



US00RE48015E

(19) **United States**
(12) **Reissued Patent**
Refai-Ahmed et al.

(10) **Patent Number: US RE48,015 E**
(45) **Date of Reissued Patent: May 26, 2020**

(54) **INTERCONNECT DEVICES FOR ELECTRONIC PACKAGING ASSEMBLIES**

(71) Applicant: **General Electric Company**, Schenectady, NY (US)
(72) Inventors: **Gamal Refai-Ahmed**, Santa Clara, CA (US); **David Mulford Shaddock**, Troy, NY (US); **Arun Virupaksha Gowda**, Rexford, NY (US); **John Anthony Vogel**, Charlton, NY (US); **Christian Michael Giovanniello**, Schenectady, NY (US)

(73) Assignee: **General Electric Company**, Schenectady, NY (US)

(21) Appl. No.: **15/886,478**

(22) Filed: **Feb. 1, 2018**

Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **9,252,138**
Issued: **Feb. 2, 2016**
Appl. No.: **14/287,237**
Filed: **May 27, 2014**

(51) **Int. Cl.**
H01L 33/02 (2010.01)
H01L 25/16 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC **H01L 25/167** (2013.01); **H01L 23/5386** (2013.01); **H01L 25/50** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H01L 25/167; H01L 25/50; H01L 33/62; H01L 33/647; H01L 33/05; H01L 23/5368; H01L 51/50; H01L 51/52
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,829,128 A * 11/1998 Eldridge H01L 24/72 228/180.21
6,002,163 A 12/1999 Wojnarowski
(Continued)

FOREIGN PATENT DOCUMENTS

CN 1565055 A 1/2005
CN 102593035 A 7/2012
(Continued)

OTHER PUBLICATIONS

Office Action issued in connection with corresponding TW Application No. 104115088 dated Jun. 13, 2018 (English Translation not available).

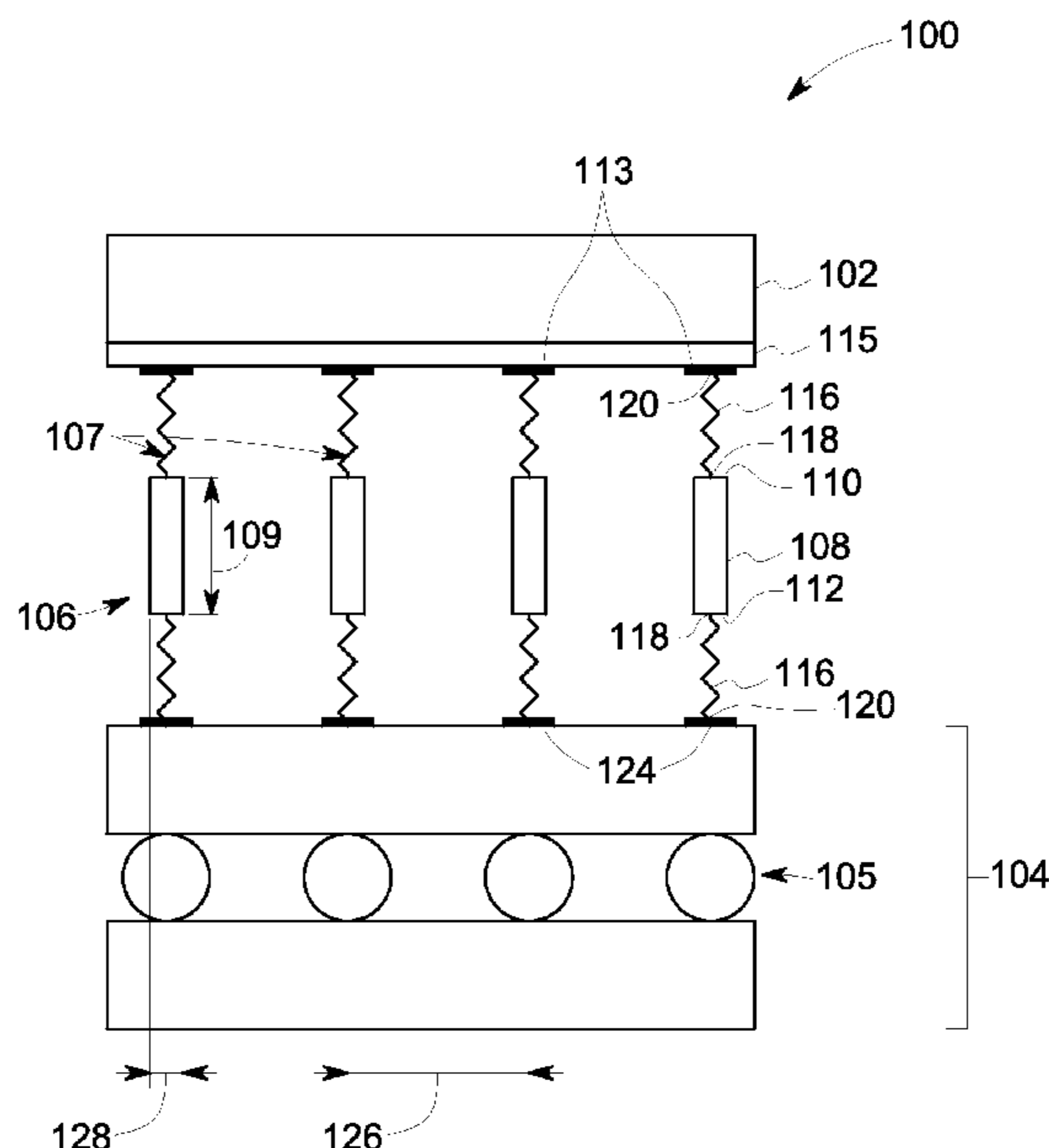
(Continued)

Primary Examiner — Tuan H. Nguyen
(74) *Attorney, Agent, or Firm* — Ziolkowski Patent Solutions Group, SC

(57) **ABSTRACT**

An electronic packaging assembly having a semiconductor integrated circuit and a plurality of interconnect components is provided. The plurality of interconnect components is operatively coupled to the semiconductor integrated circuit. Further, one or more interconnect components include one or more support elements having a first surface and a second surface, and one or more spring elements having a first end and a second end, and wherein first ends of the one or more spring elements are coupled to the first surface or the second surface of a respective support element.

25 Claims, 7 Drawing Sheets



US RE48,015 E

- (51) **Int. Cl.**
H01L 25/00 (2006.01)
H01L 33/62 (2010.01)
H01L 33/64 (2010.01)
H01L 33/54 (2010.01)
H01S 5/022 (2006.01)
H01S 5/024 (2006.01)
H01L 23/538 (2006.01)

- (52) **U.S. Cl.**
 CPC *H01L 33/54* (2013.01); *H01L 33/62*
 (2013.01); *H01L 33/647* (2013.01); *H01S*
5/02248 (2013.01); *H01S 5/02256* (2013.01);
H01S 5/02476 (2013.01); *H01L 2933/0033*
 (2013.01); *H01L 2933/0066* (2013.01)

- (58) **Field of Classification Search**
 USPC 257/734, 782
 See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,246,247	B1 *	6/2001	Eldridge	.....	B23K 20/004	257/E21.503
6,441,315	B1 *	8/2002	Eldridge	.....	G01R 1/06711	174/260
6,491,968	B1 *	12/2002	Mathieu	.....	G01R 1/06727	156/750
6,672,875	B1 *	1/2004	Mathieu	.....	G01R 1/06727	257/E23.078
6,741,085	B1 *	5/2004	Khandros	.....	H23K 1/0016	257/E21.503
8,384,203	B2	2/2013	Toh et al.			
8,405,996	B2	3/2013	Shaddock et al.	.....	B82Y 30/00	165/185
8,955,215	B2 *	2/2015	Rathburn	.....	H01R 12/7082	174/254
2001/0012739	A1 *	8/2001	Grube	.....	G01R 1/06727	439/862
2001/0020546	A1 *	9/2001	Eldridge	.....	B23K 20/004	174/261
2003/0063450	A1 *	4/2003	Miller	.....	H01L 23/13	361/783
2004/0046248	A1	3/2004	Waelti et al.			
2004/0152348	A1 *	8/2004	Pedersen	.....	B23K 1/0016	439/70

2005/0124181	A1 *	6/2005	Brown	.....	H01L 24/72	439/66
2006/0186540	A1 *	8/2006	Buchwalter	.....	H01L 21/4853	257/737
2007/0152024	A1	7/2007	Pang et al.			
2007/0247175	A1 *	10/2007	Khandros	.....	G01R 1/06727	324/754.07
2007/0273018	A1 *	11/2007	Onozuka	.....	B81C 1/0023	257/690
2008/0100323	A1 *	5/2008	Mayder	.....	G01R 1/07378	324/754.18
2010/0032096	A1 *	2/2010	Yu	.....	H01L 21/67103	156/345.52
2010/0328896	A1	12/2010	Shaddock et al.			
2011/0084383	A1	4/2011	Mizutani			
2012/0068319	A1	3/2012	Choi et al.			
2013/0021669	A1	1/2013	Xi et al.			
2013/0062775	A1	3/2013	Ryan			
2013/0105993	A1 *	5/2013	Bahadur	.....	H01L 24/11	257/782
2014/0124940	A1 *	5/2014	Bhagavat	.....	H01L 23/147	257/773
2014/0261608	A1 *	9/2014	Wang	.....	H01L 35/32	136/224

FOREIGN PATENT DOCUMENTS

EP	2270852	A2	1/2011
EP	2466643	A2	6/2012
JP	2007531243	A	11/2007
JP	2008135428	A	6/2008
JP	2010219397	A	9/2010
JP	2013065761	A	4/2013
WO	2008025004	A2	2/2008

OTHER PUBLICATIONS

First Office Action and Search issued in connection with corresponding CN Application No. 201510363890.7 dated Jul. 25, 2018 (English Translation not available).
 Second Office Action issued in connection with corresponding CN Application No. 201510363890.7 dated Dec. 20, 2018 (English Translation not available).
 Milena Vujosevic, "Thermally induced deformations in die-substrate assembly", Theoret. Appl. Mech, pp. 305-322, vol. 35, Issue 1-3, 2008.

* cited by examiner

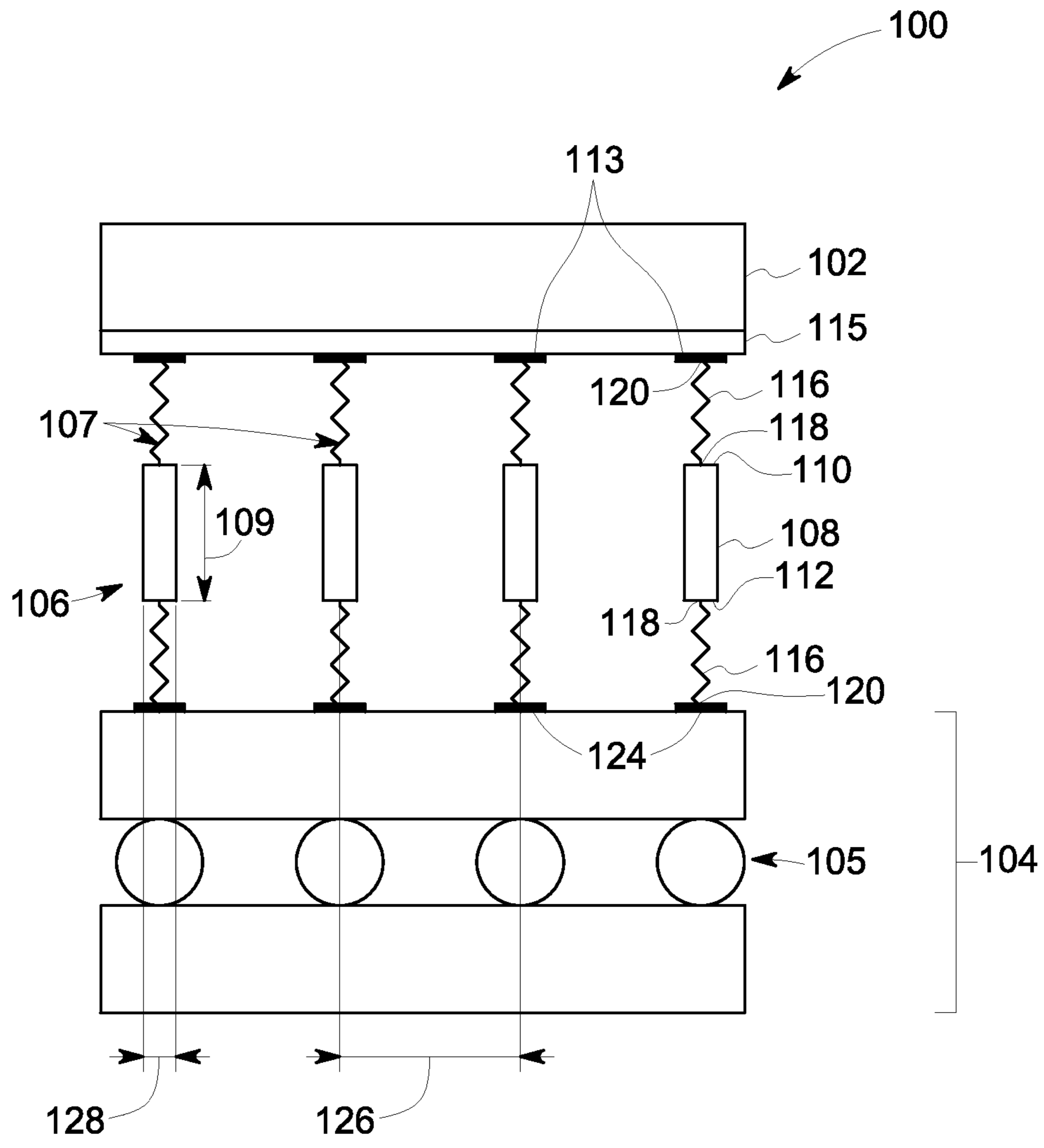


FIG. 1

200

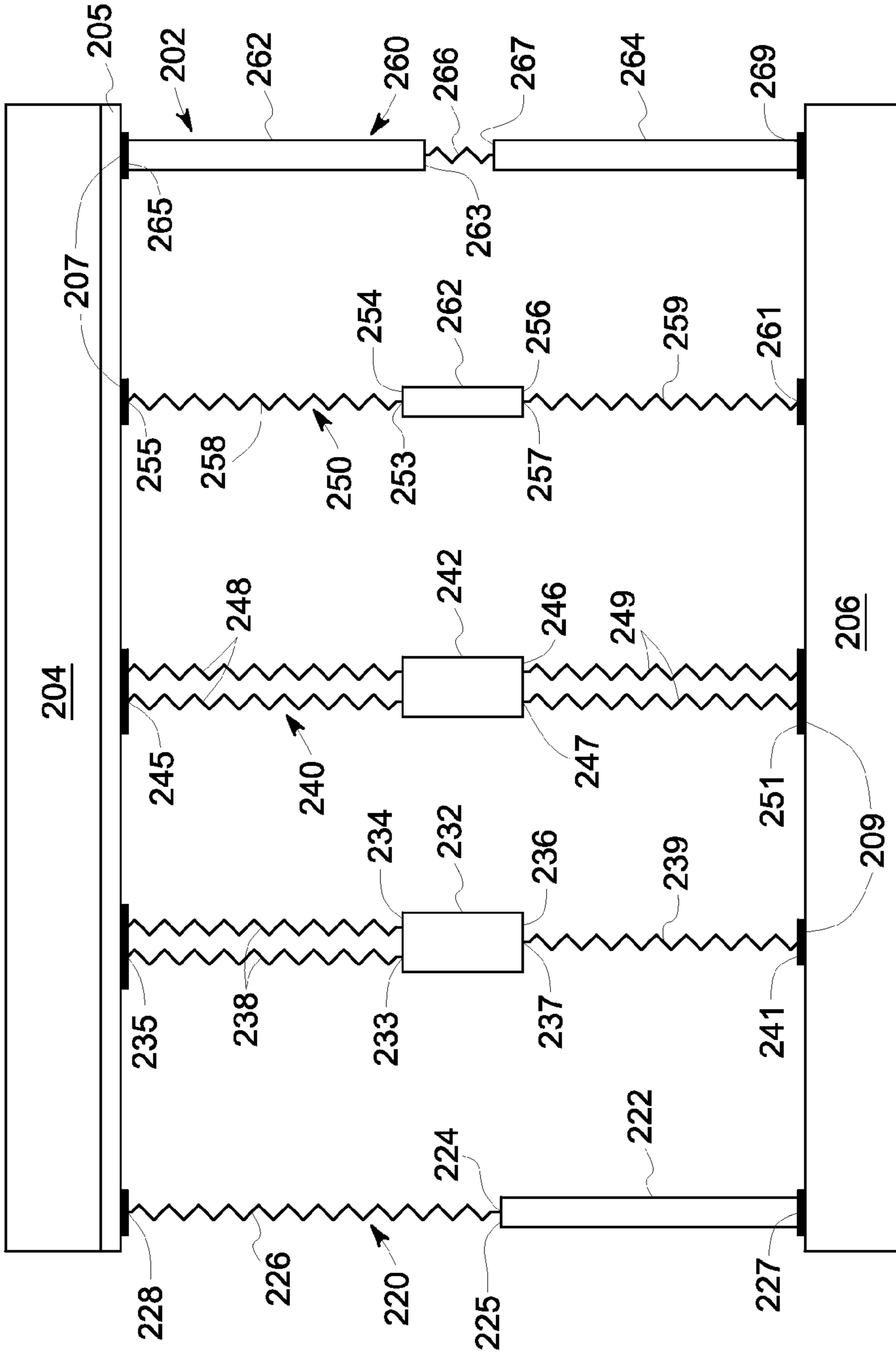


FIG. 2

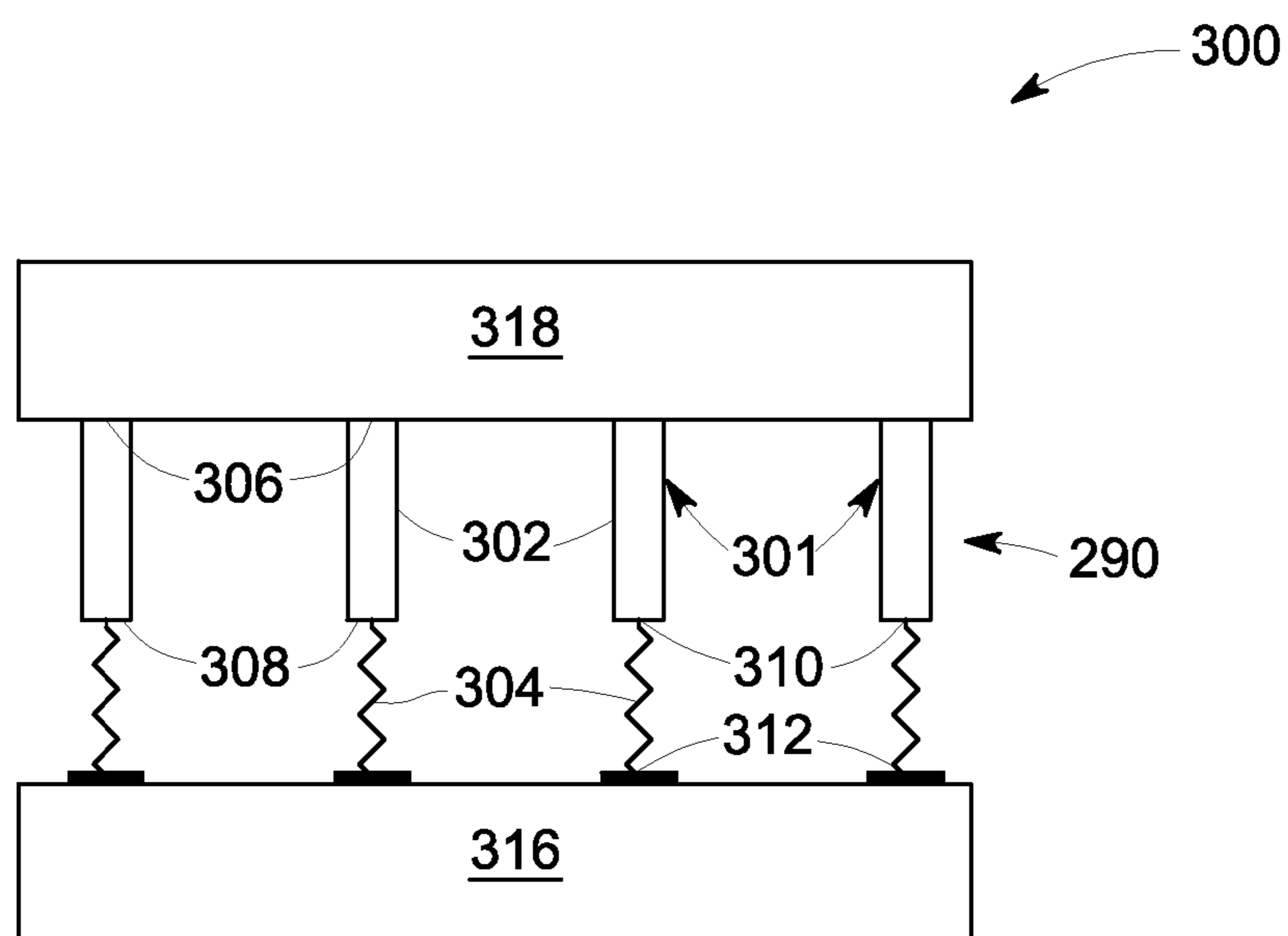


FIG. 3

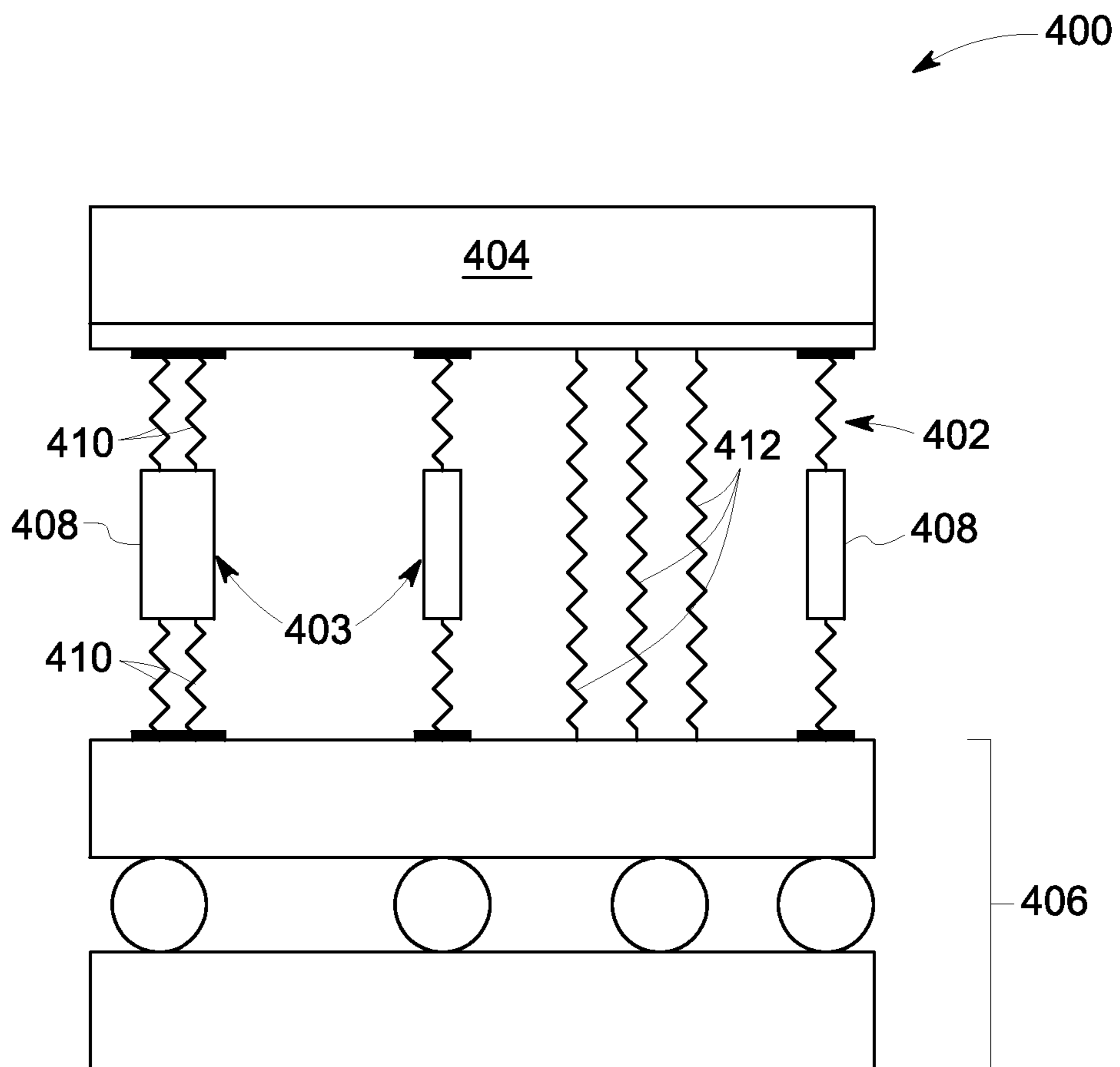


FIG. 4

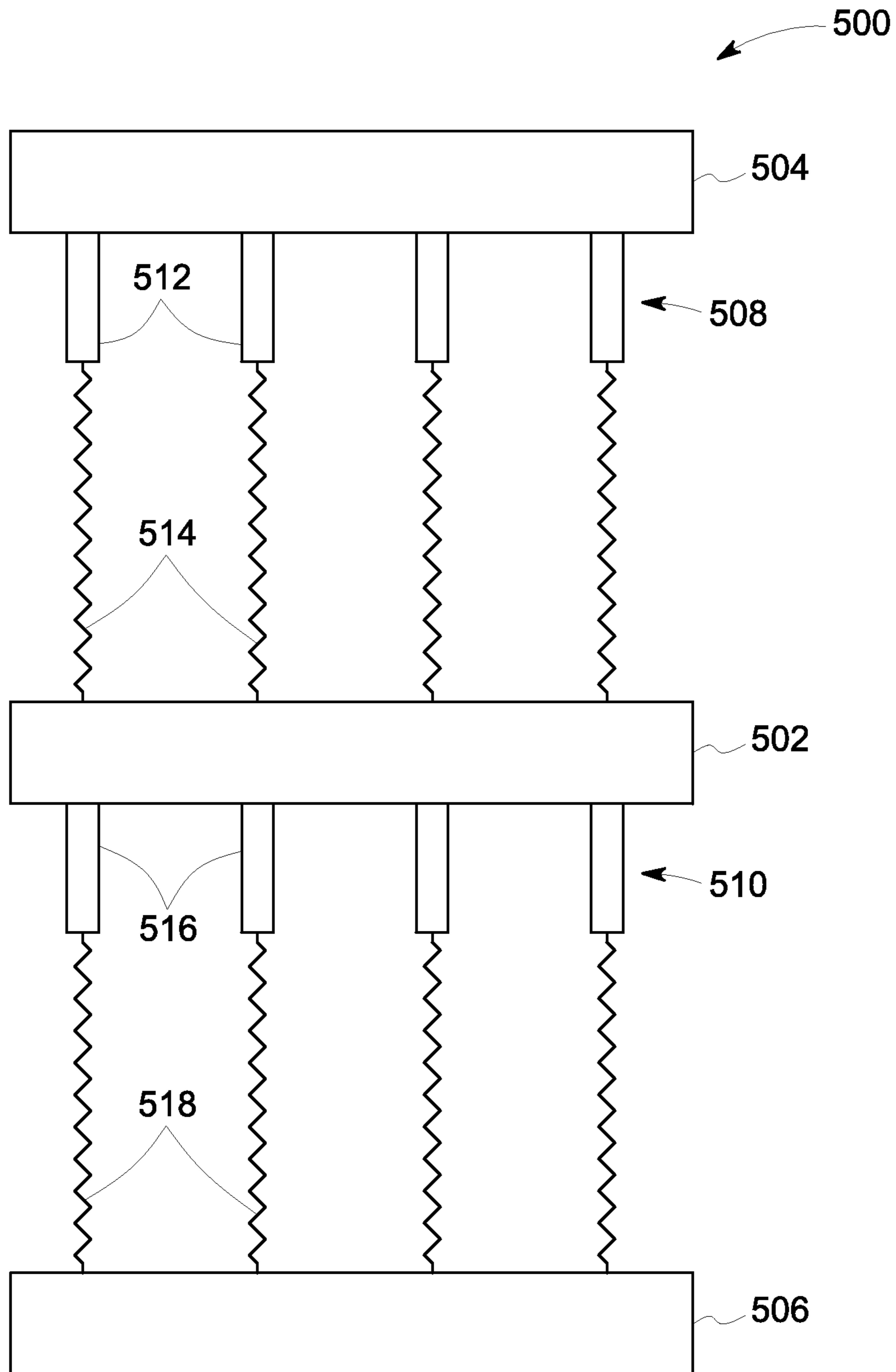


FIG. 5

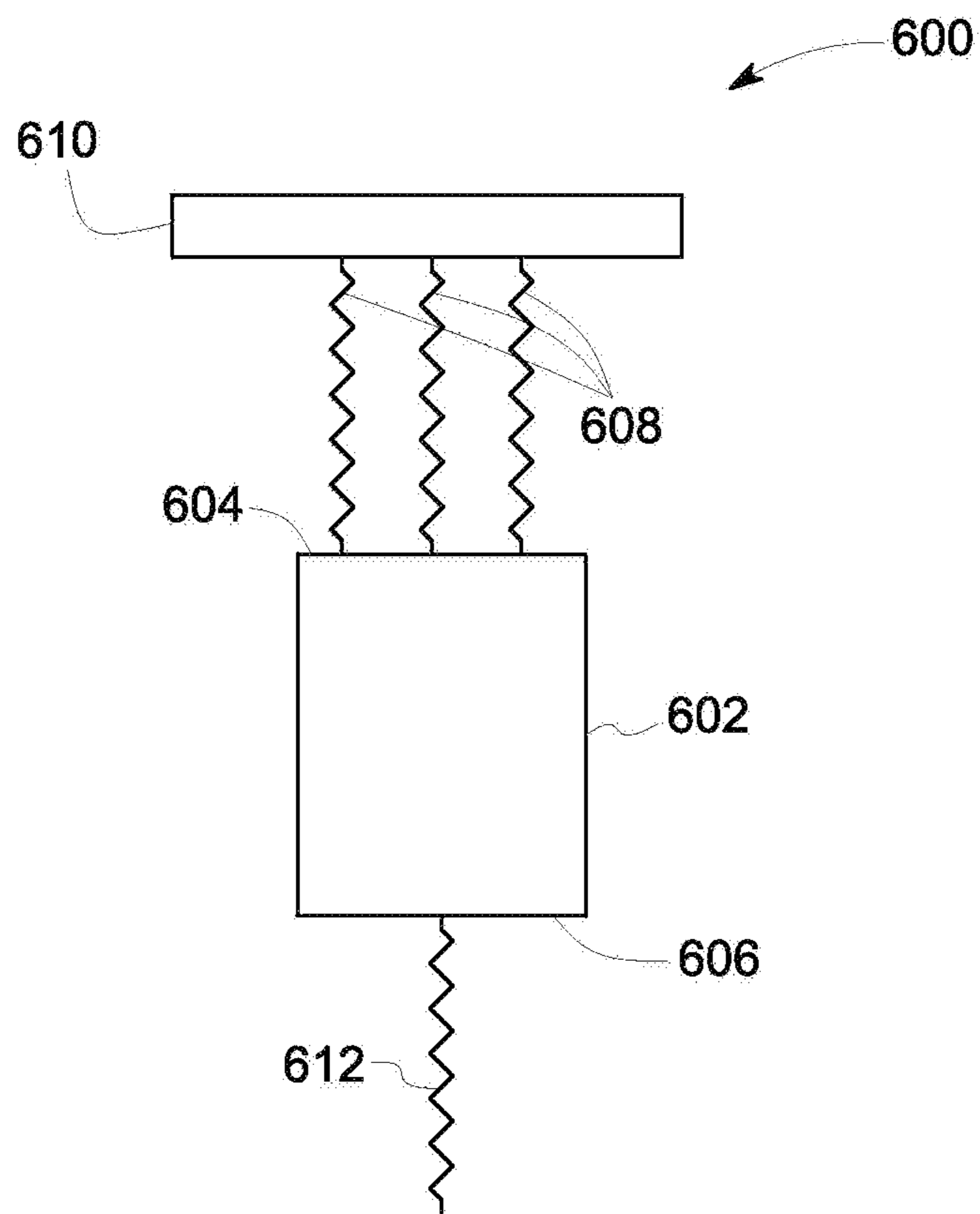


FIG. 6
AMENDED

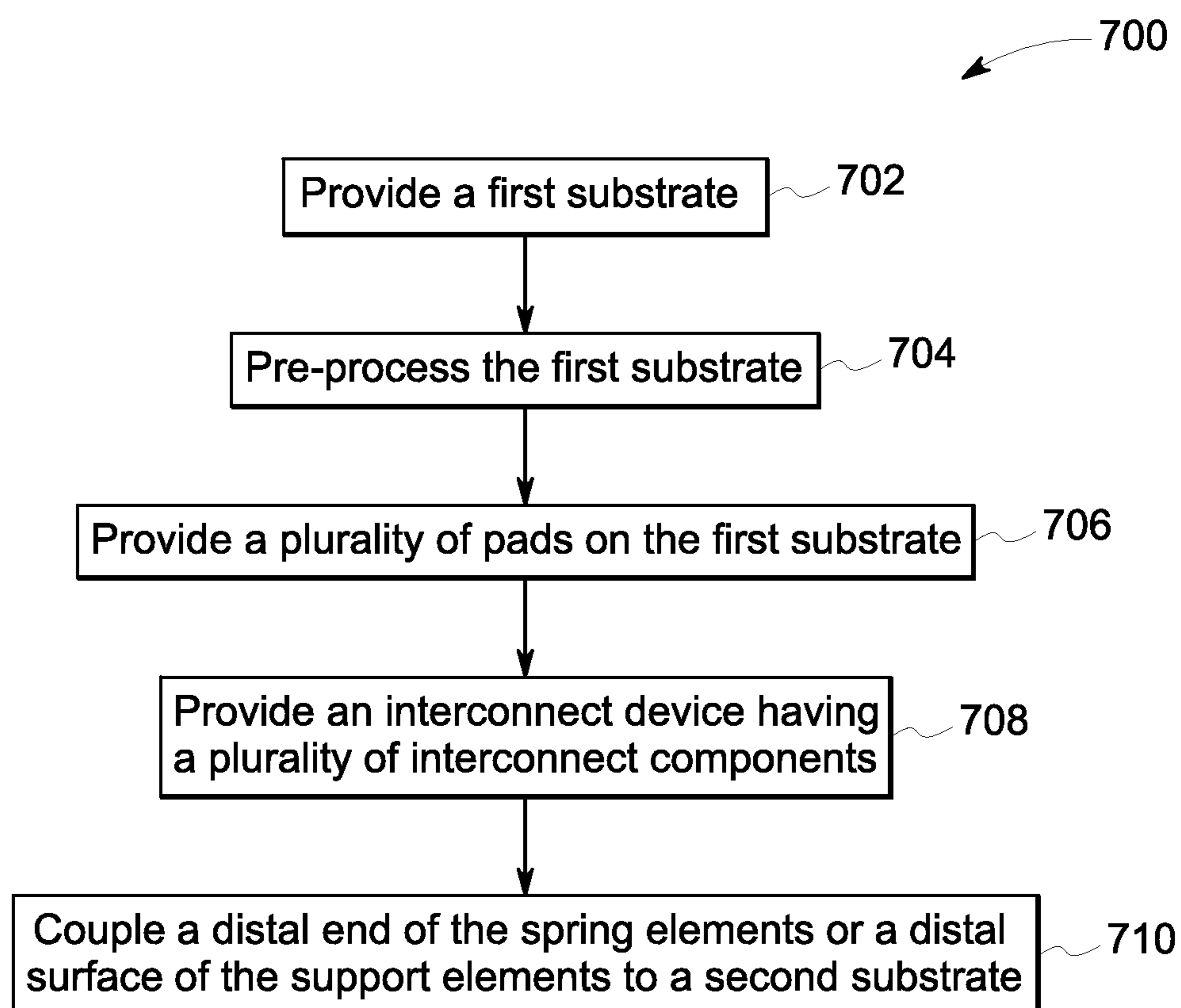


FIG. 7

INTERCONNECT DEVICES FOR ELECTRONIC PACKAGING ASSEMBLIES

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

BACKGROUND

Embodiments of the present specification relate to interconnects, and more particularly to interconnects for semiconductor devices.

Commercially available semiconductor devices employ a variety of different interconnect technologies. For example, leaded semiconductor devices feature lead plates having a series of leads or pins. For connecting the semiconductor devices to a printed circuit board (PCB) the leads are pressed into the PCB and soldered.

Further, flip chip semiconductor devices employ solder bumps and/or copper pillars for connection to an external article such as a semiconductor device or a printed circuit board. As will be appreciated, a semiconductor integrated circuit of a semiconductor device includes a series of pads on one or more surfaces. Typically, solder bumps are formed on the series of pads and subsequently, the integrated circuit is flipped to interface with the external article. With solder bumps interfaced to the external article, the solder bumps are re-melted to form an electrical connection with the external article. In addition, a mounted semiconductor integrated circuit may be subject to under-filling to dispose underfill material between an underside of the semiconductor integrated circuit and the external article. The underfill material may include an electrically insulated adhesive.

BRIEF DESCRIPTION

In accordance with aspects of the present specification, an electronic packaging assembly having a semiconductor integrated circuit and a plurality of interconnect components is provided. The plurality of interconnect components is operatively coupled to the semiconductor integrated circuit. Further, one or more interconnect components include one or more support elements having a first surface and a second surface, and one or more spring elements having a first end and a second end, and wherein first ends of the one or more spring elements are coupled to the first surface or the second surface of a respective support element.

In accordance with another aspect of the present specification, an electronic packaging assembly having a semiconductor device, an interconnect device operatively coupled to the semiconductor device, and an external article operatively coupled to the interconnect device such that a plurality of interconnect components of the interconnect device extend between the semiconductor device and the external article. Further, one or more interconnect components of the plurality of interconnect components include a plurality of support elements, where each support element of the plurality of support elements include a first surface and a second surface. Further, the one or more interconnect components include a plurality of spring elements, where each spring element of the plurality of spring elements include a first end and a second end, and where one or more spring elements

are coupled to the first surface or the second surface of a respective support element at the first end.

In accordance with yet another aspect of the present specification, a method for making an electronic packaging assembly is provided. The method includes providing a semiconductor device having an interface layer, providing an interconnect device having a plurality of interconnect components, and coupling at least a portion of the interconnect device to the interface layer of the semiconductor device. Further, the interconnect device includes a plurality of support elements, where each support element of the plurality of support elements comprises a first surface and a second surface, and a plurality of spring elements. Moreover, each spring element of the plurality of spring elements includes a first end and a second end. Also, one or more spring elements are coupled to the first surface or the second surface of a respective support element at the first end.

DRAWINGS

These and other features, aspects, and advantages of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

FIG. 1 is a schematic representation of an electronic packaging assembly employing an interconnect device having a plurality of interconnect components, in accordance with embodiments of the present specification;

FIG. 2 is a schematic representation of an exemplary electronic packaging assembly employing an interconnect device having a plurality of interconnect components having different structural designs, in accordance with embodiments of the present specification;

FIG. 3 is a schematic representation of an exemplary electronic packaging assembly employing an interconnect device, where the interconnect device includes a plurality of interconnect components having a spring element disposed on a first [surfaces] *surface* of each support element of the plurality of support elements, in accordance with embodiments of the present specification;

FIG. 4 is a schematic representation of an exemplary electronic packaging assembly employing an interconnect device, where the interconnect device includes interconnect components having a plurality of support elements and a plurality of spring elements, and where the interconnect device also includes other spring elements, in accordance with embodiments of the present specification;

FIG. 5 is a schematic representation of an exemplary electronic packaging assembly having a thermo-electric cooler operatively coupled to a laser and a substrate, in accordance with embodiments of the present specification;

FIG. 6 is a schematic representation of an exemplary interconnect component having a support element, a plurality of spring elements and a cap; and

FIG. 7 is an exemplary method for forming an interconnect device, in accordance with embodiments of the present specification.

DETAILED DESCRIPTION

Embodiments of the present specification relate to interconnect devices for electronic packaging assemblies. In some embodiments of the present specification, the interconnect devices may be configured to operatively couple a semiconductor device and an external article. In operation, the interconnect devices may be configured to provide

electrical and/or thermal connection between the semiconductor device and the external article. In certain embodiments, the interconnect devices may be configured to provide connection between two silicon dies, or a silicon die and an organic substrate, or a silicon die and an inorganic substrate.

Further, in some embodiments, the interconnect devices may be configured to facilitate reduced or zero warpage of the semiconductor device and/or the external article. As used herein, the term “warpage” entails physical deforming in a device caused by internal stresses within that device. Non-limiting example of such internal stresses may include thermal stresses and/or mechanical stresses. In one embodiment, the interconnect devices may be configured to tolerate stresses generated in the electronic packaging assembly. Further, the interconnect devices may be configured to at least partly prevent occurrence of warpage in the semiconductor device and/or the external article.

In certain embodiments, the semiconductor device may include a microprocessor, a microprocessor integrated circuit, a semiconductor integrated circuit, a laser, a light emitting diode (LED), or combinations thereof. Further, the semiconductor integrated circuit may include a two-dimensional (2D) packaging configuration or a three-dimensional (3D) packaging configuration. Non-limiting examples of the semiconductor integrated circuits may include a flip chip, a multi-chip module, a 2.5 stacked die package, a 3D stacked die package, or combinations thereof.

It may be noted that typically in an electronic packaging assembly, a reflow process is used to operatively couple a die of the semiconductor device and a die of the external article or any other substrate. Generally, during the reflow process internal stresses may be generated within the electronic packaging assembly. By way of example, these internal stresses may be generated due to thermal mismatch between materials of different components of the electronic packaging assembly. Non-limiting examples of the different components may include dies of the semiconductor device, bumps or ball grid arrays of the integrated circuit, and a die or a substrate of the external article. Electronic packaging assemblies employing conventional interconnects may experience a build-up of internal stresses. For example, the conventional interconnects may not be configured to suitably address a thermal mismatch between materials of the different components of the electronic packaging assemblies. As a result there may be an occurrence of warpage in the resultant electronic packaging assembly during or after the reflow process. Further, if not controlled, the warpage may result in cracks in the electronic packaging assembly. By way of example, the warpage may be caused in the substrate of the semiconductor device interconnect device, the die, the substrate, or combinations thereof.

In certain embodiments, the interconnect device may be configured to compensate for at least a portion of a thermal mismatch between the semiconductor device and the external article during the reflow process. Accordingly, the electronic packaging assembly employing the interconnect device may experience minimal or zero internal stresses, thereby at least in part addressing the warpage issue. In certain embodiments, the interconnect device may be configured to distribute loads attributable to thermal expansion resulting from self-heating of the semiconductor device or the integrated circuit. In some instances, such loads may occur due to the presence of hot spots and/or cold spots in the electronic packaging assembly. As used herein, the term “hot spots” refers to one or more areas of the semiconductor device and/or the external article of the electronic packaging

assembly that have relatively high thermal energy relative to other areas of the semiconductor device and/or the external article. Further, as used herein, the term “cold spots” refers to one or more areas of the semiconductor device and/or the external article of the electronic packaging assembly that have relatively low thermal energy relative to other areas of the semiconductor device and/or the external article. The hot spots and the cold spots inducing circuitries may be present in a variety of integrated circuit applications, such as, but not limited to, microprocessor integrated circuitry for power delivery applications, integrated circuit interface for microcontroller applications, memory applications, or combinations thereof. By way of example, the hot spots may be present in processor cores, and the cold spots may be present in processor cache, for example in microprocessor applications.

In certain embodiments, the interconnect device of the present specification is configured to provide a desirable amount of flexibility to the electronic packaging assembly to minimize or eliminate occurrence of warpage that may otherwise be caused due to the internal stresses in the electronic packaging assembly. Further, the interconnect device may be configured to prevent occurrence of cracks in the electronic packaging assembly by enhancing the flexibility of the electronic packaging assembly.

In some embodiments, the interconnect device may include a plurality of interconnect components. Further, one or more interconnect components may include a combination of one or more support elements and one or more spring elements. In certain embodiments, a support element may have a first surface and a second surface, and the spring elements may have a first end and a second end. Additionally, one or more spring elements may be disposed on the first surface, the second surface, or both the first and second surfaces of the support element. Further, the spring elements may be coupled to the support elements at the first ends, whereas, the second ends also referred to as “distal ends” of the spring elements may be coupled to another support element, the substrate of the semiconductor device, or the external article. As used herein, the term “ends” may be used to refer to at least a portion of an end surface of the spring element, or one or more of a curved, a coiled, or kinked portion adjacent the first or second end of the spring elements. In one embodiment, one or more interface layers may be disposed between the interconnect device and the semiconductor device, and/or the interconnect device and the external article. The interface layers may be configured to facilitate coupling and/or thermal management in the electronic packaging assembly.

In some embodiments, various support elements of an interconnect device may be same or different. In one example, materials, dimensions and/or shape of a support element may be determined based on thermal and electrical requirements of the electronic packaging assembly. Further, in certain embodiments, various spring elements of the interconnect device may be same or different. In one embodiment, the various spring elements may have same or different spring constants. By way of example, the spring constants of the spring elements disposed in and around the hot spots, or the regions with relatively high thermal energy, may be comparatively larger than the spring constants of the spring elements disposed closer to the spots, or the regions with comparatively low thermal energy.

FIG. 1 illustrates an electronic packaging assembly having a semiconductor device 102, an external article 104, and an interconnect device 106. The interconnect device 106 is disposed between the semiconductor device 102 and the

5

external article 104. In the illustrated embodiment, the external article 104 includes a ball grid array 105. Further, in one embodiment, the external article 104 may be a part of an integrated circuit apparatus. Non-limiting examples of the external article 104 may include a printed circuit board, an integrated circuit, such as a flip chip.

In one embodiment, one or more interface layers 115 may be disposed between the interconnect device 106 and the semiconductor device 102, and/or the interconnect device 106 and the external article 104. The one or more interface layers 115 may be configured to facilitate coupling between the interconnect device 106 and the semiconductor device 102 and/or the external article 104. Further, the one or more interface layers 115 may be configured to facilitate thermal and/or electrical conductivity of the interconnect device 106 to the semiconductor device 102, the external article 104, or both. In a non-limiting example, the interface layer 115 may be in the form of a layer that is configured to facilitate coupling, thermal conductivity, electrical conductivity, or combinations thereof between adjacently disposed devices, such as the semiconductor device 102 and the interconnect device 106. In alternative embodiments, the interface layer may be in the form of a plurality of independent portions that are physically disconnected from one another.

Additionally, in some embodiments, the interconnect device 106 includes a plurality of interconnect components 107. In one embodiment, all the plurality of interconnect components 107 may be similar to one another. Alternatively, in another embodiment, one or more interconnect components 107 of the plurality of interconnect components 107 may be different from other interconnect components 107. In one embodiment, a structure of an individual interconnect component 107 may be selected based on thermal energy requirements, mechanical requirements, or the like of a respective location in the electronic packaging assembly where a given interconnect component 107 is being employed. In the illustrated embodiment, the plurality of interconnect components 107 include support elements 108 having a first surface 110 and a second surface 112.

Moreover, the interconnect device 106 includes a plurality of spring elements 116, where each spring element 116 includes a first end 118 and a second end, also referred as a "distal end" 120. Further, the first ends 118 of one or more spring elements 116 may be coupled to the first surface 110 or the second surface 112 of a respective support element 108.

Further, the first surface 110 and/or the second surface 112 of the support elements 108 may include one or more coupling layers (not shown in FIG. 1) to facilitate coupling of the spring elements 116 to the support elements 108, or coupling of the support elements 108 to other surfaces, such as, but not limited to surfaces of the semiconductor device 102, or the external article 104. Alternatively, the first and/or second ends 118 and 120 of the spring elements 116 may include the coupling layers. In one example, the coupling layer of the spring elements 116 may be in the form of a layer or a curved structure, such as a cap. Further, the coupling layer may include aluminum, copper, silver, platinum, silicon, silica, alumina, aluminum nitride, or combinations thereof. In one embodiment, a thickness of the one or more coupling layers may be less than about 1 mm. In another embodiment, the thickness of the one or more coupling layers may be less than about 30 microns.

In certain embodiments, the support elements 108 may include a pillar structure, a tubular structure, a columnar structure, a cylindrical structure, a bump, a cube, a cuboid, or combinations thereof. Further, in one embodiment, a

6

diameter 128 of the support element 108 is about 50% of a pitch of the interconnect device. Furthermore, the diameter 128 of the support element 108 may be in a range from about 10 microns to about 60 microns. In another embodiment, the diameter 128 of the support elements 108 may be in a range from about 20 microns to about 40 microns. In some embodiments, the plurality of support elements 108 and/or the plurality of spring elements 116 may be manufactured to have relatively smaller diameters than bumps that are typically used in conventional interconnect devices. Moreover, the support elements 108 may be made of an electrically and thermally conductive material, such as, but not limited to, aluminum, copper, silver, platinum, or combinations thereof. In a non-limiting example, the one or more interface layers 115 may be made of an electrically and thermally conductive adhesive material, such as silver epoxy adhesive. Further, the one or more interface layers 115 may include an alloy of copper, aluminum, silver, gold, platinum, tungsten, silicon, zinc oxide, silicon nitride, titanium, or any combinations of these materials. In one embodiment, the one or more interface layers 115 may have similar thermal conductivity and bonding characteristics as adjoining structures.

Further, in certain embodiments, the spring elements 116 may include helical springs, nano-springs, kinked structures, or combinations thereof. As used herein, the term "nano-springs" refers to a structure having at least one dimension that measures less than about 10 microns and that has an initial shape that is compliant under an applied load and returns to substantially the initial shape upon removal of the load. As used herein, the term "substantially" is accommodative of up to about 5% deviation in the initial shape of the nano-springs. Further, the term "compliant" refers to the quality of having a reversible deformation in a load-unload cycle. Moreover, "reversible deformation" entails an elastic deformation in the range of about 1% to 1000% of coefficient of thermal expansion (CTE) mismatch of the semiconductor device 102 and external article 104.

In some embodiments, the spring elements 116 may be made of electrically and thermally conductive materials, such as, but not limited to, a metal, a metal alloy, a ceramic, or a composite material. In one embodiment, the spring elements 116 may be made of copper, aluminum, silver, gold, platinum, tungsten, silicon, zinc oxide, silicon nitride, titanium, molybdenum, tantalum, or any combinations of these materials. In one embodiment, one or more spring elements 116 may have a thermal conductivity of greater than about 1 watt/mK. In one embodiment, one or more spring elements 116 may have a thermal conductivity of greater than about 10 watt/mK. In one embodiment, one or more spring elements 116 may have a thermal conductivity of greater than about 100 watt/mK. Further, one or more spring elements 116 may have a thermal conductivity that is different from the thermal conductivity of the other spring elements 116.

In one embodiment, an average diameter of the spring elements 116 may be less than about 2 micrometers. As used herein, the term "diameter" is indicative of the cross-sectional width of the spring elements 116. The "cross sectional width" refers to the largest dimension in a cross section of the spring elements 116 in a direction perpendicular to a length of the spring elements 116 at any given point of the spring elements 116. For example, if a spring element 116 having a given length is of a regular rectangular shape all throughout the length of the spring element 116, the cross sectional width is the diagonal length of the rectangle in a direction perpendicular to the length of the spring element 116. In an example with cylindrical spring

elements 116 of different diameters through the length, the cross sectional width is the largest diameter of the spring elements 116 in a direction perpendicular to the length of the spring elements 116. In a further embodiment, the median spring diameter of the plurality of spring elements 116 is in a range from about 10 nm to about 2 microns. In a specific embodiment, the plurality of spring elements 116 has a median spring cross sectional width in a range from about 100 nm to about 1 microns.

In certain embodiments, the interconnect device 106 may be bonded to the semiconductor device 102 and/or the external article 104 through metallic bonding. In one specific embodiment, the interconnect device 106 is bonded to the semiconductor device 102 and/or the external article 104 through soldering. A variety of low temperature melting and high thermal conductivity materials may be used for soldering. One non-limiting example of such a material is indium and low melting alloys of indium. In one embodiment, the bonding force between the interconnect device 106 and adjacent surface is in a range from about 10 N/cm² to about 400 N/m².

In the illustrated embodiment, each of the interconnect components 107 is coupled to a respective pad 113 of the interface layer 115 of the semiconductor device 102 and a respective pad 124 of the external article 104. In particular, the second or distal ends 120 of the one or more spring elements 116 are coupled to the pads 113 of the semiconductor device 102 or the pads 124 of the external article 104. Further, in some embodiments, a pattern of the pads 113 and 124 may match a pattern of the interconnect components 107. The pads 113 and 124 may be made of thermally conductive material, such as, but not limited to, aluminum, copper, gold, silver, or combinations thereof. Further, the material of the pads 113 and 124 may be selected so as to facilitate coupling of the semiconductor device 102 and/or the external article and the interconnect components 107. In particular, the material of the pads 113 and 124 may be selected to facilitate coupling of the distal ends 120 of the spring elements 116 to the pads 113 and 124.

In certain embodiments, a pitch 126 of the interconnect device 106 may be defined as a gap between two adjacently disposed interconnect components 107. In particular, the pitch 126 may be defined as a gap between center lines of two adjacently disposed support elements 108 of respective interconnect components 107. In one embodiment, the pitch 126 may be in a range from about 20 microns to about 100 microns. In another embodiment, the pitch 126 may be in a range from about 30 microns to about 40 microns. The pitch 126 may be tuned to accommodate internal stresses that may be present in the electronic packaging assembly 100 to at least partially prevent warpage in the electronic packaging assembly 100. As the value of the pitch 126 decreases, that is, as the distance between any two adjacently disposed interconnect components 107 decreases, the thermal conductivity of the interconnect device 106 increases. Further, in some embodiments, the pitch 126 may be decided based on the desirable interconnect density. The interconnect density in turn may be decided based on an amount of flexibility required by the electronic packaging assembly 100. In instances where the system has a higher amount of internal stresses, the pitch 126 may be modified to allow suitable amount of flexibility by the interconnect device 106. In some embodiments, the interconnect components 107 may have uniform pitch. However, in some other embodiments, the value of the pitch 126 may vary for different interconnect components 107. In these embodiments, the pitch 126 may be defined as an average distance between two adjacently

disposed interconnect components 107. Moreover, although not illustrated in FIG. 1, in some embodiments, an underfill material may be disposed between one or more interconnect components 107 to further enhance the mechanical strength of the electronic packaging assembly 100. In certain embodiments, the pitch 126 may be suitable to facilitate the reflow process, and/or allow the underfill material to be disposed between the interconnect components 107 of the interconnect device 106.

In general, as the number of the interconnect components 107 with physical contact with a surface in a particular area increases, the thermal conductivity between the interconnect components 107 and the surface also increases. In one embodiment, the interconnect device 106 may include at least 50 interconnect components 107 in 1 cm² of area. In a further embodiment, the interconnect device 106 may include at least 100 interconnect components 107 in 1 cm² of area.

In certain embodiments, advantageously, the interconnect device [100] 106 is configured to accommodate at least in part stresses attributable to mismatched thermal expansion of the semiconductor device 102 with respect to the external article 104 that may result from self-heating of the semiconductor device 102. In some embodiments, another advantage of the interconnect device 106 of the present specification may include avoiding use of the underfill. As will be appreciated, typically, the underfill may be provided for distribution of loading attributable to the thermal expansion resulting from the self-heating of the semiconductor device 102 may be avoided when the interconnect device [102] 106 is configured to accommodate thermal expansion between the semiconductor device 102 and the external article 104.

Moreover, because use of the underfill may be avoided, material cost of the electronic packaging assembly 100 may be reduced relative to a conventional assembly that uses the underfill. Still further, manufacturing problems associated with providing the underfill may be avoided. In some embodiments, where smaller pitch dimensions may be used for the plurality of support elements 108 and/or the plurality of spring elements 116, processing time required to provide the underfill between the plurality support elements 108 and/or the plurality of spring elements 116. By way of example, the underfill within the plurality of using a vacuum underfill process or jet dispensed underfill processes in excess of thirty minutes or hours have been observed. Still further, as use of the underfill may be avoided in the electronic packaging assembly 100, a spacing distance between the plurality of support elements 108 and/or the plurality of spring elements 116 may be reduced.

FIG. 2 illustrates another embodiment of an electronic packaging assembly of the present specification. In the illustrated embodiment, the electronic packaging assembly 200 includes an interconnect device 202 operatively coupled to a semiconductor device 204 and an external article 206. The semiconductor device 204 includes an interface layer 205 having a plurality of pads 207. In the illustrated embodiment, the interconnect device 202 includes a plurality of interconnect components 220, 230, 240, 250, and 260 each having different structural design. The structural designs of the interconnect components 220, 230, 240, 250, and 260 may be chosen based on thermal management requirements, load requirements, internal stresses, and the like in the electronic packaging assembly. In the illustrated embodiment, each interconnect component includes one or more support elements and one or more spring elements. In particular, the interconnect component 220 includes a sup-

port element **222** having a first surface **225** and a second surface **227**. Further, the interconnect component **220** includes a spring element **226** having a first end **224** and a second end **228**. The first surface **225** of the support element **222** is coupled to the first end **224** of the spring element **226**. Whereas, the second surface **[224]** **227** of the support element **222** is coupled to the external article **206** using pads **209**. Further, the distal end **228** of the spring element **226** is coupled to the semiconductor device **204** via the pads **207**.

Moreover, the interconnect component **230** of the interconnect device **202** includes a support element **232** having a first surface **234** and a second surface **236**. Further, the interconnect component **230** includes two spring elements **238** having first ends **233** and second ends **235**. Moreover, the interconnect component **230** includes a spring element **239** having a first end **237** and a second end **241**. The first ends **233** of the spring elements **238** are disposed on the first surface **234** of the support element **232**, and the second ends **235** are coupled to the pads **207**. Further, the first end **237** of the spring element **239** is disposed on the second surface **236** of the support element **232** and the second end **241** is coupled to the pads **209**. The spring elements **238** and **239** may be same or different in structure, dimensions and/or properties.

Further, the interconnect component **240** of the interconnect device **202** includes a support element **242** having a first surface **244** and a second surface **246**. Further, the interconnect components **240** includes two spring elements **248** having first ends **243** and second ends **245**, and another two spring elements **249** having first ends **247** and *second ends* **251**. The first ends **243** of the spring elements **248** are disposed on the first surface **244** of the support element **242**, and the second ends **245** of the spring elements **248** are coupled to the pads **207**. Further, the first ends **247** of the spring elements **249** are coupled to the second surface **246** of the support element **242**, and the second ends **[251]** **245** of the spring elements **249** are coupled to the pads **209**.

In addition, the interconnect component **250** includes a support element **252** having a first surface **254** and a second surface **256**. Further, the first and second surfaces **254** and **256** are each coupled to spring elements **258** and **259**. The first ends **253** and **257** of the spring elements **258** and **259** are disposed on the first and second surfaces **254** and **256** of the support element **252**. Further, the distal ends **255** and **261** are coupled to the pads **207** and **209**, respectively.

Moreover, the interconnect component **260** includes a support element **262** having a first surface **263** and a second surface **265**. Further, the interconnect component **260** includes another support element **264** having a first surface **267** and a second surface **269**. The first surfaces **263** and **267** of the support elements **262** and **264** are coupled to one another by a spring element **266**. Further, the second surfaces **265** and **269** of the support elements **262** and **264** are coupled to the pads **207** and **209**, respectively.

It may be noted that the structural designs of each of the interconnect components **220**, **230**, **240**, **250**, and **260** may be used in combination with each other in an electronic packaging assembly. For example, a given electronic packaging assembly may employ a combination of the interconnect components **230** and **240**. Alternatively, two or more of a single type of the interconnect components **220**, **230**, **240**, **250**, and **260** may be used in the electronic packaging assembly. For example, a given electronic packaging assembly may have a plurality of interconnect components **230** as an interconnect device. Further, the individual interconnect components **220**, **230**, **240**, **250**, or **260** may be used in combination with conventional interconnect devices. Also,

several other variations of the interconnect components **220**, **230**, **240**, **250**, and **260** may be envisioned. By way of example, in one embodiment, a first surface of a given support element may be coupled to two or more spring elements, whereas, a second surface of the given support element may be coupled to an external article.

FIG. **3** illustrates an example of a variation of the interconnect components **220**, **230**, **240**, **250**, and **260** of FIG. **2**. In the illustrated embodiment, an electronic packaging assembly **300** includes an interconnect device **290** having a plurality of interconnect components **301**. Further, one or more interconnect components **301** of the plurality of interconnect components **301** may include one or more support elements **302** and one or more spring elements **304**. Each support element **302** includes a first surface **306** and a second surface **308**. Further, the spring elements **304** include a first end **310** and a second end **312**. In the illustrated embodiment, the first ends **310** of the spring elements **304** are coupled to the second surface **308** of the support elements **302**. The second or distal ends **312** of the spring elements **304** may be configured to be coupled to an external article **316**. Further, the first surface **306** of the support elements **302** may be configured to be coupled to a semiconductor device **318**. In a non-limiting example, the semiconductor device **318** may be a LED.

FIG. **4** illustrates yet another embodiment of an electronic packaging assembly of the present specification. In the illustrated embodiment, the electronic packaging assembly **400** includes an interconnect device **402** disposed between a semiconductor device **404** and an external article **406** to thermally and electrically connect the semiconductor device **404** and the external article **406**.

As illustrated, the interconnect device **402** includes a plurality of interconnect components **403**. Further one or more interconnect components **403** of the plurality of interconnect components **403** may include one or more support elements **408** and one or more spring elements **410**. Moreover, one or more spring elements **410** may be operatively coupled to a support element **408**. Further, in the illustrated embodiment, the interconnect device **402** may also include other plurality of spring elements **412**. The other spring elements **412** may be disposed as a set as illustrated. Alternatively, the other spring elements **412** may be dispersed intermittently between the support elements **408**. The other spring elements **412** may be configured to provide enhanced tolerance or flexibility to the interconnect device **402**. Alternatively, the bumps, micro-bumps, underfill material may be used in place of or in combination with other spring elements **412**.

FIG. **5** illustrates an alternate embodiment of an electronic packaging assembly of the present application. In the illustrated embodiment, the electronic packaging assembly **500** includes a thermo-electric cooler **502** operatively coupled to a laser **504** and a substrate **506**. In one example, the substrate **506** may be a substrate of an external article, such as a processor. In particular, the thermo-electric cooler **502** is coupled to the laser **504** using an interconnect device **508**. Further, the thermo-electric cooler **502** is coupled to the substrate **506** using another interconnect device **510**. The interconnect devices **508** and **510** may be similar or different based on thermal management and stress management requirements of the electronic packaging assembly **500**. The interconnect device **508** includes a plurality of support elements **512** and a plurality of spring elements **514**. Likewise, the interconnect device **510** includes a plurality of support elements **516** and a plurality of spring elements **518**.

FIG. 6 illustrates an exemplary interconnect component 600 having a support element 602 having a first surface 604 and a second surface 606. Further, the interconnect component 600 includes a plurality of spring elements 608 coupled to the first surface 604 of the support element 602. The plurality of spring elements 608 are coupled together using a coupling layer or a cap 610. The different spring elements 608 may be similar or different. In the illustrated embodiments, the cap 610 is in the form of a layer, however, other shapes of the cap 610 are also envisioned. By way of example, the cap 610 may have curved surfaces. Further, in the illustrated embodiment, the spring elements 608 may be coupled to the cap 610 at different locations, however, in alternative embodiments, the spring elements 608 may converge and couple to a common location on the cap 610. Advantageously, the cap 610 may be configured to act as a protection layer configured to provide mechanical and chemical protection to the spring elements 608. By way of example, the cap 610 may be configured to [provide] prevent undesirable interaction between the materials of the spring elements 608 and adjacent structure, such as a semiconductor device. Additionally, the interconnect component 600 may include a spring element 612 coupled to the second surface 606 of the support element 602. In alternative embodiments, the second surface 606 may include two or more spring elements 612.

FIG. 7 illustrates an exemplary method 700 for making interconnect devices of the present specification. At step 702, the method 700 may commence by providing a suitable first substrate. In one example, the first substrate may be a substrate (e.g., a die) of a semiconductor device. In another embodiment, the first substrate may be a substrate of an external article. Further, the first substrate may be made of silicon, copper, glass, semiconductor materials, or combinations thereof. Optionally, at step 704, the first substrate may be pre-processed to clean one or more surfaces of the substrate. By way of example, the substrate may be pre-processed to remove any dirt or grease from the surfaces of the substrate.

Further, at step 706, a plurality of pads corresponding to a plurality of support elements and/or a plurality of spring elements may be provided on the first substrate. Moreover, at step 708, an interconnect device may be formed on the substrate. In particular, the interconnect device may be formed by: (1) forming one or more spring elements of the plurality of spring elements, or (2) forming one or more support elements of the plurality of support elements on one or more pads of the plurality of pads. In particular, if a spring element is formed first on the pad, next a support element may be formed on a second end of the spring element. Likewise, if first a support element is formed first on the pad next, one or more spring elements may be formed on the support element to form the interconnect device.

Optionally, in instances where the spring elements are formed on the pads, and support elements having the first and second surfaces are formed on the spring elements, another spring element may be formed on other surface of the support element. Similarly, in instances where the support elements are formed on the pads, and spring elements are formed on the support elements, another support element may be formed on other end of the spring element.

In one embodiment, the interconnect device may be formed using a glancing angle deposition (GLAD) process. In certain embodiments, the GLAD process may be used to provide a pattern of support elements and/or spring elements to match a pattern of pads on a surface of the substrate. In

one example, the pattern of the pads may be a pattern of the pads of the semiconductor integrated circuit.

Whether the interconnect device is formed on the substrate of the semiconductor device, the substrate of the integrated circuit, or the substrate of the external article, a positioning of individual interconnects of the plurality of interconnect components may be controlled by controlling a position of nucleation centers of the substrate. Further, a size of the spring element or the support element may depend on a size of a nucleation center. In some embodiments, nucleation centers may be formed by depositing a polystyrene colloid film on a monolayer which comprises domains and depletion areas. Colloid defects may be defined in the depletion areas. The defects can serve as nucleation centers during glancing angle deposition (GLAD).

A cross sectional shape and morphology of the individual components grown using the GLAD process may be controlled by controlling one or more GLAD input controls including oblique angle of deposition and substrate positional control. A cross-sectional shape of a GLAD formed column may be controlled by controlling an angle of incidence by controlling a ratio of a deposition rate to a substrate rotation rate. Further, column morphology may be controlled e.g., to form spring shaped (helical) columns as set forth in various embodiments herein. In other embodiments, columns formed as interconnects can be cylindrical or matchstick in morphology.

Although described primarily with respect to the GLAD process, in some embodiments, the interconnect components may be formed on the substrate or coupled to the substrate using one or more processes other than the GLAD process. Non-limiting example of the one or more processes may include electro deposition, plasma deposition, chemical vapor deposition (CVD), physical vapor deposition (PVD), sol-gel, micromachining, laser ablation, rapid prototyping, sputtering, or any combination of these processes. In one of these embodiments, the plurality of interconnect components may be disposed using the CVD deposition.

Further, at step 710, one or more interconnect components may be coupled to the first substrate and/or the second substrate. In one example, a distal end (e.g., the second end) of the spring elements or a distal surface (e.g., the second surface) of the support elements may be coupled to a second substrate. In one example, the first substrate may be a substrate of a semiconductor device, an integrated circuit, an external article, or combinations thereof. In the same or different example, the second substrate may be a substrate of a semiconductor device, an integrated circuit, an external article, or combinations thereof. In a non-limiting example, the first substrate may be a substrate of the integrated circuit, where the integrated circuit is coupled to the semiconductor device, further, the second substrate may be a substrate of the external article. In one embodiment, the interconnect components may be coupled to the first and/or second substrates using thermal pressure bonding, soldering, or combinations thereof.

Advantageously, the interconnect device may be configured to provide flexibility to the electronic assembly during the reflow flow process. Further, while the support elements are configured to provide rigidity and structure to the interconnect device and the electronic packaging assembly, the spring elements are configured to provide flexibility and tolerance to the interconnect device.

While only certain features of the disclosure have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore,

13

to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the disclosure.

The invention claimed is:

1. An electronic packaging assembly, comprising:
 - a semiconductor [integrated circuit] device;
 - a plurality of interconnect components operatively coupled to the semiconductor [integrated circuit] device, wherein one or more interconnect components comprise:
 - at least one support element having a first surface and a second surface; and
 - [a] first and [a] second nano-spring elements each having a first end and a second end, and wherein [first ends of the first and the second nano-spring elements are coupled to the first surface and] *the first end of the first nano-spring element is coupled to the first surface of one support element and the first end of the second nano-spring element is coupled to the second surface of [a same] the one support element* and, wherein said nano-spring elements are less than 10 microns in one dimension;
 - wherein the at least one support element comprises a pillar structure, a bump structure, a tubular structure, a columnar structure, or combinations thereof.*
2. The electronic packaging assembly of claim 1, wherein the at least one support [elements] element and the first and second nano-spring elements are made of electrically and thermally conductive materials.
3. The electronic packaging assembly of claim 1, further comprising a coupling layer disposed on *at least one of* the first surface and[,] the second surface of the *one* support element, wherein the coupling layer is configured to couple the first surface or the second surface of the *one* support element to the first end of the *first* nano-spring [spring] element *or the first end of the second nano-spring element.*
4. The electronic packaging assembly of claim 1, wherein the second [end] ends of the first and the second nano-spring elements [comprises] *comprise* a cap.
5. The electronic packaging assembly of claim 1, wherein the support element comprise a pillar structure, a bump structure, a tubular structure, a columnar structure, or combinations thereof.]
6. The electronic packaging assembly of claim 1, wherein [two] *one* or more [spring] *additional nano-spring* elements [nano-spring] are coupled to the first surface or the second surface of a respective support element.
7. The electronic packaging assembly of claim 1, wherein the first and second nano-spring elements comprise an average diameter of equal to or less than about 550 nm.
8. The electronic packaging assembly of claim 1, wherein the semiconductor [integrated circuit] device comprises a light emitting diode, a laser, or both.
9. The electronic packaging assembly of claim 1, wherein *the at least one support element comprises a cylindrical element having a [diamater of the support element] diameter that is about 50% of a pitch of the plurality of interconnect [device] components.*
10. An electronic packaging assembly, comprising:
 - a semiconductor device;
 - an interconnect device operatively coupled to the semiconductor device, wherein the interconnect device comprises a plurality of interconnect components, wherein [one] *two* or more *of the plurality of* interconnect components [comprise] *each comprises*:
 - [a plurality of support elements] *at least one support element*, wherein each support element of the [plu-

14

rality of support elements] *at least one support element* comprises a first surface and a second surface; *and*

- a plurality of nano-spring elements, wherein each nano-spring element of the plurality of nano-spring elements comprises a first end and a second end, and wherein a first [and a second] *nano-spring element of the plurality of nano-spring elements [are] is* coupled to the first surface [and] *of one support element, and wherein a second nano-spring element of the plurality of nano-spring elements is coupled to the second surface of the one support element; and*
- an external article operatively coupled to the interconnect device such that the plurality of interconnect components of the interconnect device extend between the semiconductor device and the external article;
 - wherein the at least one support element of a respective interconnect component of the two or more of the plurality of interconnect components is separate from the at least one support element of another respective interconnect component of the two or more of the plurality of interconnect components.*
11. The electronic packaging assembly of claim 10, [further comprising] *wherein the semiconductor device comprises* an integrated interconnect circuit, wherein the integrated interconnect circuit comprises a flip chip, a ball grid array, a multi chip module, a stacked die, or combinations thereof.
12. The electronic packaging assembly of claim 11, wherein the stacked die comprises vertically stacked die.
13. The electronic packaging assembly of claim 10, wherein the semiconductor device comprises a microprocessor, a microprocessor integrated circuit, a semiconductor integrated circuit, a laser, a light emitting diode, or combinations thereof.
14. The electronic packaging assembly of claim 13, further comprising an integrated interconnect circuit, wherein the integrated interconnect circuit is disposed between the interconnect device and the semiconductor device, or the interconnect device and the external article, or both.
15. The electronic packaging assembly of claim 10, wherein the interconnect device further comprises other spring elements, bumps, micro-bumps, underfill material, or combinations thereof.
16. The electronic packaging assembly of claim 10, wherein the interconnect device further comprises a coupling layer disposed on the second [end] ends of the first and second nano-spring elements.
17. *An electronic packaging assembly comprising:*
 - a semiconductor device;*
 - an external article;*
 - a plurality of interconnect components disposed between the semiconductor device and the external article, wherein two or more of the plurality of interconnect components each comprises:*
 - at least one support element; and*
 - at least one spring element coupled to the at least one support element; and*
 - at least one interface layer disposed between the plurality of interconnect components and the semiconductor device;*
 - wherein the at least one support element of a respective interconnect component of the two or more of the plurality of interconnect components is separate from the at least one support element of another respective*

15

interconnect component of the two or more of the plurality of interconnect components.

18. *The electronic packaging assembly of claim 17 wherein each of the plurality of interconnect components are coupled to a respective pad of the at least one interface layer.*

19. *The electronic packaging assembly of claim 17 further comprising at least another interface layer disposed between the plurality of interconnect components and the external article.*

20. *The electronic packaging assembly of claim 17 wherein the at least one interface layer is configured to facilitate coupling, thermal conductivity, electrical conductivity, or combinations thereof between the plurality of interconnect components and the semiconductor device.*

21. *The electronic packaging assembly of claim 17 wherein the at least one interface layer comprises an electrically and thermally conductive adhesive material.*

22. *An electronic packaging assembly comprising:*

a light emitting device;

a first interconnect device comprising a first plurality of interconnect components, at least one of the first plurality of interconnect components comprising:

a support element having a first surface coupled to the light emitting device so as to be in direct contact therewith; and

16

at least one spring element having a first end coupled to a second surface of the support element; and a substrate coupled to a second end of the at least one spring element.

23. *The electronic packaging assembly of claim 22 wherein the light emitting device comprises a light emitting diode.*

24. *The electronic packaging assembly of claim 22 wherein the light emitting device comprises a laser.*

25. *The electronic packaging assembly of claim 22 further comprising:*

a thermo-electric cooler; and

a second interconnect device comprising a second plurality of interconnect components;

wherein the substrate is coupled to the second end of the at least one spring element by way of the thermo-electric cooler and the second interconnect device.

26. *The electronic packaging assembly of claim 25 wherein the second plurality of interconnect components comprise a plurality of support elements coupled to the thermo-electric cooler and a plurality of spring elements coupling the plurality of support elements to the substrate.*

* * * * *