplastics, and conductive elastomers, are often formed by suspending metal particles in an organic matrix. The non-conductive organic material of the non-conductive fill layer may include thermally (but not electrically) conductive particle within its organic matrix to enhance its thermal conductivity. It may be desirable for conductive bumps **500** and the non-conductive fill layer to include the same organic matrix, but different suspended particles to simplify the curing process of step **410**.

The non-conductive fill layer may desirably provide for addition thermal and mechanical coupling of electronic device **100** and flexible circuit board **102**. This layer may also assist in forming a hermetic seal around electronic components, such as active material **110**, coupled to the back surface of device substrate **104**. Device substrate **104** and/or flexible substrate **118** may also form part of this hermetic seal.

Following either step **402** or step **404**, the plurality of device electrical contacts **112** and the corresponding plurality of circuit board electrical contacts **116** are aligned with one another, step **406**. FIGS. **5**A–C show exemplary devices at this stage of manufacture according to the method of FIG. **4**. The different embodiments are based on the locations in which conductive bumps **500** are formed in step **402**.

Electronic device **100** and flexible circuit board **102** are then pressed together until each conductive bump contacts either the corresponding conductive bump (the exemplary embodiment of FIG. **5**A) or electrical contact (the exemplary embodiments of FIGS. **5**B and **5**C), step **408**. To ensure proper contact between the conductive bumps and the corresponding conductive bump or electrical contact, flexible circuit board **102** may be pressed using a surface, such as a rubber sheet over a hard surface, with sufficient elasticity to allow relatively even pressure over the surface even as flexible circuit board **102** flexes to desirably conform to the back surface of electronic device **100**. Alternatively, an isostatic lamination method may be used to press electronic device **100** and flexible circuit board **102** together, using a flexible compressing membrane and a pressurized liquid, such as water. Isostatic lamination may be particularly useful exemplary embodiments in which the back surface of electronic device **100** is significantly non-planar, and/or significant deformation of the conductive bumps is desirable.

Conductive bumps **500** are then "cured" to form the Z-interconnections **114**, step **410**. The non-conductive fill layer may also be "cured" to form non-conductive fill **800**, as shown in FIG. **8**, at this step if alternative step **404** is used. The means of "curing" the conductive bumps (and possibly non-conductive fill layer) depends on the material from which they are formed, and may include, for example, heating or irradiating at least the conductive bumps.

It is contemplated that steps **406**, **408**, and **410** may be performed in stages with only a subset of the Z-interconnections being aligned, contacted, and cured at one time. This "piece meal" method may allow for improved yield of large area array devices, by allowing alignment corrections between sequential operations across the large surface area and numerous Z-interconnections.

For indium, or other cold welded Z-interconnections, the curing process involves applying sufficient pressure to electronic device **100** and flexible circuit board **102** to deform and cold weld conductive bumps **500** into Z-interconnections **114**. This pressure may be applied uniformly or a pressor such as a roller may move across the back surface of the flexible substrate. This moving pressor method may be particular useful when large camber and/or non-uniformity of Z-interconnection size is expected, or a non-planar substrate is used.

Conductive bumps formed on conductive solder may be cured into Z-interconnections by using standard solder reflow techniques. It is noted that although a solder interconnection may be preferred to achieve high electrical conductivity, the desirable use of flux to facilitate solder wetting and the relatively high temperatures needed for solder reflow may be detrimental to the device. Therefore it may be desirable in some applications to combine a conductive solder bump on electrical contact with a conductive organic material on the other electrical contact to form a hybrid Z-interconnection. These exemplary hybrid Z-interconnections are cured according to the type of conductive organic material used.

To cure conductive bumps formed of conductive epoxies or elastomers it is desirable to press electronic device **100** and flexible circuit board **102** together to desirably deform the conductive epoxy or elastomer bumps into the shape of the Z-interconnections. For radiation-curable conductive epoxy, the deformed bumps are then irradiated with the appropriate light, i.e. UV for UV-curable epoxies, to harden the epoxy. Thermally-curable conductive epoxy bumps are heated to their curing temperature and allowed to harden.

Conductive elastomer Z-interconnections are held in place until the elastomer material has set.

Conductive thermoplastic bumps are cured by heating the bumps to above the softening temperature of the thermoplastic. Electronic device **100** and flexible circuit board **102** are then desirably pressed together to desirably deform the conductive thermoplastic bumps into the shape of the Z-interconnections. The Z-interconnections are then cooled to below the softening temperature to harden the Z-interconnection.

If a non-conductive fill layer was formed in alternative step **404**, this layer may be cured using the same method as the corresponding conductive bump material. If identical organic matrices are used, the curing parameters may be almost identical, greatly simplifying the curing process.

With the possible exception of the embodiment using conductive solder Z-interconnections, which may require high reflow temperatures, this method does not introduce any stresses to the glass device panel during assembly. In addition, when the module is thermal cycled, thermal expansion mismatch between the glass front panel and the flex circuit does not lead to significant stresses because of the relatively low elastic modulus of the flex circuit.

It is noted that, flexible substrate **118** may have a thermal expansion coefficient which is significantly different from the thermal expansion coefficient of electronic device **100** and they may be at different temperatures, which may lead to large differences in thermal expansion. Differences in the thermal expansion of the electronic device and a rigid circuit board are largely absorbed by the elasticity of the Z-interconnections, but this may lead to failure of some of the Z-interconnections. The relatively much larger elasticity of flexible circuit board **102** compared to standard rigid circuit boards results in less strain on the Z-interconnections due to thermal expansion differences.

FIG. **8** illustrates two additional alternative features to reduce mechanical strain on the Z-interconnections due to thermal cycling. Non-conductive fill **800** may desirably improve thermal coupling between electronic device **100** and flexible circuit board **102**, thereby decreasing their thermal gradients. Non-conductive fill **800** may be formed as described above in relation to the exemplary method of FIG. **4**, or it may be formed by using a back fill technique after Z-interconnections **114** have been cured. It is noted that the Z-interconnections and non-conductive fill may alternatively be formed together using an anisotropic conductive adhesive disposed between electronic device **100** and flexible circuit **102**.

The second alternative exemplary feature shown in FIG. **8** is laminated substrate **802**. Desirably, laminated substrate **802** has a thermal expansion coefficient approximately equal to the thermal expansion coefficient of device substrate **104**. This substrate may desirably be laminated to flexible substrate **118** before or after the curing of Z-interconnections **114**, depending on the interconnection tolerance and density desired. Laminated substrate **802** may reduce strain on Z-interconnections **114** and electronic device **100** by reducing differences in lateral thermal expansion between electronic device **100** and flexible circuit board **102**. Also, laminated substrate **802** may improve the lateral diffusion of heat in flexible substrate **118**.

FIGS. **6**, **7**, **10**A and **10**B illustrate several alternative exemplary embodiments of flexible circuit board **102**. In FIG. **6** exemplary flexible circuit board **102** includes extended flexible substrate **600** and heat sinks **604**. Extended flexible substrate **600** may include a connector portion **602**

that extends beyond the edge of electronic device **100**. Electrical traces **122**, **124**, **126**, and **128** may be extended along this portion of the flexible substrate to provide easily accessible connections to the flexible substrate from off of the device. This feature may be particularly useful for tiled optical display applications in which it is desirable for electronic device (display element array) **100** to butt directly up to an adjacent tile. Because of its flexibility, connector portion **60** of extended flexible substrate **600** may extend behind the adjacent tile and allow connection to off-device circuitry without interfering with the adjacent tiles.

Heat sinks **604** may be mounted on the back surface of the flexible substrate to assist with heat dissipation. Due to high heat transfer through the relatively thin, flexible substrate these heat sink may have a significant effect.

FIG. **7** illustrates two more alternative features that may be added to flexible circuit board **102**, dual-sided flexible substrate **700** with electrical traces on both the front and back surfaces and back surface mounted electronics **704**. A subset of front surface electrical traces **122**, **124**, **126**, and **128** may be electrically coupled to a subset of the back surface electrical traces by wirebond **702** and or vias in the flexible substrate (not shown). Back surface mounted electronics **704** are desirably electrically coupled to the backside electrical traces. Exemplary back surface mounted electronics may include integrated circuits, memory circuitry, power supply circuitry to provide operational power for the electronic components of electronic device **100**, control circuitry to control the electronic components, and analysis circuitry to analyze output signals from the electronic components.

FIGS. **9**, **10**A and **10**B include the additional feature of a flexible circuit board with an elevated portion which may be used to mount additional circuit board electronic components **904** similar to back surface mounted electronics **704** of FIG. **7**. Exemplary flexible circuit board **102** of FIG. **9** includes Y-shaped flexible circuit board **900**. Circuit board electronic components **904** may desirably be mounted to elevated portion **902** to provide a degree of thermal, and possibly electrical and electromagnetic, isolation from the rest of Y-shaped flexible circuit board **900**. Thermal isolation may be improved by lengthening this elevated portion. Heat sinks may be added to elevated portion **902** to remove heat directly from electronic components **904**.

Exemplary dual-sided folded flexible substrate **1000** in FIG. **10**A and exemplary single-sided folded flexible substrate **1002** in FIG. **10**B achieve this isolation by folding the flexible substrate away from electronic device **100** and then back between at least a pair of Z-interconnections to create folded elevated portion **1004**. These folded flexible substrates may desirably be formed using the alternative "piece meal" method of manufacturing described above with reference to FIG. **4**.

Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

What is claimed is:

1. An electronic device and coupled flexible circuit board comprising:

the electronic device, including;

a substrate having a back surface;

a plurality of electronic components coupled to the substrate; and

a plurality of device electrical contacts coupled to the back surface of the substrate and electrically coupled to the plurality of electronic components;

the flexible circuit board including;

a flexible substrate having a front surface and a back surface; **[**and**]**

a plurality of circuit board electrical contacts coupled to the front surface of the flexible substrate corresponding to plurality of device electrical contacts;

a plurality of Z-interconnections, each Z-interconnection electrically and mechanically coupling one device electrical contact to a corresponding circuit board electrical contact; and

a fill layer mechanically coupling a portion of the back surface of the electronic device to a corresponding portion of the front surface of the flexible substrate.

2. The electronic device **[**end**]** *and* coupled flexible circuit board of claim **1**, wherein the plurality of electronic components of the electronic device are sized and arranged to form a matrix array of electronic components.

3. The electronic device and coupled flexible circuit board of claim **1**, wherein the plurality of electronic components of the electronic device are at least one of liquid crystal devices, light emitting diodes, organic light emitting diodes, **[**and**]** *or* optical detectors.

4. The electronic device and coupled flexible circuit board of claim **1**, wherein a substrate material of the substrate of the electronic device includes at least one of glass, alumina, epoxy resin, fiberglass, polyester, **[**and**]** *or* polyimide.

5. The electronic device and coupled flexible circuit board of claim **1**, wherein a flexible substrate material of the flexible substrate of the flexible circuit board includes at least one of polyester **[**and**]** *or* polyimide.

6. The electronic device and coupled flexible circuit board of claim **1**, wherein**[**;**]***:*

the plurality of device electrical contacts formed on the back surface of the substrate are formed of at **[**east**]** *least* one conductor selected from a group consisting of aluminum, aluminium-calcium, gold, silver, copper, nickel, titanium, tungsten, platinum, germanium, polyaniline, polyamide, and polysilicon; and

[the**]** *an* electrical trace and the plurality of circuit board electrical contacts formed on the front surface of the flexible substrate are formed of at least one conductor selected from a group consisting of aluminum, aluminum-calcium, gold, **[**sliver**]** *silver*, copper, nickel, titanium, tungsten, platinum, germanium, polyaniline, polyamide, and polysilicon.

7. The electronic device and coupled flexible circuit board of claim **1**, wherein the plurality of Z-interconnections are formed of at least one conductor selected from a group consisting of indium, a conductive solder, a conductive thermally-curable epoxy, a conductive radiation-curable epoxy, a conductive thermoplastic, and a conductive elastomer.

8. The electronic device and coupled flexible circuit board of claim **1**, further comprising:

a rigid substrate laminated to the flexible circuit board;

wherein the substrate of the electronic device has a first thermal expansion coefficient and the rigid substrate has second thermal expansion coefficient, which is approximately equal to the first thermal expansion coefficient.

9. The electronic device and coupled flexible circuit board of claim **1**, wherein the back surface of the substrate of the electronic device is non-planar.

10. The electronic device and coupled flexible circuit board of claim **1**, wherein:

a connection portion of the front surface of the flexible substrate of the flexible circuit board extends past an

edge of the back surface of the substrate of the electronic device; and

a connector portion [the] *of an* electrical trace is formed on the connection portion of the front surface of the flexible substrate.

11. The electronic device and coupled flexible circuit board of claim **1**, wherein the flexible circuit board further includes:

a backside electrical trace formed on the back surface of the flexible substrate, the backside electrical trace electrically coupled to at least one of plurality of electrical contacts formed on the front surface of the flexible substrate; and

at least one circuit board electronic component coupled to the back surface of the flexible substrate and electrically coupled to the backside electrical trace.

12. The electronic device and coupled flexible circuit board of claim **1**, wherein the fill layer is formed of an organic material including at least one of a non-conductive epoxy, a non-conductive thermoplastic, [and] *or* a non-conductive elastomer.

13. The electronic device and coupled flexible circuit board of claim **12**, wherein the fill layer further includes a plurality of thermally conductive*, non-electrically conductive* particles within the organic material.

14. An electronic device and coupled flexible circuit board comprising:

the electronic device including:

a substrate having a back surface;

a plurality of electronic components coupled to the substrate; and

a plurality of device electrical contacts coupled to the back surface of the substrate and electrically coupled to the plurality of electronic components;

the flexible circuit board including:

a flexible substrate having a front surface and a back surface; [and]

a plurality of circuit board electrical contacts coupled to the front surface of the flexible substrate corresponding to plurality of device electrical contacts;

a plurality of Z-interconnections, each Z-interconnection electrically and mechanically coupling one device electrical contact to a corresponding circuit board electrical contact;

wherein the flexible substrate of the flexible circuit board includes an elevated portion which extends away from the back surface of the substrate of the electronic device, and none of the plurality of circuit board electrical contacts is formed on the elevated portion of the flexible substrate of the flexible circuit board.

15. The electronic device and coupled flexible circuit board of claim **14**, wherein the flexible circuit board further includes a circuit board electronic component coupled to the elevated portion of the flexible substrate and electrically coupled to at least one of the plurality of electrical contacts formed on the front surface of the flexible substrate.

16. An electronic device and coupled [flexible] circuit board comprising:

the electronic device including:

a substrate having a back surface;

a plurality of electronic components coupled to the substrate; and

a plurality of device electrical contacts coupled to the back surface of the substrate and electrically coupled to the plurality of electronic components;

the [flexible] circuit board including;

a [flexible] substrate having a front surface and a back surface; [and]

a plurality of circuit board electrical contacts coupled to the front surface of the [flexible] substrate corresponding to plurality of device electrical contacts;

a plurality of Z-interconnections, each Z-interconnection electrically and mechanically coupling one device electrical contact to a corresponding circuit board electrical contact;

wherein:

the [flexible] circuit board further includes a [thermal conduction] *thermally conductive* coating formed on at least a portion of the front surface of the [flexible] substrate; and

the [thermal conduction] *thermally conductive* coating is not electrically coupled to the plurality of electrical contacts formed on the front surface of the [flexible] substrate.

17. The electronic device and coupled [flexible] circuit board of claim **16**, wherein the [thermal conduction] *thermally conductive* coating is formed of at least one of aluminum, aluminum-calcium, gold, silver, copper, nickel, titanium, tungsten, platinum, [and] *or* germanium.

18. An electronic device and coupled [flexible] circuit board comprising:

the electronic device, including;

a substrate having a back surface;

a plurality of electronic components coupled to the substrate; [and]

a plurality of device electrical contacts coupled to the back surface of the substrate and electrically coupled to the plurality of electronic components;

the [flexible] circuit board including;

a [flexible] substrate having a front surface and a back surface; and

a plurality of circuit board electrical contacts coupled to the front surface of the [flexible] substrate corresponding to plurality of device electrical contacts; *and*

a plurality of Z-interconnections, each Z-interconnection electrically and mechanically coupling one device electrical contact to a corresponding circuit board electrical contact;

wherein the [flexible] circuit board further includes a [thermal conduction] *thermally conductive* coating formed on at least a portion of the back surface of the [flexible] substrate.

[**19**. An electronic device and coupled flexible circuit board comprising:

the electronic device including:

a substrate having a back surface;

a plurality of electronic components coupled to the substrate; and

a plurality of device electrical contacts coupled to the back surface of the substrate and electrically coupled to the plurality of electronic components;

the flexible circuit board including;

a flexible substrate having a front surface and a back surface; and

a plurality of circuit board electrical contacts coupled to the front surface of the flexible substrate corresponding to plurality of device electrical contacts;

a plurality of Z-interconnections, each Z-interconnection electrically and mechanically coupling one device electrical contact to a corresponding circuit board electrical contact;

wherein the flexible circuit board further includes a heat sink coupled to the back surface of the flexible substrate.]

20. The electronic device and coupled flexible circuit board of claim 1, wherein the flexible circuit board is substantially spherically concave, substantially spherically convex, or bent at an angle.

21. An apparatus, comprising:

a first substrate having a front surface and a back surface;

a plurality of electrical contacts coupled to the front surface of the first substrate and corresponding to a plurality of device electrical contacts coupled to an electronic device;

a plurality of Z-interconnections, wherein the individual Z-interconnections are configured to couple an electrical contact to a corresponding device electrical contact coupled to the electronic device; and

a fill layer configured to couple the front surface of the first substrate to a corresponding portion of a back surface of the electronic device, wherein the fill layer comprises a plurality of thermally conductive, non-electrically conductive particles within an organic material.

22. The apparatus of claim 21, wherein the first substrate comprises a flexible substrate.

23. The apparatus of claim 21, wherein the plurality of electrical contacts are formed of at least one conductor selected from the group consisting of aluminum, aluminum-calcium, gold, silver, copper, nickel, titanium, tungsten, platinum, germanium, polyaniline, polyamide, and polysilicon.

24. The apparatus of claim 21, wherein the plurality of Z-interconnections are formed of at least one conductor selected from a group consisting of indium, a conductive solder, a conductive thermally-curable epoxy, a conductive radiation-curable epoxy, a conductive thermoplastic, and a conductive elastomer.

25. The apparatus of claim 21, wherein the electronic device comprises:

a second substrate; and

a plurality of electronic components coupled both to the second substrate and to the plurality of device electrical contacts, wherein the plurality of device electrical contacts are coupled to the back surface of the second substrate.

26. The apparatus of claim 25, wherein the plurality of electronic components are sized and arranged to form a matrix.

27. The apparatus of claim 25, wherein the plurality of electronic components comprises at least one liquid crystal devices, light emitting diodes, organic light emitting diodes, or optical detectors.

28. The apparatus of claim 25, wherein the second substrate comprises at least one of glass, alumina, epoxy resin, fiberglass, polyester, or polyimide.

29. The apparatus of claim 25, wherein the plurality of device electrical contacts are formed of at least one conductor selected from a group consisting of aluminum, aluminum-calcium, gold, silver, copper, nickel, titanium, tungsten, platinum, germanium, polyaniline, polyamide, and polysilicon.

30. The apparatus of claim 24, wherein:

the first substrate is a flexible substrate;

the apparatus further comprises a rigid substrate coupled to the flexible substrate;

wherein the second substrate has a first thermal expansion coefficient; and

the rigid substrate has a second thermal expansion coefficient approximately equal to the first thermal expansion coefficient.

31. The apparatus of claim 25, wherein:

the first substrate is a flexible substrate; and

the back surface of the second substrate is non-planar.

32. The apparatus of claim 25, wherein:

a connection portion of the front surface of the first substrate extends past an edge of the back surface of the second substrate; and

a connector portion of an electrical trace is formed on the connection portion of the front surface of the first substrate.

33. The apparatus of claim 25, further comprising:

a backside electrical trace formed on the back surface of the first substrate, wherein the backside electrical trace electrically couples to at least one of the plurality of electrical contacts formed on the front surface of the first substrate; and

at least one electronic component coupled to the back surface of the first substrate and electrically coupled to the backside electrical trace.

34. The apparatus of claim 21, wherein the fill layer is formed of an organic material comprising at least one of a non-conductive epoxy, a non-conductive thermoplastic, or a non-conductive elastomer.

35. The apparatus of claim 21, wherein the Z-interconnections comprise a plurality of electrically conductive particles within an organic material.

36. The apparatus of claim 35, wherein the organic material in the fill layer and the organic material in the Z-interconnections are the same material.

37. An apparatus, comprising:

a flexible substrate having a front surface and a back surface;

a plurality of electrical contacts coupled to the front surface of the flexible substrate and corresponding to a plurality of device electrical contacts coupled to a device substrate of an electronic device; and

a plurality of Z-interconnections, wherein the individual Z-interconnections are configured to couple an electrical contact to a corresponding device electrical contact in the electronic device, wherein the flexible substrate comprises an elevated portion extending away from a back surface of the device substrate and none of the plurality of electrical contacts is formed on the elevated portion of the flexible substrate.

38. The apparatus of claim 37, further comprising an electronic component coupled to the elevated portion of the flexible substrate and electrically coupled to at least one of the plurality of electrical contacts formed on the front surface of the flexible substrate.

39. The apparatus of claim 37, wherein the electronic device further comprises a plurality of electronic components coupled to a front surface of the device substrate and coupled to the plurality of device electrical contacts, and wherein the plurality of device electrical contacts are coupled to a back surface of the device substrate.

40. The apparatus of claim 39, wherein the plurality of electronic components comprises at least one of liquid crystal devices, light emitting diodes, organic light emitting diodes, or optical detectors.

41. An apparatus comprising:

a first substrate having a front surface and a back surface;

a thermally conductive coating formed on at least a portion of the first substrate and configured for lateral heat diffusion;

a plurality of electrical contacts coupled to the front surface of the first substrate and corresponding to a plurality of device electrical contacts coupled to an electronic device; and

a plurality of Z-interconnections, wherein the individual Z-interconnections are configured to couple an electrical contact to a corresponding device electrical contact of the electronic device.

42. The apparatus of claim 41, wherein the thermally conductive coating is formed on at least a portion of the front surface of the first substrate, and wherein the thermally conductive coating is not electrically coupled to the plurality of electrical contacts coupled to the front surface of the first substrate.

43. The apparatus of claim 41, wherein the thermally conductive coating is formed on at least a portion of the back surface of the first substrate.

44. The apparatus of claim 41, wherein the thermally conductive coating is formed of at least one aluminum, aluminum-calcium, gold, silver, copper, nickel, titanium, tungsten, platinum, or germanium.

45. The apparatus of claim 41, wherein the electronic device comprises:

a second substrate; and

a plurality of electronic components coupled both to a front surface of the second substrate and to the plurality of device electrical contacts, wherein the plurality of device electrical contacts is coupled to a back surface of the second substrate.

46. The apparatus of claim 45, wherein the plurality of electronic components comprises at least one of liquid crystal devices, light emitting diodes, organic light emitting diodes, or optical detectors.

47. An electronic device, comprising:

a substrate having a surface;

a plurality of electrical contacts coupled to the surface of the substrate;

a plurality of Z-interconnections coupled to the electrical contacts; and

a thermally conductive, non-electrically conductive fill layer around the Z-interconnections;

wherein the fill layer comprises thermally conductive, non-electrically conductive particles in an organic matrix and the Z-interconnections comprise electrically conductive particles in an organic matrix.

48. The electronic device of claim 47, wherein the organic matrix of the fill layer and the organic matrix of the Z-interconnections comprise the same organic material.

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