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(54) **Titre : PILE A COMBUSTIBLE A OXYDE SOLIDE AYANT UNE STRUCTURE DE SUPPORT DE BARRE FLEXIBLE**
(54) **Title: SOLID OXIDE FUEL CELL WITH FLEXIBLE FUEL ROD SUPPORT STRUCTURE**

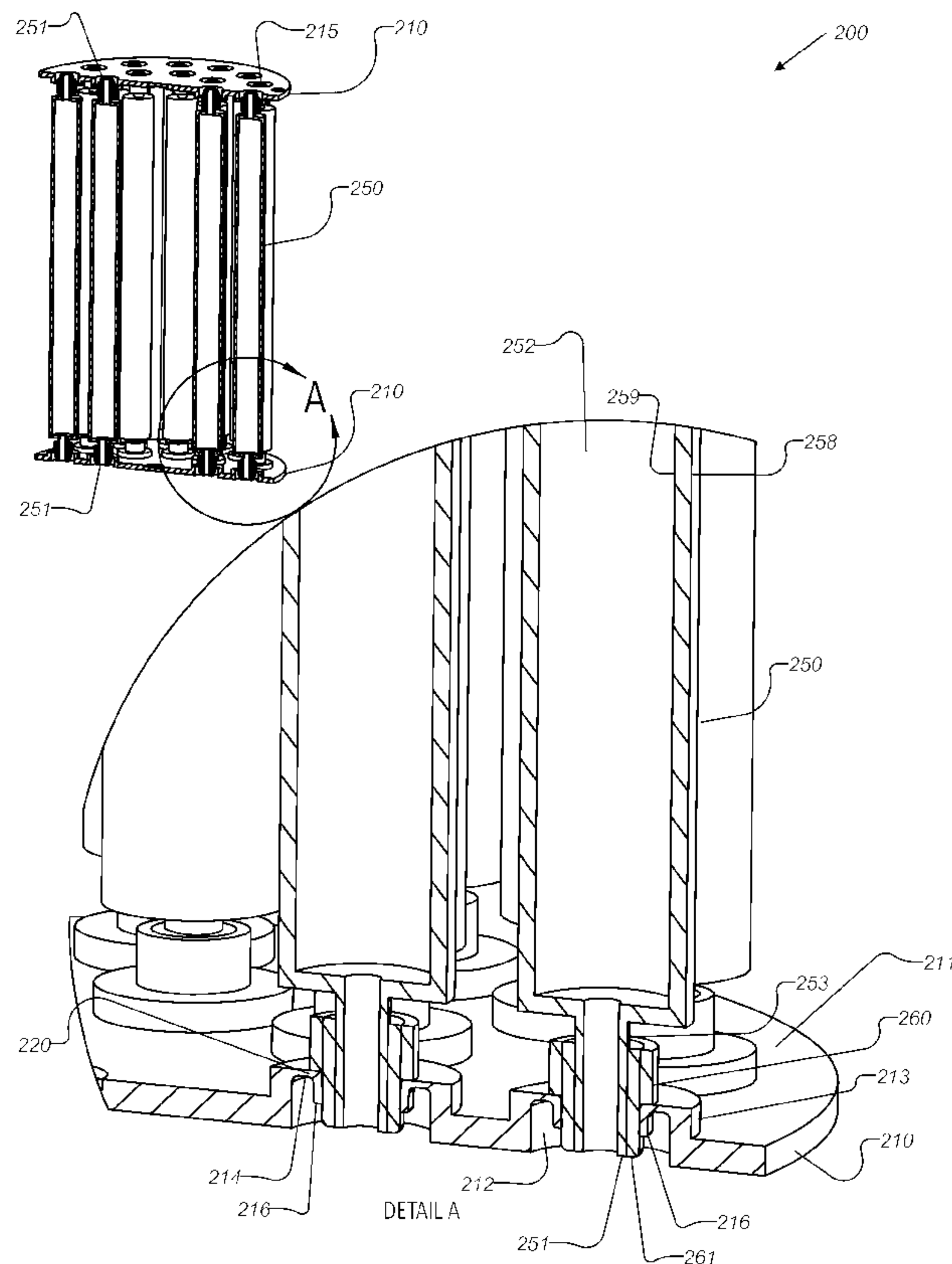


FIG. 3B

(57) **Abrégé/Abstract:**

A rod assembly and method for supporting rods includes opposing end plates for supporting opposing ends of a plurality of solid oxide fuel cell rods with each rod comprising a hollow gas conduit passing there through. Each rod end is supported by an annular

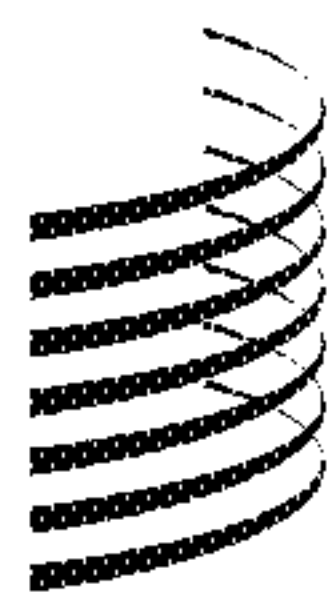


(57) Abrégé(suite)/Abstract(continued):

flexure configured to provide a gas/liquid tight seal between the rod ends and the end plates. Each annular flexure includes a flexible portion surrounding the rod end such that forces imparted to either or both of the rod and the end plate act to elastically deform the annular flexure without damaging the rods. The rod assembly operates and a Solid Oxide Fuel Cell (SOFC) with operating temperatures of 500 to 1000°C.

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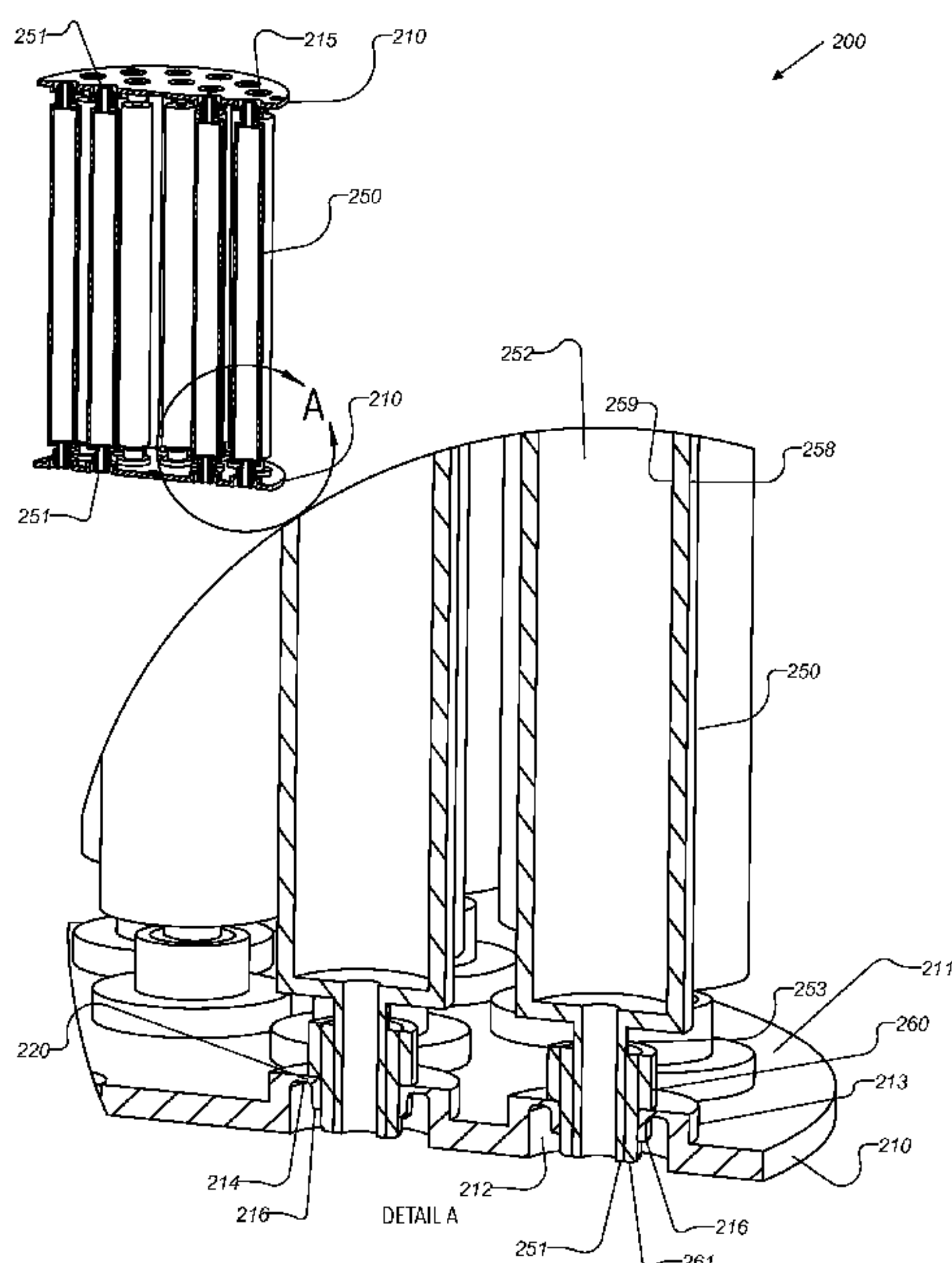


FIG. 3B

(57) Abstract: A rod assembly and method for supporting rods includes opposing end plates for supporting opposing ends of a plurality of solid oxide fuel cell rods with each rod comprising a hollow gas conduit passing there through. Each rod end is supported by an annular flexure configured to provide a gas/liquid tight seal between the rod ends and the end plates. Each annular flexure includes a flexible portion surrounding the rod end such that forces imparted to either or both of the rod and the end plate act to elastically deform the annular flexure without damaging the rods. The rod assembly operates and a Solid Oxide Fuel Cell (SOFC) with operating temperatures of 500 to 1000°C.

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SOLID OXIDE FUEL CELL WITH FLEXIBLE FUEL ROD SUPPORT STRUCTURE

RELATED APPLICATIONS

This application claims the benefit of and priority to U.S. Provisional Patent Application No. 61/859,587 filed July 29, 2013, the contents of which are incorporated herein by reference in their entirety.

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Background of the Invention

1.1 Field of the Invention

[0002] The exemplary, illustrative, technology herein relates to Solid Oxide Fuel Cell (SOFC) systems, methods, and methods of manufacturing. In particular the exemplary, illustrative technology relates to manufacturing and using solid oxide fuel cells.

1.2 The Related Art

[0003] Fuel cells are used to generate power by an electrochemical process. The components that generate power are commonly referred to as “cells.” As the voltage for an individual cell may be relatively low, it is often necessary to connect a plurality of cells, either in parallel or in series, to provide power to a device having a desired operating voltage. Such an array of cells is generally referred to as a “stack” or “bundle.”

[0004] Solid oxide fuel cells (SOFCs) are a particularly useful type of fuel cell because they can operate on an expanded list of fuels, which includes pure hydrogen but also includes hydrocarbon fuels such as propane, gasoline, diesel, kerosene (JP-8 military fuel), ethanol, and other bio-fuels. SOFCs use a ceramic electrolyte and generate current when oxygen ions cross the electrolyte. However, one drawback of SOFCs is the need to operate the fuel cell at high temperature (*e.g.* above 500°C) to process the fuels. The high temperature operation leads to a variety of problems, including thermal creep and increased susceptibility to corrosion, which creates the need to select heat resistant materials (*e.g.* ceramics, Inconel, and other high temperature metal alloys) for such components as the fuel cell stacks, structural elements supporting the fuel cell stacks, and various gas seals.

[0005] Referring now to Figure 1A and 1B, an example conventional SOFC stack (100) comprises two cup shaped opposing end plates (110) with multiple electrolyte rods (150) supported between the opposing end plates. Each rod comprises a ceramic electrolyte, formed from nickel oxide or the like, and each rod acts as a single fuel cell in a fuel cell stack (100) that comprises a plurality of rods. Each rod (150) comprises a hollow conduit (152) surrounded by an outer wall (154) with the conduit having opposing open ends (156). Each conduit conveys a gas or vapor fuel from an input end to an output end. The exterior surface (158) of each rod is coated with a cathode material and the interior surface (159) of each rod is coated with an anode material. One example conventional SOFC device is disclosed in commonly assigned U.S. Appl. Ser. No. 12/367,168 now U.S. Pat. No. 8,304,122 to Poshusta et al., filed on Feb. 6, 2009, entitled *Solid oxide fuel cell system with hot zones having improved reactant distribution* which is incorporated herein by reference in its entirety.

[0006] Fuel is simultaneously flowed through each of the hollow conduits (152) as an oxidant, (*e.g.* air or another oxidant) is flowed over the external surfaces (158) (*e.g.* by a fan, blower, natural convection, or the like).

[0007] Alternatively, conventional solid oxide fuel cells are made with a cathode coating on the interior of the cell (159) and an anode coating on the exterior of the cell (158). These cells

operate with the oxidant flowing through the interior of the rods while fuel passes over the external surface.

[0008] In operation the rods electrochemically react with the fuel flowing over the anode (*e.g.* through the conduit) (152), and with the oxidant passed over the cathode (*e.g.*, the outer surface of the rods) (158). The electrochemical reaction generates a current flow along longitudinal surfaces of each rod. Each of the rods is connected to an anode terminal at a first end and a cathode terminal at an opposing end (not shown) as required for delivering the current flow generated in each rod out of the fuel cell.

[0009] In some conventional SOFC systems, an electric heater or burner burning the same fuel being delivered to the rods is disposed to initially heat the rods from ambient temperature to an operating temperature range of 650 -1000°C in order to initiate the desired electrochemical reaction. Thereafter the heater or burner may not be required as the electrochemical reaction is exothermic and produces sufficient heat to activate and maintain subsequent reaction.

[0010] In a conventional SOFC system, the rods are captured between the opposing end plates (110) which support the rods in an operating position, such that the rods are oriented parallel to each other in a bundle. The end plates also serve as input and output manifolds functioning as end plates of a cylindrical cathode chamber can, which encloses a cylindrical volume between the end plates. Additionally a feed can (not shown) is disposed on an inlet side of rod stack wherein the input end plate acts as a manifold between the feed can and the cathode chamber to prevent fuel from entering the cathode chamber. In particular the input end plate directs fuel through the hollow portion of each rod where it reacts with anode materials disposed on internal surfaces (159) of the rods. Meanwhile oxidant flows through the cathode chamber rod where it reacts with cathode materials disposed on external surfaces (158) of the rods. Accordingly there is a need to seal the flow can at each rod/endplate interface to prevent oxidant from escaping the cathode can and to prevent fuel from entering the cathode can. The end plates (110) may also serve as conductors for conducting current from each fuel cell rod to appropriate electrical terminals (*e.g.* to power connected electrical

loads). In particular opposing end plates (110) may comprise anode and cathode conductors respectively. Moreover, it is desirable to electrically connect the anodes and cathodes of each rod in series so there is a further need to electrically isolate rod external surfaces from rod internal surfaces at the interface between each rod end and the end plates. Accordingly there is a need to electrically isolate the rod/endplate interface to prevent electrical shorts between the rod anode and cathode surfaces.

[0011] One problem with conventional SOFC designs is that it is difficult to attach the ceramic rods (150) to the metal end plates (110) without gas leaks developing at the rod end plate interface after the system reaches a steady state operating temperature (*e.g.* between 650 - 1000°C). This is because the metal end plates and the ceramic rods have different thermal expansion characteristics and thus expand at different rates with increasing temperature. This non-uniform thermal expansion leads to gaps developing at the interface between the rods and the end plates, causing gas leaks, especially after the system reaches its operating temperature.

[0012] Another problem with the rod-to-plate interface is that the materials tend to permanently deform over time as a result of thermal creep which can occur after prolonged high temperature operation even when the stresses involved are below the yield strength of the material. Thermal creep is especially severe in materials subjected to high temperature environments for long periods. Moreover the ceramic rods and metal end plates have different creep characteristics. In the example of the conventional rod end plate interface, the metal end plates (110) are more likely to become permanently deformed at operating temperatures than the ceramic rods because creep in the metal end plates occurs at a lower temperature than creep in the ceramic rods.

[0013] Another problem with conventional SOFC systems is that the high temperature operation leads to excessive oxidation of the metal end plates as a result of constant exposure to the oxidant. Over prolonged use, a buildup of oxidation degrades electrical conductivity across the end plates and may lead to further gas leaks.

[0014] The rod to end plate interface problem has been addressed in conventional SOFC fuel cells by potting the rods in place using a high temperature ceramic potting material such as Aremco's Ceramabond 552 and 668, or the like. More specifically each end plate (110) is formed cup-shaped with a circular base wall (111) and an annular side wall (112) extending toward the opposing end plate. Each base wall (111) includes a plurality of through holes (115) with each through hole sized to receive a rod end there through. Thus the rods (150) are installed through the base walls (111) with a slight protrusion at each end and the annular side wall height is about 0.1 -0.2 inches. Conventionally the rod ends have a clearance fit with respect to holes passing through the end plates. The end plates with installed rod ends are filled with the liquid ceramic potting material (160) which is then cured. In another embodiment, each end plate may include a circular ceramic plate that fits over the outer diameter of each rod and mates with the annular side wall such that liquid ceramic potting material is poured between the end plate and circular ceramic plate and cured to create a seal. The cured potting material (160) seals any gaps between the rods and base wall and mechanically supports each rod in a desired operating position. Thus the potting material (160) overcomes the problems associated with expansion and creep in the metal end plates by sealing each end of the ceramic rods for a length of about 0.1 to 0.2 inches.

[0015] One problem with potting the rod in places is the cost of labor to pot the end plates and the cost of the potting material.

[0016] A second problem with potting the rods in place is that the cured potting material is very stiff and the rods, which are made from brittle, inflexible ceramic materials such as nickel oxide, can break or crack when the rod assembly is bent or twisted during insertion of the rod assembly into its housing. Any cracks in the rods will result in a fuel leak. Moreover due to the permanent attachment of the end plates to the rods by potting, even if only one rod cracks the entire rod assembly becomes unusable and must be replaced.

[0017] A third problem with potting the ends of each rod is that the potted ends do not participate in the electrochemical reaction which reduces the effective length of each rod. This leads to an overall lowering of current generating capacity of each rod of the rod assembly.

[0018] Therefore, there is a need for an SOFC end plate seal that ensures a strong and robust mechanical connection between the rod ends and the end plates and a mechanical connection that is less susceptible to rod damage due to bending or twisting forces applied to the rods during assembly and handling. Meanwhile there is still a need to reliably gas seal the rod end plate interface at operational temperatures (*e.g.* between 650 -1000°C, for example at or around 750 °C), to prevent electrical shorts between anode and cathode surfaces and to provide good electrical terminal contact at each rod end to fully utilize current generated in each rod. There is a further need avoid gas leaks from occurring after prolonged use such as may be caused by dissimilar thermal creep associated with the metal end plates and the ceramic rod ends and or caused by excessive oxidation. Additionally, a desirable end plate seal reduces cost and may allow disassembly and reassembly of individual rods.

Summary of the Invention

[0019] In view of the problems associated with conventional methods and apparatus set forth above it is an object of the present invention to provide an SOFC rod-end plate interface that is less susceptible to rod damage due to bending or twisting of the fuel cell stack. It is a further object of the invention to provide a rod-end plate interface that is less susceptible to developing gas leaks at operating temperatures of the SOFC. It is a still further object of the invention to provide a rod-end plate interface that is less susceptible to developing electrical shorts at operating temperatures of the SOFC system. It is also an object of the invention to provide a rod-end plate interface that electrically isolates anode rod surfaces from cathode rod surfaces at operating temperatures of the SOFC system. It is a further object of the invention to provide a rod-end plate interface with improved manufacturability and reliability and reduced cost. It is another object of the invention to provide an SOFC stack wherein rods may be removed to be cleaned, replaced, or reused.

- [0020] The present inventors have found that a flexible end plate aperture configured to capture a rod ends at room temperature generates sufficient clamping force to hold the rod end in place without fuel leaks. The flexible end plate aperture holds the rod end with sufficient clamping force to overcome changes in clamping force caused by dissimilar coefficients of thermal expansion, and thermal creep associated with ceramic rods mated with metal end plates or other dissimilar materials. The flexible aperture of the present invention maintains leak-free clamping of the rod ends even when the rod assembly is substantially permanently operating at temperatures up to and above 600 °C and preferably between about 650 to 1000°C.
- [0021] In one example a solid oxide fuel cell comprising a fuel rod assembly. The rod assembly includes a fuel rod formed with an outer wall enclosing a hollow longitudinal conduit. Both the outer rod and the conduit are preferable cylindrical. A cylindrical tube stub extends from each end of the outer wall and the hollow longitudinal conduit passes completely through the outer wall and each of the tube stubs.
- [0022] The tube assembly includes a first end plate base wall for supporting one end of the rod and a second end plate wall for supporting the other end of the rod. Each base wall includes a through hole positioned to receive one of the tube stubs extending from each end of the rod. Each through holes includes a flexure element that engages with the tube stub. In one instance the flexure element is integral with the base wall. In another instance the flexure element is a flexure insert installed into the base wall through hole. In another instance the flexure element is formed on a flexure plate attached to the end plate base wall.
- [0023] Each flexure element comprises a flexible portion surrounding a flexure through hole. Each flexure through hole receives an end stub therein. Each flexure through hole is surrounded by a flexible portion formed with a mechanical stiffness that is less than a mechanical stiffness of the rod and each of the end plate base walls and other non-flexible portions of the flexible element.
- [0024] An outside diameter of each tube stub is engaged with the flexure through hole with an interference fit. The interference fit is sized to provide a mechanical retention force suitable

for holding the fuel rod in place and maintaining a gas tight seal between the outside diameter of the tube stub and the inside diameter of the flexure or base wall through hole when the fuel rod assembly is operated at temperatures ranging from 500°C to 1000°C.

[0025] In another example a method includes supporting a plurality of hollow fuel rods between a pair of opposing end plates. In this example each fuel cell rod includes a hollow tube stub extending from each end. The method includes associating a plurality of flexure elements with each end plate. The flexure elements are positioned to interface with rod stubs at locations where the rod stubs are to be supported. In particular each rod is supported between the two end plates with both of its rod stubs supported by a flexure element.

[0026] Each tube stub is engaged with a flexure element with an interference fit between the tube stub and a flexure through hole passing through the flexure element. The interference fit provides a mechanical retention force suitable for holding the fuel rod in place. Additionally the interference fit provides a gas tight seal between the tube stub and the flexure element even when the fuel rod assembly is operated at temperatures ranging from 500°C to 1000°C.

[0027] These and other aspects and advantages will become apparent when the Description below is read in conjunction with the accompanying Drawings.

Brief Description of the Drawings

[0028] The features of the present invention will best be understood from a detailed description of the invention and example embodiments thereof selected for the purposes of illustration and shown in the accompanying drawings in which:

[0029] Figure 1A depicts an isometric view of an exemplary conventional SOFC rod assembly.

[0030] Figure 1B is a cross sectional view of the exemplary conventional SOFC stack depicted in Figure 1A.

[0031] Figure 1C depicts an exploded isometric view of an exemplary conventional SOFC stack end plate and rod.

[0032] Figure 2 is a cross sectional view of an exemplary conventional rod end plate interface.

[0033] Figure 3A depicts an isometric side front view of an exemplary rod assembly according to the present invention.

[0034] Figure 3B depicts an isometric cross sectional detail view of an exemplary rod assembly and an exploded isometric cross sectional detail view of a first exemplary end plate rod interface according to the present invention.

[0035] Figure 3C depicts an isometric cross sectional view of an exemplary end plate formed according to the present invention.

[0036] Figure 4 depicts a cutaway sectional view of a second exemplary rod end plate interface according to the present invention.

[0037] Figure 5A through 5D each depict a cross sectional view of exemplary end plate hole configurations that include annular flexure profile for receiving rod ends according to the present invention.

[0038] Figure 6 depicts a side cross sectional view of a third exemplary rod end plate interface according to the present invention.

[0039] Figure 7A depicts a side cross sectional view of a fourth exemplary rod end plate interface according to the present invention.

[0040] Figure 7B depicts a side section view of an example two piece annular flexure and rod end configuration according to the present invention.

[0041] Figure 8A depicts an isometric section view depicting a fifth exemplary rod end interface according to the present invention.

[0042] Figure 8B depicts an isometric section view depicting a fifth exemplary rod end interface according to the present invention.

[0043] Figure 9A depicts a front section view depicting a sixth exemplary rod end interface according to the present invention.

[0044] Figure 9B depicts a front section view depicting a seventh exemplary rod end interface according to the present invention.

[0045] Figure 10A is an axial view of an exemplary SOFC rod of the present invention

[0046] Figure 10B is a side view of an exemplary SOFC rod of the present invention

[0047] Figure 11A and 11B depict an exemplary embodiment of a two piece end plate according to the present invention.

[0048] Figures 12A, 12B, and 12C depict an exemplary embodiment of an endplate that includes an annular flexure associated rod end plate interface according to the present invention.

[0049] Figure 13 depicts an isometric cross sectional detail view of an exemplary rod assembly and an exploded isometric cross sectional detail view of an exemplary end plate rod interface according to the present invention.

[0050]

Description of Some Embodiments of the Invention

1.3 Overview

[0051] In an embodiment of the invention, an SOFC stack includes at least one end plate formed with a plurality of through holes passing there through for a receiving a rod end therein. In various embodiments each through hole is formed to include an annular flexure for receiving the rod end therein. The annular flexure provides a mechanical interface suitable for engaging with a rod end to mechanically secure the rod end to the end plate and to engage with the rod end with a gas/liquid tight seal. A second end of each rod is preferably interfaced with a second end plate formed with a plurality of through holes passing there

through for a receiving the second end of each rod end therein. Each through hole on the second end plate is formed to include an annular flexure for receiving the second rod end therein. The second rod ends are preferably longitudinally movable with respect to annular flexures they are interfaced therewith to allow for growth in the rod length due to thermal expansion.

[0052] In some non-limited example embodiments described below, each annular flexure associated with a through hole is formed integral with the end plate. In another non-limited example embodiment each end plate mates with a separate flexure plate which includes annular flexures aligned with through holes of the main end plate such that rod ends are received into the annular flexures formed by the flexure plate and the flexure plate and the main end plate are coupled together. In a further non-limited example embodiment, each through hole mates with a flexure insert formed to mate with the through hole and the flexure insert includes a through hole for receiving a rod end there through and flexure elements for engaging with the rod end and allowing movement of the rod end with respect to the end plate.

[0053] In each of the below described embodiments, rod ends are assembled into annular flexures by engaging the rod ends into a through hole of the annular flexure. Preferably in each embodiment, the annular flexure is configured to allow assembly of rod ends with annular flexures without heating either of the mating parts. In a first embodiment each annular flexure is configured to provide an interference fit between the rod end and the annular flexure. In particular this assembly method is used at rod input ends where a liquid/gas seal is preferred to ensure that fuel components enter the rod ends and are prevented from passing through the main end plate at the gas input side. Moreover the interference fit elastically deforms the rod end and the annular flexure and the deformation generates a mechanical retention force that holds the rod end in place while also creating a gas and liquid tight seal not only at ambient temperature but also at desired operating temperatures (*e.g.* ranging from 500°C to 1000°C). Thus the annular flexures of the present invention eliminate the need for potting of the rod ends, thereby reducing assembly labor, improving reliability, and allowing

rod removal for cleaning and or replacement. Preferably the annular flexures of the present invention are configured with a tight enough interference fit that gas leaks associated with thermal creep are avoided even after extensive thermal cycling and extended periods at operating temperatures of the SOFC and is resistant to creep. In an alternate embodiment rod ends are brazed to annular flexures at input ends to provide the desired mechanical retention force and liquid/gas seal.

[0054] In a further embodiment of the invention, the SOFC stack includes two end plates, each including through holes for receiving rod ends and each formed with or interfaced with an annular flexure such that both ends of each rod are engaged with an annular flexure. However only one rod end, e.g. the fuel input end is mechanically retained and liquid/gas sealed at the interface with the annular flexure. At the opposing or gas output end, the rod end interfaces with a second end plate which preferably includes an annular flexure but allows longitudinal movement of the rod end with respect to the annular flexure over the full operating temperature range of the SOFC. Thus each rod end is held in place by an annular flexure which flexes to accommodate some twisting, bending and lateral movement of rod ends during assembly and handling without unduly stressing the rods.

[0055] In another aspect of the invention, a method of assembling an SOFC stack includes assembling first rod ends of a plurality of fuel cell rods into through holes of a first end plate wherein each through hole is configured as an annular flexure such that, when a rod end is inserted into the annular flexure the annular flexure mechanically engages with the rod end in a manner that provides a liquid and gas tight seal.

[0056] In a further aspect of the invention, a method of assembling an SOFC stack includes assembling second ends of the plurality of fuel cell rods into through hole formed through a second end plate wherein each through hole is configured as an annular flexure and wherein, when the second rod end is inserted into the annular flexure the annular flexure mechanically engages with the second rod end in a manner that provides a gas and liquid tight seal.

- [0057] In a further aspect of the invention, a method of assembling an SOFC stack includes assembling second ends of the plurality of fuel cell rods into through hole formed through a second end plate wherein each through hole is configured as an annular flexure and wherein, when the second rod end is inserted into the annular flexure the second rod end is longitudinally movable with respect to the annular flexure.
- [0058] In a still further aspect of the invention, each annular flexure is configured for disassembly from a rod end without causing undesirable damage to the rod end. Thus the present invention includes a method of assembling an SOFC stack and then disassembling the SOFC stack to remove one of more rods and, optionally replace the removed rods with other rods or the same rods (*e.g.* after cleaning). Preferably the annular flexure configurations of the present invention allow assembly and disassembly of rods without application or removal of a potting material, a sealing element, or an adhesive. Thus the SOFC stack of the present invention is configured so that rods may be replaced or reused and is configured so that rods may be removed, cleaned, and reinstalled.
- [0059] In an embodiment of the invention, an SOFC stack is provided with rod end and annular flexure configurations formed to allow assembled rod ends and end plates to be held in place by clamping forces or retaining forces generated by the annular flexures, wherein the flexibility of the annular flexures enables bending and twisting of the assembly without breaking or cracking the rods. More specifically, rod ends and annular flexures of the present invention are configured to transfer mechanical stresses applied to the rods to the annular flexures such substantially all material deformation associated with the mechanical stress applied is transferred to the annular flexure in order to substantially avoid or minimize mechanical deformation of the rods.

1.4 Item Number List

- [0060] The following item numbers are used throughout, unless specifically indicated otherwise.

#	DESCRIPTION	#	DESCRIPTION
100	Prior art SOFC Stack	810	End plate
110	Prior art end plate	815	Through hole
111	End plate base wall	816	Annular flexure
112	End plate side wall	817	End plate bottom surface
115	End plate through hole	818	Flexure top surface
150	SOFC electrolyte rod	851a	Rod end
152	Rod hollow conduit	851b	Rod end
154	Rod outer wall	856	First mating surface feature
156	Rod end	857	Second mating surface feature
158	Rod exterior surface		
159	Rod interior surface	910	End plate
160	Ceramic potting material	915	Through hole
		916	Annular flexure
200	SOFC stack	917	Flexure bottom surface
210	End plate	918	Flexure top surface
211	End plate base wall	951a	Rod end
212	Annular region	951b	Rod end
213	Flexure boss	956	First mating protrusion
214	Annular top wall	957	Second mating protrusion
215	End plate through hole		
220	Annular flexure	1050	SOFC rod
216	Sleeve wall	1052	Hollow conduit

217	Flexure taper start	1053	Tube stub
218	Flexure taper engagement	1055	Rod main body
219	Flexure taper end		
250	SOFC rod	1100	Two component end plate
251	Rod end	1120	Flexure plate
252	Rod hollow cavity	1125	Flexure plate through hole
253	Rod tube stub	1126	Annular flexure
258	Rod exterior surface	1130	Backing plate
259	Rod interior surface	1131	Backing plate body
260	Insulator	1135	Backing plate through hole
261	Insulator leading edge		
		1200	Flexure insert end plate
510	End plate	1220	Flexure insert
515	Through hole	1222	Top annular wall
516a	Annular flexure	1225	End plate through hole
516b	Annular flexure	1226	Sleeve wall
516c	Annular flexure	1235	Backing plate through hole
516d	Annular flexure	1221	Top annular wall surface
		1228	Flexure sidewall mating feature
650	SOFC Rod	1230	Backing plate
651	SOFC rod end	1231	Backing plate surface
		1235	Backing plate through hole
710a	End plate	1238	Through hole side wall

710b	End plate		
716a	Annular flexure		
716b	Annular flexure	1310	End Plate
717	Annular flexure mating feature	1315	Through hole
751a	Rod end	1316	Annular flexure
751b	Rod end	1350	SOFC rod
755a	Recessed capture ring	1353	Tube stub
755b	Recessed capture ring	1360	Electrical insulator
		1370	3rd joint
		1375	Second joint

1.5 Exemplary System Architecture

[0061] Referring now to Figures 3A-4 a first non-limiting example embodiment of the present invention comprises an SOFC stack (200) that includes a pair of opposing disk shaped end plates (210) each including a plurality of through holes (215) positioned to receive an SOFC rod end (251) there through wherein each through hole is associated with an annular flexure described below. Each end plate comprises a disk shaped base wall (211) comprising a material having low susceptibility to oxidation and other heat catalyzed chemical reactions while also possessing suitable elastic deformation and stiffness characteristics to perform as an annular flexure or to support an annular flexure while also providing low thermal creep at SOFC operating temperatures. Preferably the end plates comprise a chromium free high temperature alloy wherein the lack of chromium avoids the potential of poisoning the cathode. In the present example embodiment a nickel-copper alloy is especially preferred, such as Monel 400, which in one example comprises a minimum of 63% nickel, 28-34% copper, a maximum of 2.5% iron, and a maximum of 2% manganese and has a linear coefficient of thermal expansion of 13.9 microns per meter per Kelvin.

[0062] Each of the end plate through holes (215) extends through the end plate and includes an annular flexure (220) surrounding the through hole. In the present embodiment (200) the annular flexure is integrally formed with the end plate as show in Figure 3B and 3C. The annular flexure (220) includes a flexure boss (213) comprising an annular wall extending substantially orthogonally from the end plate base wall (211), an annular top wall (214) extending from the flexure boss and substantially parallel with the end plate base wall (211) wherein the annular top wall (214) comprises a flexible portion having a low mechanical stiffness as compared with the mechanical stiffness of the end plate base wall (211) and compared with the mechanical stiffness of the rods (250a, 250b) so the flexible portion (214) elastically deforms in response to any bending or twisting forces imparted to the rods or the end plate base wall to prevent permanent deformation or breakage of the rods. In addition the annular flexure (220) includes a sleeve wall (216) extending substantially orthogonally from the annular top wall (214).

[0063] The sleeve wall (216) bounds the end plate through hole (215) and engages with the rod end. In particular in cases where a liquid/gas seal is desirable the sleeve wall and the rod ends are configured to provide an interference fit between the rod end outside diameter and the inside diameter of the sleeve wall (216). Alternately a liquid/gas seal may be provided by a brazed joint between the rod end outside diameter and the inside diameter of the sleeve wall (216). Preferably the inside diameter of the sleeve wall (216) is tapered from a larger diameter at the end where it receives the rod end to a smaller diameter at the end where the rod end is engaged with the sleeve wall at a desired engagement length. In particular the sleeve wall has an initial diameter that is larger than the outer diameter of the rod end for receiving the rod end therein and is tapered to a smaller diameter that is smaller than the outer diameter of the rod end for capturing the rod end therein. Alternately or additionally the rod end diameter may be tapered to provide a clearance fit at one end where the rod end is inserted into the sleeve wall (216) and an interference fit at the other end when the rod end is engaged with the sleeve wall to a desired engagement depth.

[0064] In either case when configured for interference fit the sleeve wall (216) is configured to be flexed or substantially deflected by the rod end being inserted through the through hole bounded by the sleeve wall during assembly. Meanwhile the sleeve wall material resists the deformation and responds by maintaining a clamping spring force against the exterior surface of the rod end. At operating temperature the metal end plate expands more than the ceramic rod or ceramic insulator due to the dissimilar thermal expansion coefficients of the mating materials. However according to an important aspect of the present invention the sleeve wall (216) is configured to continue to apply its clamping spring force against the exterior surface of the rod end with sufficient force as required to securely hold the rod end in place and to maintain liquid/gas sealing between the rod end and the sleeve wall (216a) over the entire operating temperature range of the fuel cell. Additionally, at operating temperature the metal end plate and annular flexure may permanently deform more due to thermal creep than the ceramic rod end or ceramic insulator assembled at the rod end due to the dissimilar thermal creep characteristics of the mating materials. However according to an important aspect of the present invention the sleeve wall (216) at least at the gas input end is configured to continue to apply its clamping spring force against the exterior surface of the rod end with sufficient force as required to securely hold the rod end in place and to maintain liquid/gas sealing between the rod end and the sleeve wall (216) over the entire operating temperature range of the fuel cell even when thermal creep tends to permanently deform the mating materials.

[0065] The sleeve wall (216) is configured to be flexed radially outward from the center of the through hole (215), to allow deformation of the sleeve wall along the depth of the through hole (215) as the rod end (251) is engaged. The sleeve wall (216) is further configured to provide a radially inward engaging force in response to the rod end being inserted into the through hole (215) to a desired engagement length. The inward engaging force is sufficient to capture the rod end with a clamping force that is maintained even after prolonged exposure to a temperature ranging from 500 – 1000°C. The clamping force generated by the sleeve wall (216) is sufficient to prevent liquids and gases from passing between the rod end and the through hole (215). Moreover according to an aspect of the present invention, the clamping

force provided by the deformation of the sleeve wall (216) is sufficient to maintain a liquid/gas seal substantially indefinitely at the operating temperature range of the SOFC stack. In one example embodiment, the gas seal is maintained at an operating temperature range is 650 to 1000°C. Other embodiments may be configured to operate at temperatures greater than or less than this range without deviating from the present invention.

[0066] Each of the rods (250) comprises an annular tube wall having an inner wall surface (259) and an outer wall surface (258). The inner wall surface (259) bounds a hollow cavity or conduit (252) that longitudinally penetrates through the entire longitudinal length of the rod from end to end. The interior surface (259) of the rods (250) includes an anode region, such as may be formed by coating internal surfaces of the rod with an anode material layer that is exposed to fuels passing through the hollow cavity. The exterior surface (258) of the rods includes a cathode region, such as may be formed by coating external surfaces of the rod with a cathode material layer that is exposed to an oxidant flowing across the exterior surface. In some embodiments the cathode and anode regions comprise substantially the entire internal and external rod surfaces respectively. In further alternate embodiments SOFC rods are configured with a cathode region on the interior surface of the rod and an anode region on the exterior of the rod. The interior of these rods is exposed to an oxidant while the exterior is exposed to fuel.

[0067] In a specific example embodiment of the present invention a fuel is delivered into each rod at rod input ends and exits each rod at rod output ends and reacts with the anode layer on the internal surfaces of the conduit. As will be understood by those skilled in the art it is desirable to liquid/gas seal the interface between rod input ends and the end plate to prevent fuel components from passing through the end plate except through the hollow conduits inside each rod. Conversely a liquid/gas seal may not be required at the rod output ends but may be desirable in some embodiments. Instead it may be preferable to allow rod output ends to move longitudinally with respect to the end plate and or with respect to the annular flexure supporting the rod output ends. In particular longitudinal movement at the output ends allows the rods to increase in longitudinal length as rod temperature increases without

inducing longitudinal stresses in the rods. While some rod length increase can be accommodated by deformation of the annular flexure and or the end plate, in a preferred embodiment the interface between rod output ends and the through hole receiving the rod output ends, whether passing through the end plate or the annular flexure, provides a slight clearance fit with sufficient clearance to allow movement of the rod end with respect to the through hole.

[0068] Thus the annular flexures (220) of the present invention provide a gas and liquid tight seal and a retention force to each rod input end irrespective of whether the rod comprises an internal or external anode surface. Additionally the annular flexures (220) of the present invention at each rod output end provide a restraining force substantially preventing the rod output end from lateral movement while allowing longitudinal movement of the rod output end due to thermal expansion. However annular flexures at both ends deform to accommodate lateral movement of the rods due to rod bending and or twisting during assembly and handling of the SOFC stack. The annular flexures of the invention are also useful for SOFCs that include rods with anode and cathode surface area coverage that includes less than the entire rod length.

[0069] The rods (250) themselves are made of a material with low thermal expansion, such as a metal ceramic blend. In an embodiment rods are made from a nickel oxide ceramic, which has a linear coefficient of thermal expansion of 9 to 12 microns per meter per Kelvin at 25 °C. Any ceramic with a low thermal expansion that does not adversely chemically react with the fuel or oxidant is sufficient for use in the rods. In the present example embodiment, rods (250) are substantially cylindrical tubes with an outer diameter of 10mm, a 1mm wall thickness, and a 120mm length. In the present example embodiment, rod ends (251) comprise tube stubs (253) that have a smaller diameter than the main body of the rods (250), for example having outer rod stud diameter of 3mm with a main body rod outer diameter of 10mm. Each tube end (253) includes an annular wall surrounding a through conduit. In a preferred embodiment each tube stub (253) is formed by a metal end cap (1352) such as

shown in Figure 13, which attaches to the rod end such as by a press fit or solder joint and protects the rod end from damage.

[0070] In the first example embodiment each rod end interfaces with a metal end cap (1352) which in turn interfaces with an electrical insulator (260, 1360) assembled with the tube stub (253) so that when assembled, the electrical insulator (260) is positioned between the tube stub and the annular flexure (220). Insulator (260) serves to prevent an electrical connection between surfaces of the rod (250) or the metal end cap (1352) and the metal end plate (210) or annular flexure (220). Thus in the present example embodiment, the internal diameter of the end plate through hole (215) and the external diameter of the electrical insulator (260) are sized to provide an interference fit on the input side and a slight clearance fit on the output side as described above. In the case of the interference fit between the electrical insulator and the sleeve wall (216), a radially inward engaging clamping force engages the electrical insulator such that the electrical insulator (260) is captured by the sleeve wall (216). In the case of a slight clearance fit the electrical insulator and attached rod end is maintained in a desired axial position while allowing longitudinal movement responsive to thermal expansion.

[0071] The electrical insulator (260) may be formed using any material that is electrically insulating and that is capable of withstanding the operating temperatures of the fuel cell. In the present example embodiment, insulators are made from non-conductive ceramic material such as high temperature ceramic insulator material comprising alumina, zirconia, and/or silica. In other non-limiting example embodiments, the electrical insulators are made from electrically insulating high temperature glass. In the present example embodiment, insulator (260) has an outer diameter of 0.182 inches and an inner diameter of approximately 3mm, sized to fit tube stub (253). In a further embodiment, a tube stub (253) is made from an electrically insulating ceramic material and integrally formed with or attached to the rod end. In an example of such an embodiment, the outer diameter of the tube stub is 0.182 inches.

[0072] In the present example embodiment, illustrated in Figure 3B, an insulator distal end (261) is assembled flush with tube stub distal end (251). In other non-limiting example embodiments, a portion of rod end (251) protrudes from the insulator (260) to expose surfaces of the tube stub (253) below the insulator and the end plate to provide a terminal end for attaching an electrical connector to the rod tube stub (253).

[0073] Referring now to Figure 4, a side section view shows the insertion of rod end tube stubs (253a, 253b) into mating through holes extending through electrical insulators (260a, 260b) and wherein each electrical insulator includes an outside diameter sized to insert into through holes formed by the into annular flexures (220a, 220b) to illustrate the deformation of the sleeve wall (216a) and generation of clamping force in the present example embodiment. In this embodiment, each tube stub (253a, 253b) is surrounded by an insulator (260a, 260b). Insulators (260a, 260b) comprise insulating ceramic material and function to electrically insulate each rod (250a, 250b) from the metal plate (210). The insulators may be attached to the tube stubs (253) by brazing, potting with liquid ceramic material, by interference fit, or by other suitable attaching process. In other embodiments, the rod tube stub comprises an electrical insulator (260) otherwise formed as a portion of rod (250) or as a separate end cap (1352).

[0074] A first fuel rod or tube (250a) is shown partially assembled into the end plate through hole formed by the sleeve wall (216a). In this embodiment, the sleeve wall (216a) is formed with a tapered through hole diameter wherein at the beginning of the taper (217a) the inner diameter of the sleeve wall is oversized relative to the outer diameter of the insulator (260a). When assembled so that the outer diameter of the insulator is concentric with inner diameter of the sleeve wall, the outer surface of the insulator proximate to the leading edge of the insulator (261a) makes contact with the inner surface of the sleeve wall at engagement (218a) that is approximately half-way along the sleeve wall length. At engagement (218a) the inner diameter of the sleeve wall (216a) is approximately equal to the outer diameter of the insulator (260a) or rod end. At the end of the taper (219a), the inner diameter of the sleeve wall (216a) in a non-deformed, as built, state is undersized relative to the outer diameter of

the insulator (260a). In a particular embodiment the sleeve wall (216a) is manufactured with 0.005 inch interference fit at the end (219a) of the flexure, relative to the outer diameter of the insulator (260) or rod tube stub, as the case may be.

[0075] A second fuel rod or tube (250b) is shown fully assembled into sleeve wall (216b). The assembly of rod (250b) into sleeve wall (216b) has deformed the flexure so that the inner diameter of the flexure tapered end (219b) is defined by the outer diameter of the insulator (216b). When fully assembled into sleeve wall (216b), the leading edge (261b) of insulator (260b) protrudes from the end (219b) of the sleeve wall so that it may be contacted by an electrical connector. The portion of the sleeve wall (216a) that was built with an inner diameter undersized relative to the outer diameter of the insulator (260a) has been deformed by the insertion of the insulator (260a) (or tube stub end) into the through hole (215). This portion of the sleeve wall (216b) has been flexed or elastically deformed to an inner diameter substantially equal to the outer diameter of the insulator. This deformation of the sleeve wall (216a) is sufficient to create a clamping force on the insulator or tube stub end without annealing the flexure material (*e.g.* without heating the end plate to inset the rod as is sometimes done to assemble interference fit assemblies). The clamping force creates a liquid and gas tight seal and the interference fit is maintained with thermal expansion and contraction of the mating materials as the material are cycled to operating temperature and subsequently cooled. In some embodiments, a portion of tube stub (253) protrudes from insulator (260), extending beyond insulator leading edge (261) for interfacing with an electrical connector. It is further noted that the thickness, engagement length, surface finish, interference fit dimensions and material composition of the sleeve wall (216a) are each variables that can be adjusted to modify the clamping force provided by engagement with a rod end and that each of the these parameters may be changeable without deviating from the present invention.

[0076] In a further aspect of the present invention the flexure annular top wall (214) comprises a flexible portion surrounding the through hole which is flexed or elastically deformed when bending or twisting forces acting on the SOFC rods (250) are transferred to the annular top

wall (214). In particular the top annular wall (214) is formed with a small material thickness as compared to the material thickness of the end plate (211) such that the annular top wall (214) or flexible portion is less mechanically stiff than the end plate which has a thicker base wall (211). Preferably the annular top wall (214) is also less stiff than the rod end caps or the SOFC rods such that forces acting on the rods or the end caps tend to flex or elastically deform the annular top wall (214) rather than deform the brittle rods or rod end caps. In particular the present invention includes a low stiffness annular flexible region surrounding each of the end plate through holes (215) for elastically deforming in response to bending or twisting forces imparted to the SOFC rods while the rod are being assembled to the end plate and while the end plates are being assembled as a fuel cell.

[0077] The low stiffness annular region is formed by reducing the thickness of the end plate base wall (211) proximate to each through hole (215) to reduce the stiffness of the end plate surrounding each through hole. The material thickness may be reduced by machining material thickness from one or both sides of the end plate and in particular in the patterns shown in Figures (3C, 4, and 5-9). In one non-limiting example the annular top wall (214) and the sleeve wall (216a) are formed with 25-50% less material thickness than the end plate base wall. It is further noted that at least the thickness, area and material composition of the annular flexure are each variables that can be adjusted to modify the mechanical stiffness of the annular flexure and that any of these parameters may be changeable without deviating from the present invention.

[0078] In the present exemplary, non-limiting embodiment, the annular flexures and corresponding through holes are machined into the end plates which are formed from Monel 400. In a preferred embodiment, the end plate base wall (211) has a thickness of approximately 0.068 inches. Each through hole (215) is surrounded by a circular flexure boss (213) extending from a top surface of the plate (210) and with an overall plate thickness of the base wall plus the flexure boss of approximately 0.140 inches at the boss (213). The sleeve wall (216) and the annular top wall (214) are formed by reducing wall thicknesses by machining. In a preferred embodiment each of the sleeve wall (216) and the annular top wall (214) has a

material thickness of approximately 0.02 inches. In alternative embodiments the plate and flexure dimensions are adjusted based on design parameters such as, for example, operating temperatures, designed clamping force, and tube or insulator material properties, as will be readily understood by a person having skill in the art.

[0079] In additional embodiments annular flexures are formed in end plates that are not round. In an exemplary embodiment, one or more rows of through holes are formed in a plate that is formed with a rectangular shape. At least one of the through holes, and in some embodiments all of the through holes, are each surrounded by an annular flexure. In an embodiment, a plate is configured with a single through hole, surrounded by an annular flexure.

[0080] In further embodiments, end plate (210) may be formed from material other than Monel 400. For example, an alternative high temperature, low chromium alloy may be used. In an embodiment, end plate (210) is formed from inconel material. The thickness of the end plates and thickness of the flexure, as well as other dimensions such as taper of the flexure, may be changed in alternate embodiments to accommodate the properties of alternative material. For example, a flexure is formed with a reduced thickness when end plate material is stiffer than Monel 400.

[0081] Manufacturing processes other than machining may be used to form the end plates. For example, end plates and end plate features may be formed by one or more processes, or a combination of processes, such as casting, machining, EDM, laser cutting, stamping, forming, etc.

[0082] In further example embodiments shown in Figures 5A, 5B, 5C, and 5D the end plate (510) comprises a plurality of end plate holes (515) positioned to receive rod end stubs therein. Each end plate through hole (515) is surrounded by flexible region which is the present example is an annular flexure (516a-d) formed in the end plate (510) by removing metal from one or both sides of the end plate (510) in an annular pattern surrounding the through hole. The reduced material thickness of the annular pattern reduces the mechanical stiffness of the

annular pattern as compared to the mechanical stiffness of the surrounding end plate. In particular this allows the reduced thickness material of the annular flexure to flex or substantially elastically deform in response to forces acting on the annular flexure. Moreover by proper selection of the flexure material and flexure material thickness the flexure material can be caused to flex or elastically deform in response to typical assembly forces imparted to the rod ends or end plates without plastically or permanently deforming the annular flexure or either of the rods or the end plates.

[0083] Each of the annular flexures (516) surrounds a through hole (515) for installing a rod end there through. The through hole (515) is configured to have an effective inner diameter that is undersized relative to the outer diameter of the rod end to be installed there through. As shown in Figure 6, rod (650) is installed in end plate (510) which includes annular flexure (516a) having reduced material thickness as compared to the surrounding end plate. When a rod end (*e.g.*, 651) is inserted into through hole (515) the annular flexure (516a) flexes or elastically deforms in response to the rod end insertion forces, deforming to an extent that allows the rod end to be inserted into the through hole. Deformation of the flexure provides clamping force on the rod end and creates a gas and liquid tight seal between the flexure and rod end. Moreover the diameter of the through hole (515) and the rod end are sized to allow insertion without heating either part in order to avoid annealing the flexure material which would tend to alter the material spring constant, possibly preventing good seal and or clamping. Similarly any of flexures (516b, 516c, or 516d) operate in substantially the same manner.

[0084] Referring now to Figure 13, an isometric section view shows the insertion of rod end (1350) into a rod end cap (1352) which includes a tube stub (1353) extending therefrom. The tube stub is formed with a longitudinal fluid conduit (1320) extending there through. The conduit (1320) is in fluid communication with the fluid conduit extending through the rod (1350) such that fuel enters or exits the rod conduit through the fluid conduit (1320). An annular electrical insulator (1360) surrounds the tube stub (1353). The electrical insulator includes a through bore for receiving the rod stub there through and is formed with an outside diameter

sized to mechanically interface with annular flexure through hole (1315) which passes through an annular flexure (1316) formed in end plate (1310). The rod end includes three joints or mechanical interfaces, one used to attach the rod end cap to the rod end, a second (1375) used to attach the electrical insulator (1360) to the tube stub (1353) and a third (1370) used to attach the electrical insulator (1360) to the annular flexure (1316). At the gas input side each of the three joints is preferable liquid and gas sealing. According to the present invention all three joints may be brazed or press fit to provide the desired mechanical attachment and liquid/gas seal. At the gas output side a liquid gas tight seal may be desirable in some embodiments, however a preferred embodiment is to liquid gas seal the first and second joints using a press fit or solder joint and provide a clearance fit at the third joint (1370) to accommodate rod lengthening as the rod heats up during operation. In particular the clearance fit is at the third joint between the electrical insulator and the annular flexure through hole allows movement of the electrical insulator outside diameter with respect to the diameter of the flexure through hole.

[0085] In one non-limiting example embodiment the rod end cap (1352) including the tube stub (1353) comprises a corrosion resistant high temperature steel alloy e.g. Inconel which is used to avoid thermal creep, corrosion and the electrical insulator comprises a high temperature ceramic material. In another non-limiting example embodiment the rod end cap including the tube stub comprise an electrical insulating material such as a high temperature ceramic material and in that case the electrical insulator (1360) is not required between the tube stub and the annular flexure.

[0086] Each brazed interface joint includes high temperature metallic braze preferably including a brazing material comprising alloys that include silver and or a palladium. Preferably the brazing material maintains its mechanical and sealing properties between room temperature and the operating temperature of the SOFC system e.g. 500-1000°C. As will be recognized by those skilled in the art, different brazing materials and techniques will be used to braze metal to ceramic, ceramic to ceramic and ceramic to metal. Generally the brazing compounds may include metallic alloys comprising one or more of the following elements:

Ni, Cu, Ti, Zr, Y, La, Ag, Au, V, Si, Sn, and/or their oxides or nitrides. In an example embodiment the brazing material includes ceramic oxide or non-oxide phases or ceramic particle dispersed throughout.

[0087] In addition to providing the clamping force, the annular flexures of the present invention flex or elastically deform in response to bending or twisting forces applied to the rods (*e.g.* rods 250) or transferred to the rods by forces acting on the entire rod assembly (*e.g.* 200). Thus the annular flexures of the present invention tend to prevent rod damage during assembly or disassembly of the fuel cell rod assembly by transferring bending and twisting forces from the rods to the annular flexures. In particular according to the present invention the annular flexure is less mechanically stiff than either the rods or the end plates specifically to transfer any forces that tend to bend or twist the rods or the rod assembly to annular flexures. Moreover forces applied to or transferred to the rod ends are transferred to the annular flexures which flex or elastically deform in response to the transferred forces. This is in contrast with conventional rod assemblies, which tend not to transfer bending or twisting forces applied to the rods or the rod assembly to a flexible element, thereby allowing the bending or twisting forces applied to the rods to act on the rod with resulting cracking and or breaking of the rods.

[0088] According to a further aspect of the present invention each rod ends are removable from annular flexures. In this case a longitudinal force is applied to a rod that tends to pull the rod end out of engagement with the annular flexure. The longitudinal force flexes or elastically deforms the annular flexure in response to the rod end insertion forces, deforming the annular flexure to an extent that allows the rod end to be pulled out of engagement. Thereafter another rod end or the same rod end can be reinserted into the flexure without causing undesirable damage to the flexure or the rod such that any one of or all of the rods can be disassembled from each end plate and the end plate and or the rods can be reused to build another rod assembly.

[0089] In another example embodiment shown in Figure 7A and 7B, each rod end (751a, 751b) is formed with a recessed capture ring (755a, 755b) provided to engage with the annular flexure (716a, 716b) of end plate (710a, 710b) when the rod end is installed. Annular flexure (716b) includes a mating feature (717) that mates with recessed capture ring (755b) when rod end (751b) is installed. The capture ring (755a, 755b) is machined or formed in the rod ends and conveniently defines an engagement length of the rod ends. The annular flexure (716b) is further formed with a mating feature (717) formed inside the end plate through hole for engaging with the rod end mating feature (755b) and defining an engagement length of rod end (751b). Additionally the engaged features (717) and (755b) provide a partial labyrinth seal or tortuous path that improves the gas and liquid tight seal formed by the annular flexure surface (717). As described above, the rod ends are the ends of metal rod stubs such as are provided by a rod end cap (1352) shown in Figure 13.

[0090] In embodiments shown in Figures 8A and 8B, each rod end (851a, 851b) includes one or more mating surface features (856, 857) having an outer diameter larger than the outer diameter of the rod end. As depicted in Figure 8A, rod end (851a) includes a mating surface feature (856) configured to contact a first surface (817) of end plate (810) when rod end (851a) is installed. The contact of mating surface (856) with plate surface (817) defines an engagement length of the rod end as well as provides a partial labyrinth seal tortuous path that improves the gas and liquid tight seal formed by the flexure surface (817).

[0091] As depicted in Figure 8B, rod end (851b) includes first mating surface (856) configured to mate with surface (817) of end plate (810) and additionally include second mating surface (857). The second mating surface (857) is configured to pass through the circular through hole (815) that is surrounded by annular flexure (816). When rod end (851b) is installed, second mating surface (857) is positioned in contact with top surface (818) of flexure (816) while first mating surface (856) is in contact with end plate surface (817). Second mating surface (857) and first mating surface (856) further define engagement length of rod end (851b). Mating surface (857) is further configured to provide a partial labyrinth seal tortuous path that improves the gas and liquid tight seal formed by the flexure surface (818). In

further embodiments either one or both mating surfaces (856, 857) plastically or elastically deform when rod end (851a, 851b) is assembled with flexure (816), wherein the deformed mating surface conforms to the shape of flexure (816). In each case the surface feature (856, 857) may comprise an electrical insulating material that improves electrical isolation of the rod end from the end plate. In each case the surface feature (856, 857) may be integrally formed on the rod end stub on the electrical insulator attached to the rod end stub or separately attached to the rod end stub.

[0092] In embodiments shown in Figures 9A and 9B, each rod end (951a, 951b) includes one or more annular mating protrusions (956, 957). As illustrated in Figure 9A, rod end (951a) includes mating protrusion (956) which is configured to contact a bottom surface (917) of flexure (916) when rod end (910a) is assembled into through hole (915) that is surrounded by flexure (916). Mating protrusion (956) defines an engagement depth of rod end (951a) and provides a partial labyrinth seal tortuous path that improves the gas and liquid tight seal formed by the flexure surface (917). As shown in Figure 9B, rod end (951b) includes first mating protrusion (956) that, when rod end (951b) and flexure (916) are assembled, contacts with first surface (917). Rod end (951b) further includes second mating protrusion (957) that passes through flexure (916) and mates with second surface (918) when the rod end (951b) and flexure (916) are assembled. Second mating protrusion (957) further defines engagement length of rod end (951b) and provides a partial labyrinth seal tortuous path that improves the gas and liquid tight seal when installed in contact with flexure (916) and flexure surfaces (918, 917).

[0093] In each of the above described embodiments, the rod outside diameter provided to engage with the end plate through hole is larger than the end plate through hole diameter of the annular flexure provided to receive the rod end stub therein and in the case of the capture ring the base diameter of the capture ring is larger than the inside diameter of the annular flexure. The rod end is inserted into the annular flexure by applying a longitudinal force to the rod directed to insert the rod end through the inside diameter of the annular flexure. The longitudinal force is sufficient to bend or flex the annular flexure sufficiently to allow

engagement with the rod end. The depth of engagement may be defined by a depth gauge tool or by engagement with a capture ring (*e.g.*, 755a, 755b) or other locating features (*e.g.*, 856, 857, 956, or 957).

[0094] In still further fuel cell designs the SOFC tube stack (*e.g.*, 200) includes an inlet tube sheet and an outlet tube sheet, which are end plates at an inlet end of the fuel cell rods and at an outlet end of the fuel cell rods. In such an embodiment, a gas tight seal is required at the inlet end of the fuel cell stack to prevent the mixing of fuel and oxidant. However, a gas tight seal may not be required at the outlet end of the stack, downstream of which the inlet fuel and oxidant streams mix in an exhaust chamber adjacent to and downstream of the outlet tube sheet. In an embodiment, the inlet tube sheet includes annular flexures to tightly engage one end (*i.e.*, the inlet end) of each rod while the outlet rod ends are more loosely mounted at the outlet tube sheet where a gas seal is not required. In such an embodiment, the inlet tube sheet includes annular flexures while the outlet tube sheet may include through holes slightly oversized relative to the fuel cell rods to allow for ease of assembly and to allow for expansion and contraction of tube sheet and fuel cell rod materials. In this example embodiment each rod is substantially supported by single annular flexure engaged with one end of the rod. In further embodiments the outlet tube sheet rod ends are held in place with annular flexures that provide reduces clamping force relative to the clamping force provided by the flexures at the inlet tube sheet. .

[0095] Referring to Figures 10A and 10B, an alternative rod (1050) according to the present invention comprises a hollow cavity or conduit (1052) that longitudinally penetrates through the entire rod from end to end and a rod main body (1055) with hexagonal cross section for the majority of the rod length and rod end tube stubs (1053) with circular cross sections, configured to fit into annular flexures on end plates of the invention. In a particular embodiment a rod is formed with a polyhedral cross section and the rod ends or tube stubs are formed with a circular cross sectional shape. In still further embodiments, rod ends or tube stubs are formed with polyhedral cross sections and annular flexures are formed with polyhedral shape designed flex and form a gas and liquid tight seal when the rod ends are

assembled into the flexures. Rods of the invention include rods with internal cavities formed with various lumens, including round and non-round rods with two or more cavities or hollow passages extending longitudinally along the length of the rod.

[0096] As shown in Figures 11A and 11B, an alternative embodiment of an end plate that includes annular flexures surrounding through holes comprises a two plate assembly (1100). In particular, a backing plate (1130) and a flexure plate (1120) are assembled together to form a composite end plate (1100). Backing plate (1130) comprises a relatively stiff disk shaped plate body (1131) formed with through holes (1135) passing there through at locations corresponding to rod end positions. Flexure plate (1120) comprises a relative less stiff disk shaped plate body (1120) formed with through holes (1125) passing there through sized to receive rod ends therein and with an annular flexures (1126) surrounding each through hole (1125). The flexure plate (1120) is mated with the backing plate (1130) to form a composite support plate (1100) wherein the annular flexures (1126) of the flexure plate are concentrically aligned with and positioned within the through holes (1135) of the backing plate (1130). The two plates are bonded together, for example by mechanical fasteners, brazing, welding, or other joining process suitable for the high temperature in-use environment of the plate.

[0097] The backing plate (1130) and the flexure plate (1120) are each made from a high temperature, low chromium alloy material such as Monel 400. In a further embodiment flexure plate (1120) is made from Monel 400 and the backing plate (1130) is made from another material such as a different high temperature, low chromium alloy or a ceramic material. The backing plate (1130) may be formed using a first machining process while the flexure plate (1120) is formed using a second machining process. For example, the backing plate (1130) is formed by drilling, machining, or laser cutting through holes in a plate while the flexure plate (1120) is formed using a stamping process. Other machining processes may be used for the backing plate, the flexure plate, or both. In operation rod ends engage with the through holes (1125) and are held by the annular flexures (1126) as described above.

[0098] In a further embodiment, illustrated in Fig. 12A, 12B, and 12C, an end plate (1200) that includes annular flexures surrounding through holes comprises a backing plate (1230) with multiple through holes (1235) passing there through at locations corresponding to rod end positions and flexure inserts (1220) installed in each of the through holes (1235). Each of the flexure inserts (1220) includes an end plate through hole (1225) passing there through sized to receive rod ends therein surrounded by an annular sleeve wall (1226). Each flexure insert (1220) comprises a top annular wall (1222) comprising a flexible portion. Top annular wall (1222) includes a surface (1221) that mates with backing plate surface (1231) to prevent the flexure insert from passing through backing plate holes (1235). The sidewall (1228) extending from the top annular wall (1222) has an outside diameter sized to install into backing plate through hole (1235) with an interface fit that is maintained at operating temperatures of the rod assembly. Alternately flexure inserts may be bonded or brazed in place. A sleeve wall (1226) extends from top annular wall (1222) to receive the rod end therein and engage the rod end with a clamping force as described above. In addition the top annular wall (1222) is formed with a material thickness corresponding with a desired elastic deformation or flexure amplitude to prevent tube damage when bending and twisting forces experienced by the rods are transferred to the annular flexure.

[0099] The individual flexure inserts (1220) may be produced using high volume production method and then assembled into through holes (1235) on a backing plate (1230), which may be produced by a different manufacturing method. In an embodiment flexure inserts (1220) are bonded to the backing plate (1230) by, for example, brazing. In another embodiment flexure inserts are press fit into through holes of the backing plate. The backing plate may be made from the same material as the flexure inserts or may be made from a different material. In an embodiment both the flexure inserts and the backing plate are made using Monel 400 material to provide a matched coefficient of thermal expansion. In a further embodiment the flexure inserts are made from Monel 400 while the backing plate is made from a different material, such as a different high temperature, low chromium alloy. In a still further embodiment, the backing plate is made from a ceramic material, for example an electrically insulating ceramic material, such as an alumina/zirconia/silica ceramic insulator high temp

material while the inserts are made from a high temperature metal alloy such as Monel 400. In such an embodiment the ceramic backing plate electrically isolates each fuel cell rod and separate ceramic insulators for each rod are not required. In a further embodiment flexure inserts (1220) are bonded to a backing plate (1230) with an electrically insulating material disposed between the inserts and the backing plates. For example, flexure inserts (1220) are potted in through holes (1235) of backing plate (1230) with electrically insulating potting material disposed between each of the mating surfaces (1228, 1221) of the inserts and mating surfaces (1238, 1231) of the backing plate.

[00100] The present invention is usable with any suitable fuel for an SOFC. The fuel can be hydrogen, ethanol, light hydrocarbon fuels—such as methane, ethane, propane, butane, pentane, or hexane—or the fuel can be heavier hydrocarbons—such as gasoline, diesel fuel, kerosene, JP-8 military fuel, jet fuel, or biofuels. Kerosene is a preferred fuel.

[00101] It will also be recognized by those skilled in the art that, while the invention has been described above in terms of preferred embodiments, it is not limited thereto. Various features and aspects of the above described invention may be used individually or jointly. Further, although the invention has been described in the context of its implementation in a particular environment, and for particular applications (*e.g.* within a solid oxide fuel cell comprising an SOFC stack with a cylindrical shape) those skilled in the art will recognize that its usefulness is not limited thereto and that the present invention can be beneficially used in any number of environments and implementations where it is desirable to mount tubes without potting material, and in general to provide a flexible mounting arrangement for tubes and especially tubes made of a brittle material such as a ceramic material. Moreover the present invention provides an alternative to gas seals usable in a high temperature environment. Accordingly, the claims set forth below should be construed in view of the full breadth and spirit of the invention as disclosed herein.

WHAT IS CLAIMED

1. A solid oxide fuel cell comprising a fuel rod assembly comprising:
 - a fuel rod comprising an outer wall enclosing a hollow longitudinal rod conduit extending there through, wherein the rod conduit has a gas input end and a gas output end,
 - a first end cap attached to the outer wall at the gas input end comprising a cup shaped cap for receiving the outer wall therein and a first cylindrical tube stub extending therefrom wherein the first end cap includes a hollow longitudinal stub conduit extending there through wherein the stub conduit and the rod conduit are in communication at the input end;
 - a first end plate base wall formed with a first base wall through hole positioned to receive the first cylindrical tube stub there through;
 - a first annular flexure element associated with the first base wall through hole, wherein the first annual flexure element includes an annular flexure through hole for mechanically engaging with an outside diameter of the first cylindrical tube stub.
2. The solid oxide fuel cell of claim 1 further comprising:
 - a second end cap attached to the outer wall at the gas output end comprising a cup shaped cap for receiving the outer wall therein and a second cylindrical tube stub extending therefrom wherein the second end cap includes a hollow longitudinal stub

- conduit extending there through wherein the stub conduit and the rod conduit are in communication at the output end;
- a second end plate base wall formed with a second base wall through hole positioned opposed to the first base wall through hole to receive the second cylindrical tube stub there through;
 - a second annular flexure element associated with the second base wall through hole, wherein the second annular flexure element includes an annular flexure through hole for mechanically engaging with an outside diameter of the second cylindrical tube stub.
3. The solid oxide fuel cell of claim 1 wherein the first tube stub comprises an electrical insulating portion disposed between the outer wall and the annular flexure through hole of the first annular flexure element.
4. The solid oxide fuel cell of claim 1 further comprising a first electrical insulator comprising an annular outer wall formed from an electrically insulating material surrounding a longitudinal through bore wherein an outside diameter of the annular outer wall mechanically engages with the annular flexure through hole of the first annular flexure element and an inside diameter of the longitudinal through bore mechanically engages with an outside diameter of the first cylindrical tube stub.
5. The solid oxide fuel cell of claim 4 wherein the mechanical engagement between each of the cup shaped cap and the outer wall, the longitudinal through bore and the outside diameter of

the annular outer wall and the outside diameter of the annular outer wall and the annular flexure through hole of the first annular flexure element comprises one of an interference fit and a soldered joint suitably configured to maintain a substantially liquid and gas tight seal over an operating temperature range of 500 to 1000°C.

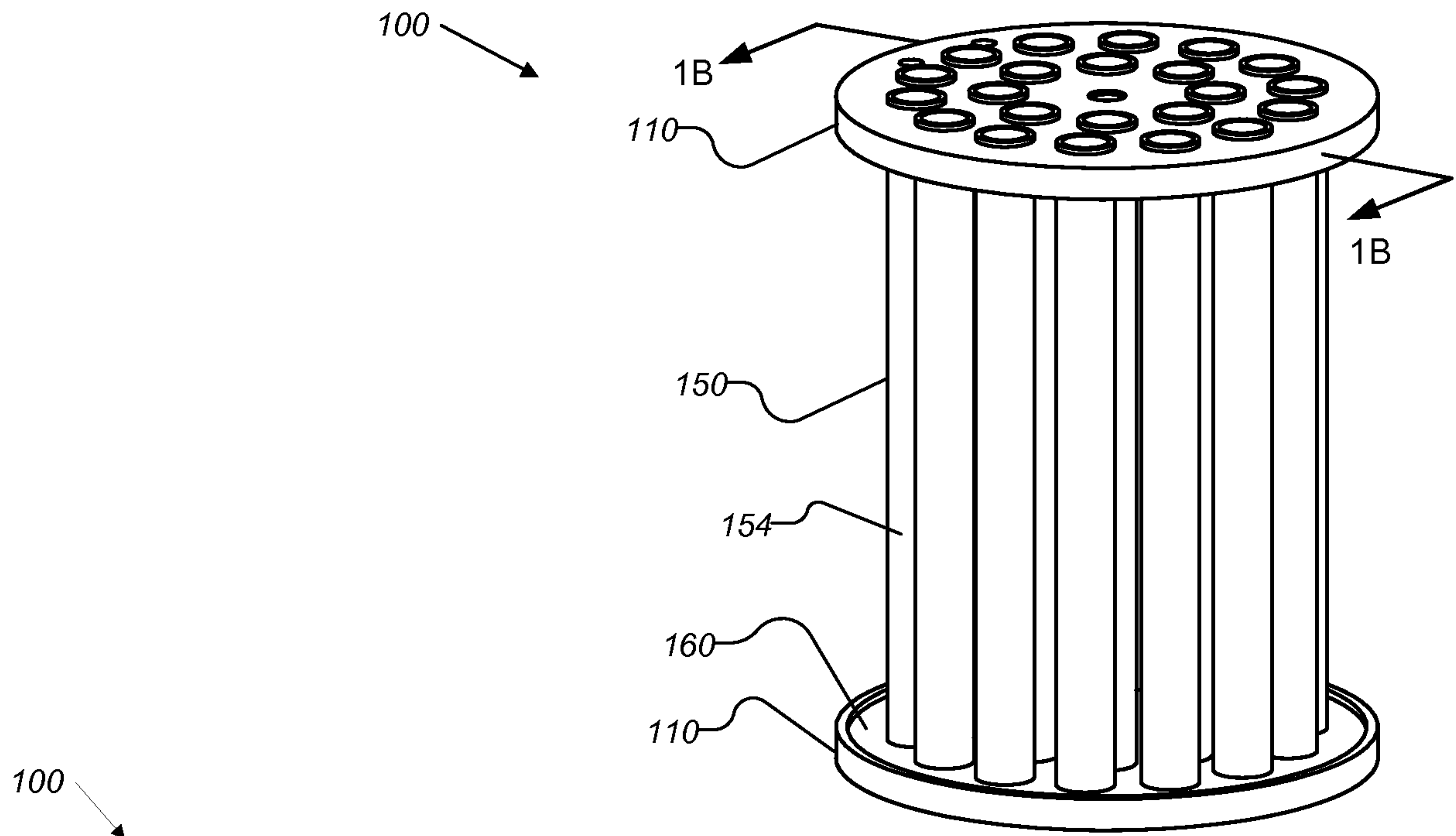
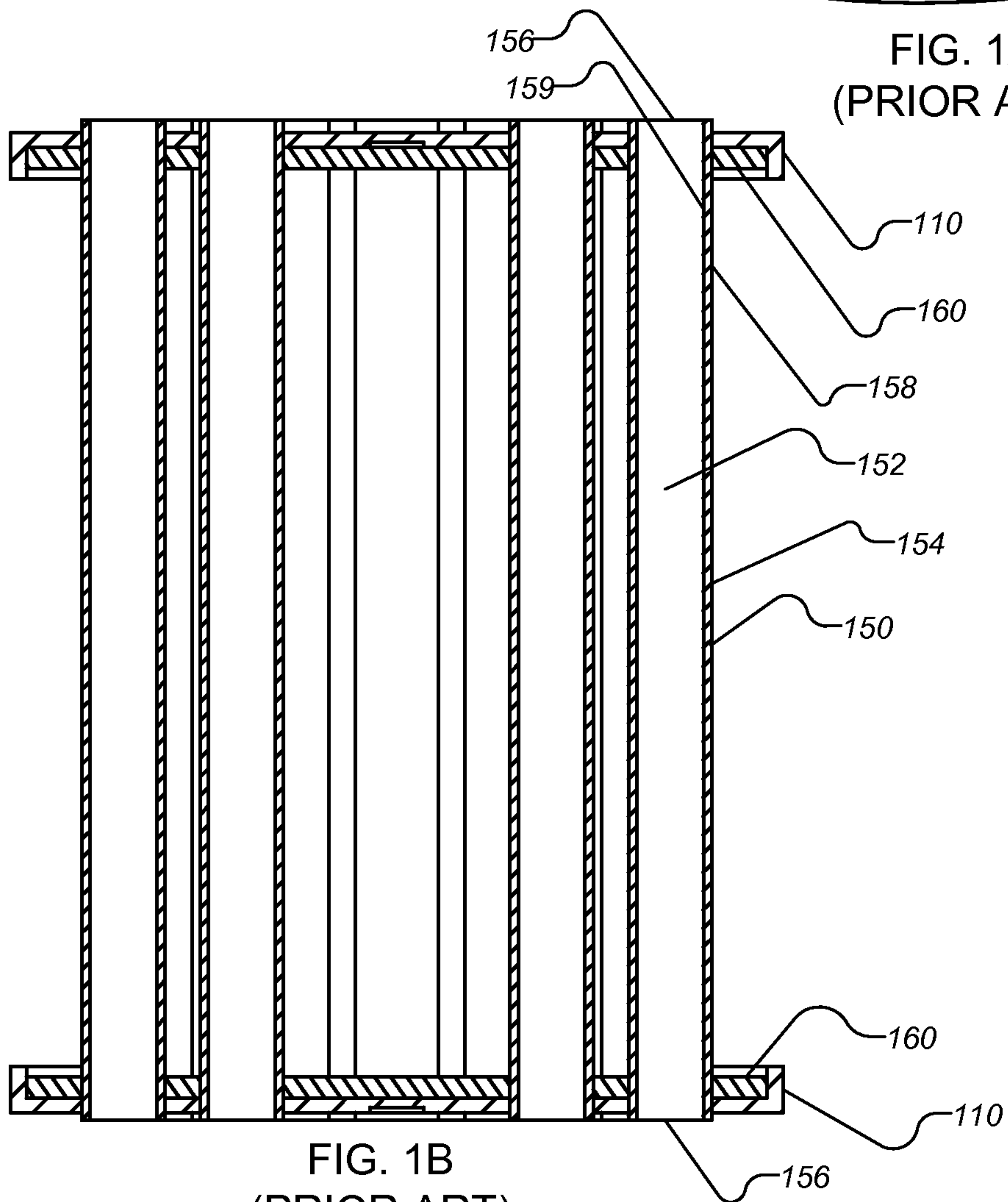
6. The solid oxide fuel cell of claim 2 wherein the second tube stub comprises an electrical insulating portion disposed between the outer wall and the annular flexure through hole of the second annular flexure element.
7. The solid oxide fuel cell of claim 2 further comprising a second electrical insulator comprising an annular outer wall formed from an electrically insulating material surrounding a longitudinal through bore wherein an outside diameter of the annular outer wall mechanically engages with the annular flexure through hole of the second annular flexure element and an inside diameter of the longitudinal through bore mechanically engages with an outside diameter of the second cylindrical tube stub.
8. The solid oxide fuel cell of claim 7 wherein the mechanical engagement between the electrical insulator annular outer wall and the of the annular flexure through hole of the second annular flexure element is a clearance fit that allows longitudinal movement of the electrical insulator with respect to the annular flexure through hole of the second annular flexure element over an operating temperature ranging from 500 to 1000 °C.

9. The solid oxide fuel cell of any one of the above claims wherein the fuel rod comprises a plurality of fuel rods with each of the plurality of fuel rods is mechanically engaged with the first end plate base wall through a first annular flexure through hole and with each of the plurality of fuel rods is mechanically engaged with the second end plate base wall through a second annular flexure through hole.
10. The solid oxide fuel cell of claim 9 wherein each first and second annular flexure comprises a flexible portion having a low mechanical stiffness as compared with a mechanical stiffness each of the first and second end plate base walls and as compared with a mechanical stiffness of each the plurality of fuel rods and the associated cup shaped caps and end stubs such that the flexible portion elastically deforms in response to any bending and twisting forces imparted to the rods by movement of one of the first and second end plate base walls.
11. The solid oxide fuel cell of claim 10 wherein each first flexure element comprises an annular region of the first end plate base wall surrounding the base wall through hole wherein the annular region is formed with a reduced material thickness as compared to other regions of the first end plate base wall and wherein each second flexure element comprises an annular region of the second end plate base wall surrounding the base wall through hole wherein the annular region is formed with a reduced material thickness as compared to other regions of the second end plate base wall.

12. The solid oxide fuel cell of claim 1 wherein the first annular flexure element is integrally formed with the first end plate base wall such that the first base wall through hole and the first annular flexure through hole are the same through hole.
13. The solid oxide fuel cell of claim 11 wherein the second annular flexure element is integrally formed with the second end plate base wall such that the second base wall through hole and the second annular flexure through hole are the same through hole.
14. The solid oxide fuel cell of claim 1 wherein the first annular flexure is formed by a flexure insert installed into the first end plate base wall through hole.
15. The solid oxide fuel cell of claim 1 wherein the second annular flexure is formed by a flexure insert installed into the second end plate base wall through hole
16. A method comprising:
 - supporting a plurality of fuel rods between a first end plate base wall at a gas input end of each of the plurality of fuel rods and a second end plate base wall at a gas output end of each of the plurality of fuel rods wherein each fuel rod comprises an outer wall enclosing a hollow longitudinal rod conduit wherein the rod conduit has a gas input end and a gas output end,

- providing a first end cap attached to the outer wall of each fuel rod at the gas input end wherein each first end cap includes a longitudinal gas conduit in fluid communication with the rod conduit;
 - providing a second end cap attached to the outer wall of each fuel rod at the gas output end wherein each second end cap includes a longitudinal gas conduit in fluid communication with the rod conduit;
 - engaging each first end cap with the first end plate base wall through a first annular flexure element with a first engagement method wherein the first engagement method forms a substantially liquid and gas tight seal between the fuel rod and the first base plate over an operating temperature range of 500°C to 1000°C;
 - engaging each second end cap with the second end plate through a second annular flexure element with a second engagement method wherein the second engagement method allows longitudinal movement of the second end cap with respect to the second base plate over an operating temperature range of 500°C to 1000°C.
17. The method of claim 16 further comprising the step of electrically isolating each first end cap from the first end plate base wall and electrically isolating each second end cap from the second end plate base wall.

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FIG. 1A
(PRIOR ART)FIG. 1B
(PRIOR ART)

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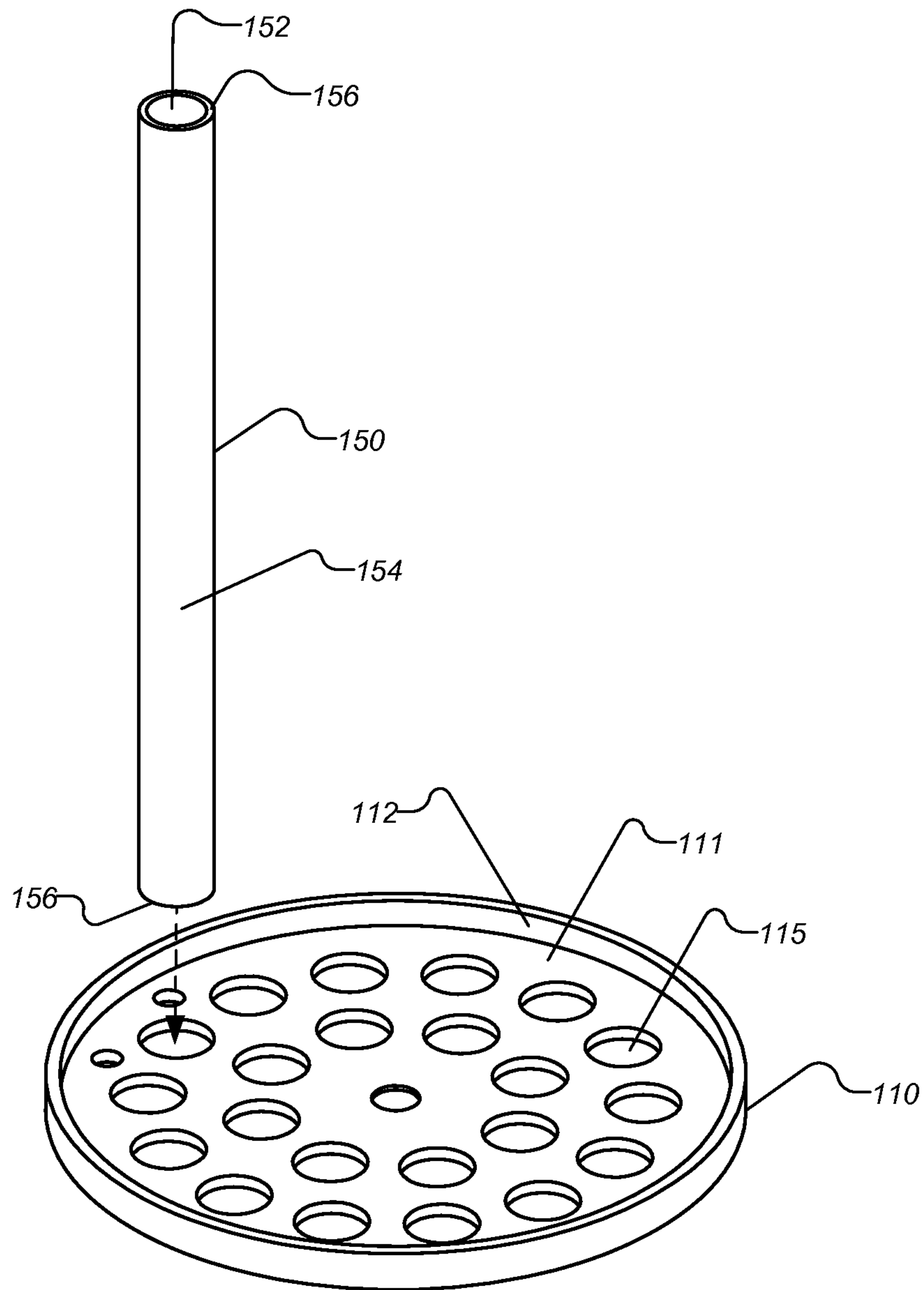


FIG. 1C
(PRIOR ART)

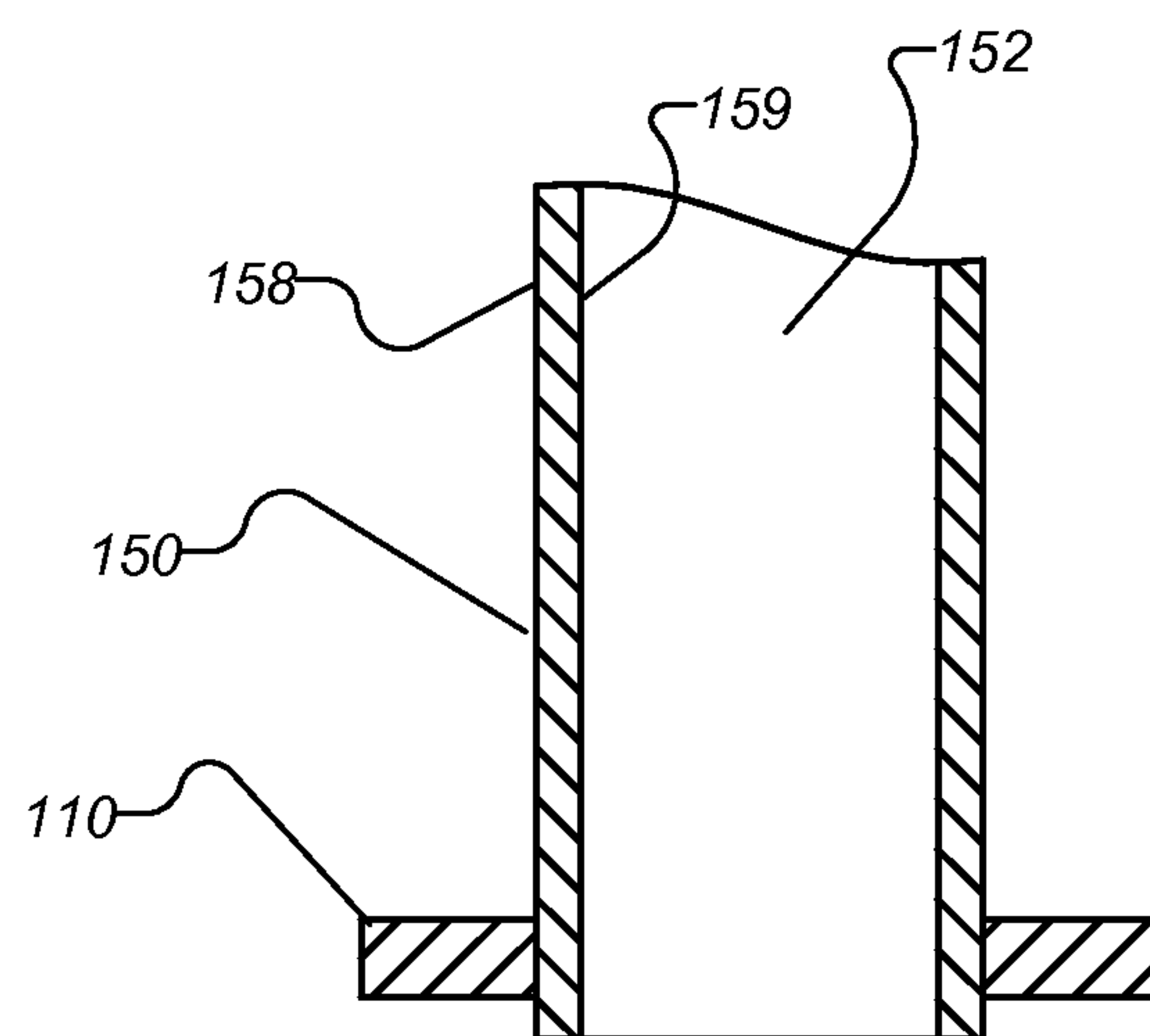


FIG. 2
(PRIOR ART)

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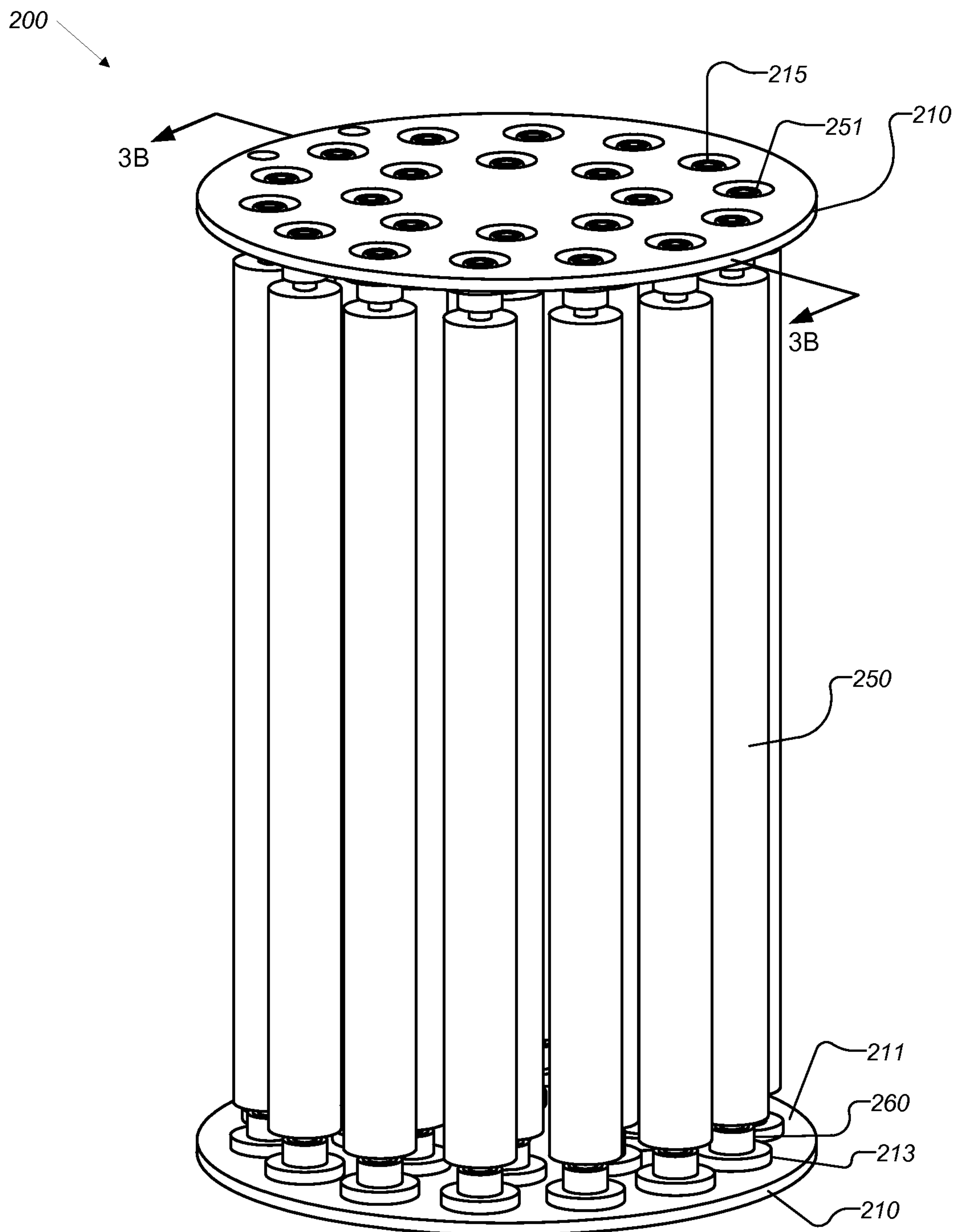


FIG. 3A

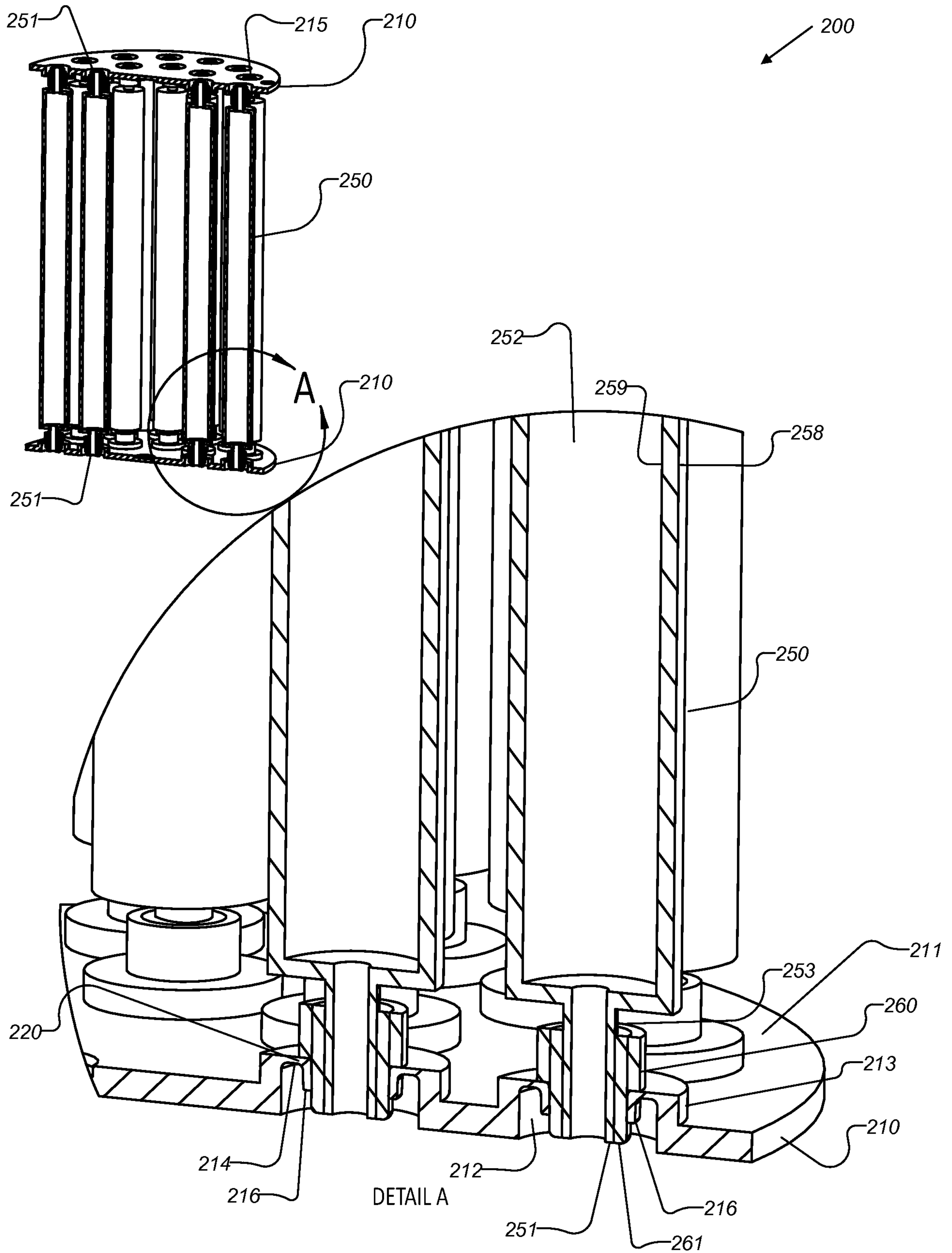


FIG. 3B

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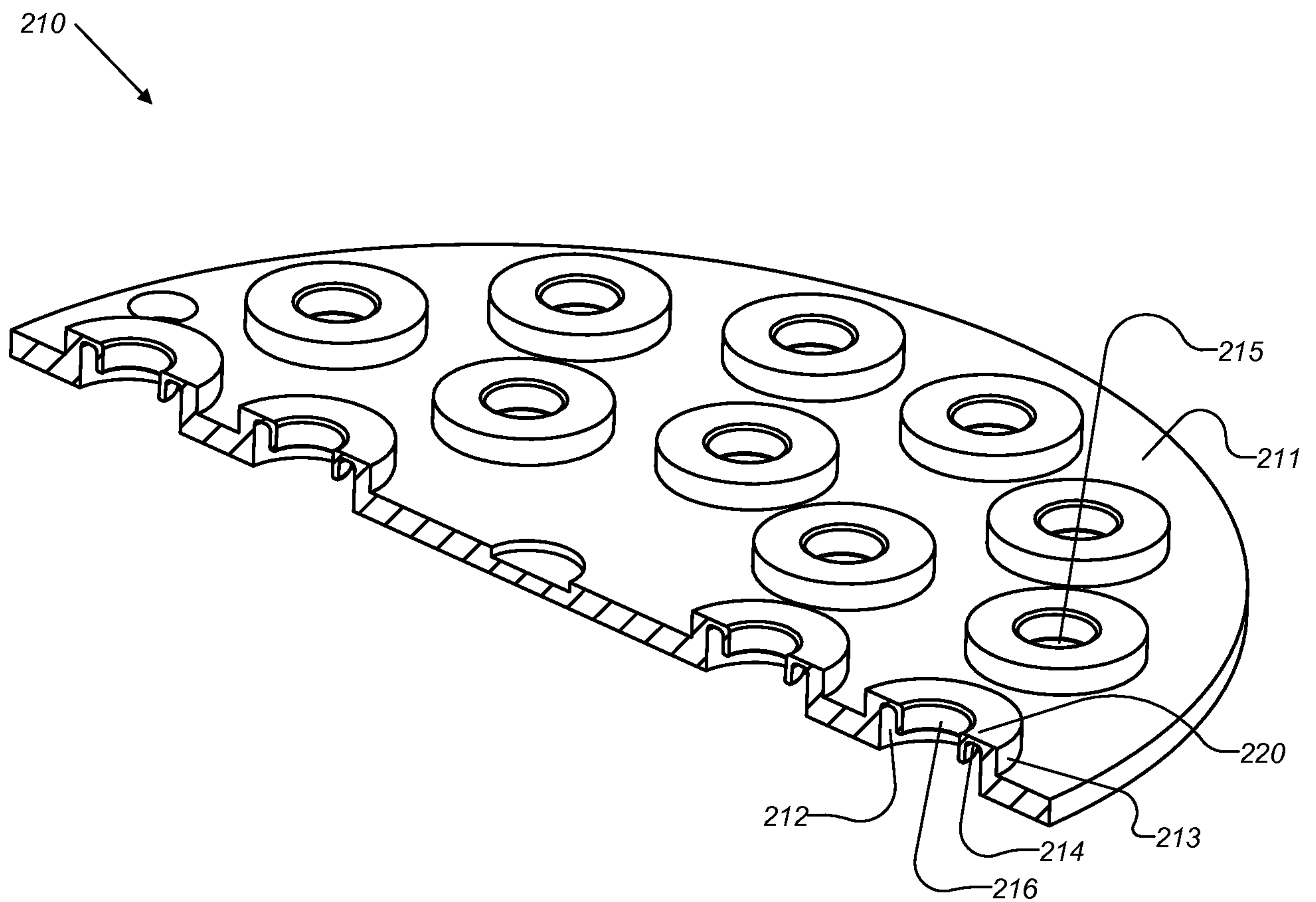


FIG. 3C

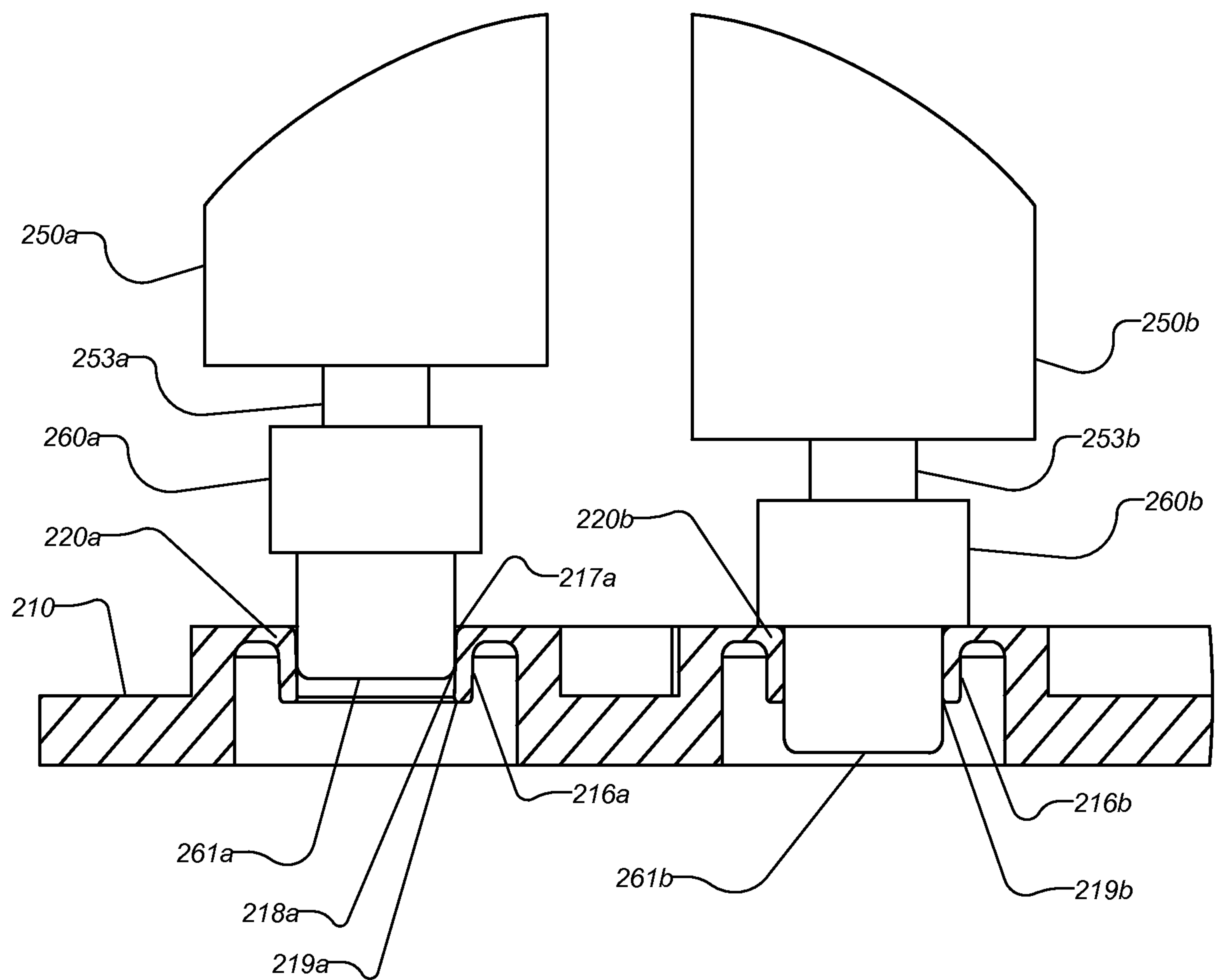


FIG. 4

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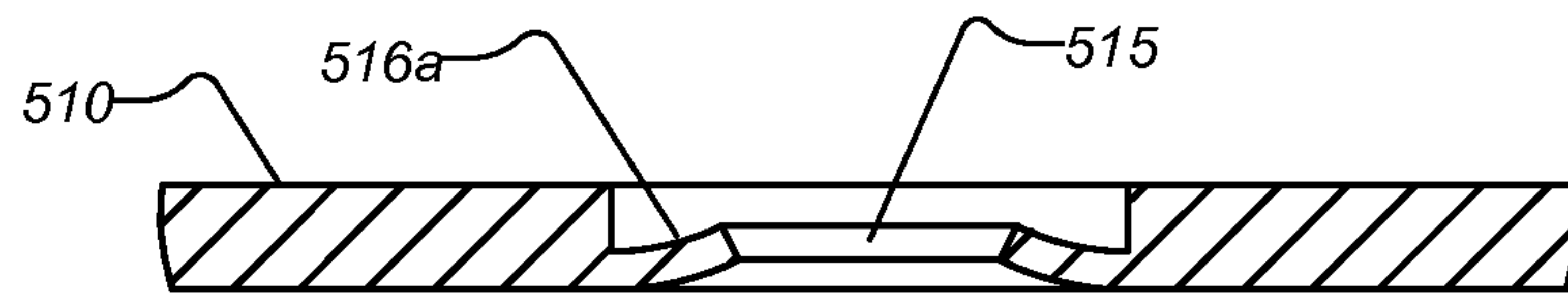


FIG. 5A

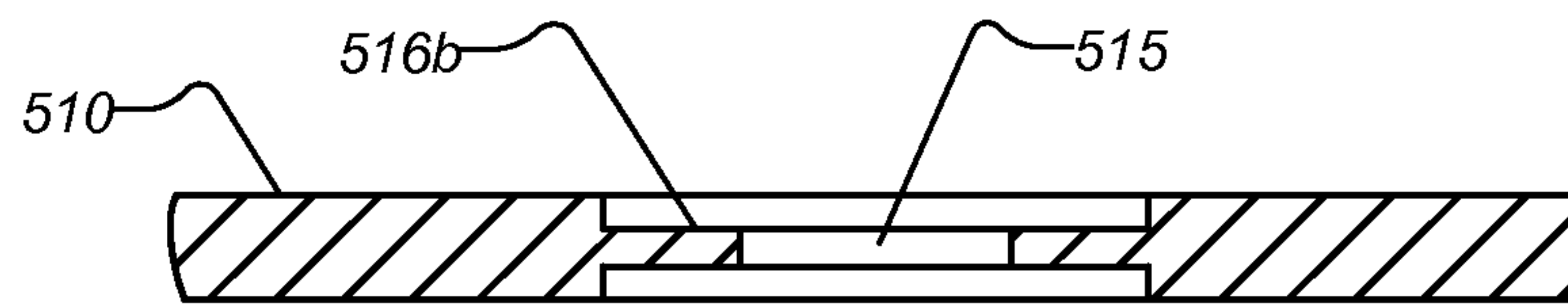


FIG. 5B

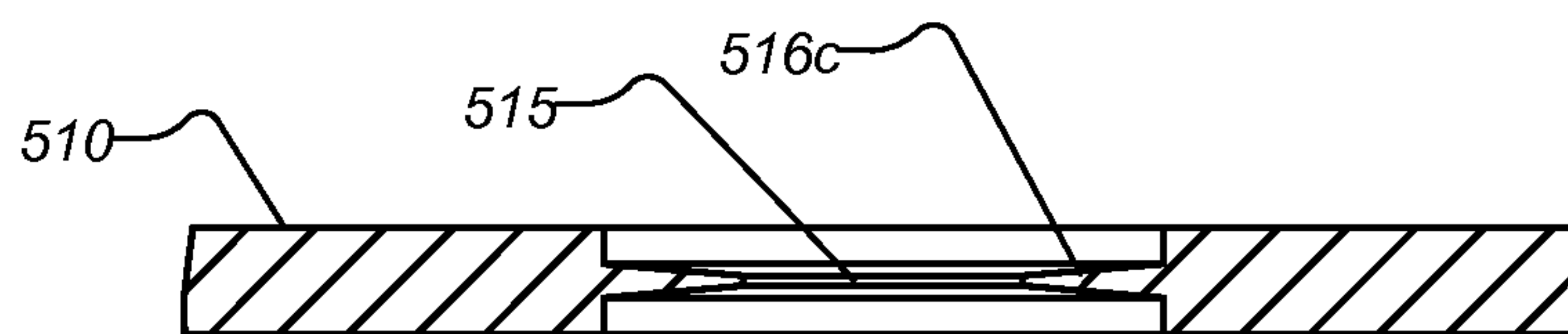


FIG. 5C

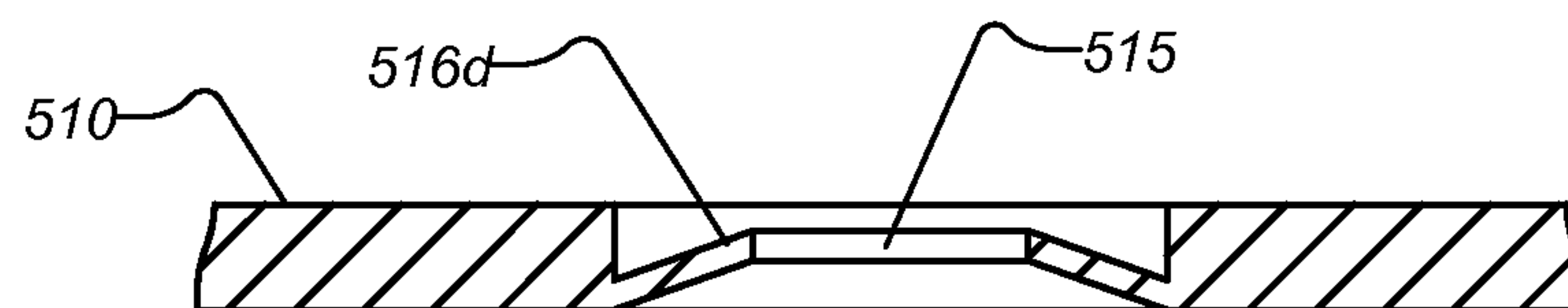


FIG. 5D

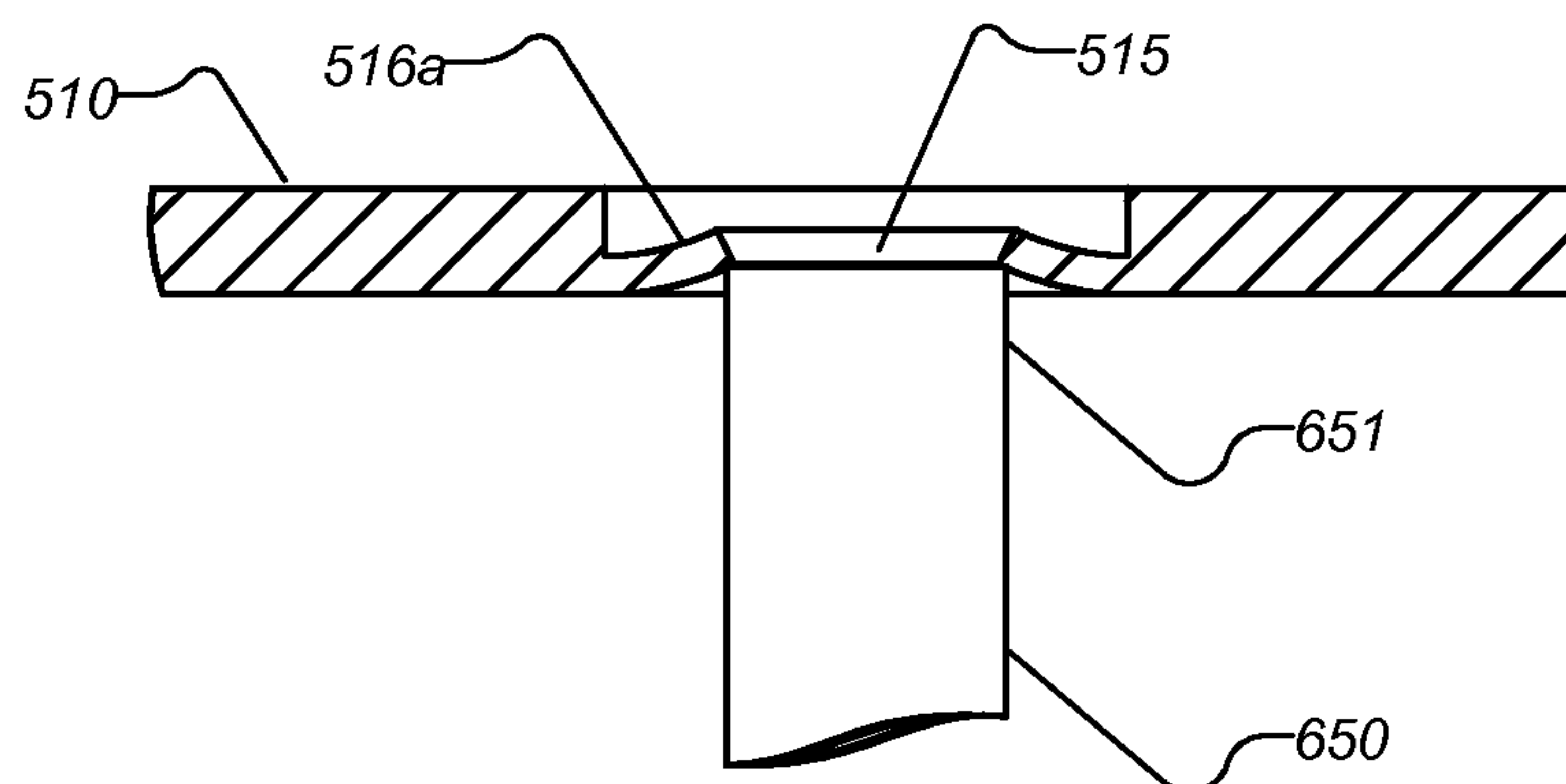


FIG. 6

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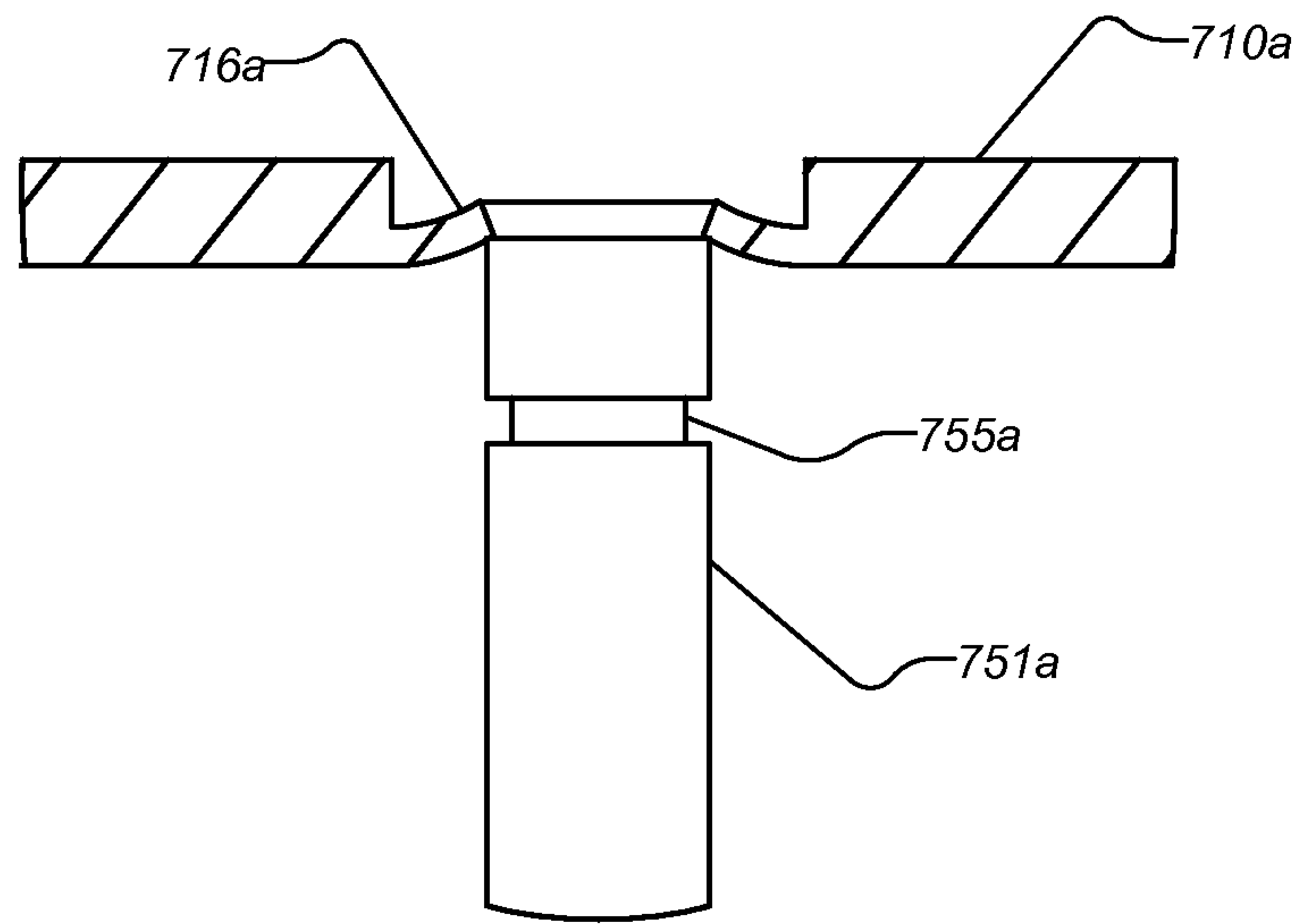


FIG. 7A

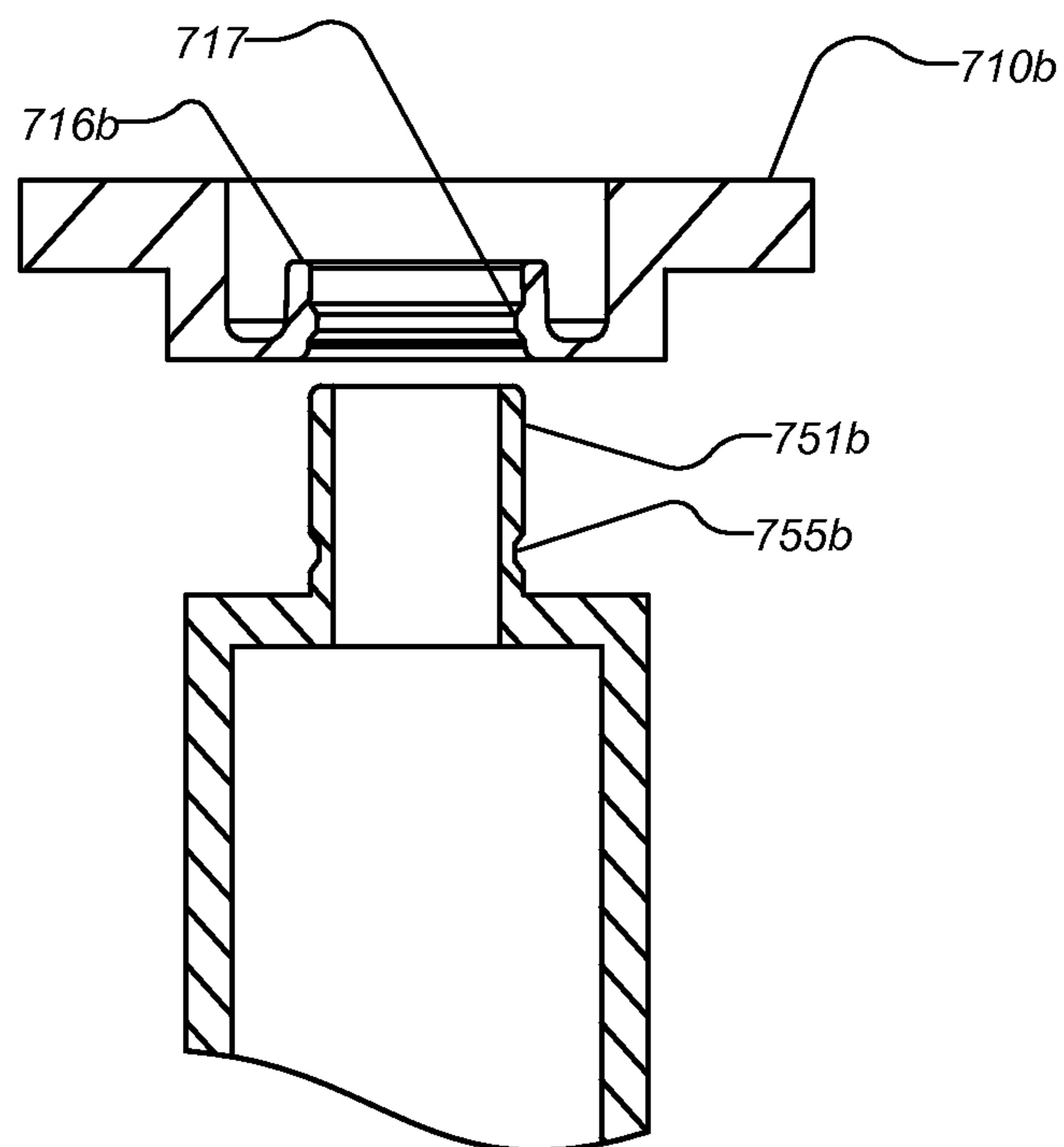


FIG. 7B

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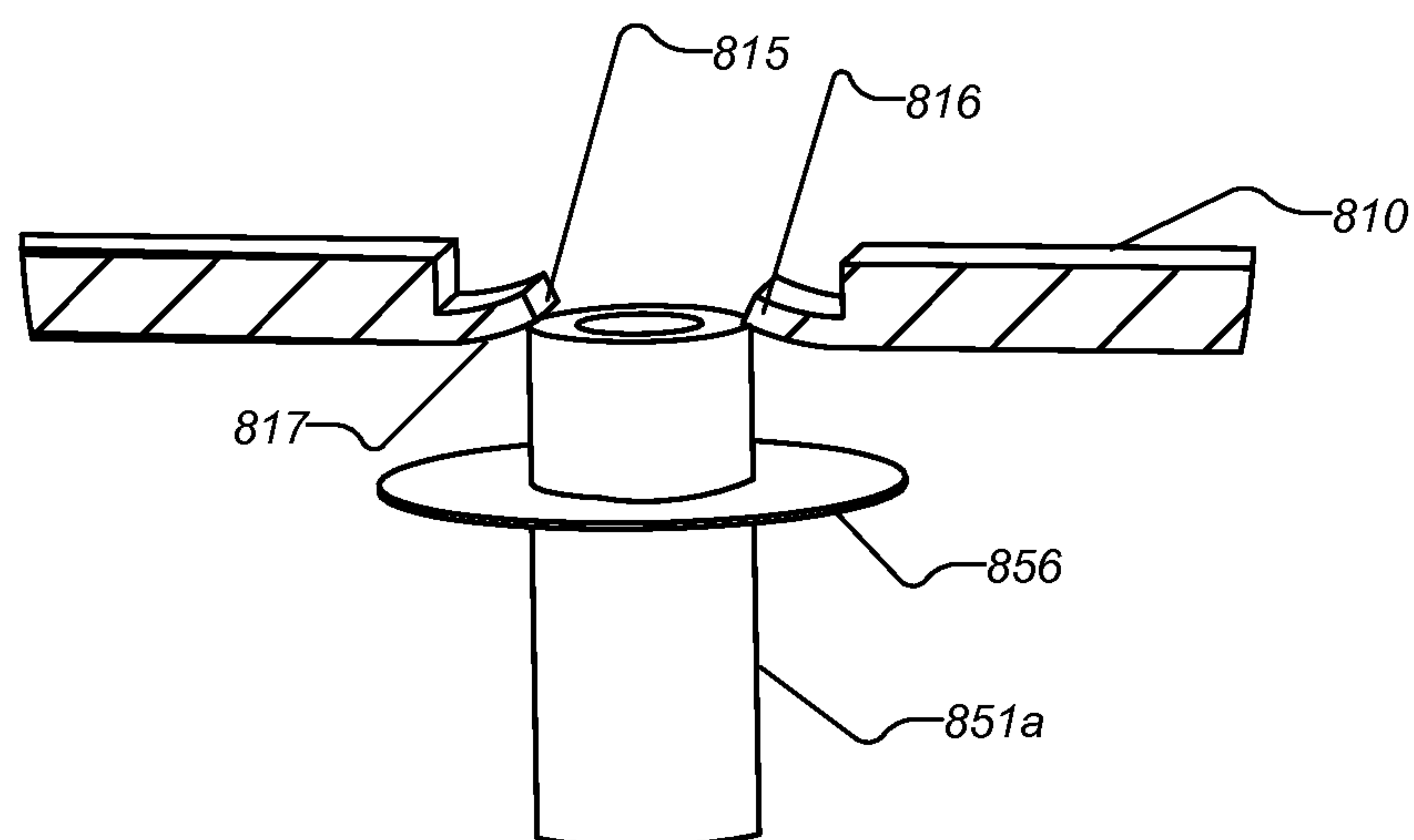


FIG. 8A

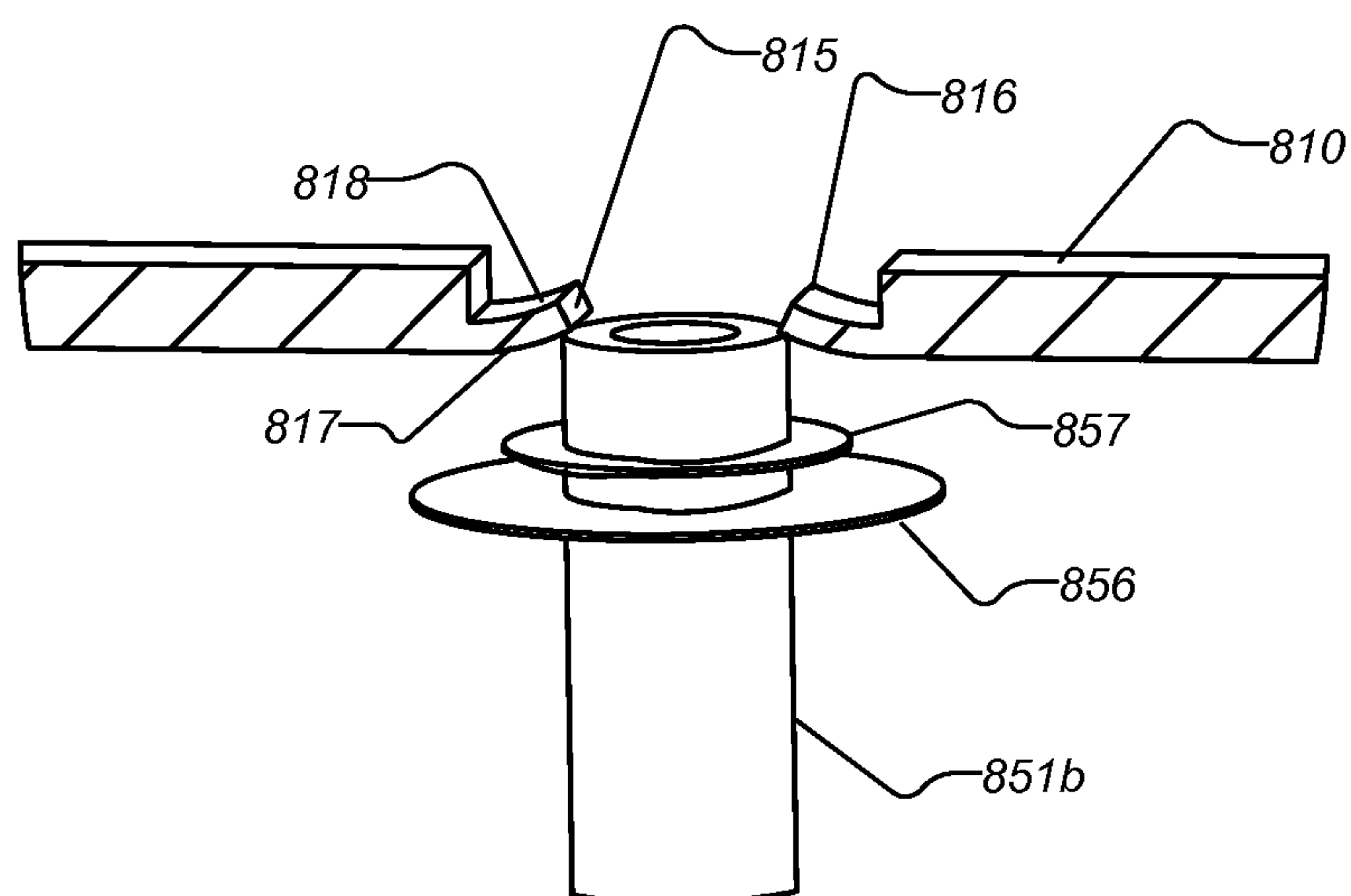


FIG. 8B

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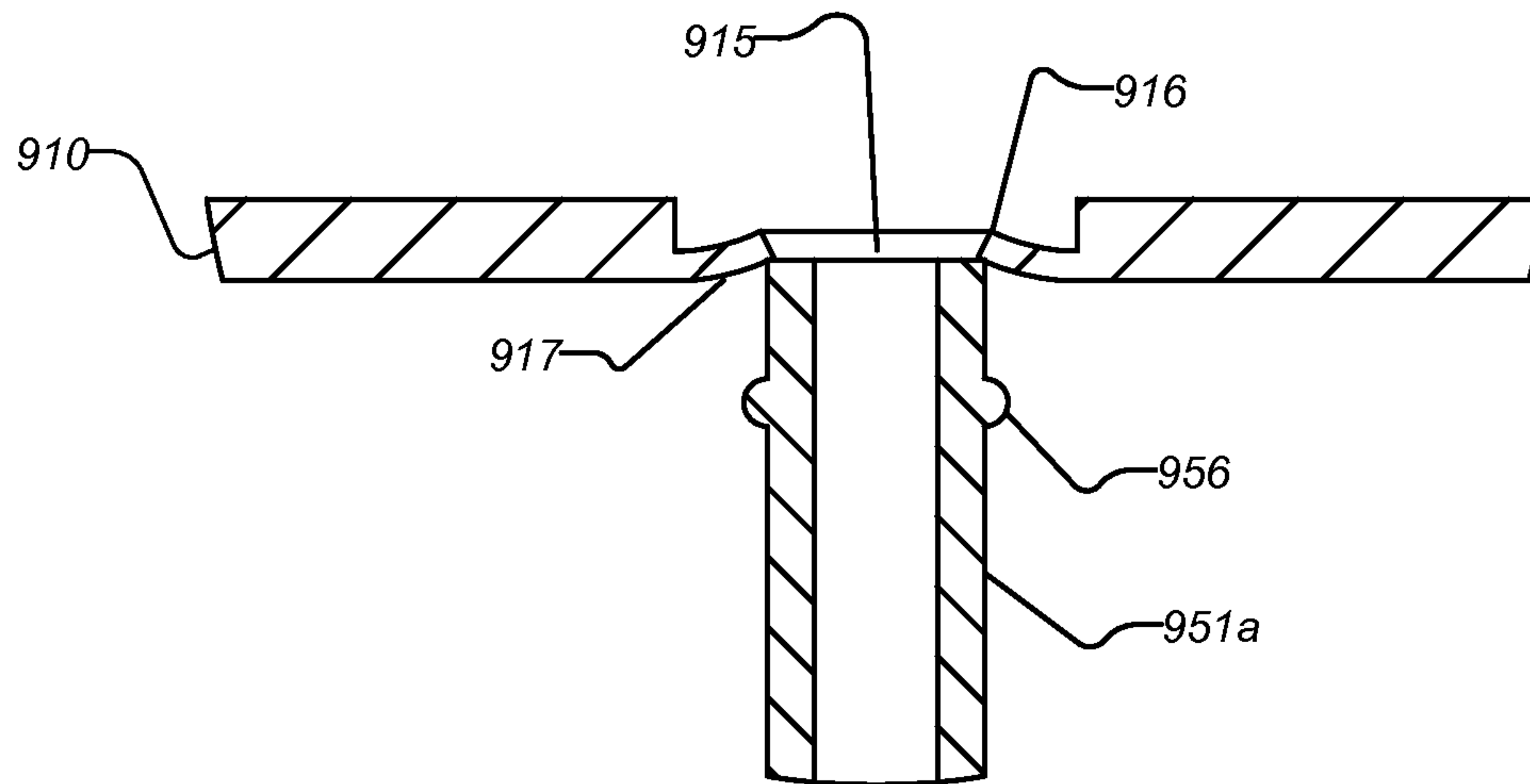


FIG. 9A

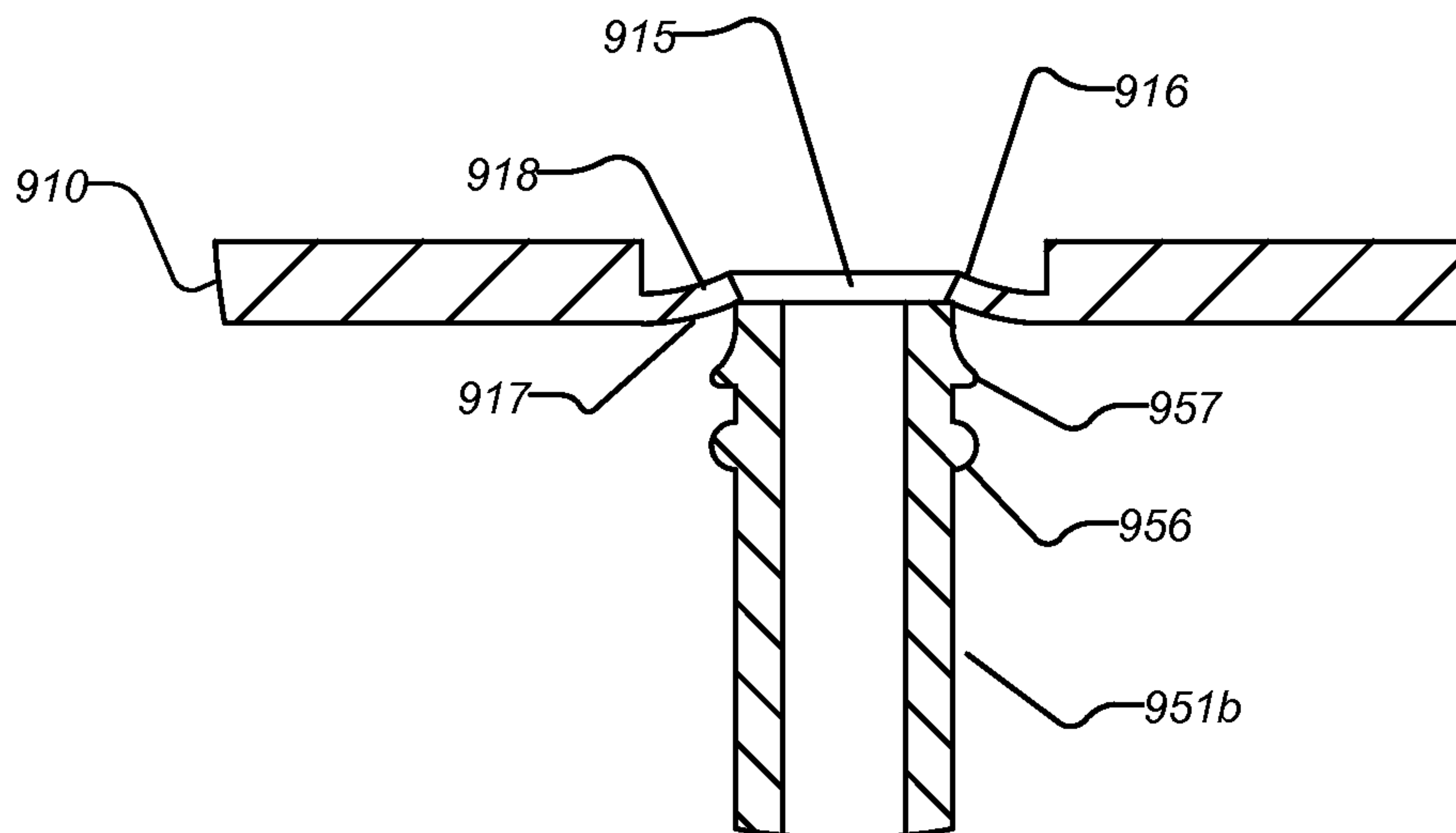


FIG. 9B

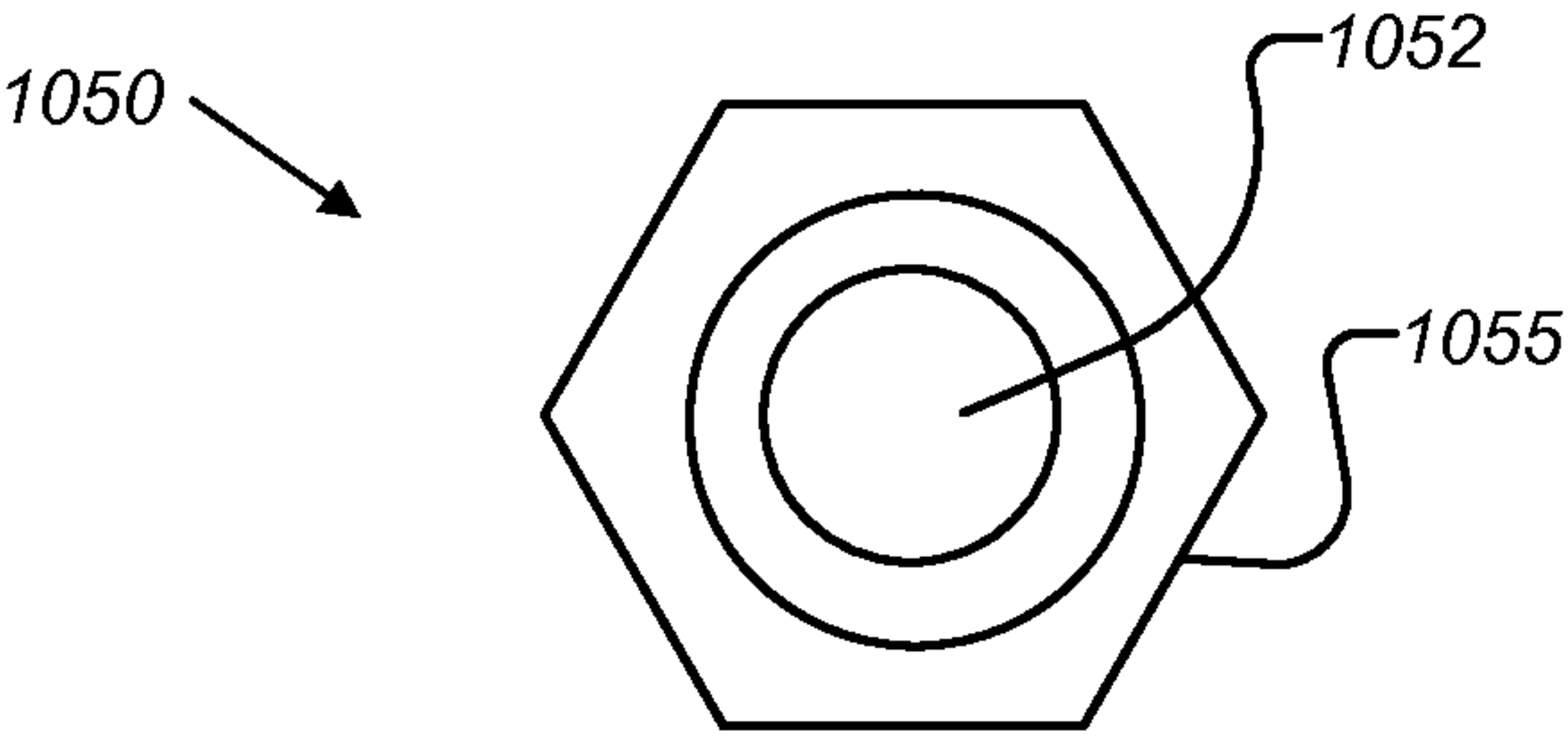


FIG. 10A

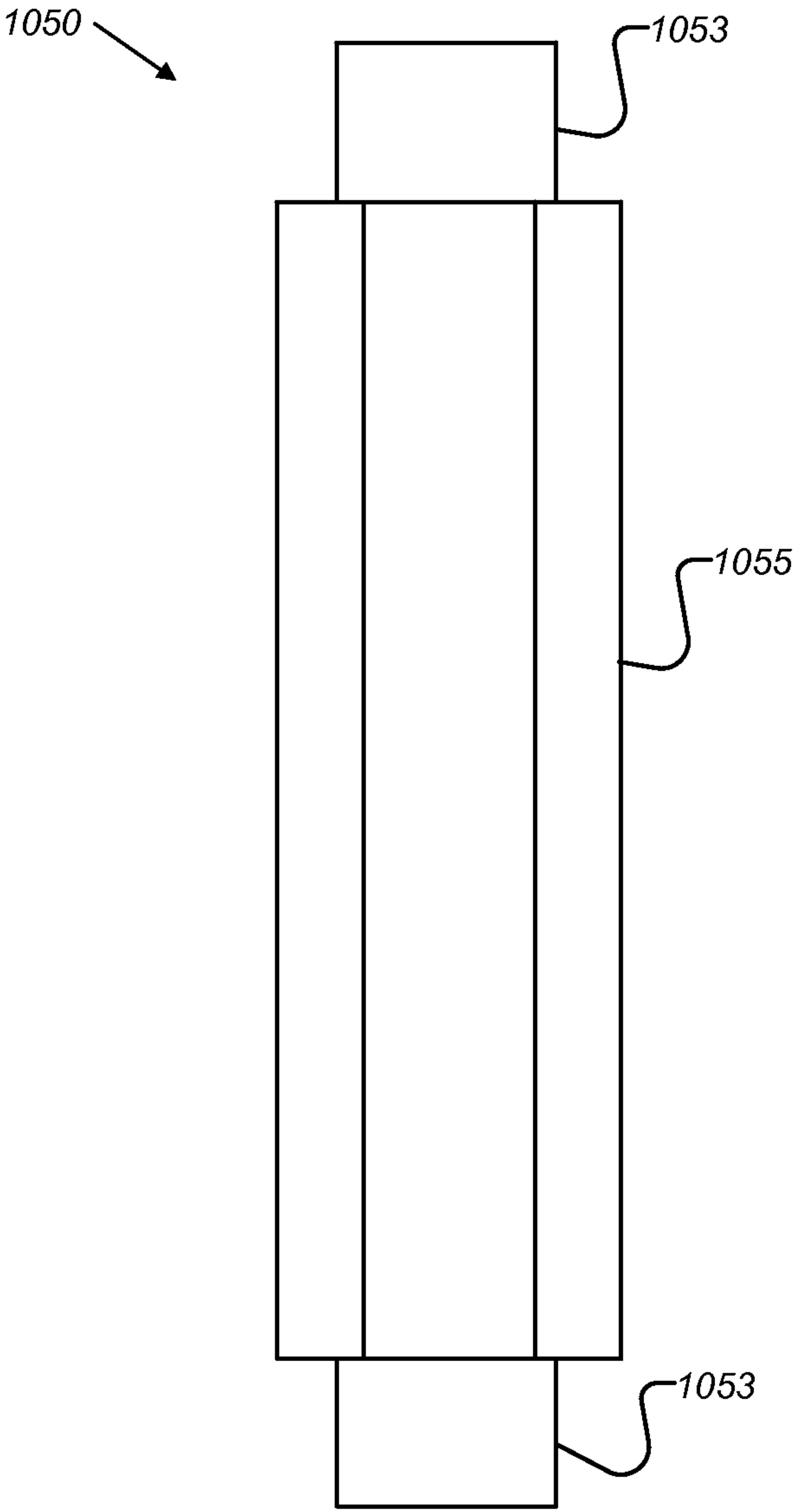


FIG. 10B

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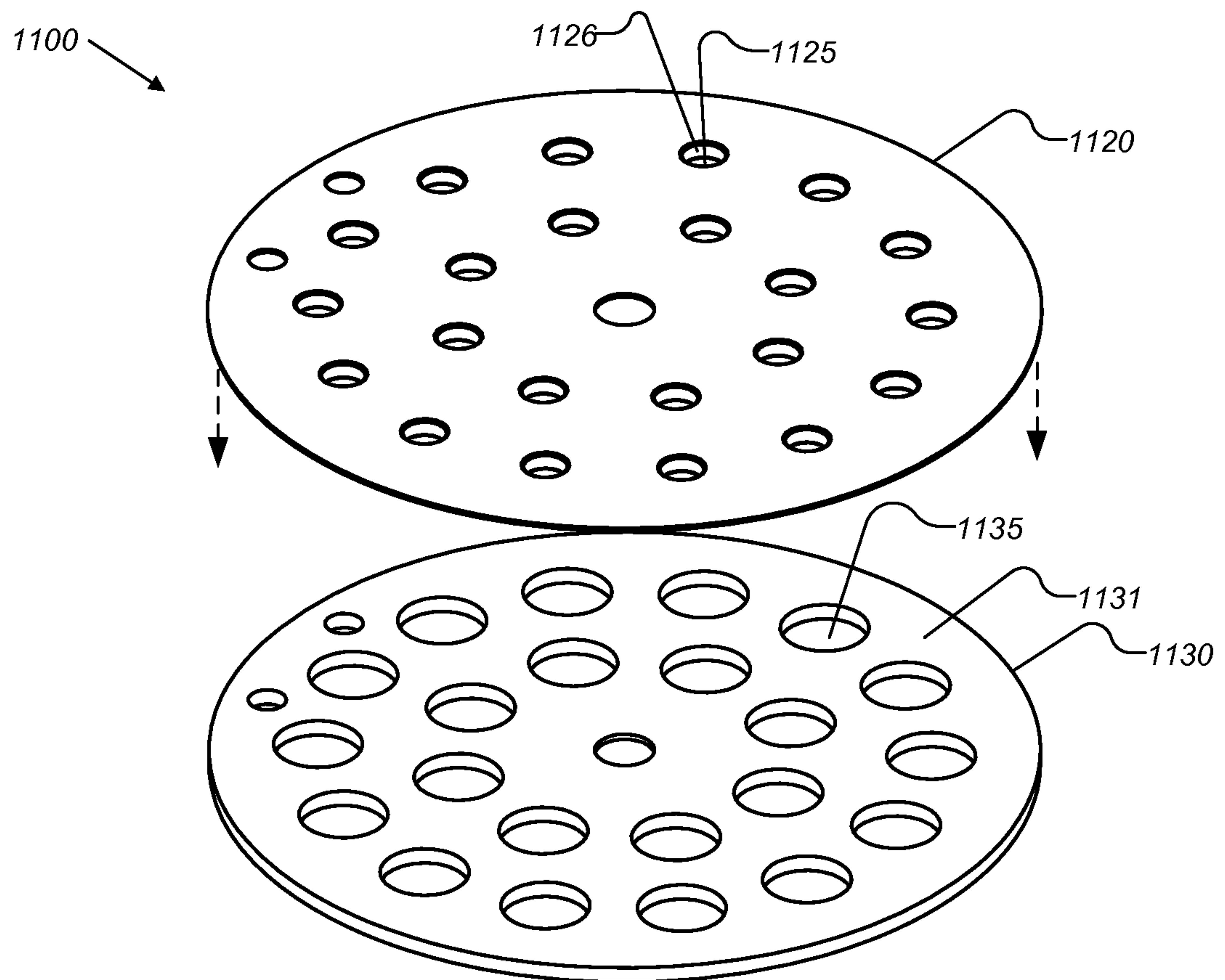


FIG. 11A

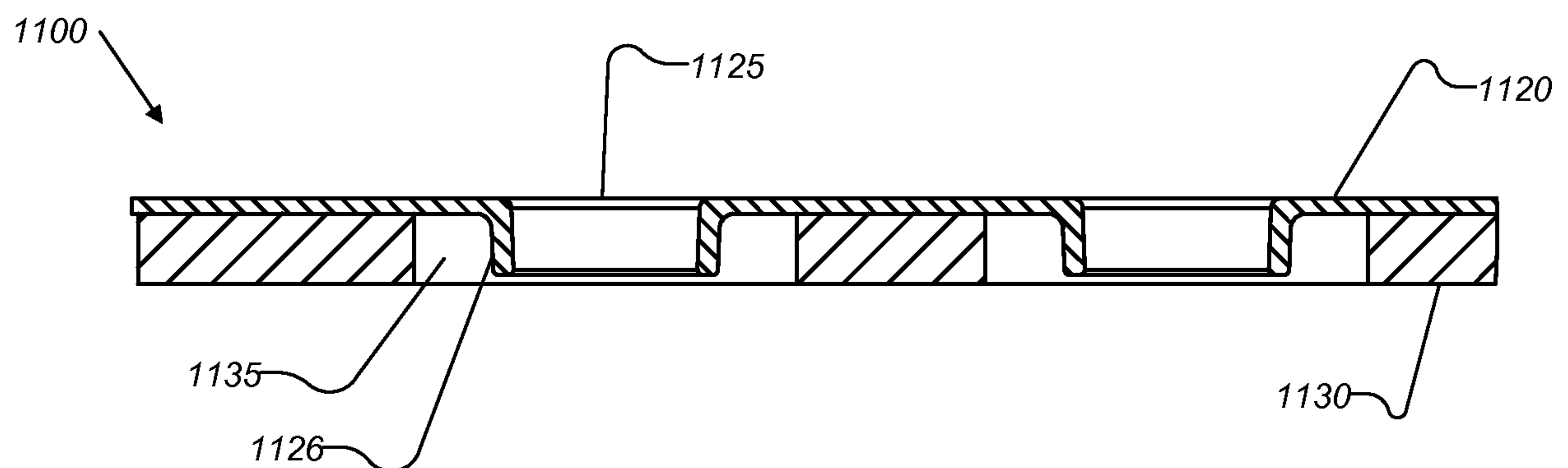


FIG. 11B

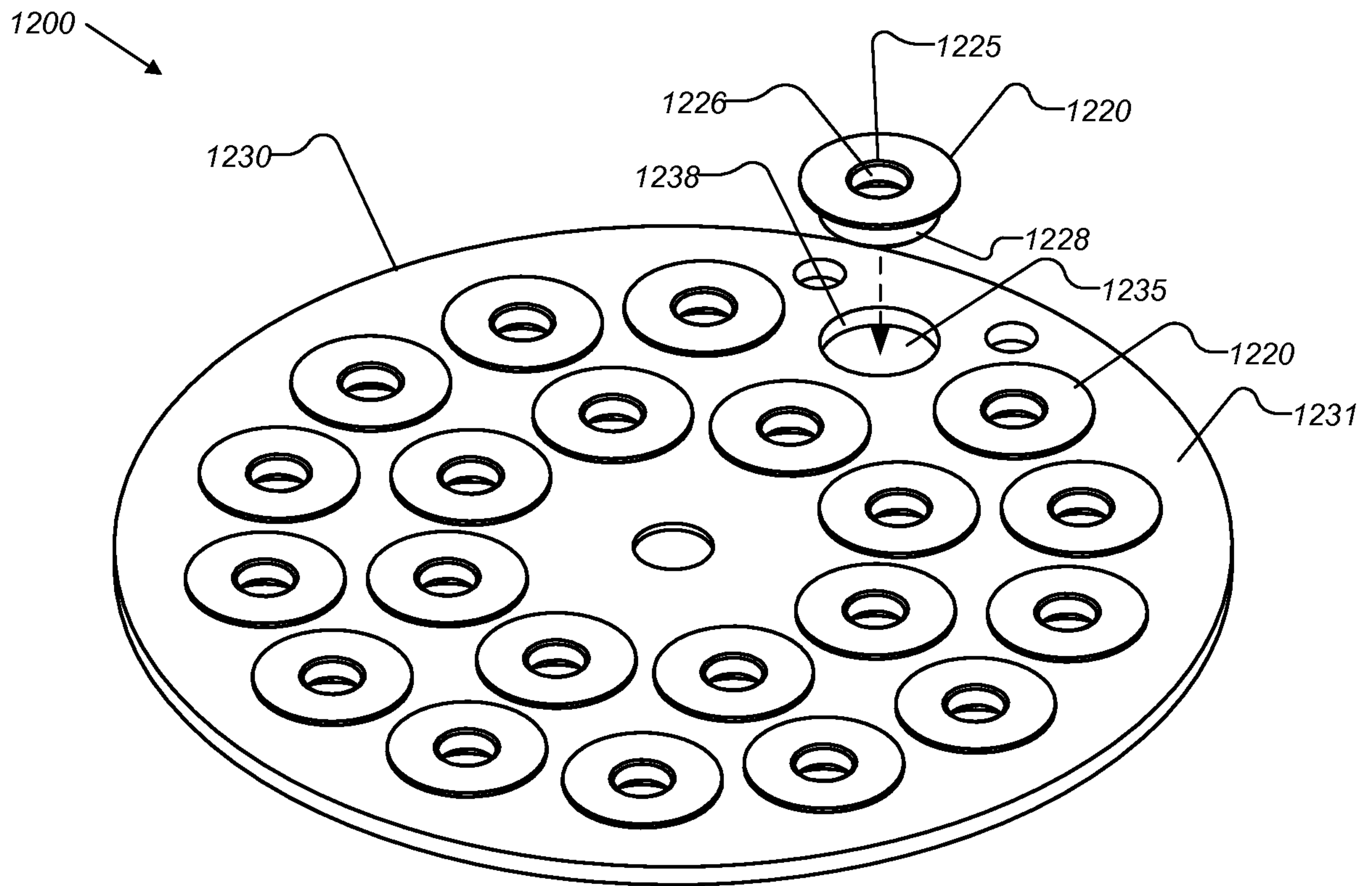


FIG. 12A

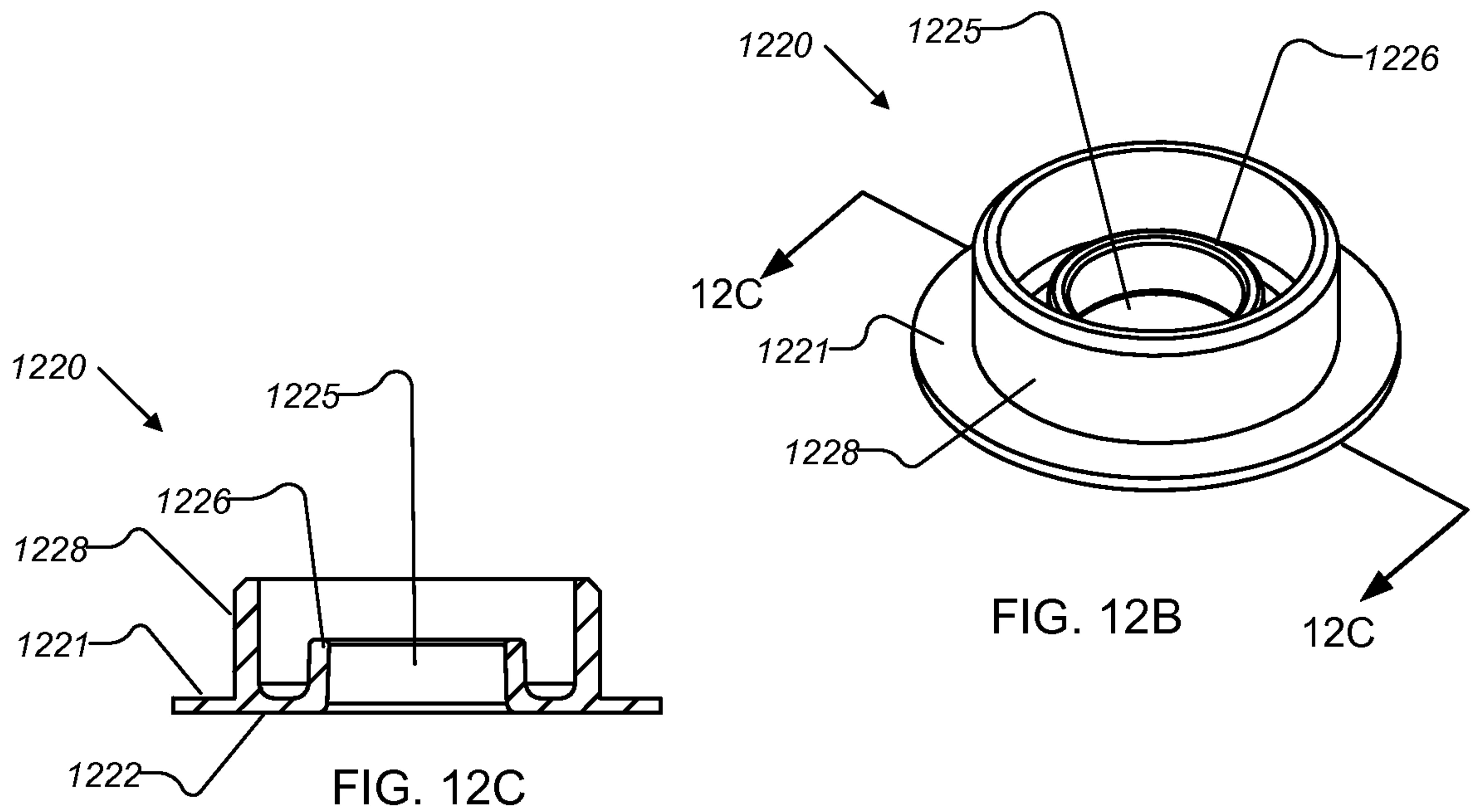


FIG. 12B

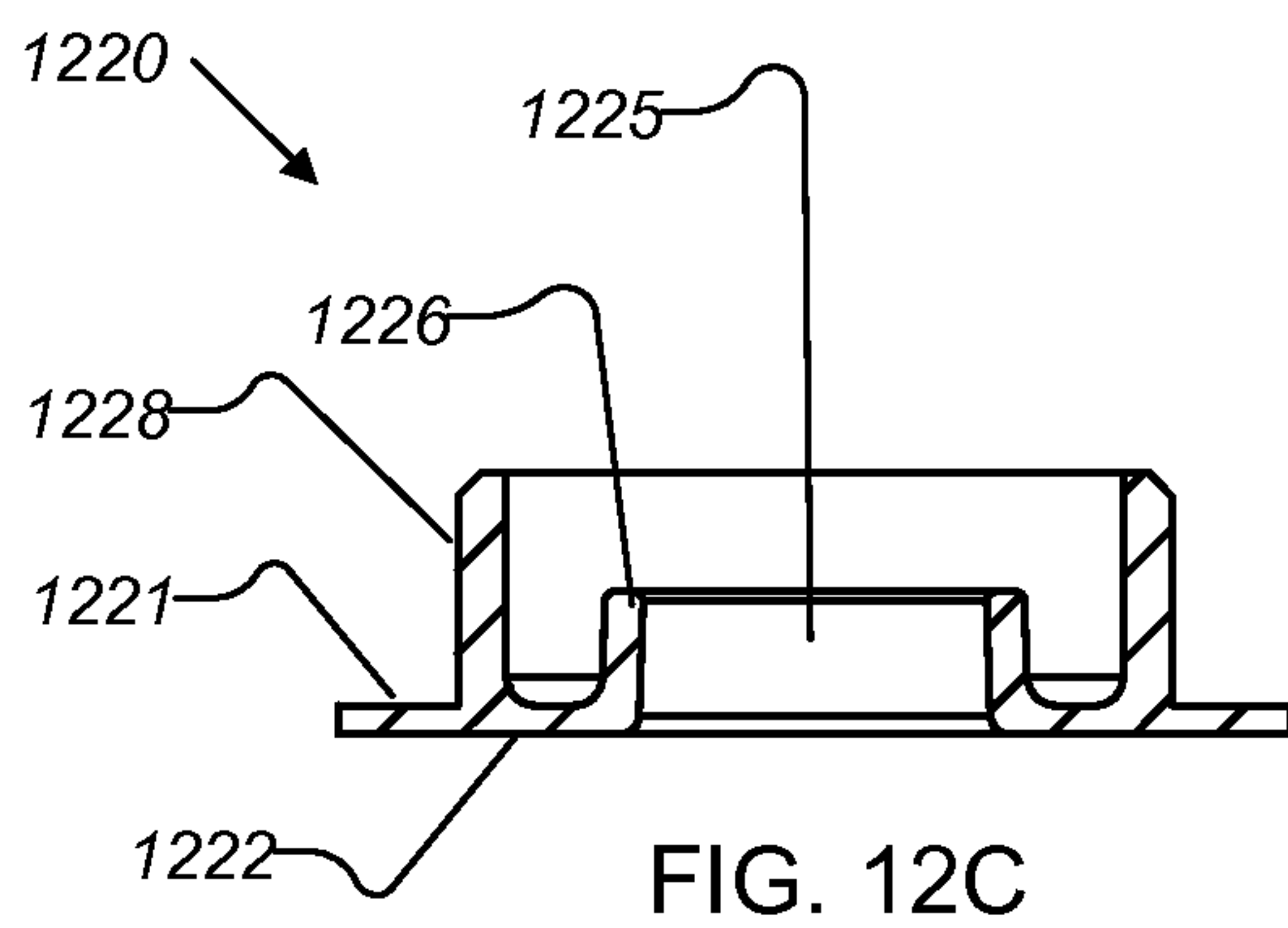


FIG. 12C

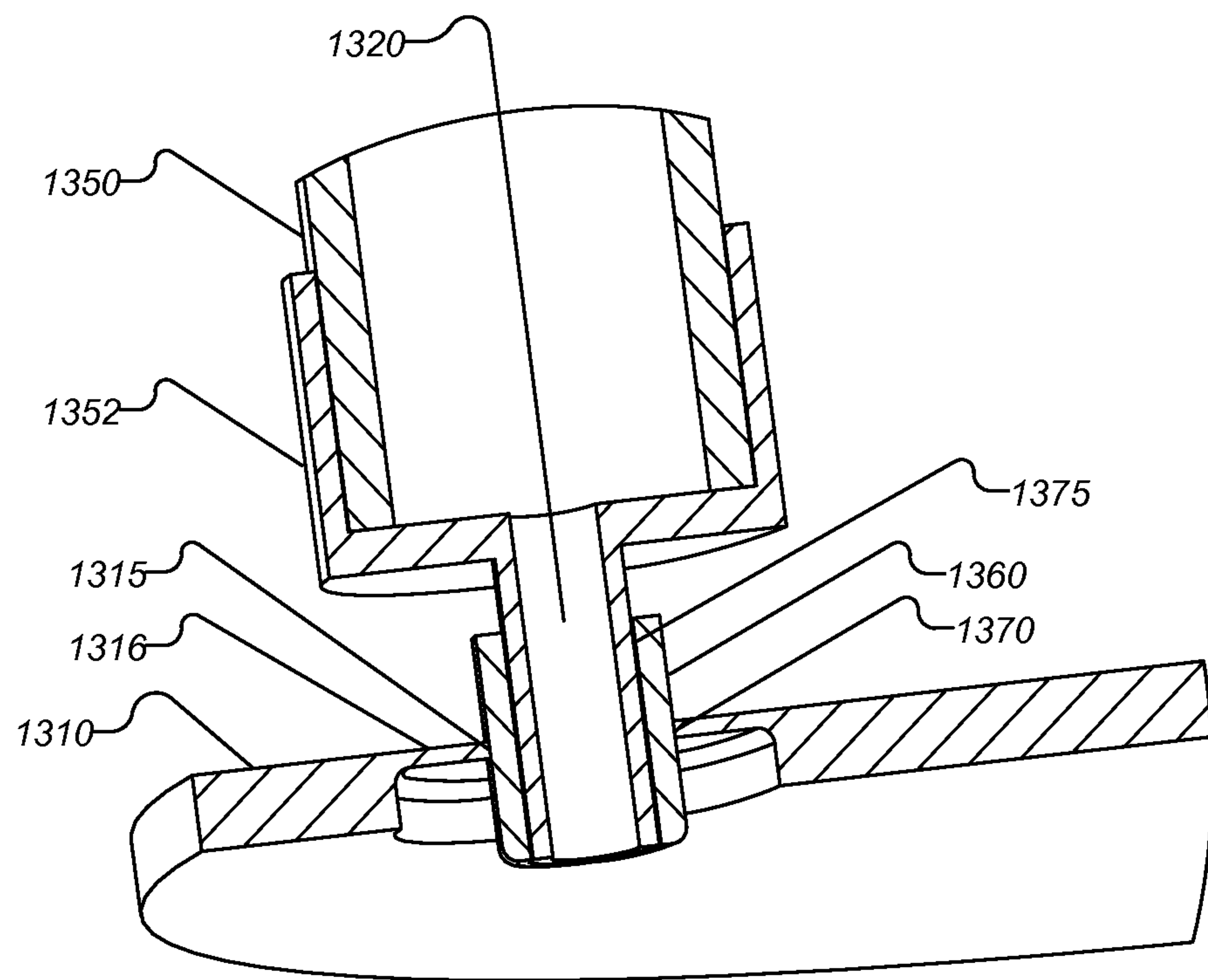


FIG.13

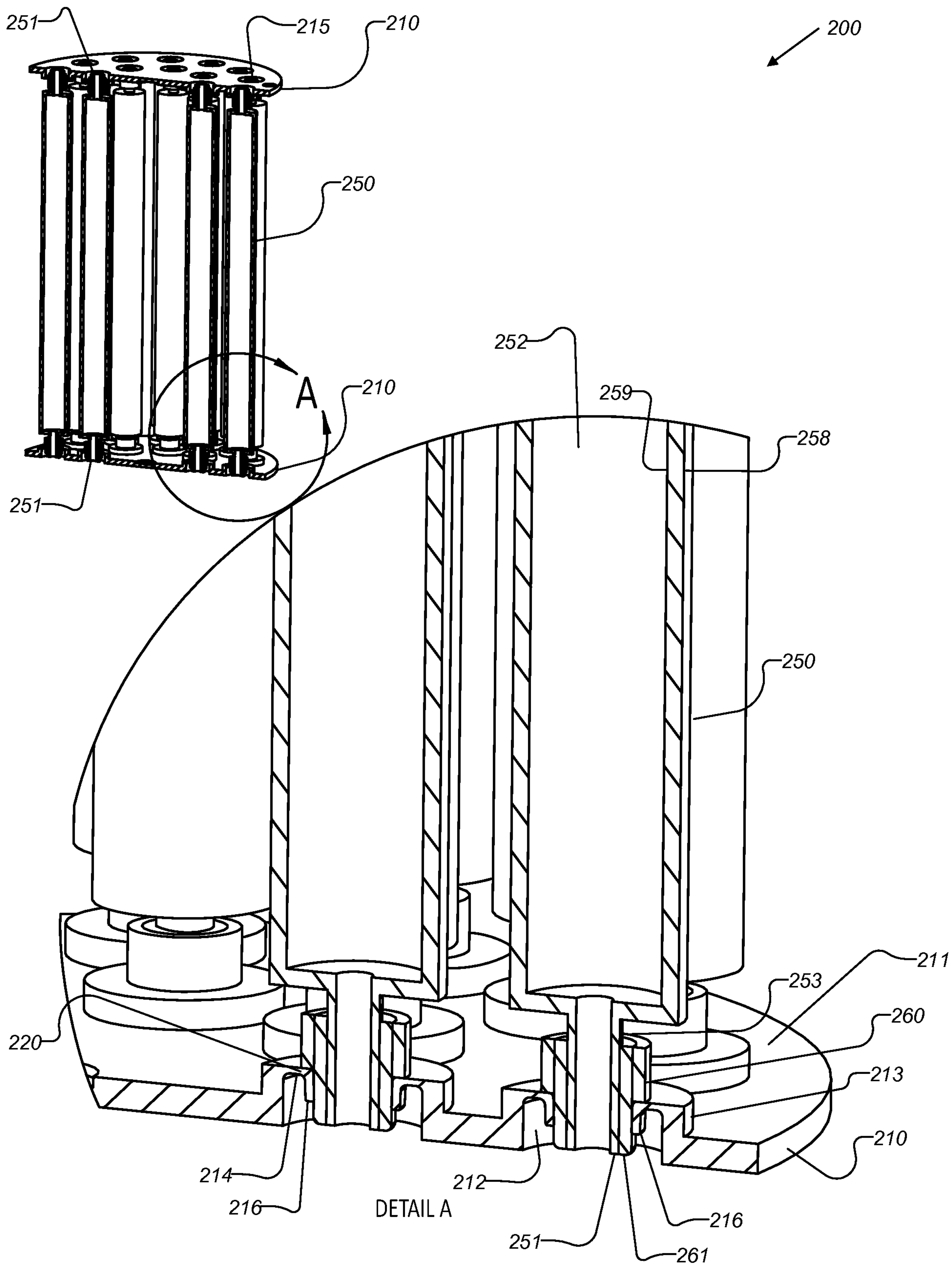


FIG. 3B