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(71) Applicant (for all designated States except US): VEECO
INSTRUMENTS INC. [US/US]; Terminal Drive, Plain-
view, NY 11803 (US).

(72) Inventor; and

(75) Inventor/Applicant (for US only): PRIDDY, Scott, W.
[US/US]; 9101 22nd Street West, St. Louis Park, MN
55426 (US).

(74) Agents: HUBBARD, Kevin, J. et al.; Kagan Binder,
PLLC, Suite 200, Maple Island Building, 221 Main Street
North, Stillwater, MN 55082 (US).

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(54) Title: ELECTRICAL CONTACTS FOR USE WITH VACUUM DEPOSITION SOURCES

(57) Abstract: The present invention provides electrical contact assemblies
can be used with vacuum deposition sources. In one exemplary application,
the electrical contact assemblies of the present invention provide electrical
contact to an arcuate or otherwise curved surface of a heating device used
with a vacuum deposition source.

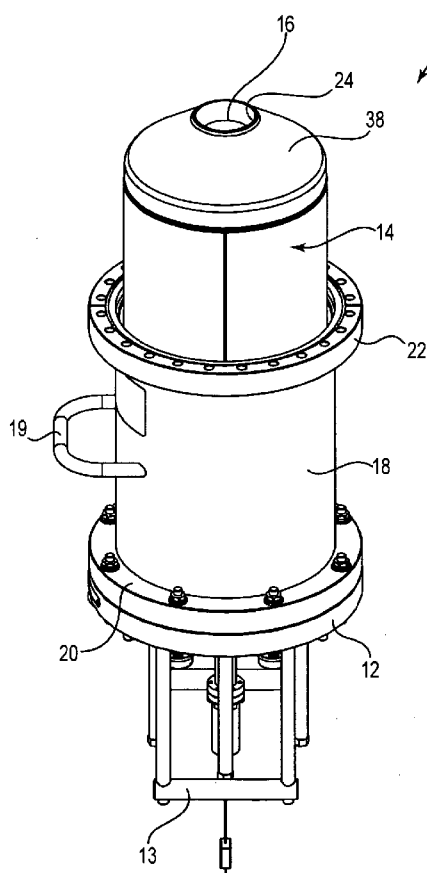


Fig. 1



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ELECTRICAL CONTACTS FOR USE WITH VACUUM DEPOSITION SOURCES

Cross Reference to Related Applications

5 This application claims the benefit of U.S. Provisional Application Serial
No. 61/188,671 filed August 11, 2008 entitled HIGH TEMPERATURE
DEPOSITION SOURCES AND METHODS, which is hereby incorporated by
reference in its entirety for all purposes.

Technical Field

10 The present invention is directed to vacuum equipment. In particular, the
present invention is directed to electrical contacts used for providing power to
heaters used in vacuum deposition equipment.

Background

15 A typical vacuum deposition source includes a mounting flange, crucible for
holding deposition material, and a heating device. Both the crucible and the heating
device are typically structurally supported relative to the mounting flange, which is
secured to a similar flange of a vacuum chamber to position the crucible of the
heating device within a desired vacuum environment. The vacuum chamber
typically includes a substrate to receive deposition material from the deposition
source, during use.

20 One commonly used heating device comprises a metal wire that is supported
relative to the mounting flange in a configuration that at least partially surrounds a
desired portion of the crucible. Often, a serpentine pattern is used. In use, the metal
wire is heated resistively in the vacuum chamber and radiated heat from the hot wire
causes deposition material provided within the crucible to form a vapor that is
25 directed to a substrate to form a thin film of the deposition material on a surface of a
substrate.

30 In order to resistively heat the metal wire, electrical current needs to be
provided from the ambient environment, through the mounting flange, and through
the metal wire. Typically, a vacuum feed-through device is used and typically
includes a conductive rod surrounded by an insulating material that is sealed to a
suitable vacuum flange that can be attached to the mounting flange. Such feed-
through devices are well-known for passing electric current from the ambient

environment outside a vacuum chamber to the vacuum environment inside the vacuum chamber.

On the vacuum side of the mounting flange, an electrical connection between the metal wire of the heating device and the conductive rod of the feed-through device needs to be made. Typically, such connection is made using conventional fasteners and connectors such as those that function by clamping the wire to the conductive post. The connection needs to remain secure during the range of temperatures that the vacuum deposition source experiences.

Alternative heating devices that can be used for vacuum deposition sources include those available from Momenitive Performance Materials of Strongville, Ohio. These heating devices comprise layers of pyrolytic boron nitride and pyrolytic graphite wherein the pyrolytic graphite functions as the resistive element and is sandwiched between layers of pyrolytic boron nitride. Typically, a region of the graphite resistive element is exposed and functions as the electrical contact.

Such layered heating devices are available in various configurations including flat plates as well as cylindrical or otherwise tubular structures. In such cylindrical configurations, the electrical contacts to the resistive element comprise an arcuate surface in one configuration. In another configuration the electrical contact surface can be transitioned to a flat surface. Generally, transitioning an arcuate surface to a flat surface makes the heating device more complex and often increases cost. Moreover, transitioning an arcuate surface to a flat surface can add undesirable stress to the region of the electrical contact. Such stresses may cause undesirable cracking or delamination of the layered structure. Accordingly, for cylindrical heating devices, arcuate contacts are preferred. When used in a vacuum deposition source, the arcuate electrical contact needs to be connected to a suitable electrical feed-through device.

Summary

The present invention provides electrical contact assemblies that can be used to make electrical contact with an arcuate, cylindrical or otherwise curved surface of an electrical contact such as an electrical contact of a heating device for a vacuum deposition source, for example. In an exemplary embodiment, electrical contact is made to such curved contact surface using one or more of a pressure pin and

conformal conductive washer that is loaded against the curved contact surface with one or more pyrolytic boron nitride springs. One or more loading pins are preferably used to apply pressure to the pyrolytic boron nitride spring, which applies pressure to the conductive washer that is in contact with the curved contact surface.

5 In an exemplary embodiment, a rotational engagement element, such as a cylinder with a flat engagement surface is used. Advantageously, electrical contact assemblies of the present invention function by use of uniform pressure and require minimal use of fasteners.

10 In an exemplary aspect of the present invention, a vacuum deposition source is provided. The vacuum deposition source preferably comprises: a base flange configured to mount the vacuum deposition source to a vacuum chamber, the base flange comprising an electrical power feed-through; a crucible operatively supported relative to the base flange and configured to hold vacuum deposition material, the crucible comprising a body portion and an effusion orifice; a heater operatively
15 supported relative to the base flange and at least partially surrounding the crucible, the heater comprising a cylindrical electrical contact surface; and an electrical contact assembly comprising a power strap electrically connected to the electrical power feed-through at a first end of the power strap, electrically connected to the electrical contact surface of the heater at a second end of the power strap, and
20 comprising a pyrolytic boron nitride spring applying pressure to the second end of the power strap.

In another exemplary aspect of the present invention, a vacuum deposition source is provided. The vacuum deposition source preferably comprises: a base flange configured to mount the vacuum deposition source to a vacuum chamber, the
25 base flange comprising an electrical power feed-through; a crucible operatively supported relative to the base flange and configured to hold vacuum deposition material, the crucible comprising a body portion and an effusion orifice; a heater operatively supported relative to the base flange and at least partially surrounding the crucible, the heater comprising a cylindrical body portion configured and
30 positioned to provide thermal radiation to at least a portion of the crucible, the heater comprising a layered structure comprising a cylindrical pyrolytic graphite electrically resistive layer positioned between cylindrical pyrolytic boron nitride

electrically insulative layers and having an electrical contact comprising an exposed surface region of the graphite electrically resistive layer; an electrical contact assembly comprising a power strap electrically connected to the electrical power feed-through at a first end of the power strap, electrically connected to the electrical contact of the heater at a second end of the power strap, and comprising a pyrolytic boron nitride spring applying pressure to the second end of the power strap.

In yet another exemplary aspect of the present invention, an electrical contact assembly for providing an electrical connection to an electrical contact comprising a cylindrical contact surface is provided. The electrical contact assembly comprises a conductive washer in contact with the cylindrical electrical contact surface, a power strap positioned between a contact washer and the conductive washer, a pressure pin in contact with the contact washer, a first surface of a pyrolytic boron nitride spring in contact with the pressure pin, and at least one loading pin in contact with a second surface of the pyrolytic boron nitride spring thereby providing a compressive load on the conductive washer.

Brief Description of the Drawings

The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate several aspects of the present invention and together with description of the exemplary embodiments serve to explain the principles of the present invention. A brief description of the drawings is as follows:

Figure 1 is a perspective view of an exemplary deposition source in accordance with the present invention and showing in particular a conical heat shield assembly comprising a conical cover.

Figure 2 is a cross-sectional view of the deposition source shown in Figure 1 and showing in particular an exemplary liquid cooling enclosure in accordance with the present invention.

Figure 3 is a partial exploded view of the deposition source shown in Figure 1 and showing in particular an exemplary removable crucible support assembly in accordance with the present invention.

Figure 4 is a perspective view of the removable crucible support assembly shown in Figure 3 in accordance with the present invention.

Figure 5 is a partial exploded view of the deposition source shown in Figure 1 and showing in particular an exemplary heater support assembly with an exemplary heater and an exemplary tubular heat shield assembly in accordance with the present invention.

5 Figure 6 is a partial exploded view of the heater support assembly and heater shown in Figure 5 in accordance with the present invention.

Figure 7 is an exploded view of the tubular heat shield assembly shown in Figure 5 in accordance with the present invention.

10 Figure 8 is an exploded view of the liquid cooling enclosure shown in Figure 2 in accordance with the present invention.

Figure 9 is a partial cross-sectional view of the deposition source shown in Figure 1 in accordance with the present invention.

Figure 10 is a partial cross-sectional perspective view of the deposition source shown in Figure 1 in accordance with the present invention.

15 Figure 11 is an exploded view of the conical heat shield assembly shown in Figure 1 and showing in particular plural layers of conical heat shielding and the conical cover in accordance with the present invention.

20 Figure 12 is a partial side view of the deposition source shown in Figure 1 and showing in particular exemplary electrical contacts in accordance with the present invention.

Figure 13 is a partial exploded view of the deposition source shown in Figure 1 and further showing electrical contacts in accordance with the present invention.

Figure 14 is a partial exploded view of the deposition source shown in Figure 1 and further showing electrical contacts in accordance with the present invention.

25 Figure 15 is a partial cross-sectional perspective view of the deposition source shown in Figure 1 and further showing electrical contacts in accordance with the present invention.

30 Figure 16 is a partial cross-sectional perspective view of the deposition source shown in Figure 1 and further showing electrical contacts in accordance with the present invention.

Figure 17 is a partial top down cross-sectional view of the deposition source shown in Figure 1 and further showing electrical contacts in accordance with the present invention.

5 Figure 18 is a partial perspective view of another exemplary deposition source in accordance with the present invention and showing in particular electrical contacts in accordance with another exemplary embodiment of the present invention.

Figure 19 is a partial cross-sectional perspective view of the deposition source shown in Figure 18.

10 Figure 20 is a schematic top down cross-sectional view of another exemplary deposition source in accordance with the present invention and showing in particular electrical contacts in accordance with another exemplary embodiment of the present invention.

Detailed Description

15 The exemplary embodiments of the present invention described herein are not intended to be exhaustive or to limit the present invention to the precise forms disclosed in the following detailed description. Rather the exemplary embodiments described herein are chosen and described so those skilled in the art can appreciate and understand the principles and practices of the present invention. Structural aspects of the present invention that are illustrated and described are exemplary and
20 alternative structures that provide the desired functionality will be apparent to those of skill in the art and can be used in accordance with the present invention.

An exemplary vacuum deposition source 10 in accordance with the present invention is illustrated in Figures 1 through 17. In an exemplary application vacuum deposition source 10 is used to provide efficient deposition of copper, indium, and
25 gallium for forming CIGS based photovoltaic devices such as those used in solar cells. In such application, one or more deposition sources 10 of the present invention are used with one or more selenium deposition sources in a vacuum deposition system (not shown) for deposition of such CIGS based materials. Preferably, when deposition sources in accordance with the present invention are
30 used in a selenium environment materials used for construction of such deposition sources are selected accordingly. In particular, materials that are known to corrode

when in the presence of selenium and high temperatures are preferably avoided when possible.

Deposition sources in accordance with the present invention are particularly useful in harsh vacuum environments such as those where corrosive materials such as selenium are used. It is contemplated, however, that deposition sources in accordance with the present invention can be used for deposition of any desired material in any desired vacuum environment including but not limited to metals, ceramics, semiconductors, and elemental materials, for example. Vacuum deposition sources in accordance with the present invention are also particularly useful in vacuum environments having a background pressure less than about 1 millitorr. Vacuum deposition sources in accordance with the present invention can also be used in vacuum environments having a background pressure in the high vacuum and ultrahigh vacuum regime such as those used in conventional thermal evaporation and molecular beam epitaxy, for example. When deposition sources in accordance with the present invention are used in an environment free from corrosive materials such as selenium, materials used for construction of such deposition sources are preferably selected in view of a particular operating environment in which a deposition source is to be used. When appropriate, conventional materials for construction of vacuum equipment are preferably used such as stainless steel, refractory metals, and pyrolytic boron nitride, for example.

Deposition sources in accordance with the present invention can be used for deposition on any desired substrates such as glass, semiconductor materials, and/or plastic materials, for example.

Referring initially to Figure 1 exemplary vacuum deposition source 10 in accordance with the present invention is illustrated. Vacuum deposition source 10 includes base flange 12, deposition source body 14, and effusion orifice 16. Base flange 12 supports deposition body 14 and functions to attach deposition source 10 to a vacuum deposition system (not shown). Base flange 12 also preferably includes optional handles 13 as shown in the exemplary illustrated embodiment. As is common with vacuum deposition equipment, base flange 12 preferably comprises stainless steel.

As illustrated, deposition source 10 includes optional nipple 18 having flange 20 attached to base flange 12. Nipple 18 also include optional handle 19 as shown in the exemplary illustrated embodiment. Nipple 18 is typically used to adapt deposition source 10 to a particular vacuum deposition system (not shown). When
5 nipple 18 is used, vacuum deposition source 10 is attached to a vacuum deposition system (not shown) with flange 22 of nipple 18. Stainless steel construction is preferably used for nipple 18.

Referring to Figure 2 generally, exemplary deposition source 10 preferably includes crucible 24, crucible support assembly 26, heater 28, heater support
10 assembly 30, tubular heat shield assembly 32, liquid cooling enclosure 34, conical heat shield assembly 36, and conical cover 38.

Crucible 24 is removably and adjustably positioned relative to base flange 12 with crucible support assembly 26, which can be seen in more detail in Figures 3 and 4. Advantageously, crucible support assembly 26 allows crucible 24 to be
15 removed from deposition source 10 through base flange 12 of deposition source 10. This rear loading capability allows for easier reloading of deposition material into crucible 24 because deposition source 10 does not need to be completely removed from the vacuum deposition system (not shown) as is needed for top loading deposition sources. Moreover, the rear loading design of deposition source 10 of the
20 present invention allows greater flexibility in designing the effusion end of a deposition source because the crucible does not need to be removed from the effusion end of the deposition source and can be removed from the opposite end.

Crucible 24 preferably comprises a monolithic restricted-orifice vessel capable of holding a desired deposition material. As can be seen in Figures 2 and 3
25 crucible 24 comprises spherical end 25, cylindrical body portion 27, first conical portion 29, and second conical portion 31. An exemplary preferred crucible material is pyrolytic boron nitride, however, other materials can be used for crucible 24 as would be apparent to those of skill in the art. Pyrolytic boron nitride is a preferred material for vacuum deposition crucibles as well as for components used for vacuum
30 deposition equipment. Pyrolytic boron nitride is generally inert, can withstand high temperatures, is generally clean and does not contribute undesirable impurities to the

vacuum environment, is generally transparent to certain wavelengths of infrared radiation, and can be fabricated into complex shapes, for example.

Crucible material is preferably selected based on parameters such as material compatibility, operating temperature, thermal conductivity, and electrical conductivity, for example. Alternatives crucible materials that can be used include graphite, ceramics, and refractory metals, for example. Crucible 24 does not need to be monolithic and does not need to utilize the restricted-orifice design of exemplary crucibles 24. Crucible material and geometry is preferably selected based on factors such as the deposition material to be used in the environment in which the crucible will be located. Exemplary crucibles are described in US Patent 5,820,681, US Patent 5,827,371, and US Patent 5,932,294, the entire disclosures of which are incorporated by reference herein for all purposes. Crucibles that can be used with deposition sources in accordance with the present invention are available from Veeco Instruments, Inc. of St. Paul, Minnesota and Momenive Performance Materials of Strongsville, Ohio.

Referring to the perspective view of Figures 3 and 4 and the cross-sectional view of Figure 2 crucible support assembly 26 includes support flange 40 that removably and sealingly mates to base flange 12 of deposition source 10. Support flange 40 preferably comprises stainless steel as is conventionally used for vacuum equipment. Preferably, as can be seen in Figure 2 an o-ring seal 42 is used between support flange 40 and base flange 12. O-ring seals are preferred over metal gaskets when used in certain corrosive environments such as in the presence of selenium vapor, for example. Alternatively, depending on the application, a Conflat® style seal can be used, for example, which seal comprises flanges having knife-edges that embed into a soft metal seal gasket such as a copper or nickel gasket or the like. Appropriate sealing techniques for various vacuum applications are well known to those skilled in the art of vacuum equipment.

Further referring to Figures 2, 3, and 4, crucible support assembly 26 includes vacuum feed-through 44 that provides linear motion through support flange 40 from the ambient atmosphere side of support flange 40 to the vacuum side of support flange 40. Vacuum feed-through 44 preferably includes shaft 46 coupled to shaft assembly 48 and crucible support cup 50 attached to shaft assembly 48.

Shaft assembly 48 and crucible support cup 50 are preferably made from graphite while shaft 46 preferably comprises a dissimilar material such as titanium or stainless steel to provide a thermal break to help prevent heat from damaging feed-through 44, which preferably comprises an o-ring seal as noted below.

5 Graphite is a preferred material because graphite provides a readily machinable material resistant to reaction with corrosive materials such as selenium and the like as well as deposition materials such as copper, indium, and gallium and is tolerant to the necessary process temperatures. Such processing temperatures, for example, can be as high as 1500°C for some applications. Graphite also has thermal expansion
10 properties compatible with pyrolytic boron nitride. Graphite is also relatively soft and thus provides a suitable support for crucibles made from pyrolytic boron nitride or other fragile or otherwise delicate materials. Graphite material is available from Poco Graphite, Inc. of Decatur, Texas, for example. A preferred graphite material is referred to as fine grain isostatically molded graphite.

15 Vacuum feed-through 44 also preferably includes adjustment knob 52 and lock nut 54. Rotation of adjustment knob 52 causes shaft 46, shaft assembly 48, and crucible support cup 50 to linearly translate along the direction indicated by reference numeral 56. Vacuum feed-through 44 preferably comprises a stainless steel shaft (shaft 46), threaded connection to provide linear motion, and an o-ring
20 based vacuum seal. Vacuum feed-through 44 is exemplary and any device or mechanism that can provide linear motion of crucible support 50 along the direction indicated by reference to a 56 can be used. Such linear motion feed-through devices are well known to those skilled in the art of vacuum equipment.

Crucible support assembly 26 also includes liquid cooling enclosure 58 and
25 heat shield assembly 60. Liquid cooling enclosure 58 and heat shield assembly 60 are preferably designed to shield vacuum feed-through 44 from direct radiant heat and help prevent o-ring seal of linear feed-through 44 from excess heat. Liquid cooling enclosure 58 and heat shield assembly 60 illustrate exemplary structure for providing such shielding and any desired structure that functions to help provide the
30 desired cooling and heat shielding functionality can be used. As can be seen in Figure 2, liquid cooling enclosure 58 preferably comprises inside wall 60 and outside wall 62 spaced apart from inside wall 60. Liquid cooling enclosure 58 is

preferably welded to support flange 40 but other connection techniques such as those including use of removable fasteners can be used to attach liquid cooling enclosure 58 to support flange 40. Liquid cooling enclosure 58 preferably comprises stainless steel.

5 Heat shield assembly 64 preferably comprises plural layers of refractory metal sheets such as those made from tantalum, tungsten, niobium, and molybdenum, for example. Such refractory metal sheets may be flat, knurled, dimpled, or otherwise embossed to help space apart adjacent sheets to provide thermal breaks between adjacent sheets. Preferably, plural dimpled sheets are used.
10 In another exemplary embodiment a combination of alternating flat and dimpled sheets is used. Alternative materials that can be used include ceramics and graphite, for example. Refractory metal sheets are available from Plansee LLC of Franklin, Massachusetts, for example.

Heat shield assembly 64 is preferably attached to tube assembly 58 and
15 includes opening 70 that allows shaft assembly 48 to translate along linear direction 56 discussed above. An exemplary attachment technique is illustrated in Figure 4 and includes using wire 66 to attach heat shield assembly 64 to anchor 68 of outside wall 62 of tube assembly 58 at plural locations. Use of wire 66 and anchor 68 to
attach heat shield assembly 64 to outside wall 62 of tube assembly 58 is exemplary
20 and other attachment techniques that achieve the same result can be used such as those including use of fasteners or spot welding or the like.

Vacuum deposition source 10 preferably comprises an optional alignment system to aid in positioning crucible support assembly 26 relative to base flange 12 during assembly as can be seen with reference to Figures 2 and 3. Base flange 12
25 includes alignment rods 72 extending from base flange 12. Crucible support assembly 26 includes alignment tubes 74 that extend from support flange 40 and correspond with openings 76 provided in support flange 40. During assembly, alignment rods 72 are aligned with and inserted into openings 76 and are subsequently linearly guided by alignment tubes 74 as crucible support assembly 26
30 is moved into position to be attached to base flange 12.

As can be seen in Figure 2, crucible support assembly 26 also preferably includes thermocouple 78 that functions to measure temperature and provide control

feedback. Thermocouple 78 is removably attached to port 80 of support flange 40. Thermocouple 78 includes junction 82 that is preferably positioned within heater 28 adjacent to crucible support cup 50. Preferably, thermocouple 78 is encapsulated in pyrolytic boron nitride, which helps to protect thermocouple 78 from deposition materials and also helps to provide mechanical support for thermocouple 78. An appropriate thermocouple can be selected based on the particular temperature range to be measured as well as the vacuum environment in which the thermocouple will be used. For example, a Type-C thermocouple can be used. Any desired temperature measurement device can be used, however, as such devices are well known to those skilled in the art of vacuum equipment. Temperature measurement devices including thermocouples are available from Omega Engineering, Inc. of Stamford, Connecticut, for example.

Referring to Figures 5 and 6 in particular, heater 28 is preferably removably and adjustably positioned relative to base flange 12 by heater support assembly 30. Heater support assembly 30 preferably comprises support base 84, heat shield assembly 86, and height adjustment legs 88. Support base 84 comprises a generally cylindrical ring-like structure having recessed region 90 that receives end 92 of heater 28. Preferably, recessed region 90 and end 92 are designed to have a close sliding fit. Threaded openings 94 of support base 84 along with openings 96 of heater 28 when end 92 of heater 28 is positioned in recessed region 90 of support base 84. Fasteners 98 comprise a threaded portion 100 and a non-threaded portion 102. When positioned in openings 94 of support base 84 non-threaded portions 102 of fasteners 98 engage with openings 96 of heater 28 to secure heater 28 in place relative to heater support base 84. Heater support base 84 and fasteners 98 preferably comprises graphite. Graphite material is available from Poco Graphite, Inc. of Decatur, Texas, for example. A preferred graphite material is referred to as fine grain isostatically molded graphite.

Heater support assembly 30 further preferably comprises plural rotatable height adjustment legs 88 that rotatably engage with respective fixed support legs 104 of base flange 12. Adjustment legs 88 each comprise threaded portion 106 that threads into each respective threaded bore 108 of heater support base 84. Adjustment legs 88 also each include bore 110 that rotatably engages with a shaft

portion (not shown) of each respective fixed support leg 104 of base flange 12. Height adjustment legs 88 preferably comprise graphite. Graphite material is available from Poco Graphite, Inc. of Decatur, Texas, for example. A preferred graphite material is referred to as fine grain isostatically molded graphite. Fixed support legs 104 preferably comprise stainless steel and are preferably welded or otherwise secured to base flange 12.

In use, rotation of height adjustment legs 88 varies the height of support base 84 relative to base flange 12 as well as the height of orifice 16 of crucible 24 relative to base flange 12. Such height adjustment is described in further detail below.

Height adjustment legs 88 also each include opening 112 that can be aligned with a corresponding opening (not shown) of each fixed leg 104. A suitable wire or the like (not shown) is preferably positioned in opening 112 and the corresponding opening of fixed leg 104 to prevent rotation of height adjustment 88 relative to fixed leg 104.

Continuing to refer to Figures 5 and 6, heater support assembly 30 also comprises heat shield assembly 86 as noted above. Heat shield assembly 86 preferably comprises support plate 114 and plural layers of refractory metal sheets 116 such as those made from tantalum, tungsten, niobium, and molybdenum, for example. With reference to Figure 6, in particular, heat shielding assembly 86 includes openings 118 that receive height adjustment legs 88. Height adjustment legs 88 each comprise shoulder 120, which supports heat shield assembly 86 when assembled as shown in Figure 5. Height adjustment legs 88 also each comprise channel 122 spaced apart from shoulder 120 and which can receive a wire or retaining clip (not shown) to secure heat shield assembly 86 relative to height adjustment legs 88. Support plate 114 preferably comprises pyrolytic boron nitride. Alternative materials that can be used include ceramics and graphite, for example. Refractory metal sheets 116 may be flat, knurled, dimpled, or otherwise embossed to help space apart adjacent sheets to provide thermal breaks between adjacent sheets. Preferably, plural and knurled (or dimpled or the like) sheets are used. In another exemplary embodiment a combination of alternating flat and dimpled sheets is used.

Vacuum deposition source 10 also preferably includes tubular heat shield assembly 32 as noted above. Heat shield assembly 32 functions to help prevent

radiant heat from escaping from vacuum deposition source 10, which helps to improve efficiency and controllability of vacuum deposition source 10 during operation. Heat shield assembly 32 also functions to help position and support heater 28 as explained in more detail below.

5 Referring to Figure 7, exemplary tubular heat shield assembly 32 comprises support rings 124, first heat shield 126, and second heat shield 128. Support rings 124 preferably comprise plural arcuate sections 130. Support rings 124 may, however, comprise a single monolithic ring structure as plural sections are not required but are used in a preferred embodiment to provide efficient use of material.
10 Although three support rings 124 are illustrated in exemplary tubular heat shield assembly 32, it is contemplated that any desired number of support rings can be used. Preferably, support rings 124 comprise pyrolytic boron nitride but other materials can be used.

Preferably, arcuate sections 130 are interconnected using refractory metal
15 wire that passes through openings in overlapping ends of adjacent arcuate sections 130. Any desired attachment technique can be used, however, such as by using fasteners or the like, for example. As illustrated, support rings 124 also optionally comprise openings 132 that function to provide conductance for pumping. In one preferred embodiment, at least one of support rings 124 provides a close fit with
20 either 28. Preferably, such support ring includes an identifying mark or the like such as by using square openings in contrast with round openings 132, for example.

Support rings 124 additionally include plural tabs 134 spaced apart around the circumference of the outside diameter of support rings 124. When assembled, tabs 134 mate with slots 136 provided in first and second heat shields 126 and 128,
25 respectively. Wires 125 are preferably wrapped around first and second heat shields 126 and 128 and join together such as by twisting respective ends together. Preferably, wires 125 are also engaged with tabs 134. Edges of first and second heat shields 126 and 128 maybe overlapped or may be butted together.

First and second heat shields 126 and 128, respectively, preferably comprise
30 arcuate refractory metal sheets such as those made from tantalum, tungsten, niobium, and molybdenum, for example. While two heat shields are illustrated in the exemplary heat shield assembly 32 it is contemplated that any number of arcuate

heat shield portions having plural seams can be used to form heat shield assembly 32 including use of a single sheet of refractory material that is rolled to form a cylindrical structure having a single seam. First and second heat shields 126 and 128, respectively, each comprise a single layer, as shown. It is contemplated, however, that plural layers of refractory metal material can be used. For example, plural layers of alternating flat and knurled (or dimpled or the like) refractory metal sheets can be used.

Referring back to Figures 5 and 6, support base 84 comprises outside surface 140 that preferably removably and slidably couples with inside surface 142 of heat shield assembly 32. When assembled, end 144 of heat shield assembly 32 preferably rests against shoulder 146 of support base 84. Preferably, outside surface 140 of support base 84 and inside surface 142 of heat shield assembly 32 are designed to have a sliding fit. Such a sliding fit is exemplary and it is contemplated that other coupling techniques can be used to couple heat shield assembly 32 with support base 84 such as by using one or more of fasteners, pins, and mechanical devices, for example.

With reference to the cross-sectional view of Figure 2 and the exploded view of Figure 8, liquid cooling enclosure 34 preferably comprises inside and outside spaced apart walls, 146 and 148, respectively, end ring 149, and mounting flange 150. Preferably, walls 146 and 148, end ring 149, and mounting flange 150 comprise stainless steel. Inside and outside spaced apart walls, 146 and 148, respectively, at least partially define fluid channel 152. Fluid channel 152 is in fluid communication with tubes 154 that allow a desired cooling fluid, such as water, for example, to be circulated through fluid channel 152. Liquid cooling enclosure 34 functions to help prevent radiant heat from escaping from vacuum deposition source 10, which helps to improve efficiency and controllability of vacuum deposition source 10 during operation.

When assembled, mounting flange 150 is attached to base flange 12 of deposition source 10 using conventional threaded fasteners or the like. Tubes 154 pass through base flange 12 via sealing feed-throughs (not visible). Such feed-throughs are conventional and well-known and typically include an o-ring and ferrule that provide an appropriate vacuum seal suitable for the desired vacuum level

and operating temperatures. Suitable feed-throughs are available from Swagelok, Fluid System Technologies of Solon, Ohio, for example.

Referring to the exploded view of Figure 8 and the detail views of Figures 9 and 10, in particular, liquid cooling enclosure 34 preferably comprises heat shield sheets 156, heat shield sheets 158, and support ring 162. When assembled, heat shield sheets 156 and 158 preferably form a cylindrical layered assembly 160. Heat shield sheets 156 and 158 are preferably attached to support ring 162 and can be attached to each other, if desired, such as by using one or more of refractory metal wire, fasteners, clips, and spot welding.

As illustrated, heat shield sheets 156 and 158 are provided in pairs and are preferably arranged so an overlapping layer covers seams between ends of sheets. Heat shield sheets 156 and 158 do not need to be provided as pairs, however, and can be provided as any number of arcuate sheet portions comprising plural seams or as a single sheet comprising a single seam. Although heat shield sheets 156 and 158 are illustrated as providing three layers of heat shielding, any number of layers can be used to achieve a desired heat shielding function. For example, plural layers of alternating flat and knurled (or dimpled or the like) refractory metal sheets can be used.

Cylindrical layered assembly 160 is preferably positioned inside liquid cooling enclosure 34 as can be seen in the cross-sectional detail views of Figures 9 and 10. As shown, heat shield sheets 156 and 158 are in contact with support ring 162. Support ring 162 engages with end ring 149 of liquid cooling enclosure 34, as shown, preferably to secure cylindrical layer assembly 160 relative to liquid cooling enclosure 34. Preferably, as can be seen in Figure 8, cylindrical layered assembly 160 is also held in place within liquid cooling enclosure 34 using plural holding clips 164 that are preferably spot welded to the inside wall 146 of liquid cooling enclosure 34. Engagement between support ring 162 and end ring 149 and use of holding clips 164 as illustrated is exemplary and any suitable structure can be used to provide appropriate heat shielding for vacuum deposition source 10.

As shown, cylindrical layered assembly 160 extends along a portion of the length of liquid cooling enclosure 34 less than the overall length of liquid cooling enclosure 34. Cylindrical layered assembly 160 can, however, be designed to extend

along any desired portion of inside wall 146 of liquid cooling enclosure 34. Also, it is contemplated that cylindrical layer assembly 160 can comprise plural sections that are assembled or positioned relative to each other to form a structure having a desired length.

5 Heat shield sheets 156 and 158 as well as support ring 162 preferably comprise refractory metal sheets such as those made from tantalum, tungsten, niobium, and molybdenum, for example. In one exemplary preferred embodiment heat shield sheets 156 comprise molybdenum and heat shield sheets 158 comprise tungsten and support ring 162 comprises tantalum. In such exemplary preferred
10 embodiment, heat shield sheets 158 form the innermost layer of cylindrical layered assembly 160. That is, heat shield sheets 156 preferably surround heat shield sheets 158. Such arrangement is exemplary and heat shield sheets 156 and 158 can be arranged in any desired order, comprise any desired material, and comprise any desired knurling, dimpling, or embossing to achieve a desired heat shielding
15 function.

 As noted above, vacuum deposition source 10 includes conical heat shield assembly 36 and conical cover 38. Conical heat shield assembly 36 and conical cover 38 can be seen in cross-section in Figures 9 and 10 and can be seen as an exploded perspective view in Figure 11. Conical heat shield assembly 36 preferably
20 comprises plural conical heat shield sheets 166 and conical base 168. Preferably, conical heat shield sheets 166 and conical base 168 are made from refractory metals such as tantalum, tungsten, niobium, and molybdenum, for example. In an exemplary preferred embodiment, conical heat shield sheets 166 comprise molybdenum and conical base 168 comprises tantalum. Also, in an exemplary
25 preferred embodiment, conical heat shield sheets 166 comprise one or more of knurling, dimpling, and embossing. Although conical heat shield sheets 166 are illustrated as providing three layers of heat shielding, any number of layers can be used to achieve a desired heat shielding function. Also, plural layers of alternating flat and knurled (or dimpled or the like) refractory metal sheets can be used. The
30 illustrated embodiment of Figure 11 is exemplary and heat shield sheets 166 can be arranged in any desired order, comprise any desired material, and comprise any

desired knurling, dimpling, or embossing to achieve a desired heat shielding function.

Conical base 168, as can be seen in Figures 9, 10, and 11, comprises annular lip 170, opening 172, and end 174. When assembled as shown in Figures 9 and 10, end 174 rests on support ring 162 and opening 172 is positioned over heater 28. Conical heat shield sheets 166 preferably rest on and are supported by conical base 168, as illustrated in the exemplary embodiment. Annular lip 170 helps to retain and position conical heat shield sheets 166 relative to conical base 160. Preferably, conical base 168 and conical heat shield sheets 166 are held in place by gravity and by conical cover 38 as noted below. If desired, however, fasteners, holding devices, retaining devices, and the like may be used to secure any of conical base 168 and conical heat shield sheets 166 relative to one or more of each other and end ring 149.

Continuing to refer to Figures 9, 10, and 11, conical cover 38 preferably comprises opening 172, conical portion 174, and cylindrical portion 176. When assembled as shown in Figures 9 and 10, cylindrical portion 174 mates with recessed portion 178 of end ring 149 of liquid cooling enclosure 34. Opening 172 is positioned over heater 28 and preferably rests on annular lip 170 of conical base 168. Assembled as such, conical cover 38 helps to trap conical heat shield sheets 166 between support ring 162 and conical cover 38. Preferably, cylindrical portion 176 and recessed portion 178 of end ring 149 are designed to provide a close friction fit when assembled together. That is, preferably friction between cylindrical portion 176 and recessed portion 178 functions to hold conical cover 38 removably in place on end ring 149 without the use of additional fasteners or holding devices. It is contemplated, however, that any desired fasteners, holding devices, retaining devices, and the like may be used to secure conical cover 38 to end ring 149.

In an exemplary embodiment, conical cover 38 comprises pyrolytic boron nitride. It is contemplated, however, that conical cover 38 may comprise any desired material depending on the particular application of deposition source 10. Exemplary materials that can be used to form conical cover 38 include refractory metals and ceramics, for example. Pyrolytic boron nitride is a preferred material for construction of components used for vacuum deposition. Pyrolytic boron nitride is generally inert, can withstand high temperatures, is generally clean and does not

contribute undesirable impurities to the vacuum environment, is generally transparent to certain wavelengths of infrared radiation, and can be fabricated into complex shapes, for example.

As noted above in the Background section, undesirable accumulation of deposition material in the vicinity of the effusion orifice of vacuum deposition sources can occur under certain deposition conditions. Typically, such deposition conditions include one or more of high deposition temperatures and high deposition rates such as those used for deposition of metals or semiconductors materials, such as copper, indium, and gallium, for example. For purposes of the present invention, high deposition temperatures refer to the operating temperature of the region near the effusion orifice of a crucible. Continued accumulation of deposition material can reduce the area of the effusion orifice and thereby reduce the deposition rate. Ultimately, continued accumulation of deposition material can effectively close the effusion orifice so the deposition rate is unacceptably low or non-existent.

Deposition sources in accordance with the present invention such as exemplary deposition source 10 can advantageously provide high deposition rates at high operating temperatures of materials without the above-described problem related to accumulation of deposition material at the effusion orifice. For example, as can be seen in Figures 9 and 10, heater 28 includes cylindrical portion 180 and conical portion 182. Conical portion 182 of heater 28 is preferably designed to provide uniform radiant heat to first and second conical portions, 29 and 31, respectively of crucible 24. Such uniform heating can be accomplished by designing heater 28 to be closely fit or otherwise slidingly engaged with crucible 24, provide heating to substantially all surfaces of crucible 24, and by designing heat shielding that helps to keep radiant heat within a predetermined region of the deposition source 10. When designed as such, cold surfaces of crucible 24 are minimized and undesirable condensation of deposition material on the inside surface of crucible 24 is accordingly minimized or eliminated.

Another aspect of the present invention that is believed to help to minimize or eliminate the above-described problem related to accumulation of deposition material at the effusion orifice relates to conical cover 38. Because of the conical shape of conical cover 38, any particles that might be ejected from effusion opening

16 and land on conical cover 38 will tend to slide off of conical cover 38.

Preferably, the slope of conical cover 38 is selected based on factors such as a particular deposition material to be used in the angle at which deposition source 10 is positioned in a vacuum deposition system. In a preferred exemplary embodiment, the angle of deposition source 10 is less than the angle of conical cover 38. In a preferred exemplary embodiment the angle of deposition source 10 as measured with respect to vertical is less than 40° and more preferably less than 30°.

Determination of the geometry of conical cover 38 and the angle of deposition source 10 can be determined empirically for the particular deposition material and vacuum environment.

Yet another aspect of the present invention that is believed to help to minimize or eliminate the above-described problem related to accumulation of deposition material at the effusion orifice relates to the relative positions of conical cover 38 and heater 28. Referring to Figure 9, edge 184 of heater 28 preferably extends past edge 186 of conical cover 38. In an exemplary embodiment, edge 184 of heater 28 preferably extends past edge 186 of conical cover 38 by approximately 0.0-5.0 millimeters. In another exemplary embodiment, edge 184 of heater 28 preferably extends past edge 186 of conical cover 38 by approximately 2.0-5.0 millimeters. In yet another exemplary embodiment, edge 184 of heater 28 preferably extends past edge 186 of conical cover 38 by approximately 2.0-2.4 millimeters. The ranges indicated above are exemplary and the distance by which edge 184 of heater 28 extends past edge 186 of conical cover 38 can also be determined empirically for the particular deposition material and vacuum environment.

Adjustment of edge 184 of heater 28 with respect to edge 186 of conical cover 38 can be performed using height adjustment legs 88 of heater support assembly 36. Referring back to Figure 5, height adjustment legs 88 can be rotated with respect to fixed legs 104 to translate heater support base 84 and heater 28 relative to the base flange 12. Preferably, a fixture (not shown) is used to set the height of edge 184 of heater 28 with respect to a known surface such as a surface of base flange 12.

Yet another aspect of the present invention that is believed to help to minimize or eliminate the above-described problem related to accumulation of

deposition material at the effusion orifice relates to the relative positions of heater 28 and crucible 24. Referring to Figure 9, edge 188 of crucible 24 preferably extends past edge 184 of heater 28. In an exemplary embodiment edge 188 of crucible 24 preferably extends past edge 184 of heater 28 by approximately 0.0-2.0 millimeters.

5 In another exemplary embodiment edge 188 of crucible 24 preferably extends past edge 184 of heater 28 by approximately 0.0-2.0 millimeters. In another exemplary embodiment edge 188 of crucible 24 preferably extends past edge 184 of heater 28 by approximately 0.2-1.0 millimeters. In yet another exemplary embodiment edge 188 of crucible 24 preferably extends past edge 184 of heater 28 by approximately 0.2-0.5 millimeters. The ranges indicated above are exemplary and the distance by which edge 188 of crucible 24 extends past edge 184 of heater 28 can also be determined empirically for the particular deposition material and vacuum environment.

Adjustment of edge 188 of crucible 24 with respect to edge 184 of heater 28 can be performed using adjustment knob 52 of crucible support assembly 26. Referring to Figure 2 rotation of knob 52 translates crucible support cup 50 and crucible 24 relative to base flange 12. When a desired position for crucible 24 is obtained lock not 54 is engaged to lock the position of crucible 24.

Heater 28 preferably comprises a monolithic heating device comprising pyrolytic graphite conductive material sandwiched between insulating pyrolytic boron nitride. Such heaters are available from Momentive Performance Materials of Strongsville, Ohio. Preferably, heater 28 includes two distinct serpentine resistive elements that provide two distinct heating zones that can be controlled independently from each other. One heating zone is preferably used to heat cylindrical portion 180 and the second heating zone is preferably used to heat conical portion 182. Advantageously, conical portion 182 can be operated at a higher temperature than cylindrical portion 180, which can help prevent condensation of deposition material near the effusion orifice 16 of crucible 24. It is contemplated that heater 28 may comprise any desired number of resistive elements including a single resistive element.

Referring now to Figures 12-17 generally, and Figures 12-13 in particular, support base 84 further preferably comprises cutout regions 190 that align with

electrical contacts 192 of heater 28 when end 92 of heater 28 is positioned in recessed region 90 of support base 84. As illustrated, heater 28 comprises four electrical contacts 192 that provide power to two distinct resistive elements. Power is provided to electrical contacts 192 via power feed-throughs 194 that are
5 preferably removably coupled with base flange 12. Power feed-throughs 194 each comprise power conductor 196, which typically comprises a molybdenum post and an o-ring vacuum seal.

Electrical contacts 192, as can be seen in Figure 6, each comprise an exposed region of the associated graphite resistive element. Because end 92 of heater 28 is
10 generally cylindrical, electrical contacts 192 comprise a cylindrical curvature having a known radius. Accordingly, structure used for electrical connection to cylindrically curving electrical contacts 192 is preferably designed to maximize contact area with electrical contacts 192 and provide consistent pressure to electrical contacts 192 throughout the operating temperature range of deposition source 10.

Power feed-throughs 194 are electrically removably connected to power
15 straps 198 by flexible power cables 200. Preferably, power straps 198 are cylindrically curved to correspond with the radius of end 92 of heater 28 and taking into consideration the thickness of conductive washer 226 (described below). Cable connectors 202 receive flexible power cables 200 and power conductors 196 and
20 function to clamp flexible power cables 200 to power conductors 196. Insulating power strap isolators 204 are preferably positioned on power conductors 196 below cable connectors 202, as illustrated. Insulating power strap isolators 204 each include curved slot 206 that receives end 208 of each power strap 198 and helps to hold each power strap 198 in place. In a preferred embodiment, insulating power
25 strap isolators 204 comprise pyrolytic boron nitride although it is contemplated that other insulating materials can be used. Alternative structures for positioning ends 208 of power straps 198 can also be used. Use of cable connectors 202 and flexible power cables 200 illustrates an exemplary technique to removably electrically
30 connect power conductors 196 to power straps 198 and those of skill in the art will recognize that other suitable techniques can be used to make such connection such as the use of one or more of alternative clamping structures, fasteners, connectors, and spot welding, for example.

Flexible power cables 200 are connected to power straps 198 with cable clamps 210. As illustrated, cable clamps 210 comprise clamping plates 212 and fasteners 214 that function to compressively clamp flexible power cables 200 to power straps 198. Cable clamps 210 illustrates an exemplary technique to
5 removably electrically connect flexible power cables 200 to power straps 198 and those of skill in the art will recognize that other suitable techniques can be used to make such connection such as the use of one or more of alternative clamping structures, fasteners, connectors, and spot welding, for example. Preferably, a vacuum deposition source 10 is used in the presence of a corrosive vapor such as
10 selenium, cable clamps 210 preferably comprise molybdenum with a stainless steel screw. Power straps 198 preferably comprise tungsten. Power cables 200 preferably comprise multi-stranded molybdenum wire.

In each connection, power strap 198 is preferably electrically removably connected to electrical contact 192 of heater 28 as illustrated by the exemplary
15 connection technique shown in Figures 13-17. Power strap 198 preferably passes through notch 216 provided in support base 84. Electrical connection to electrical contact 192 is preferably maintained using spring 218 and loading pins 220 provided at each end of spring 218. Spring 218 applies spring force to pressure pin 222, which applies pressure to contact washer 224. As can be seen best in the cross-
20 sectional view of Figure 15, power strap 198 is preferably sandwiched between contact washer 224 and conductive washer 226.

As illustrated in the exemplary embodiment, loading pins 220 each preferably comprise cylindrical shoulder 236 rotatably positioned in bore 230 of support base 84. Referring to the cross-sectional view of Figure 16, cylindrical
25 shoulder 228 of each spring loading pin 220 includes opening 232 that receives retaining wire 234 that helps to hold spring loading pin 220 in place. It is contemplated that other retaining structure could be used such as use of a retaining clip and groove or the like. Referring back to Figure 14, each spring loading pin 220 also preferably comprises flat portion 236 that engages with surface 238 of spring
30 218 when assembled, such as is illustrated in Figures 15 and 16. Varying the location of flat portion 236 can be used for adjustment of spring force.

Referring now to Figures 14 and 15, each pressure pin 222 preferably comprises head portion 240 and post portion 242. Post portion 242 of each pressure pin 222 preferably passes through opening 244 of contact washer 224, opening 246 of conductive washer 226, and opening 248 of heater 28 associated with each electrical contact 192. Preferably, surface 243 of head portion 240 comprises a spherically curving surface and is in contact with surface 250 of spring 218. A spherically curving surface preferred because a spherically curving is not orientation dependent when contacting surface 250. Preferably, the radius of spherically curving surface 243 comprises the radius that is less than or equal to than the distance that spring 218 needs to flex.

Surface 252 of head portion 240 preferably comprises a flat surface that mates with flat surface 253 of contact washer 244. Surface 257 of contact washer 224 preferably comprises a cylindrically curving surface and preferably has a radius determined by considering the radius of electrical contact 192, thickness of conductive washer 226, and thickness of power strap 198. Power strap 198 also preferably at a cylindrically curving shape that corresponds with the radius of electrical contact 192.

Springs 218 preferably comprise a resilient material that can maintain its ability to apply consistent pressure throughout the operating temperature range of deposition source 10. An exemplary preferred material comprises pyrolytic boron nitride because pyrolytic boron nitride is vacuum compatible, insulating, and can maintain a spring force at high temperatures. Other materials that can be used include insulating materials having suitable elastic properties, for example.

As shown in the exemplary illustrated embodiment, springs 218 preferably comprise a generally rectangular plate. The dimensions, geometry, and thickness of springs 218 are preferably designed to provide the desired spring force. Suitable characteristics for springs 218 can be determined empirically. Preferably, in an exemplary embodiment, a load of between about 3 to 8 pounds, as applied to electrical contacts 192, is used. Springs 218 may have any desired geometry, however such as that including serpentine structures or the like. Also, plural layers of material can be used to form springs 218 such as to provide a leaf spring structure, for example.

Loading pins 220, pressure pin 222, and contact washer 224 preferably comprise graphite. Other suitable materials can be used, however, for loading pins 220, pressure pin 222, and contact washer 224. Conductive washer 226 preferably comprises graphite. Other suitable materials can be used, however, for conductive washer 226. Graphite material is available from GrafTech Advanced Energy Technology, Inc. of Lakewood, OH. One preferred graphite material is referred to as nuclear grade GTA material.

In Figures 18 and 19, another exemplary electrical contact assembly that can be used in accordance with the present invention is illustrated. In the embodiment illustrated in Figures 18 and 19, a flat power strap 254 is used instead of the arcuate power strap 198 described above. As shown, loading pins 220 and spring 218 apply force to pressure pin 222 in a similar manner as described above. Flat power strap 254 is preferably sandwiched between pressure pin 222 and conductive washer 256. Conductive washer 256 is in contact with contact washer 258, which is in contact with conductive washer 226. Conductive washer 226 contacts electrical contact 192 (not visible in Figures 18 and 19) of heater 28.

In Figure 20, another exemplary electrical contact assembly that can be used in accordance with the present invention is illustrated. In the embodiment illustrated in Figure 20, spring 260 is positioned inside heater 262. Pressure pin 264 applies pressure to contact washer 266 and arcuate power strap 268 is sandwiched between contact washer 266 and conductive washer 270. Conductive washer 270 is in contact with an electrical contact (not shown) of heater 262. Pressure pin 264 includes post portion 272 that passes through contact washer 266, arcuate power strap 268, conductive washer 270, heater 262, and spring 260. End 274 of post portion 272 includes retaining clip 276 and loading tube 278 that function to maintain pressure of conductive washer 270 with the electrical contact (not shown) of heater 262 by the spring force provided by spring 260. Spring 260 may comprise a pyrolytic boron nitride spring as described above.

Vacuum deposition sources that can use electrical contacts described in the present invention are described in Applicant's co-pending US Patent Application entitled Vacuum Deposition Sources Having Heated Effusion Orifices, filed on

August 11, 2009 and having attorney docket number VII0025/US, the entire disclosure of which is incorporated by reference herein for all purposes.

5 The present invention has now been described with reference to several exemplary embodiments thereof. The entire disclosure of any patent or patent application identified herein is hereby incorporated by reference for all purposes. The foregoing disclosure has been provided for clarity of understanding by those skilled in the art of vacuum deposition. No unnecessary limitations should be taken from the foregoing disclosure. It will be apparent to those skilled in the art that changes can be made in the exemplary embodiments described herein without
10 departing from the scope of the present invention. Thus, the scope of the present invention should not be limited to the exemplary structures and methods described herein, but only by the structures and methods described by the language of the claims and the equivalents of those claimed structures and methods.

What is claimed is:

1. A vacuum deposition source comprising:
 - a base flange configured to mount the vacuum deposition source to a vacuum chamber, the base flange comprising an electrical power feed-through;
 - a crucible operatively supported relative to the base flange and configured to hold vacuum deposition material, the crucible comprising a body portion and an effusion orifice;
 - a heater operatively supported relative to the base flange and at least partially surrounding the crucible, the heater comprising a cylindrical electrical contact surface; and
 - an electrical contact assembly comprising a power strap electrically connected to the electrical power feed-through at a first end of the power strap, electrically connected to the electrical contact surface of the heater at a second end of the power strap, and comprising a pyrolytic boron nitride spring applying pressure to the second end of the power strap.
2. The vacuum deposition source of claim 1, wherein the power strap comprises one or more of a flat electrical contact surface and an arcuate electrical contact surface.
3. The vacuum deposition source of claim 1, wherein the heater comprises a layered structure comprising a pyrolytic graphite electrically resistive layer positioned between pyrolytic boron nitride electrically insulative layers.
4. The vacuum deposition source of claim 1, wherein the electrical contact assembly comprises a conductive washer in contact with the cylindrical electrical contact surface.
5. The vacuum deposition source of claim 4, wherein the conductive washer comprises flexible graphite.
6. The vacuum deposition source of claim 4, wherein the electrical contact assembly comprises a contact washer in contact with the second end of the

power strap and positioned between the contact washer and conductive washer.

7. The vacuum deposition source of claim 6, wherein the electrical contact assembly comprises a pressure pin in contact with the contact washer.
- 5 8. The vacuum deposition source of claim 7, wherein the pressure pin comprises a head portion and an alignment post portion and wherein the alignment post portion passes through an opening in the contact washer, an opening in the power strap, an opening in the conductive washer, and an opening in the heater.
- 10 9. The vacuum deposition source of claim 7, wherein the electrical contact assembly comprises a first surface of the pyrolytic boron nitride spring in contact with the pressure pin, and at least one loading pin in contact with a second surface of the pyrolytic boron nitride spring thereby providing a compressive load on the conductive washer.
- 15 10. The vacuum deposition source of claim 9, wherein the at least one loading pin comprises a cylindrical post comprising a flat surface that engages with an end of the pyrolytic boron nitride spring.
11. The vacuum deposition source of claim 1, wherein the pyrolytic boron nitride spring comprises a rectangular plate.
- 20 12. The vacuum deposition source of claim 1, wherein the electrical connection between the electrical power feed-through at the first end of the power strap comprises a flexible metal cable connected to the electrical power feed-through at a first end of the flexible metal cable and connected to the first end of the power strap at a second end of the flexible metal cable.
- 25 13. The vacuum deposition source of claim 1, wherein the heater comprising a plurality of cylindrical electrical contact surfaces.
14. A vacuum deposition source comprising:
 - a base flange configured to mount the vacuum deposition source to a vacuum chamber, the base flange comprising an electrical power feed-through;
- 30

a crucible operatively supported relative to the base flange and configured to hold vacuum deposition material, the crucible comprising a body portion and an effusion orifice;

a heater operatively supported relative to the base flange and at least partially surrounding the crucible, the heater comprising a cylindrical body portion configured and positioned to provide thermal radiation to at least a portion of the crucible, the heater comprising a layered structure comprising a cylindrical pyrolytic graphite electrically resistive layer positioned between cylindrical pyrolytic boron nitride electrically insulative layers and having an electrical contact comprising an exposed surface region of the graphite electrically resistive layer;

an electrical contact assembly comprising a power strap electrically connected to the electrical power feed-through at a first end of the power strap, electrically connected to the electrical contact of the heater at a second end of the power strap, and comprising a pyrolytic boron nitride spring applying pressure to the second end of the power strap.

15. The vacuum deposition source of claim 1, wherein the electrical contact assembly comprises a conductive washer in contact with the cylindrical electrical contact surface, a contact washer in contact with the second end of the power strap and positioned between the contact washer and conductive washer, a pressure pin in contact with the contact washer, a first surface of the pyrolytic boron nitride spring in contact with the pressure pin, and at least one loading pin in contact with a second surface of the pyrolytic boron nitride spring thereby providing a compressive load on the conductive washer.

16. The vacuum deposition source of claim 14, wherein the pyrolytic boron nitride spring comprises a rectangular plate.

17. The vacuum deposition source of claim 16, wherein the electrical contact assembly comprises a first loading and in contact with a first end of the

rectangular plate and a second loading pin spaced apart from the first loading pin and in contact with a second end of the rectangular plate.

18. An electrical contact assembly for providing an electrical connection to an electrical contact comprising a cylindrical electrical contact surface, the electrical contact assembly comprising a conductive washer in contact with the cylindrical electrical contact surface, a power strap positioned between a contact washer and the conductive washer, a pressure pin in contact with the contact washer, a first surface of a pyrolytic boron nitride spring in contact with the pressure pin, and at least one loading pin in contact with a second surface of the pyrolytic boron nitride spring thereby providing a compressive load on the conductive washer.
19. The electrical contact assembly of claim 18, wherein the power strap comprises one or more of a flat electrical contact surface and an arcuate electrical contact surface.
20. The electrical contact assembly of claim 18, wherein the conductive washer comprises flexible graphite.
21. The electrical contact assembly of claim 18, wherein the pressure pin comprises a head portion and an alignment post portion and wherein the alignment post portion passes through an opening in the contact washer, an opening in the power strap, an opening in the conductive washer, and an opening corresponding with the cylindrical contact surface.
22. The electrical contact assembly of claim 21, wherein the head portion of the pressure pin comprises a spherical surface.
23. The electrical contact assembly of claim 18, wherein the electrical contact surface comprises an electrical contact of a heater of a vacuum deposition source.

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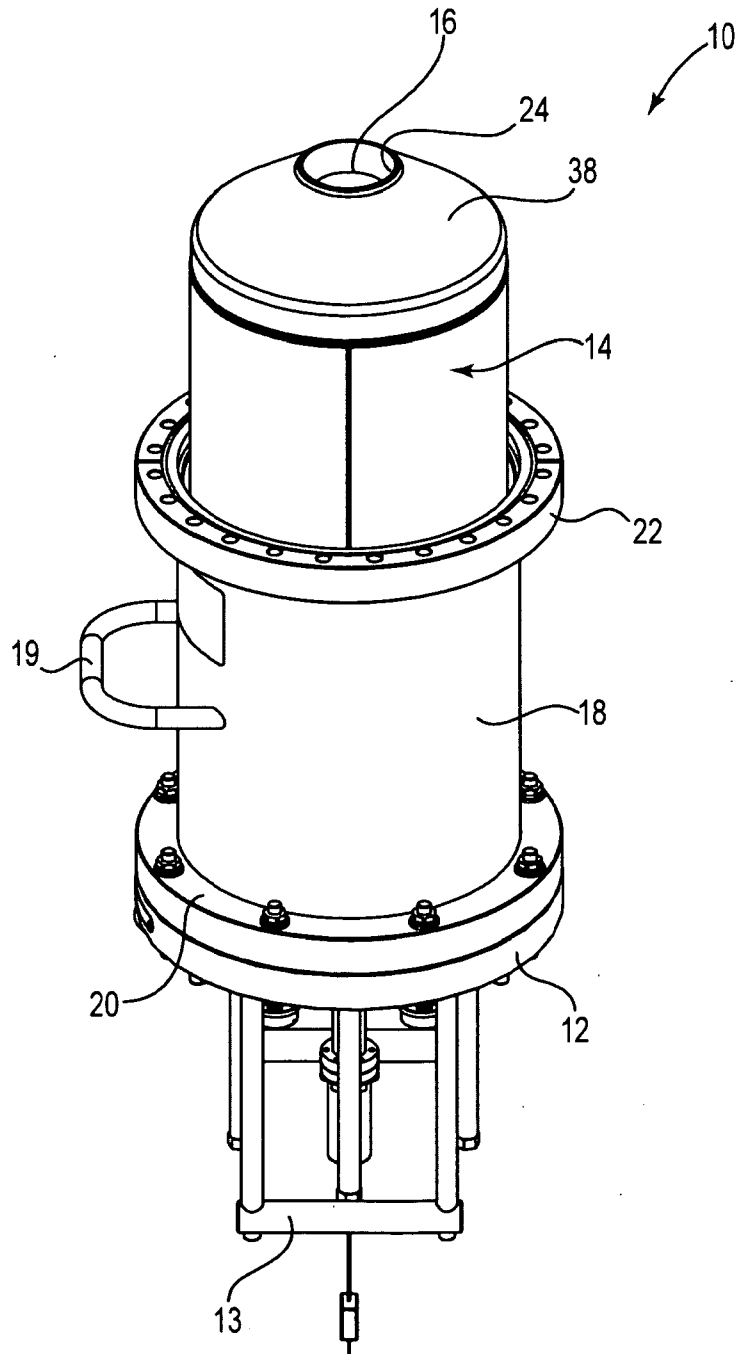
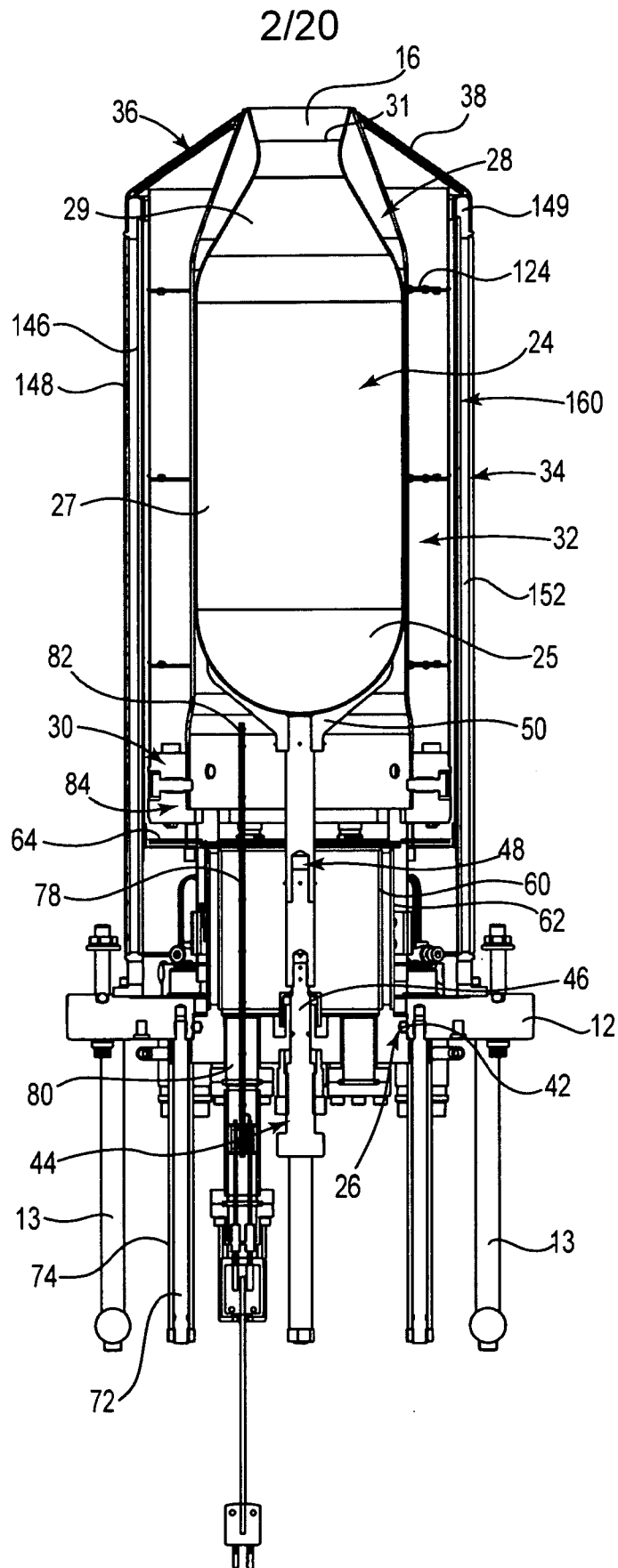


Fig. 1

**Fig. 2**

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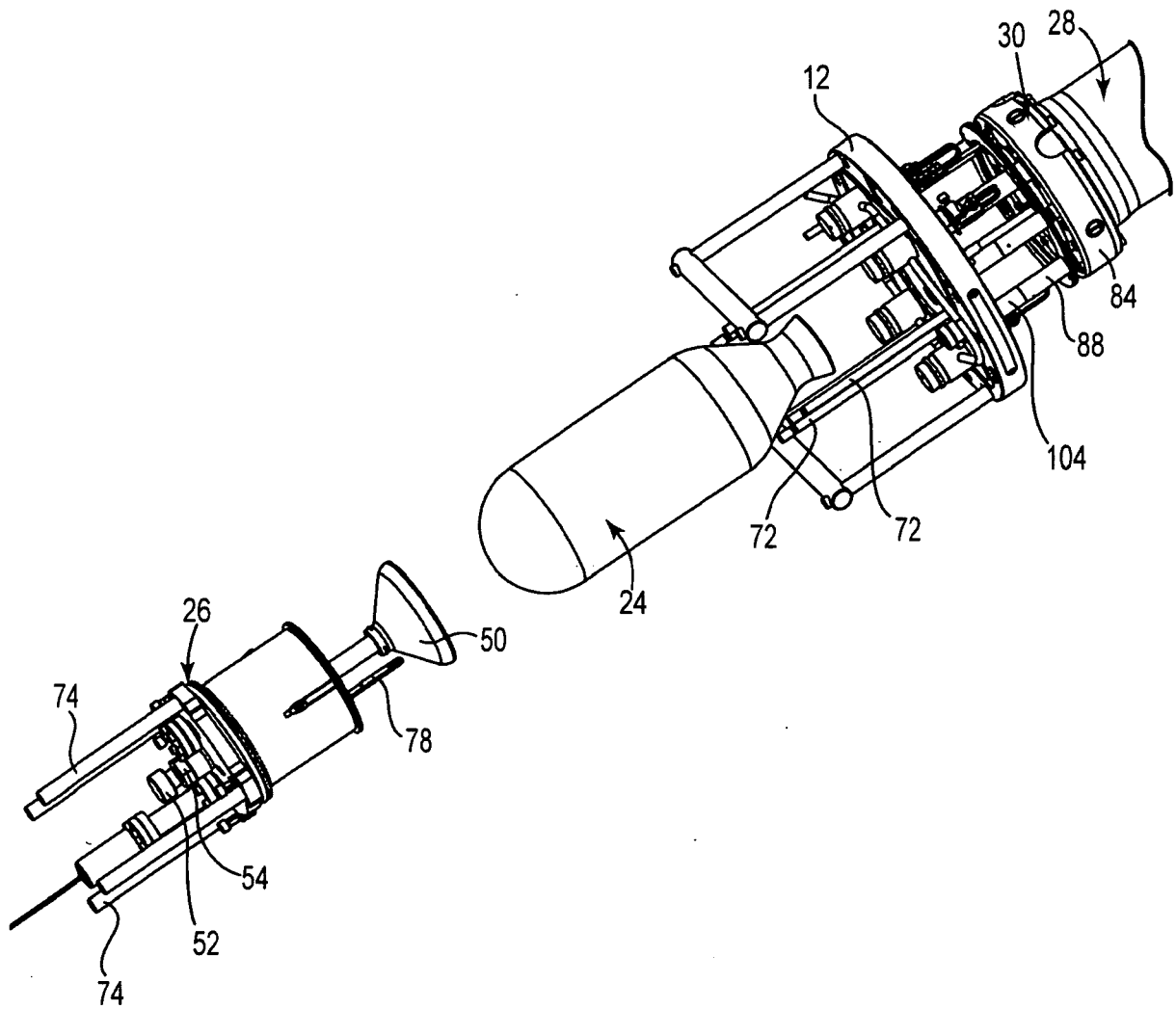


Fig. 3

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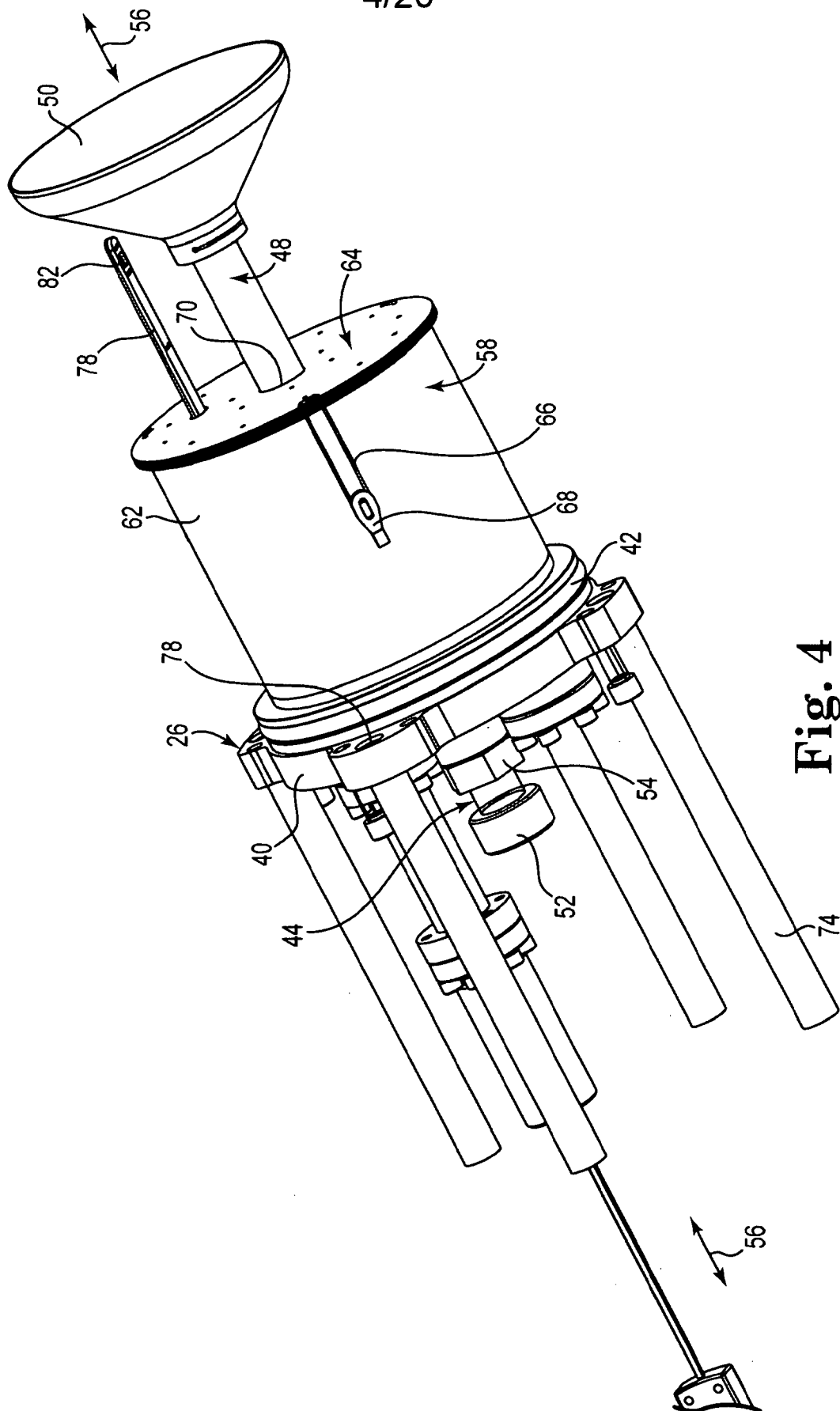


Fig. 4

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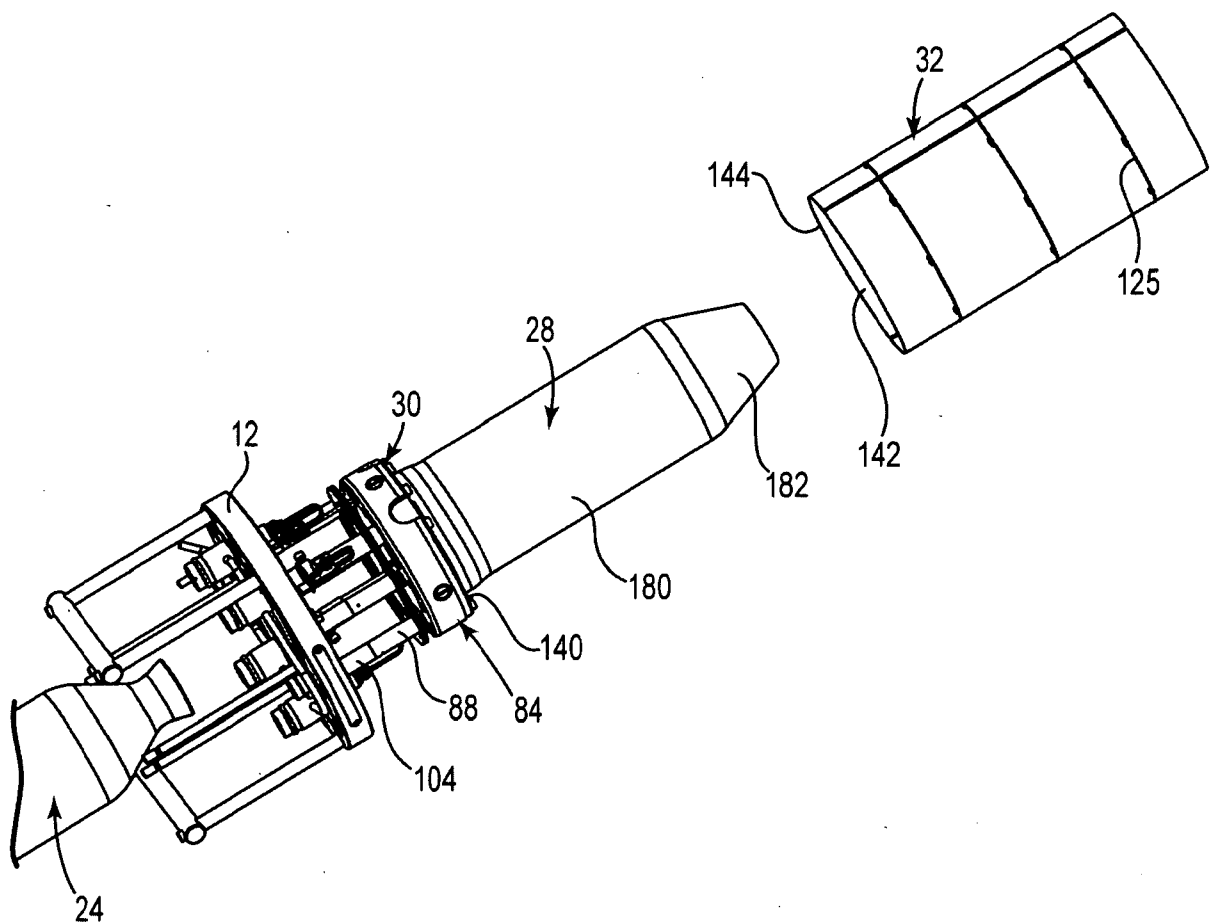


Fig. 5

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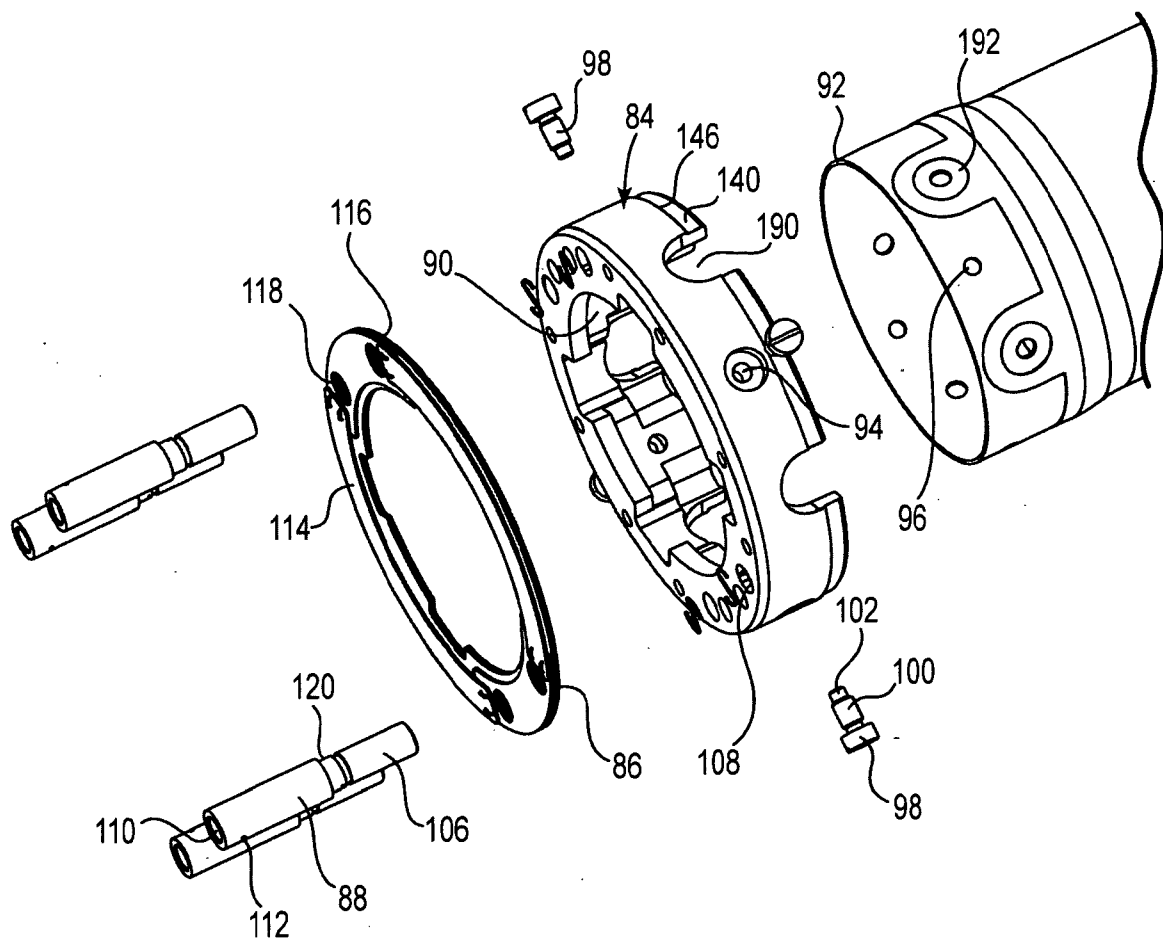


Fig. 6

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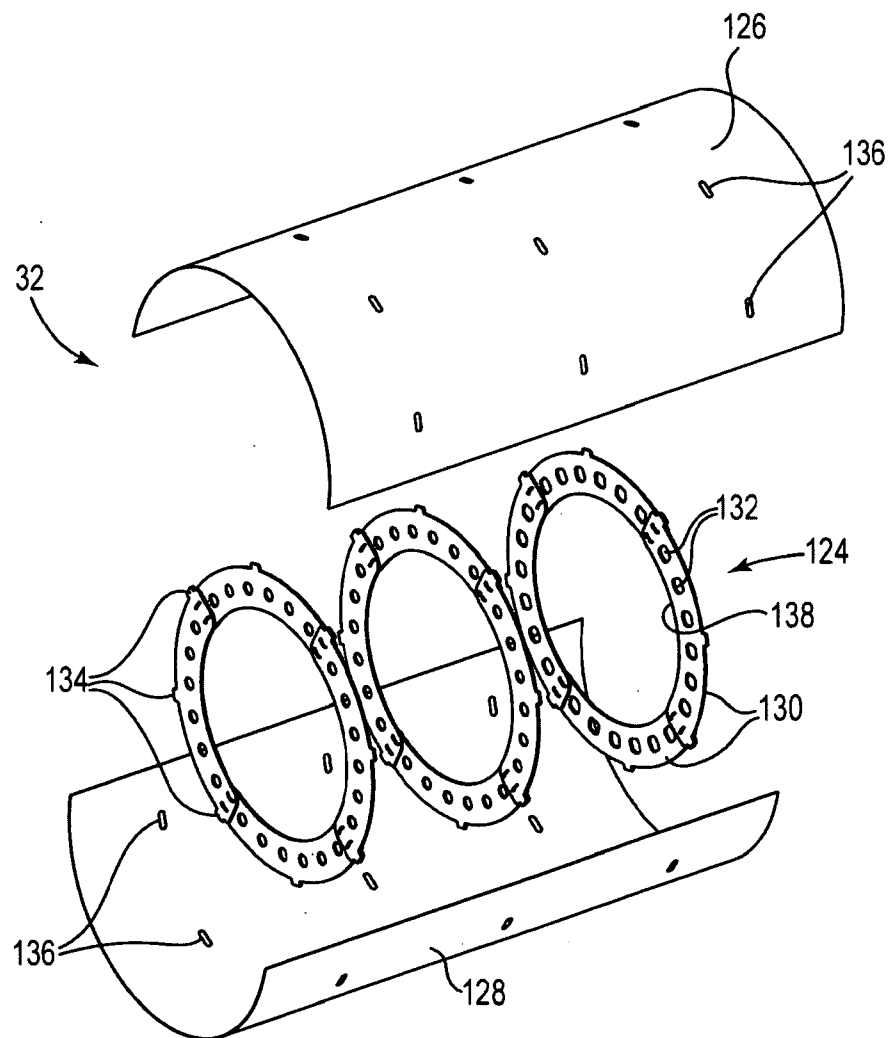


Fig. 7

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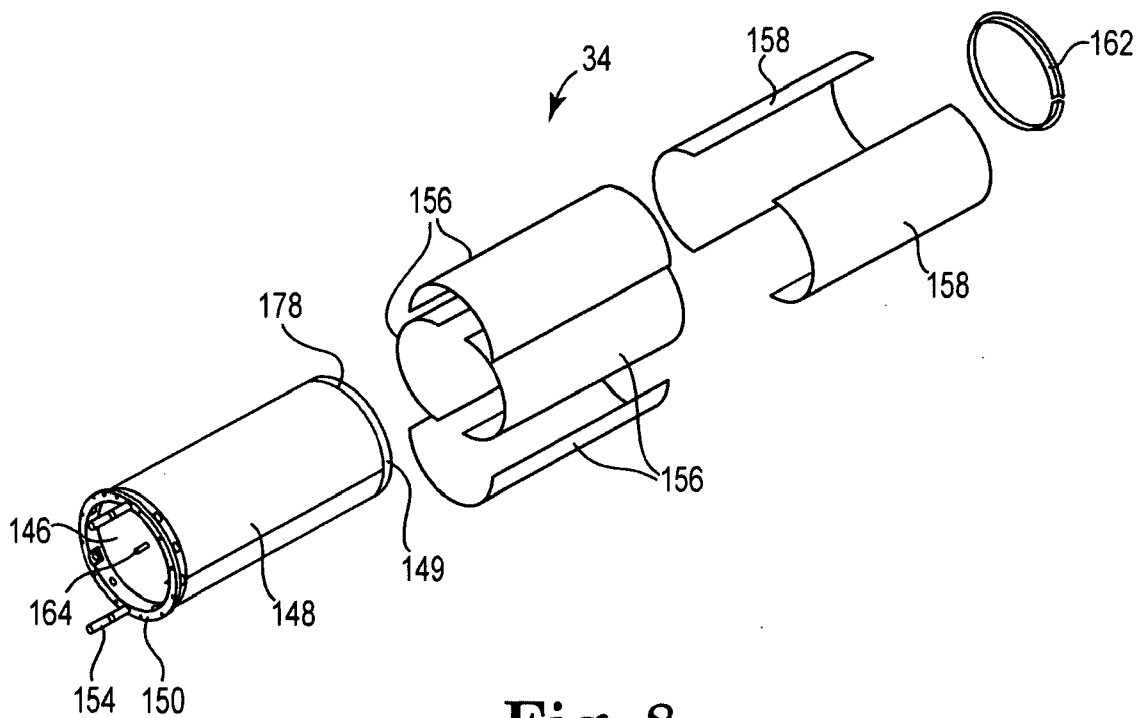


Fig. 8

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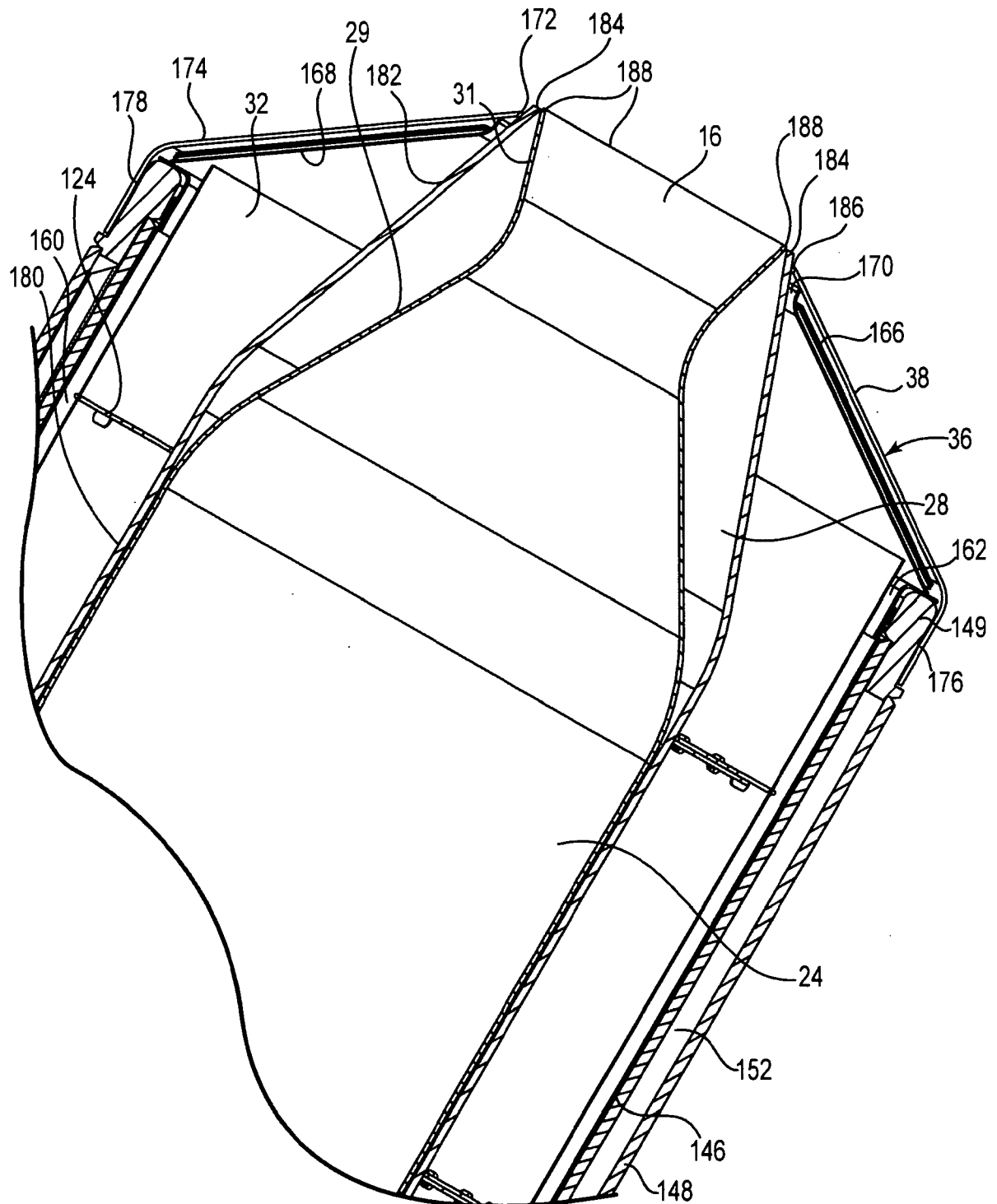


Fig. 9

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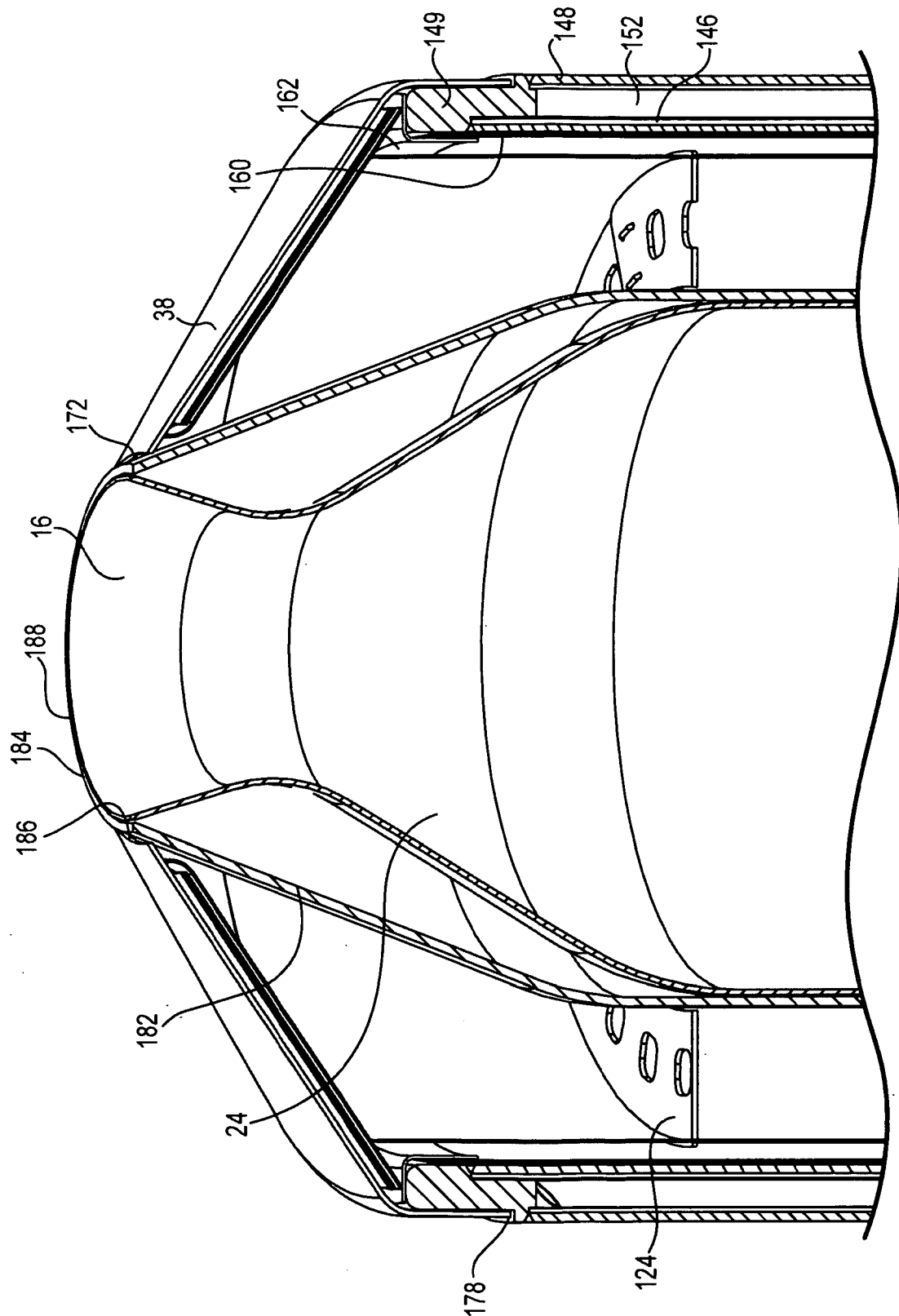


Fig. 10

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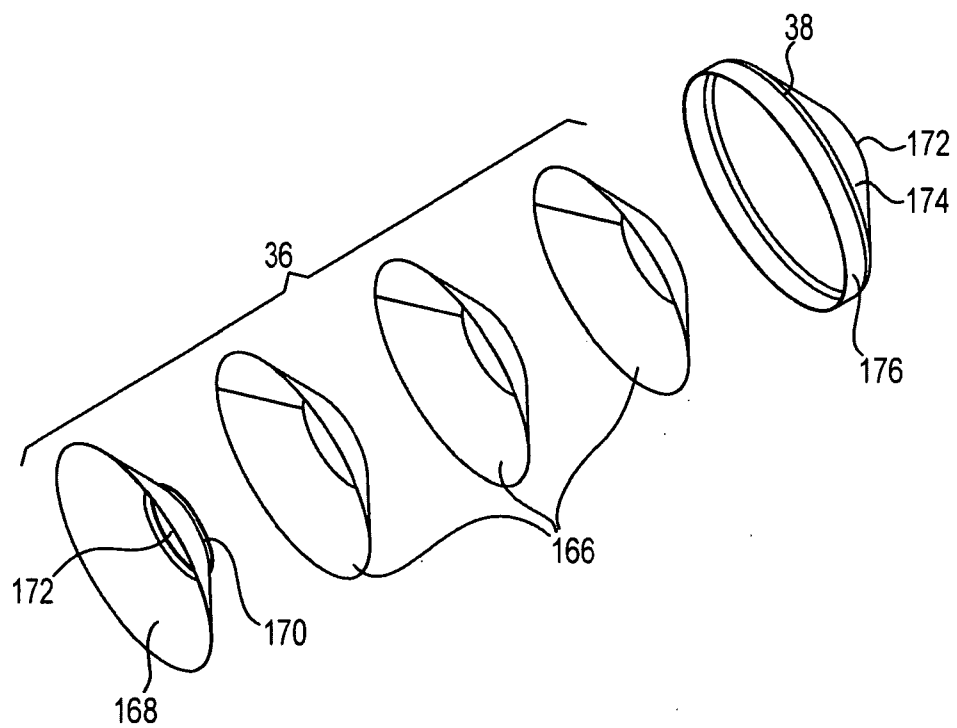


Fig. 11

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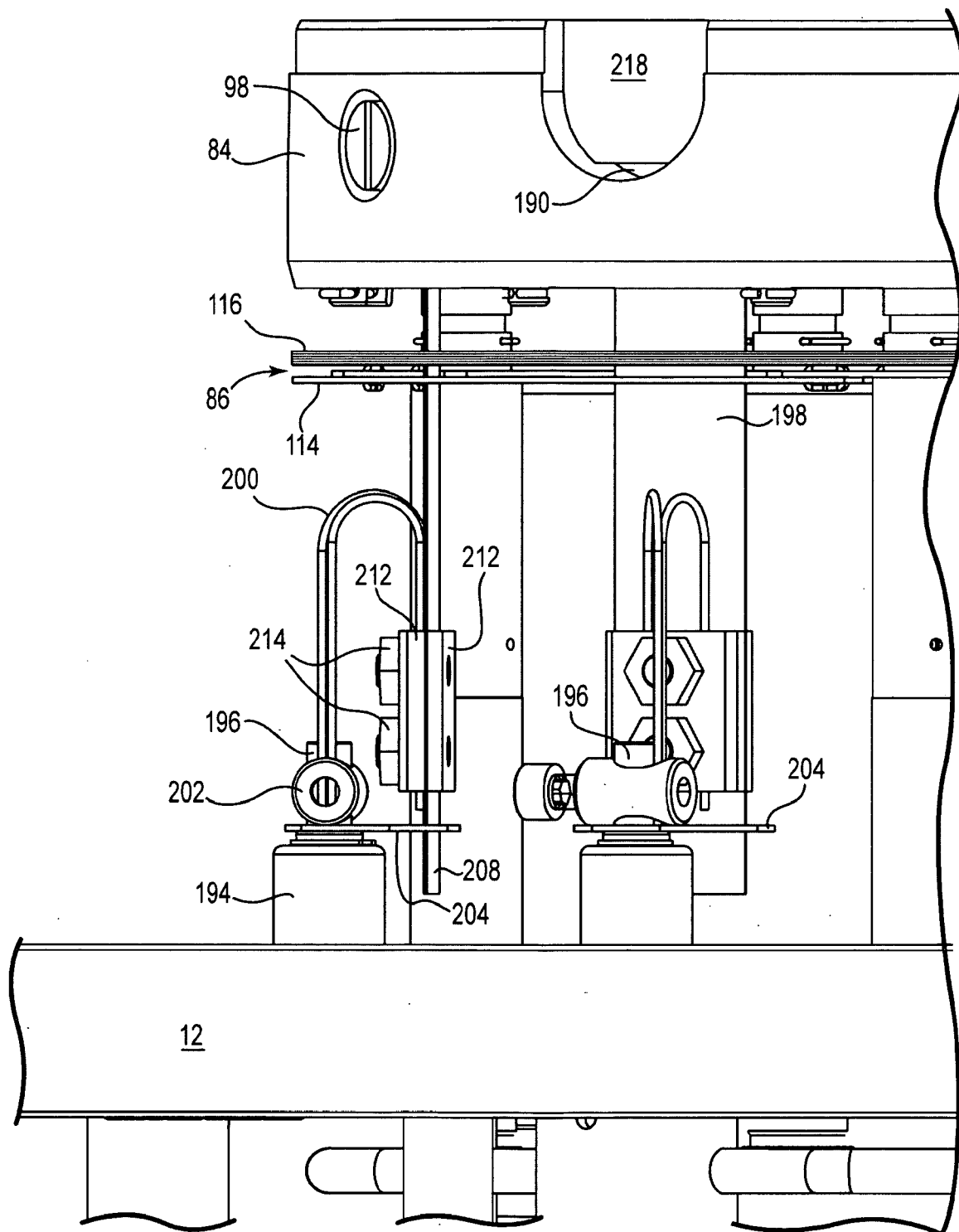
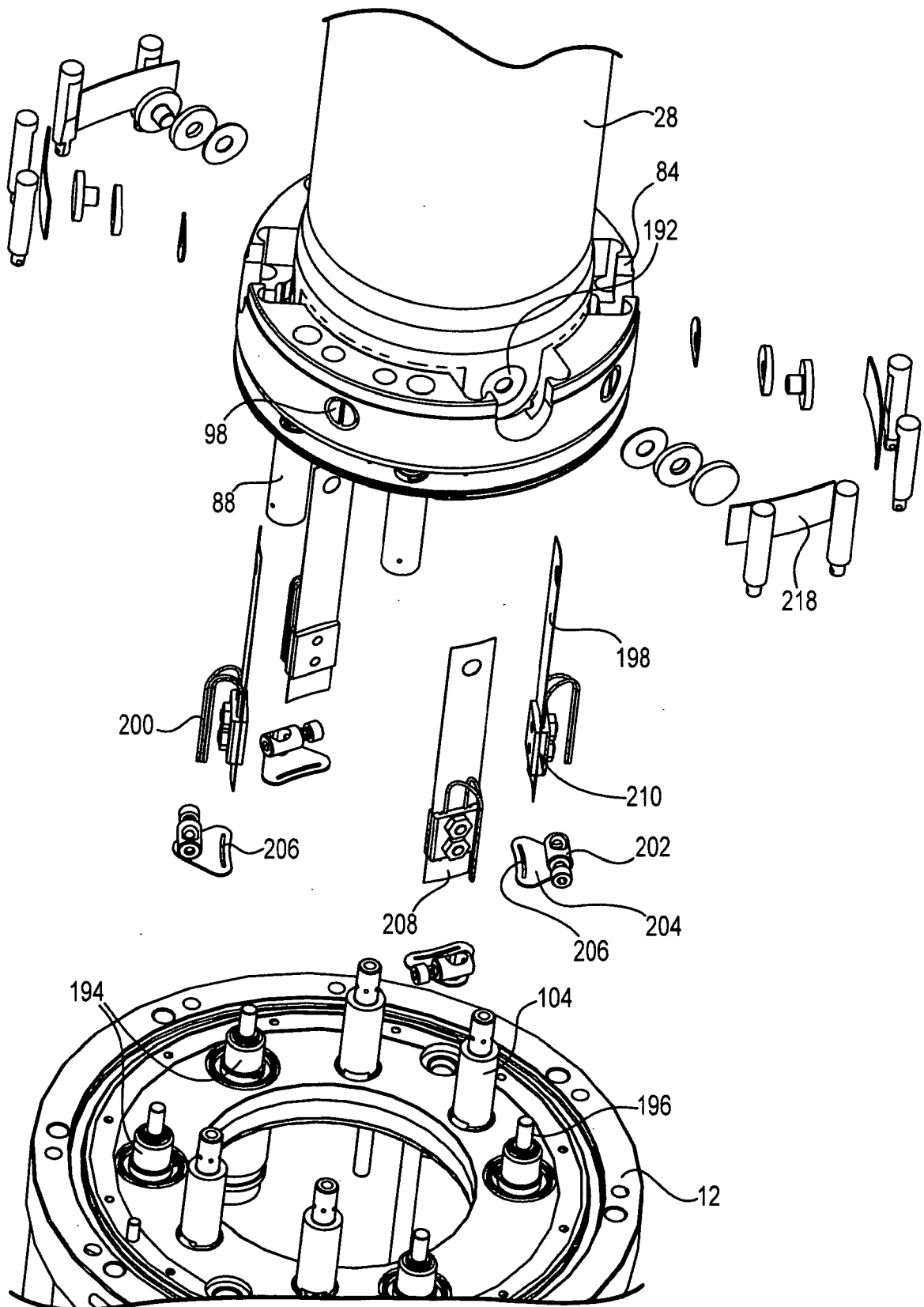


Fig. 12

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**Fig. 13**

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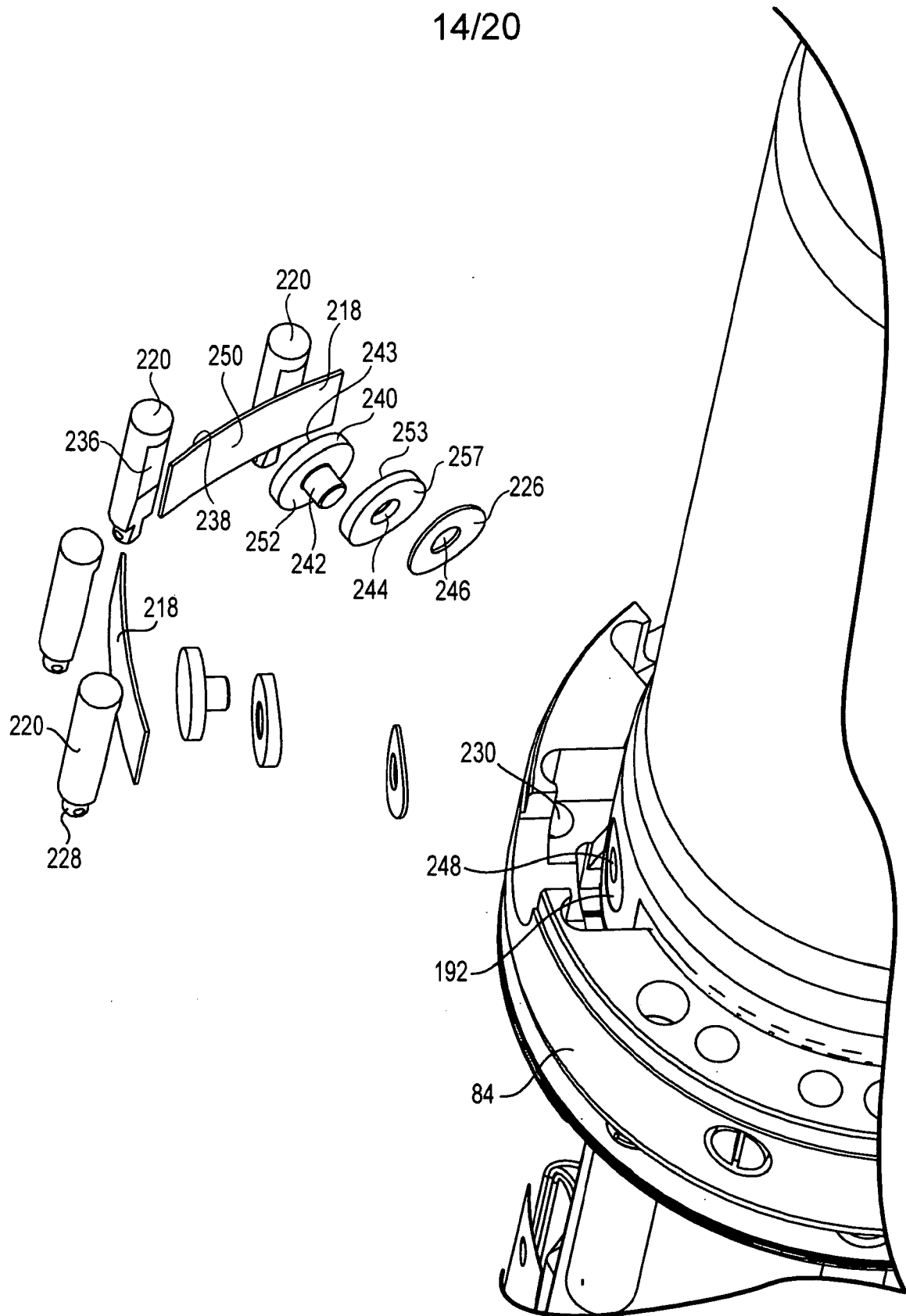


Fig. 14

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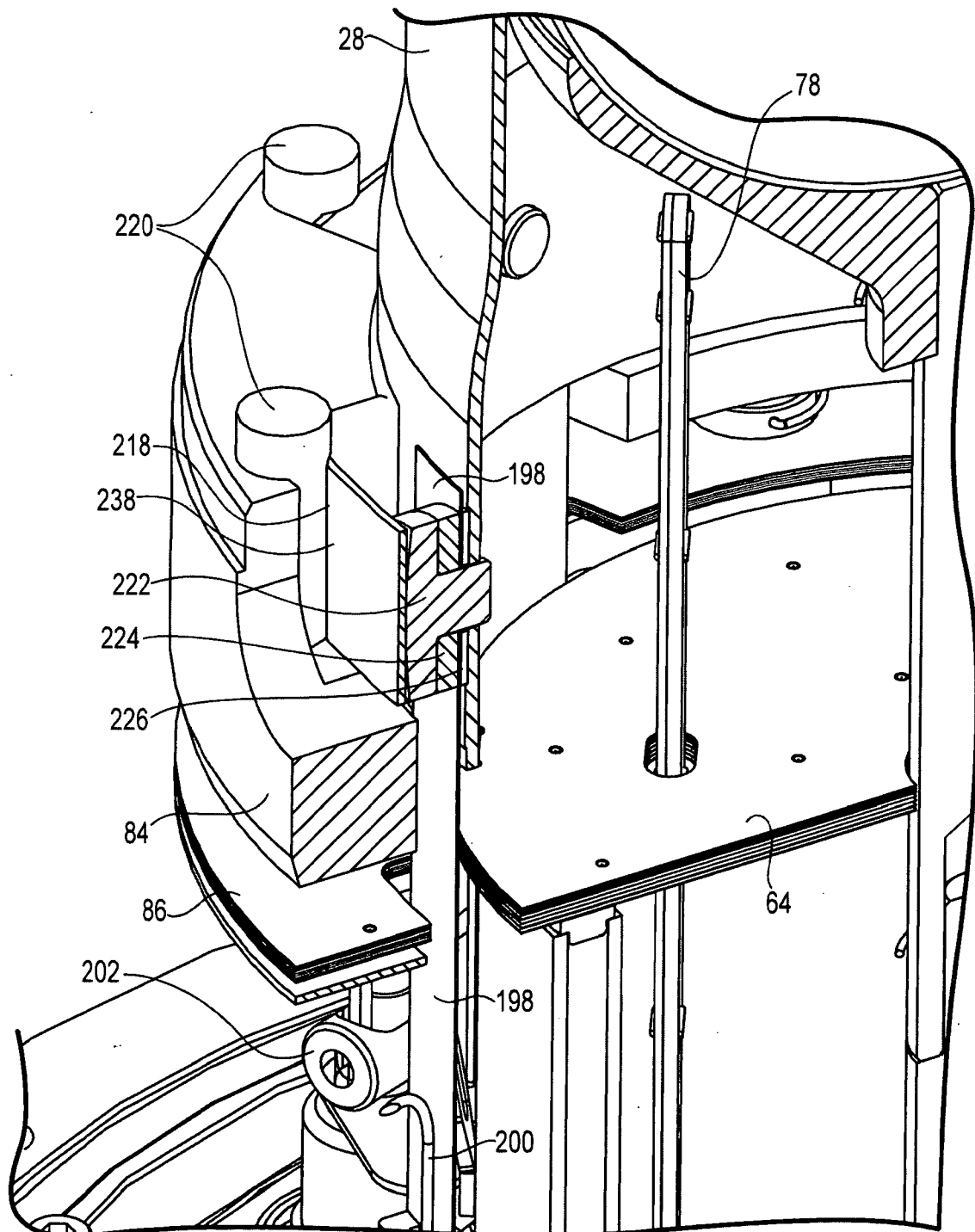


Fig. 15

16/20

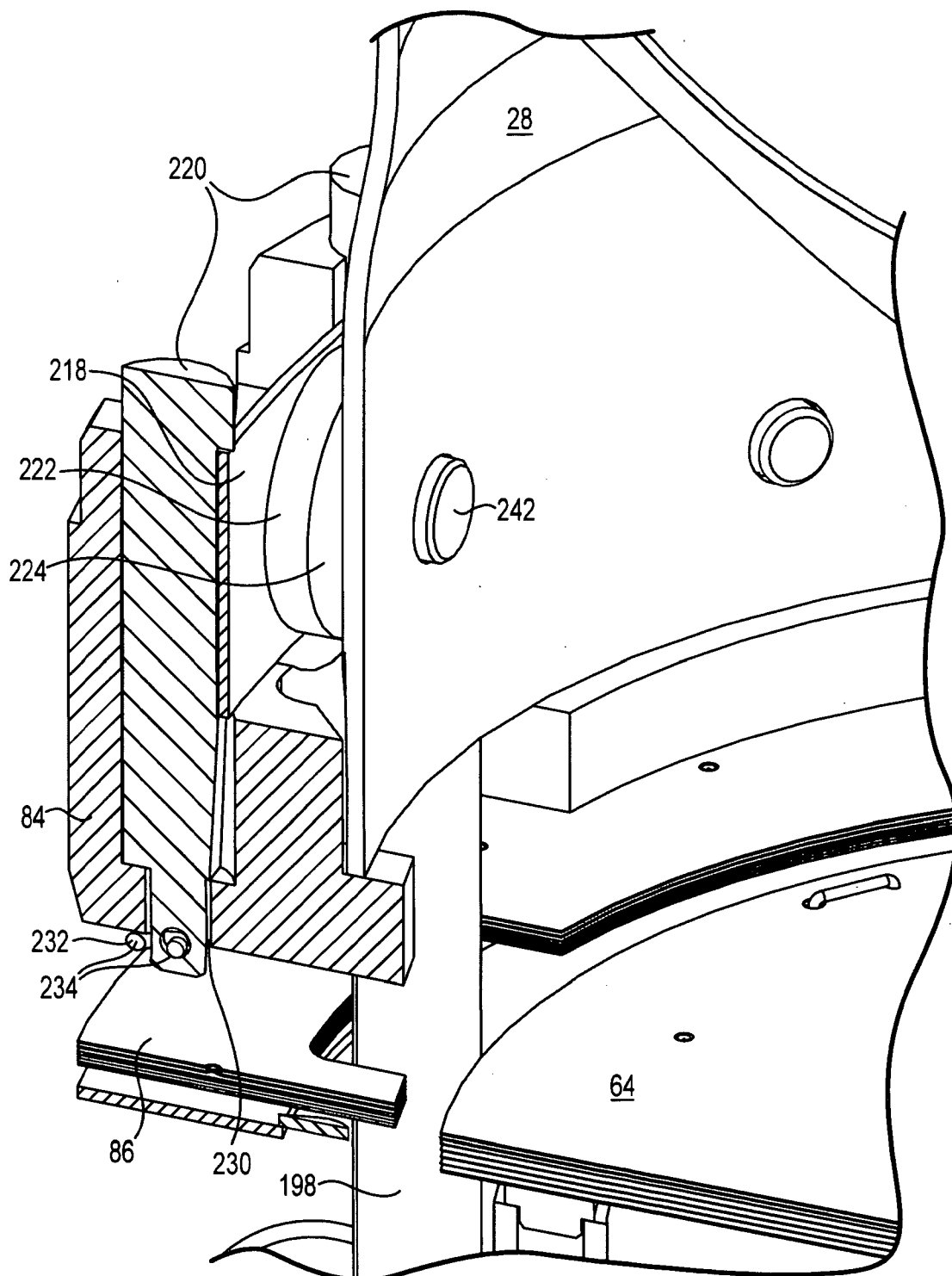


Fig. 16

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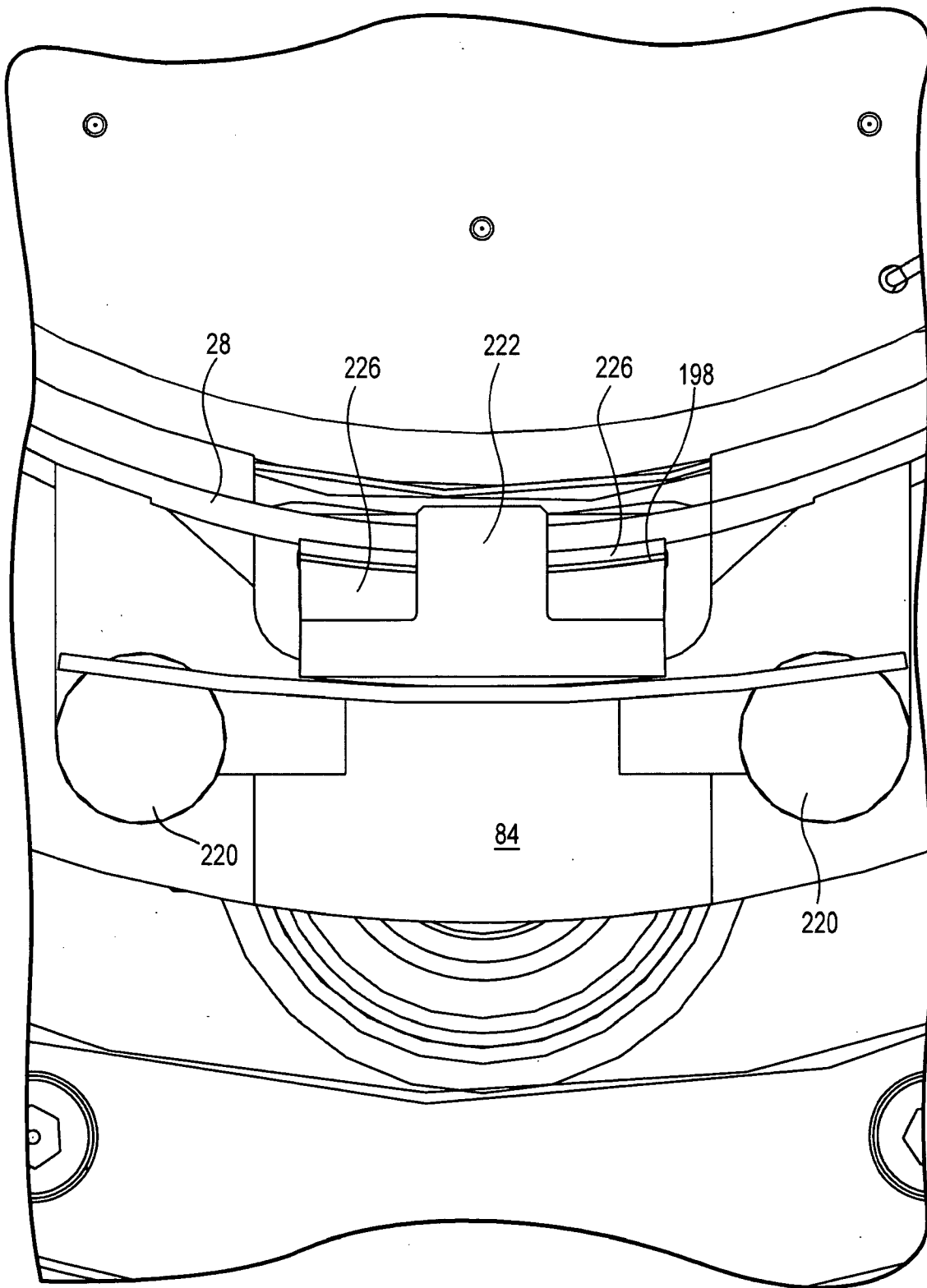


Fig. 17

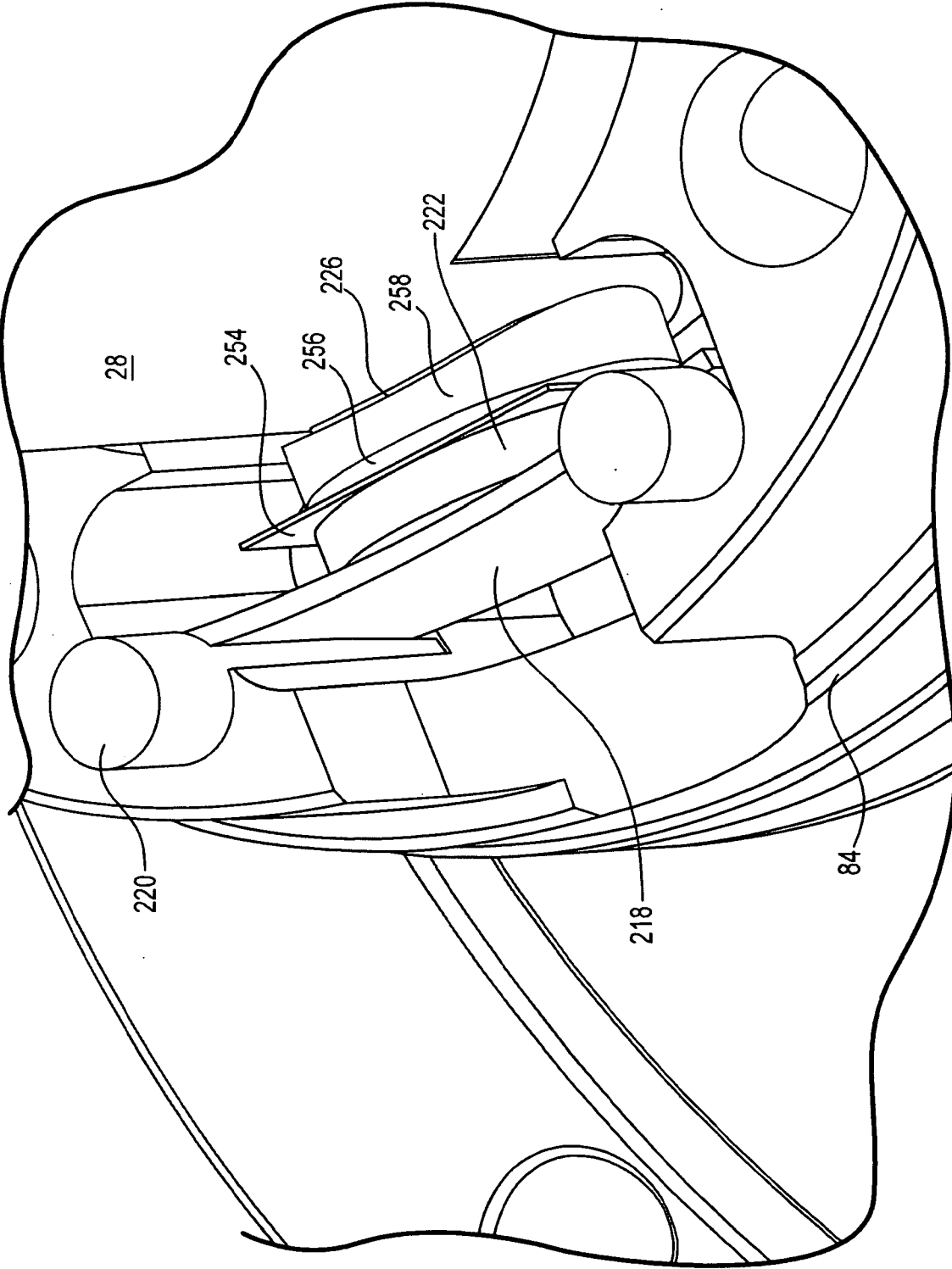


Fig. 18

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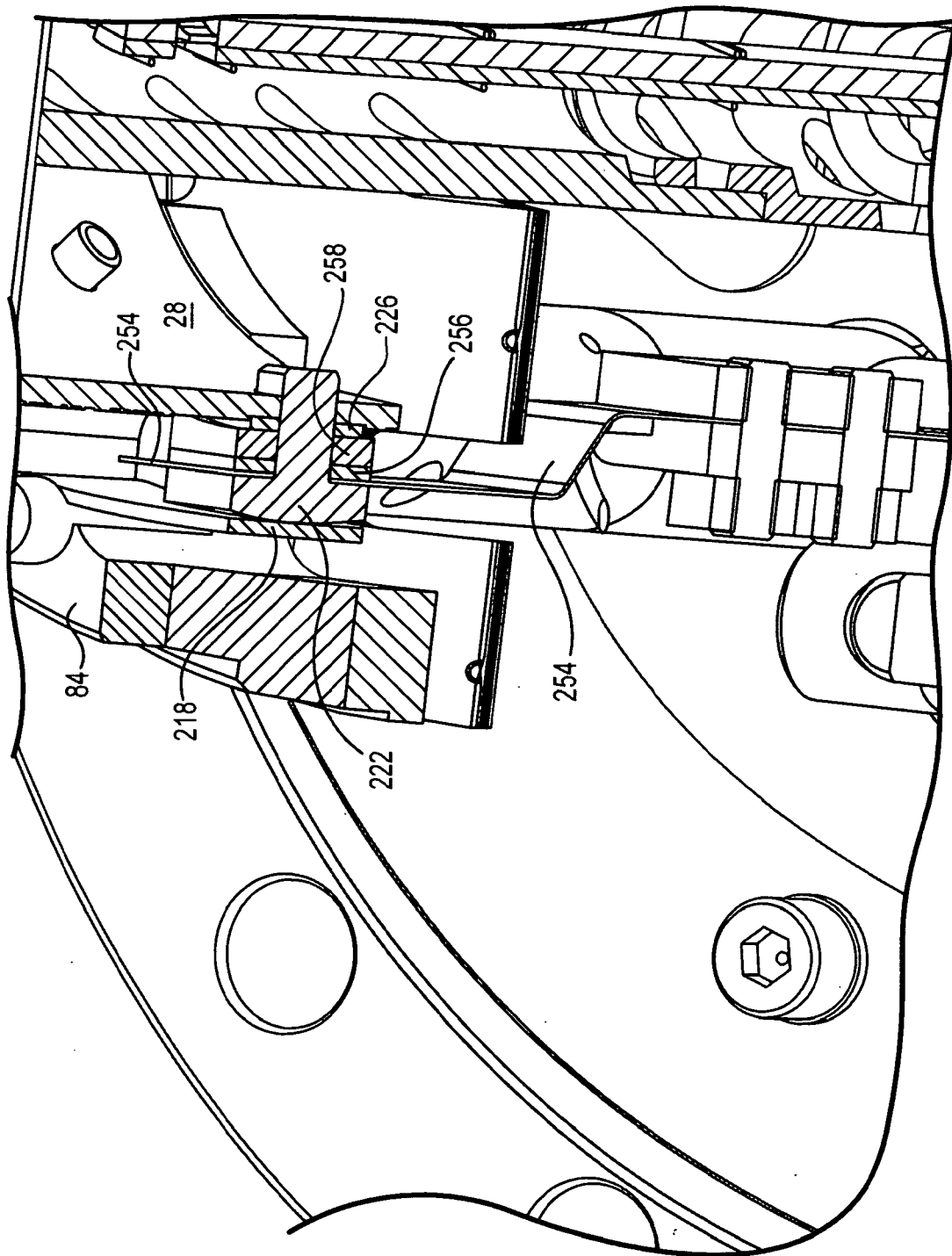


Fig. 19

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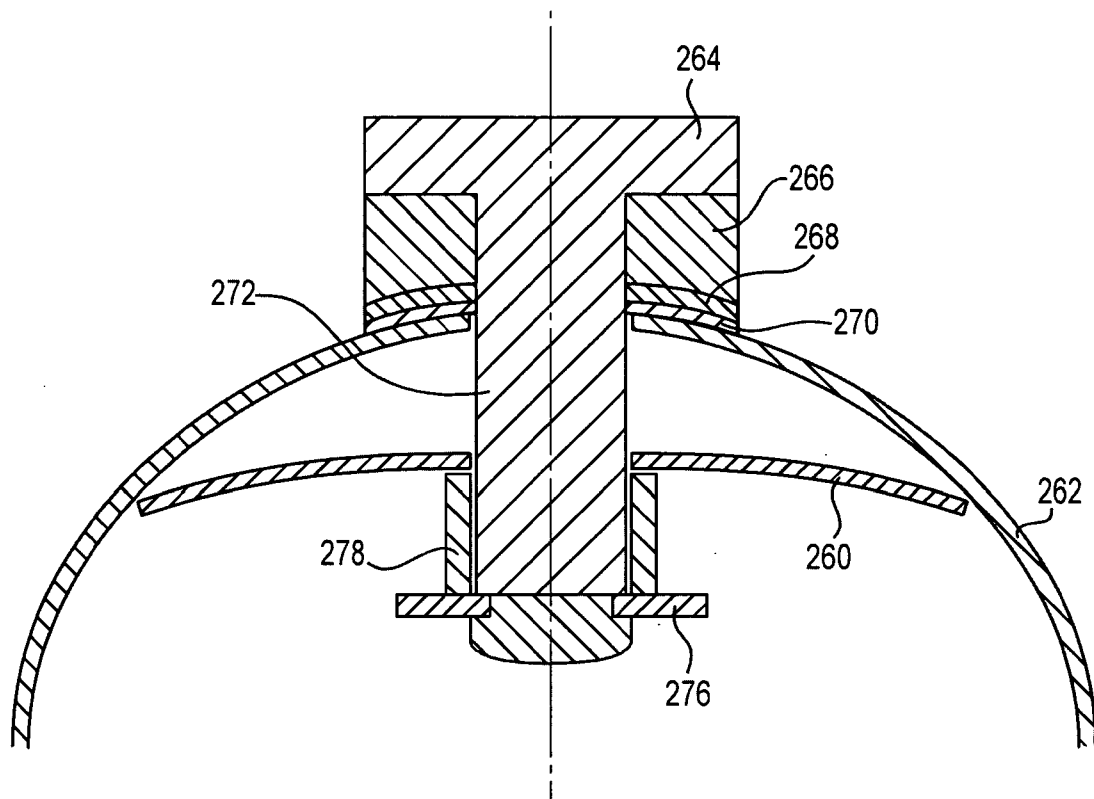


Fig. 20