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(54) TRANSMISSION-LINE SPRING STRUCTURE

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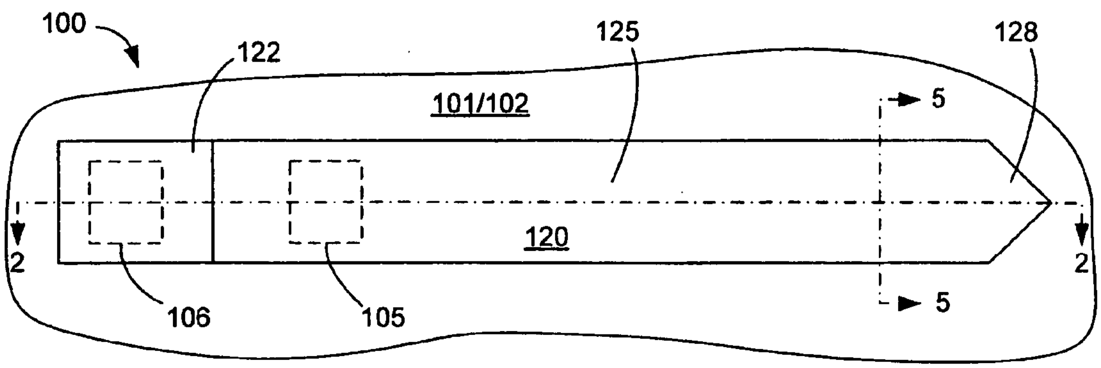
(57) **ABSTRACT**

A curved transmission-line spring structure formed by self-bending materials (e.g., stress-engineered materials, intermetallic compounds and/or bimorphs) that are layered to form a stripline or microstrip transmission line. A dielectric layer is sandwiched between two conductive layers, which form the signal and ground lines of the structure. The various layers are etched to form an elongated spring structure, and then one end of the spring structure is released from the underlying substrate, causing the tip of the released end to bend away from the substrate for contact with a second device. One or both of the conductive layers is fabricated using self-bending spring metals to facilitate the bending process, and plated metal is utilized for conductivity. Alternatively, or in addition, the dielectric layer is formed using a stress-engineered dielectric material. Two-tip and three-tip structures are used to facilitate connection of both the ground and signal lines.



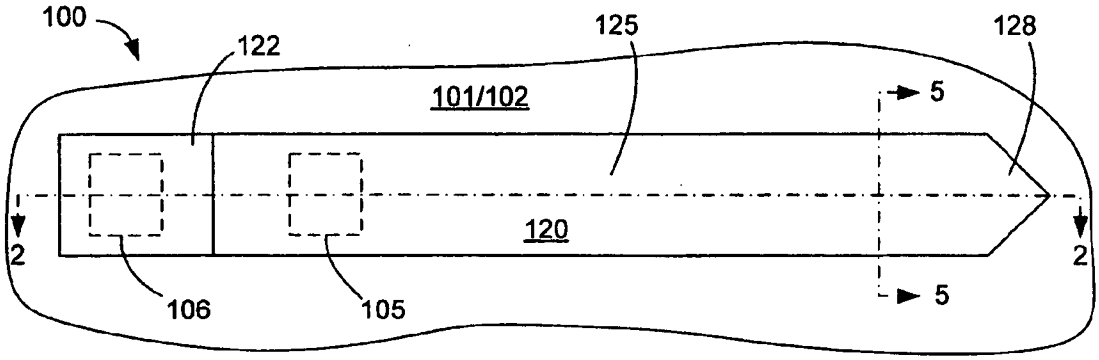

100
122
125
128
101/102
5
120
2
2
106
105
5

FIG. 1

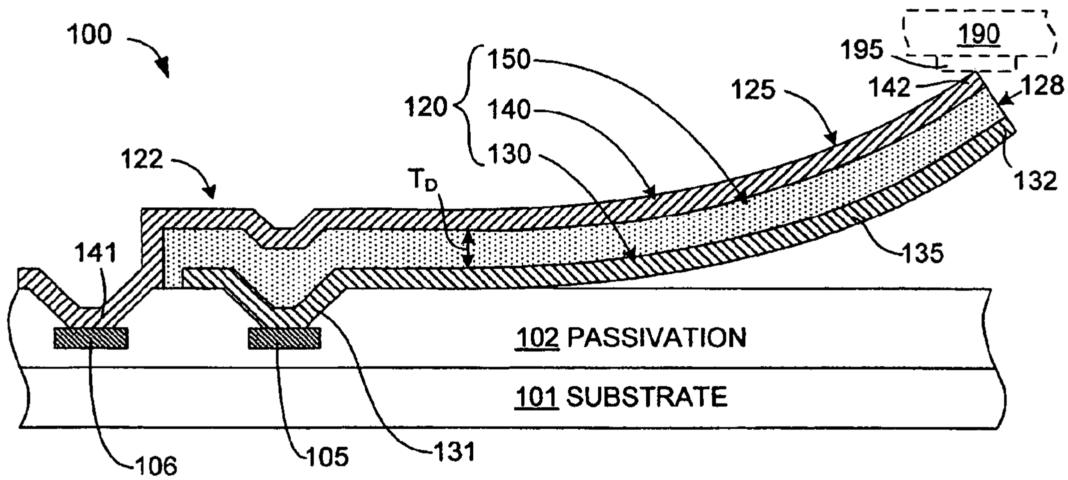

100
190
195
150
142
128
125
120
140
130
132
122
T_D
141
135
102 PASSIVATION
101 SUBSTRATE
106
105
131

FIG. 2

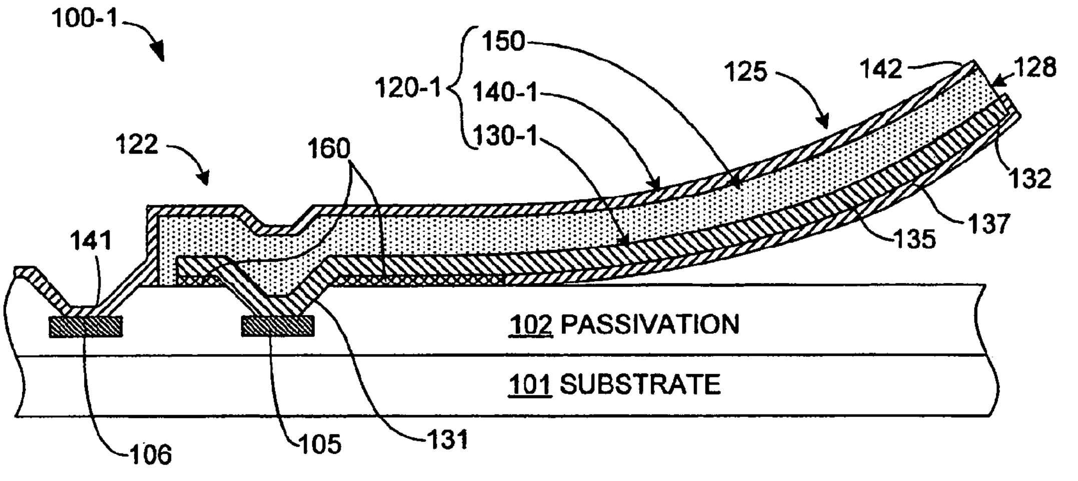


FIG. 3

FIG 4(A)

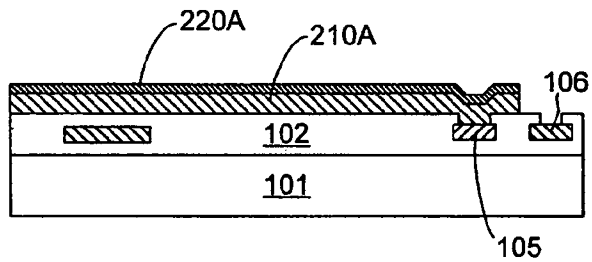


FIG 4(B)

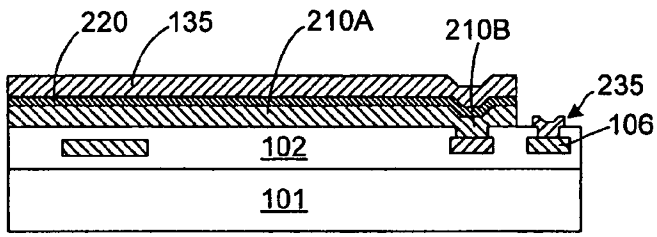


FIG 4(C)

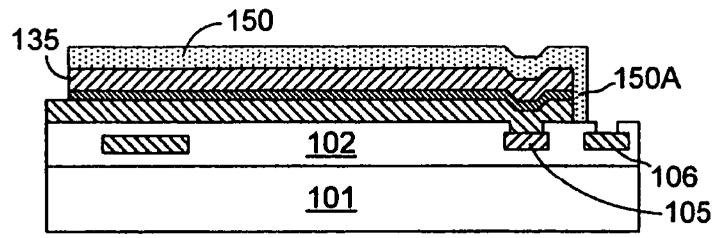


FIG 4(D)

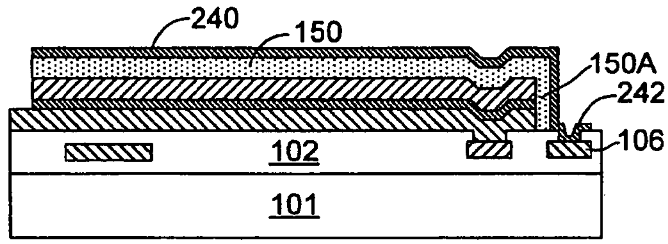


FIG 4(E)

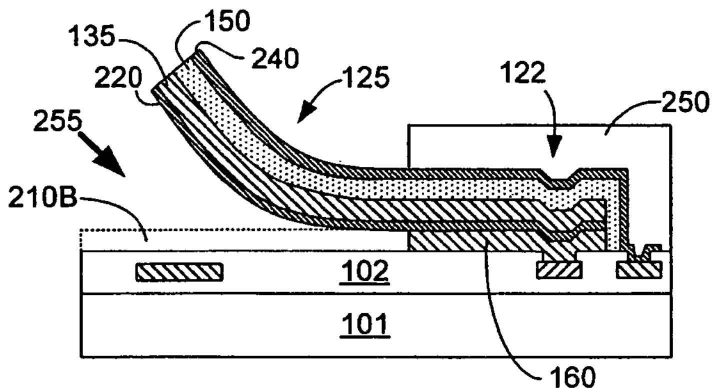


FIG 4(F)

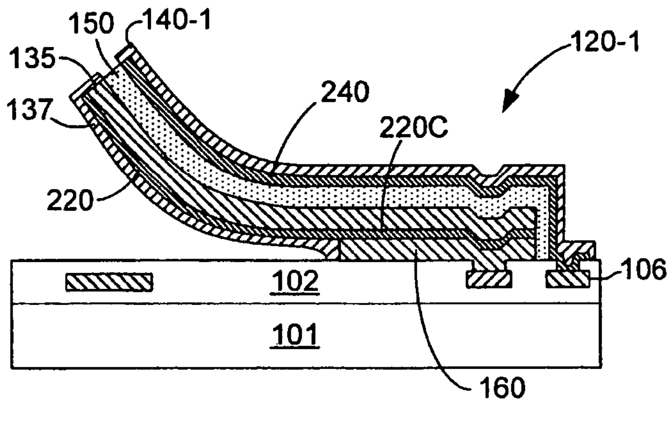


FIG. 5(A)

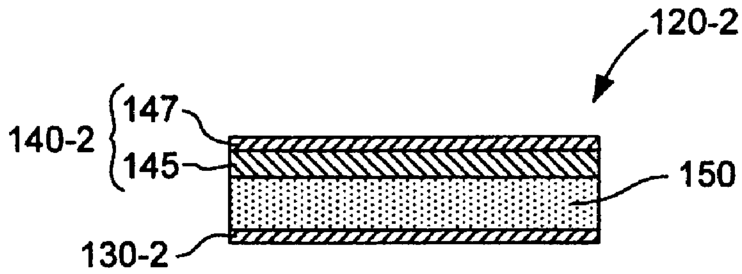


FIG. 5(B)

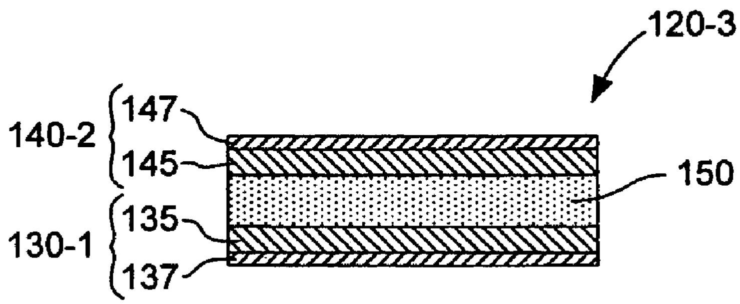


FIG. 5(C)

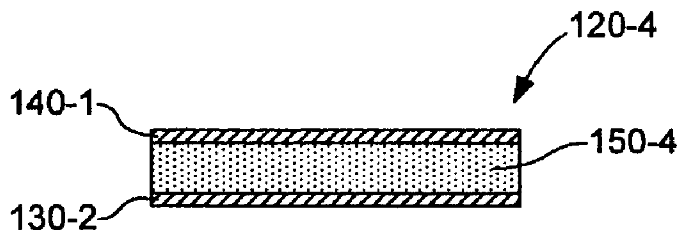


FIG. 5(D)

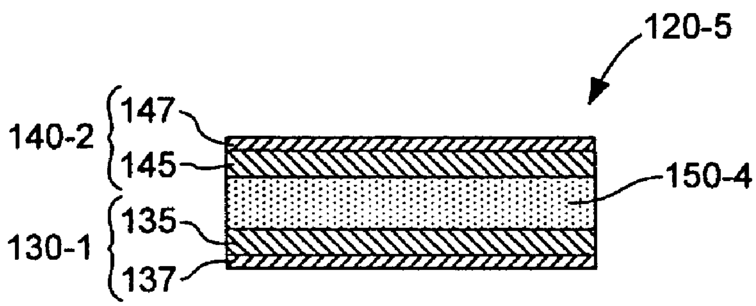
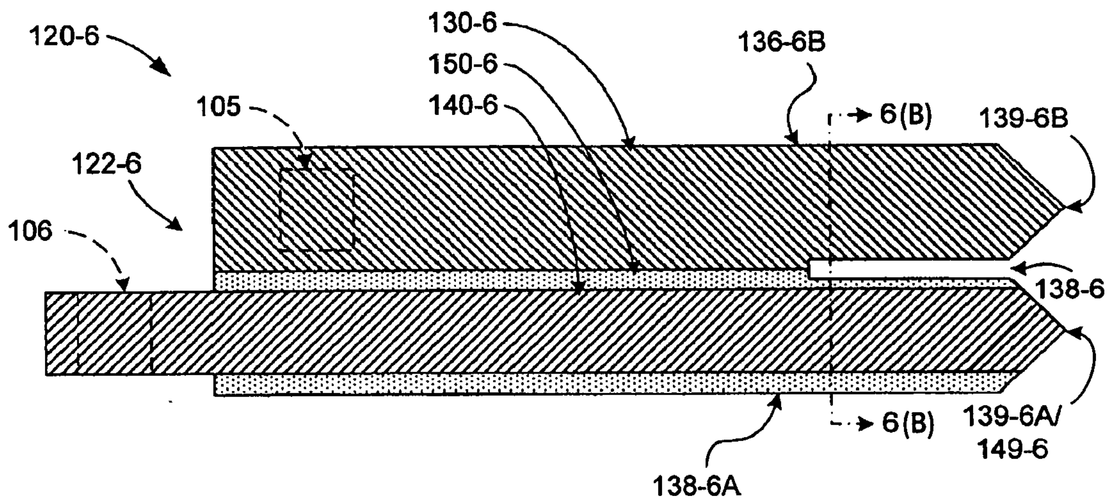


FIG. 6(A)


120-6
130-6
150-6
140-6
136-6B
105
6(B)
139-6B
122-6
106
138-6
6(B)
139-6A/
149-6
138-6A

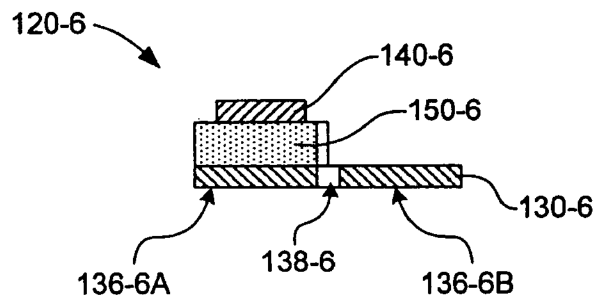
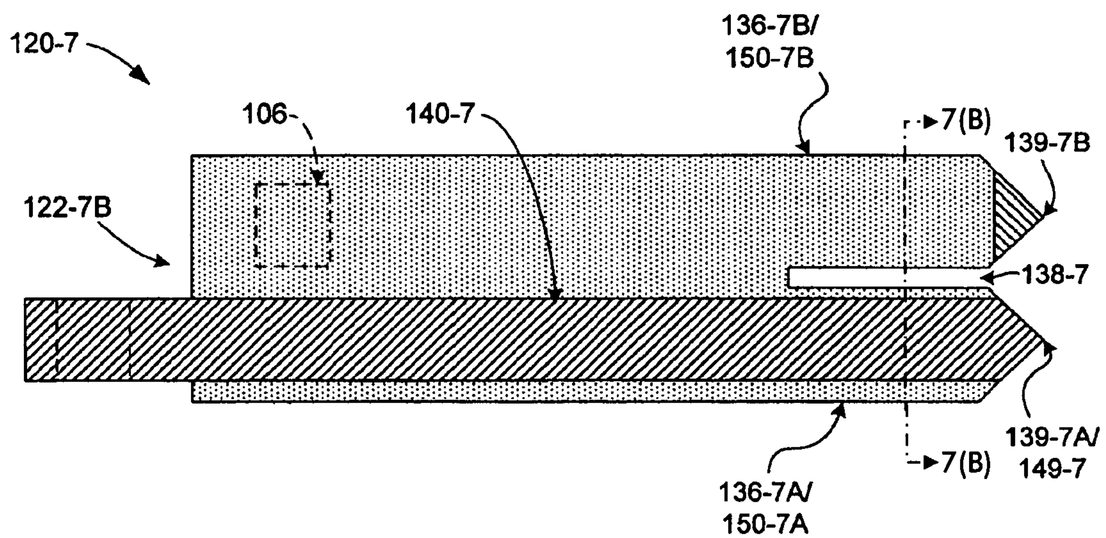

120-6
140-6
150-6
130-6
136-6A
138-6
136-6B

FIG. 6(B)

FIG. 7(A)


120-7
136-7B/
150-7B
106
140-7
7(B)
139-7B
122-7B
138-7
7(B)
139-7A/
149-7
136-7A/
150-7A

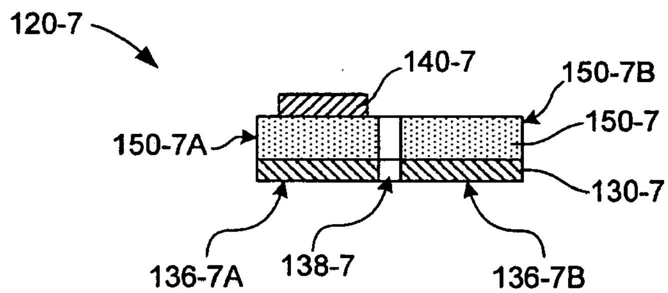
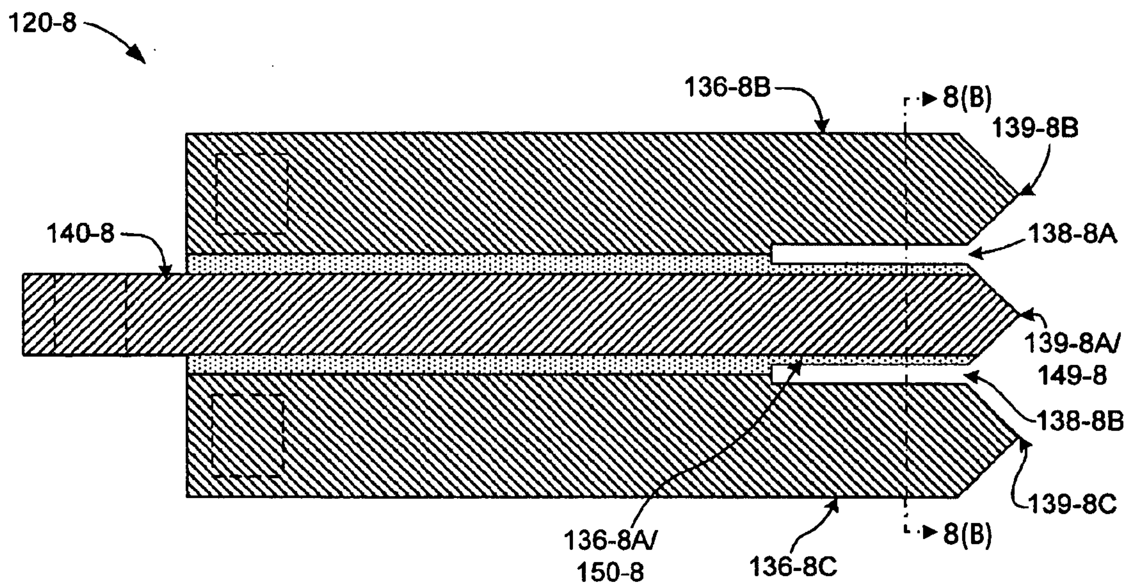

120-7
140-7
150-7B
150-7A
150-7
130-7
136-7A
138-7
136-7B

FIG. 7(B)

FIG. 8(A)


120-8
136-8B
8(B)
139-8B
140-8
138-8A
139-8A/
149-8
138-8B
139-8C
136-8A/
150-8
136-8C
8(B)

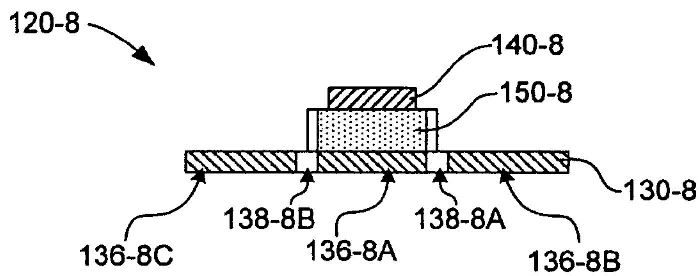
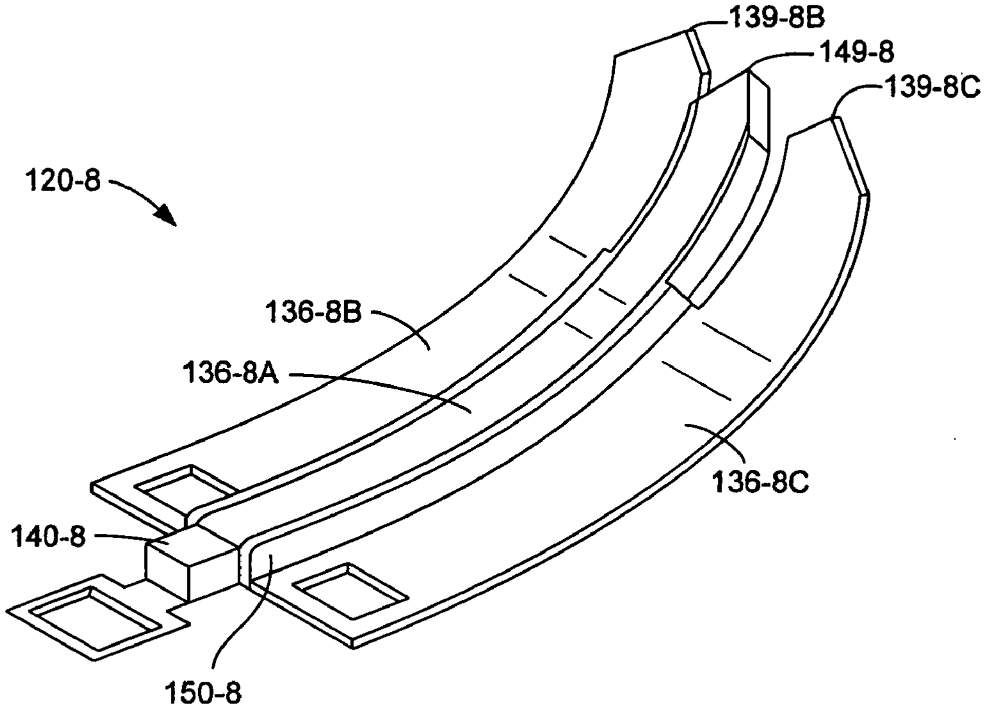
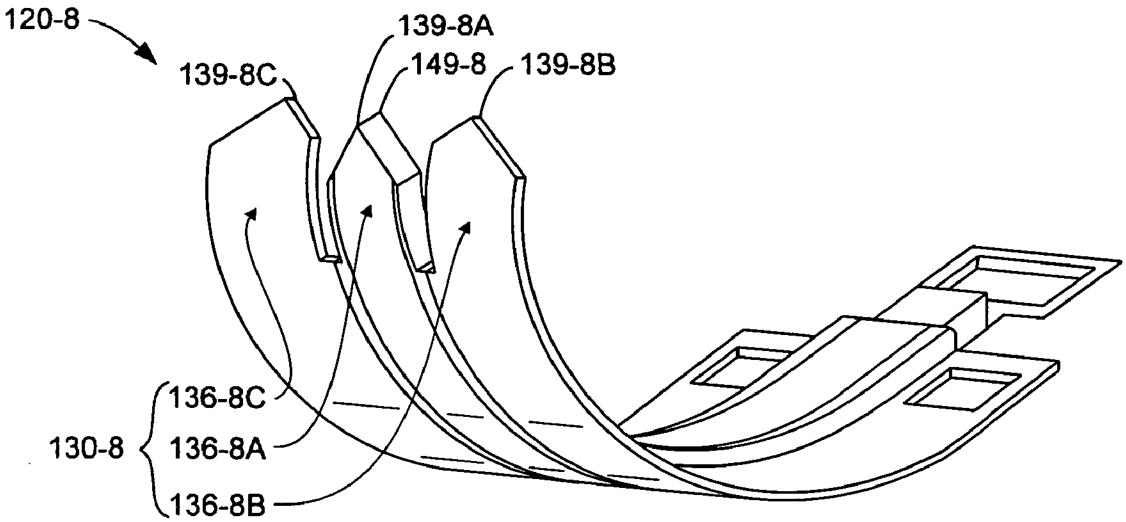

120-8
140-8
150-8
130-8
136-8C
138-8B
136-8A
138-8A
136-8B

FIG. 8(B)



139-8B
149-8
139-8C
120-8
136-8B
136-8A
136-8C
140-8
150-8

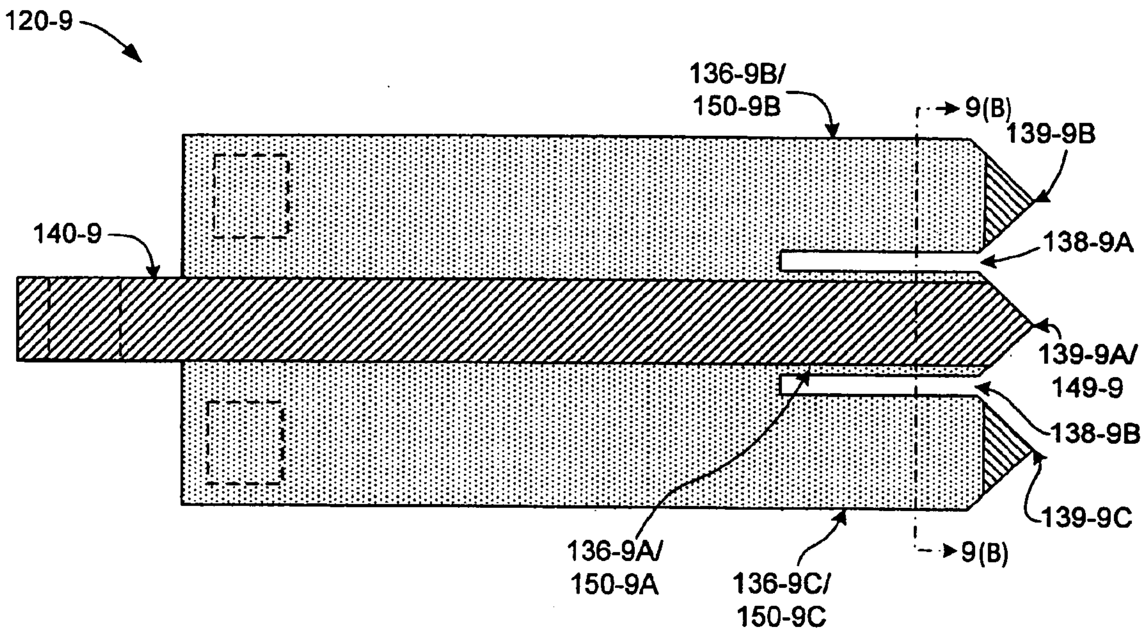
FIG. 8(C)



120-8
139-8A
139-8C
149-8
139-8B
136-8C
130-8
136-8A
136-8B

FIG. 8(D)

FIG. 9(A)


120-9
136-9B/
150-9B
9(B)
139-9B
140-9
138-9A
139-9A/
149-9
138-9B
139-9C
136-9A/
150-9A
136-9C/
150-9C
9(B)

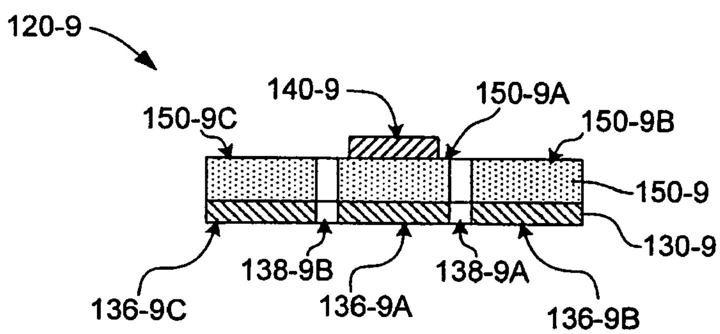
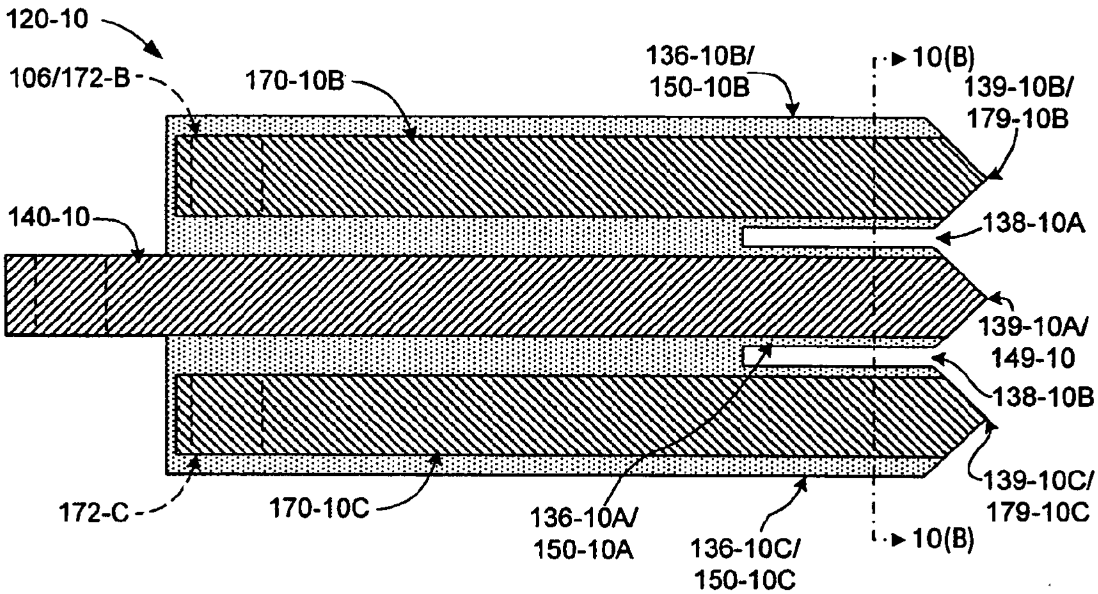

120-9
140-9
150-9A
150-9C
150-9B
150-9
130-9
136-9C
138-9B
136-9A
138-9A
136-9B

FIG. 9(B)

FIG. 10(A)



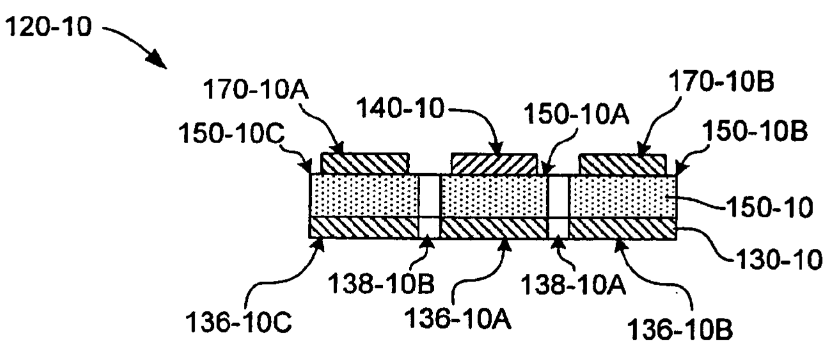
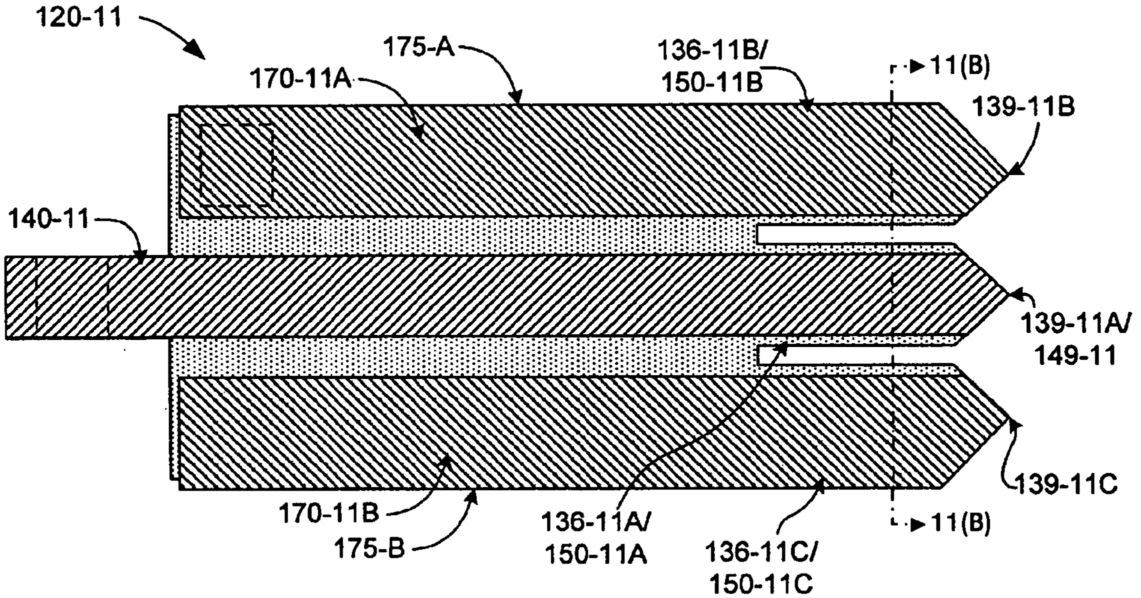


FIG. 10(B)

FIG. 11(A)



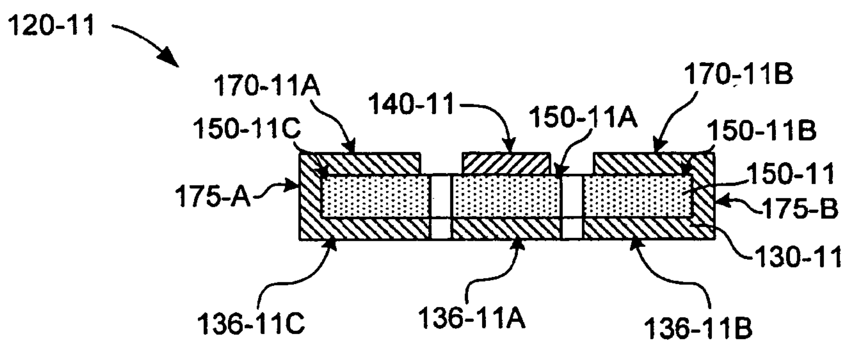


FIG. 11(B)

TRANSMISSION-LINE SPRING STRUCTURE

FIELD OF THE INVENTION

[0001] This invention relates to transmission-line spring structures formed from self-bending materials, and more particularly to transmission-line test probes and interconnect structures formed from such spring structures.

BACKGROUND OF THE INVENTION

[0002] With clock frequencies rapidly approaching the microwave range, maintaining signal integrity and controlling electromagnetic interference in electronic (digital) systems is becoming increasingly difficult. Crosstalk through mutual trace inductances and capacitors, ground bounce, clock skew, signal reflections in incorrectly terminated routes, RF radiation and pickup can no longer be ignored as in previous, relatively low frequency digital systems. The various integrated circuit (IC)-to-package and package-to-printed circuit board (PCB) interconnects must now be treated as RF transmission lines, and the characteristic line impedances of the interconnects must be matched to the signal source impedance and kept constant over the various transitions from IC, through the IC package and socket, to the PCB.

[0003] Conventional IC-to-package and package-to-PCB interconnect structures (e.g., wirebond or flip-chip structures) are difficult to shield, and exhibit impedances that are very hard to control. The resulting signal integrity problem is fundamentally ignored in commercial high pin count, mass produced ICs (e.g., memory devices, microprocessors, and linear ICs) and associated systems. As a result, the maximum operation speed of these devices is limited by signal distortions due to interconnect mismatch, rather than transistor performance. In radio frequency integrated circuits (RFIC), the number of interconnects is much smaller (a few dozen at most), but the frequency limitations of bondwires significantly impact circuit performance. Careful bondwire shaping and extensive modeling of their artifacts are expensive but common practice in the industry. However, the inherent parasitic inductance of these bondwires remains an unaddressed problem.

[0004] What is needed is an efficient and economical spring structure for IC probing or permanent IC interconnects that overcomes the signal integrity problems of conventional structures.

SUMMARY OF THE INVENTION

[0005] The present invention is directed to a curved test probe or interconnect structure in which self-bending materials (e.g., stress-engineered materials, intermetallic compounds and/or bimorphs) are utilized to produce a transmission-line spring structure that, similar to a stripline or microstrip, includes a dielectric layer sandwiched between two elongated conductive layers, which form the signal and ground lines of the structure. Low cost and highly efficient photolithographic techniques are used to sequentially form the lower (first) conductive layer, the intermediate dielectric layer, and then the upper (second) conductive layer over a host substrate. The various layers are then processed (e.g., etched, released and annealed) to form curved transmission-line spring structures, each spring structure having an anchor region attached to the host substrate, a cantilever region extending from the anchor region and curving away from the substrate, and at least one tip structure located at a distal (free) end of the cantilever region. The upper conductive layer of the transmission-line spring structure provides a signal path between a contact pad on the host substrate and a second structure contacted by the tip. The lower conductive layer provides the ground path for the transmission line, and is connected to ground structures formed on the host substrate and/or second structure. Thus, the present invention provides a transmission-line spring structure that enables shielded and impedance matched transmission/probing of radio frequency (RF) or very fast logic signals. In addition, the transmission-line spring structures utilize substantially less contact area than conventional macro-scale RF probes, thereby facilitating placement directly over signal sources (e.g., over the center of an IC chip), thus producing shorter signal paths.

[0006] According to an aspect of the present invention, at least one of the two conductive layers is fabricated using one or more self-bending spring metals (e.g., stress-engineered, intermetallic and/or bimorphs) that facilitate selective and controllable bending of the transmission-line spring structure. In one specific embodiment, the first (lower) conductive layer is fabricated using one or more self-bending spring metals that lift the dielectric layer and second conductive layer formed thereon. In another specific embodiment, the second (upper) conductive layer is fabricated using self-bending spring metal(s) that lift the underlying dielectric and first conductive layers. In yet another specific embodiment, both the first and second conductive layers are fabricated using self-bending spring metals that cooperatively lift the intervening dielectric layer. In each of the above-mentioned specific embodiments, one or both of the first and second conductive layers includes a plated metal (e.g., gold, nickel and/or copper) to facilitate low resistance transmission of the applied signal.

[0007] According to an aspect of the present invention, the dielectric layer is formed using a stress-engineered dielectric material (e.g., silicon, silicon oxide, or silicon oxynitride deposited while gradually changing the atmospheric pressure inside the deposition chamber).

[0008] According to another aspect of the present invention, the transmission-line spring structure is formed with two or more tip structures by which the first and second elongated conductors are reliably and conveniently connected to corresponding contact pads on a second device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] These and other features, aspects and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings, where:

[0010] **FIG. 1** is a top plan view showing a spring structure assembly according to an embodiment of the present invention;

[0011] **FIG. 2** is a cross-sectional side view taken along section line **2-2** of **FIG. 1**;

[0012] **FIG. 3** is a cross-sectional side view showing a spring structure assembly according to another embodiment of the present invention;

[0013] FIGS. 4(A), 4(B), 4(C), 4(D), 4(E), and 4(F) are cross-sectional side views depicting a fabrication process for generating the spring structure of **FIG. 3**;

[0014] FIGS. 5(A), 5(B), 5(C), and 5(D) are cross-sectional end views showing portions of spring structures according to various alternative embodiments of the present invention;

[0015] FIGS. 6(A) and 6(B) are top plan and cross-sectional end views showing a two-tip spring structure according to another embodiment of the present invention;

[0016] FIGS. 7(A) and 7(B) are top plan and cross-sectional end views showing a two-tip spring structure according to another embodiment of the present invention;

[0017] FIGS. 8(A) and 8(B) are top plan and cross-sectional end views showing a three-tip spring structure according to another embodiment of the present invention;

[0018] FIGS. 8(C) and 8(D) are perspective views showing the spring structure of **FIG. 8**(A) in additional detail;

[0019] FIGS. 9(A) and 9(B) are top plan and cross-sectional end views showing a three-tip spring structure according to another embodiment of the present invention;

[0020] FIGS. 10(A) and 10(B) are top plan and cross-sectional end views showing a three-tip spring structure according to another embodiment of the present invention; and

[0021] FIGS. 11(A) and 11(B) are top plan and cross-sectional end views showing a three-tip spring structure according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0022] **FIGS. 1 and 2** are top plan and cross-sectional side views, respectively, showing a spring structure assembly **100** according to a first embodiment of the present invention. Assembly **100** includes a substrate **101** having a passivation (or other insulator) layer **102** formed thereon, and contact pads **105** and **106** that are supported by passivation layer **102** such that contact pads **105** and **106** are electrically insulated from each other. In addition, assembly **100** includes a transmission-line spring (i.e., test probe or interconnect) structure **120** having an anchor region **122** attached to substrate **101** (i.e., via passivation layer **102** and/or zero or more intervening structures), a curved cantilever region **125** extending from anchor region **122** away from substrate **101**, and at least one tip **128** located at a distal (free) end of cantilever region **122**. The curved shape of transmission-line spring structure **120** is generated using one or more self-bending materials in the manner described below with reference to the specific embodiments.

[0023] Referring to **FIG. 2**, according to an aspect the present invention, transmission-line spring structure **120** includes a lower (first) elongated conductive layer **130** and an upper (second) elongated conductive layer **140** that are separated by a dielectric layer **150**. Lower conductive layer **130** includes a fixed (first) end **131** electrically connected to (first) contact pad **105**, and a free (second) end **132** located adjacent to tip **128**. Similarly, upper conductive layer **140** includes a fixed (first) end **141** connected to (second) contact pad **106**, and a free (second) end **142** located adjacent to tip **128**. Dielectric layer **150** is located between lower conductive layer **130** and upper conductive layer **140** such that the conductive layers are separated by a uniform distance (i.e., the thickness TD of dielectric layer **150**) along their respective lengths (i.e., between anchor region **122** and tip **128**).

[0024] When utilized as a test probe or interconnect structure in an electronic system, transmission-line spring structure **120** provides a microstrip-type transmission line structure that greatly enhances the transmission of high frequency signals between a host device (e.g., an integrated circuit formed on substrate **101**) and a target (second) device **190** that is contacted by tip **128**. In one embodiment, lower conductive layer **130** is maintained at a predetermined ground potential via contact pad **105**, and a high frequency signal that is generated, for example, by electronic circuitry formed on substrate **101**, is transmitted onto upper elongated conductor **140** via contact pad **106**. As indicated in **FIG. 2**, a contact pad **195** of a second device **190** is contacted by end **142** of upper conductive layer **140**, thereby forming a conductive path for transmitting the high frequency signal from substrate **101** to a corresponding circuit associated with second device **190**. An optional second connection to first conductive layer **130** (not shown), which is typically required to support high frequency transmissions, is discussed below with reference to multi-tip embodiments. Due to the proximity of the ground plane provided by first conductive layer **130**, the signal is transmitted on second conductive layer **140** with a substantially greater efficiency than is possible using conventional single-wire test probe and interconnect structures. Thus, transmission-line spring structures formed in accordance with the present invention provide a substantial improvement over conventional wire-bond IC interconnect and test probe structures by facilitating lew matched impedance transmissions from a first IC device to a host PCB, and/or from the host PCB to a second IC device, thereby providing a highly versatile and extremely clean signal transfer mechanism.

[0025] Another advantage of transmission-line spring structure **120** over conventional interconnect and test probe structures is that transmission-line spring structure **120** requires substantially less contact area than conventional transmission-line structures, thereby facilitating shorter signal distances because transmission-line spring structures **120** can be placed closer to the signal source. The landing pads for the commercially available transmission-line probes are rather big (e.g., 50 μm by 50 μm each on a 100 μm pitch), and are therefore often placed in the dicing lanes of a wafer to preserve precious wafer space. This approach, however, requires routing signals of interest that are generated in the center of the IC to the circuit perimeter, thus increasing the overall signal path. Due to the substantially smaller contact region of transmission-line spring probe **120** (i.e., approximately 25 μm by 25 μm on a 38 μm pitch), the present invention facilitates placing transmission-line contact structures directly over the locations where signals of interest are generated (e.g., in the center of the chip), thereby simplifying signal routing and reducing chip size by eliminating interconnects to the external chip regions.

[0026] As described below with reference to following practical embodiments, at least one of lower conductive layer **130**, upper conductive layer **140**, and dielectric layer **150** is fabricated using one or more self-bending materials that facilitate selective and controllable bending of transmission-line spring structure **120**, thereby producing the characteristic curved shape depicted in **FIG. 2**.

[**0027**] According to an embodiment of the present invention, at least one of lower conductive layer **130** and upper conductive layer **140** is fabricated using one or more self-bending spring metals (e.g., stress-engineered metals, intermetallic compositions, and/or bimorph metal structures) that facilitate selective and controllable bending of transmission-line spring structure **120**. The phrase "spring metal" is defined herein as a metal film having a non-zero internal mechanical stress when formed or subsequently annealed that causes the metal film to bend (curl) away from the substrate after release. In one embodiment, spring metals include one or more stress-engineered metal films (described below), intermetallic compositions, and/or bimorphs. Spring metals may include non-metal components.

[**0028**] According to another embodiment of the present invention, one or both of lower conductive layer **130** and upper conductive layer **140** includes a plated metal layer that serves to increase electrical conductivity. The phrase "plated metal" refers to one or more electrically conductive metals that are formed using established plating techniques (e.g., electroplating or electroless plating) either before or after the release process. For example, lower conductive layer **130** and/or upper conductive layer **140** may be formed using stress-engineered plated metal that is deposited prior to release of the spring structure. Alternatively, one or more plated metal layers may be formed after release of the spring structure (e.g., electroplating Copper, Nickel and/or gold over selected regions of the released spring structure). Although thick plated metal layers have superior conductive characteristics to thin sputtered metal layers, it may not in all cases be necessary to perform post-release plating of such sputtered metals. Therefore, the use of plated metals may be omitted in some embodiments.

[**0029**] **FIG. 3** is a cross-sectional side view showing an assembly **100-1** according to a first specific embodiment of the present invention. Structures that are similar or identical to those introduced above with reference to assembly **100** are assigned the same or similar reference numbers, and structures identical to those utilized in assembly **100** will not be discussed in detail for sake of brevity.

[**0030**] Assembly **100-1** includes an intermediate structure **160** that is formed between anchor region **122** of transmission-line spring structure **120-1** and substrate **101**. As described in additional detail below, intermediate structure **160** is formed from a retained portion of a sacrificial (release material) layer that is removed (e.g., etched) during the release process.

[**0031**] Assembly **100-1** also includes a transmission-line spring structure **120-1** having a two-part lower conductive layer **130-1**, dielectric layer **150** formed on lower conductive layer **130-1**, and a plated metal upper conductive layer **140** formed on dielectric layer **150**. Lower conductive layer **130-1** includes a spring metal layer **135** and a plated metal layer **137**. Fixed end **131** of spring metal layer **135** is formed on intermediate structure **160** and extends through an opening thereof to contact first contact pad **105**. Plated metal layer **137** is formed during a post-release plating process over all exposed portions of spring metal layer **135** including free end **132**.

[**0032**] FIGS. **4**(A) to **4**(F) depict a fabrication process for generating assembly **100-1** according to an exemplary embodiment of the present invention.

[**0033**] Referring to **FIG. 4**(A), after defining vias through passivation layer **102** that expose contact pads **105** and **106**, a release layer and a seed layer are sequentially deposited and patterned to form a network of release layer islands **210A** that include a (first) seed layer **220** formed thereon, with, in one embodiment, the network of release layer islands **210A** connected together to facilitate subsequent electroplating. Note that the vias exposing contact pads **105** and **106** are already provided on commercially manufactured wafers.

[**0034**] The purpose of release layer island **210A** is to facilitate a selective etching process that releases portions of the spring film from substrate **101**/passivation layer **102** to form curved spring structures. As described below, the material utilized to form release layer island **210A** is selected such that substrate **101**/passivation layer **102** and the spring structures are not significantly damaged (e.g., etched) during the release process (i.e., the selective under-etching of the spring structure in the manner described below), and an anchor region of each spring structure remains connected to substrate **101** via a portion of release layer island **210A** (i.e., intermediate structure **160**; see **FIG. 3**) after the release process is completed. In these embodiments, release layer island **210A** is matched with the subsequently formed spring film material such that the spring material adheres to the release material. Suitable release materials include, for example, one or more of silicon (Si), a silicon nitride composition (SiNx), a silicon oxide composition (SiOx), silicon oxynitride, or titanium (Ti) that is deposited onto passivation layer **102** using known techniques. In an alternative embodiment (not shown), a separate anchor pad is formed adjacent to the release material that is not removed during the selective etch, and serves to connect the spring probe to substrate **101**. In yet another alternative embodiment, passivation layer **102** may itself be used as a release layer, (i.e., release film island **210A** is not formed, and spring metal film **220** is formed directly on passivation layer **102**), and the release process involves, for example, selectively etching into the passivation layer **102** to release the spring structure (note that removing a protective passivation layer would under most circumstances be undesirable, but may be utilized, for example, when a two-layer passivation is provided).

[**0035**] **FIG. 4**(B) depicts the formation (e.g., sputtering and/or electroplating) of spring metal portion **135**, and an optional second seed layer (not shown), which is utilized in some two-tip and three-tip embodiments described below. In one embodiment, spring metal portion **135** is formed in a subtractive manner by depositing (e.g., sputtering) a layer of stress-engineered spring metal in a controlled manner such that lowermost portions (i.e., the film material located closest to release layer island **210A**) has a higher internal compressive stress than uppermost portions (i.e., the film material located furthest to release layer island **210A**), thereby forming internal stress variations in the growth direction (e.g., a stress gradient that increases in the direction perpendicular to the upper surface of substrate **101**). A mask is then formed over the spring metal layer, and the layer is etched using known techniques to form spring metal portion **135**. The thickness of spring metal portion **135** is determined in part by the selected spring material, formation technique, desired spring constant, and shape of the final spring structure.

[0036] Sputter-based methods for forming spring metal portion **135** such that it has a suitable stress gradient are taught, for example, in U.S. Pat. No. 3,842,189 (depositing two metals having different internal stresses) and U.S. Pat. No. 5,613,861 (e.g., single metal sputtered while varying process parameters), both of which being incorporated herein by reference. In one embodiment, stress-engineered spring metal portion **135** includes one or more metals suitable for forming a spring structure (e.g., one or more of molybdenum (Mo), a "moly-chrome" alloy (MoCr), tungsten (W), a titanium-tungsten alloy (Ti:W), chromium (Cr), nickel (Ni) and a nickel-zirconium alloy (NiZr)).

[0037] According to another embodiment, spring metal portion **135** is formed in an additive manner by first forming a mask, and then depositing a plated metal (e.g. Ni, Cu, alloys) onto seed layer **220** (e.g. Au, Ni) through an opening in the mask using electroplating or electroless plating techniques. Similar to the sputtered embodiment described above, in one embodiment the process parameters are changed during plating to generate a suitable stress gradient, although it is possible to form a suitable film without changing the process parameters. According to an aspect of the present embodiment, a plating chemistry is used that deposits at least two elements into the film that can subsequently be transformed to an intermetallic phase using an annealing process to initiate bending of the spring structure such that its tip is positioned at the target distance away from the underlying substrate. In one specific embodiment, an Au seed layer is lithographically patterned and then sequentially exposed to an Ni_3P (first) solution, which forms a relatively compressive lower spring layer portion on the release layer, and then an Ni_3B (second) solution, which forms a relatively tensile upper spring layer portion on the lower spring layer portion. Other plated spring types may include Cu with various hardening materials added thereto that are formed using either electroless plating or electroplating.

[0038] As indicated at the right side of **FIG. 4**(B), the resulting island of layered material is formed over contact pad **105**, but contact pad **106** spaced from the stack. To prevent possible damage to contact pad **106** during subsequent processing, an optional protective cap **235** is formed over contact pad **106** during the subsequent spring metal deposition. Note that the protective cap is omitted in subsequently discussed FIGS. **4**(C) through **4**(F) for brevity. Note also that release layer island **210A** includes a portion **210**B that provides electrical contact between the stack and contact pad **105** (i.e., when a conductive release material is used).

[0039] **FIG. 4**(C) depicts the process of depositing and subsequently patterning dielectric layer **150** over spring metal portion **135**. Dielectric layer **150** (e.g., polyimide, BCB, or an organic dielectric such as silicon oxide, silicon nitride, or silicon oxynitride) is formed using known techniques, and includes a portion **150**A that extends vertically along the layered stack between contact pads **105** and **106**.

[0040] **FIG. 4**(D) shows a plating seed layer **240** patterned over dielectric layer **150** using well-known techniques such that a portion **242** extends down dielectric portion **150**A and contacts contact pad **106** (or protective cap **235**, shown in **FIG. 4**(B), when used).

[0041] **FIG. 4**(E) depicts a release process in which the stack is released by forming a release mask **250** over anchor region **122** of the stack, and under-etching cantilever region **125** of the stack. Release mask **250** is spun and patterned using known techniques. Under-etching is performed using a suitable etchant **255** (e.g., hydrofluoric acid) for Ti release material), and is timed to obtain the desired undercut distance (i.e., such that a portion **210**B located under the cantilever is removed, but intermediate structure **160** is retained under anchor portion **122**). Perforations in the stack facilitate faster etching and tighter process control. Upon removing portion **210**B, cantilever region **125** bends relative to substrate **101** according to the self-bending characteristics of the selected spring metal (e.g., stress gradient and/or in response to a post-release annealing process).

[0042] Finally, as indicated in **FIG. 4**(F), plating is performed, for example, on all exposed surfaces of seed layers **220** and **240** to form plated metal layer **137** on spring metal layer **135**, and plated metal layer **140-1** on the upper surface of dielectric layer **150**, thereby completing spring structure **120-1**. Note that spring metal layer **135** is electrically connected to contact pad **105** by way of a seed layer portion **220**C and/or intermediate structure **160**, both comprising conductive materials. Note also that plated metal layer **140-1** is separated from spring metal layer **135** by dielectric layer **150**, and contacts contact pad **106**. The release mask is then removed, and any remaining exposed release material covered by the release mask is etched.

[0043] Plating adds metal either in the presence of an applied current, electroplating, or through a surface chemical reaction (i.e., electroless plating). One of the factors to consider is that conventional methods for plating released springs, such as those described in U.S. Pat. No. 6,528,350 (incorporated herein by reference in its entirety), are able to plate the entire surface of the spring, including its top, edges and underside. In the case of a released transmission-line spring structure, such as spring structure **120-1**, it is desired to avoid shorting the upper and lower conductive layers together, as this would produce a shunt in the transmission-line spring structure. One needs also consider what the increase in the dimensions of the conductor will have on the transmission line impedance. The avoidance of shorts can be accomplished by ensuring that the starting unplated surfaces and edges are of the proper dimensions to produce the final desired geometry after plating. This may require locating the edges of the plating seed layers inboard from the edges of the dielectric layer such that the subsequently formed plated metal remains on the dielectric surface and does not extend over the side edge. It will be well understood within this area of practice that proper mask design and etch times can be employed to achieve this result.

[0044] Those skilled in the art will recognize that the embodiment depicted by FIGS. **4**(A) through **4**(F) represents only one of several possible methods that can be utilized to produce assembly **100-1**. For example, in an alternative embodiment, silicon may be used in place of Ti to form release layer island **210**A (described above), with the subsequent release operation performed using a dry XeF_2 etch. **FIG. 5**(A) is a cross-sectional end view taken along line **5-5** of **FIG. 1** showing a spring structure **120-2** according to another embodiment of the present invention. Similar to spring structure **120-1** (**FIG. 3**), spring structure **120-2** includes a dielectric layer **150** sandwiched between a lower conductive layer **130-2** and an upper conductive layer **140-2**. Lower conductive layer **130-2** in this case comprises a plated metal layer formed in a manner similar to that described above with reference to upper conductive layer **140-1**. In addition, upper conductive layer **140-2** is made up of a two-part structure including a spring metal layer **145** and an optional plated metal layer **147** respectively formed in a manner similar to spring metal layer **135** and a plated metal layer **137** of spring structure **120-1**. Spring structure **120-2** operates in a manner similar to spring structure **120-1**, with the exception that spring metal layer **145** acts to lift dielectric layer **150** into the characteristic bent position (as opposed to pushing up dielectric layer **150**, which is described above with reference to spring structure **120-1**).

[**0045**] **FIG. 5**(B) is a cross-sectional end view taken along line **5-5** of **FIG. 1** showing a spring structure **120-3** according to another embodiment of the present invention. Spring structure **120-3** includes a dielectric layer **150** sandwiched between two-part lower conductive layer **130-1** (described above with reference to **FIG. 3**) and a two-part upper conductive layer **140-2** (described above with reference to **FIG. 5**(A)). That is, lower conductive layer **130-1** includes both spring metal layer **135** and plated metal layer **137**, and upper conductive layer **140-2** includes spring metal layer **145** and plated metal layer **147**. By providing two spring metal layers on opposite sides of dielectric layer **150**, and by making upper spring metal layer **145** relatively tensile and lower spring metal layer **135** relatively compressive, spring structure **120-3** exhibits a greater bending moment for given film stresses than the embodiments described above using only a single spring metal layer.

[**0046**] Although the use of spring metal is presently preferred for achieving the self-bending characteristics of the transmission-line spring structures associated with the present invention, it is also possible to utilize stress-engineered dielectric materials, such as oxides and/or nitrides of silicon, thus facilitating the omission of spring metals from the transmission-line spring structure.

[**0047**] **FIG. 5**(C) is a cross-sectional end view taken along line **5-5** of **FIG. 1** showing a spring structure **120-4** including a stress-engineered dielectric layer **150-4** sandwiched between plated metal conductive layers **130-2** and **140-1** (both described above). Suitable stress-engineered inorganic dielectric materials including oxides and/or nitrides of silicon that are sputter deposited in the manner described above with reference to stress-engineered metal layers (e.g., by gradually changing deposition chamber pressure during layer formation).

[**0048**] **FIG. 5**(D) is a cross-sectional end view taken along line **5-5** of **FIG. 1** showing yet another spring structure **120-5** including stress-engineered dielectric layer **150-4** sandwiched between two-part lower conductive layer **130-1** and two-part upper conductive layer **140-2** (both described above). By combining the lifting (bending) forces generated by spring metal layers **135** and **145** and stress-engineered dielectric layer **150-4**, a maximum upward bending force is provided upon release of spring structure **120-5**. Note that, as above, plated metal layers **137** and **147** are optional, and may be omitted when spring metal layers **135** and **145** exhibit sufficient conductivity.

[**0049**] The single-tip spring structures described above are suitable for applications in which only the signal line (e.g., upper conductive layer **140**) is connected to a second IC device (e.g., device **190**, as shown in **FIG. 2**). However, due to the very small offset between the tips of the upper and lower conductive layers, in some applications it may be very difficult to connect the ground line (e.g., lower conductive layer **130**) to the second device. Thus, the single-tip arrangement may not be suitable for applications in which it is desired to connect both signal and ground lines to the second device.

[**0050**] According to another aspect of the present invention, which is described with reference to the various embodiments presented below, transmission-line spring structures of the present invention are provided with two or more separated tip (contact) structures by which both the upper and lower conductors are reliably and conveniently connected between a host substrate and a second structure. As mentioned above, at high frequencies where the spring structure would work as a transmission line, the signal transfer is only going to work properly if the ground path also connects to the second device **190** (i.e., proximity alone will not produce the desired electrostatic shielding effect).

[**0051**] FIGS. **6**(A) and **6**(B) are top plan and cross-sectional side views showing a spring structure **120-6** according to a first two-tip embodiment of the present invention. As in the previous embodiments, spring structure **120-6** includes a lower conductive layer **130-6**, an upper conductive layer **140-6**, and a dielectric layer **150-6** sandwiched therebetween. However, as indicated in **FIG. 6**(A), lower conductive layer **130-6** includes two parts: a first layer portion **136-6**A defining a first tip **139-6**A, and a second layer portion **136-6**B that extends parallel to first layer portion **136-6**A and defines a second tip **139-6**B. Dielectric layer **150-6** is formed on first layer portion **136-6**A, and extends along its length to tip **139-6**A. Note that second layer portion **136-6**B of lower conductive layer **130-6** is exposed along its entire length between anchor region **1226** and second tip **139-6**B (also shown in **FIG. 6**(A)). Upper conductive layer **140-6** is formed as described above on dielectric layer **150-6**, and extends from contact pad **106** to a tip portion **149-6** that is located over tip **139-6**A of layer portion **136-6**A. With this two-tip structure, spring structure **120-6** provides a convenient mechanism for connecting lower conductive layer **130-6** and upper conductive layer **140-6** to a second IC device by way of tip **139-6**B and tip portion **149-6**, respectively (i.e., by bringing these tip structures into contact with corresponding contact pads of the second device). Note that lower conductive layer **130-6**, dielectric layer **150-6**, and upper conductive layer **140-6** are formed using, for example, spring metal, plated metal and/or stress-engineered material, according to any of the exemplary embodiments described above. Note also that layer portions **136-6**A and **136-6**B are integrally formed near anchor region **122-6** of spring structure **120-6**, but are separated by a slot **138-6** adjacent to the free end of spring structure **120-6**. This slot arrangement and lack of dielectric material on second layer portion **136-6**B facilitates a greater upward displacement of tip **139-6**B (as compared to tip **139-6**A), thereby allowing tip **139-6**B to become parallel with tip portion **149-6**.

[**0052**] FIGS. **7**(A) and **7**(B) are top plan and cross-sectional side views showing a spring structure **120-7** according to a second two-tip embodiment of the present invention. Similar to spring structure **120-6**, spring structure

120-7 includes a lower conductive layer 130-7 and an upper conductive layer 140-7 separated by a dielectric layer 150-7. Lower conductive layer 130-7 includes a first layer portion 136-7A defining a first tip 139-7A, and a second layer portion 136-7B defining a second tip 139-7B. In this embodiment, dielectric layer 150-7 includes a first portion 150-7A formed on layer portion 136-7A, and a second dielectric portion 150-7B extending along second layer portion 136-7B. Upper conductive layer 140-7 is formed on portion 150-7A of dielectric layer 150-7, and extends from contact pad 106 to a tip portion 149-7 that is located over tip 139-7A. Finally, dielectric portion 150-7B terminates adjacent to the free end of spring structure 120-7 such that second tip 139-7B is exposed (i.e., extends from an edge of dielectric portion 150-7B).

[0053] Spring structure 120-7 operates essentially as described above, but the additional dielectric portion 150-7B that covers second cantilever region 136-7B produces a balanced stiffness over lower conductive layer 130-7, which can in some instances prevent twisting of the completed structure. That is, a potential problem with first two-tip structure 120-6 is that, due to the unbalanced stiffness on lower conductive layer 136-6 (i.e., due absence of dielectric material on second cantilever region 136-6B), second cantilever region 136-6B may twist along its length, thereby resulting in an undesirable curled structure (e.g., with tip 139-6B located over tip portion 149-6). This twisting problem is addressed in spring structure 120-7 by providing dielectric portion 150-7B to balance the stiffness on lower conductive layer 136-7, thereby reducing the chance of twisting and causing the tip portions 139-7B and 149-7 to achieve a uniform height above an underlying substrate (not shown).

[0054] As suggested above, two-tip spring structure 120-6 may exhibit undesirable twisting that may be remedied by forming dielectric material over most of the lower conductor layer. Another approach to resist twisting and to further enhance electrical characteristics by further shielding the signal line is to utilize a three-tip spring structure arrangement, such as those described in the following exemplary embodiments.

[0055] FIGS. 8(A) and 8(B) are top plan and cross-sectional side views showing a spring structure 120-8 according to a first three-tip embodiment of the present invention. Spring structure 120-8 includes a lower conductive layer 130-8 and an upper conductive layer 140-8 separated by a dielectric layer 150-8. Lower conductive layer 130-8 includes a first layer portion 136-8A defining a first tip 139-8A, a second layer portion 136-8B defining a second tip 139-8B, and a third layer portion 136-8C defining a third tip 139-8C. All three layer portions extend in parallel, with first layer portion 136-8A located between second layer portion 136-8B and third layer portion 136-8C, with a first slot 138-8A defined between layer portions 136-8A and 136-8B, and a second slot 138-8B defined between layer portions 136-8A and 136-8C. Dielectric layer 150-8 is formed only on layer portion 136-8A, and extends along its entire length to tip 139-8A (i.e., both second layer portion 136-8B and third layer portion 136-8C are exposed). Upper conductive layer 140-8 is formed on dielectric layer 150-8 in the manner described above, and extends from contact pad 106 to a tip portion 149-8 that is located over tip 139-8A.

[0056] FIGS. 8(C) and 8(D) are front and rear perspective views showing spring probe 120-8 in additional detail. As indicated in these figures, a benefit of the three-tip structure is the balanced bending force generated by layer portions 136-8B and 136-8C that resists twisting due to the presence of dielectric layer 150-8 on layer portion 136-8A. Note also that, as indicated in FIG. 8(D), due to the absence of dielectric material on layer portions 136-8B and 136-8C, tips 139-8B and 139-8C are positioned somewhat higher than tip 139-8A, which under ideal conditions brings tips 139-8B and 139-8C level with tip portion 149-8. An advantage of spring structure 120-8 is reduced ground strip resistance due to the exposure (and plating) of layer portions 136-8B and 136-8C.

[0057] FIGS. 9(A) and 9(B) are top plan and cross-sectional side views showing a spring structure 120-9 according to a second three-tip embodiment of the present invention. Spring structure 120-9 includes a lower conductive layer 130-9 and an upper conductive layer 140-9 that are essentially identical to those of spring structure 120-8, but utilizes a dielectric layer 150-9 that extends across all three portions of lower conductive layer 130-9. In particular, dielectric layer 150-9 includes a first dielectric portion 150-9A extending along first layer portion 136-9A, a second dielectric portion 150-9B extending along second layer portion 138-9B, and a third dielectric portion 150-9C extending along the third layer portion 138-9C. Similar to spring structure 120-7 (discussed above), second dielectric portion 150-9B and third dielectric portion 150-9C terminate at a point adjacent to second tip 139-9B and the third tip 139-9C, respectively, thereby exposing these tips for contact with a second device. A first slot 138-9A is defined between layer portions 136-9A and 136-9B, and a second slot 138-9B is defined between layer portions 136-9A and 136-9C. Upper conductive layer 140-9 is formed on dielectric layer 150-9 over first layer portion 136-9A in the manner described above, and includes a tip portion 149-8 that is located over tip 139-9A.

[0058] In one exemplary embodiment, spring structures having lengths of 400 μm that are consistent with spring structures 120-8 and 120-9 (discussed above) can be produced using MoCr spring metal having a thickness of 0.5 μm and an internal stress of 1 GPa (compressive), and the dielectric layers produced using BCB having a thickness of 13.5 μm and an internal stress of 0.028 GPa (tensile). Gold plating seed (0.1 μm thick) can be provided on the lower side of the lower conductive layer and on the dielectric layer prior to release. A Ti release layer can be utilized in the manner described above. Based on calculated values, after release (prior to plating), spring structures consistent with spring structure 120-9 would achieve an approximately 935 μm radius and an approximately 84 μm lift (tip) height. In contrast, spring structures consistent with spring structure 120-8, due to the reduced dielectric weight, would achieve a lift height of 183 μm. However, the stiff BCB "spine" extending along the length of the spring structure would increase its tendency to cup instead of curl during release (i.e., the outer layer portions twisted inward toward the central layer portion). Using the full width BCB associated with spring structure 120-9, but only partially curing the BCB layer before release, a tighter radius and higher lift can be produced without this cupping problem. The BCB can then be cured to completion (i.e., after spring release).

[0059] As indicated above, ground strip resistance can be reduced by plating exposed upper surfaces of the lower conductive layer, but this plating is not possible when a full width dielectric layer is used. The embodiments described below with reference to **FIGS. 10 and 11** combine a full-width dielectric and additional conductive layers to both reduced ground strip resistance and increase shielding of the signal line.

[0060] FIGS. **10**(A) and **10**(B) are top plan and cross-sectional side views showing a spring structure **120-10** according to a third three-tip embodiment of the present invention. Spring structure **120-10** includes a lower conductive layer **130-10**, an upper conductive layer **140-10**, and a full-width dielectric layer **150-10** that are similar to those of spring structure **120-9**. However, second dielectric portion **150-10**B and third dielectric portion **150-10**C extend all the way to tips **139-10**B and **139-10**B, and spring structure **120-10** further includes a (third) elongated conductive layer **170-10**B that is formed on second dielectric portion **150-10**B, and a fourth elongated conductive layer **170-10**C formed on third dielectric portion **150-10**C. Similar to tip portion **149-10**, which is located over tip **139-10**A in the manner described above, elongated conductive layer **170-10**B includes a second tip portion **179-10**B formed on dielectric portion **150-10**B over the second tip **139-10**B, and elongated conductive layer **170-10**C includes a third tip portion **179-10**C formed on dielectric portion **150-10**C over the second tip **139-10**B. Finally, to facilitate electrical connection between lower conductor **130-10** and conductive layers **170-10**B and **170-10**C, spring structure **120-10** includes a first metal via **172**-B extending between layer portion **136-10**B and conductive layer **170-10**A through dielectric portion **150-10**B, and a second metal via **172**-C extending between the layer portion **136-10**C and conductive layer **170-10**B through dielectric portion **150-10***c*.

[0061] FIGS. **11**(A) and **11**(B) are top plan and cross-sectional side views showing a spring structure **120-11** according to a fourth three-tip embodiment of the present invention. Spring structure **120-11** includes a lower conductive layer **130-11**, an upper conductive layer **140-11**, and a full-width dielectric layer **150-11**, a third conductive layer **170-11**B, and a fourth conductive layer **170-10**C that are essentially identical to those of spring structure **120-10**. However, instead of using vias to connect lower conductive layer **130-11** to conductive layers **170-11**B and **170-11**C, spring structure utilizes a first metal side structure **175**-B extending between layer portion **136-11**B and conductive layer **170-11**A along a side edge of dielectric portion **150-11**B, and a second metal side structure **175**-C extending between layer portion **136-11**C and conductive layer **170-11**B along a side of dielectric portion **150-10**C.

[0062] Although the present invention has been described with respect to certain specific embodiments, it will be clear to those skilled in the art that the inventive features of the present invention are applicable to other embodiments as well, all of which are intended to fall within the scope of the present invention. For example, although the spring structures discussed above include pointed tips, one could also opt for flat tips depending on the contact pad material and geometry, and whether the spring is for a probe or for a permanent IC interconnect application. In addition, although metal-dielectric-metal structures are disclosed, the methods described herein can be used to generate sandwich structures having any number of metal and intervening dielectric layers.

1. An assembly comprising:

a substrate including first and second contact pads;

an elongated transmission-line spring structure having an anchor region attached to the substrate, a curved cantilever region extending from the anchor region away from the substrate, and at least one tip located at a distal end of the cantilever region,

wherein said transmission-line spring structure includes:

a first elongated conductive layer having a first end connected to the first contact pad and a second end located adjacent to the at least one tip;

a second elongated conductive layer having a first end connected to the second contact pad and a second end located adjacent to the at least one tip; and

a dielectric layer formed between the first and second conductive layers such that the first and second conductive layers are separated by the dielectric layer.

2. The assembly according to claim 1,

wherein the first elongated conductive layer is formed between the dielectric layer and the substrate, and

wherein the first elongated conductive layer comprises spring metal.

3. The assembly according to claim 2,

wherein the second conductive layer is formed on a surface of the dielectric layer opposite to the first elongated conductive layer, and

wherein at least one of the first elongated conductive layer and the second elongated conductive layer comprises plated metal.

4. The assembly according to claim 1,

wherein the dielectric layer is formed between the second elongated conductive layer and the substrate, and

wherein the second elongated conductive layer comprises spring metal.

5. The assembly according to claim 4,

wherein the first conductive layer is formed between the dielectric layer and the substrate, and

wherein at least one of the first elongated conductive layer and the second elongated conductive layer comprises plated metal.

6. The assembly according to claim 1, wherein both the first elongated conductive layer and the second elongated conductive layer comprise spring metal.

7. The assembly according to claim 6, wherein at least one of the first elongated conductive layer and the second elongated conductive layer further comprises plated metal.

8. The assembly according to claim 1, wherein the dielectric layer comprises a stress-engineered dielectric material.

9. The assembly according to claim 8, wherein at least one of the first elongated conductive layer and the second elongated conductive layer comprise spring metal.

10. The assembly according to claim 8, wherein at least one of the first elongated conductive layer and the second elongated conductive layer comprises plated metal.

11. The assembly according to claim 1,

wherein the first elongated conductive layer includes a first layer portion defining a first tip and a second layer portion defining a second tip,

wherein the dielectric layer extends along the first layer portion to the first tip, and

wherein the second elongated conductive layer extends along the dielectric layer over the first layer portion, and includes a tip portion located over the first tip.

12. The assembly according to claim 1,

wherein the first elongated conductive layer includes a first layer portion defining a first tip and a second layer portion defining a second tip,

wherein the dielectric layer includes a first dielectric portion extending along the first layer portion and a second dielectric portion extending along the second layer portion,

wherein the second elongated conductive layer extends along the dielectric layer over the first layer portion, and includes an upper tip portion located over the first tip, and

wherein the second dielectric portion terminates adjacent to the second tip such that the second tip extends from an end of the second dielectric portion.

13. The assembly according to claim 1,

wherein the first elongated conductive layer includes a first layer portion defining a first tip, a second layer portion defining a second tip, and a third layer portion defining a third tip, the first layer portion being located between the second and third layer portions,

wherein the dielectric layer extends along the first layer portion to the first tip, and

wherein the second elongated conductive layer extends along the dielectric layer over the first layer portion, and includes an upper tip portion located over the first tip.

14. The assembly according to claim 1,

wherein the first elongated conductive layer includes a first layer portion defining a first tip, a second layer portion defining a second tip, and a third layer portion defining a third tip, the first layer portion being located between the second and third layer portions,

wherein the dielectric layer includes a first dielectric portion extending along the first layer portion, a second dielectric portion extending along the second layer portion, and a third dielectric portion extending along the third layer portion,

wherein the second elongated conductive layer extends along the dielectric layer over the first layer portion, and includes an upper tip portion located over the first tip, and

wherein the second dielectric portion and the third dielectric portion terminate adjacent to the second tip and the third tip, respectively, such that the second tip and the third tip extend from ends of the second and third dielectric portions, respectively.

15. The assembly according to claim 1,

wherein the first elongated conductive layer includes a first layer portion defining a first tip, a second layer portion defining a second tip, and a third layer portion defining a third tip, the first layer portion being located between the second and third layer portions,

wherein the dielectric layer includes a first dielectric portion extending along the first layer portion, a second dielectric portion extending along the second layer portion, and a third dielectric portion extending along the third layer portion,

wherein the second elongated conductive layer extends along the dielectric layer over the first layer portion, and includes an upper tip portion located over the first tip, and

wherein the spring structure further comprises:

a third elongated conductive layer formed on the second dielectric portion and having a second tip portion located over the second tip; and

a fourth elongated conductive layer formed on the third dielectric portion and having a third tip portion located over the third tip.

16. The assembly according to claim 15, wherein the spring structure further comprises:

a first metal via extending between the second layer portion and the third elongated conductive layer through the second dielectric portion; and

a second metal via extending between the third layer portion and the fourth elongated conductive layer through the third dielectric portion.

17. The assembly according to claim 15, wherein the spring structure further comprises:

a first metal side structure extending between the second layer portion and the third elongated conductive layer along a side of the second dielectric portion; and

a second metal side structure extending between the third layer portion and the fourth elongated conductive layer along a side of the third dielectric portion.

18. A transmission-line spring structure having an anchor region, a curved cantilever region extending from the anchor region, and at least one tip located at a distal end of the cantilever region, wherein said transmission-line spring structure comprises:

a first elongated conductive layer extending between the anchor region and the at least one tip;

a dielectric layer formed on the first elongated conductive layer; and

a second elongated conductive layer formed on the dielectric layer and extending between the anchor region and the at least one tip,

wherein the dielectric layer extends along the first and second elongated conductive layers such that the first and second conductive layers are separated by the dielectric layer.

19. A transmission-line spring structure comprises:

a first elongated conductive layer including an anchor region, a first layer portion extending from the anchor region to a first tip, and a second layer portion extending from the anchor region to a second tip,

a dielectric layer formed on the first elongated conductive layer and extending along the first layer portion between the anchor region and the first tip, and

a second elongated conductive layer formed on the dielectric layer and extending over the first layer portion, wherein the second elongated conductive layer includes a tip portion located over the first tip.

20. The transmission-line spring structure of claim 19,

wherein the first elongated conductive layer further comprises a third layer portion extending from the anchor region to a third tip, and

wherein the first layer portion is located between the second layer portion and the third layer portion.

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