US 20130135001A1

(19) **United States**

(12) **Patent Application Publication**

Breinlinger

(10) **Pub. No.: US 2013/0135001 A1**

(43) **Pub. Date: May 30, 2013**

(54) **HYBRID ELECTRICAL CONTACTOR**

(71) Applicant: **FormFactor, Inc.**, Livermore, CA (US)

(72) Inventor: **Keith J. Breinlinger**, Livermore, CA (US)

(73) Assignee: **FORMFACTOR, INC.**, Livermore, CA (US)

(21) Appl. No.: **13/681,896**

(22) Filed: **Nov. 20, 2012**

Related U.S. Application Data

(60) Provisional application No. 61/564,679, filed on Nov. 29, 2011.

Publication Classification

(51) **Int. Cl.**
G01R 1/067 (2006.01)
G01R 1/073 (2006.01)

(52) **U.S. Cl.**
CPC ***G01R 1/067*** (2013.01); ***G01R 1/07342*** (2013.01)
USPC **324/754.03**; 324/756.05; 324/756.03

(57) **ABSTRACT**

An electrical connection between an electrically conductive probe on one device and a compliant pad on another device can be formed by piercing the compliant pad with the probe. The probe can contact multiple electrically conductive elements inside the pad and thereby electrically connect to the pad at multiple locations inside the pad.

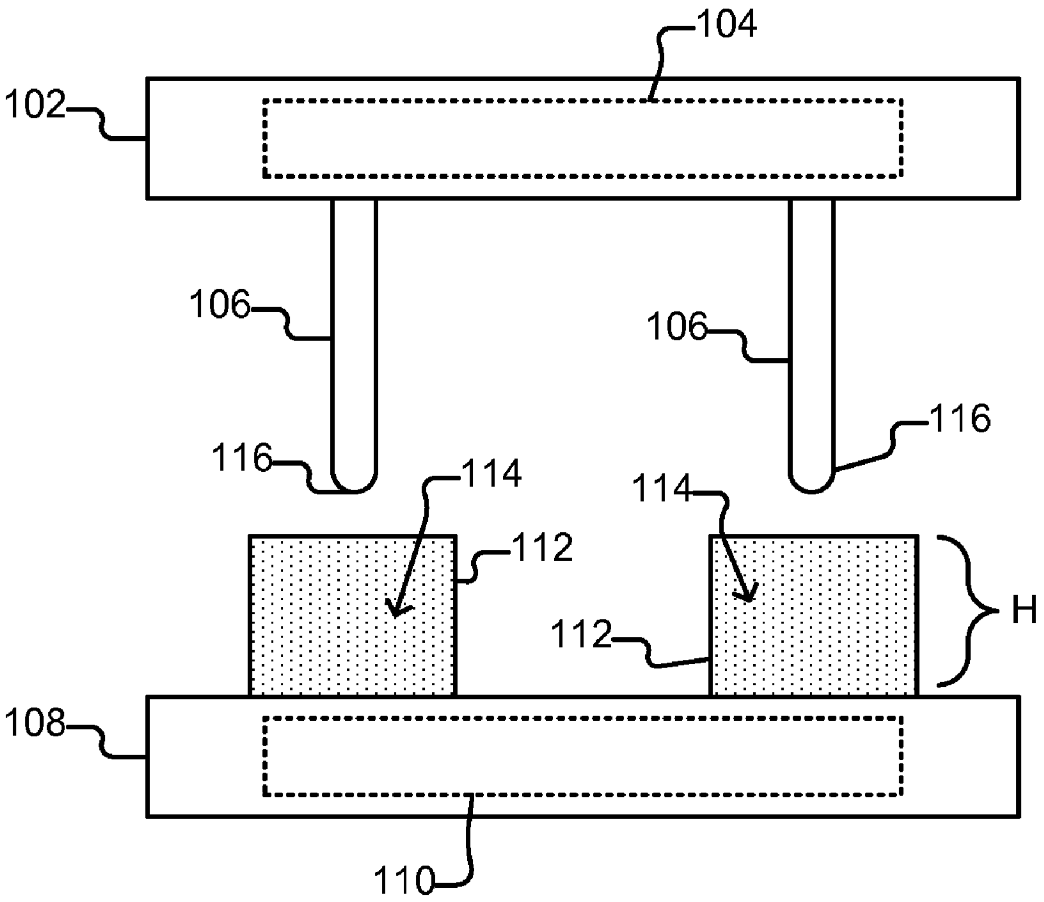


Figure 1A

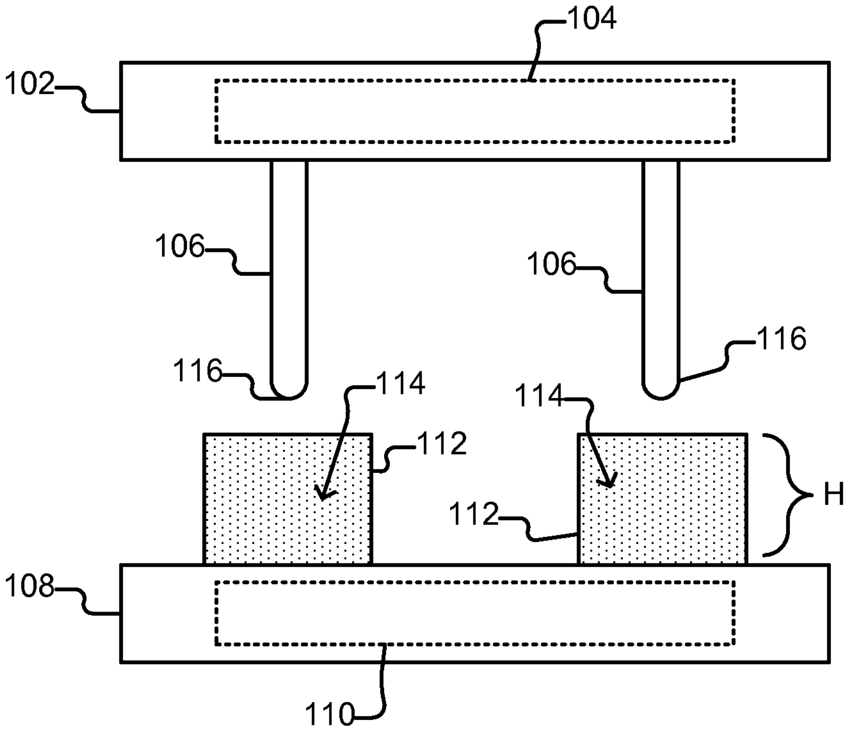


Figure 1B

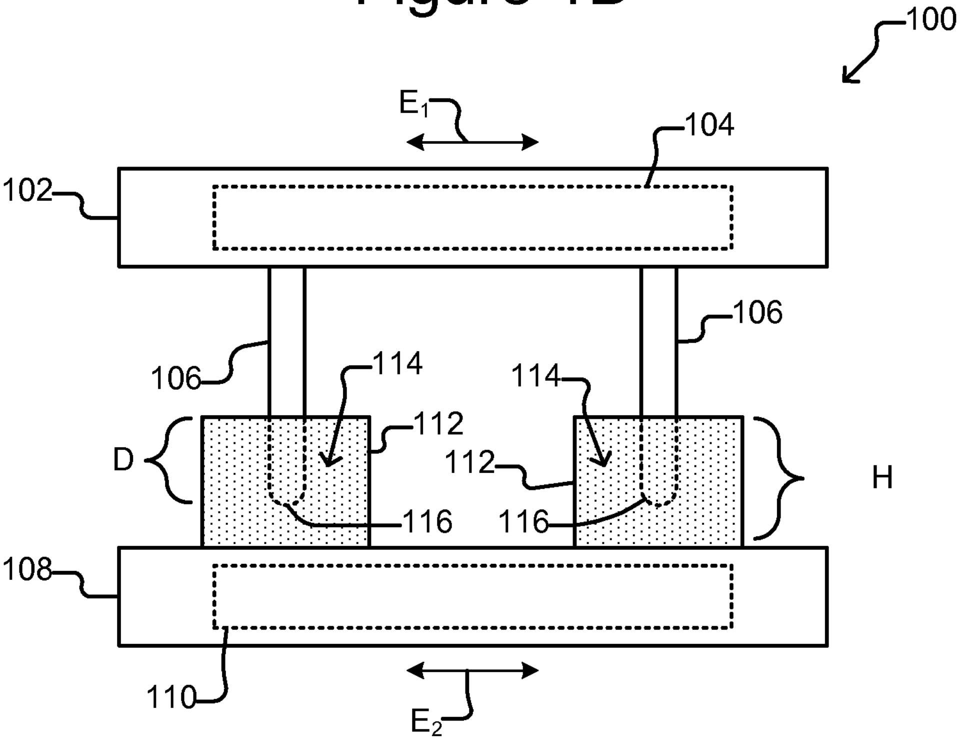


Figure 2

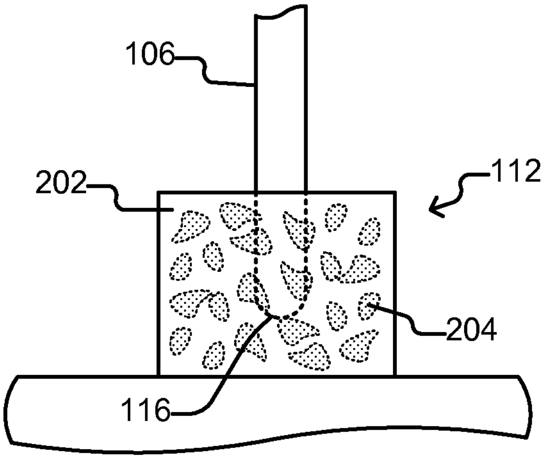


Figure 3

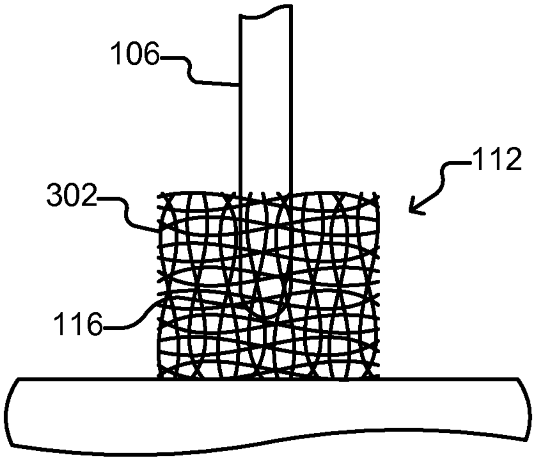


Figure 4

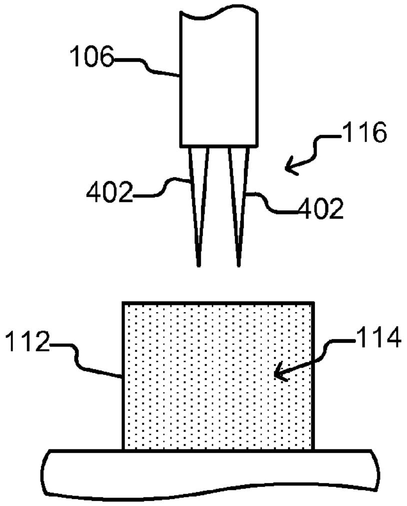


Figure 5

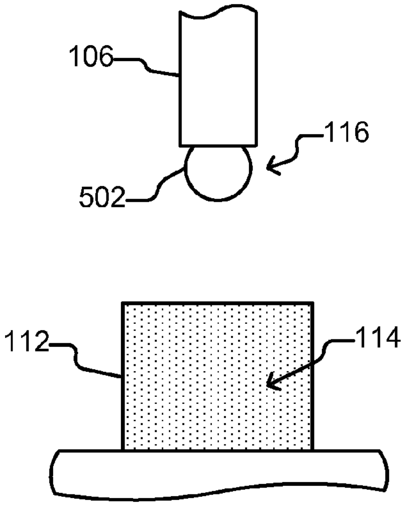


Figure 6A

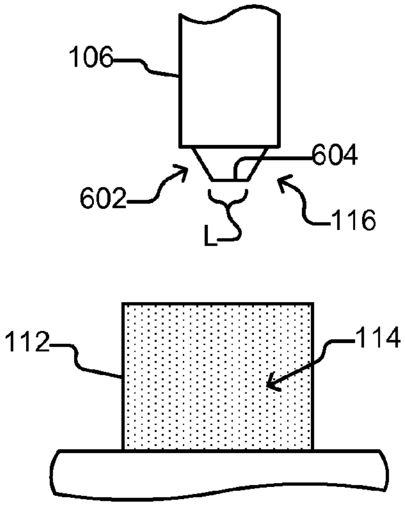


Figure 6B

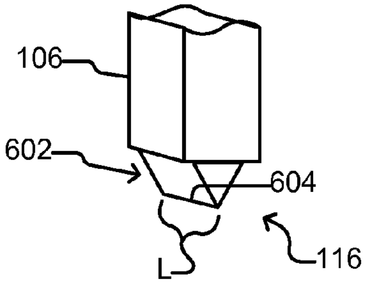


Figure 7

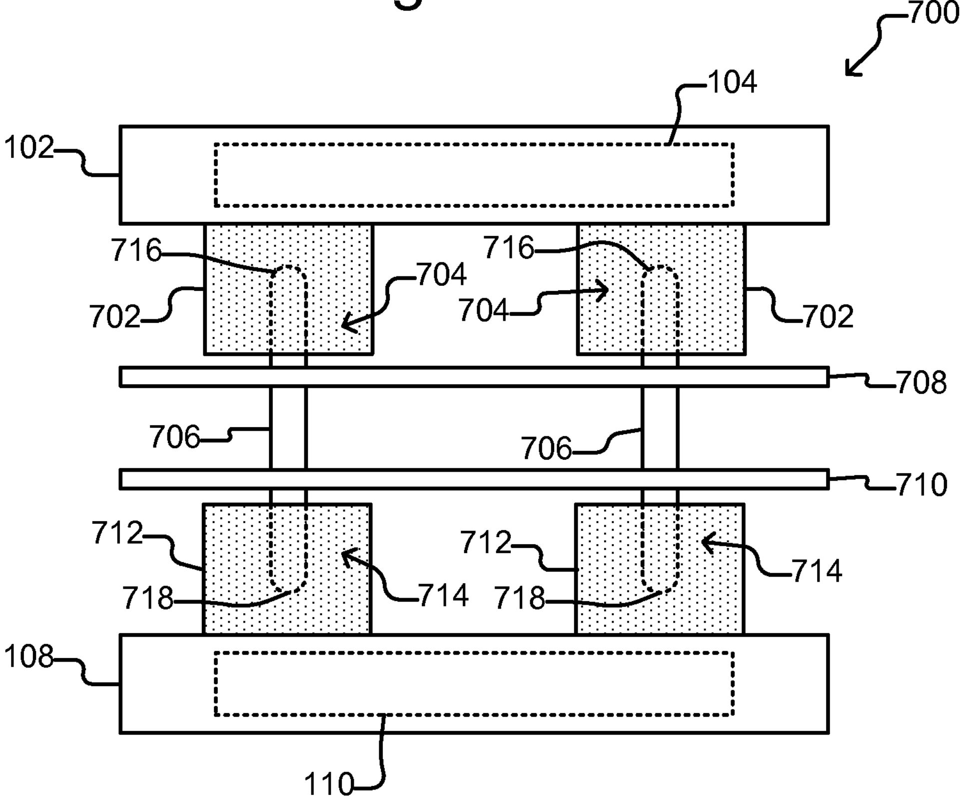

700
104
102
716
716
704
704
702
702
708
706
706
710
712
712
714
714
718
718
108
110

Figure 8

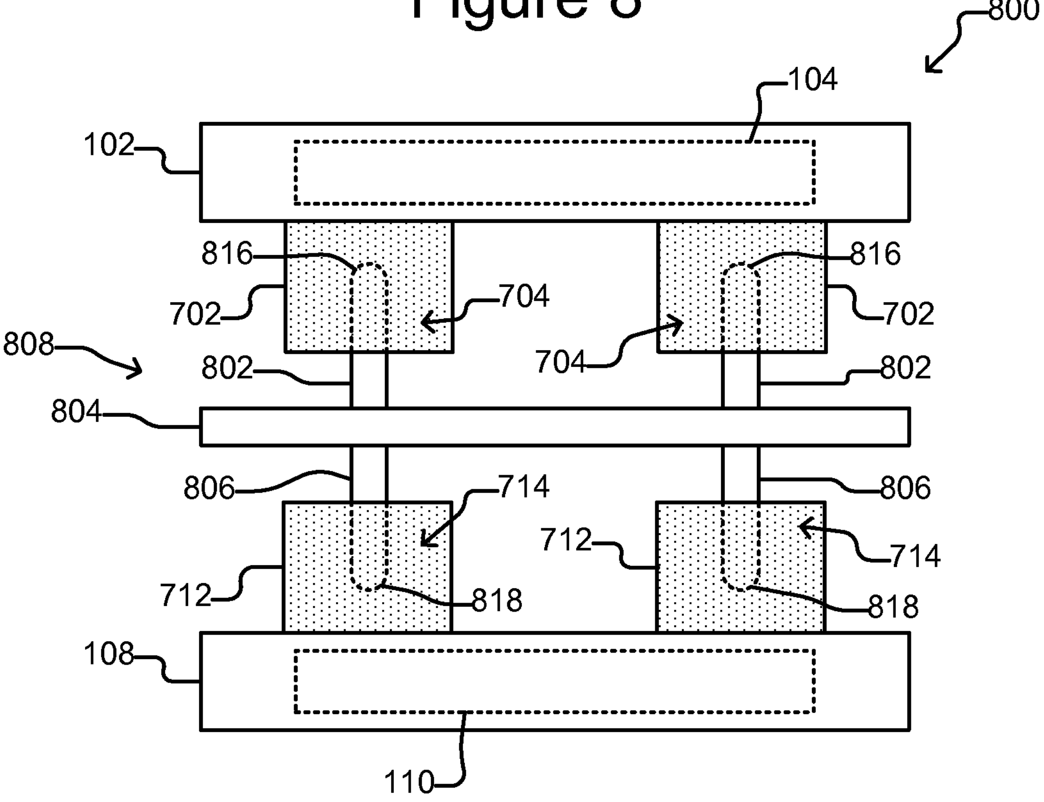

800
104
102
816
816
702
704
702
808
704
802
802
804
806
806
714
712
714
712
818
818
108
110

Figure 9

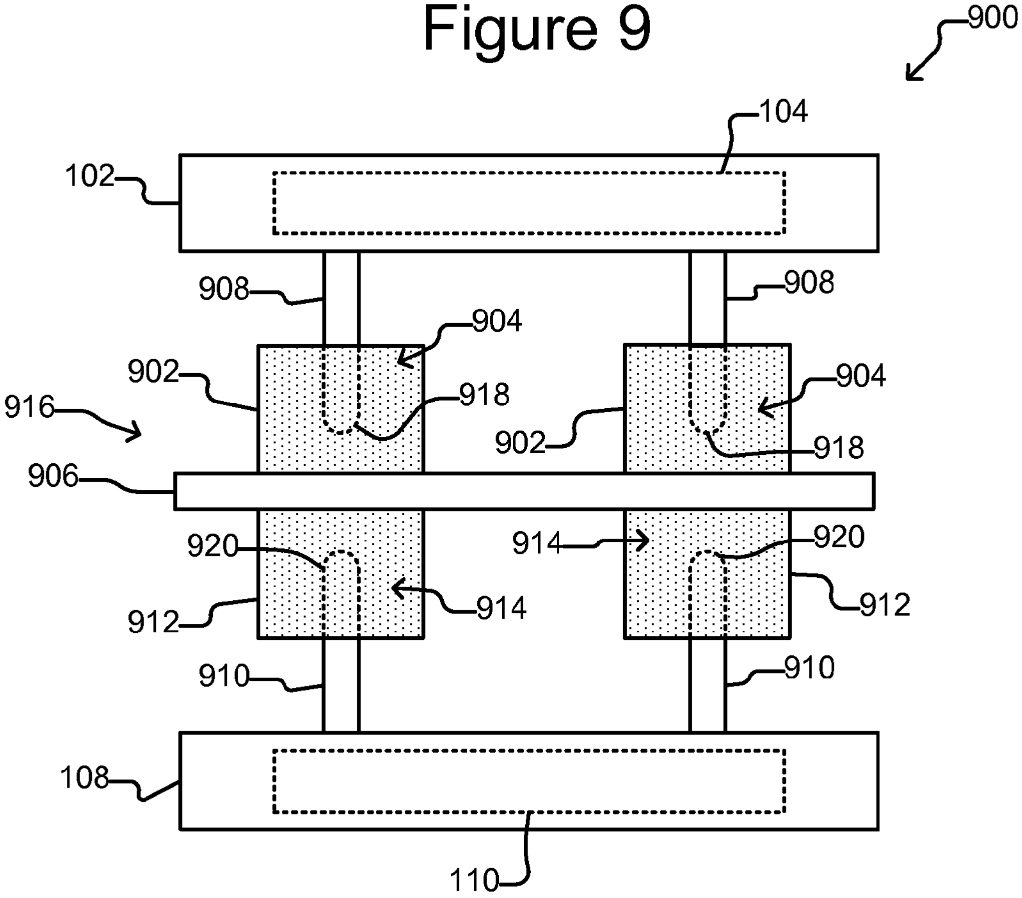

900
104
102
908
908
904
902
918
904
916
902
918
906
920
914
920
912
914
912
910
910
108
110

Figure 10

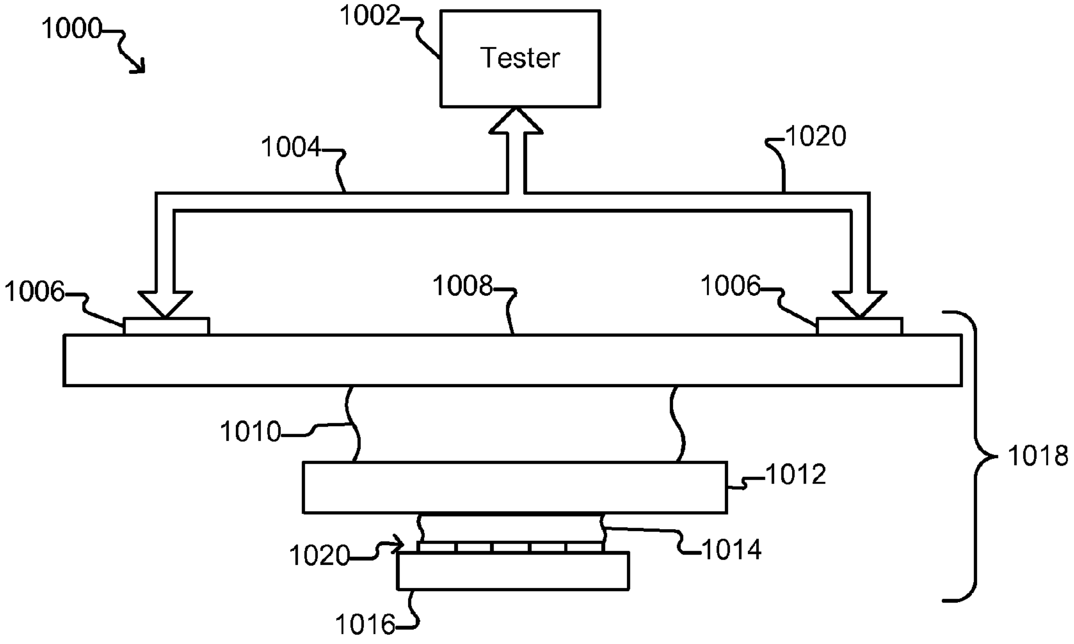
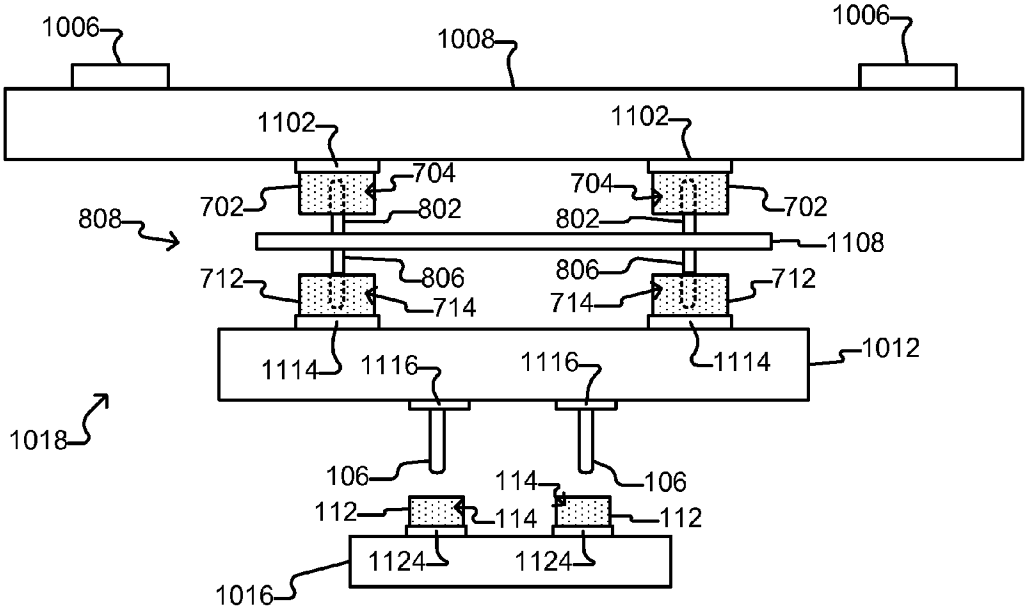

1000
1002
Tester
1004
1020
1006
1008
1006
1010
1012
1018
1020
1014
1016

Figure 11


1006
1008
1006
1102
1102
704
704
702
702
802
802
808
1108
712
806
806
712
714
714
1114
1116
1116
1114
1012
1018
106
106
114
112
114
112
1124
1124
1016

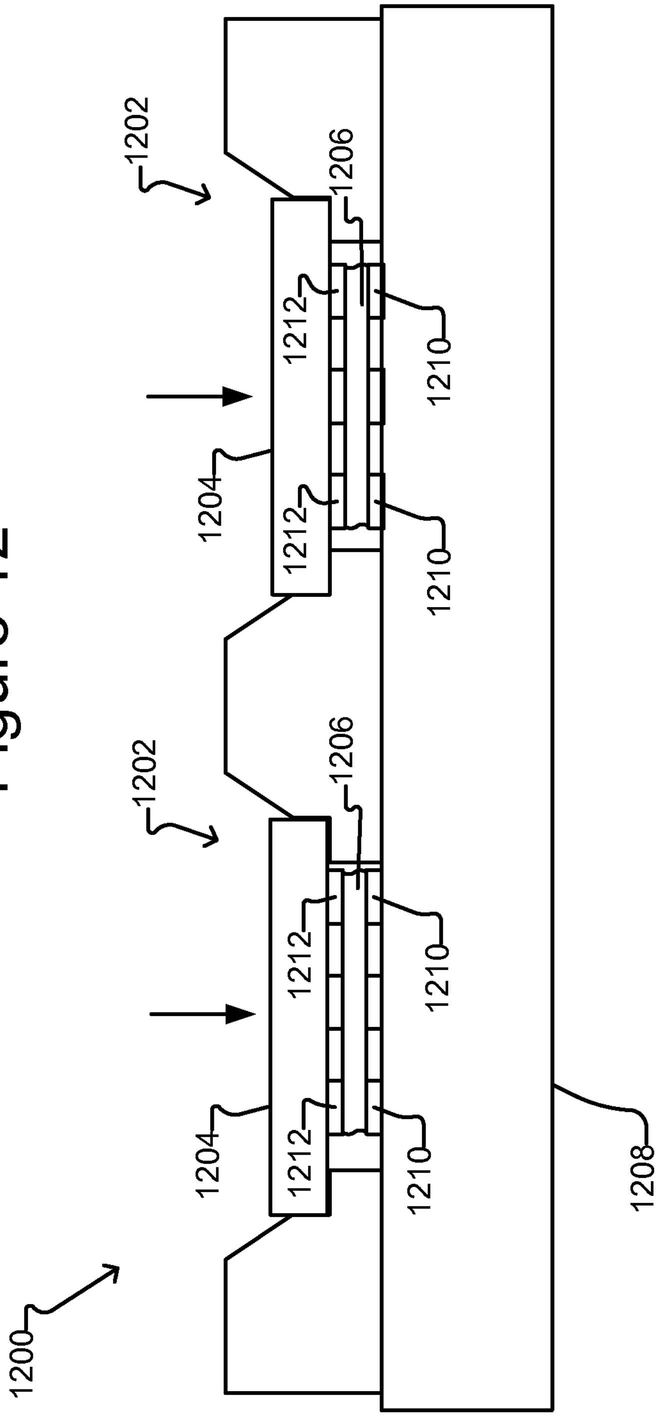
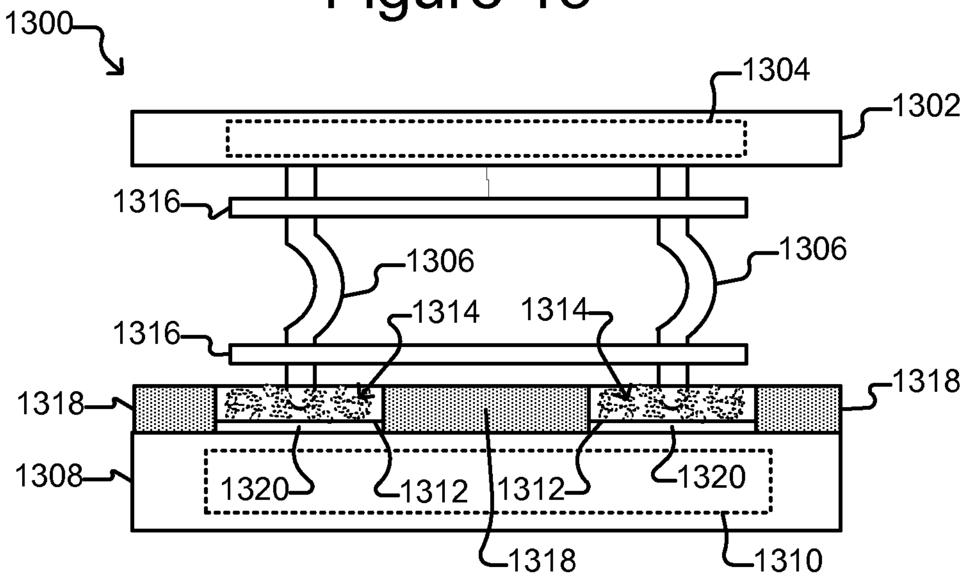


Figure 12

Figure 13


1300
1304
1302
1316
1306
1306
1316
1314
1314
1318
1318
1308
1320
1312
1312
1320
1318
1310

HYBRID ELECTRICAL CONTACTOR

CROSS REFERENCE TO RELATED APPLICATION(S)

[0001] This application is a non-provisional (and thus claims the benefit of the filing date) of U.S. provisional patent application Ser. No. 61/564,679, which was filed Nov. 29, 2011 and is incorporated herein by reference in its entirety.

BACKGROUND

[0002] A variety of techniques exist to connect electrically two or more electronic devices. One type of well known electrical connection technique is solder. Electrical connections consisting of solder between to electronic devices are generally reliable and have a relatively low electrical resistance. Also, once solder connections between electronic devices are made, the solder connections do not typically exert forces on either of the electronic devices. Solder connections, however, have some disadvantages. For example, solder connections between electronic devices cannot easily be undone and remade between one of the electronic devices and a different electronic device. As another example, solder connections typically do not allow appreciable relative movement between the electronic devices, and in fact, relative movement between the electronic devices (e.g., due to mismatched thermal expansion or contraction of the electronic devices) can break the solder connections.

[0003] Pressure based electrical connections in which an electrically conductive probe on one electronic device is pressed against a contact on another electronic device overcomes some of the disadvantages of solder connections. For example, such pressured based electrical connections are readily undone and reformed between one electronic device and a different electronic device. Also, the probe on one electronic device can typically slide with respect to the contact on the other electronic device in response to relative movement between the electronic devices. There are, however, disadvantages to pressure based electrical connections. For example, the electrical resistance of pressured based electrical connections is typically greater than that of solder connections. As another example, pressured based electrical connections, by definition, require a given amount of force between the probe on one electronic device and the contact on the other electronic device.

[0004] Other types of electrical connections also suffer from disadvantages. For example, mechanical force fitting electrical connections (e.g., zero insertion force connectors) often require secondary actuators and typically provide a relatively low density of individual connections. As another example, liquid metals can be difficult to contain and control and typically can be used only in relatively narrow temperature ranges.

[0005] Various embodiments of the present invention address one or more of the foregoing disadvantages in prior art electrical connection techniques.

SUMMARY

[0006] In some embodiments of the invention, an electronic apparatus can include a first electronic device having first circuitry. The electronic apparatus can also include compliant pads, and electrically conductive probes piercing the pads. There can be electrical paths from the first circuitry, and each of the electrical paths can include electrical connections formed by one of the probes at a plurality of locations inside one of the pads pierced by the probe.

[0007] In some embodiments of the invention, a process of electrically connecting electronic devices can include piercing with electrically conductive probes electrically connected to first circuitry of a first electronic device compliant pads that are electrically connected to second circuitry of a second electronic device. Moreover, for each pair of one of the probes and a corresponding one of the pads, the piercing comprises contacting electrically conductive elements of the corresponding pad to complete an electrically conductive path through the probe and the corresponding pad from the first circuitry to the second circuitry.

[0008] In some embodiments of the invention, a probe card assembly can include a wiring substrate, which can include an electrical interface to a tester for controlling testing of an electronic device under test (DUT). The probe card assembly can also include a probe head that includes electrically conductive contacts configured to connect electrically to terminals of the DUT. The probe card assembly can also include an interconnector, which can include compliant pads configured to provide electrical paths between the wiring substrate and the probe head. Each of the electrical paths can include electrical connections formed at a plurality of locations inside one of the pads.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIGS. **1**A and **1**B illustrate formation of electrical connections in which electrically conductive probes pierce pads comprising electrically conducive elements according to some embodiments of the invention.

[0010] FIG. **2** illustrates an example of a pad comprising electrically conductive elements suspended in a electrically non-conductive material according to some embodiments of the invention.

[0011] FIG. **3** illustrates an example of a pad comprising a bundle or column of intertwined electrically conductive elements according to some embodiments of the invention.

[0012] FIG. **4** illustrates an example of a probe with a piercing end comprising one or more spikes according to some embodiments of the invention.

[0013] FIG. **5** illustrates an example of a probe with a piercing end comprising one or more balls according to some embodiments of the invention.

[0014] FIGS. **6**A and **6**B illustrate an example of a probe with a piercing end comprising one or more blades according to some embodiments of the invention.

[0015] FIGS. **7**, **8**, and **9** illustrate examples of an electronic apparatus comprising electronic devices electrically connected by electrical paths that include a probe piercing a pad comprising electrically conductive elements according to some embodiments of the invention.

[0016] FIG. **10** illustrates a test system comprising a probe card assembly in which one or more connectors can include electrical connections comprising a probe piercing a pad comprising electrically conductive elements according to some embodiments of the invention.

[0017] FIG. **11** illustrates an example of a probe card assembly showing examples of electrical connections comprising a probe piercing a pad comprising electrically conductive elements according to some embodiments of the invention.

[0018] FIG. **12** illustrates an electrical socket in which one or more connectors can include electrical connections comprising a probe piercing a pad comprising electrically conductive elements according to some embodiments of the invention.

[0019] FIG. **13** illustrates another embodiment of an electronic apparatus comprising electronic devices electrically connected by electrical paths that include a probe piercing a pad comprising electrically conductive elements according to some embodiments of the invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0020] This specification describes exemplary embodiments and applications of the invention. The invention, however, is not limited to these exemplary embodiments and applications or to the manner in which the exemplary embodiments and applications operate or are described herein. Moreover, the Figures may show simplified or partial views, and the dimensions of elements in the Figures may be exaggerated or otherwise not in proportion for clarity. In addition, as the terms "on," "attached to," or "coupled to" are used herein, one object (e.g., a material, a layer, a substrate, etc.) can be "on," "attached to," or "coupled to" another object regardless of whether the one object is directly on, attached, or coupled to the other object or there are one or more intervening objects between the one object and the other object. Also, directions (e.g., above, below, top, bottom, side, up, down, under, over, upper, lower, horizontal, vertical, "x," "y," "z," etc.), if provided, are relative and provided solely by way of example and for ease of illustration and discussion and not by way of limitation. In addition, where reference is made to a list of elements (e.g., elements a, b, c), such reference is intended to include any one of the listed elements by itself, any combination of less than all of the listed elements, and/or a combination of all of the listed elements.

[0021] As used herein, circuitry means passive and/or active electrical circuitry. Passive circuitry refers to a collection of interconnected electrically conductive vias, wires, traces, or other electrically conductive structures that provide electrical paths through which electrical signals can pass. Active circuitry refers to a collection of interconnected electrical elements such as switches, transistors, amplifiers, or the like that process, operate on, or alter electrical signals or the paths of electrical signals.

[0022] As used herein, the term elements refers to a plurality of structurally distinct individual elements.

[0023] As used herein, blade refers to a structure with a cutting edge having a length that is greater than any width of the cutting edge. The edge can be sharpened to essentially a line or can be dull and thus constitute a surface such as a flat surface.

[0024] As used herein, compliant means able to move or give in response to a force. The term compliant covers plastic deformation and/or elastic deformation. Plastic deformation refers to deformation—i.e., a change in shape or position—of an object in response to a force from which the object does not completely recover after removal of the force. A structure that elastically deforms in response to a force recovers substantially its original shape or position after removal of the force. An object that elastically deforms is referred to herein as being elastic or an elastic object.

[0025] As used herein, pierce means to force or make a way into or through. Thus, a probe that pierces a pad forces or makes a way into or through the pad.

[0026] Elongated Means Relatively Long and Thin.

[0027] Embodiments of the invention include electrical connections comprising an electrically conductive probe that pierces a compliant pad. The probe can contact multiple electrically conductive elements inside the pad and thereby electrically connect to the pad at multiple locations inside the pad.

[0028] FIGS. **1**A and **1**B illustrate making an electrical connection between a first electronic device **102** and a second electronic device **108** according to some embodiments of the invention. As shown, electrically conductive probes **106** can pierce (and thus penetrate into) pads **112**, each of which can comprise electrically conductive elements **114**. (Although two probes **106** and two pads **112** are shown, there can be more of fewer.) Each probe **106** can contact multiple conductive elements **114** in a pad **112** and thereby make multiple electrical connections with the conductive elements **114** inside the pad **112**. The conductive elements **114** can be of sufficient density inside the pads **112** that electrical connections are created between the probe **106** and the conductive elements **114** inside the pad **112** pierced by the probe **106**. The probes **106** and pads **112** pierced by the probes can thus be part of continuous electrical paths (which can be electrically insulated one from another) from the first electronic device **102** to the second electronic device **108**. Although not shown, the probes **106** in FIGS. **1**A and **1**B (or any other figure of the drawings), can be held in place by one or more guide plates (e.g., like guide substrates **708** or **710** in FIG. **7** of guide plates **1316** in FIG. **13**). Although also not shown, the pads **112** can be disposed on an electrically conductive structure (e.g., a pad or terminal) that is hard or otherwise not readily pierceable, and a probe **106** can pierce a pad **112** through to and thus contact and electrically connect to the non-pierceable pad. In such an embodiment, a probe **106** can thus make electrical connections with both the conductive elements inside a pad **112** and the electrically conductive non-pierceable pad on which the pad **112** is disposed.

[0029] The probes **106** can be electrically connected to first circuitry **104** of the first electronic device **102**, and conductive elements **114** in the pads **112** can be electrically connected to second circuitry **110** of the second electronic device **108**. The probes **106** and conductive elements **114** in the pads **112** can thus be part of the above-described continuous electrical paths (comprising the probes **106** piercing the pads **112**), which can electrically connect the first circuitry **104** of the first electronic device **102** to the second circuitry **110** of the second electronic device **110**. Non-limiting examples of electronic devices **102** and **108**—which can be the same or different types of devices—include semiconductor devices (e.g., dies) and circuitry **104** and/or **110** can be active circuitry integrated into the dies; printed circuit boards; electrical sockets; test devices such as probe card assemblies or test sockets; or the like.

[0030] Conductive elements **114** can be any type of electrically conductive particle (which can include micro particles, flakes, spheres, or the like) or fiber (which can include filaments, strings, or the like), or the like. For example, conductive elements **114** can be metal (e.g., copper, silver, gold, carbon, or the like) particles, fibers, or the like.

[0031] Pads **112** can be any structure that can be penetrated by probes **106**. FIGS. **2** and **3** illustrate examples of a pad **112** according to some embodiments of the invention.

[0032] As shown in FIG. **2**, in some embodiments, a pad **112** can comprise a non-conductive material **202** in which conductive elements **204** (which can the same as or similar to any of the examples of conductive elements **114** discussed above) are embedded or suspended. (Conductive elements **204** are thus examples of conductive elements **114** in FIGS. 1A and 1B.) The non-conductive material **202** can be compliant and easily pierced by a probe **106**. For example, non-conductive material **202** can comprise elastomer, rubber, neoprene, silicone, or the like. In some embodiments, non-conductive material **202** can be self-healing such that the piercing mark into a pad **112** made by a probe **106** self heals after the probe **106** is removed. Suitable pads **112** include HXC125 Material System available from Tyco Electronics Corporation or similar material systems comprising conductive metal (e.g., copper, gold, silver, or the like) elements (e.g., flakes, spheres, or the like) in an elastomer (e.g., silicone).

[0033] FIG. **3** illustrates another example of a pad **112**. As shown in FIG. **3**, a pad **112** can comprises a mesh or bundle of conductive elements **302**, which are examples of conductive elements **114** in FIGS. 1A and 1B. For example, conductive elements **302** can be intertwined metal (e.g., copper, silver, gold, or the like) fibers. As another example, conductive elements **302** can be carbon nanotubes.

[0034] The mesh or bundle of conductive elements **302** can be a standalone mesh or bundle generally as illustrated in FIG. **3**. Alternatively, the mesh or bundle of conductive elements **302** can be embedded partially or completely in a material (e.g., like material **202** of FIG. **2**).

[0035] Probes **106** can be any shape conducive to piercing a pad **112**. For example, probes **106** can be generally elongated structures as illustrated in FIGS. 1A and 1B. The ends **116** of the probes **106** that pierce a pad **112** (hereinafter the "piercing ends") can likewise take any shape conductive to piercing a pad **112**. Examples of suitable piercing ends **116** of probes **106** are illustrated in FIGS. **4**, **5**, **6**A, and **6**B according to some embodiments of the invention.

[0036] As shown in FIG. **4**, the piercing end **116** of a probe **106** can comprise one or more spikes **402**. Although two spikes **402** are shown in FIG. **4**, there can be only one spike **402** or more than two spikes **402**. FIG. **5** illustrates an example of a piercing end **116** of a probe **106** in the general shape of a ball **502**. Again, although one ball **502** is shown, there can be more. FIGS. **6**A and **6**B illustrate yet another example of a piercing end **116** of a probe **106**. As shown, the piercing end **116** can comprise a blade **602** with a cutting edge **604** having a length L. Again, although one blade **602** is shown, there can be more. Other non-limiting examples of a piercing end **116** of a probe **106** include needles or structures in the shape of a square, rectangle, pyramid, truncated pyramid, or the like.

[0037] Some embodiments of the electrical connections between the probes **106** and the conductive elements **114** (including electrical elements **204** and **302** in FIGS. **2** and **3**) illustrated in FIG. 1B (or in any figure or discussion herein) can provide advantages over various prior art electrical connections.

[0038] For example, the material of the probes **106** and the conductive elements **114** of the pads **112** as well as the density of the conductive elements **114** in the pads **112** can be selected so that the contact resistance between a probe **106** and conductive elements **114** in a pad **112** pierced by the probe **106** is low. For example, in some embodiments, the contact resistance between a probe **106** and conductive elements **114** in a pad **112** can be less than ten ohms, less than one ohm, less than half an ohm, or less than ten milliohms In other embodiments, however, the contact resistance can be ten ohms or more.

[0039] As another example, the material of the pads **112** and the material and shape of the piercing ends **116** of the probes **106** can be selected so that the force required for a probe **106** to pierce a pad **112** can be substantially low. For example, in some embodiments, the force required for the probe **106** to pierce a pad **112** to a depth D that is at least one quarter of the height H of the pad **112** (see FIG. **1**B) can be less than ten grams, less than five grams, less than one gram, or less than one tenth of a gram. In other embodiments, however, that force can be ten grams or more. In some embodiments, the height H of a pad **112** can be at least five microns, at least ten microns, at least fifteen microns, at least twenty microns, at least fifty microns, or at least five-hundred microns. In other embodiments, the height H can be one or more millimeters. The depth D (see FIG. **1**B) that a probe **106** penetrates into a pad **112** can be at least one tenth, at least one fifth, at least one quarter, at least one third, at least one half, or at least three quarters of the height H of the pad **112**. For example, a probe **106** can penetrate into a pad **112** at least one micron, at least two microns, at least three microns, at least four microns, or at least five microns. In other embodiments, the depth D that a probe **106** penetrates into a pad **112** can be the entire height H of the pad **112** such that the probe **106** penetrates all the way through the pad **112**. Of course, a probe **106** can alternatively pierce a pad **112** to a depth D that is less than a tenth of the height H of the pad **112** or less than one micron.

[0040] As yet another example of an advantage some embodiments of the invention can provide over the prior art, each of the probes **106** can pierce a corresponding pad **112** to a different depth D (which, as shown in FIG. **1**B, can be less than the height H of a pad **112**). This can compensate for irregularities in the lengths of the probes **106** and/or lack of planarity of one or both of the electronic devices **102** and **108**.

[0041] A still further advantage of some embodiments of the invention is an ability to compensate for relative movement between the electronic devices **102** and **108**. For example, compliance of the pads **112** can maintain the electrical connections between the probes **106** and the conductive elements **114** in the pads **112** even if the first electronic device **102** expands or contracts E_1 to a greater or lesser degree than the second electronic device **108** expands or contracts E_2 in response, for example, to temperature differences or changes.

[0042] As yet another advantage, the electrical connections between the first electronic device **102** and the second electronic device **108** in FIG. **1**B can be easily removed by simply moving one of the electronic devices (e.g., **102**) away from the other electronic device (e.g., **108**) and thus pulling the probes **106** out of the pads **112**. The electronic devices **102** and **108** can then readily be connected to another electronic devices. For example, the probes **106** of electronic device **102** can be pushed into—and thus pierce—the pads (e.g., like pads **112**) of another electronic device (e.g., like the second electronic device **108**). Although not shown, probes **106** and pads **112** can also be configured to connect pads **112** of an electronic device (e.g., device **102**) to other pads (e.g., like pads **112**) on the same electronic device, for example, in loopback testing or as a jumper. Although also not shown, pads **112** can also be configured in many well known electronic structures such as coaxial arrangements, triaxial arrangements, shielded differential pair arrangements, and the like.

[0043] As still another advantage, in some embodiments, it need not be necessary to compress pads **112** to form electrical connections with the probes **106**. Thus, although a pad **112** can be compressed, it need not be.

[0044] The electrical apparatus **100** shown in FIG. **1**B in which probes **106** and conductive elements **114** in pads **112** are part of electrical paths between circuitry **104** of a first electronic device **102** and circuitry **110** of a second electronic device **108** is an example only. There are other configurations and applications for electrical connections comprising probes **106** piercing pads **112** and contacting conductive elements **114** in the pads. FIGS. **7-9** illustrate alternative embodiments in which a first electronic device **102** is connected to a second electronic device **108** by electrical paths that include a probe piercing a pad comprising conductive elements, and FIGS. **10-12** illustrate examples of applications in which such electrical connections can be used.

[0045] FIG. **7** illustrates an electrical apparatus **700** comprising the first electronic device **102** with circuitry **104** and the second electronic device **108** with circuitry **110** as discussed above. As shown, pads **702** comprising conductive elements **704** can be disposed on (e.g., attached to) the first electronic device **102**, and the conductive elements **704** can be electrically connected to circuitry **104**. Pads **712** comprising conductive elements **714** can similarly be disposed on (e.g., attached to) the second electronic device **108**, and the conductive elements **714** can be electrically connected to circuitry **110**. The pads **702** and **712** can be the same as pads **112** (including any embodiment or variation of pads **112** illustrated in FIGS. **2** and **3** and/or described herein), and the conductive elements **704** and **714** can be the same as conductive elements **114** (including any embodiment or variation of pads **112** illustrated in FIGS. **2** and **3** and/or described herein).

[0046] As shown in FIG. **7**, piercing ends **716** of probes **706** (which can be like probes **106**) can pierce pads **702** and contact and thereby make electrical connections with conductive elements **704** inside the pads **702**. Also shown, opposite piercing ends **718** of probes **706** can pierce pads **712** and contact and thereby make electrical connections with conductive elements **714** inside the pads **712**. Electrically conductive paths (which can be electrically insulated one from another) can thus be provided from circuitry **104** of the first electronic device **102** to circuitry **110** of the second electronic device **108**, and each of those conductive paths can comprise conductive elements **704** in a pad **702** in contact with one piercing end **716** of a probe **706**, the probe **706**, and conductive elements **714** in a pad **712** in contact with an opposite piercing end **718** of the probe **706**. The piercing end **716** and the opposite piercing end **718** of a probe **706** can be the same as a piercing end **116** of a probe **106** as described herein including having any of the piercing end configurations **116** illustrated in FIGS. **4-6**B. One or more guide substrates **708** and **710** (two are shown but there can be more or fewer including none) can hold the probes **706** in place.

[0047] FIG. **8** illustrates an electrical apparatus **800** that can be generally the same as the electrical apparatus **700** of FIG. **7** except that interposer **808** in FIG. **8** replaces probes **706** of FIG. **7**. Interposer **808** can comprise a substrate **804**, first probes **802** extending from a first side of the substrate **804**, and second probes **806** extending from a second side of the substrate **804**. Electrical connections (not shown) through the substrate **804** can connect individual ones of the first probes **802** with individual ones of the second probes **806**.

[0048] As shown in FIG. **8**, piercing ends **816** of the first probes **802** can pierce pads **702** and contact and thereby make electrical connections with conductive elements **704** inside the pads **702**. Also shown, piercing ends **818** of the second probes **806** can pierce pads **712** and contact and thereby make electrical connections with conductive elements **714** inside the pads **712**. Electrically conductive paths (which can be electrically insulated one from another) can thus be provided from circuitry **104** of the first electronic device **102** to circuitry **110** of the second electronic device **108**, and each of those conductive paths can comprise conductive elements **704** in a pad **702** in contact with one piercing end **816** of a first probe **802**, the first probe **802**, an electrical connection through the substrate **804** from the first probe **802** to a second probe **806** whose piercing end **818** is in contact with conductive elements **714** in a pad **712**, and the conductive elements **714** in the pad **712**.

[0049] First probes **802** can be like probes **106**, and second probes **806** can also be like probes **106**. In addition, the piercing end **816** of a probe **802** and the piercing end **818** of a probe **806** can be the same as a piercing end **116** of a probe **106** as described herein including having any of the piercing end configurations **116** illustrated in FIGS. **4-6**B.

[0050] FIG. **9** illustrates an electrical apparatus **900** comprising the first electronic device **102** with circuitry **104** and the second electronic device **108** with circuitry **110** as discussed above. As shown, the electrical apparatus **900** can also comprise an interposer **916**, which can comprise a substrate **906**, first pads **902** comprising conductive elements **904** disposed on (e.g., attached to) a first side of the substrate **906**, and second pads **912** comprising conductive element **914** disposed on (e.g., attached to) a second side of the substrate **906**. The pads **902** and **912** can be the same as pads **112** (including any embodiment or variation of pads **112** illustrated in FIGS. **2** and **3** and/or described herein), and the conductive elements **904** and **914** can be the same as conductive elements **114** (including conductive elements **202** and **302** illustrated in FIGS. **2** and **3** and/or described herein). Electrical connections (not shown) through the substrate **906** can connect conductive elements **904** in individual ones of the first pads **902** with conductive elements **914** in individual ones of the second pads **912**.

[0051] As also shown in FIG. **9**, first probes **908** (which can be like probes **106**) can extend from the first electronic device **102**, and second probes **910** (which can be like probes **106**) can extend from the second electronic device **108**. The first probes **908** can be electrically connected to circuitry **104**, and the second probes **910** can be electrically connected to circuitry **110**. As shown, piercing ends **918** of the first probes **908** can pierce the first pads **902** and contact and thereby make electrical connections with conductive elements **904** inside the first pads **902**. As also shown, piercing ends **920** of the second probes **910** can pierce the second pads **912** and contact and thereby make electrical connections with conductive elements **914** inside the second pads **912**. Electrically conductive paths (which can be electrically insulated one from another) can thus be provided from circuitry **104** of the first electronic device **102** to circuitry **110** of the second electronic device, and each of those conductive paths can comprise a first probe **908**, conductive elements **904** in a first pad **902**, an electrical connection through the substrate **916** from the conductive elements **904** of the first pad **902** to the conductive elements of a second pad **912**, and a probe **910** piercing the second pad **912**.

[0052] There are many possible uses and applications for electrical connections that comprise probes (e.g., **106**) piercing pads (e.g., **112**) comprising conductive elements (e.g., **114**) as disclosed herein. FIGS. **10-12** illustrate examples.

[0053] FIG. **10** illustrates test system **1000** that includes a probe card assembly **1018** for testing DUT **1016**. DUT **1016** (which can be an acronym for device under test) can be any electronic device or devices to be tested, including without limitation one or more dies of an unsingulated semiconductor wafer, one or more semiconductor dies singulated from a wafer (packaged or unpackaged), one or more dies of an array of singulated semiconductor dies disposed in a carrier or other holding device, one or more multi-die electronic devices, one or more printed circuit boards, or any other type of electronic device or devices. FIG. **10** shows an exemplary probe card assembly **1018** and a simplified block diagram of a test system **1000** in which the probe card assembly **1018** can be used to test DUT **1016** according to some embodiments of the invention.

[0054] As shown in FIG. **10**, the probe card assembly **1018** can comprise a wiring substrate **1008**, an interconnector **1010**, and a probe head **1012**, which can be held together by brackets (not shown) and/or other suitable means. As also shown, an interconnector **1014** can be provided between the probe head **1012** and terminals **1020** of the DUT **1016**. The interconnector **1014**, which can be located in part on the probe head **1012** and in part on the DUT **1016**, can electrically connect the probe head **1012** to the terminals **1020** of the DUT **1016**.

[0055] The wiring substrate **1008** can be a printed circuit board, ceramic substrate, or the like. The wiring substrate **1008** can include electrical connectors **1006** (e.g., an electrical interface to a tester **1002**) configured to make electrical connections with a plurality of communications channels **1004** to and from a tester **1002**. Connectors **1006** can be pads for receiving pogo pins, zero-insertion-force connectors, or any other electrical connection device suitable for making electrical connections with communications channels **1004**. Electrically conductive paths (not shown) can be provided through the probe card assembly **1018** to provide electrical connections from individual electrical connections in connectors **1006** (each such individual electrical connection can correspond to one of communication channels **1004**) to input and/or output terminals **1020** of the DUT **1016**. Those conductive paths (not shown) through the probe card assembly **1018** can comprise electrically conductive connections, such as traces and/or vias (not shown), from the connectors **1006** through the wiring substrate **1008** to the interconnector **1010**; the interconnector **1010**; electrically conductive connections, such as traces and vias (not shown), through the probe head **1012**; and interconnector **1014**. In this way, a plurality of signal paths comprising the communications channels **1004** and the above-described conductive paths through the probe card assembly **1018**, are provided between the tester **1002** and the input and/or output terminals **1020** of DUT **1016**.

[0056] The interconnector **1010** and/or the interconnector **1014** can comprise probes (e.g., **106**) piercing pads (e.g., **112**) comprising conductive elements (e.g., **114**). FIG. **11** illustrates an example of the probe card assembly **1018** in which the interconnector **1010** is implemented by the interposer **808** and pads **702** and **712** in FIG. **8**, and the interconnector **1014** is implemented by the probes **106** and the pads **112** illustrated in FIG. **1**B.

[0057] As shown in FIG. **11**, the pads **702** of the interposer **808** of FIG. **8** can be disposed on (e.g., attached to) electrical terminals **1102** of the wiring substrate **1008**. The conductive elements **704** in pads **702** can thus be electrically connected to the terminals **1102**. The pads **712** of the interposer **808** can similarly be disposed on (e.g., attached to) electrical terminals **1114** of the probe head **1012**, and the conductive elements **714** of the pads **712** can thus be electrically connected to the terminals **1114**. The wiring substrate **1008** of FIG. **11** can thus be an example of the first electronic device **102** in FIG. **8**, and the electrical connectors **1006**, the terminals **1102**, and electrical connections (not shown), such as vias and/or traces (not shown), through the wiring substrate **1008** between the connectors **1006** and the terminals **1102** can be an example of the circuit **104** in FIG. **8**. The probe head **1012** can similarly be an example of the second electronic device **108** in FIG. **8**, and the terminals **1114** and **1116** and electrical connections (not shown), such as vias and/or traces (not shown), through the probe head **1012** between the terminals **1114** and **1116** can be an example of the circuit **110** in FIG. **8**.

[0058] As also shown in FIG. **11**, the probes **106** of FIG. **1**B can be disposed on (e.g., attached to) electrical terminals **1116** of the probe head **1012**. The pads **112** of FIG. **1**B can similarly be disposed on (e.g., attached to) electrical terminals **1124** of the DUT **1016**, and the conductive elements **114** of the pads **112** can thus be electrically connected to the terminals **1124**. The probe head **1012** of FIG. **11** can thus be an example of the first electronic device **102** in FIG. **1**B, and the terminals **1114** and **1116** and electrical connections (not shown), such as vias and/or traces (not shown), through the probe head **1012** between the terminals **1114** and **1116** can be an example of the circuit **104** in FIG. **1**B. The DUT **1016** can similarly be an example of the second electronic device **108** in FIG. **1**B, and the terminals **1124** and internal circuitry (not shown) of DUT **1016** can be an example of the circuit **110** in FIG. **8**. In the foregoing example, the probes **106** extending from the probe head **1012** can be examples of contacts of the probe head configured to electrically connect to terminals **1020** of the DUT **1016**.

[0059] The configuration of the probe card assembly **1018** illustrated in FIG. **11** is an example only, and variations are possible. For example, pads **112** can alternatively be disposed on terminals **1116** of the probe head **1012** and probes **106** can be disposed on terminals **1124** of the DUT **1016**. In the foregoing example, the pads **112** disposed on terminals **1116** of the probe head **1012** can be examples of contacts of the probe head configured to electrically connect to terminals **1020** of the DUT **1016**. As other examples, the interconnector **1010** of FIG. **10** can alternatively be implemented as the probes **706** and the pads **702** and **712** shown in FIG. **7**, or the interposer **916** and probes **908** and **910** in FIG. **9**. As still other examples, the interconnector **1014** of FIG. **10** can alternatively be implemented as the probes **706** and the pads **702** and **712** shown in FIG. **7**; the interposer **808** and pads **702** and **712** in FIG. **8**; or the interposer **916** and probes **908** and **910** in FIG. **9**. As yet other examples, the interconnector **1010** and/or the interconnector **1014** can be implemented by means other than a probe (e.g., **106**) piercing a pad (e.g., **112**) comprising conductive elements (e.g., **114**).

[0060] Regardless of how the probe card assembly **1018** is configured, the DUT **1016** can be tested using the test system **1000** of FIG. **10** as follows. Terminals **1020** of the DUT **1016** can be electrically connected to interconnector **1014**. The tester **1002** can generate test signals, which can be provided through the communications channels **1004**, probe card assembly **1018**, and interconnector **1014** to terminals **1020** of the DUT **1016**. Response signals generated by the DUT **1016**

can be provided from the DUT **1016** through the interconnector **1014**, probe card assembly **1018**, and channels **1004** to the tester **1002**. The tester **1002** can analyze the response signals to determine whether DUT **1016** responded properly to the test signals and, consequently, whether DUT **1016** passes or fails the testing. The tester **1002** can alternatively or in addition rate the performance of DUT **1016**.

[0061] FIG. **12** illustrates an exemplary socket **1200** having a wiring substrate **1208** with device sites **1202** for electronic devices **1204**. Interconnectors **1206** can electrically connect electrical terminals **1212** of each electronic device **1204** to electrical terminals **1210** of the wiring substrate **1208**. The wiring substrate **1208** can include electrical connections (not shown) that electrically connect the terminals **1210** to interfaces (not shown) and/or other electronic devices (not shown).

[0062] The interconnectors **1206** can comprise probes (e.g., **106**) piercing pads (e.g., **112**) comprising conductive elements (e.g., **114**). For example, the interconnectors **1206** can be implemented by the probes **106** and pads **112** of FIG. **1**B. In such a case, the probes **106** of FIG. **1**B can be disposed on (e.g., attached to) and thus electrically connected to either the terminals **1212** of the electronic devices **1204** or the terminals **1210** of the wiring substrate **1208**. The pads **112** of FIG. **1**B can similarly be disposed on (e.g., attached to) and the conductive elements **114** of the pads thus electrically connected to the other of terminals **1212** of the electronic devices **1204** or the terminals **1210** of the wiring substrate **1208**. In the foregoing examples, an electronic device **1204** of FIG. **12** can correspond to one of first electronic device **102** or the second electronic device **108** in FIG. **1**B, and the wiring substrate **1208** can correspond to the other of the first electronic device **102** or the second electronic device **108**. The terminals **1212** and internal circuitry (not shown) of an electronic device **1204** can thus correspond to the circuitry **104** or **110** in FIG. **1**B, and the terminals **1208** and internal electrical connections (not shown) of the wiring substrate **1208** can correspond to the other of the circuitry **104** or **110**.

[0063] As other examples, the interconnectors **1206** of FIG. **12** can be implemented as the probes **706** and the pads **702** and **712** shown in FIG. **7**; the interposer **808** and pads **702** and **712** in FIG. **8**; or the interposer **916** and probes **908** and **910** in FIG. **9**. In such cases, an electronic device **1204** can correspond to the first electronic device **102** in FIG. **7**, **8**, or **9**, and the wiring substrate **1208** can correspond to the second electronic device **108**. The terminals **1212** and internal circuitry (not shown) of an electronic device **1204** can thus correspond to the circuitry **104** in FIG. **1**B, and the terminals **1208** and internal electrical connections (not shown) of the wiring substrate **1208** can correspond to the circuitry **110**.

[0064] FIG. **13** illustrates another embodiment of an electronic apparatus comprising electronic devices electrically connected by electrical paths that include a probe piercing a pad comprising electrically conductive elements according to some embodiments of the invention. As shown, an electronic apparatus **1300** can comprise a semiconductor die or wafer **1302** (which can comprise a plurality of unsingulated dies) having circuitry **1304**. (The die or wafer **1302** can be an example of a first or a second electronic device, and circuitry **1304** can be an example of first or second circuitry.) For example, circuitry **1304** can be active circuitry integrated into the die or wafer **1302**. Probes **1306** (which can be generally like probes **106**) can extend from the die or wafer **1302** and be electrically connected to circuitry **1304**. Guide plates **1316** (two are shown but there can be more or fewer) can stabilize and/or hold the probes **1306** in place.

[0065] Pads **1312** can be disposed on electrically conductive terminals **1320** of an electronic device **1308**. The terminals **1320** can be electrically connected to circuitry **1310** of the electronic device **1308**. (The electronic device **1308** can be an example of a first or a second electronic device, and circuitry **1310** can be an example of first or second circuitry.) Each pad **1312** can be similar to the embodiment of pad **112** shown in FIG. **2** and can thus comprise electrically conductive elements **1314** (which can be like conductive particles **204** in FIG. **2**) embedded in a non-electrically conductive material (e.g., like material **202** in FIG. **2**). The conductive particles **1314** can be electrically connected to the terminal **1320**. As shown ends (which can be like piercing ends **116** of the probes **106**) of probes **1306** can pierce the pads **1312**. A non-electrically conductive material **1318** can be disposed between the pads **1312** generally as shown.

[0066] Each probe **1306** can pierce a pad **1312**. The probe **1306** can thus contact and thereby make multiple electrical connections with ones of the conductive particles **1314** inside a pad **1312**. Electrically conductive paths (which can be electrically insulated one from another) can thus be formed from the circuitry **1304** of the die or wafer **1302** to the circuitry **1310** of the electronic device **1308**. Each such conductive path can comprise a probe **1306** contacting and making electrical connections with conductive particles **1314** in a pad **1312** and a terminal **1320**.

[0067] Although specific embodiments and applications of the invention have been described in this specification, these embodiments and applications are exemplary only, and many variations are possible.

We claim:

1. An electronic apparatus comprising:

a first electronic device comprising first circuitry;

compliant pads;

electrically conductive probes piercing said pads; and

electrical paths from said first circuitry,

wherein each said electrical path comprises electrical connections formed by one of said probes at a plurality of locations inside one of said pads pierced by said one of said probes.

2. The electronic apparatus of claim **1** further comprising a second electronic device comprising second circuitry, wherein said electrical paths are between said first circuitry and said second circuitry.

3. The electronic apparatus of claim **2**, wherein said electrical connections of each said conductive path are between electrically conductive elements inside one of said pads and one of said probes that pierces said one of said pads and contacts ones of said conductive elements inside said one of said pads.

4. The electronic apparatus of claim **3**, wherein each said pad comprises:

a non-electrically conductive compliant material, and

said conductive elements are suspended in said compliant material.

5. The electronic apparatus of claim **4**, wherein said compliant material is substantially elastic.

6. The electronic apparatus of claim **4**, wherein said compliant material comprises a polymer material or a plastic material.

7. The electronic apparatus of claim **3**, wherein:

said conductive elements are electrically conductive fibers, and

each said pad comprises a mesh or bundle of said fibers.

8. The electronic apparatus of claim **3**, wherein:

said probes extend from said first electronic device and are electrically connected directly to said first circuitry, and

said pads are disposed on said second electronic device and said conductive elements inside said pads are electrically connected directly to said second circuitry.

9. The electronic apparatus of claim **3** further comprising an interposer disposed between said first electronic device and said second electronic device, wherein said interposer comprises at least some of said pads or at least some of said probes.

10. The electronic apparatus of claim **9**, wherein:

a first set of said probes extend from said first electronic device and are electrically connected directly to said first circuitry, and a second set of said probes extend from said second electronic device and are electrically connected directly to said second circuitry; and

said interposer comprises:

a first set of said pads facing said first electronic device and pierced by said first set of probes, and

a second set of said pads facing said second electronic device and pierced by said second set of probes.

11. The electronic apparatus of claim **10**, wherein said interposer further comprises a substrate between said first set of pads and said second set of pads, wherein said first set of pads are electrically connected to said second set of pads through said substrate.

12. The electronic apparatus of claim **9**, wherein:

a first set of said pads are disposed on said first electronic device and are electrically connected directly to said first circuitry, and a second set of said pads are disposed on said second electronic device and are electrically connected directly to said second circuitry; and

said interposer comprises:

a first set of said probes extending toward said first electronic device and piercing said first set of pads, and

a second set of said probes extending toward said second electronic device and piercing said second set of pads.

13. The electronic apparatus of claim **12**, wherein said interposer further comprises a substrate between said first set of probes and said second set of probes, wherein said first set of probes are electrically connected to said second set of probes through said substrate.

14. The electronic apparatus of claim **3**, wherein:

a first set of said pads are disposed on said first electronic device and are electrically connected directly to said first circuitry,

a second set of said pads are disposed on said second electronic device and are electrically connected directly to said second circuitry,

first ends of said probes pierce said first set of pads; and

second ends of said probes pierce said second set of pads.

15. The electronic apparatus of claim **14** further comprising a guide substrate holding said probes in place.

16. The electronic apparatus of claim **3**, wherein each said probe comprises a spike that pierces one of said pads.

17. The electronic apparatus of claim **16**, wherein each said probe comprises a plurality of spikes that pierce one of said pads.

18. The electronic apparatus of claim **3**, wherein each said probe comprises one or more blades that pierce one of said pads.

19. The electronic apparatus of claim **3**, wherein each said probe comprises a ball that pierces one of said pads.

20. The electronic apparatus of claim **3**, wherein:

said first electronic device is a semiconductor device and said first circuitry comprises active circuitry integrated into said semiconductor device, and

said second electronic device is a socket for receiving said semiconductor device.

21. The electronic apparatus of claim **3**, wherein:

said first electronic device is a semiconductor device and said first circuitry comprises active circuitry integrated into said semiconductor device, and

said second electronic device is a probe card assembly configured to make temporary electrical connections with said semiconductor device to test said semiconductor device.

22. The electronic apparatus of claim **21**, wherein:

said pads are disposed on said semiconductor device, and

said probes are part of said probe card assembly, and

said probes comprise piercing ends that pierce said pads.

23. A process of electrically connecting electronic devices, said process comprising:

piercing with electrically conductive probes electrically connected to first circuitry of a first electronic device compliant pads that are electrically connected to second circuitry of a second electronic device,

wherein for each pair of one of said probes and a corresponding one of said pads, said piercing comprises said one of said probes contacting electrically conductive elements of said corresponding one of said pads to complete an electrically conductive path through said one of said probes and said corresponding one of said pads from said first circuitry to said second circuitry.

24. The method of claim **23**, wherein each said pad comprises:

a non-electrically conductive compliant material, and

said conductive elements suspended in said compliant material.

25. The method of claim **24**, wherein said compliant material is elastic.

26. The method of claim **24**, wherein said compliant material comprises a polymer material or a plastic material.

27. The method of claim **23**, wherein:

said conductive elements are electrically conductive fibers, and

each said pad comprises a mesh of intertwined ones of said fibers.

28. The process of claim **23**, wherein each said probe comprises a spike that pierces one of said pads.

29. The process of claim **23**, wherein each said probe comprises a plurality of spikes that pierce one of said pads.

30. The process of claim **23**, wherein each said probe comprises one or more blades that pierce one of said pads.

31. The process of claim **23**, wherein each said probe comprises a ball that pierces one of said pads.

32. The process of claim **23**, wherein:

said first electronic device is a semiconductor device and said first circuitry comprises active circuitry integrated into said semiconductor device, and

said second electronic device is a socket for receiving said semiconductor device.

33. The process of claim **23**, wherein:

said first electronic device is a semiconductor device and said first circuitry comprises active circuitry integrated into said semiconductor device, and

said second electronic device is a probe card assembly configured to make temporary electrical connections with said semiconductor device to test said semiconductor device.

34. The process of claim **33** further comprising providing test signals from a tester configured to test said semiconductor device through said probe card assembly to said semiconductor device.

35. A probe card assembly comprising:

a wiring substrate comprising an electrical interface to a tester for controlling testing of an electronic device under test (DUT);

a probe head comprising electrically conductive contacts configured to connect electrically to terminals of said DUT; and

an interconnector comprising compliant pads and configured to provide electrical paths between said wiring substrate and said probe head,

wherein each said electrical path comprises electrical connections formed at a plurality of locations inside one of said pads.

36. The probe card assembly of claim **35**, wherein:

said interconnector further comprises electrically conductive probes piercing said pads, and

said electrical connections of each said conductive path are between electrically conductive elements inside one of said pads and one of said probes that pierces said one of said pads and contacts ones of said conductive elements inside said one of said pads.

37. The probe card assembly of claim **36**, wherein each said pad comprises:

a non-electrically conductive compliant material, and

said conductive elements are suspended in said compliant material.

38. The probe card assembly of claim **36**, wherein:

said conductive elements are electrically conductive fibers, and

each said pad comprises a mesh or bundle of intertwined ones of said fibers.

39. The probe card assembly of claim **36**, wherein:

a first set of said probes extend from said wiring substrate and are electrically connected to said electrical interface;

a second set of said probes extend from said probe head and are electrically connected to said contacts of said probe head; and

said interconnector further comprises an interposer comprising a first set of said pads facing said wiring substrate and pierced by said first set of said probes, and a second set of said pads facing said probe head and pierced by said second set of said probes;

40. The probe card assembly of claim **36**, wherein:

a first set of said pads are disposed on said wiring substrate and are electrically connected to said electrical interface;

a second set of said pads are disposed on said probe head and are electrically connected to said contacts of said probe head; and

said interconnector further comprises an interposer comprising a first set of said probes extending toward said first wiring substrate and piercing said first set of pads, and

a second set of said probes extending toward said probe head and piercing said second set of pads.

41. The probe card assembly of claim **36**, wherein said contacts of said probe head are electrically conductive probes.

42. The probe card assembly of claim **36**, wherein said contacts of said probe head are complaint pads comprising electrically conductive elements.

* * * * *