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(12) **United States Patent**
Beroz

(10) **Patent No.:** **US 10,128,601 B1**
(45) **Date of Patent:** **Nov. 13, 2018**

(54) **FLUID PRESSURE ACTIVATED ELECTRICAL CONTACT DEVICES AND METHODS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/895,794**

(22) Filed: **Feb. 13, 2018**

Related U.S. Application Data

(63) Continuation of application No. 15/793,270, filed on Oct. 25, 2017, now Pat. No. 10,003,149, which is a
(Continued)

(51) **Int. Cl.**
G01R 31/00 (2006.01)
H01L 23/52 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC **H01R 13/2428** (2013.01); **G01R 31/2884** (2013.01); **F15B 15/10** (2013.01)

(58) **Field of Classification Search**
CPC G01R 31/02; G01R 31/2886; G01R 31/2889; G01R 1/073; G01R 1/0735;
(Continued)

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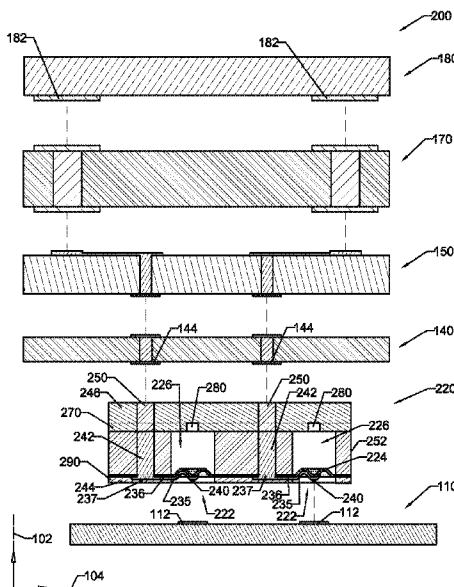
(Continued)

Primary Examiner — Minh N Tang
(74) *Attorney, Agent, or Firm* — NK Patent Law

(57) **ABSTRACT**

A contactor device includes: a first body substrate; a second body substrate; a flexible membrane connected to the first body substrate and second body substrate, wherein the second substrate body is movable relative to the first substrate body by flexure of the flexible membrane; an electrical contact member carried by the second substrate body; a microfluidic-channeled substrate coupled to the first body substrate, the microfluidic-channeled substrate having a chamber and a microfluidic channel in fluid communication with the chamber; and a 3-dimensional flexible membrane enclosing the chamber, wherein the 3-dimensional flexible membrane flexes toward the second body substrate when a fluid pressure is applied to the chamber through the microfluidic channel whereby a force or a movement is transferred to the second body substrate by the 3-dimensional flexible membrane.

26 Claims, 29 Drawing Sheets



Related U.S. Application Data

continuation-in-part of application No. 14/921,030, filed on Oct. 23, 2015, now Pat. No. 9,805,891, application No. 15/895,794, which is a continuation of application No. 15/651,531, filed on Jul. 17, 2017, which is a continuation-in-part of application No. 15/498,188, filed on Apr. 26, 2017, now abandoned.

- (60) Provisional application No. 62/327,807, filed on Apr. 26, 2016, provisional application No. 62/068,663, filed on Oct. 25, 2014, provisional application No. 62/069,843, filed on Oct. 29, 2014, provisional application No. 62/076,072, filed on Nov. 6, 2014, provisional application No. 62/077,941, filed on Nov. 11, 2014, provisional application No. 62/079,255, filed on Nov. 13, 2014, provisional application No. 62/080,434, filed on Nov. 17, 2014, provisional application No. 62/080,435, filed on Nov. 17, 2014, provisional application No. 62/128,495, filed on Mar. 4, 2015.

(51) **Int. Cl.**

H01R 13/24 (2006.01)
G01R 31/28 (2006.01)
F15B 15/10 (2006.01)

(58) **Field of Classification Search**

CPC ... H01L 23/528; H01L 23/5386; H01L 24/17; H01L 24/09; H01L 24/49
 See application file for complete search history.

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 USPTO, Non-Final Rejection in U.S. Appl. No. 15/651,531 dated Aug. 24, 2018.

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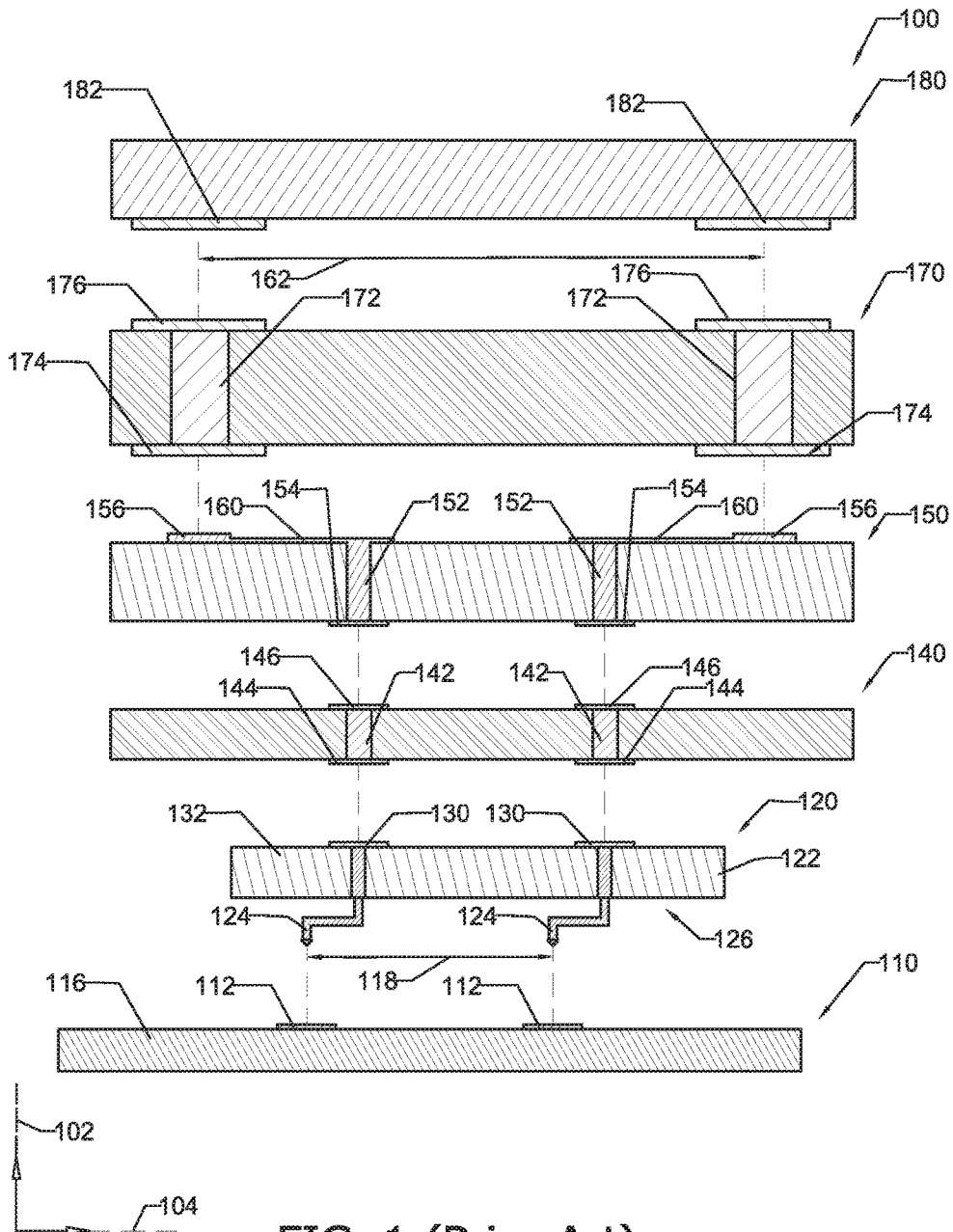


FIG. 1 (Prior Art)

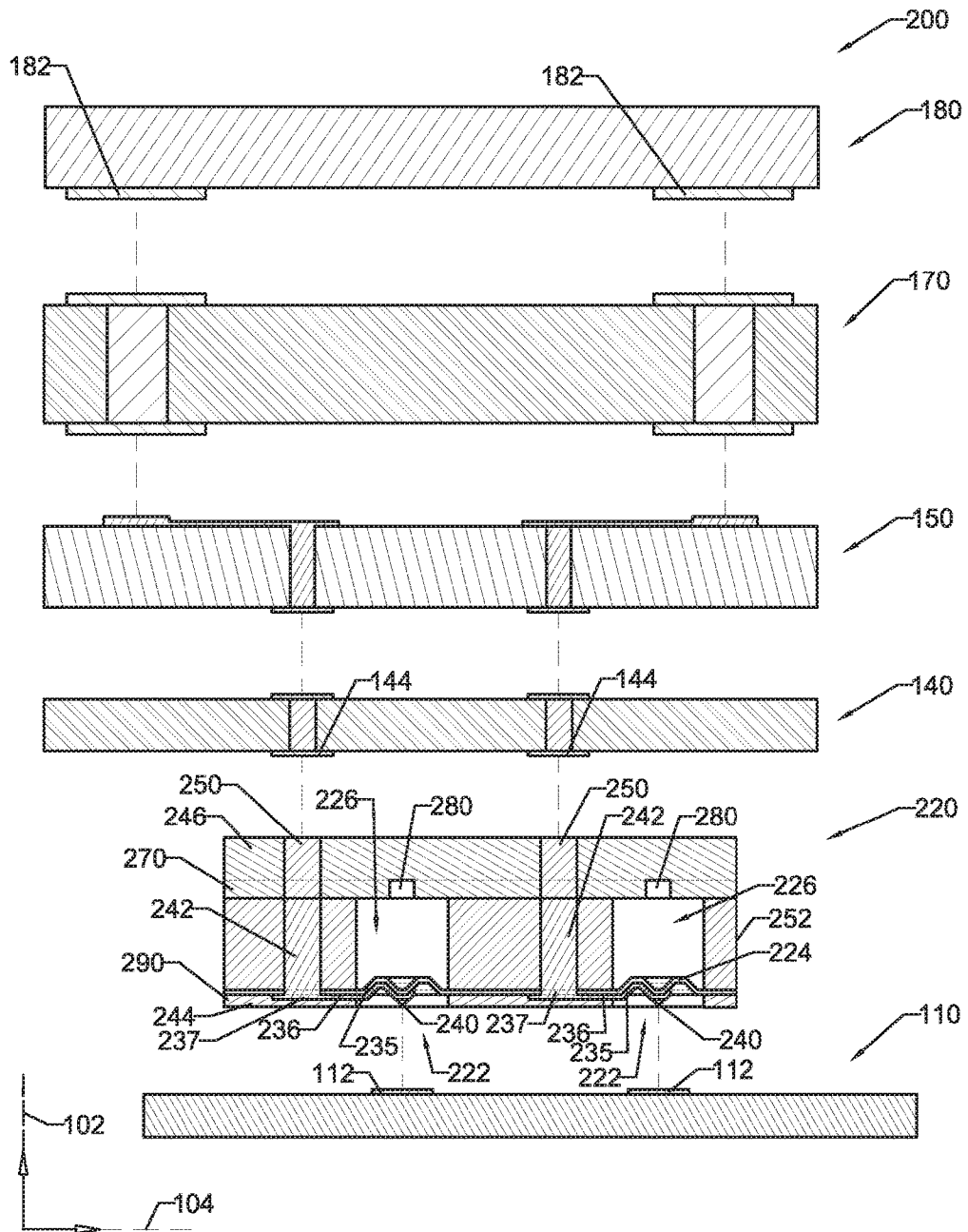


FIG. 2

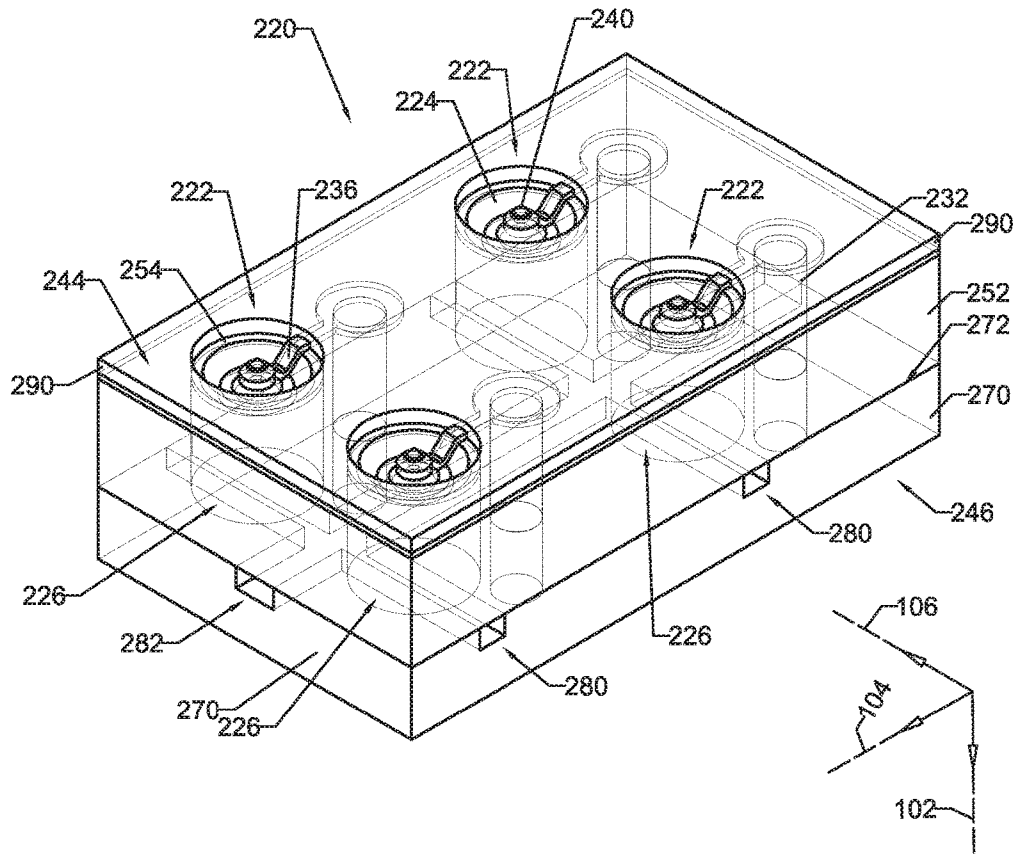


FIG. 3

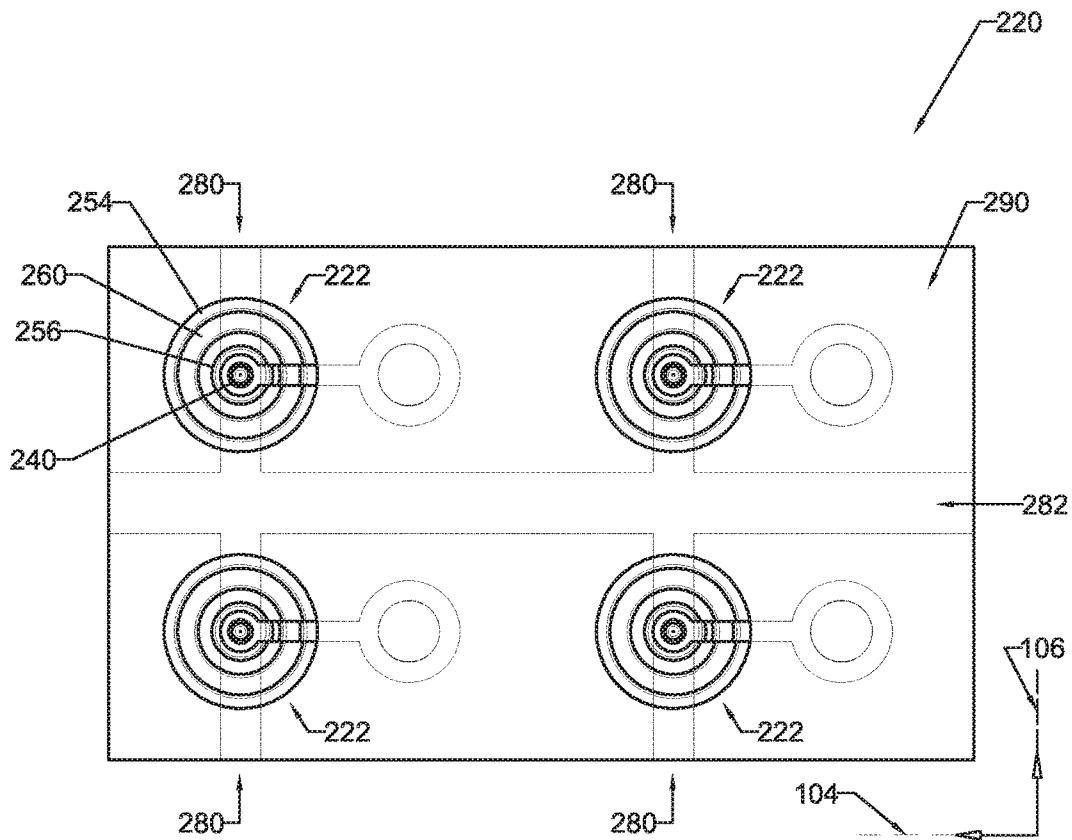


FIG. 4

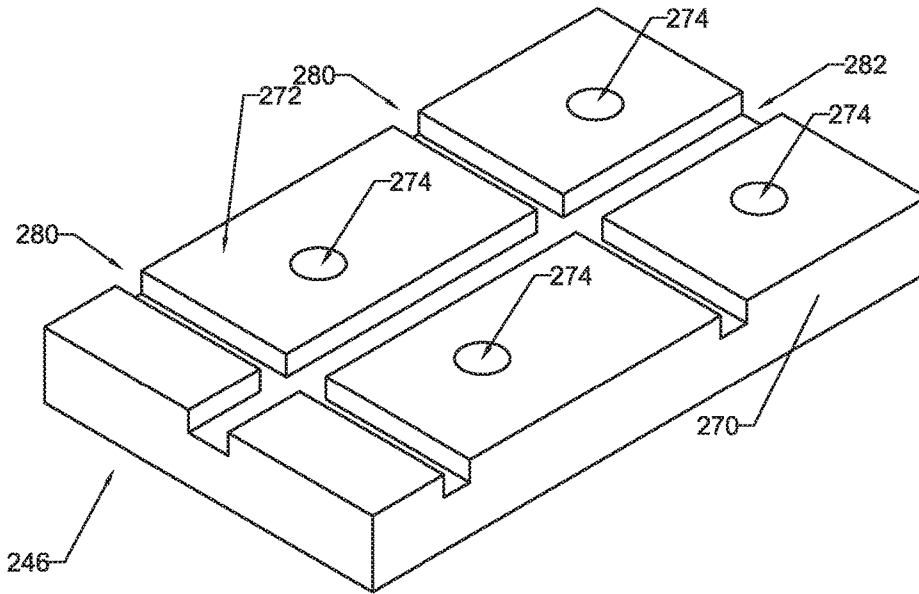


FIG. 5

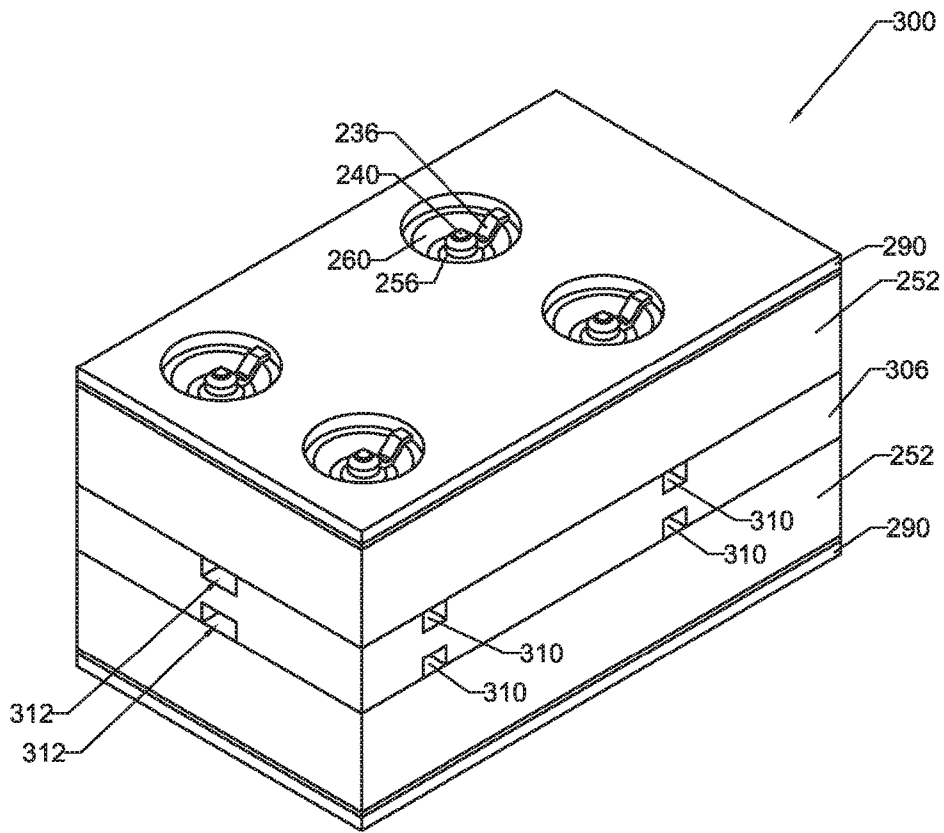


FIG. 6

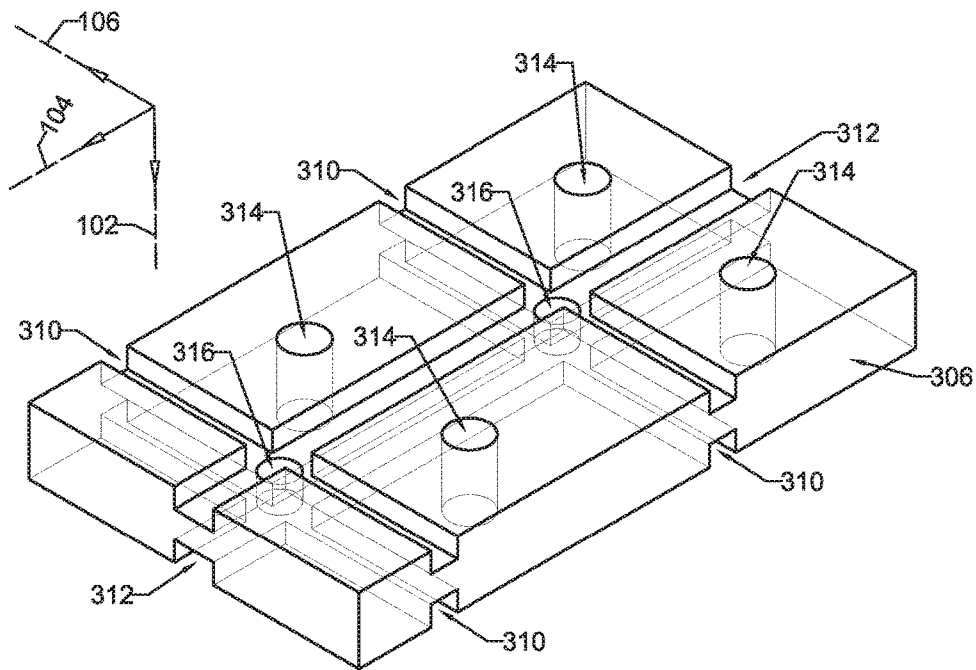


FIG. 7

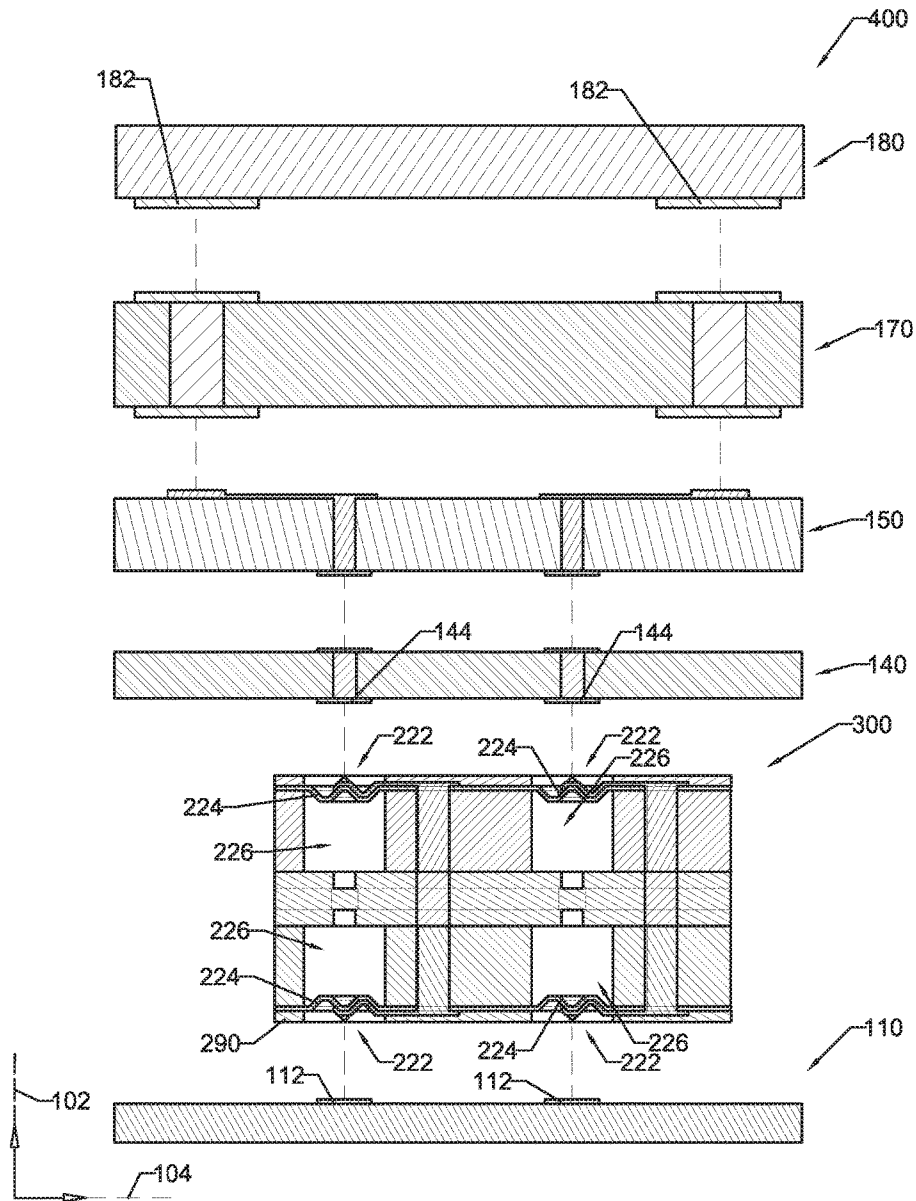
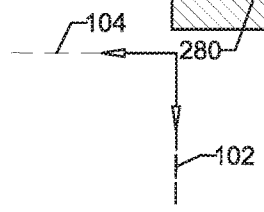
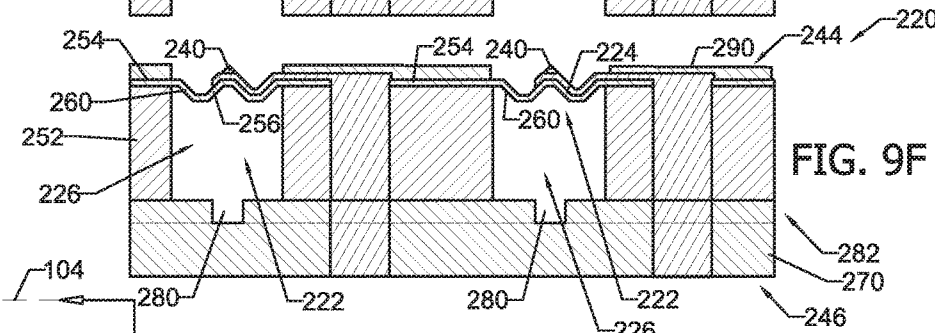
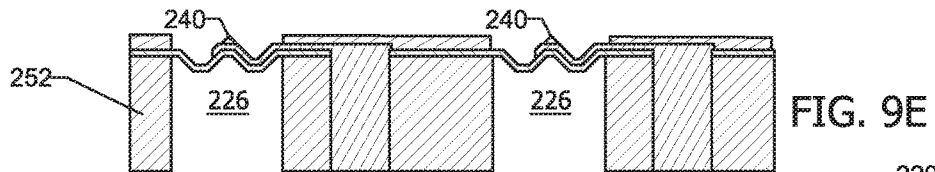
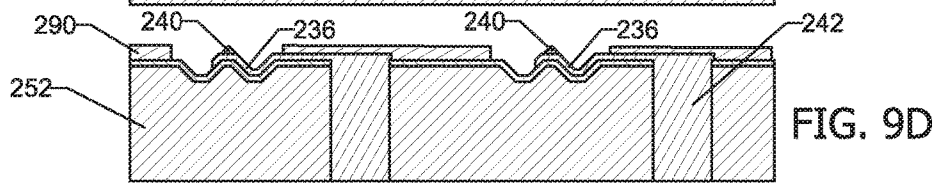
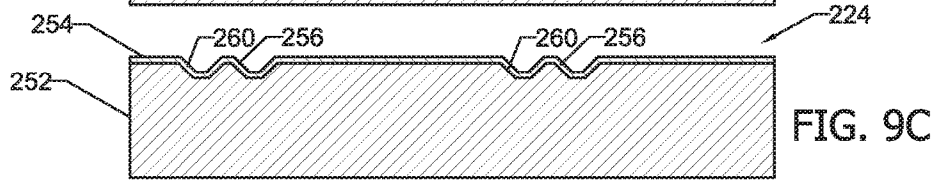
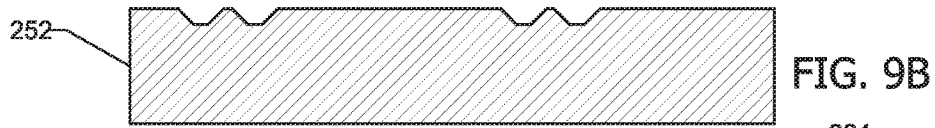
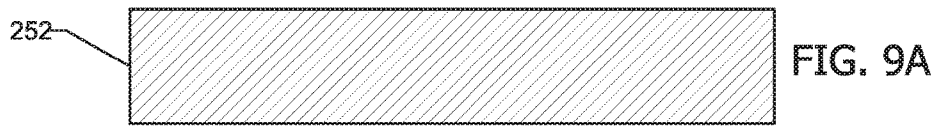
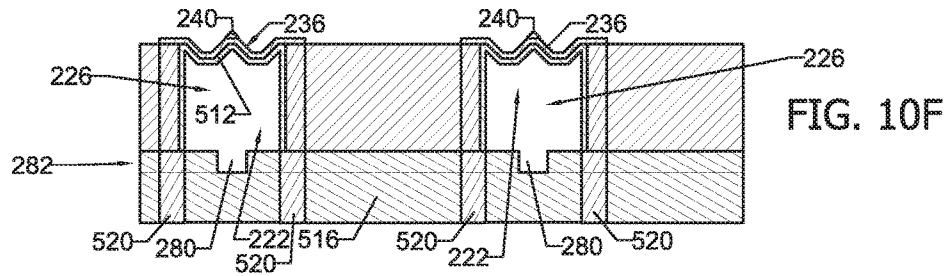
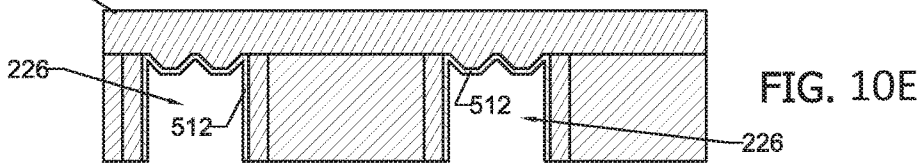
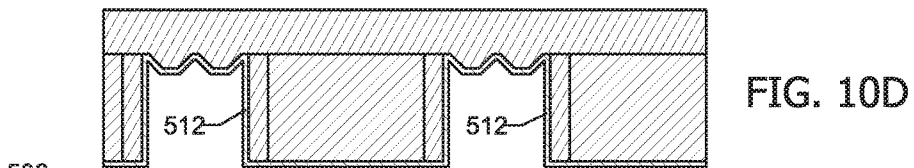
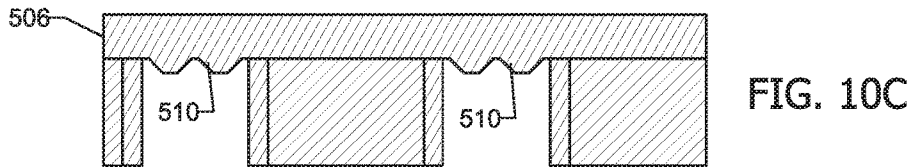
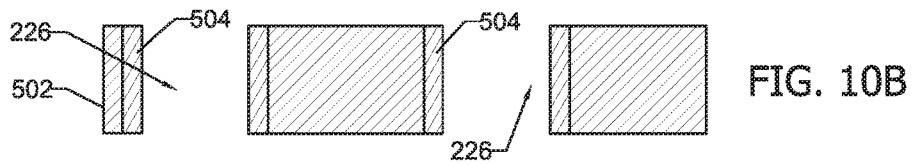
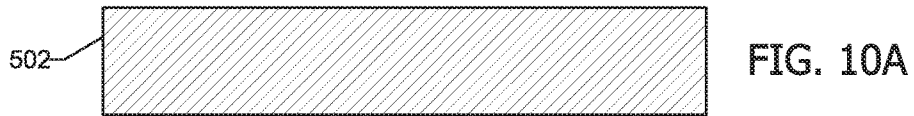


FIG. 8





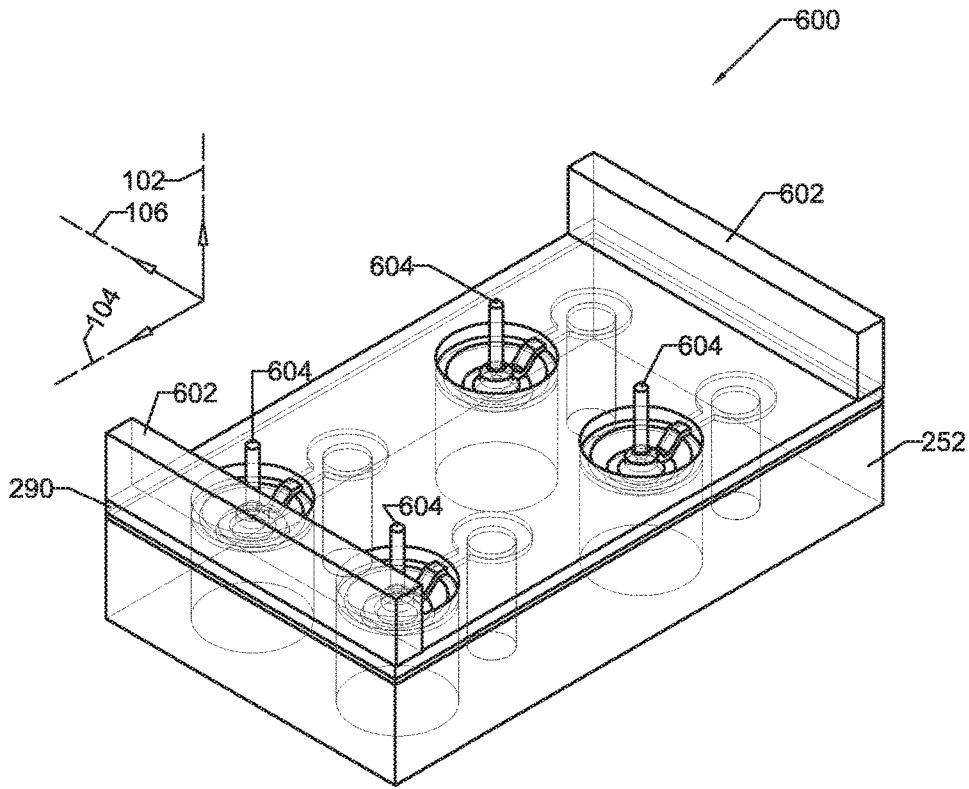


FIG. 11A

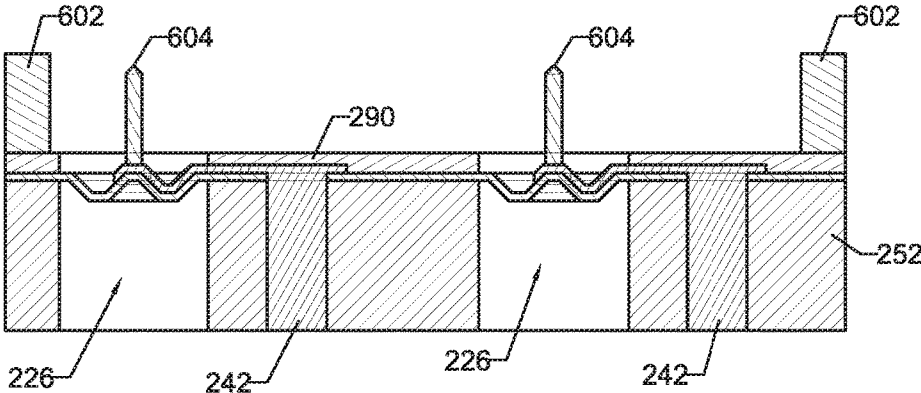


FIG. 11B

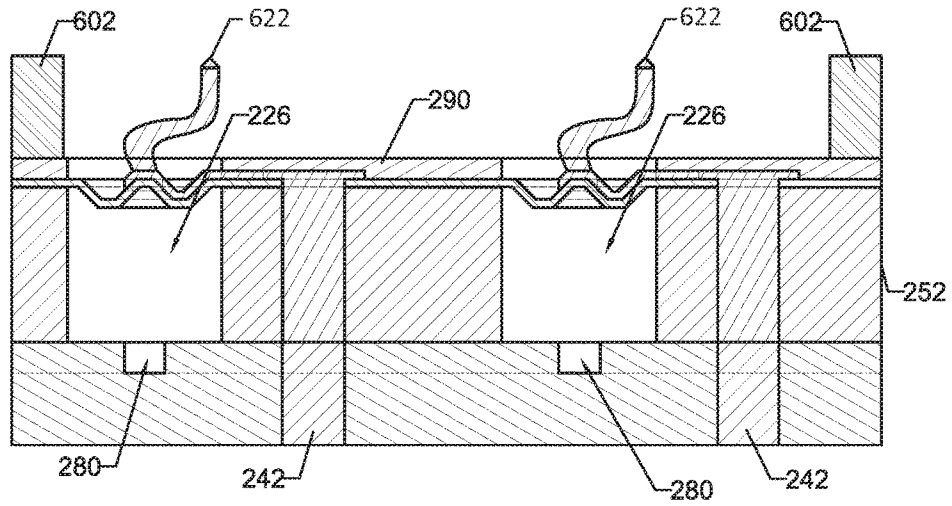


FIG. 12

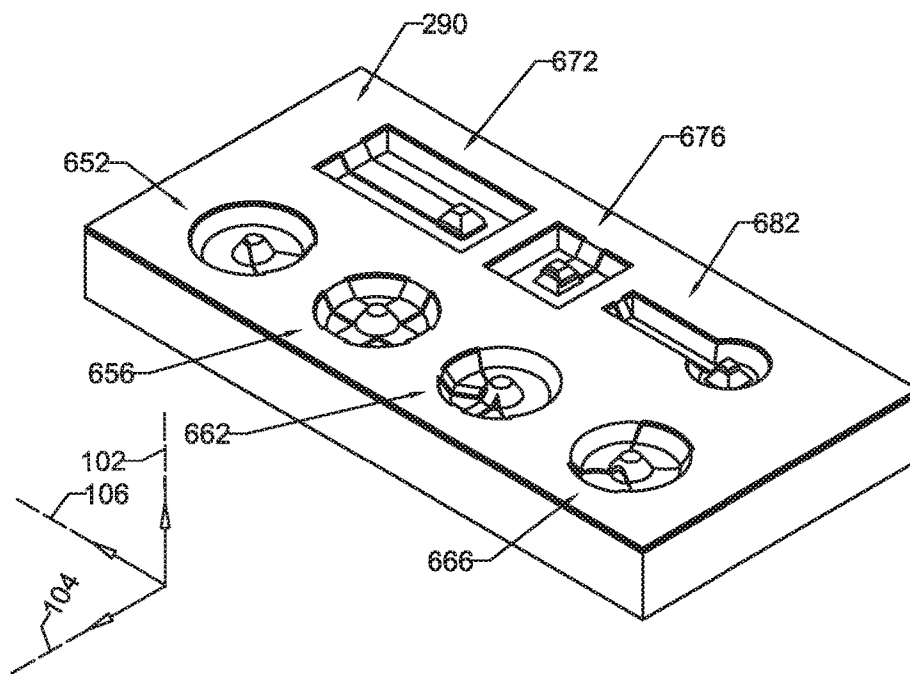


FIG. 13A

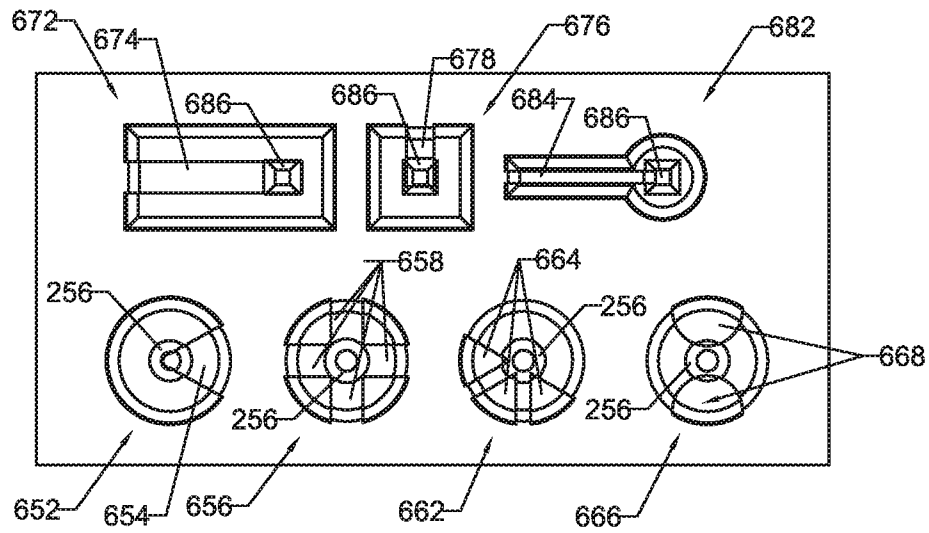


FIG. 13B

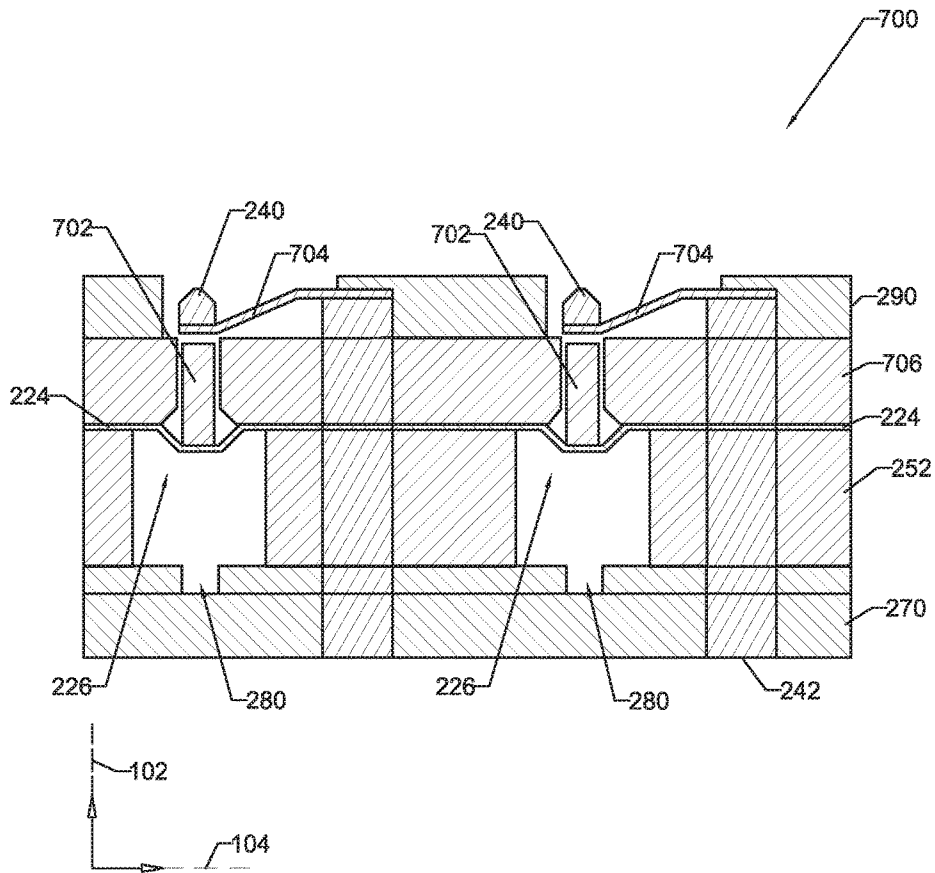
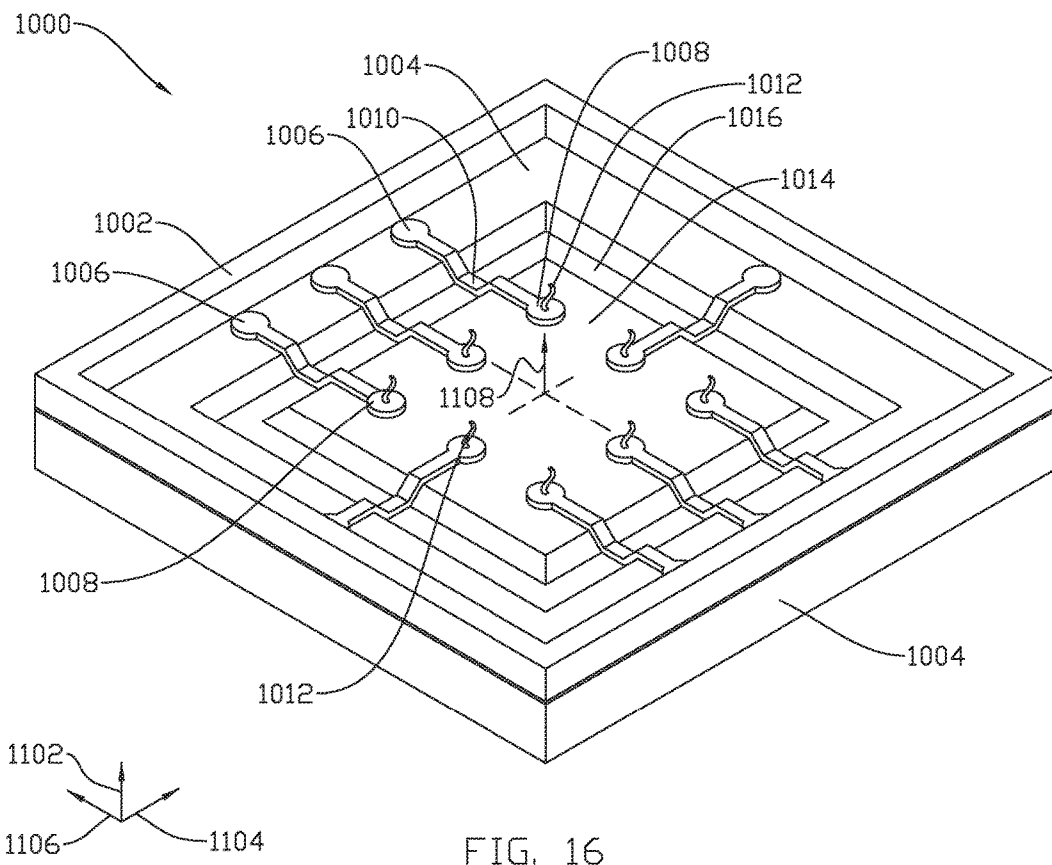


FIG. 14



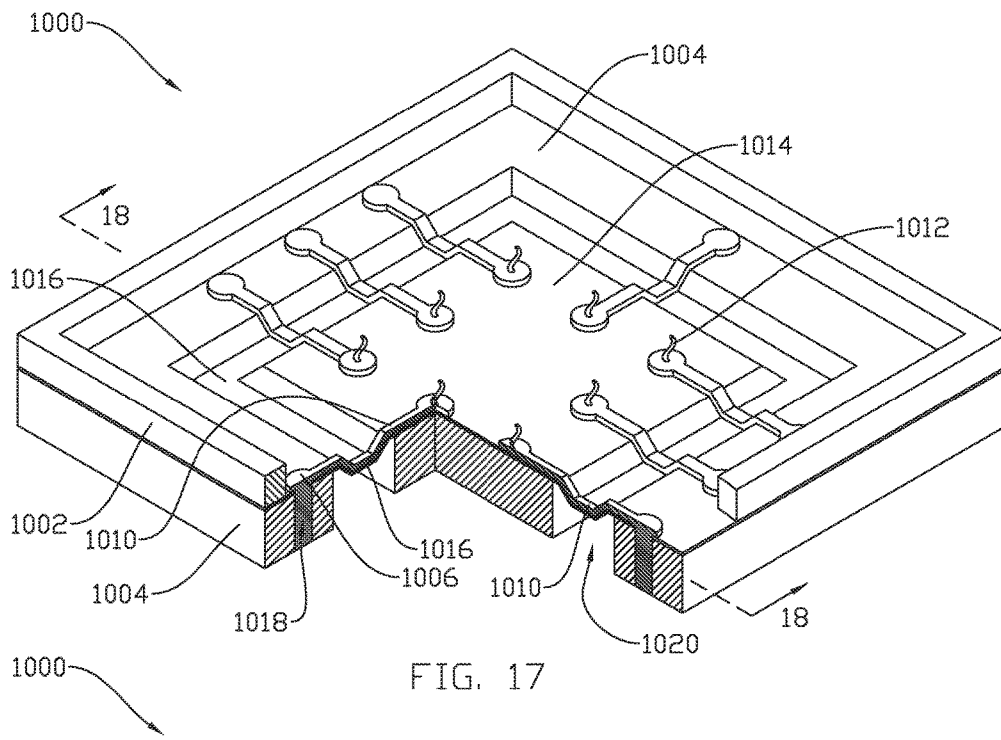


FIG. 17

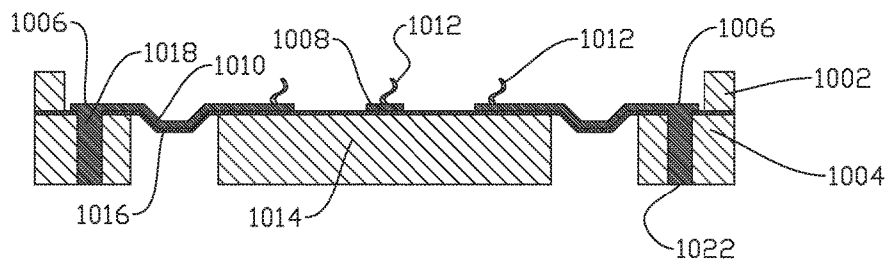


FIG. 18

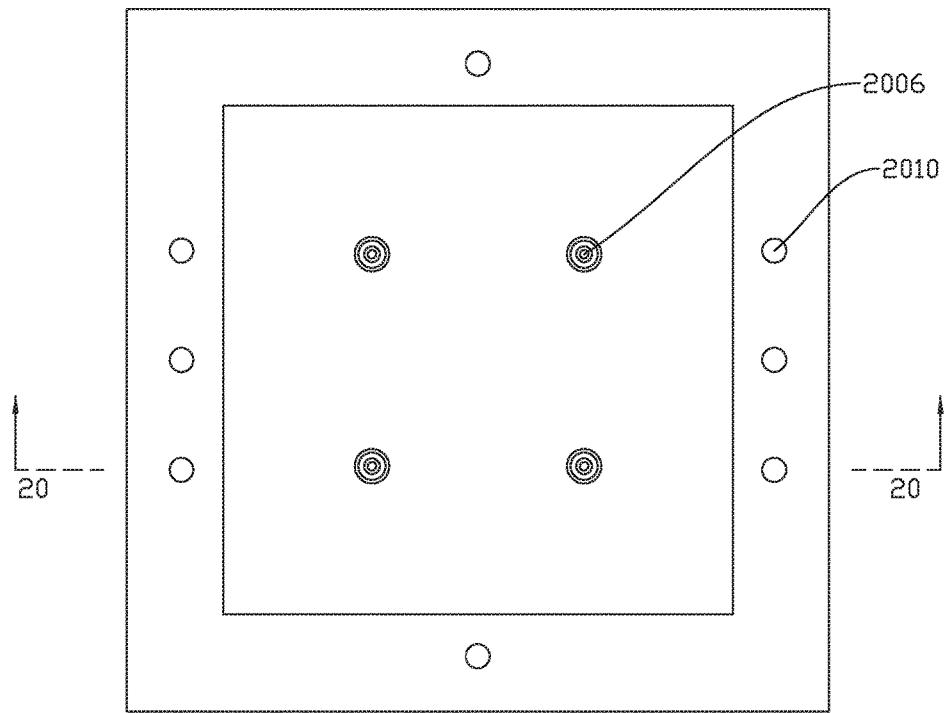


FIG. 19

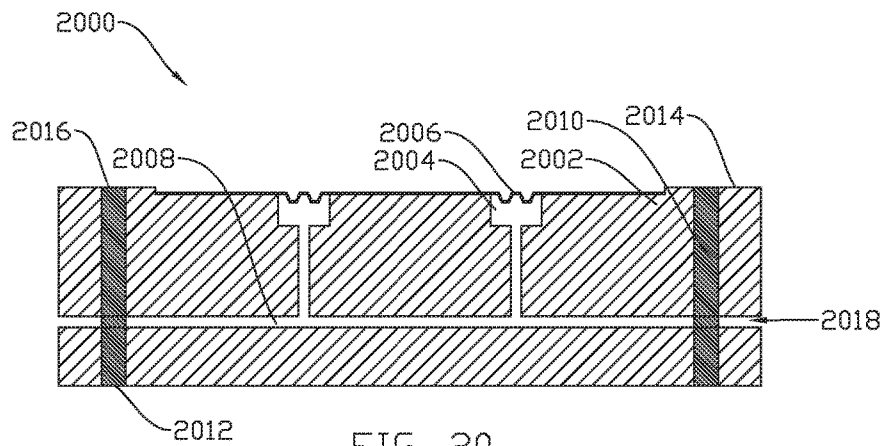


FIG. 20

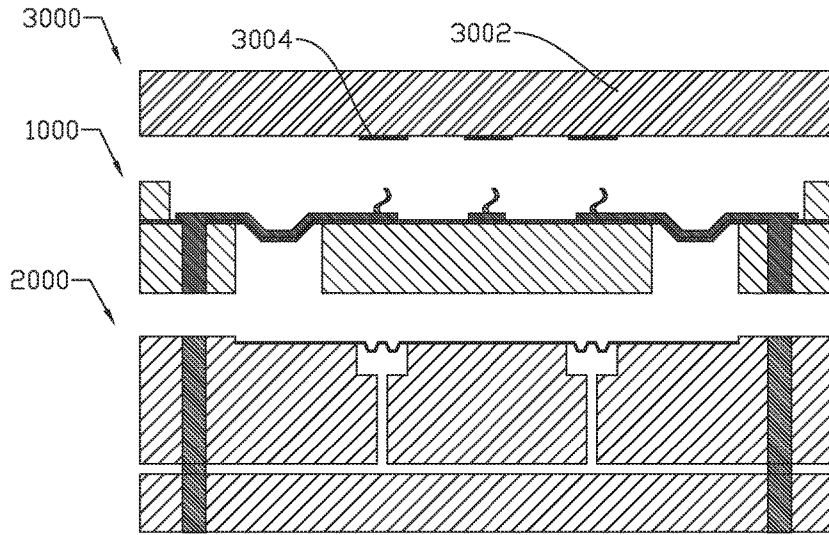


FIG. 21

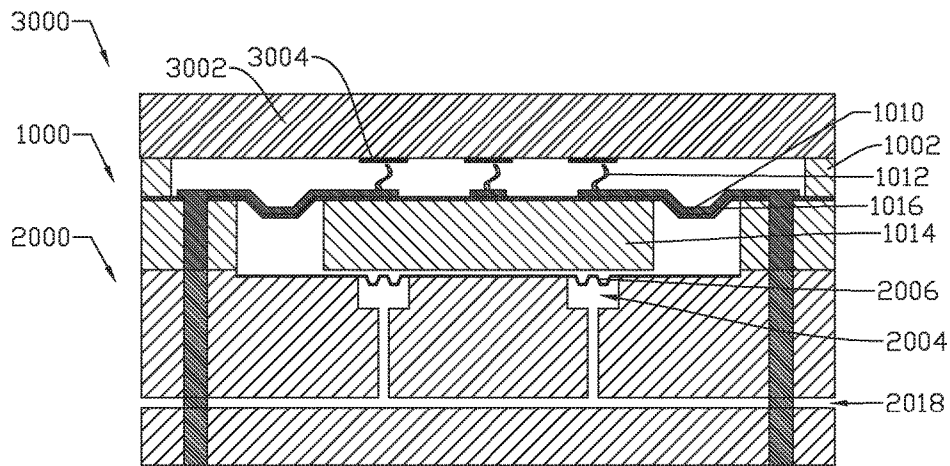


FIG. 22

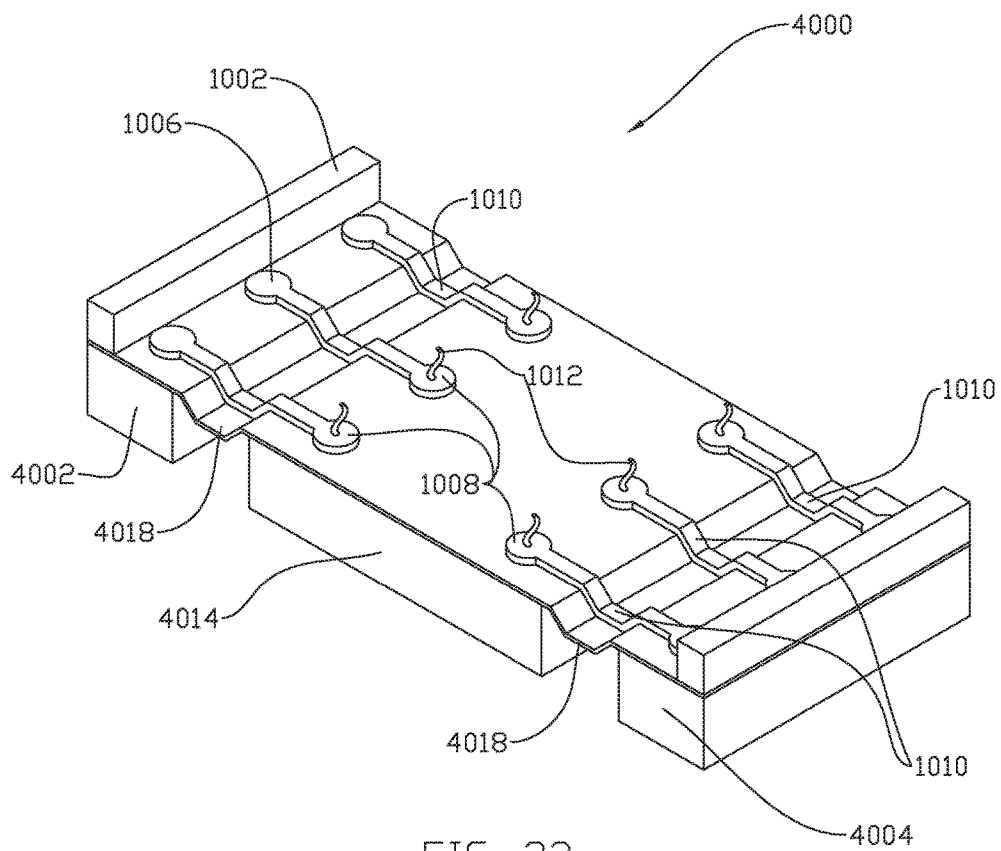
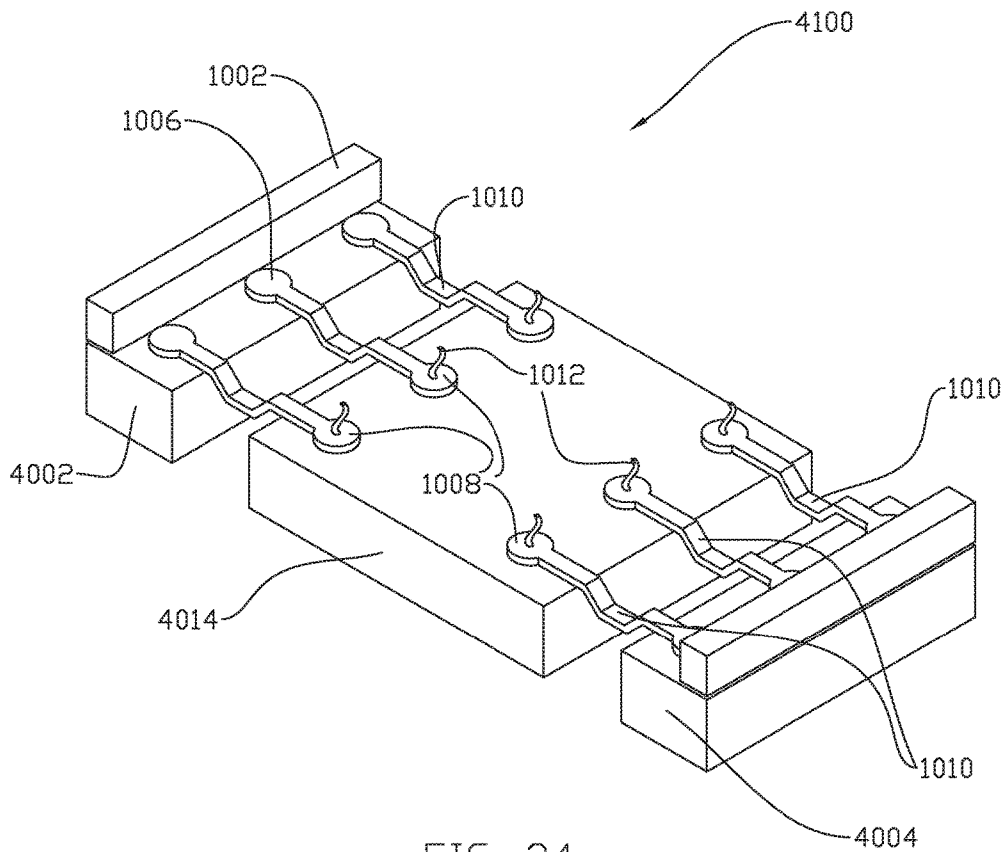


FIG. 23



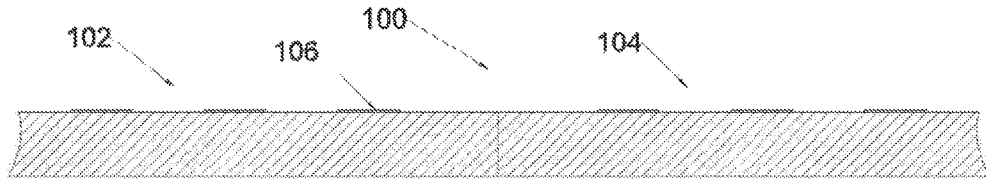


FIG. 25

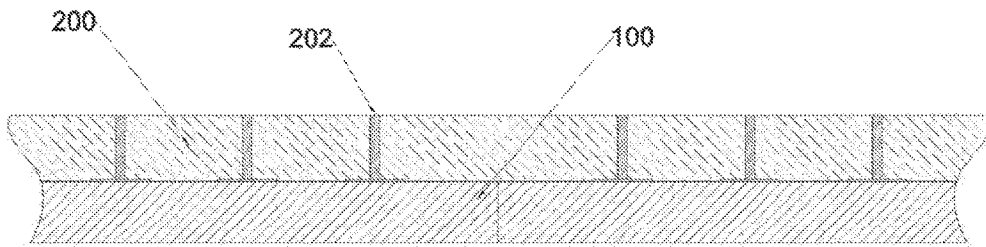


FIG. 26

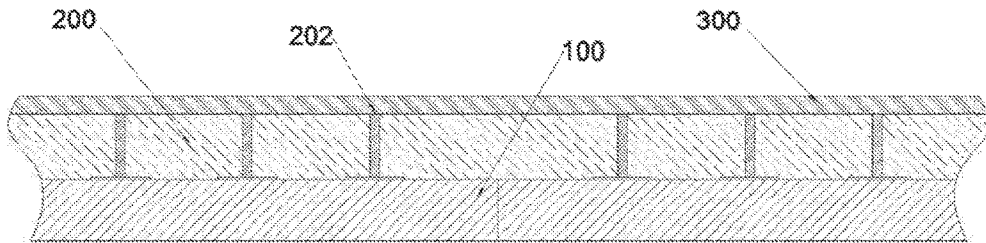


FIG. 27

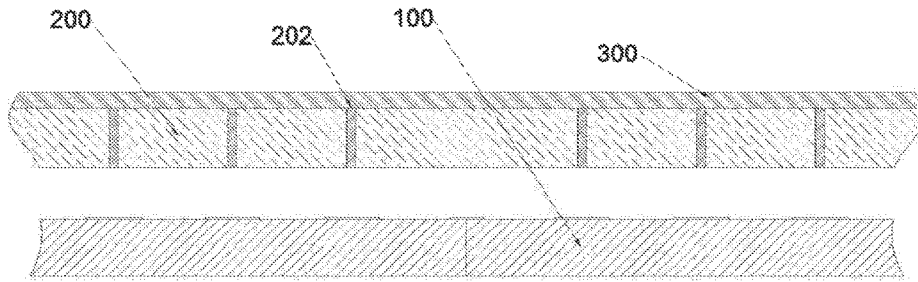


FIG. 28

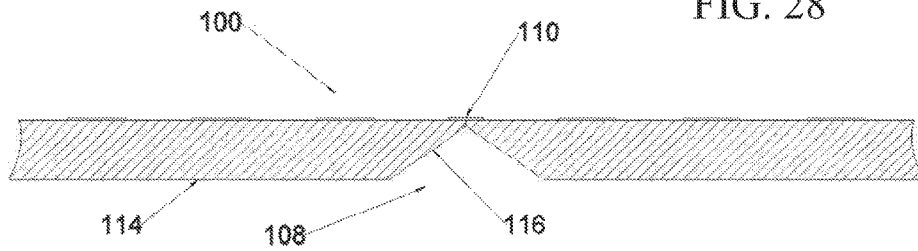


FIG. 29

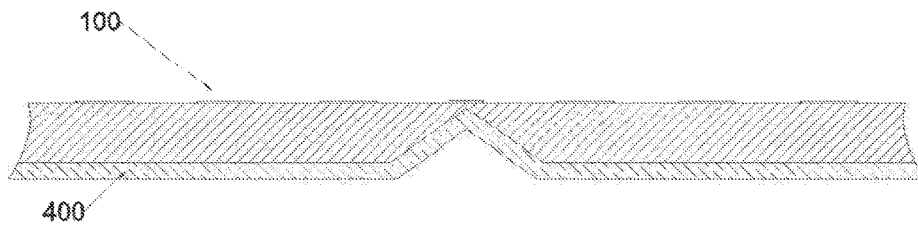


FIG. 30

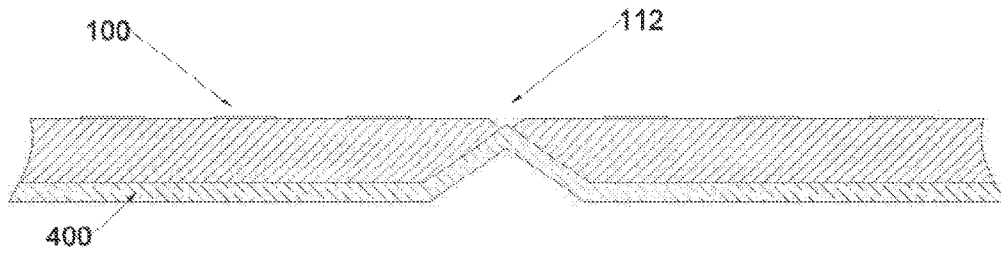


FIG. 31

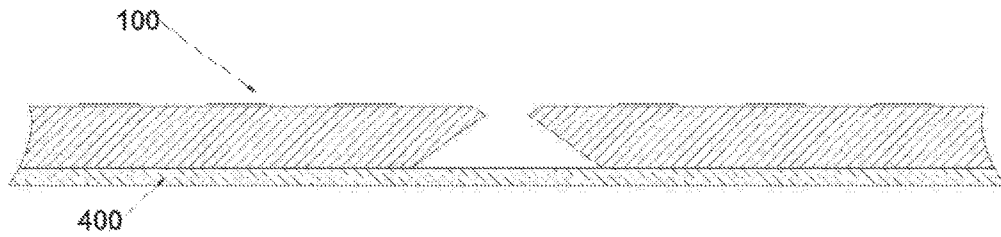


FIG. 32

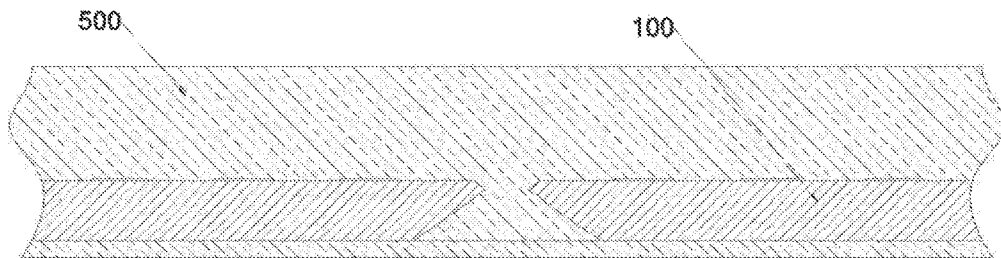


FIG. 33

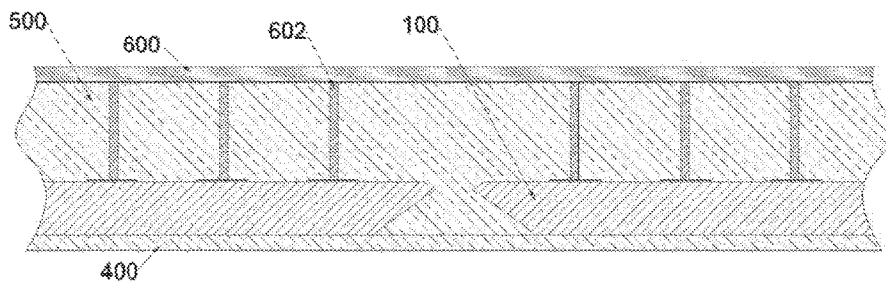


FIG. 34

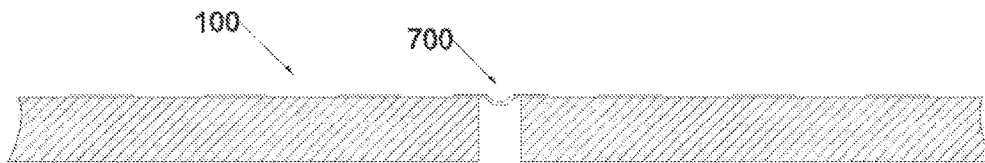


FIG. 35

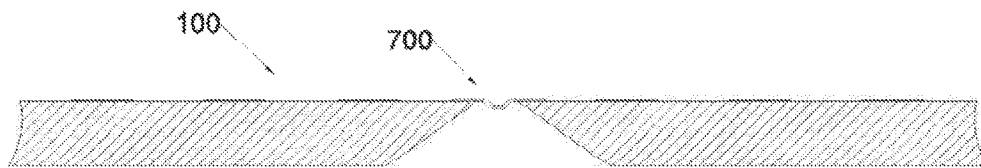


FIG. 36

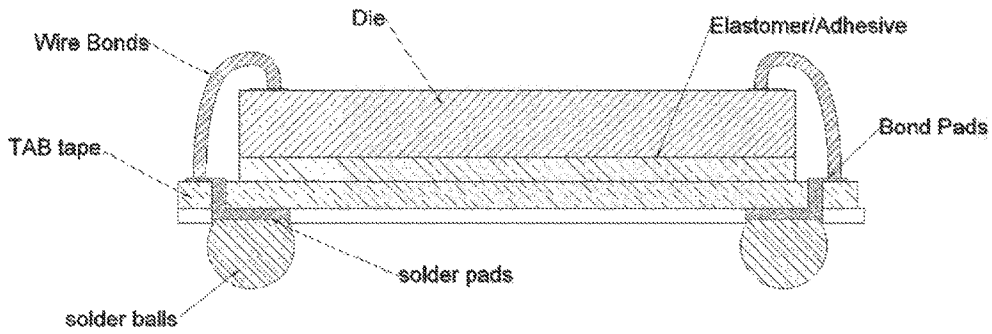


FIG. 37

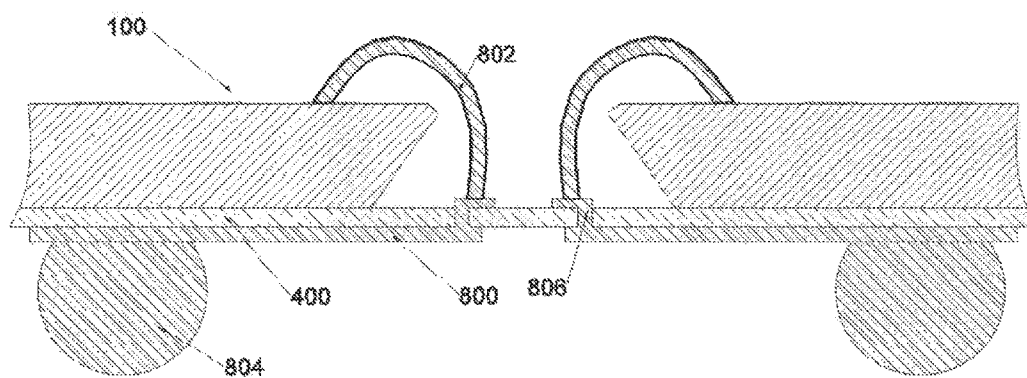


FIG. 38

**FLUID PRESSURE ACTIVATED
ELECTRICAL CONTACT DEVICES AND
METHODS**

CROSS-REFERENCE TO RELATED
APPLICATION

This application is a Continuation of U.S. non-provisional patent application Ser. No. 15/793,270, filed on Oct. 25, 2017, and titled "FLUID PRESSURE ACTIVATED ELECTRICAL CONTACT DEVICES AND METHODS", which claims priority of U.S. non-provisional patent application Ser. No. 14/921,030, filed on Oct. 23, 2015, and issued on Oct. 31, 2017 as U.S. Pat. No. 9,805,891 titled "MULTIPLEXING, SWITCHING AND TESTING DEVICES AND METHODS USING FLUID PRESSURE", which is incorporated herein in its entirety by this reference. By chain of continuity via the afore-referenced application, this application claims the benefit of priority of: U.S. provisional patent application No. 62/068,663, titled "Fluid Pressure Activated High Density Wafer Testing Probe Card" filed on Oct. 25, 2014; U.S. provisional patent application No. 62/069,843, titled "Fluid Pressure Activated High Density Wafer Testing Probe Card and Test Socket", filed on Oct. 29, 2014; U.S. provisional patent application No. 62/076,072, titled "Fluid Pressure Activated Wafer Level Probe Card/Burn-in/Test Socket Using Fluid Pressure as Source of Potential Energy for the Application and Control of the Desired Contact Force/Pressure", filed on Nov. 6, 2014; U.S. provisional patent application No. 62/077,941, titled "High Density LED Wafer Level Testing and Sorting Probe Card Contactor", filed on Nov. 11, 2014; U.S. provisional patent application No. 62/079,255, titled "High Density LED Wafer Level Testing and Sorting Probe Card Contactor and LED Color Testing Improvements", filed on Nov. 13, 2014; U.S. provisional patent application No. 62/080,434, titled "Quick Connect/Disconnect for Robotics and Industrial Applications Using Fluid Pressure as a Contact Force", filed on Nov. 17, 2014; U.S. provisional patent application No. 62/080,435, titled "Using a Multiplexer Switching Device or Double Face Test to Reduce the Number of Routing Conduits", filed on Nov. 17, 2014; and U.S. provisional patent application No. 62/128,495, titled "Using Fluid Pressure as Multiplexing or Switching Device", filed on Mar. 4, 2015. Each above-referenced provisional patent application is incorporated herein in its entirety by this reference. This application further more incorporates by reference U.S. non-provisional patent application Ser. No. 14/723,412, filed on May 27, 2015, and issued on Feb. 21, 2017 as U.S. Pat. No. 9,577,358 titled "Fluid Pressure Activated Electrical Contact Devices and Methods."

This application is a Continuation of U.S. non-provisional patent application Ser. No. 15/651,531, filed on Jul. 17, 2017, and titled "CTE COMPENSATION FOR WAFER-LEVEL AND CHIP-SCALE PACKAGES AND ASSEMBLIES", which is a Continuation-in-part of U.S. non-provisional patent application Ser. No. 15/498,188, filed on Apr. 27, 2017, and titled "CTE COMPENSATION FOR WAFER-LEVEL AND CHIP-SCALE PACKAGES AND ASSEMBLIES", which claims the benefit of priority of U.S. provisional patent application No. 62/327,807, filed on Apr. 26, 2016, and titled "WAFER LEVEL PACKAGING CONCEPT AND SOLUTION FOR CTE MISMATCH ISSUES." The above-referenced provisional patent application is incorporated herein in its entirety by this reference.

TECHNICAL FIELD

The present disclosure relates generally to devices and methods for establishing electrical connections, and more

particularly to fluid pressure activated device and methods for establishing electrical connections.

BACKGROUND

Electronic devices fabricated on semiconductor chips such as processors and logic devices are typically tested before being placed in consumer and commercial electronics devices. Many devices in the current marketplace contain a dozen or more semiconductor chip based devices, all of which should be tested before installation. Based on statistical data, twenty percent or more of the cost of semiconductor chips is related to the cost of testing.

As the world market sales for electronic devices reaches and surpasses hundreds of billions (USD), the costs of testing reaches and surpasses tens of billions. As consumers apply commodity pricing expectations to a growing list of established trusted brand names, the criticality of reliable and cost competitive testing equipment scales with the size of the market.

Before final assembly of an electronics consumer device in which hundreds and even thousands of microelectronics components are needed, each component may need to be tested. If even one single component is defective the device may be rendered useless. Semiconductor chips within such device are commonly made on substrate wafers having diameters of hundreds of millimeters. Thousands or even hundreds of thousands of electrical contact electrodes are typically present, and most or all of these contact electrodes needs to be tested or contacted to apply power and ground signals during the test. By current technology, as further described below, most or all of the contacts are to be touched and tested simultaneously. Given the small size and staggering number of contacts on a given wafer, the demands for precision and reliability placed on testing equipment is high.

SUMMARY

This Summary is provided to introduce in a simplified form concepts that are further described in the following detailed descriptions. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it to be construed as limiting the scope of the claimed subject matter.

According to at least one embodiment, a contactor device includes: a first body substrate; a second body substrate; a flexible membrane connected to the first body substrate and second body substrate, wherein the second substrate body is movable relative to the first substrate body by flexure of the flexible membrane; an electrical contact member carried by the second substrate body; a microfluidic-channeled substrate coupled to the first body substrate, the microfluidic-channeled substrate having a chamber and a microfluidic channel in fluid communication with the chamber; and a 3-dimensional flexible membrane enclosing the chamber, wherein the 3-dimensional flexible membrane flexes toward the second body substrate when a fluid pressure is applied to the chamber through the microfluidic channel whereby a force or a movement is transferred to the second body substrate by the 3-dimensional flexible membrane.

The contactor device may include: an electrically conducting outer pad positioned on the first body substrate; and a flexible electrical trace disposed along the flexible membrane, wherein the electrical trace electrically connects the electrical contact member to the outer pad.

The flexible membrane may span a gap between the first body substrate and second body substrate.

The first body substrate and flexible membrane may surround the second body substrate in two directions.

The second body substrate may be movable relative to the first body substrate in a third direction that is orthogonal to the two directions.

The second body substrate may have a generally planar first side from which the electrical contact member extends in the third direction.

In at least one example, the chamber is defined along a first side of the microfluidic-channeled substrate that faces the third direction; and a spacer extends in the third direction from the first side of the microfluidic-channeled substrate.

The microfluidic-channeled substrate may be coupled to the first body substrate by the spacer that extends in the third direction from the first side of the microfluidic-channeled substrate.

The second body substrate may have a generally planar first side from which the electrical contact member extends in the third direction.

In one or more example: the electrical contact member extends from a first side of the second body substrate; the first side of the second body substrate faces a Z direction; an electrically conducting pad positioned on a first side of the first body substrate facing the Z direction is electrically connected to the electrical contact member by a flexible electrical trace disposed along the flexible membrane; and an electrical contact on a second side of the first body substrate is electrically connected to the electrically conducting pad by an electrically conducting via that extends through the first body substrate; and the second side of the first body substrate faces a direction opposite the Z direction.

In one or more example, the 3-dimensional flexible membrane is positioned between the chamber and a second side of the second body substrate, wherein the second side of the second body substrate is opposite the first side of the second body substrate and faces the direction opposite the Z direction.

In at least one example, the electrical contact member extends from a first side of the second body substrate, the first side facing a Z direction; an electrically conducting pad positioned on a first side of the first body substrate facing the Z direction is electrically connected to the electrical contact member by a flexible electrical trace disposed along the flexible membrane; and an electrical contact on a second side of the first body substrate, which second side faces a direction opposite the Z direction, is electrically connected to the electrically conducting pad by an electrically conducting via that extends through the first body substrate.

The 3-dimensional flexible membrane may be positioned between the chamber and a second side of the second body substrate, which is opposite the first side of the second body substrate and faces the direction opposite the Z direction.

In at least one example, when fluid pressure is applied to the chamber through the microfluidic channel, the 3-dimensional flexible membrane flexes toward the second side of the second body substrate whereby the force or movement transferred to the second body substrate by the 3-dimensional flexible membrane is in the Z direction.

The electrical contact member may include a spring.

A current path may be defined from the second side of the first body substrate to the electrical contact member by: the electrical contact on the second side of the first body substrate; the electrically conducting via; the electrically conducting pad; and the flexible electrical trace.

The second body substrate may be movable relative to the first body substrate in a Z direction; and a spacer may extend

in the Z direction from the first body substrate and frame an area into which the second body substrate is movable.

The 3-dimensional flexible membrane may have an undulating shape.

The contactor device may include multiple additional electrical contact members carried by the second substrate body, wherein: the electrical contact member extends from a first side of the second body substrate, the first side facing a Z direction; and the multiple additional electrical contact members extend from the first side of the second body substrate.

The contactor device may include multiple electrical contacts each electrically connected to a single respective one of the electrical contact member and multiple additional electrical contact members, wherein the multiple electrical contacts are on a side of the first body substrate that faces a direction opposite the Z direction.

The contactor device may include multiple flexible electrical traces disposed along the flexible membrane each electrically connecting a respective one of the electrical contact member and multiple additional electrical contact members to one of the multiple electrical contacts.

The microfluidic-channeled substrate may have multiple additional chambers each in fluid communication with the microfluidic channel, and multiple additional 3-dimensional flexible membranes each enclosing a respective one of the multiple additional chambers.

BRIEF DESCRIPTION OF THE DRAWINGS

The previous summary and the following detailed descriptions are to be read in view of the drawings, which illustrate particular exemplary embodiments and features as briefly described below. The summary and detailed descriptions, however, are not limited to only those embodiments and features explicitly illustrated.

FIG. 1 is a cross-sectional illustration of a testing arrangement in which a semiconductor device having electrical contacts is tested using a probe card of the prior art.

FIG. 2 is a cross-sectional illustration of a testing arrangement in which a semiconductor device having electrical contacts is tested using a probe card device having fluid-pressure driven actuators according to at least one embodiment of the invention.

FIG. 3 is a perspective view of the probe card device of FIG. 2, illustrating the internal layout of microfluidic channels for control of the actuators.

FIG. 4 is a plan view of the device of FIG. 3.

FIG. 5 is a perspective view of a substrate layer of the device of FIG. 3, in which the microfluidic channels are formed.

FIG. 6 is a perspective view of a double-sided device, according to at least one embodiment, having fluid-driven actuators along opposing upper and lower generally planar sides.

FIG. 7 is a perspective view of a central substrate layer of the device of FIG. 6.

FIG. 8 is a cross-sectional illustration of a testing arrangement in which a semiconductor device having electrical contacts is tested using the device of FIG. 6.

FIG. 9A is a cross-sectional illustration of a substrate material layer prepared for manufacture of the device of FIG. 3 by a method represented in a sequence of cross-sectional views in FIGS. 9B-9F according to at least one embodiment.

FIG. 9B is a cross-sectional illustration of the substrate material layer FIG. 9A formed to have surface features upon which a membrane layer will be formed in FIG. 9C.

FIG. 9C is a cross-sectional view of the structure of FIG. 9B having a membrane layer formed across the surface features.

FIG. 9D is a cross-sectional illustration of the structure of FIG. 9C having electrically conducting traces and contactor tips selectively formed thereon.

FIG. 9E is a cross-sectional illustration of the structure of FIG. 9D having chambers 226 formed such as by etching or other hole formation method.

FIG. 9F is a cross-sectional illustration of the structure of FIG. 9E, joined to the substrate layer of FIG. 5 to complete fabrication of the device 300 of FIG. 3 according to at least one embodiment.

FIG. 10A is a cross-sectional illustration of substrate material layer prepared for fabrication of a device shown in FIG. 10F by a method represented in a sequence of cross-sectional views in FIGS. 10B-10F according to at least one embodiment.

FIG. 10B is a cross-sectional illustration of the structure of FIG. 10A having chambers formed and a conductive material deposited on the walls of the chambers.

FIG. 10C is a cross-sectional illustration of the structure of FIG. 10B having a layer of conductive material on which surface features are previously formed

FIG. 10D is a cross-sectional view of the structure of FIG. 10C having flexible membrane layer conforming to the interior surface features.

FIG. 10E is a cross-sectional illustration of the structure of FIG. 10D having the membrane layer material selectively removed.

FIG. 10F is a cross-sectional illustration of the structure of FIG. 10E, having the conductive layer selectively removed leaving trace portions, and the structure joined to a substrate layer having microfluidic channels.

FIG. 11A is a perspective view of a device having spacers incorporated along marginal areas, according to at least one embodiment.

FIG. 11B is a cross-sectional illustration of the device of FIG. 11A.

FIG. 12 is a cross-sectional illustration of a device having spacers as in FIGS. 11A-B, and curvilinearly extending contactor tips, according to at least one embodiment.

FIG. 13A is a perspective view of several embodiments of fluid-pressure driven probe actuators formed as various shapes.

FIG. 13B is a plan view of the several embodiments of fluid-pressure driven probe actuators in FIG. 13A.

FIG. 14 is a cross-sectional illustration of a fluid-pressure actuable device, according to at least one embodiment, having push rods that press electrically conducting flexible levers outward.

FIG. 15 is a cross-sectional illustration of another fluid-pressure actuable device, according to at least one other embodiment, having push rods that press electrically conducting flexible levers outward.

FIG. 16 is a perspective view of a contactor device according to at least one embodiment.

FIG. 17 is a perspective view of the contactor device of FIG. 16, shown in partial cross-sectional view.

FIG. 18 is a cross-sectional view of the contactor device of FIG. 16 taken along the section line 18-18 of FIG. 17.

FIG. 19 is a plan view of a first or top side of a microfluidic-channeled substrate according to at least one embodiment.

FIG. 20 is a cross-sectional view of the microfluidic-channeled substrate of FIG. 19 taken along the section line 20-20 of FIG. 19.

FIG. 21 is an exploded cross-sectional view of a stacked assembly, according to at least one embodiment, in which the contactor device of FIG. 18 is positioned in logical order between a semiconductor device and the microfluidic-channeled substrate of FIG. 20.

FIG. 22 is a cross-sectional view of the stacked assembly of FIG. 21, showing the microfluidic-channeled substrate abutting the contactor device, and the contactor device abutting the semiconductor device.

FIG. 23 is a perspective view of a contactor device according to at least one other embodiment.

FIG. 24 is a perspective view of a contactor device according to at least yet another embodiment.

FIG. 25 is an illustration of a device according to at least one embodiment.

FIG. 26 is an illustration of a device according to at least one embodiment.

FIG. 27 is an illustration of a device according to at least one embodiment.

FIG. 28 is an illustration of a device according to at least one embodiment.

FIG. 29 is an illustration of a device according to at least one embodiment.

FIG. 30 is an illustration of a device according to at least one embodiment.

FIG. 31 is an illustration of a device according to at least one embodiment.

FIG. 32 is an illustration of a device according to at least one embodiment.

FIG. 33 is an illustration of a device according to at least one embodiment.

FIG. 34 is an illustration of a device according to at least one embodiment.

FIG. 35 is an illustration of a device according to at least one embodiment.

FIG. 36 is an illustration of a device according to at least one embodiment.

FIG. 37 is an illustration of a device according to at least one embodiment.

FIG. 38 is an illustration of a device according to at least one embodiment.

DETAILED DESCRIPTIONS

These descriptions are presented with sufficient details to provide an understanding of one or more particular embodiments of broader inventive subject matters. These descriptions expound upon and exemplify particular features of those particular embodiments without limiting the inventive subject matters to the explicitly described embodiments and features. Considerations in view of these descriptions will likely give rise to additional and similar embodiments and features without departing from the scope of the inventive subject matters. Although the term "step" may be expressly used or implied relating to features of processes or methods, no implication is made of any particular order or sequence among such expressed or implied steps unless an order or sequence is explicitly stated.

Any dimensions expressed or implied in the drawings and these descriptions are provided for exemplary purposes. Thus, not all embodiments within the scope of the drawings and these descriptions are made according to such exemplary dimensions. The drawings are not made necessarily to scale. Thus, not all embodiments within the scope of the

drawings and these descriptions are made according to the apparent scale of the drawings with regard to relative dimensions in the drawings. However, for each drawing, at least one embodiment is made according to the apparent relative scale of the drawing. Like reference numbers used throughout the drawings depict like or similar elements. Unless described or implied as exclusive alternatives, features throughout the drawings and descriptions should be taken as cumulative, such that features expressly associated with some particular embodiments can be combined with other embodiments.

FIG. 1 is a cross-sectional illustration of a testing arrangement 100 in which a semiconductor device 110 having electrical contacts 112 is tested using a probe card contactor 120 of the prior art. The probe card 120 includes a board 122 that would ideally be planar and rigid, however these expectations are not reliably or sustainably met in the prior art. Probe tips 124 extend from one surface 126 of the board, and corresponding electrically conducting contacts 130 are placed along the opposite surface 132, each contact 130 in electrical contact with a respective probe tip 124. For convenience, these descriptions refer to the surface 126 as a lower surface and to the opposite surface 132 as an upper surface.

References to elements such as upper and lower surfaces are made in these descriptions with respect to the illustrated orientations of structures and features in the drawings. Features such as planar surfaces described as facing up or down and probe tips as extending up or down are not limited in fabrication, testing, or use to any absolute vertical or other orientation.

Furthermore, with reference to the planar upper surface 116 of the semiconductor device 110, an axis normal to the surface 116 can be described for nominal purposes as the Z-axis 102, whereas axes and directions perpendicular to the normal of the surface 116 can be described as having only X-axis 104 and Y-axis components. In FIGS. 1 and 2, the Y-axis should be considered as extending into the page of the drawings, such that the expressly shown Z-axis 102, the expressly shown X-axis 104 and the inferred Y-axis constitute a set of mutually orthogonal axes upon which convenient spatial descriptions are based in the following.

The testing arrangement 100 includes a first joining mechanism 140 having a board through which electrically conducting posts 142 pass to electrically connect electrically conducting lower contacts 144 to corresponding electrically conducting upper contacts 146.

The testing arrangement 100 further includes a spatial transformer 150 having a board through which electrically conducting posts 152 pass to electrically connect electrically conducting lower contacts 154 to corresponding electrically conducting upper contacts 156 via electrically conducting spreader strips 160. The spreader strips 160 effectively increase the pitch for electrical contact. Pitch in this context refers to the distance between contacts. For example, the pitch 118 of the contacts 112 along the upper surface 116 of the semiconductor device 110 in some examples may be below one hundred micrometers, whereas the pitch 162 of the upper contacts 156 of the spatial transformer 150 is larger by the amount of spread along the X-axis 104 introduced by the spreader strips 160. The space transformation may be realized through multiple layers of spreaders 160. An advanced space transformer may consist of tens of layers of routing.

The testing arrangement 100 further includes a second joining mechanism 170 having a board through which electrically conducting posts 172 pass to electrically connect

electrically conducting lower contacts 174 to corresponding electrically conducting upper contacts 176.

A device known as a device under test (DUT) board 180 having electrically conducting lower contacts 182 is brought into electrical communication with the semiconductor device 110 through the probe card 120, first joining mechanism 140, spatial transformer 150 and second joining mechanism 170, in succession, when the adjacent elements in FIG. 1 are brought into contact. Electrical voltages and currents are conveyed from the DUT board 180 to the semiconductor device 110 and the responsive performance of the device 110 is measured.

While only two routes of connection are expressly illustrated in FIG. 1, these descriptions relate to any number of routes of connection. For example, the semiconductor device 110 can have a large number electrical contacts 112 arranged in any preferred array pattern, such as a rectangular grid pattern having regularly spaced rows and columns. While a single spatial transformer 150 is illustrated as introducing spatial spreading along the X-axis 104, these descriptions relate to arrangements in which one or more spatial transformers introduce spatial spreading along both the X-axis 104 and Y-axis. Any number of joining mechanisms is within the scope of these descriptions as well. Ultimately, the components of the testing arrangement intervening between the semiconductor device 110 and DUT board 180 are to effect the transformation of the pitch of the semiconductor device 110 contacts 112 in each of two dimensions, X-axis pitch and Y-pitch, to the DUT board 180 contacts 182, so that each contact 112 is ultimately brought into electrical communication with a corresponding contact 182, in one-to-one correspondence.

A key component in the intervening components of the testing arrangement 100, and one prone to failure, is the probe card 120 of the prior art shown in FIG. 1. The integrity and durability of the probe card 120 rely upon the resiliency of the probe tips 124. The probe tips 124 each flex to some degree as a large number of probe tips are brought into contact with corresponding electrical contacts 112 for testing of the semiconductor device 110 by the DUT board 180. Force is applied by each probe tip 124 upon contact according to its flexure and effective spring constant of its material and shape. While a uniform contact force is preferred for consistent testing standards across an array of contacts 112, even where a high degree of uniformity upon manufacture of the probe tips 124 is achieved, repeated use can cause wear and fatigue in a non-uniform manner across an array of probe tips. For example, the board 122 of the probe card 120 can lose its planar configuration, especially when subjected to a high number of testing sessions, which often include thermal cycling. Whether causing uneven wear across an array, or even causing some probe tips 124 to fail to make contact, warping of the board 122 can cause failure of the probe card. But even before a probe card 120 is put into use, many are rejected from use due to low yield of probe cards having sufficiently low Z-axis tolerance. Thus, the probe cards 120 of the prior art are manufactured with low yield and high cost and suffer limited useful lifetimes.

FIG. 2 is a cross-sectional illustration of a testing arrangement 200 in which the semiconductor device 110 having electrical contacts 112 is tested using a probe card contactor 220 according to at least one embodiment among several expressly described in detail in the following, and among many more embodiments suggested and implied by the full scope of these descriptions and the drawings in FIGS. 2-15. Elements having like reference numbers in FIG. 2 as those elements in FIG. 1 are already sufficiently described above.

In FIG. 2, the probe card contactor 220 has fluid-pressure driven probe actuators 222, each having a flexible membrane 224 that responds to fluid pressure directed into a chamber 226 formed in a planar substrate body. The membrane 224 has a first surface internally facing into the chamber 226 and a second surface externally facing outward, such that the internal surface and external surface generally face in opposite Z-axis directions. An electrically conducting trace 236 extending at least partially across the external surface is carried by movement of the membrane 224 by the control of fluid pressure directed into the chamber 226. An electrically conducting contactor tip 240 mounted upon the external side of the trace 236 has a distal end that extends outward from the probe actuator 222 to contact an electrical contact 112 of the semiconductor device 110 under testing. The trace 236 extends from the tip 240 and along the external surface of the membrane 224 to an electrically conducting post 242. The trace 236 has a flexible portion 235 over the membrane 224 and a portion 237 over the substrate surface. The portion 237 may not always be defined as flexible, especially if formed over a rigid silicon surface.

The post 242 extends along a Z-axis direction through the substrate body of the probe card contactor 220, generally from a probe card first side 244 to a probe card second side 246 that face generally in opposite Z-axis 102 directions. The conducting post 242 has a first end contacted by the trace 236 and a second end defining a contact 250 at the second side 246 of the probe card contactor 220. Thus, the conducting post 242 and trace 236 serve to bring the contactor tip 240 into electrical communication with a corresponding lower contact 144 of the joining mechanism 140 in the testing arrangement 200 of FIG. 2. In other testing and electrical communication arrangements, the tips 240 can be brought into electrical communication with other joining mechanisms, spatial transformers and other devices to convey electrical voltages and currents from the DUT board 180 to the semiconductor device 110 to test and measure the responsive performance of the device 110. Indeed, the device 220 can be applied in broad range of controllable electrical contact uses.

For control and actuation of each fluid-pressure driven probe actuator 222, a microfluidic channel 280 opens into the chamber 226 for the provision of fluid pressure into the chamber to control the Z-axis position of membrane 224 and contactor tip 240. Applying or increasing pressure within the chamber 226 bears force upon the internal surface of the membrane causing outward Z-axis extension movement of the membrane and tip to establish physical contact and electrical communication with a contact 112 of the semiconductor device 110 or other structure or device. Cessation or decreasing pressure within the chamber 226 ends or lessens force upon the internal surface causing inward Z-axis return or withdrawal movement of the membrane 224 and tip 240 to terminate physical contact and electrical communication.

Contact force of the tip 240 upon the contact 112 of the semiconductor device 110 or other structure or device is controlled by regulating the amount of pressure within the chamber 226. Greater Z axis extension may not equal greater force. When the pressure is slightly above the atmospheric pressure, at certain point all the contact will start touching the wafers electrode pads. Further increasing the fluid pressure then increases the force between contactor tips and wafer electrode pads, since there is not any space for Z-axis to move anymore, therefore once the contactor touches decreasing or increasing pressure does not increase or Decrease the Z-axis movement. Depending on the material

and thickness of the membrane, membrane slack and conductive traces material, spring constant thickness and shape, a certain minimum pressure may cause all the contactors to reach their maximum height. When the wafer surface is pressed toward the contactor substrate surface and pressure is increased the increasing pressure only brings the contactors from contactor substrate into contact with wafer electrode pads, once all the contactor tips touch the wafer electrode pads, increasing pressure does not increase the Z-axis displacement anymore, it only increases electrical contact force. The goal may not be to bring in contact all the electrodes well within the contactors movement range. For example if the movement range is 20 microns, it may be preferred for the contactors to touch the wafer electrode pads somewhere around 10 microns displacement. From here on the Z axis displacement is restricted by the wafer electrode pads, and further increase in pressure will only translate to contact force increase.

FIG. 3 is a perspective view of the probe card contactor 220 illustrating the layout of microfluidic channels for control of the fluid-pressure driven probe actuators 222 of the probe card contactor 220 of FIG. 2. FIG. 4 is a plan view taken along the Z-axis of the probe card of FIG. 2. In the illustrated embodiment, the channels 280 that open into the chambers 226 extend in Y-axis 106 directions and perpendicularly intersect microfluidic channels 282 that extend in X-axis 104 directions. As such, the channels 280 and 282 crisscross the probe card contactor 220 to distribute fluid pressure to every probe actuator 222. In the illustrated embodiment of the probe card contactor 220, the channels 280 and 282 are co-located at a Z-axis depth within the probe card contactor 220 intermediate the probe card first side 244 to a probe card second side 246, placing the channels 280 into fluid communication with the chambers 226 of the actuators 222.

FIGS. 2-3 illustrate the layered structure of the probe card contactor 220. FIG. 9F provides a similar, but enlarged, view of the probe card contactor 220 as that in FIG. 2. As shown, the chambers 226 are formed as or defined by through-holes in a first substrate layer 252 of the substrate body. Each chamber 226 in the illustrated embodiment is formed as a circular cylindrical hole extending parallel to the Z-axis 102, normal to the generally planar probe card first side 244 and opposite probe card second side 246. Other shapes (see FIGS. 13A-13B for example) are within the scope of these descriptions.

Each flexible membrane 224 has generally planar marginal regions 254 (FIG. 9C, 9F) surrounding the mouth of the corresponding chamber 226 and attached to the first side 244 facing surface of the first substrate layer 252. The membrane 224 furthermore extends and covers the mouth of the chamber 226, sealing the chamber 226 at the first side 244 facing end of the chamber. The membrane 224 is advantageously formed as having a waving or undulating shape in crossing the mouth of the chamber 226. This provides a greater range of motion of the contactor tip 240 than would likely be possible with a simple planar membrane stretched across the mouth of the chamber. The membrane 224 has a central frustum portion 256 having its tapering apex or narrowing end extending outward from the chamber 226.

Between and connecting the central frustum portion 256 and planar marginal region 254, the membrane 224 has an intermediate frustum portion 260 that is concentric with and circumferentially encircles or surrounds the central frustum portion 256. The intermediate frustum portion 260 has a tapering narrowing end extending inward toward the cham-

ber 226. The central frustum portion 256 and intermediate frustum portion 260 at least partially overlap along the Z-axis such that the central frustum portion 256 is at least partially nested within the intermediate frustum portion 260.

As such, the waving or undulating shape of the membrane 224 in crossing the mouth of the chamber 226 provides a higher total material area than would a simple planar membrane stretched across the mouth. Thus by flexure, stretching and other distortions of the concentrically arranged planar marginal region 254, intermediate frustum portion 260 and central frustum portion 256, a greater range of Z-axis motion of the contactor tip 240 is facilitated than would likely be possible with a simple planar membrane stretched across the mouth of the chamber.

In the illustrated embodiment, the flexible portion 235 of the electrically conducting trace 236 follows the waving or undulating shape of the external surface of the membrane 224, and flexes, stretches and distorts with the membrane 224. The conducting trace 236 extends from the conducting post 232 to the central cone or partial cone 256, where the contactor tip 240 is mounted.

In the embodiment illustrated in FIGS. 2-4, the membrane 224 has the concentric frustum portions 256 and 260, which narrow in opposite Z-axis directions, and which are formed as circular cone portions having circular footprints when viewed along the Z-axis 102 as in FIG. 4. The central frustum portion 256 may include an entire cone, including an apex, or may be a truncated cone. In other embodiments, the frustum portions 256 and 260 may be pyramid shaped, having polygonal footprints such as square or rectangular when viewed along the Z-axis as shown in FIGS. 13A-B for example. In other embodiments, the central portions of the membranes and intermediate portions, which connect the central portions to the marginal regions, are other shapes that narrow in opposite Z-axis directions, thus defining a waving or undulating shape of each membrane.

FIG. 5 is a perspective view of a second substrate layer 270 of the probe card contactor 220 of FIGS. 2 and 3, in which the channels 280 and 282 are formed. The second substrate layer 270 has a first surface 272 (FIG. 3), which faces the first substrate layer 252 (FIG. 3) and in which the channels 280 and 282 are formed. The opposite surface of the second substrate layer 270 defines the second side 246 of the probe card contactor 220, facing an opposite Z-axis direction from that in which the contactor tips 240 face. Through holes 274 extend at least partially parallel to the Z-axis 102 to accommodate the electrically conducting posts 242.

As shown in FIGS. 2 and 3, the outward facing surface of an electrically insulating protective passivation or cover layer 290 defines the first side 244 of the probe card contactor 220. The illustrated cover layer 290 lies over the generally planar marginal regions 254 of the membranes 224, the traces 236 beyond the chamber mouths, and the outward facing surface of the first substrate layer 252. Holes are formed through the cover layer 290 to provide openings at positions corresponding to the concentric locations of the chambers 226 and frustum portions 256 and 260 of the membranes 224 to permit electrical contact of the contactor tips 240 through the cover layer 290.

The cover layer 290 in the illustrated embodiment is sufficiently thick in its Z-axis dimension to provide a first side 244 of the probe card contactor 220 flush with the distal ends of the contactor tips 240. In other embodiments, the cover layer thickness can be selected to cause the contactor tips 240 to extend from the first side 244. In yet other embodiments, the cover layer thickness can be selected to

cause the contactor tips 240 to terminate at or below the first side 244 to prevent contact with external surfaces until the membrane 224 is extended by fluid pressure.

The membrane 224 (FIGS. 2-3) can be constructed of one or more flexible and resilient materials including both electrically conducting and non-conducting materials. In many embodiments, each contactor tip 240 and trace 236 are to be electrically isolated from the others while being electrically connected to a corresponding conducting post 142, thereby permitting electrical contact of a respective individual electrical contact of a device via a particular individual fluid-pressure driven probe actuator 222. In one example construction, the membrane 224 is constructed of Parylene, and the trace 236 and contactor tip 240 are formed of electrically conducting metal or alloy. Graphene, having advantageous strength and being highly electrically conductive, may be used in the construction of the membrane 224. Graphene can be used as a layer or trace upon a Parylene layer. In such an example, the Parylene electrically isolates the graphene from unwanted shorting or mutual connection among traces. The membrane 224 can be a composite or layered membrane. For example, a first layer adjacent the first substrate layer 252 can be Parylene, with a graphene layer upon the first layer to strengthen the membrane. In that example, any number of conducting or non-conducting layers can be added, so long as the top layer of the membrane is electrically non-conducting to permit independent electrical connection of each contactor tip 240 and corresponding trace 236 to a unique corresponding conducting post 142. Other conducting metals for use in or on the membrane 224 include, but are not limited to, nickel and copper. The entire membrane could consist of conducting material, where electrical signals isolation is provided in the form of isolation rings or gaps around each membrane member. For example mono layers of Graphene sandwiched between multiple very thin layers of conductive material (metals), where electrical conductivity and flexibility is maintained, while the strength of the conductive membrane is kept by its composite multilayer nature. Mono layer Graphene is very flexible, but imperfections make a mono layer graphene prone to breakage. Also a mono layer of graphene may not provide enough conductivity, while multiple layers of graphene on top of each other diminishes flexibility. The membrane material can also be Graphene oxide and other composite membrane type. A benefit is to marginalize the role of spring constant and rather rely on the fluidic pressure to apply contact force. A very flexible membrane and metal trace, with zero spring constant is used in at least one embodiment.

As shown in FIG. 3, the microfluidic channels 280 and 282 extend in Y-axis 106 and X-axis 104 directions to lateral margins of the probe card contactor 220. FIG. 3 expressly illustrates four fluid-pressure driven probe actuators 222 but relates as well to a probe card having any number of actuators 222 and any corresponding dimensions along the X and Y axes. The channels 280 and 282 are configured to receive pressured fluid from an external fluid source to actuate any number of actuators 222. The fluid driven into the inlets of the channels 280 and 282 may be gaseous or liquid in various embodiments. The fluid in at least one embodiment is air. The fluid in other embodiments of gaseous fluids can be other gases. The fluid in at least one embodiment is water, and in other embodiments of liquid fluids can be other liquids. The fluid can be gas, liquid, and any material or phase thereof to apply hydrostatic pressure. Forces applied by fluid pressure to the membranes 224 may be uniform across the probe card contactor 220, according to

Pascal's law, by way of the intersecting channels **280** and **282** that maintain the chambers **226** in pressure equilibrium. Some channels or all channels may be isolated from some or all other channels in case the device is used as a switching or multiplexing device, where as the pressure underneath a membrane is lower than the pressure above a membrane, will cause the electrical contact to terminate by collapsing the membrane below the surface.

Using the testing arrangement **100** of FIG. **1**, when the probe card **120** of the prior art and semiconductor device **110** are brought together, the total mechanical contact force is as same as the total electrical contact force, and are thus not separately controlled. Variations from buckling or material fatigue result in random variations of contact force across the many electrical contacts **112** that are typically under testing. This can lead to damage of the contacts **112** and probe tips **124** as well.

Using the testing arrangement **200** of FIG. **2**, when the probe card contactor **220** and semiconductor device **110** are brought together, the cover layer **290** can first contact the upper surface of the semiconductor device **110** before the fluid-pressure driven probe actuators **222** are actuated. Once mechanical contact of the probe card contactor **220** and semiconductor device **110** is accomplished, fluid pressure within the chambers **226** can be increased by injecting fluid into the microfluidic channels **280** and **282**, thus causing the membranes **224** to extend and the distal ends of the contactor tips **240** to contact the contacts **112**. The forces of contact across many contactor tips **240** and contacts **112**, governed by Pascal's law which dictates pressure equilibration among the interconnected chambers **226**, are both uniform and controllable.

The above descriptions with reference to FIGS. **2-5** relate to a fluid driven actuatable electrical contact device **220** thus far described as a probe card. It should be understood that these descriptions relate to other uses for an electrical contact device controlled to extend electrical contacts by driving pressured fluid into channel inlets. Furthermore, the above descriptions expressly describe a device **220** having fluid-driven actuators **222** along one generally planar side **244**. FIGS. **6-8** relate to a fluid driven actuatable electrical contact device **300** having fluid-driven actuators **222** along two generally planar sides **302** and **304**.

FIG. **6** is a perspective view of a double-sided device **300** having fluid-driven actuators along opposing upper and lower generally planar sides according to at least one embodiment. The device **300** has a sufficient degree of symmetry above and below the substrate layer **306** such that description of the device **300** above the layer **306** suffices for a complete description. The central substrate layer **306** differs from the second substrate layer **270** of FIG. **5**, for example in that the layer **306** has microfluidic channels formed along upper and lower surfaces and Z-axis extending through holes to effect fluid communication among the upper and lower channels.

FIG. **7** is a perspective view of the central substrate layer (micro fluidic channels substrate) **306** of the probe card **300** of FIG. **6**. Above the central plane of the central substrate layer **306**, microfluidic channels **310** and **312** crisscross an upper surface of the layer **306** parallel to the Y-axis **106** and X-axis **104** respectively. Through holes **314** extend along the Z-axis **102** to accommodate electrically conducting posts **242** as shown in FIG. **8**. Through holes **316** formed at intersections of the channels **310** and **312** effect fluid communication between the microfluidic channels along the upper and lower surfaces of the layer **306**. They don't need to be necessarily at the intersections. It is also possible to

have only channels along the Y axis or only along the X axis. Thus, by way of the through holes **316** that extend at least partially parallel to the Z-axis **102**, the fluid-driven actuators **222** along the upper and lower sides of the double-sided probe card **300** are actuated simultaneously by fluid pressure driven into inlets of the microfluidic channels **310** and **312**. For switching applications, the bottom and top cavity chambers may be driven by separate valves and/or separate pressure sources, in order to terminate some electrical connections and activate some. Instead of microfluidic channels, a porous ceramic substrate material **306** could be used.

The fluid-driven actuators **222** having flexible membranes **224** that respond to fluid pressure directed into the chambers **226** are described above with reference to FIGS. **2-4**. Elements in FIGS. **6-8** having reference numbers the same as elements in FIGS. **1-5** are already described above.

FIG. **8** is a cross-sectional illustration of a testing arrangement **400** in which the semiconductor device **110** having electrical contacts **112** is tested using the probe card **300** of FIG. **6**. In the testing arrangement **400** of FIG. **8**, the double-sided probe card **300** is positioned between the semiconductor device **110** and first joining mechanism **140**. Once the lower cover layer **290** of the probe card **300** mechanically contacts the semiconductor device **110**, and mechanical contact of the upper cover layer **290** to the first joining mechanism **140** is also established, fluid pressure within the chambers **226** of the probe card can be increased, thus causing extension of the lower membranes **224** toward the semiconductor device **110** and extension of the upper membranes **224** toward the first joining mechanism **140**. Because the upper and lower membranes **224** extend in opposite Z-axis **102** directions, the effective actuating reach of the double-sided probe card **300** is advantageously maximized. The joining mechanism **140** can be eliminated in this configuration, since **300** may act sufficiently as a temporary joining mechanism. In at least one embodiment, use of a double sided contactor eliminates the need for a permanent joining mechanism. Though in certain cases it could help the permanent joining process, such as eutectic, gold to gold or diffusion bonding.

Like the device **200**, the expressly described use of the device **300** permits reference to the device as a probe card **300**. It should be understood that both the device **200** and the device **300** are not limited to uses as probe cards in the context of FIGS. **2** and **8**, which illustrate non-limiting examples of uses for the devices described herein having many possible other uses.

A method of manufacturing the device **300** (FIGS. **2-4**, **9F**) according to at least one embodiment, is represented in a sequence of cross-sectional views in FIGS. **9A-9F**. All materials and treatment methods are provided as non-limiting examples. Other materials and methods are within the scope of these descriptions.

FIG. **9A** is a cross-sectional illustration of substrate material layer **252**. Example materials include, but are not limited to: silicon, glass, copper, polyimide, and other electronics materials.

FIG. **9B** is a cross-sectional view of the substrate material layer **252** of FIG. **9A** formed to have surface features upon which membranes **224** will be formed. Methods of forming the features include, but are not limited, to using: chemical etch; stamping; mechanical forming; plasma/RIE etching; and plating.

FIG. **9C** is a cross-sectional view of the structure of FIG. **9B** having the membrane **224** formed across the surface features, forming the planar marginal region **254**, intermediate frustum portions **260** and central frustum portions **256**

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of the membrane. Example membrane materials include, but are not limited to: Parylene, polyimide, SiN, graphene, and graphene oxide. Additional descriptions of the membrane 224 are provided above with reference to FIGS. 2 and 3. The membrane material can be a monolithic later or a combination of different materials. The order of layers can be changed and different materials can be used to increase the flexibility and flexural and mechanical strength of the membrane material.

FIG. 9D is a cross-sectional view of the structure of FIG. 9C having the electrically conducting trace 236 and contactor tip 240 layers selectively formed. The traces 236 are formed of flexible conducting material, whereas the tips 240 may be formed of harder conductive metals or conductive carbon fibers. The trace 236 and contactor tip 240 layers may be applied in a variety of ways including, but not limited to: plating; CVD; PCVD; and sputtering. FIG. 9D also shows the passivation cover layer 290 formed on the structure.

FIG. 9E is a cross-sectional view of the structure of FIG. 9D having chambers 226 formed such as by etching or other hole formation method.

FIG. 9F is a cross-sectional view of the structure of FIG. 9E, joined to the second substrate layer 270 (FIG. 5) having microfluidic channels to complete fabrication of the device 220 (FIGS. 2-4) according to at least one embodiment.

Additional and intermediate processes and steps may be involved to achieve the structures shown in FIGS. 9A-9F. Such processes and steps may include, photo resist steps, application exposure steps, development, stripping, chemical etching, masking, plasma etching, and others.

A method of manufacturing an alternative device 500 (FIG. 10F) according to at least one embodiment, is represented in a sequence of cross-sectional views in FIGS. 10A-10F. All materials and treatment methods are provided as non-limiting examples. Other materials and methods are within the scope of these descriptions. Like reference numbers in FIGS. 10A-10F as in other drawings refer to like features.

FIG. 10A is a cross-sectional illustration of substrate material layer 502. Example materials include, but are not limited to: silicon, glass, copper, polyimide, and other electronics materials.

FIG. 10B is a cross-sectional view of the structure of FIG. 10A having chambers 226 formed such as by etching or other hole formation method. A conductive material 504 is deposited on the walls of the chambers. If metal is used as the substrate material layer (FIG. 10A), the chamber walls may be electrically isolated by an intervening insulating layer before depositing conductive material.

FIG. 10C is a cross-sectional view of the structure of FIG. 10B having a layer 506 of electrically conductive material, such as a metal, which may be copper for example. Surface features 510 are previously formed on the chamber-facing side of the layer 506 are faced into the chambers 226. The conductive layer 506 closes one end of each chamber.

FIG. 10D is a cross-sectional view of the structure of FIG. 10C having flexible membrane layer 512 additionally applied to the interiors of the conductive chamber walls and conductive closure layer 506 of FIG. 10C. The membrane layer 512 conforms to the interior surface features 510 of the conductive layer 506.

FIG. 10E is a cross-sectional view of the structure of FIG. 10D having the membrane layer 512 material removed from the base of the structure opposite the conductive layer 506, leaving the membrane layer 512 coating the interiors of the chambers 226.

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FIG. 10F is a cross-sectional view of the structure of FIG. 10E, having conductive layer 506 selectively etched or otherwise removed leaving trace portions 236 along the exteriors of the membrane layer 512. Contactor tips 240 are formed exterior to the remaining trace portions 236 of the conductive layer 506. The structure is also joined to a second substrate layer 516 having microfluidic channels 280 and 282 to complete fabrication of the device 500 according to at least one embodiment. Electrically conducting columns 520 pass entirely through the second substrate layer 516 to complete electrical contact from the traces 236 to the opposite side of the device 500.

The device 500 can be used similarly as the probe card or device 220 of FIGS. 2-4. The conducting columns 520 (FIG. 10F) serve a similar function as the posts 242 (FIG. 2) in establishing electrical communication from the tips 240 and traces 236 to the lower contacts 144 of the first joining mechanism 140 (FIG. 2). Fluid pressure applied to the interiors of the chambers 226 (FIG. 10F) via the microfluidic channels 280 and 282 causes extension of the membrane layer 512 which extends the contactor tips 240 to contact, for example, the contacts 112 of the semiconductor device 110 (FIG. 2).

In some cases, the active surface of wafer or semiconductor device 110 (FIG. 2) is preferably not to be touched other than at electrical contacts 112 due to sensitivity of the device 110. To accommodate, spacers can be formed on a probe card along marginal areas. FIG. 11A is a perspective view of a device 600 having spacers 602 incorporated along marginal areas such as dice separation lines (saw lines), and linearly extending contactor tips 604. FIG. 11B is a cross-sectional illustration of the device of FIG. 11A. The device 600 can be understood according to descriptions above with reference to, for example, FIG. 3 having several reference numbers in common with FIG. 11A relating to like features. In FIGS. 11A-B, marginal spacers 602 extend in a Z-axis 102 direction from the cover layer 290. Contactor tips 604 in FIGS. 11A-B bear similar function and arrangement as the contactor tips 240 in FIG. 3. The contactor tips 604 extend in the same Z-axis 102 direction as that of the spacers 602 to compensate for the height of the spacers 602.

FIG. 12 is a cross-sectional illustration of a device 620 having spacers 602 as in FIGS. 11A-B, and curvilinearly extending contactor tips 622, according to at least one embodiment. The device 620 can be understood according to descriptions above with reference to, for example, FIG. 3 having several reference numbers in common with FIG. 12 relating to like features. The curvilinear contactor tips 604 extend in the same Z-axis 102 direction as that of the spacers 602 to compensate for the height of the spacers 602. Each contactor tip 604 includes an intermediate X and/or Y axis direction extension portion 606 that displaces the X-Y position of the distal contact end of the tip from the X-Y position of the central point of the membrane 224.

FIG. 13A is a perspective view of several embodiments of fluid-pressure driven probe actuators formed as various shapes. FIG. 13B is a plan view of the several embodiments of fluid-pressure driven probe actuators in FIG. 13A. Each is formed over a substrate layer 252 under an electrically insulating protective passivation or cover layer 290 (FIG. 13A).

Viewed along the Z-axis 102, normal to the cover layer 290, probe actuator 652 has a circular shape and a wedge-shaped conducting trace 654. Probe actuator 656 has a circular shape and perpendicularly crossing linear conducting traces 658. Probe actuator 662 has a circular shape and multiple wedge-shaped conducting traces 664. Probe actua-

tor **666** has a circular shape and two partial-circularly shaped conducting traces **668** arranged diametrically opposite each other. Probe actuator **672** has an elongate rectangular shape and a linear strip conducting trace **674**. Probe actuator **676** has a square shape and a linear strip conducting trace **678**. Probe actuator **682** has a shape including an elongate rectangular portion and a circular portion, in which a linear strip conducting trace **684** extends along the rectangular portion to the center of the circular portion.

Each of these actuators has a membrane with a frustum portion that narrows in a Z-axis direction. The actuators **652**, **656**, **662** and **666** have central frustum portions **256** formed as circular cone portions having circular footprints when viewed along the Z-axis **102** as in FIG. **13B**. The central frustum portion **256** may include an entire cone, including an apex, or may be a truncated cone. In the other embodiments in FIGS. **13A-B**, the frustum portions **686** are pyramid shaped, having square footprints when viewed along the Z-axis as shown in FIG. **13B**.

The actuators **656** and **666** (FIGS. **13A-B**), and those illustrated in FIG. **10F**, have conducting traces with a high degree of symmetry, and thus are expected to extend and withdraw linearly along a Z-axis direction. Conversely, actuators **652**, **662**, **672**, **676**, **682** (FIGS. **13A-B**) and actuators **222** (FIGS. **2-4**, **6**, **8** and **9F**) have more asymmetric conducting trace arrangements, which are expected to cause some X-Y directional travel of conductor tips as the actuators are extended and withdrawn in Z-axis directions by fluid-pressure control. Such X-Y directional travel or wiping may be beneficial in some uses, by causing scratching of contact surfaces to improve electrical contact by removal or breaching of surface oxidation or contamination at electrical contacts, such as contacts **112** of the device **112** under testing in FIG. **2**.

FIG. **14** is a cross-sectional illustration of a fluid-pressure actuatable device **700** having push rods **702** that press electrically conducting flexible levers **704** outward to bring contactor tips **240** into electrical contact with contacts of another device or structure. The device **700** has a membrane **224** above chambers **226**, which are formed in a first substrate layer **252**. Fluid pressure directed into the chambers **226** via the channels **280** in the second substrate layer **270** cause actuation of the device. The cover layer **290** defines the top surface of the device **200**.

A spacer layer **706** is formed over the membrane **224**. The push rods **702** are fixed in X-Y positions by holes formed through the spacer layer **706**. The push rods **702** move in Z-axis **102** directions under fluid pressure control. Each push rod **702** presses upon a respective resilient flexible lever **704**, which is connected to a respective conducting post **242**, which passes through the device **700** to a bottom surface of the device, where bottom ends of the posts **242** define electrical contacts.

The membrane **224** presses upward when fluid pressure is applied. This raises the push rods **702**, flexing the levers **704** outward and carrying the contactor tips **240** into contact with another device or structure, thus establishing electrical communication between bottom ends of the posts **242** and other device or structure contacted by the tips **240**.

FIG. **15** is a cross-sectional illustration of another fluid-pressure actuatable device **720** having push rods **702** that press electrically conducting flexible levers **704** outward to bring contactor tips **240** into electrical contact with contacts of another device or structure. In this embodiment, the membranes **224** are positioned below pistons **722** within the chambers **226**. The pushrods **702** are positioned over the pistons **722**. The membranes **224** press upward when fluid

pressure is applied via the channels **280**. This raises the pistons **722** and push rods **702**, flexing the levers **704** outward and carrying the contactor tips **240** into contact with another device or structure, thus establishing electrical communication between bottom ends of the posts **242** and other device or structure contacted by the tips **240**. In this case the membrane maybe constructed from stretchable material. Some types of Parylene for example can stretch two hundred percent. There is a variety of stretchable polymer and Silicones available.

The membranes **224** in FIGS. **14-15** can be pre-formed as having frustum portions over the chambers **226** (FIG. **14**), or as flat (FIG. **15**) in their relaxed shapes. Parylene C and/or other materials described herein may be used for stretchable flexible flat or otherwise shaped membranes. The pistons **722** and push rods **702** may be formed on silicon substrate or form by methods including but not limited to plating and etching.

In at least one embodiment, electrical contact force is mainly the function of fluidic pressure, even if in certain embodiments there a spring may reside over the membrane. It is also important to note that during the initial touchdown it is the goal to bring in contact the semi-conductor wafer first surface with the contactor substrate surface, while the contactor electrical tips are either not touching the wafer electrode pads (pressure in a chamber is less or equal than the pressure between the top surface of the membrane and the contactors are residing either below the surface of the contactor substrate or at the level of contactor substrate, so at the initial touchdown even if the pressure between the wafer surface and contactor substrate surface may exceed hundreds of mega Pascals, the force between the contactor tip and the wafer electrode pads is still close to zero or in single digit grams.

In at least one embodiment, at initial touchdown all the membranes just give way and without any resistance fall back in the cavities. This way it is proven that it is only the fluidic pressure which contributes to the main portion of the electrical contact force.

Frustums described above can have various shapes, including other shapes that are not shown in the drawings and those shown including squares, rectangles and odd shapes.

Regarding fluidic chamber communication: some chambers may not be connected to each other and in some embodiment as in a switching multiplexer, they need to be connected to a different fluidic pressure source.

There may be only one contactor over each membrane. That does not exclude the case where same contactor consists of multiple sub-contactors, all connected to the same electrical route.

Traditionally contactors built or attached to a space transformer or any other interposer, which interfaces the DUT board may be defined as a probe card. In embodiments described above, the contactor and micro fluidic channel substrate could be used as a stand-alone contactor substrate which may not need any permanent joining to any intermediate interposer or space transformer. Where these descriptions refer to a contactor and microfluidic substrate as a probe card, this reference is for example purposes only without otherwise limiting these descriptions. Thus, the above contactors can be used as a wafer and die level electrical testing contactors, switches, and can be used in multiplexers and RF switches, quick connects and disconnects and anywhere where temporary connections are needed between electrically conductive terminals.

A probe card or contactor substrate may not be a rigid substrate itself, it could have a flexible embodiment/version where, as whole, it could conform to any shape a semiconductor wafer may have. If the semiconductor wafer takes a convex or concave shape, a flexible contactor substrate can wrap over and conform to the shape. Once the two surfaces are locked, then the contactors itself can be activated using fluid pressure and it still contacts all the electrodes with close to identical force.

An advantage is not just the possibility to keep both the wafer and contactor flat, but also the capability to always have a conformal physical contact between the surface of the two, without exerting any force on the contactors and wafer electrode pads, until the contactors are activated/actuated using the external fluidic pressure.

The external pressure force which causes the surface to surface conformal contact could also be fluid pressure, bladder or mechanical, which conforms the two surfaces to each other, thus a smallest movement of the contactor caused by the fluidic pressure increase under the membrane will create electrical contact, since unlike conventional technologies most of the Z-Axis tolerance is already eliminated or neutralized by physical contact pressure.

A joining mechanism is not necessarily a board. It could have a collection of springs on a board or solder balls places on the terminals of the contactor and space transformer. It could be gold to gold, thermo-sonic or any method of joining (metal to metal and dielectric to dielectric) joining technologies.

A factor often behind probe card contactor failure is during burn-in tests, as due to temperature cycling, CTE mismatch between different material in semiconductor wafer and probe card construction causes warpage, independent of the initial planarity values between the wafer and the probe card contactor.

The probe card contactor can be built in its entirety in a wafer level format on a substrate equal to the final size of the wafer, or can be built in clusters or diced into pieces equal to the semiconductor chip size, and then being picked-placed and joined on a carrier substrate having corresponding conductive through vias. This way the total yield loss of the wafer will not have much effect of the cost of the device.

Where the semiconductor wafer electrode pads are made of aluminum, aluminum oxide may form on the electrode. It may be necessary to create a wiping scrub action at the time of contact of the contactors and wafer electrode pads. Asymmetric shaped contactor traces or asymmetric membrane shapes in combination of each other or by itself could result in non-vertical movement of the contactor under increased pressure. This will add a small X-Y component movement to the contactor tips along the Z axis movement to result in wiping actions, thus scratching the aluminum oxide on the wafer electrode pads, making a metal to metal low resistance electrical contact possible.

A larger pitch version of the single or double-sided contactor substrate could exactly be placed between the DUT and the space transformer to absorb some planarity or even totally overcome planarity issues. In some existing technologies, some sort of springs may be used to match and electrically connect the space transformer to the DUT board.

An advantage of embodiments described below is to mechanically isolate the X-Y, and Z movement of contactors either at a single contact level or at a "clusters of contacts" level or at a die level over a large scale wafer having a plurality of devices. Using three-dimensional membranes in conjunction with microfluidic pressure, the below described devices mechanically isolate contactors or a cluster of the

contactors in X-Y-Z planes, and therefore compensate for Z-axis planarity and semiconductor device and contactor substrate bulging tolerances and create a uniform and reliable contact force over any size of wafer or substrate panel for testing, independent to the magnitude of the bulging or Z-Axis tolerances.

In some above-described embodiments, electrical contacts are disposed over individual flexible membranes. The contacts are moved by fluidic pressure exerted under these flexible and slightly stretchable membranes, and are actuated to move up and contact the semiconductor wafer electrical terminals. Fluidic pressure is injected from an external pressure source, either a tank of gas, compressor, or any other possible source, to inflate the membrane. This inflation expands the membrane and thereby moves the contacts to touch the electric terminals of the semiconductor wafer. Since these contacts are all mechanically coupled to the same membrane, the pressure applied by each contact to the terminals will be uniform by virtue of Pascal's law.

In FIGS. 16-22, at least one device is shown on an illustrated portion of a wafer, but the concept may be applicable over an entire larger wafer, mechanically isolating each die at X-Y-Z planes, so each device can move up and down independently. The same concept is applicable to a cluster of terminals within each single device as well.

FIG. 16 in particular is a perspective view of a contactor device 1000, according to at least one embodiment, that includes a stationary body substrate 1004 that serves as a base and a movable inner substrate body 1014 suspended by a flexible membrane 1016 that connects the body 1014 to the substrate 1004. The flexible membrane 1016 spans a gap 1020 (see FIG. 17) between the movable inner substrate body 1014 and stationary body substrate 1004. In the illustrated embodiment, the body substrate 1004 and flexible membrane 1016 surround the movable inner substrate body 1014 in two dimensions, for example in an X-Y plane with respect to an X direction 1104 and a Y direction 1106. The Z direction 1102, the X direction 1104, and the Y direction are mutually orthogonal.

Electrically conducting inner pads 1008 are mounted upon a first or top side of the inner substrate body 1014. A respective electrical contact spring 1012 extends upward from each inner pad 1008. Each electrical contact spring 1012 is in electrical communication with a respective electrically conducting outer pad 1006 by way of a respective electrical trace 1010 disposed along the flexible membrane 1016. Each electrical trace 1010 electrically connects an inner pad 1008 to an outer pad 1006. The outer pads 1006 are positioned along a first or top side of the stationary body substrate 1004. The electrical trace 1010 can be, for non-limiting example, a flexible micro strip, coax or strip line, over the flexible window for increased RF performance.

FIG. 17 is a perspective view of the contactor device 1000, shown in partial cross-sectional view. FIG. 18 is a cross-sectional view of the contactor device 1000 of FIG. 16 taken along the section line 18-18 of FIG. 17. As shown, each outer pad 1006 is connected to a respective electrically conducting element, nominally referenced as via 1018 herein. Each via 1018 extends from the top side of the stationary body substrate 1004 to an opposite second or bottom side of the stationary body substrate 1004. Each conducting via 1018 has a lower end 1022 (FIG. 18) along the bottom side of the stationary body substrate 1004 that serves as a bottom-side electrical contact or terminal in electrical communication with a respective electrical contact spring 1012, which serves as a top-side electrical contact or terminal of the contactor device 1000.

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The lower ends **1022** (FIG. **18**) of the conducting vias **1018** conduct electrical currents or signals to an interposer (not shown), which in turn will be connected to test instrumentation or power ground signals. A current or signal path is defined from the bottom side to the top side of the contactor device **1000** by, in one-to-one correspondence and in ordered succession: the lower end **1022** of each conducting via **1018**; the body of the via **1018** extending through the stationary body substrate **1004**; and the associated outer pad **1006**, electrical trace **1010**, inner pad **1008**, and electrical contact spring **1012**.

Terms such as top and bottom, above and below, up and down, and upper and lower are used nominally in these descriptions with reference to the Z direction **1102** (FIG. **16**) as upward without regard to the actual orientation of the contactor device **1000** in use. The Z direction **1102** is parallel to the normal vector **1108** of the generally planar top side surface of the movable inner substrate body **1014**. Thus the Z-direction **1102**, in which the movable inner substrate body **1014** is movable relative to the body substrate **1004**, is perpendicular to the generally planar top side surface of the movable inner substrate body **1014**.

A spacer **1002** along the outer perimeter of the top side of the illustrated portion of the stationary body substrate **1004** frames an area into which the inner substrate body **1014** can move upward in the positive Z direction **1102** and return in the negative Z direction (up and down). The flexible membrane **1016** is 3-dimensional and deformable, permitting movement of the inner substrate body **1014**, which can move in the Z direction while being generally constrained against X direction **1104** and Y direction **1106** movements. The spacer **1002** serves to abut a structure to be contacted by the electrical contact springs **1012** when the inner substrate body **1014** is extended upward in the Z direction. Upon return of the inner substrate body **1014** along the negative Z direction to a lower position, the electrical contact springs **1012** will lose contact with or lessen their contact force against such a structure.

FIG. **19** is a plan view of a first or top side of a microfluidic-channeled substrate **2000** according to at least one embodiment. FIG. **20** is a cross-sectional view of the microfluidic-channeled substrate **2000** of FIG. **19** taken along the section line **20-20** of FIG. **19**. The microfluidic-channeled substrate **2000** has a body **2002** in which chambers **2004** are formed below and opening to a top surface of the body **2002**. A flexible membrane layer is applied across portions of the top surface of the body **2002** such that the layer portions across the mouths of the chambers **2004** form 3-dimensional flexible membranes **2006** enclosing the chambers and effecting fluid seal of the chambers **2004** from the environment above the microfluidic-channeled substrate **2000**.

Microfluidic channels **2008** are formed in the substrate **2000** leading from an inlet **2018** to feeder channels that open to the chambers **2004**. Fluidic pressure is injected through inlet **2018**, into the chambers **2004** in fluid communication with the inlet **2018** via microfluidic channels **2008**, causing the flexible membranes **2006** to actuate by flexure and bulging outward from the top surface of the body **2002**. A spacer **2014** along the outer perimeter of the top side of the illustrated portion of the microfluidic-channeled substrate **2000** frames an area in which the flexible membranes **2006** can actuate.

As shown in FIG. **20**, electrically conducting vias **2010** extend, in electrical isolation from each other, from the top side of the microfluidic-channeled substrate **2000** to an opposite bottom side thereof. Each conducting via **2010** has

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a first contact end **2016** along the top surface of the spacer **2002** and a second contact end **2012** along the bottom side of the substrate **2000**. Each via **2010** thus provides a current or signal path through the microfluidic-channeled substrate **2000**, an operation of which is described with reference to FIGS. **21-22**. The second contact ends **2012** of the microfluidic-channeled substrate **2000** can contact a space transformer or other device.

FIG. **21** is an exploded cross-sectional view of a stacked assembly, according to at least one embodiment, before touch down, in which the contactor device **1000** is shown from the perspective of FIG. **18**. The contactor device **1000** is positioned in logical order between a semiconductor device **3000** and the microfluidic-channeled substrate **2000** of FIGS. **19** and **20**. Only two adjacent dice are shown, but any feasible number can be used. FIG. **22** shows the semiconductor wafer device **3000** is pressed over the contactor substrate.

FIG. **22** is a cross-sectional view of the stacked assembly of FIG. **21**, after touch down, showing the microfluidic-channeled substrate **2000** abutting the contactor device **1000**, and the contactor device **1000** abutting the semiconductor device **3000**. The contactor device **1000** may be joined permanently to the microfluidic substrate **2000**, where the spacer **2014** makes it possible to only join the bottom surface of the stationary body substrate **1004** to the top surface of the spacer **2014**, thus leaving the movable inner substrate body **1014** free to move up toward and down away from the semiconductor device **3000**. The inner substrate body **1014** is mechanically floating, suspended between the microfluidic-channeled substrate **2000** and the semiconductor device **3000**. The inner substrate body **1014** is movable in the positive and negative Z directions in the enclosed space defined in part by the spacers **2014** and **1002** but is held in a relatively fixed X-Y position by the portions of the flexible membranes **1016** that surround the movable inner substrate body **1014** in two dimensions.

The semiconductor device **3000** is aligned and placed over spacers **1002**. The entire structure is then constrained from multiple sides. For example the stacked assembly in FIG. **22** can be constrained from above the top surface of the semiconductor device **3000** and from below the bottom surface of microfluidic substrate **3000**. The bottom surface of the semiconductor device **3000** has electrode pads **3004** that are aligned respectively with the electrical contact springs **1012** of the contactor device **1000**.

In operation, before fluidic pressure is injected into the chambers **2004**, the contact springs **1012** and electrode pads **3004** may be spaced from each other without contact or they may be touching with negligible contact force at the moment the semiconductor device **3000** is constrained upon the contactor device **1000**. To actuate the contactor device **1000**, pressured fluid is injected under membranes **2006**, into the chambers **2004**, through the inlet **2018**. When the cavities **2004** are pressurized by an external pressure source, the associated membrane **2006** will move outward from the microfluidic substrate **2000**, upward toward the inner substrate body **1014**, thus transferring upward movement to the floating inner substrate body **1014**. The pressure forces the flexible 3-dimensional membranes **2006** to actuate upward, and therefore extend the movable inner substrate body **1014** toward the semiconductor device **3000**, causing the electrical contact springs **1012** springs to come into contact with electrode pads **3004** or increase their contact force, thus closing the circuits for testing or burn-in.

The membranes **2006** are advantageously each formed as having a waving or undulating shape in crossing the mouth

of the chamber **2004**. This provides a greater range of motion than would likely be possible with a simple planar membrane stretched across the mouth of the chamber.

In prior-existing wafer-level probe card testing, the spring contactors typically have a large Z-direction movement to accommodate total-thickness variation (TTV), wafer planarity, and wafer and probe card warping over the entire area of the wafer.

In embodiments described herein, contributing Z non-planarity factors may be localized in small clusters of contacts or at single or multiple die level, not necessarily at the entire wafer.

Pressuring membranes will contribute to the bulk actuation of the movable inner substrate body **1014**, and therefore the Z axis compensation at the wafer level, while the Z axis movement of the springs **1012** will compensate for the remaining Z axis planarity tolerance. In other words both the movement of the substrate body **1014** actuated by pressure increase under the membranes **2006**, and the contact springs **1012** will compensate for Z-axis non planarity tolerance, and create a uniform and stable electrical contact between the wafer electrode pads and test apparatus (not shown).

The electrical contact springs **1012** serving as electrical contact members are shown as curvilinear springs. Other shapes and forms for electrical contact members can be used. For example, other electrical contact members can have the shape of a solid pyramid, a stud, and a post.

In the embodiments illustrated in FIGS. **16-17**, the body substrate **1004** and flexible membrane **1016** surround the movable inner substrate body **1014** in two dimensions. Other arrangements are within the scope of these descriptions.

For example, in FIG. **23** stationary body substrate portions **4002** and **4004** serve as a base members and a movable inner substrate body **4014** is suspended along two sides thereof by respective membrane sections **4016** and **4018**. The conducting inner pads **1008** mounted upon the top side of the inner substrate body **4014** are electrically connected to the outer pads **1006** by way of respective electrical traces **1010** disposed along the membrane sections **4016** and **4018**. A respective electrical contact spring **1012** extends upward from each inner pad **1008**.

The contactor device **4000** of FIG. **23** differs from the contactor device **1000** in that, instead of the flexible membrane **1016** that surrounds the inner body **1014** as in contactor device **1000**, the membrane sections **4016** and **4018** suspend the movable inner substrate body **4014** in FIG. **23**.

In FIG. **24**, the stationary body substrate portions **4002** and **4004** serve as a base members and the movable inner substrate body **4014** is suspended between them. The contactor device **4100** of FIG. **24** differs from the contactor device **4000** in that, instead of the flexible membrane **4016** and **4018** that partially surround the inner body **4014** as in contactor device **4000**, the movable inner substrate body **4014** in FIG. **24** is suspended along two sides thereof by the flexible electrical traces **1010**.

FIGS. **25-29** show a brief illustrating of common approaches used.

FIG. **25** illustrates a semiconductor wafer, with only two dice depicted, where **100** is the semiconductor wafer, **106** are the electrodes, **102** is one of the dice, and **104** is an adjacent die on the semiconductor wafer.

FIGS. **26-27** illustrates a spacer **200** is formed sequentially over the semiconductor substrate/wafer **100**, conductive vias **202** are formed and plated metallicity to access the semiconductor electrode pads, then passives **300** are built over the spacer **200**.

Spacer **200** is of a lower loss dielectric material, which besides improving the Q-factor, it also elevate the sources of interference between the passives and active circuitry of the semiconductor wafer.

In the above described cases whether the spacer is built sequentially or in parallel and attached to the semiconductor wafer later, the CTE mismatch between the semiconductor wafer and the spacer material is always a huge problem. It could cause the entire substrate to bulge, curl or even break.

FIGS. **25-29**, show a brief illustrating of common approaches used.

FIG. **25** illustrates a semiconductor wafer, with only two dice depicted, where **100** is the semiconductor wafer, **106** are the electrodes, **102** is one of the dice, and **104** is an adjacent die on the semiconductor wafer.

FIGS. **27-28** illustrates a spacer **200** is formed sequentially over the semiconductor substrate/wafer **100**, conductive vias **202** are formed and plated metallicity to access the semiconductor electrode pads, then passives **300** are built over the spacer **200**.

Spacer **200** is of a lower loss dielectric material, which besides improving the Q-factor, it also elevate the sources of interference between the passives and active circuitry of the semiconductor wafer.

FIGS. **29-36** briefly illustrate some novel approaches to go around the CTE mismatch problems between the semiconductor and the spacer substrates.

FIG. **29** shows that a trench is formed, either chemically or using dry etch around the saw lines of at least every die, or a cluster of dice. The trench **108** initially is either stopped close to the surface of silicon to keep the wafer in one piece, or stopped by a deposited layer of oxide, nitride, or polymer **110**.

Then in FIG. **30** dielectric material **400**, such as Parylene is deposited on the back side of the wafer. An adhesion promoter is applied to the back surface **114** of the semiconductor wafer, while the sloped surfaces **116** of the trenches are masked to not be treated with adhesion promoter.

FIG. **30** shows that some polymer material **400** or some metal such as copper, is evaporated on the back surface of the wafer, including the trenches.

In FIG. **31** it has been illustrated that the access semiconductor material **110** which has been holding the dice together in wafer form, will be removed, either using chemical or dry etch.

In FIG. **32** the entire wafer is stretched with slight force to break the poor adhesion between **400** and **116**, thus separating each die on the wafer, but still in wafer format.

The semiconductor substrate from this point on will still can be handled as a wafer with precise X-Y-Z coordinates for each die.

FIG. **33** illustrates that spacer material **500** which closely matches the CTE of **400** is attached/deposited/or applied to the surface of the wafer.

The CTE mismatch is still present, but in this case it only propagates over the area of each single die, which even at 200 degree C. and a CTE difference of 50 PPM/degree C. between the semiconductor wafer **100** and spacer material **500**, which is only 100 microns over the areas of a 1 cmx1 cm die, in X-Y dimensions. The bottom line is that the wafer still stays flat and free of stress through out of the subsequent process steps.

FIG. **34** shows that subsequently vias **602** are formed and plated, and passives **600** are formed over the spacer **500**.

FIGS. 35-36 illustrate the same concept approach with where a 30 membrane 700 is formed around the periphery of each dice on the wafer before any processing of passive of spacers.

The purpose of the 700 is as same, where it acts as a spring or CTE cushion of absorbent.

The idea beyond this concept is to absorbed the CTE mismatch at the periphery of each die, instead of allowing it to propagate over the entire wafer and have an accumulative affect toward stressing and bulging the wafer.

700 can be silicon nitride, or some other ceramics or polymer which can still keep the wafer in one pieces but move and give way under CTE induced expansion, thus preventing the wafer from breaking or bulging.

There is another given advantage with the approach shown in FIG. 32. Depending of semiconductor substrate 100 thickness and the wall angle of the trench, and the stretching capabilities of the material 400, we can actually increase the overall size of the semiconductor wafer, in case we need more real estate over the semiconductor dice, for building more passives.

Some material like Parylene C can stretch up to 200% of their length.

This concept gives way to a number of possibilities where we can actually make chip scale packages, at wafer level. (Chip scale packages are usually processed in strip or lead frame format, using Singulated dice, since the size of a chip scale package, based on industry definitions are slightly larger than the die size, since the wire bonds locations on the tape have to extend beyond the actual size of the die.)

FIG. 37 shows a typical CSP (Chip Scale Package).

Using our concept of expanding the wafer size, shown in FIGS. 29-32, we can further process the deposited material 400 at the back of the wafer to create metallization, bonding pads and solder pads, it is possible to create a novel CSP at wafer level.

FIG. 38 illustrates a simplified example of such wafer level CSP.

There could be a number of derivative structures of such concept, where we can apply material at the back of a wafer with trenches as shown in FIGS. 29-32.

Such trenches can be formed either from the front side or back side of the wafer, and then traces can be formed on the sloped trench walls, where instead of wire bonds we can directly extend conductive traces metallization from one side of the wafer to the other side, or onto a substrate on either side of the wafer, thus scaling the X-Y dimensions of the wafer, while still keep our process at wafer level, for parallel and cost effective processes.

Particular embodiments and features have been described with reference to the drawings. It is to be understood that these descriptions are not limited to any single embodiment or any particular set of features, and that similar embodiments and features may arise or modifications and additions may be made without departing from the scope of these descriptions and the spirit of the appended claims.

What is claimed is:

1. An microelectronic structure having CTE (co-efficient of thermal expansion) compensation for use in wafer-level and chip-scale packages, comprising a plurality of substrate tiles each having a generally planar upper surface, the upper surfaces of the tiles disposed within a common plane to provide a generally planar grid of the tiles, each respective pair of adjacent tiles having a gap disposed therebetween and a spring structure spanning the gap and connecting the adjacent tiles, the spring structure configured to permit

movement of the adjacent tiles relative to one another to provide compensation for thermal expansion or contraction of the tiles;

a respective opening extending through each substrate tile from the upper surface to an opposing lower surface; an electrically conductive post extending through each opening from the upper surface to the lower surface; and

a device layer attached above the upper surfaces of the common plane.

2. The microelectronic structure of claim 1, wherein the substrate tiles comprise a semiconductor material.

3. The microelectronic structure of claim 1, wherein the substrate tiles comprise metal.

4. The microelectronic structure of claim 1, wherein the substrate tiles comprise a dielectric body on which electrically conductive traces are exposed.

5. The microelectronic structure of claim 1, wherein the spring structure comprises a membrane.

6. The microelectronic structure of claim 1, wherein the spring structure comprises a membrane having a 3 dimensional profile.

7. The microelectronic structure of claim 1, wherein the spring structure comprises a metal.

8. The microelectronic structure of claim 1, wherein the spring structure comprises a dielectric material on which conductive traces are disposed.

9. The microelectronic structure of claim 1, wherein the spring structure comprises a membrane having a channel with a longitudinal axis that is disposed parallel to an edge of the upper surface of a selected tile to which the membrane is attached.

10. The microelectronic structure of claim 9, wherein the membrane has at least one of a U shape, a trapezoid shape, a V-shape, and a W-shape.

11. The microelectronic structure of claim 1, wherein the spring structure is attached to the upper surfaces of the adjacent tiles.

12. The microelectronic structure of claim 1, comprising a dielectric material disposed on the common plane and disposed within the gap.

13. The microelectronic structure of claim 12, further comprising a device layer attached to the common plane.

14. The microelectronic structure of claim 13, wherein the device layer is attached to the common plane with the dielectric material disposed therebetween, and wherein the device layer is electrically connected to a selected one of the tiles by one or more vias extending through the dielectric material.

15. The microelectronic structure of claim 1, wherein the plurality of substrate tiles is electrically continuous.

16. The microelectronic structure of claim 1, wherein at least one electrical terminal is disposed over at least one of the tiles.

17. The microelectronic structure of claim 1, wherein the spring structure comprises a 3 dimensional conductive membrane connecting the tiles formed over a polymer.

18. A method of forming a three-dimensional microstructure by a sequential build process, comprising: disposing a plurality of layers over a substrate, wherein the layers comprise one or more layers of a conductive material and one or more layers of a sacrificial material, thereby forming a structure above the substrate, comprising: a plurality of conductive tiles formed of one or more layers of the conductive material, each tile having a generally planar upper surface, the upper surfaces of the tiles disposed within a common plane to provide a generally planar grid of the tiles,

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each respective pair of adjacent tiles having a gap disposed therebetween and a spring structure spanning the gap and connecting the adjacent tiles, the spring structure configured to permit movement of the adjacent tiles relative to one another to provide compensation for thermal expansion or contraction of the tiles;

a respective opening extending through each substrate tile from the upper surface to an opposing lower surface; an electrically conductive post extending through each opening from the upper surface to the lower surface; and a device layer attached above the upper surfaces of the common plane.

19. The method of claim 18, wherein the spring structure is formed of the conductive material.

20. The method of claim 18, comprising removing the sacrificial material.

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21. The method of claim 18, wherein the spring structure comprises a membrane.

22. The method of claim 21, wherein the membrane has at least one of a U shape, a trapezoid shape, a V-shape, and a W-shape.

23. The method of claim 18, wherein the spring structure is attached to the upper surfaces of the adjacent tiles.

24. The method of claim 18, wherein the step of disposing a plurality of layers over a substrate comprises disposing one or more layers of a dielectric material.

25. The method of claim 18, comprising electrically connecting a device layer to the common plane.

26. The method of claim 18, wherein the tiles each comprise a lower surface opposing the upper surface and comprising electrically connecting a semiconductor chip or wafer to the lower surface.

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