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(54) Title: LAMINATED SHOWERHEADS WITH EDGE-FED PLENUMS

(57) Abstract: Semiconductor processing tool showerhead designs suitable for multi-gas delivery and for being made through additive manufacturing or multi-layer lamination are provided. Such showerhead designs may feature one or more internal plenums with a plurality of pillars spanning between upper and lower surfaces thereof distributed throughout.

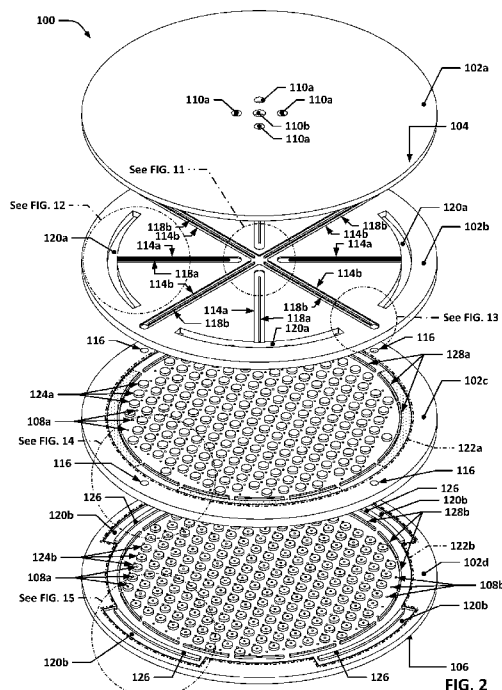


FIG. 2

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LAMINATED SHOWERHEADS WITH EDGE-FED PLENUMS

INCORPORATION BY REFERENCE

[0001] A PCT Request Form is filed concurrently with this specification as part of the present application. Each application that the present application claims benefit of or priority to as identified in the concurrently filed PCT Request Form is incorporated by reference herein in its entirety and for all purposes.

BACKGROUND

[0002] Semiconductor processing tools frequently utilize gas distribution systems, often referred to as showerheads, to distribute process gas or gases across a semiconductor wafer being processed. Such showerheads typically have a plurality of gas distribution ports distributed across, or arranged on, a bottom surface thereof to allow process gases from an internal plenum or plenums of such a showerhead to be flowed onto the semiconductor wafer from above. In some instances, a showerhead may be a single, integrated structure, e.g., made in multiple pieces that are then welded together, while in other instances, a showerhead may be a multi-piece structure that is able to be disassembled, e.g., consisting of multiple pieces that are fastened together, e.g., using screws.

SUMMARY

[0003] Details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims.

[0004] In some implementations, an apparatus may be provided that includes a main body having a first side and a second side on an opposite side of the main body from the first side of the main body, the main body having within it a first plenum volume and a second plenum volume, wherein the first plenum volume is interposed between the first side of the main body and the second plenum volume and the second plenum volume is interposed between the second side of the main body and the first plenum volume. The apparatus may also include one or more first inlet ports fluidically connected with the first plenum volume within the main body, one or more second inlet ports fluidically connected with the second plenum volume within the main body, a plurality of first pillars distributed throughout the second plenum

volume, each first pillar extending between an upper surface bounding the second plenum volume and a lower surface of the second plenum volume, a plurality of first gas distribution ports, each first gas distribution port extending between the second side of the main body and the first plenum volume and passing through one of the first pillars, and a plurality of second gas distribution ports, each second gas distribution port extending between the second side of the main body and the second plenum volume.

[0005] In some implementations, the apparatus may further include a plurality of second pillars, each second pillar extending between an upper surface bounding the first plenum volume and a lower surface bounding the first plenum volume.

[0006] In some implementations, the first gas distribution ports may be arranged in a first triangular lattice pattern, the second gas distribution ports may be arranged in a second triangular lattice pattern, and the first and second triangular lattice patterns may be arranged to form a hexagonal lattice pattern with inner hexagonal cells each having three first gas distribution ports and three second gas distribution ports arranged in alternating fashion.

[0007] In some implementations, the first pillars may also be arranged in the first triangular lattice pattern.

[0008] In some implementations, the second pillars may also be arranged in the second triangular lattice pattern.

[0009] In some implementations, at least some of the second pillars may each be positioned in a center of a corresponding one of the inner hexagonal cells.

[0010] In some implementations, the first gas distribution ports and the second gas distribution ports may be arranged in a plurality of concentric circular patterns.

[0011] In some implementations, the first pillars may be arranged in a plurality of concentric circular patterns.

[0012] In some implementations, the apparatus may further include a plurality of outer arcuate elements positioned within the second plenum volume, the outer arcuate elements each generally co-radial and concentric with one another and each defining, in part, a corresponding sub-plenum of the second plenum volume. Each sub-plenum may be fluidically connected with at least one of the one or more second inlet ports within the main body.

[0013] In some implementations, the plurality of first pillars may be located within a perimeter defined by the outer arcuate elements.

[0014] In some implementations, the second plenum volume may include a plurality of outer openings, each outer opening extending radially inward and located at a different end of one of the outer arcuate elements.

[0015] In some implementations, the apparatus may further include a plurality of first inner arcuate elements positioned within the second plenum volume, the first inner arcuate elements each generally co-radial and concentric with one another.

[0016] In some implementations, the second plenum volume may include a plurality of first inner openings that extend radially inward, each first inner opening positioned between ends of two of the first inner arcuate elements.

[0017] In some implementations, each first inner arcuate element may be azimuthally centered on one of the outer openings, and each first inner opening may be azimuthally centered on one of the outer arcuate elements.

[0018] In some implementations, a radial gap may exist between the outer arcuate elements and the first inner arcuate elements.

[0019] In some implementations, the plurality of first pillars may be located within a perimeter defined by the first inner arcuate elements.

[0020] In some implementations, the apparatus may further include a plurality of second inner arcuate elements positioned within the first plenum volume, the second inner arcuate elements each generally co-radial and concentric with one another.

[0021] In some implementations, the first plenum volume may include a plurality of second inner openings that extend radially inward, each second inner opening positioned between ends of two of the second inner arcuate elements.

[0022] In some implementations, the one or more first inlet ports may be located in a center region of the main body and on the first side of the main body, a plurality of first radial spoke passages may be interposed between the first plenum volume and the first side of the main body, each first radial spoke passage may extend from a first inlet port of the one or more first inlet ports to a respective first location proximate an outer periphery of the first plenum volume, and each first radial spoke passage may fluidically connect the first inlet port from which it extends with the first plenum volume.

[0023] In some implementations, each first radial spoke passage may be defined by two opposing perimeter walls spanning between a first side of that first radial spoke passage and a second side of that first radial spoke passage, and the first side of the main body may be closer to the first side of that first radial spoke passage than to the second side of that first radial spoke

passage and the second side of the main body may be closer to the second side of that first radial spoke passage than to the first side of that first radial spoke passage. In some such implementations, each first radial spoke passage may have one or more first support structures spanning between the first side of that first radial spoke passage and the second side of that first radial spoke passage, and each first support structure of that first radial spoke passage may be interposed between the opposing perimeter walls defining that first radial spoke passage.

[0024] In some implementations, at least one of the first support structures may include a radial wall that extends along at least a part of the corresponding first radial spoke passage, thereby dividing the corresponding first radial spoke passage into multiple sub-passages along the length of that first support structure.

[0025] In some implementations, at least one of the first support structures may include a radial wall that extends from a position proximate the corresponding first inlet port of the corresponding first radial spoke passage to a position proximate the respective first location of the corresponding first radial spoke passage.

[0026] In some implementations, at least one of the first radial spoke passages may have one or more first sets of first support structures with the first support structures in each first set of first support structures each comprising a radial wall and each first set of first support structures having multiple first support structures arranged end-to-end such that the first support structures in that first set of first support structures are separated from each other by corresponding first radial gaps.

[0027] In some implementations, one (or more) of the first radial spoke passages may have multiple first sets of first support structures and the multiple first sets of first support structures for that first radial spoke passage may be arranged in parallel.

[0028] In some implementations, each first support structure may be smaller in maximum dimension than a maximum distance between the opposing perimeter walls of the first radial spoke passage having that first support structure.

[0029] In some implementations, at least some of the first support structures may be circular in cross-section.

[0030] In some implementations, one (or more) of the first radial spoke passages may have a plurality of the first support structures and the first support structures in the plurality of first support structures may be arranged in a rectangular array with one axis of the array aligned with a direction along which that first radial spoke passage extends.

[0031] In some implementations, one (or more) of the first radial spoke passages may have a plurality of the first support structures and the first support structures in the plurality of first support structures may be arranged in a triangular lattice pattern.

[0032] In some implementations, one (or more) of the first radial spoke passages may have a plurality of the first support structures and the first support structures in the plurality of first support structures may each be elongate in cross-section.

[0033] In some implementations, the first support structures in the plurality of first support structures may be arranged in a rectangular array with a first axis of the array aligned with a direction along which that first radial spoke passage extends.

[0034] In some implementations, each of the first support structures in the plurality of first support structures may have a long axis that is at an oblique angle relative to the first axis, and the first support structures in the plurality of first support structures arranged in the rectangular array may be arranged such that the first support structures in every other row of the rectangular array have long axes with slopes relative to the first axis that are opposite in sign to slopes of the long axes of the first support structures in the other rows of the rectangular array relative to the first axis.

[0035] In some implementations, there may be multiple first support structures in each row of the rectangular array.

[0036] In some implementations, the first support structures in the rectangular array may each have an obround cross-section.

[0037] In some implementations, the one or more second inlet ports may be located in the center region of the main body and on the first side and include a plurality of second inlet ports, a plurality of second radial spoke passages may be interposed between the first plenum volume and the first side of the main body, each second radial spoke passage may extend from a second inlet port of the one or more second inlet ports to a location proximate an outer periphery of the second plenum volume, each second radial spoke passage may fluidically connect the second inlet port from which it extends with the second plenum volume, and each second radial spoke passage may be defined by two opposing perimeter walls spanning between a first side of that second radial spoke passage and a second side of that second radial spoke passage. The first side of the main body may be closer to the first side of that second radial spoke passage than to the second side of that second radial spoke passage and the second side of the main body may be closer to the second side of that second radial spoke passage than to the first side of that second radial spoke passage. Moreover, each second radial spoke passage may have

one or more second support structures spanning between the first side of that second radial spoke passage and the second side of that second radial spoke passage, and each second support structure of that second radial spoke passage may be interposed between the opposing perimeter walls defining that second radial spoke passage.

[0038] In some implementations, at least one of the second support structures may include a radial wall that extends along at least a part of the corresponding second radial spoke passage, thereby dividing the corresponding second radial spoke passage into multiple sub-passages along the length of that second support structure.

[0039] In some implementations, at least one of the second support structures may include a radial wall that extends from a position proximate the corresponding second inlet port of the corresponding second radial spoke passage to a position proximate the respective second location of the corresponding second radial spoke passage.

[0040] In some implementations, at least one of the second radial spoke passages may have one or more second sets of second support structures with the second support structures in each second set of second support structures each including a radial wall and each second set of second support structures having multiple second support structures arranged end-to-end such that the second support structures in that second set of second support structures are separated from each other by corresponding second radial gaps.

[0041] In some implementations, one (or more) of the second radial spoke passages may have multiple second sets of second support structures and the multiple second sets of second support structures for that second radial spoke passage may be arranged in parallel.

[0042] In some implementations, each second support structure may be smaller in maximum dimension than a maximum distance between the opposing perimeter walls of the second radial spoke passage having that second support structure.

[0043] In some implementations, at least some of the second support structures may be circular in cross-section.

[0044] In some implementations, one (or more) of the second radial spoke passages may have a plurality of the second support structures and the second support structures in the plurality of second support structures may be arranged in a rectangular array with one axis of the array aligned with a direction along which that second radial spoke passage extends.

[0045] In some implementations, one (or more) of the second radial spoke passages may have a plurality of the second support structures and the second support structures in the plurality of second support structures may be arranged in a triangular lattice pattern.

[0046] In some implementations, one (or more) of the second radial spoke passages may have a plurality of the second support structures and the second support structures in the plurality of second support structures may each be elongate in cross-section.

[0047] In some implementations, the second support structures in the plurality of second support structures may be arranged in a rectangular array with a second axis of the array aligned with a direction along which the corresponding second radial spoke passage extends.

[0048] In some implementations, each of the second support structures in the plurality of second support structures may have a long axis that is at an oblique angle relative to the second axis, and the second support structures in the plurality of second support structures arranged in the rectangular array may be arranged such that the second support structures in every other row of the rectangular array have long axes with slopes relative to the second axis that are opposite in sign to slopes of the long axes of the second support structures in the other rows of the rectangular array relative to the second axis.

[0049] In some implementations, there may be multiple second support structures in each row of the rectangular array.

[0050] In some implementations, the second support structures in the rectangular array may each have an obround cross-section.

[0051] In some implementations, the first radial spoke passages and the second radial spoke passages may be arranged in a circumferentially alternating circular pattern.

[0052] In some implementations, each first radial spoke passage may terminate in the middle of a corresponding arcuate plenum that leads to the first plenum volume.

[0053] In some implementations, the first plenum volume may have no pillars extending through it.

[0054] In some implementations, the apparatus may further include a baffle plate located within the first plenum volume. The one or more first inlet ports may be positioned above the center of the baffle plate, the baffle plate may have a circular interior region with a diameter larger than a diameter of a reference circle encircling and touching the outermost first gas distribution ports, and the baffle plate may be spaced apart from surfaces that bound the first plenum volume and are parallel to the first side of the main body.

[0055] In some implementations, the one or more first inlet ports may be located in a center region of the main body and on the first side and fluidically connect with the first plenum volume in a center region of the first plenum volume.

[0056] In some implementations, the main body may include or be made from a ceramic material.

[0057] In some implementations, the apparatus may further include a semiconductor processing chamber and the second side of the main body may be located within an interior of the semiconductor processing chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

[0058] FIG. 1 depicts an isometric view of an example showerhead having two edge-fed internal plenums with pillars spanning between upper and lower surfaces of each plenum.

[0059] FIG. 2 depicts an isometric exploded section view of the example showerhead of FIG. 1, with each section shown as a separate sub-body.

[0060] FIG. 3 depicts an isometric exploded view of the example showerhead of FIG. 1 from an opposing perspective.

[0061] FIG. 4 depicts a side view of the showerhead of FIG. 1 and various section lines that define the section planes for FIGS. 6–8.

[0062] FIG. 5 depicts a top view of the showerhead of FIG. 1.

[0063] FIGS. 6, 7, and 8 depict section views of the showerhead of FIG. 4 along the section lines marked 6-6, 7-7, and 8-8, respectively.

[0064] FIG. 9 depicts a bottom view of the showerhead 100.

[0065] FIG. 10 is a duplicate of FIG. 8 that also shows the footprints of various pillars.

[0066] FIG. 11 depicts a detail view of the region in FIG. 2 indicated by the corresponding view callout.

[0067] FIG. 12 depicts a detail view of the region in FIG. 2 indicated by the corresponding view callout.

[0068] FIG. 13 depicts a detail view of the region in FIG. 2 indicated by the corresponding view callout.

[0069] FIG. 14 depicts a detail view of the region in FIG. 2 indicated by the corresponding view callout.

[0070] FIG. 15 depicts a detail view of the region in FIG. 2 indicated by the corresponding view callout.

[0071] FIG. 16 is similar to FIG. 6 but shows an alternative implementation in which the support structures are not continuous.

[0072] FIG. 17 is also similar to FIG. 6 but shows a different alternative implementation in which there are multiple support structures for each radial spoke passage.

[0073] FIG. 18 is also similar to FIG. 6 but shows another different alternative implementation in which there are a large number of smaller support structures for each radial spoke passage.

[0074] FIG. 19 is also similar to FIG. 18 but shows a different alternative implementation in which there are a large number of smaller support structures for each radial spoke passage.

[0075] FIG. 20 is also similar to FIG. 18 but shows another different alternative implementation in which there are a large number of smaller support structures for each radial spoke passage.

[0076] FIG. 21 depicts an isometric view of the underside of an alternative example showerhead.

[0077] FIGS. 22 and 29 depict exploded isometric views of the showerhead of FIG. 21.

[0078] FIGS. 23 and 24 show exploded isometric views of an example showerhead that features a baffle plate.

[0079] FIG. 25 depicts a section view of the showerhead of FIGS. 23 and 24.

[0080] FIGS. 26 and 27 show exploded isometric views of another example showerhead that features a baffle plate.

[0081] FIG. 28 depicts a section view of the showerhead of FIGS. 26 and 27.

[0082] FIG. 30 depicts an example of a showerhead that is manufactured using a lamination technique.

[0083] FIG. 31 depicts a schematic of a chamber that may include a showerhead such as is described herein.

[0084] FIGS. 1 through 31 are not necessarily to-scale, and it will be appreciated that implementations beyond the specific examples provided here and shown in the Figures are within the scope of this disclosure, and the disclosure is not limited to the specific examples shown in the Figures.

DETAILED DESCRIPTION

[0085] A showerhead, in the context of this disclosure, refers to a structure that typically features a main body that houses within it one or more passages or internal volumes that form one or more internal plenum volumes. Showerheads also include a plurality of gas distribution ports that are each fluidically connected with the internal plenum volume or with one of the internal plenum volumes (if multiple such internal plenum volumes exist). The gas distribution

ports are typically distributed across the underside (or top side) of the main body and positioned so as to deliver process gas supplied thereby across the upper surface of a wafer being processed (or across the underside of the wafer if backside deposition or etching is being performed). Showerheads may be positioned above and/or below a wafer within a semiconductor processing chamber, depending on the context. In some instances, a showerhead may have gas distribution ports that pass completely through the showerhead and which are not fluidically connected with any internal plenum volumes of the showerhead. When such a showerhead is then interfaced with one or more other components in order to form another plenum volume that is bounded on one side by an exterior surface of the showerhead, this allows another gas to be delivered to that newly created plenum volume and then flowed through the gas distribution ports that pass completely through the showerhead.

[0086] Disclosed herein are various showerhead designs that are specially designed so as to be able to be manufactured using additive manufacturing techniques such as selective laser melting (SLM) (which may be used to produce ceramic or silicon versions of such showerheads) or direct metal laser melting (DMLM) (which may be used to produce metal versions thereof). In particular, the showerhead designs discussed herein may be particularly suitable for being manufactured using laser powder-bed fusion (LPBF) additive manufacturing techniques, which may include manufacturing processes such as SLM, DMLM, SLS (selective laser sintering), and DMLS (direct metal laser sintering), all of which may be used to create metal-based components (and some of which, like SLS and SLM, may be used to create ceramic-based components).

[0087] In most additive manufacturing processes, a part is manufactured by adding material to the part one horizontal layer at a time; such layers may be extremely thin, e.g., 0.02mm at a time is possible for DMLM parts. In DMLM, for example, a platen supporting a part is gradually lowered relative to a reference plane. The platen forms the “floor” of a cavity that is used to contain the part being manufactured. Each time the platen is lowered, powdered material is added to the cavity and then leveled so as to be level with the reference plane. A laser then scans across the reference plane and applies heat to the uppermost layer of powdered material in the regions where structure is desired, melting the powder granules to each other and to any underlying, previously fused structure. Once a particular layer is done, the platen may be lowered slightly, a new layer of powdered material may be applied, and the laser melting process repeated. This process is repeated until the part is complete, at which point

the cavity of the DMLM device will be filled with unmelted powdered material having buried within it the additively manufactured component.

[0088] Such additively manufactured components typically have a very fine grain microstructure as compared with bulk-manufactured components (e.g., such as components made by casting in which molten material is formed into the desired component in generally a single operation as opposed to a small number of grains being fused together at a time over the course of many sequential operations as is done in SLM or DMLM)), i.e., a structure that is formed through the fusion of small grains of solid material through the selective application of heat provided by a laser. Such additively manufactured components also, in many cases, tend to have a microstructure that is noticeably directional, with micrograins having profiles in the XY plane that are more rounded and larger than the profiles of such micrograins in a plane parallel to the Z direction (with the XY plane corresponding to the horizontal plane, and the Z direction corresponding to the vertical direction, relative to the component as positioned during the additive manufacturing process). The size of the grains in the vertical plane may exhibit a high degree of asymmetry with respect to their size in the Z-direction compared to their size in either the X or Y directions. The micrograins tend to be much longer in the X and/or Y directions than they are thick in the Z direction. This micrograin structure may be referred to herein as being an anisotropic micrograin structure, which should be understood to differentiate it from micrograin structures in which the micrograins, while exhibiting variation in size and shape, do not generally exhibit dimensional variance that is tied to a particular axis. It will be understood that at least some of the additively manufactured showerheads discussed herein may exhibit such anisotropic micrograin structure.

[0089] The use of such additive manufacturing techniques permits the adoption of showerhead geometries that would be extremely difficult or impossible to achieve using only conventional machining (subtractive machining) techniques such as milling, drilling, or turning. Such showerhead geometries may allow, for example, showerheads to have smaller interior volumes (thus decreasing the amount of gas needed to provide a desired gas flow through the showerhead and reducing the amount of time needed before the showerhead reaches steady state flow) and, in some cases, an increased number of different fluidically isolated flow paths within the showerhead (or at least a higher density of such flow paths).

[0090] Alternatively, such showerheads may be manufactured by laminating multiple, separately manufactured layers together. For example, such showerheads may be made as a laminated ceramic structure, e.g., with one or more ceramic plates that are machined or

otherwise formed, e.g., by pressing, so as to have the various features discussed below, e.g., open plenums with a plurality of pillars extending therethrough, open-channel features that may define radial spoke passages, etc. Such a ceramic plate or ceramic plates may then be bonded to another ceramic plate and/or to each other so as to cap such open-channel features or pillar-containing plenum volumes to form enclosed passages or enclosed plenums. For example, such ceramic plates may be bonded together by sintering the ceramic plates together. Such approaches may also be used to provide multi-plenum structures in which there are multiple levels of such passages or plenum volumes at different elevations, with the plenum volume or passages of each elevation being provided by a corresponding machined or formed ceramic plate.

[0091] The showerhead designs discussed herein are designed to be made of ceramic materials, such as aluminum oxide or silicon nitride, which may make them relatively non-reactive with most process gases and permit their use in challenging semiconductor processing environments. Such showerheads may permit flow or delivery of two or more different gases used during semiconductor processing operations (including, for example, precursors, reactants, or inert or non-reactive purge gases) from or through a common showerhead while segregating those gas flows from one another within the showerhead.

[0092] FIG. 1 depicts an isometric view of an example showerhead having two edge-fed internal plenums with pillars spanning between upper and lower surfaces of each plenum. In this implementation, the showerhead 100 includes a main body 102 that features a plurality of inlet ports 110, e.g., one or more first inlet ports 110a (in this example, there are four, although other implementations may feature a different number) and one or more second inlet ports 110b (in this example, there is one, but other implementations may feature more than one). The inlet ports 110 may be provided respective process gases via a stem or other component(s) that may interface to a first side 104 of the main body 102. A plurality of gas distribution ports (not shown) may be provided on a second side 106 of the main body that faces in an opposite direction from the first side 104.

[0093] As discussed earlier, the showerhead 100 in this example may, for example, be additively manufactured or may be manufactured in discrete layers that are then bonded together to form a laminated stack. In the depicted implementation, for example, the main body 102 may be made of four layers that are bonded together. Each layer may, for example, have features machined or formed into it prior to bonding, such as passages, pillars, gas

distribution ports, etc. It will be understood that in other implementations, a different number of layers may be laminated together, e.g., five layers or six layers.

[0094] FIG. 1 also shows circumferential dashed lines that indicate cut lines for the cross-sections shown in FIGS. 2 and 3. FIG. 2 depicts an isometric exploded section view of the example showerhead of FIG. 1, with each section 102a–d shown as a separate sub-body. FIG. 3 depicts an isometric exploded view of the example showerhead of FIG. 1 from an opposing perspective. FIG. 4 depicts a side view of the showerhead 100 and various section lines that define the section planes for FIGS. 6–8. FIG. 5 depicts a top view of the showerhead 100. FIGS. 6, 7, and 8 depict section views of the showerhead 100 along the section lines marked 6-6, 7-7, and 8-8, respectively. FIG. 9 depicts a bottom view of the showerhead 100, while FIG. 10 is a duplicate of FIG. 8 that also shows the footprints of the first pillars 124a.

[0095] As can be seen, the showerhead 100 in this example includes a first plenum volume 122a and a second plenum volume 122b. The first plenum volume 122a may be provided with process gas from the first inlet ports 110a, while the second plenum volume 122b may be provided with process gas from the second inlet ports 110b. The first plenum volume 122a may be interposed between the second plenum volume 122b and the first side 104, while the second plenum volume 122b may be interposed between the first plenum volume 122a and the second side 106.

[0096] The showerhead 100 may also include a plurality of first radial spoke passages 114a and a plurality of second radial spoke passages 114b. Each first radial spoke passage 114a may have a first end that is collocated with, and fluidically connected with, one of the first inlet ports 110a and a second end that is positioned radially outward from the first end and terminates in a corresponding first arcuate plenum 120a. Similarly, each second radial spoke passage 114b may have a first end that is collocated with a second inlet port 110b (in this case, the single second inlet port 110b) and a second end that is positioned radially outward from the first end thereof and which terminates in corresponding riser passage 116 that leads to a second arcuate plenum 120b. The first radial spoke passages 114a and the second radial spoke passages 114b may be arranged in a circumferentially alternating pattern, e.g., in repeating instances of first/second/first/second radial passages.

[0097] A first process gas that is introduced into the showerhead 100 via the first inlet ports 110a will flow radially outward via the first radial spoke passages 114a and into the first arcuate plenums 120a and then into a first plenum volume 122a via the shaded zones 120a'. Put another

way, the first plenum volume 122a may be fluidically connected with the one or more first inlet ports 110a within the main body 102 by the first radial spoke passages 114a.

[0098] As shown in FIG. 2, the radial spoke passages 114 may, in some implementations, include one or more support structures 118. The support structures 118 may, for example, extend along the lengths of the radial spoke passages 114 and may span between first sides of the radial spoke passages 114 and second sides of the radial spoke passages 114 (the first side 104 of the main body 102 may be closer to the first side of each radial spoke passage 114 than to the second side of that radial spoke passage 114, and the second side 106 of the main body 102 may be closer to the second side of each radial spoke passage 114 than to the first side of that radial spoke passage 114; the first side and the second side of each radial spoke passage 114 may, for example, correspond with the upper and lower surfaces of the radial spoke passages 114 when the showerhead is in an installed configuration).

[0099] For example, each first radial spoke passage 114a may have one or more first support structures 118a that are in the form of radial walls and that extend along most or all of the length of the first radial spoke passage 114a, traveling along the same path as the first radial spoke passage 114a but arranged such that a gap is maintained between the first support structure(s) 118a and the opposing perimeter walls that partially define the first radial spoke passage 114a (for example, the opposing perimeter walls may be understood to be the long, vertical walls that are visible in FIG. 2 and that extend parallel to the axis along which the first radial spoke passages 114 extend). In effect, the radial wall-like first support structure(s) 118a of a first radial spoke passage 114a may subdivide the respective first radial spoke passage 114a into multiple first radial spoke passages 114a that are each smaller in cross-section than the original cross-section of the first radial spoke passage 114a. Including such first support structure(s) 118a in a first radial spoke passage 114a may help prevent potential delamination effects that might occur between the main body layers used to form the portion of the main body 102 containing the first radial spoke passages 114a. For example, if a first radial spoke passage 114a is of a sufficient width, e.g., 3 mm or greater, there may be an increased risk of the bond(s) between the two or more layers of the main body 102 that form the first radial spoke passage 114a developing cracking or otherwise weakening or failing, thereby allowing those layers to pull apart. Such failures may, for example, allow process gases that are flowed through the first radial spoke passages 114a to potentially come into contact with the process gases that are flowed through the second radial spoke passages 114b (or vice versa). This may, for example, lead to undesirable reaction between the two process gases and may cause

deposition, etching, or other chemical processes to occur within the first radial spoke passages 114a and/or the second radial spoke passages 114b.

[0100] The radial wall-like first support structure(s) 118a may help provide additional reinforcement to the first radial spoke passage(s) 114a, thereby distributing the potential loads that may be transmitted across the locations within the first radial spoke passage(s) 114a where two of the layers of the main body 102 are bonded together, e.g., the interior corner edges of the first radial spoke passage(s) 114a. Such load redistribution may act to reduce the magnitude of such loads across each such bond interface and correspondingly reduce the potential for crack initiation at those interfaces.

[0101] The radial wall-like first support structure(s) 118a are shown as being contiguous, e.g., each extending between the first and second ends of the corresponding first radial spoke passage 114a in an unbroken manner. However, in other implementations, a first support structure 118a may, in effect, be subdivided into discrete segments, e.g., a series of separate, smaller radial wall-like first support structure(s) 118a that are arranged, for example, along a common path. Such arrangements may also provide the structural reinforcement that may reduce the potential for delamination occurring but may also provide for more potential for turbulence in the process gases being flowed. This may, for example, be beneficial in inducing mixing of a process gas. For example, if a process gas directed through a first radial spoke passage 114a is actually a mixture of gases, flow through such a first radial spoke passage 114a with such a multiple first support structures 118a may further promote mixing between the two or more gases.

[0102] The second radial spoke passages 114b may similarly be equipped with second support structures 118b that may function similarly to the first support structures 118a with respect to the first radial spoke passages 114b.

[0103] The first process gas may flow throughout the first plenum volume 122a before exiting the first plenum volume 122a via a plurality of first gas distribution ports 108a that each exit the showerhead 100 via the second side 106 of the showerhead 100. The first plenum volume 122a, in this example, also includes a plurality of first pillars 124a that are distributed throughout the first plenum volume 122, e.g., in a triangular lattice patterns, and span or extend between upper and lower surfaces that bound, at least in part, the first plenum volume 122a. Such first pillars 124a may serve to provide structural rigidity to the showerhead 100 and may also act to help to more evenly distribute the flow of the first process gas throughout the first plenum volume 122a and to conduct heat more efficiently between the bottom of the

showerhead 100 and the top of the showerhead 100. In some implementations, the first pillars 124a may be omitted, e.g., if increased heat conduction between the bottom of the showerhead 100 and the top of the showerhead 100 is not required and/or if there is sufficient structural rigidity in the first plenum volume 122a of the showerhead 100 such that the first pillars 124a are unnecessary.

[0104] Similarly, a second process gas that is introduced into the showerhead 100 via the second inlet port 110b will flow radially outward via the second radial spoke passages 114b and then downward, past the first plenum volume 122a, through the riser passages 116 and into the second arcuate plenums 120b, after which it may flow through second gas distribution ports 108b in the second side 106 of the showerhead 100. The second arcuate plenums 120b may, for example, be part of a second plenum volume 122b. As can be seen in FIG. 2, the second arcuate plenums 120b may be defined, at least in part, by outer arcuate elements 126. The outer arcuate elements 126 may, for example, be arcuate walls that separate the second arcuate plenums 120b from the remainder of the second plenum volume 122b. Put another way, the second arcuate plenums 120b may be considered to be sub-plenums of the second plenum volume 122b. In some implementations, the second arcuate plenums 120b may be replaced with non-arcuate plenums, e.g., rectangular, segmented, or triangular plenums.

[0105] As can be seen, the second plenum volume 122b also features a plurality of second pillars 124b that extend between the upper and lower surfaces of the second plenum volume 122b. Each of the second pillars 124b has one of the first gas distribution ports 108a passing through it, thereby providing a flow path from the first plenum volume 122a through the second plenum volume 122b without allowing the first process gas in the first plenum volume 122a to mix with the second process gas in the second plenum volume 122b within the showerhead 100.

[0106] It will be noted that the first plenum volume 122a and the second plenum volume 122b each contain a circular array of inner arcuate elements 128a and 128b, respectively. The inner arcuate elements 128a and 128b may, for example, act to distribute process gases that are flowed radially inward from the perimeters of the first plenum volume 122a and the second plenum volume 122b in a more azimuthally uniform manner.

[0107] It can be seen that in this example, the first gas distribution ports 108a and the second gas distribution ports 108b are arranged in staggered triangular lattice patterns, such that, at least for interior instances of the first gas distribution ports 108a and the second gas distribution ports 108b, the first gas distribution ports 108a and the second gas distribution ports 108b

define a hexagonal lattice pattern in which hexagonal cell has alternating first gas distribution ports 108a and the second gas distribution ports 108b located at the vertices thereof. Such an arrangement may provide for a relatively even distribution of the first and second process gases that are delivered via the first gas distribution ports 108a and the second gas distribution ports 108b.

[0108] As can be seen in FIG. 10, the first pillars 124a and the second pillars 124b may be similarly arranged, e.g., with each first pillar 124a being positioned over, and vertically centered on, one of the second gas distribution ports 108b. It will be appreciated that the first pillars 124a and the second pillars 124b may also be arranged in an alternate manner, e.g., with a center axis of each first pillar 124a centered on a triangle defined by three closest-neighbor second pillars 124b and which does not have a second gas distribution port 108b within it. It will be further appreciated that while the depicted implementation features first pillars 124a and second pillars 124b that are all circular, the same diameter, and that have exterior surfaces that define circles that contact one another in a tangent manner, other implementations may feature first pillars 124a and/or second pillars 124b that are differently shaped (e.g., square, triangular, hexagonal, etc.) in cross-section, of different sizes (e.g., with the first pillars 124a being of one size or set of sizes, and the second pillars 124b being of different sizes or a set of sizes that is at least partially different from the set of sizes for the first pillars 124a), or that are spaced apart from closest neighbor pillars 124 in a different manner (e.g., with the center axes of the first pillars 124a and the second pillars 124b spaced apart such that the footprints of adjacent first pillars 124a and second pillars 124b either overlap one another or do not overlap one another). It will also be appreciated that showerheads such as the showerhead 100 may feature a larger or smaller number of first gas distribution ports 108a and/or second gas distribution ports 108b. For example, in the depicted example, the first gas distribution ports 108a and the second gas distribution ports 108b are spaced at a relatively coarse pitch, but in other implementations, there may be a much larger number of first gas distribution ports 108a and/or second gas distribution ports 108b, e.g., twice the density of first gas distribution ports 108a and/or second gas distribution ports 108b as that depicted.

[0109] As can be seen in FIG. 7, the first inner arcuate elements 128a may each be separated from adjacent first inner arcuate elements 128a by first inner openings 132a, thereby creating flow paths from an annular plenum that is defined between an outer perimeter of the first plenum volume 122a and the first inner arcuate elements 128 and a remainder of the first plenum volume 122a. The first inner openings 132a may be evenly spaced about the perimeter

of the first plenum volume 122a, thereby providing a circular array of gas inlets that may allow the first process gas that is delivered to the first plenum volume 122a via the first inlet ports 110a, the first radial spoke passages 114a, and the first arcuate plenums 120a to enter the interior of the first plenum volume 122a in a manner that is generally azimuthally uniform.

[0110] In a similar fashion and as can be seen in FIG. 8, the second plenum volume 122b in this example also includes second inner arcuate elements 128b that are arranged in a circular array and are concentrically positioned, and located radially inward, with respect to outer wall defining the second plenum volume 122b, thereby forming a radial gap between that outer wall and the second inner arcuate elements 128b. Similar to the first inner arcuate elements 128a, each second inner arcuate element 128b may be separated from the adjacent second inner arcuate elements 128b by corresponding second inner openings 132b.

[0111] FIG. 8 also depicts outer arcuate elements 126 that are each positioned in between a corresponding one of the second arcuate plenums 120b and the second inner arcuate elements 128b, thereby partially defining the corresponding second arcuate plenum 120b. Each outer arcuate element 126 may have a corresponding pair of outer openings 130, one located at each end of that outer arcuate element 126.

[0112] It will be observed in FIG. 8 that there are N outer arcuate elements 126 and second arcuate plenums 120a and 2N outer openings 130, and that there are 4N inner arcuate elements 128 and 4N inner openings 132 (N, in this example, is 4). Moreover, it can be seen that each inner arcuate element 128 is azimuthally positioned such that the center of that inner arcuate element 128 azimuthally aligns with or is azimuthally centered on one of the outer openings 130. "Azimuthally centered," it will be understood, refers to a condition where elements that are arranged about a common center point are aligned such that element that is azimuthally centered on another element is positioned such that the center points of both elements lie along the same radius extending from the common center point. When a second process gas is flowed into the second plenum volume 122b via the second arcuate plenums 120b, the second process gas first flows into an annular sub-plenum region that is bounded (at least in part) between the outer arcuate elements 126 and the second inner arcuate elements 128b.

[0113] It will also be observed that the outer arcuate elements 126 are all the same size, and that the first inner arcuate elements 128a and the second inner arcuate elements 128b are also all the same size. Such an arrangement has the effect of providing multiple gas flow introduction points all around the circumference of the second plenum volume 122b that generally all have equivalent flow resistance since the shortest flow path from any of the second

inner openings 132b to the second inlet port 110b that is closest thereto (in terms of fluid path length) may generally have a flow path length (and fluidic resistance) that is equivalent to the shortest flow path from any of the other second inner openings 132b to the second inlet port 110b that is closest thereto. Such an arrangement acts to divide the gas flows introduced into each of the second arcuate plenums 120b via the riser passage 116 into two generally equal-sized gas flows, and to then further subdivide each of the generally equal-sized gas flows into two more generally equal-sized gas flows, thereby partitioning the second process gas flow into $4N$ generally equal gas flows that are equidistantly spaced about the perimeter of the second plenum volume 122b. This may help ensure that the flow of second process gas from the second plenum volume 122b and through the second gas distribution ports 108b is more azimuthally uniform. It will be further understood that one or more additional concentric rings of arcuate elements may be included to further subdivide the second process gas flows, thereby further evening out the flow of the second process gas azimuthally. For example, each arcuate element in such an additional ring or rings of arcuate elements may be azimuthally centered on one of the openings between the arcuate elements in the ring of arcuate elements that is immediately radially outward from that additional ring of arcuate elements.

[0114] The depicted arrangement features the first inlet ports 110a and the second inlet ports 110b both located in a common center region of the main body 102. The first arcuate plenums 120a, as well as the outer arcuate elements 126 and the second arcuate plenums 120b, may, as shown, be arranged in circular arrays about a center axis of the showerhead 100, e.g., around the center region. Such an arrangement allows the first and second process gases to be delivered to the respective first inlet port(s) 110a and second inlet port(s) 110b near the centerline of the showerhead 100 and then flowed radially outward within the showerhead 100 main body 102 to locations distributed around the periphery of the first plenum volume 122a and the second plenum volume 122b, respectively. Such an arrangement allows the centrally delivered process gases to subsequently be flowed into the first plenum volume 122a and the second plenum volume 122b relatively evenly about the perimeters of the first plenum volume 122a and the second plenum volume 122b.

[0115] It will be appreciated that the first plenum volume 122a may also, in some implementations, feature a similar arrangement of outer arcuate elements as in the second plenum volume 122b, e.g., each defining, at least in part, a portion of a corresponding one of the first arcuate plenums 120a. Thus, both the first plenum volume 122a and the second plenum volume 122b may be configured in a substantially similar manner, e.g., each having outer

arcuate elements defining, at least in part, corresponding arcuate plenums, and each having outer openings that are azimuthally centered on corresponding inner arcuate elements (or intervening arcuate elements located radially inward, e.g., when there are one or more additional concentric rings of arcuate elements beyond the ring of outer arcuate elements and the ring of inner arcuate elements).

[0116] FIGS. 11 through 15 depict various detail views of the regions of the showerhead circled in FIG. 2, and may provide additional insight and clarity to the concepts discussed above.

[0117] For example, FIG. 11 depicts a detail view of the center of the body portion 102b. As can be seen, the radial wall-like first support structures 118a and the radial wall-like second support structures 118b are clearly visible. It will additionally be evident that the first support structures 118a and the second support structures 118b may also have rounded ends, e.g., to avoid the presence of sharp corners that may, for example, more easily be eroded (thus generating particulate contamination) and/or potentially act as stress risers that may increase the risk of delamination occurring between layers. It can also be seen that the interior corners formed when the second radial spoke passages 114b intersect are also rounded in a similar fashion in order to provide similar benefits.

[0118] FIG. 12 depicts a detail view of one of the first arcuate plenums 120a. Again, the end of the radial wall-like first support structure 118a has an endcap that is rounded, e.g., to reduce the chance of potential erosion and/or crack initiation. While not shown here, one or more of the other interior corners visible in FIG. 12 may also be similarly rounded, e.g., the four interior edge corners located at the ends of the first arcuate plenum 120a, as well as the edge formed where the first radial spoke passage 114a meets the first arcuate plenum 120a.

[0119] FIG. 13 depicts a detail view of one of the riser passages 116 that is provided second process gas via a corresponding one of the second radial spoke passages 114b. Such riser passages 116 may allow the gas flowed through a radial spoke passage 114 to travel vertically within the outer perimeter of the showerhead 100, thereby allowing such gas to vertically bypass one or more plenum volumes that may be vertically stacked within the middle of the showerhead 100. It will be understood that while not shown in this example, both the first plenum volume 122a and the second plenum volume 122b may be provided gas via corresponding riser passages 116.

[0120] FIGS. 14 and 15 provide detail views of the first pillars 124a, the second pillars 124b, the first gas distribution ports 108a, and the second gas distribution ports 108b, as well as the

first inner arcuate elements 128a, the second inner arcuate elements 128b, the outer arcuate elements 126, the first inner openings 132a, the second inner openings 132b, and the outer openings 130.

[0121] FIG. 16 is similar to FIG. 6 but shows an alternative implementation in which there are multiple radial wall-like first support structures 1618a forming, in effect, a segmented radial wall structure within each first radial spoke passage 114a composed of multiple, shorter segments (as compared with a first support structure that extends all the way from the corresponding inlet to the outer periphery of the corresponding plenum volume) that are spaced apart from one another by corresponding first radial gaps. Similarly, multiple radial wall-like second support structures 1618b that are spaced apart from one another by corresponding second radial gaps are located within each second radial spoke passage 114b.

[0122] FIG. 17 is also similar to FIG. 6 but shows a different alternative implementation in which there are multiple radial wall-like first support structures 1718a for each first radial spoke passage 114a, and multiple radial wall-like second support structures 1718b for each second radial spoke passage 114b. Elements in FIGS. 16 and 17 called out with the same callouts as elements in earlier Figures may be assumed to be the same as the corresponding structures with the same callouts in earlier Figures and the earlier descriptions of such elements may be assumed to be applicable to the corresponding elements in FIGS. 16 and 17 unless otherwise indicated.

[0123] It will be understood that the implementations of FIGS. 16 and 17 may also be blended, e.g., there may be multiple radial wall-like support structures 118 spaced apart from one another across the width of a radial spoke passage as well as along its length.

[0124] Additional implementations of such support structure-equipped radial passages are shown in FIGS. 18 through 20. Elements in FIGS. 18 through 20 called out with the same callouts as elements in earlier Figures may be assumed to be the same as the corresponding structures with the same callouts in earlier Figures and the earlier descriptions of such elements may be assumed to be applicable to the corresponding elements in FIGS. 18 through 20 unless otherwise indicated.

[0125] In some situations, the use of support structures that extend along the entire length of a radial spoke passage, or that extend along segments of the radial spoke passages that are relatively long, e.g., >20% of the total length of the radial spoke passage in question, may result in potential flow conductance mismatches between different radial spoke passages that are intended to have identical flow conductance.

[0126] Such situations may arise in ceramic material-based structures since the various features, e.g., the radial spoke passages and the support structures located therewithin, are machined into (or formed into) the corresponding ceramic layer while the ceramic is still “green,” i.e., prior to being fired to fuse the individual ceramic particles together into a sintered ceramic structure. During the firing process, the part being fired may see significant shrinkage, e.g., on the order of 15% to 20%. The amount of shrinkage may also vary depending on location of the relevant feature within the part. As a result of such part shrinkage, there may be variation in the cross-sectional areas (and thus the flow conductance) of the radial spoke passages. For example, one radial spoke passage may have a cross-sectional area that is 5% smaller than that of another radial spoke passage within the same showerhead body. Such variance in cross-sectional area of the radial spoke passages can lead to a corresponding variance in the amount of process gas that is distributed to different sectors of a common plenum that such radial spoke passages may all distribute process gas to. This, in turn, leads to uneven process gas delivery across the surface of the wafer being processed and may cause undesirable process uniformity variance, e.g., uneven deposition or uneven etching on the wafer.

[0127] The implementations of FIGS. 18 through 20 present various strategies that may be adopted to still obtain the benefits of using the support structures, e.g., to ward against potential delamination and/or manufacturing issues while avoiding the potential pitfalls of using longer-length support structures. Generally speaking, the elements of FIGS. 18 through 20 are the same as those in FIGS. 6, 16, and 17 having the same callouts, and the earlier discussion and descriptions of such elements may be understood to apply here as well unless the discussion below indicates otherwise, e.g., by describing an element differently.

[0128] In FIG. 18, the first radial spoke passages 114a and the second radial spoke passages 114b are each respectively equipped with a large number of first support structures 1818a and a large number of second support structures 1818b. As can be seen, the support structures 1818 are, in this example, cylindrical in cross-section and are each smaller in maximum dimension (in the cross-sectional plane shown) than a smallest distance between the opposing perimeter walls that define the radial spoke passage 1814 within which they are located. The support structures 1818 within each radial spoke passage 114 are, in this example, arranged in a rectangular array within that radial spoke passage, e.g., with a smaller number, e.g., 3–6, of support structures 1818 arranged along axes perpendicular to the axis along which the corresponding radial spoke passage 114 extends, and with a larger number, e.g., dozens, of

support structures 1818 arranged along axes parallel to the axis along which the corresponding radial spoke passage 114 extends.

[0129] Such an arrangement may provide the structural support that may be needed to prevent delamination issues while also reducing the potential impact on flow conductance of any dimensional variation that may occur within the radial spoke passages 114 due to shrinkage during the manufacturing process. For example, if the cross-sectional area of a radial spoke passage 114 is slightly smaller than that of another radial spoke passage 114 (which is supposed to have the same cross-sectional area), the impact of that reduced cross-sectional area would generally only significantly impact the flow conductance through that radial spoke passage 114 in the regions where the cross-sectional area was narrowest. In a radial spoke passage with a single, long support structure extending from one end to the other, the entire length of the resulting sub-passages (in between the support structure and, for example, a periphery wall of the radial spoke passage) may have a reduced flow conductance. In the implementation of FIG. 18, by contrast, the “sub-passages” that are produced by the presence of the support structures 1818 are quite short, e.g., with individual lengths no larger than the diameters of the support structures 1818. Moreover, the spaces in between the rows of support structures 1818 as one moves along the length of the radial spoke passages 114 represent zones in which the cross-sectional area is much larger (since it includes the entire height and width of the radial spoke passages, with no part of that area occluded by any support structures 1818). Accordingly, the flow conductance within such interstitial regions may be much higher than within the regions of the radial spoke passages 114 where the support structures 1818 are located. As a consequence, the gas that flows through such a radial spoke passage 114 will flow through two sets of regions—a first set that includes the longitudinal regions of the radial spoke passage 114 that contain the support structures 1818 (and that thus represent regions of flow-limiting flow conductance) and a second set that includes the longitudinal regions of the radial spoke passage 114 that do not include the support structures 1818 (which thus represent regions of non-limiting flow conductance). This has the effect of shortening the flow path in which the gas is subjected to flow-limiting conductance when flowing through such a radial spoke passage 114 (as compared with, for example, the length of the flow path where the gas is subjected to flow-limiting conductance when flowing through a radial spoke passage where the support structures are, for example, continuous wall elements extending from one end of the radial spoke passage 114 to the other end of the radial spoke passage 114). When multiple radial spoke passages 114 that all feed a common plenum include such reduced flow-limiting

flow path lengths, this reduces variation in the gas flow rate through such radial spoke passages 114, thereby leading to improved uniformity in process gas delivery from the showerhead.

[0130] It will be further noted that if the cross-sectional shapes of the support structures 1818 are, as shown, round, then the flow conductance within each region in the first set of regions will vary as one moves past the row of support structures 1818 within that region. For example, the flow conductance will be at a minimum at the location within the region that corresponds with a line that passes through the centers of all of the support structures 1818 and thus defines the diameters of the support structures 1818 and the location where the maximum amount of occlusion of the radial spoke passage 1814 occurs due to the presence of the support structure 1818. In the remainder of such regions, the flow conductance will be larger due to the diminishing amount that the support structures 1818 occlude the radial spoke passages 1814. This has the effect of further shortening the flow path in which the gas is subjected to flow-limiting conductance when flowing through such a radial spoke passage 114.

[0131] In FIG. 19, the first support structures 1918a and the second support structures 1918b, collectively support structures 1918, are arranged in a triangular lattice pattern (which may also be referred to as a staggered rectangular array) instead of the rectangular array of FIG. 18. By arranging the support structures 1918 in a triangular lattice pattern, the number of support structures 1918 in every other row of support structures 1918 may be decreased as compared with the number of support structures 1918 in the other rows of support structure 1918 (with the rows of support structures 1918 extending along directions transverse to the axis along which the corresponding radial spoke passage 114 extends). For example, as can be seen in FIG. 19, the support structures 1918 are arranged in triangular lattice patterns that result in alternating rows of four support structures 1918 and three support structures 1918. In such implementations, the radial spoke passages 114 may have three sets of regions—a first set that includes the longitudinal regions of the radial spoke passage 114 that contain the rows of four support structures 1918, a second set that includes the longitudinal regions of the radial spoke passage 114 that contain the rows of three support structures 1918, and a third set that includes the longitudinal regions of the radial spoke passage 114 that contain no support structures 1918. The flow conductances of the regions in the third set may be the highest and the flow conductances of the regions in the first set may be the lowest, with the flow conductances of the regions in the second set being in between the flow conductances of the regions in the first set and the third set. In such an implementation, the regions of the first set may act as regions with flow-limiting conductance, while the regions of the second set and the third set may act

as regions with non-limiting flow conductance. Such an arrangement may further decrease the flow path length of gas flowing through the corresponding radial spoke passage 114 that is subject to flow-limiting conductance (as compared to, for example, the arrangement of support structures 1818 shown in FIG. 18).

[0132] FIG. 20 depicts an example of a showerhead in which the first support structures 2018a and the second support structures 2018b, collectively the support structures 2018, are arranged in a rectangular array, similar to the support structures 1818 of FIG. 18. However, the support structures 2018 are directional in nature, e.g., not round in cross section. Instead, the support structures 2018 are elongate in cross-sectional shape and may each have a long axis and a short axis. In some instances, such as that depicted, the support structures 2018 may each have an obround cross-sectional shape.

[0133] In some such arrangements, the long axes of the support structures 2018 may be oriented so as to be perpendicular to or parallel to the axis along which the corresponding radial spoke passage 114 extends. From a gas flow perspective, the support structures 2018 may act in a manner similar to the support structures in FIGS. 18 and 19—the gas that flows through such a field of support structures 2018 may, as it strikes each support structure 2018, subdivide into separate gas flows and then recombine after flowing around the support structure 2018. This may induce turbulent flow of the gas, but without any bias towards one side or the other of the radial spoke passages 114.

[0134] In other implementations, the support structures 2018 may be oriented so as to have their long axes at an oblique angle relative to the axis along which the corresponding radial spoke passage extends. By angling the long axes of the support structures 2018 in this manner, the gas flows through each radial spoke passage 114 may be biased towards one side or the other of the radial spoke passage 114. If alternating rows of the support passages 2017 are angled in alternating directions, as shown in FIG. 20, the gas flow within each radial spoke passage 114 may be biased towards one side or the other of the radial spoke passage 114 in a repeating manner, thereby acting to more uniformly distribute gas flow within the radial spoke passage 114.

[0135] It will be appreciated that the various types and arrangements of support structures discussed above may be implemented in any of the showerhead designs discussed herein that include radial spoke passages or, more generally, in any generally long, wide passage in a multi-layered component in order to ward against potential delamination effects. Moreover, it will be understood that the implementations involving arrays of smaller-size support structures

may be used in configurations in which there are multiple sets of generally long, wide passages (such as the radial spoke passages discussed herein) that are all intended to have identical (or as close to identical as is feasible) flow conductances such that gas that flows into such passages from a common plenum does so in an evenly distributed manner. It will also be appreciated that a radial spoke passage (or other passage) that incorporates support structures such as are discussed herein may include support structures of different sizes or shapes, or regions of support structures arranged in different patterns. For example, a radial spoke passage might have support structures as arranged in the example of FIG. 18 along a third of its length, support structures as arranged in the example of FIG. 19 along another third of its length, and support structures as arranged in the example of FIG. 20 along the last third of its length. Generally speaking, however, radial spoke passages of the same overall length that are fed gas from a common plenum and that all deliver that gas to another common plenum may generally have the same arrangements of support structures within them so as to cause gas flow within such radial spoke passages to be balanced and even.

[0136] The support structures discussed herein may generally be sized such that they are at least about 3mm in minimum dimension (in terms of their cross-section in a plane parallel to the first side or second side of the main body of the showerhead), and possibly larger. Such support structures may also, in some instances, be arranged such that there is a gap of 20mm or less in between two adjacent support structures (or between a support structure and, for example, the perimeter side wall of a radial spoke passage).

[0137] FIGS. 21 through 29 depict another alternate implementation of the showerhead 100. FIG. 21 depicts an isometric view of the underside of a showerhead 2100, while FIGS. 22 and 29 depict exploded isometric views of the showerhead 2100. The showerheads 2100 and 100 are very similar, and reference numbers with the same last two digits in FIGS. 21 through 29 as in FIGS. 1 through 15 may be assumed to be analogous to the corresponding counterpart elements in FIGS. 1 through 15 unless indicated otherwise in the discussion below. The discussion above regarding the elements of FIGS. 1 through 15 may be assumed to also be generally applicable to the corresponding counterpart elements in FIGS. 21 through 29.

[0138] The showerhead 2100 differs from the showerhead 100 in that the pattern or arrangement of the first gas distribution ports 2108a, the second gas distribution ports 2108b, the first pillars 2124a, and the second pillars 2124b in the showerhead 2100 is different from that of the pattern or arrangement of the first gas distribution ports 108a, the second gas distribution ports 108b, the first pillars 124a, and the second pillars 124b in the showerhead

100. For example, in the showerhead 100, the first gas distribution ports 108a and the second gas distribution ports 108b are arranged in triangular lattice patterns, whereas in the showerhead 2100, the first gas distribution ports 2108a and the second gas distribution ports 2108b are arranged in concentric circular arrays. The first pillars 2124a and the second pillars 2124b are also arranged in concentric circular arrays in similar fashion. It will be understood that other arrangements of gas distribution ports 108 or 2108 and/or pillars 124 or 2124 may be utilized as well, depending on the particular needs of a given semiconductor process. Generally speaking, the particular arrangement of gas distribution ports for a given showerhead may be selected from any suitable arrangement of gas distribution ports. For example, the various arrangements of gas distribution ports discussed in any of the examples discussed herein may be implemented in any of the other example implementations discussed herein.

[0139] It will also be understood that while the above-discussed implementations have included support structures, other implementations may forego such support structures. For example, in a showerhead that is made of metal layers that are brazed together, delamination issues that may arise in laminated ceramic showerheads may not be present, and the potential benefits that may arise from using such support structures may not arise in such implementations. Accordingly, the support structures may be omitted in such implementations, if desired. Even in some laminated ceramic implementations, the support structures may, in some cases, be omitted (with a higher risk of potential delamination arising).

[0140] FIGS. 23 through 25 depict an example of a showerhead with two edge-fed plenums that do not utilize radial spoke passages (although radial spoke passages could be used to feed the second plenum volume). FIGS. 23 and 24 show exploded isometric views of an example showerhead 2300 that has a main body 2302 that includes three separate layers 2302a, 2302b, and 2302c that are assembled together. FIG. 25 depicts a section view of the assembled showerhead 2300.

[0141] The showerheads 2300 and 2100 are very similar in some respects (particularly with respect to the second plenum and features contained therein), and reference numbers with the same last two digits in FIGS. 23 through 25 as in FIGS. 21 through 29 may be assumed to be analogous to the corresponding counterpart elements in FIGS. 21 through 29 unless indicated otherwise in the discussion below. The discussion above regarding the elements of FIGS. 21 through 29 may be assumed to also be generally applicable to the corresponding counterpart elements in FIGS. 23 through 25.

[0142] The showerhead 2300, it will be observed, differs from the showerhead 2100 in that the first plenum volume 2322a does not include the arcuate plenums, outer arcuate elements, or inner arcuate elements, e.g., such as the arcuate plenums 2320, the outer arcuate elements 2326, or the inner arcuate elements 2328 found in the second plenum volume 2322b. Instead, the first plenum volume 2322a includes a baffle plate 2334 that is supported within the first plenum volume 2322a by spokes 2336. The baffle plate 2334 may include a generally circular interior region and the spokes 2336 may extend radially outward from the circular interior region. The circular interior region may, for example, have a diameter that is larger than a diameter of a circle that encircles (and touches) the outermost first gas distribution ports 2308a. This has the effect of forcing the process gas that is flowed into the first plenum volume 2322a by way of the first inlet port 2310a to flow radially outward to the edge of the circular interior region of the baffle plate 2334, past the outermost first gas distribution ports 2308a, before reversing direction and flowing radially inward underneath the baffle plate 2334 to reach the first gas distribution ports 2308a, as is illustrated by the gas flows shown by the arrows in FIG. 25. In effect, the baffle plate 2334 may act to distribute the process gas flowed into the first plenum volume 2322a in an “edge-fed” manner similar to how the process gas is distributed in plenum volumes such as the second plenum volume 2322b.

[0143] The baffle plate 2334 may be supported within the first plenum volume 2322a by way of the spokes 2336, which may be connected with support ledges 2338 positioned on one of the layers 2302a or 2302b of the main body. The support ledges 2338 may support the baffle plate 2334 within the first plenum volume 2322a. The spokes 2336 may be equally spaced about the perimeter of the circular region of the baffle plate 2334 and equally sized such that the baffle plate 2334 has a radially symmetric shape so as to cause the gas flow across the baffle plate 2334 to occur in a radially symmetric manner. In an alternate design, the baffle plate 2334 may simply be circular (with no spokes 2336) with a circular array of through-holes positioned along its outer perimeter to allow process gas to flow through the baffle plate 2334 along the outer perimeter of the baffle plate 2334. The baffle plate 2334 may, in some instances, have a circular interior region that is somewhat smaller in diameter than, e.g., up to 10% or 20% smaller than, the diameter of the circle that encircles and touches the outermost first gas distribution ports 2308a—such arrangements may also generally result in a similar “edge-fed” effect, although to a somewhat lesser extent than the depicted implementation. In some implementations, the layers 2302b and 2302c may be made of ceramic material, e.g., aluminum oxide or aluminum nitride, that is fused together to form a contiguous ceramic part,

while the layer 2302a and the baffle plate 2334 may both be made of a metal, e.g., stainless steel, C22 nickel alloy, or other suitable metal material, and may be brazed, welded, diffusion bonded, or otherwise connected together via the support ledges 2338 and the spokes 2336. The metal elements and the ceramic elements may then be assembled together, e.g., via mechanical fasteners. The interface between the layers 2302a (metal) and 2302b (ceramic) may be sealed using, for example, an elastomeric O-ring seal (not shown) that may be placed in circular groove (also not shown) that may be present in one or both of the mating faces of the layers 2302a and 2302b. In other implementations, the layers 2302a through 2302c may all be made of the same material, e.g., all ceramic material, and fused together into a single part, e.g., as discussed elsewhere herein with regard to other implementations. In such instances, the baffle plate 2334, which may be made of stainless steel or a ceramic material, may be connected with the layer 2302a using mechanical fasteners, e.g., using screws that pass through the baffle plate 2334 and into threaded holes in the support ledges 2338.

[0144] FIGS. 26 through 28 depict another showerhead variant that is somewhat similar to that of FIGS. 26 through 25. The showerheads 2600 and 2300 are very similar in some respects (particularly with respect to the second plenum and features contained therein), and reference numbers with the same last two digits in FIGS. 26 through 28 as in FIGS. 23 through 25 may be assumed to be analogous to the corresponding counterpart elements in FIGS. 23 through 25 unless indicated otherwise in the discussion below. The discussion above regarding the elements of FIGS. 23 through 25 may be assumed to also be generally applicable to the corresponding counterpart elements in FIGS. 26 through 28.

[0145] As can be seen in FIGS. 26 through 28, the baffle plate 2634 is much smaller in size, e.g., having a diameter that is about one third the diameter of the diameter of the circle that encircles and touches the outermost first gas distribution ports 2608a. This configuration may serve to deflect gas flow from the first inlet port 2610a radially outward, but may not serve to turn the first plenum volume into an “edge fed” plenum, as with the example of FIGS. 23 through 25. The other difference is that the baffle plate 2634 is attached to one of the layers through post structures that extend from the upper or lower surface (upper surface, in this case) of the baffle plate 2634 and connect with the upper or lower surface bounding the first plenum volume 2622a. It will be appreciated that a similar mounting scheme may be used to support the baffle plate 2334 as well, thereby allowing the baffle plate 2334 to avoid having the spokes 2336. As with the design of FIGS. 23 through 25, the showerhead 2600 may, in some instances, be made from layers 2602 that may be assembled together. For example, the layers 2602b and

2602c may both be made of a ceramic material, such as aluminum oxide or aluminum nitride and may be fused into a single contiguous part, whereas the layer 26a and the baffle plate 2634 may be made of a metal, e.g., stainless steel, C22 nickel alloy, or other suitable metal material, and may be joined together via welding, brazing, diffusion bonding, etc. The interface between the layers 2602a (metal) and 2602b (ceramic) may be sealed using, for example, an elastomeric O-ring seal (not shown) that may be placed in circular groove (also not shown) that may be present in one or both of the mating faces of the layers 2602a and 2602b. In other implementations, the layers 2602a through 2602c may all be made of the same material, e.g., all ceramic material, and fused together into a single part, e.g., as discussed elsewhere herein with regard to other implementations. In such instances, the baffle plate 2634, which may be made of stainless steel or a ceramic material, may be connected with the layer 2602a using mechanical fasteners, e.g., using screws that pass through the baffle plate 2634 and the post structures and into threaded holes in the underside of the layer 2602a.

[0146] As mentioned, some implementations of the showerheads discussed above may be manufactured by laminating together multiple, discretely manufactured layers. FIG. 30 depicts an example of a showerhead 3000 that is manufactured using such techniques. For example, the showerhead 3000 may be made from four pieces 3002—a first piece 3002a, a second piece 3002b, a third piece 3002c, and a fourth piece 3002d, as shown in the upper half of FIG. 30. The various pieces 3002a–d may each have one or more of channel, plenum, gas distribution port, riser passage, etc., features formed therein. The pieces 3002a through 3002d may then be bonded, brazed, welded, or otherwise joined together in order to cap the various open features, e.g., open plenums and open channels, of the showerhead 3000, as shown in the lower half of FIG. 30 (the showerhead 3000 is similar, in many respects, to the showerhead 100). It will be noted that lighter and darker fill patterns are used for the various pieces 3002, but this is simply to assist with differentiating them—such pieces may be made of the same material, although in some implementations, one or more such pieces may be made from a different material from one or more others of the pieces 3002.

[0147] It will be further understood that such showerheads may be made as a laminated ceramic structure, e.g., with one or more ceramic plates that are machined or otherwise formed, e.g., by pressing, so as to have such features, e.g., open radial spoke channels or open plenums with a plurality of pillars extending therethrough. Such a ceramic plate or ceramic plates may then be bonded to another ceramic plate and/or to each other so as to cap such open channel features or pillar-containing plenum volumes to form enclosed passages or enclosed plenums.

For example, such ceramic plates may be bonded together by sintering the ceramic plates together. Such approaches may also be used to provide multi-plenum structures in which there are multiple levels of such passages or plenum volumes at different elevations, with the plenum volume or passages of each elevation being provided by a machined or formed ceramic plate similar to one of the pieces 3002a through 3002d that is then bonded to another one of the pieces 3002a through 3002d. It will also be understood that the features that are shown as being machined or formed in a particular piece 3002 may alternatively or additionally be machined or formed in an adjoining piece 3002.

[0148] The showerheads discussed herein may be used in a semiconductor processing chamber to deliver various reactants to a processing space above a semiconductor wafer that is being processed. FIG. 31 depicts a schematic of such a chamber. As seen in FIG. 31, a semiconductor processing tool may include a processing chamber 3188 that may enclose an interior volume 3189. The processing chamber 3188 may include, for example, a showerhead 3100 that may be any of the showerheads discussed herein (the depicted example is a showerhead similar to the showerhead 100, but it will be understood that other showerheads disclosed herein may be used in place of this specific design). In this example, the showerhead 3100 is a flush-mount showerhead, e.g., a showerhead that mounts acts as a lid to the chamber and seals off a large opening, e.g., an opening that is sized larger than the diameter of a semiconductor wafer 3192, and that acts as the “ceiling” or part of the ceiling of the processing chamber 3188. In other implementations, the showerhead may be supported within the interior volume 3189 by a vertical column or stem that extends into the interior volume 3189 through an aperture in the ceiling of the processing chamber 3188; such showerheads are typically referred to as “chandelier showerheads.”

[0149] The showerhead 3100 is a two-plenum showerhead that has a first plenum volume 3122a and a second plenum volume 3122b. The first plenum volume 3122a may be provided one or more first processing gases via first inlet ports 3110a that are fluidically connected with a first gas supply 3196a via a first valve 3198a. Similarly, the second plenum volume 3122b may be provided one or more second processing gases via a second inlet port 3110b that is fluidically connected with a second gas supply 3196b via a second valve 3198b. A controller 3199 may be provided that may be configured to communicate with the first valve 3198a and the second valve 3198b and to control the valves 3198 so as to selectively enable or disable gas flow to either or both of the first plenum volume 3122a and the second plenum volume 3122b. Gas that is flowed into the first plenum volume 3122a or the second plenum volume 3122b

may be flowed out of the first plenum volume 3122a or the second plenum volume 3122b via first gas distribution holes 3108a or second gas distribution holes 3108b, respectively. The semiconductor wafer 3192 may be supported within the processing chamber 3188 by a pedestal 3190. The pedestal 3190 may, for example, include a wafer support surface that is configured to support the semiconductor wafer 3192 from below.

[0150] As discussed above, in some implementations, a controller may be part of the systems having the showerheads discussed herein. The controller, depending on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, such as processes for the delivery of processing gases, including controlling other parameters potentially not discussed herein, e.g., temperature settings (e.g., heating and/or cooling), pressure settings, vacuum settings, power settings, radio frequency (RF) generator settings, RF matching circuit settings, frequency settings, flow rate settings, fluid delivery settings, positional and operation settings, wafer transfers into and out of a chamber and other transfer tools and/or load locks connected to or interfaced with a specific system.

[0151] Broadly speaking, the controller may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control operation, enable cleaning operations, enable endpoint measurements, and the like. The integrated circuits may include chips in the form of firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software). Program instructions may be instructions communicated to the controller in the form of various individual settings (or program files), defining operational parameters for carrying out a particular process on or for a semiconductor wafer or to a system. The operational parameters may, in some embodiments, be part of a recipe defined by process engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of a wafer.

[0152] The controller, in some implementations, may be a part of or coupled to a computer that is integrated with, coupled to the system, otherwise networked to the system, or a combination thereof. For example, the controller may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of the wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication operations, examine trends or performance

metrics from a plurality of fabrication operations, to change parameters of current processing, to set processing steps to follow a current processing, or to start a new process. In some examples, a remote computer (e.g. a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It should be understood that the parameters may be specific to the type of process to be performed and the type of tool that the controller is configured to interface with or control. Thus as described above, the controller may be distributed, such as by comprising one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in communication with one or more integrated circuits located remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

[0153] Without limitation, example showerheads according to the present disclosure may be mounted in or part of semiconductor processing tools with a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition (CVD) chamber or module, an atomic layer deposition (ALD) chamber or module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or module, a track chamber or module, and any other semiconductor processing systems that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

[0154] As noted above, depending on the process step or steps to be performed by the tool, the controller might communicate with one or more of other tool circuits or modules, other tool components, cluster tools, other tool interfaces, adjacent tools, neighboring tools, tools located throughout a factory, a main computer, another controller, or tools used in material transport that bring containers of wafers to and from tool locations and/or load ports in a semiconductor manufacturing factory.

[0155] It will be understood that characterizations of how the various pillars and/or gas distribution holes that are discussed herein are arranged in which statements are made regarding

“each pillar” or “each gas distribution hole or port” or the like may be general characterizations that apply only to a set of such pillars and/or gas distribution holes, e.g., pillars and/or gas distribution holes that are located within the interior of an internal plenum volume as opposed to near the outer perimeter (for example, at some point, whatever repeating pattern there may be of pillars and/or gas distribution holes will need to end, at which point the characteristics of the repeating pattern that hold true for pattern instances in the interior of the pattern will cease to hold true at the outer edges of the pattern).

[0156] It will be further appreciated that while the above examples depict multi-plenum showerheads with two plenums, the concepts discussed above may also be implemented in showerheads with three, four, or more plenum volumes, each of which may be used to deliver a different process gas (which will be understood to refer to chemically different process gases, as well as process gases that have the same constituent elements but in different concentrations or ratios). In such examples, the additional plenum volumes may be provided on layers of the showerhead in between the layers providing the other plenum volumes. Moreover, additional sets of radial spoke passages, riser passages, arcuate plenums, and so forth may be provided to respectively deliver process gases to such additional plenum volumes.

[0157] The term “radial,” when used to refer to the radial spoke passages or the radial walls, is to be understood to include “true” radial passages or walls, e.g., extending along lines or axes that intersect the center of the showerhead, as well as passages or walls that extend outward from the approximate center of the showerhead to an outer perimeter of the showerhead, e.g., passages that spiral outward or that curve outward.

[0158] For the purposes of this disclosure, the term “fluidically connected” is used with respect to volumes, plenums, holes, etc., that may be connected with one another, either directly or via one or more intervening components or volumes, in order to form a fluidic connection, similar to how the term “electrically connected” is used with respect to components that are connected together to form an electrical connection. The term “fluidically interposed,” if used, may be used to refer to a component, volume, plenum, or hole that is fluidically connected with at least two other components, volumes, plenums, or holes such that fluid flowing from one of those other components, volumes, plenums, or holes to the other or another of those components, volumes, plenums, or holes would first flow through the “fluidically interposed” component before reaching that other or another of those components, volumes, plenums, or holes. For example, if a pump is fluidically interposed between a reservoir and an outlet, fluid that flowed from the reservoir to the outlet would first flow through the pump before reaching the outlet.

The term "fluidically adjacent," if used, refers to placement of a fluidic element relative to another fluidic element such that there are no potential structures fluidically interposed between the two elements that might potentially interrupt fluid flow between the two fluidic elements. For example, in a flow path having a first valve, a second valve, and a third valve placed sequentially therealong, the first valve would be fluidically adjacent to the second valve, the second valve fluidically adjacent to both the first and third valves, and the third valve fluidically adjacent to the second valve.

[0159] It is to be understood that the phrases "for each <item> of the one or more <items>," "each <item> of the one or more <items>," or the like, if used herein, are inclusive of both a single-item group and multiple-item groups, i.e., the phrase "for ... each" is used in the sense that it is used in programming languages to refer to each item of whatever population of items is referenced. For example, if the population of items referenced is a single item, then "each" would refer to only that single item (despite the fact that dictionary definitions of "each" frequently define the term to refer to "every one of two or more things") and would not imply that there must be at least two of those items. Similarly, the term "set" or "subset" should not be viewed, in itself, as necessarily encompassing a plurality of items—it will be understood that a set or a subset can encompass only one member or multiple members (unless the context indicates otherwise).

[0160] The use, if any, of ordinal indicators, e.g., (a), (b), (c)... or the like, in this disclosure and claims is to be understood as not conveying any particular order or sequence, except to the extent that such an order or sequence is explicitly indicated. For example, if there are three steps labeled (i), (ii), and (iii), it is to be understood that these steps may be performed in any order (or even concurrently, if not otherwise contraindicated) unless indicated otherwise. For example, if step (ii) involves the handling of an element that is created in step (i), then step (ii) may be viewed as happening at some point after step (i). Similarly, if step (i) involves the handling of an element that is created in step (ii), the reverse is to be understood. It is also to be understood that use of the ordinal indicator "first" herein, e.g., "a first item," should not be read as suggesting, implicitly or inherently, that there is necessarily a "second" instance, e.g., "a second item." There may also be reference to a "zeroth" item herein, which is to be understood as simply being a reference to another ordinal indicator, e.g., one that comes before a "first" item (of course, as noted above, there is no particular order indicated by the use of ordinal indicators unless the context indicates otherwise). It will also be understood that reference to "first," "second," etc. with respect to various elements herein may not be carried

through to the claims. For example, elements that are referred to as “first” and “second” in the discussion above may instead be referred to in the claims as, respectively, the “second” and “first” elements. Such recharacterization of such ordinal indicators may be resorted to in order to avoid instances in which a “second” element might be introduced in a claim before a corresponding “first” element.

[0161] The term “between,” as used herein and when used with a range of values, is to be understood, unless otherwise indicated, as being inclusive of the start and end values of that range. For example, between 1 and 5 is to be understood to be inclusive of the numbers 1, 2, 3, 4, and 5, not just the numbers 2, 3, and 4.

[0162] Terms such as “about,” “approximately,” “substantially,” “nominal,” or the like, when used in reference to quantities or similar quantifiable properties, are to be understood to be inclusive of values within $\pm 10\%$ of the values or relationship specified (as well as inclusive of the actual values or relationship specified), unless otherwise indicated.

[0163] It is to be understood that the above disclosure, while focusing on a particular example implementation or implementations, is not limited to only the discussed example, but may also apply to similar variants and mechanisms as well, and such similar variants and mechanisms are also considered to be within the scope of this disclosure. For example, the above disclosure is directed to at least, but not exclusively, the following numbered implementations.

[0164] Implementation 1: An apparatus comprising:

- a main body having a first side and a second side on an opposite side of the main body from the first side of the main body, the main body having within it a first plenum volume and a second plenum volume, wherein the first plenum volume is interposed between the first side of the main body and the second plenum volume and the second plenum volume is interposed between the second side of the main body and the first plenum volume;

- one or more first inlet ports fluidically connected with the first plenum volume within the main body;

- one or more second inlet ports fluidically connected with the second plenum volume within the main body;

- a plurality of first pillars distributed throughout the second plenum volume, each first pillar extending between an upper surface bounding the second plenum volume and a lower surface of the second plenum volume;

a plurality of first gas distribution ports, each first gas distribution port extending between the second side of the main body and the first plenum volume and passing through one of the first pillars; and

a plurality of second gas distribution ports, each second gas distribution port extending between the second side of the main body and the second plenum volume.

[0165] Implementation 2: The apparatus of implementation 1, further comprising a plurality of second pillars, each second pillar extending between an upper surface bounding the first plenum volume and a lower surface bounding the first plenum volume.

[0166] Implementation 3: The apparatus of implementation 2, wherein the first gas distribution ports are arranged in a first triangular lattice pattern, the second gas distribution ports are arranged in a second triangular lattice pattern, and the first and second triangular lattice patterns are arranged to form a hexagonal lattice pattern with inner hexagonal cells each having three first gas distribution ports and three second gas distribution ports arranged in alternating fashion.

[0167] Implementation 4: The apparatus of implementation 3, wherein the first pillars are also arranged in the first triangular lattice pattern.

[0168] Implementation 5: The apparatus of implementation 4, wherein the second pillars are also arranged in the second triangular lattice pattern.

[0169] Implementation 6: The apparatus of implementation 4, wherein at least some of the second pillars are each positioned in a center of a corresponding one of the inner hexagonal cells.

[0170] Implementation 7: The apparatus of implementation 2, wherein the first gas distribution ports and the second gas distribution ports are arranged in a plurality of concentric circular patterns.

[0171] Implementation 8: The apparatus of implementation 7, wherein the first pillars are arranged in a plurality of concentric circular patterns.

[0172] Implementation 9: The apparatus of any of implementations 1 through 8, further comprising a plurality of outer arcuate elements positioned within the second plenum volume, the outer arcuate elements each generally co-radial and concentric with one another and each defining, in part, a corresponding sub-plenum of the second plenum volume, wherein each sub-plenum is fluidically connected with at least one of the one or more second inlet ports within the main body.

[0173] Implementation 10: The apparatus of implementation 9, wherein the plurality of first pillars is located within a perimeter defined by the outer arcuate elements.

[0174] Implementation 11: The apparatus of implementation 9, wherein the second plenum volume comprises a plurality of outer openings, each outer opening extending radially inward and located at a different end of one of the outer arcuate elements.

[0175] Implementation 12: The apparatus of implementation 11, further comprising a plurality of first inner arcuate elements positioned within the second plenum volume, the first inner arcuate elements each generally co-radial and concentric with one another.

[0176] Implementation 13: The apparatus of implementation 12, wherein the second plenum volume comprises a plurality of first inner openings that extend radially inward, each first inner opening positioned between ends of two of the first inner arcuate elements.

[0177] Implementation 14: The apparatus of implementation 13, wherein each first inner arcuate element is azimuthally centered on one of the outer openings, and each first inner opening is azimuthally centered on one of the outer arcuate elements.

[0178] Implementation 15: The apparatus of any of implementations 12 through 14, wherein a radial gap exists between the outer arcuate elements and the first inner arcuate elements.

[0179] Implementation 16: The apparatus of any of implementations 12 through 15, wherein the plurality of first pillars is located within a perimeter defined by the first inner arcuate elements.

[0180] Implementation 17: The apparatus of any of implementations 12 through 16, further comprising a plurality of second inner arcuate elements positioned within the first plenum volume, the second inner arcuate elements each generally co-radial and concentric with one another.

[0181] Implementation 18: The apparatus of implementation 17, wherein the first plenum volume comprises a plurality of second inner openings that extend radially inward, each second inner opening positioned between ends of two of the second inner arcuate elements.

[0182] Implementation 19: The apparatus of any of implementations 1 through 18, wherein:
the one or more first inlet ports are located in a center region of the main body and on the first side of the main body,

a plurality of first radial spoke passages are interposed between the first plenum volume and the first side of the main body,

each first radial spoke passage extends from a first inlet port of the one or more first inlet ports to a respective first location proximate an outer periphery of the first plenum volume, and

each first radial spoke passage fluidically connects the first inlet port from which it extends with the first plenum volume.

[0183] Implementation 20: The apparatus of implementation 19, wherein:

each first radial spoke passage is defined by two opposing perimeter walls spanning between a first side of that first radial spoke passage and a second side of that first radial spoke passage, wherein the first side of the main body is closer to the first side of that first radial spoke passage than to the second side of that first radial spoke passage and the second side of the main body is closer to the second side of that first radial spoke passage than to the first side of that first radial spoke passage, and

each first radial spoke passage has one or more first support structures spanning between the first side of that first radial spoke passage and the second side of that first radial spoke passage, wherein each first support structure of that first radial spoke passage is interposed between the opposing perimeter walls defining that first radial spoke passage.

[0184] Implementation 21: The apparatus of implementation 20, wherein at least one of the first support structures comprises a radial wall that extends along at least a part of the corresponding first radial spoke passage, thereby dividing the corresponding first radial spoke passage into multiple sub-passages along the length of that first support structure.

[0185] Implementation 22: The apparatus of implementation 20, wherein at least one of the first support structures comprises a radial wall that extends from a position proximate the corresponding first inlet port of the corresponding first radial spoke passage to a position proximate the respective first location of the corresponding first radial spoke passage.

[0186] Implementation 23: The apparatus of implementation 20, wherein at least one of the first radial spoke passages has one or more first sets of first support structures with the first support structures in each first set of first support structures each comprising a radial wall and each first set of first support structures having multiple first support structures arranged end-to-end such that the first support structures in that first set of first support structures are separated from each other by corresponding first radial gaps.

[0187] Implementation 24: The apparatus of implementation 23, wherein one of the first radial spoke passages has multiple first sets of first support structures and the multiple first sets of first support structures for that first radial spoke passage are arranged in parallel.

[0188] Implementation 25: The apparatus of implementation 20, wherein each first support structure is smaller in maximum dimension than a maximum distance between the opposing perimeter walls of the first radial spoke passage having that first support structure.

[0189] Implementation 26: The apparatus of implementation 25, wherein at least some of the first support structures are circular in cross-section.

[0190] Implementation 27: The apparatus of implementation 26, wherein one of the first radial spoke passages has a plurality of the first support structures and the first support structures in the plurality of first support structures are arranged in a rectangular array with one axis of the array aligned with a direction along which that first radial spoke passage extends.

[0191] Implementation 28: The apparatus of implementation 26, wherein one of the first radial spoke passages has a plurality of the first support structures and the first support structures in the plurality of first support structures are arranged in a triangular lattice pattern.

[0192] Implementation 29: The apparatus of implementation 25, wherein one of the first radial spoke passages has a plurality of the first support structures and the first support structures in the plurality of first support structures are each elongate in cross-section.

[0193] Implementation 30: The apparatus of implementation 29, wherein the first support structures in the plurality of first support structures are arranged in a rectangular array with a first axis of the array aligned with a direction along which the corresponding first radial spoke passage extends.

[0194] Implementation 31: The apparatus of implementation 30, wherein:

each of the first support structures in the plurality of first support structures has a long axis that is at an oblique angle relative to the first axis, and

the first support structures in the plurality of first support structures arranged in the rectangular array are arranged such that the first support structures in every other row of the rectangular array have long axes with slopes relative to the first axis that are opposite in sign to slopes of the long axes of the first support structures in the other rows of the rectangular array relative to the first axis.

[0195] Implementation 32: The apparatus of implementation 31, wherein there are multiple first support structures in each row of the rectangular array.

[0196] Implementation 33: The apparatus of implementation 32, wherein the first support structures in the rectangular array each have an obround cross-section.

[0197] Implementation 34: The apparatus of any of implementations 20–33, wherein:

the one or more second inlet ports are located in the center region of the main body and on the first side and include a plurality of second inlet ports,

a plurality of second radial spoke passages are interposed between the first plenum volume and the first side of the main body,

each second radial spoke passage extends from a second inlet port of the one or more second inlet ports to a location proximate an outer periphery of the second plenum volume,

each second radial spoke passage fluidically connects the second inlet port from which it extends with the second plenum volume,

each second radial spoke passage is defined by two opposing perimeter walls spanning between a first side of that second radial spoke passage and a second side of that second radial spoke passage, wherein the first side of the main body is closer to the first side of that second radial spoke passage than to the second side of that second radial spoke passage and the second side of the main body is closer to the second side of that second radial spoke passage than to the first side of that second radial spoke passage, and

each second radial spoke passage has one or more second support structures spanning between the first side of that second radial spoke passage and the second side of that second radial spoke passage, wherein each second support structure of that second radial spoke passage is interposed between the opposing perimeter walls defining that second radial spoke passage.

[0198] Implementation 35: The apparatus of implementation 34, wherein at least one of the second support structures comprises a radial wall that extends along at least a part of the corresponding second radial spoke passage, thereby dividing the corresponding second radial spoke passage into multiple sub-passages along the length of that second support structure.

[0199] Implementation 36: The apparatus of implementation 34, wherein at least one of the second support structures comprises a radial wall that extends from a position proximate the corresponding second inlet port of the corresponding second radial spoke passage to a position proximate the respective second location of the corresponding second radial spoke passage.

[0200] Implementation 37: The apparatus of implementation 34, wherein at least one of the second radial spoke passages has one or more second sets of second support structures with the second support structures in each second set of second support structures each comprising a radial wall and each second set of second support structures having multiple second support structures arranged end-to-end such that the second support structures in that second set of second support structures are separated from each other by corresponding second radial gaps.

[0201] Implementation 38: The apparatus of implementation 37, wherein one of the second radial spoke passages has multiple second sets of second support structures and the multiple second sets of second support structures for that second radial spoke passage are arranged in parallel.

[0202] Implementation 39: The apparatus of implementation 34, wherein each second support structure is smaller in maximum dimension than a maximum distance between the opposing perimeter walls of the second radial spoke passage having that second support structure.

[0203] Implementation 40: The apparatus of implementation 39, wherein at least some of the second support structures are circular in cross-section.

[0204] Implementation 41: The apparatus of implementation 40, wherein one of the second radial spoke passages has a plurality of the second support structures and the second support structures in the plurality of second support structures are arranged in a rectangular array with one axis of the array aligned with a direction along which that second radial spoke passage extends.

[0205] Implementation 42: The apparatus of implementation 40, wherein one of the second radial spoke passages has a plurality of the second support structures and the second support structures in the plurality of second support structures are arranged in a triangular lattice pattern.

[0206] Implementation 43: The apparatus of implementation 39, wherein one of the second radial spoke passages has a plurality of the second support structures and the second support structures in the plurality of second support structures are each elongate in cross-section.

[0207] Implementation 44: The apparatus of implementation 43, wherein the second support structures in the plurality of second support structures are arranged in a rectangular array with a second axis of the array aligned with a direction along which the corresponding second radial spoke passage extends.

[0208] Implementation 45: The apparatus of implementation 44, wherein:

each of the second support structures in the plurality of second support structures has a long axis that is at an oblique angle relative to the second axis, and

the second support structures in the plurality of second support structures arranged in the rectangular array are arranged such that the second support structures in every other row of the rectangular array have long axes with slopes relative to the second axis that are opposite in sign to slopes of the long axes of the second support structures in the other rows of the rectangular array relative to the second axis.

[0209] Implementation 46: The apparatus of implementation 45, wherein there are multiple second support structures in each row of the rectangular array.

[0210] Implementation 47: The apparatus of implementation 46, wherein the second support structures in the rectangular array each have an obround cross-section.

[0211] Implementation 48: The apparatus of any of implementations 34 through 47, wherein the first radial spoke passages and the second radial spoke passages are arranged in a circumferentially alternating circular pattern.

[0212] Implementation 49: The apparatus of any of implementations 19 through 48, wherein each first radial spoke passage terminates in the middle of a corresponding arcuate plenum that leads to the first plenum volume.

[0213] Implementation 50: The apparatus of any of implementations 1 through 49 but not including the elements of implementations 2 or 4 through 6, wherein the first plenum volume has no pillars extending through it.

[0214] Implementation 51: The apparatus of any of implementations 1 through 18 or 50, further comprising a baffle plate located within the first plenum volume, wherein:

the one or more first inlet ports are positioned above the center of the baffle plate,

the baffle plate has a circular interior region with a diameter larger than a diameter of a reference circle encircling and touching the outermost first gas distribution ports, and

the baffle plate is spaced apart from surfaces that bound the first plenum volume and are parallel to the first side of the main body.

[0215] Implementation 52: The apparatus of any of implementations 1 through 50, wherein the one or more first inlet ports are located in a center region of the main body and on the first side and fluidically connect with the first plenum volume in a center region of the first plenum volume.

[0216] Implementation 53: The apparatus of any of implementations 1 through 52, wherein the main body comprises a ceramic material.

[0217] Implementation 54: The apparatus of any one of implementations 1 through 53, further comprising a semiconductor processing chamber, wherein the second side of the main body is located within an interior of the semiconductor processing chamber.

CLAIMS

What is claimed is:

1. An apparatus comprising:

a main body having a first side and a second side on an opposite side of the main body from the first side of the main body, the main body having within it a first plenum volume and a second plenum volume, wherein the first plenum volume is interposed between the first side of the main body and the second plenum volume and the second plenum volume is interposed between the second side of the main body and the first plenum volume;

one or more first inlet ports fluidically connected with the first plenum volume within the main body;

one or more second inlet ports fluidically connected with the second plenum volume within the main body;

a plurality of first pillars distributed throughout the second plenum volume, each first pillar extending between an upper surface bounding the second plenum volume and a lower surface of the second plenum volume;

a plurality of first gas distribution ports, each first gas distribution port extending between the second side of the main body and the first plenum volume and passing through one of the first pillars; and

a plurality of second gas distribution ports, each second gas distribution port extending between the second side of the main body and the second plenum volume.

2. The apparatus of claim 1, further comprising a plurality of second pillars, each second pillar extending between an upper surface bounding the first plenum volume and a lower surface bounding the first plenum volume.

3. The apparatus of claim 2, wherein the first gas distribution ports are arranged in a first triangular lattice pattern, the second gas distribution ports are arranged in a second triangular lattice pattern, and the first and second triangular lattice patterns are arranged to form a hexagonal lattice pattern with inner hexagonal cells each having three first gas distribution ports and three second gas distribution ports arranged in alternating fashion.

4. The apparatus of claim 3, wherein the first pillars and the second pillars are also arranged in the first triangular lattice pattern.

5. The apparatus of claim 4, wherein at least some of the second pillars are each positioned in a center of a corresponding one of the inner hexagonal cells.

6. The apparatus of claim 2, wherein the first gas distribution ports and the second gas distribution ports are arranged in a plurality of concentric circular patterns.

7. The apparatus of claim 6, wherein the first pillars are arranged in a plurality of concentric circular patterns.

8. The apparatus of any of claims 1 through 7, wherein:
the one or more first inlet ports are located in a center region of the main body and on the first side of the main body,

a plurality of first radial spoke passages are interposed between the first plenum volume and the first side of the main body,

each first radial spoke passage extends from a first inlet port of the one or more first inlet ports to a respective first location proximate an outer periphery of the first plenum volume, and

each first radial spoke passage fluidically connects the first inlet port from which it extends with the first plenum volume.

9. The apparatus of claim 8, wherein:

each first radial spoke passage is defined by two opposing perimeter walls spanning between a first side of that first radial spoke passage and a second side of that first radial spoke passage, wherein the first side of the main body is closer to the first side of that first radial spoke passage than to the second side of that first radial spoke passage and the second side of the main body is closer to the second side of that first radial spoke passage than to the first side of that first radial spoke passage, and

each first radial spoke passage has one or more first support structures spanning between the first side of that first radial spoke passage and the second side of that first radial

spoke passage, wherein each first support structure of that first radial spoke passage is interposed between the opposing perimeter walls defining that first radial spoke passage.

10. The apparatus of claim 9, wherein at least one of the first support structures comprises a radial wall that extends along at least a part of the corresponding first radial spoke passage, thereby dividing the corresponding first radial spoke passage into multiple sub-passages along the length of that first support structure.

11. The apparatus of claim 9, wherein at least one of the first support structures comprises a radial wall that extends from a position proximate the corresponding first inlet port of the corresponding first radial spoke passage to a position proximate the respective first location of the corresponding first radial spoke passage.

12. The apparatus of claim 9, wherein at least one of the first radial spoke passages has one or more first sets of first support structures with the first support structures in each first set of first support structures each comprising a radial wall and each first set of first support structures having multiple first support structures arranged end-to-end such that the first support structures in that first set of first support structures are separated from each other by corresponding first radial gaps.

13. The apparatus of claim 12, wherein one of the first radial spoke passages has multiple first sets of first support structures and the multiple first sets of first support structures for that first radial spoke passage are arranged in parallel.

14. The apparatus of claim 9, wherein each first support structure is smaller in maximum dimension than a maximum distance between the opposing perimeter walls of the first radial spoke passage having that first support structure.

15. The apparatus of claim 14, wherein at least some of the first support structures are circular in cross-section.

16. The apparatus of claim 15, wherein one of the first radial spoke passages has a plurality of the first support structures and the first support structures in the plurality of first

support structures are arranged in a rectangular array with one axis of the array aligned with a direction along which that first radial spoke passage extends.

17. The apparatus of claim 15, wherein one of the first radial spoke passages has a plurality of the first support structures and the first support structures in the plurality of first support structures are arranged in a triangular lattice pattern.

18. The apparatus of claim 14, wherein one of the first radial spoke passages has a plurality of the first support structures and the first support structures in the plurality of first support structures are each elongate in cross-section.

19. The apparatus of claim 18, wherein the first support structures in the plurality of first support structures are arranged in a rectangular array with a first axis of the array aligned with a direction along which the corresponding first radial spoke passage extends.

20. The apparatus of claim 19, wherein:
each of the first support structures in the plurality of first support structures has a long axis that is at an oblique angle relative to the first axis, and
the first support structures in the plurality of first support structures arranged in the rectangular array are arranged such that the first support structures in every other row of the rectangular array have long axes with slopes relative to the first axis that are opposite in sign to slopes of the long axes of the first support structures in the other rows of the rectangular array relative to the first axis.

21. The apparatus of claim 20, wherein there are multiple first support structures in each row of the rectangular array.

22. The apparatus of claim 21, wherein the first support structures in the rectangular array each have an obround cross-section.

23. The apparatus of any of claims 1 through 7, further comprising a baffle plate located within the first plenum volume, wherein:
the one or more first inlet ports are positioned above the center of the baffle plate,

the baffle plate has a circular interior region with a diameter larger than a diameter of a reference circle encircling and touching the outermost first gas distribution ports, and

the baffle plate is spaced apart from surfaces that bound the first plenum volume and are parallel to the first side of the main body.

24. The apparatus of any of claims 1 through 7, wherein the one or more first inlet ports are located in a center region of the main body and on the first side and fluidically connect with the first plenum volume in a center region of the first plenum volume.

25. The apparatus of any of claims 1 through 24, wherein the main body comprises a ceramic material.

26. The apparatus of any one of claims 1 through 25, further comprising a semiconductor processing chamber, wherein the second side of the main body is located within an interior of the semiconductor processing chamber.

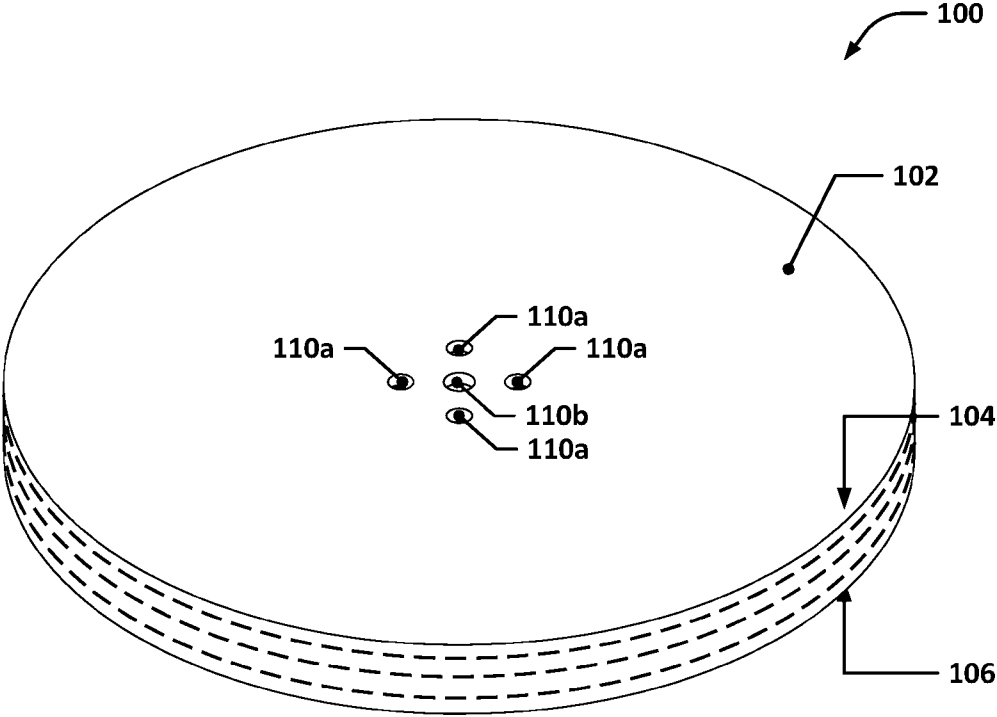
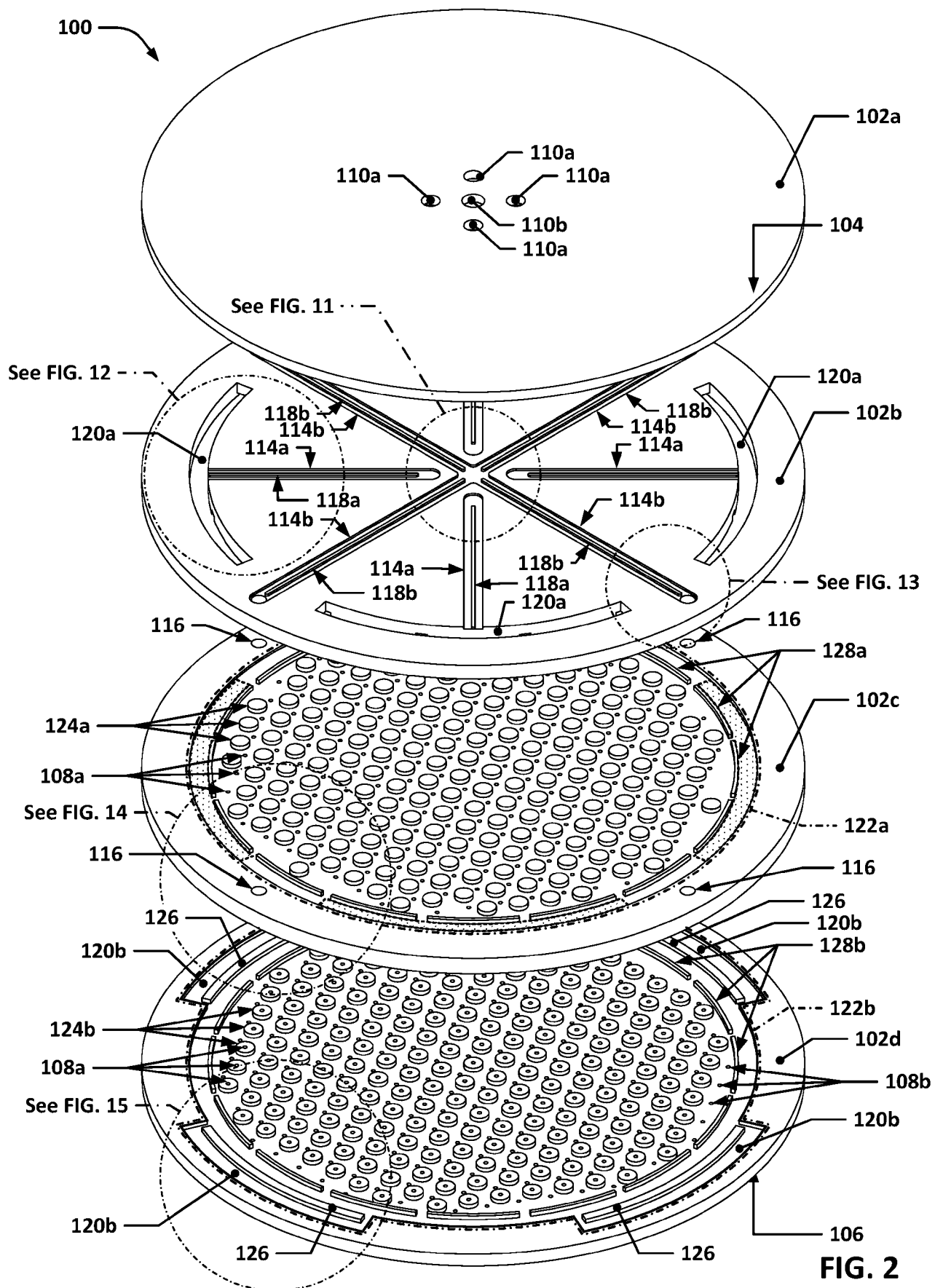


FIG. 1



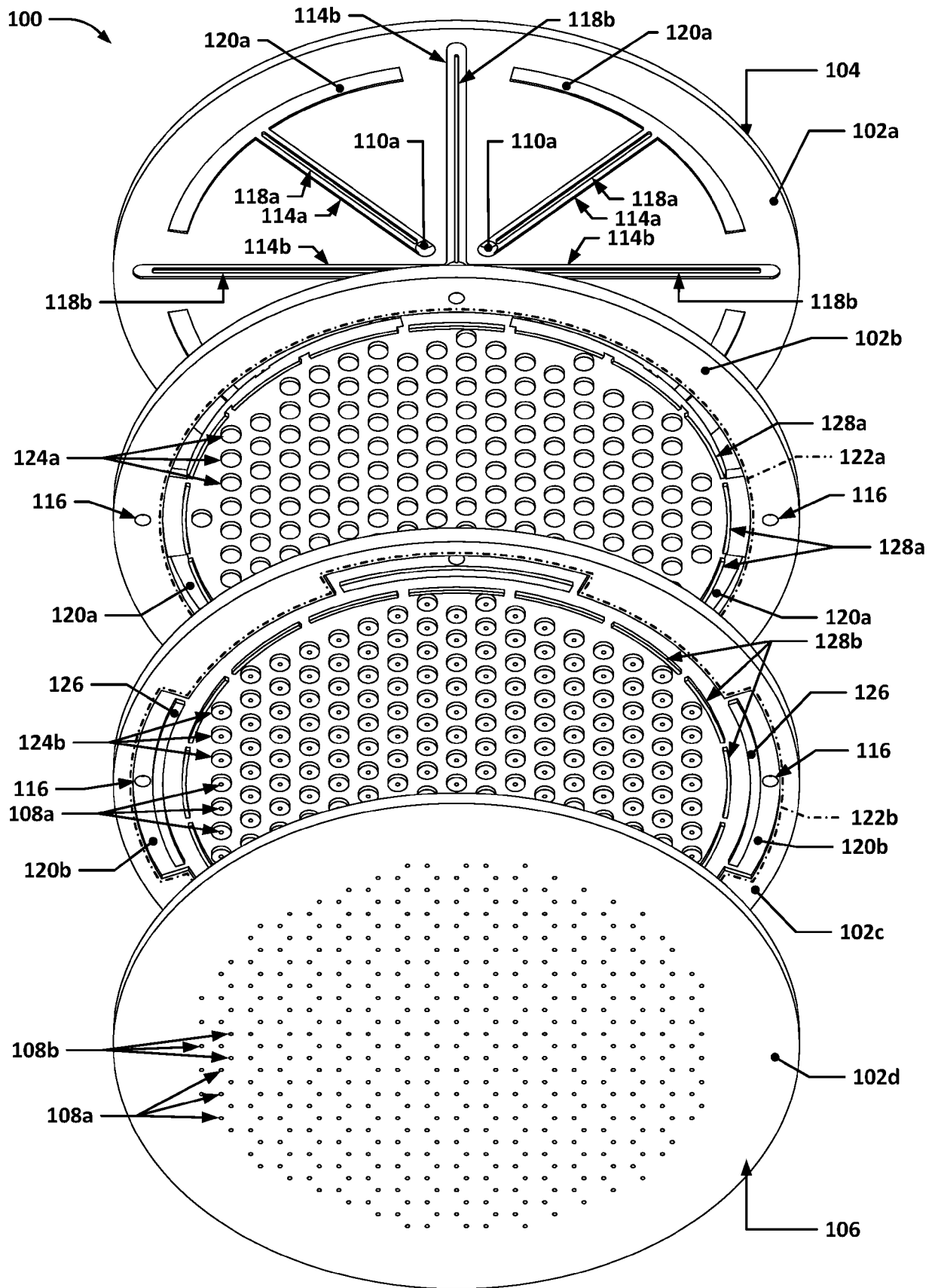


FIG. 3

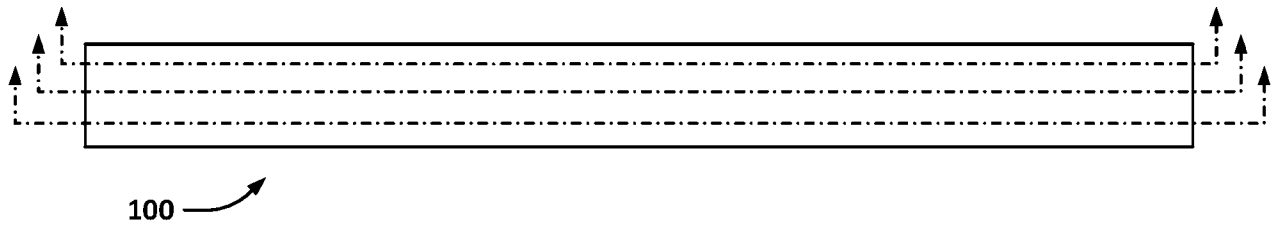


FIG. 4

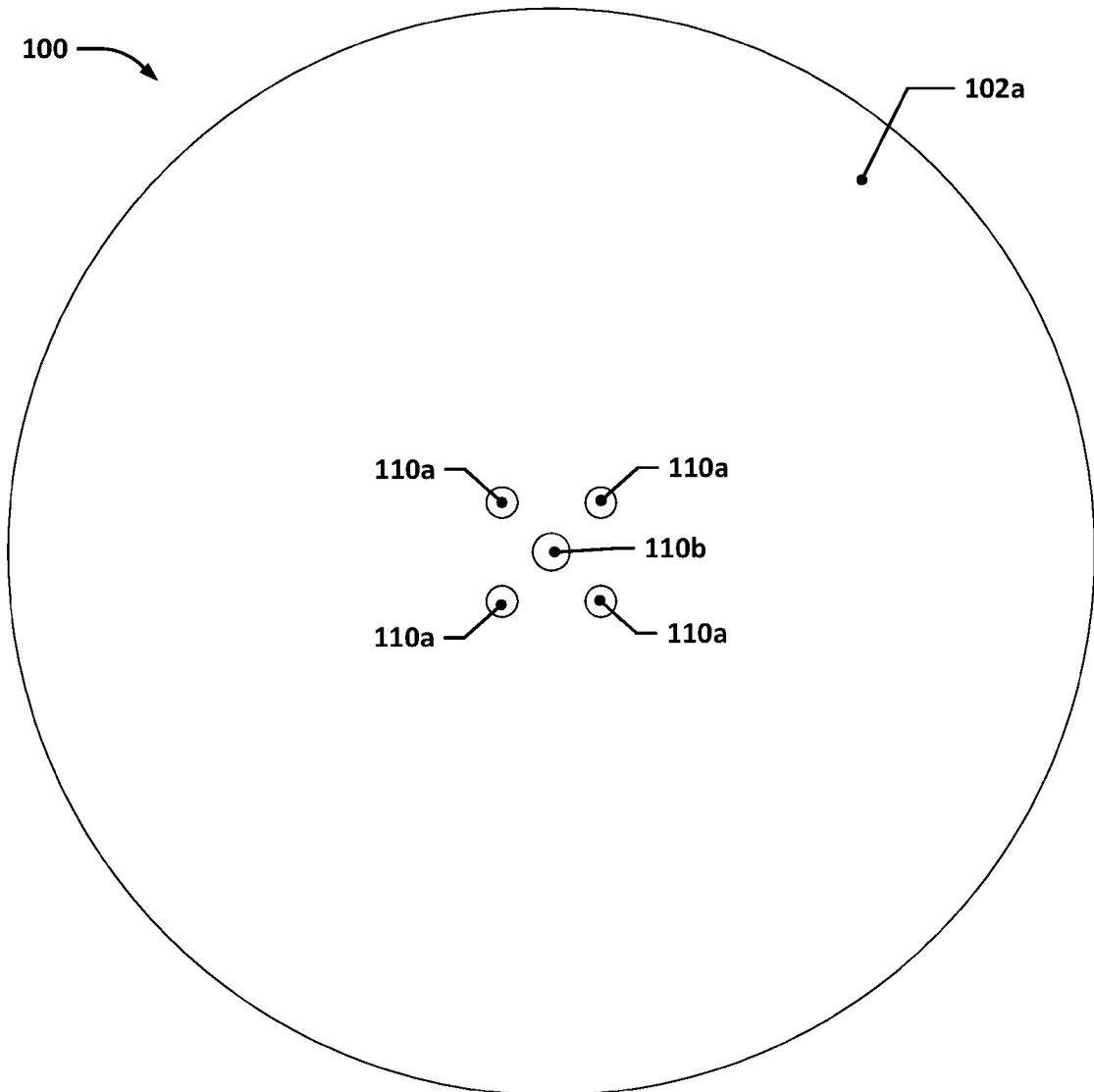


FIG. 5

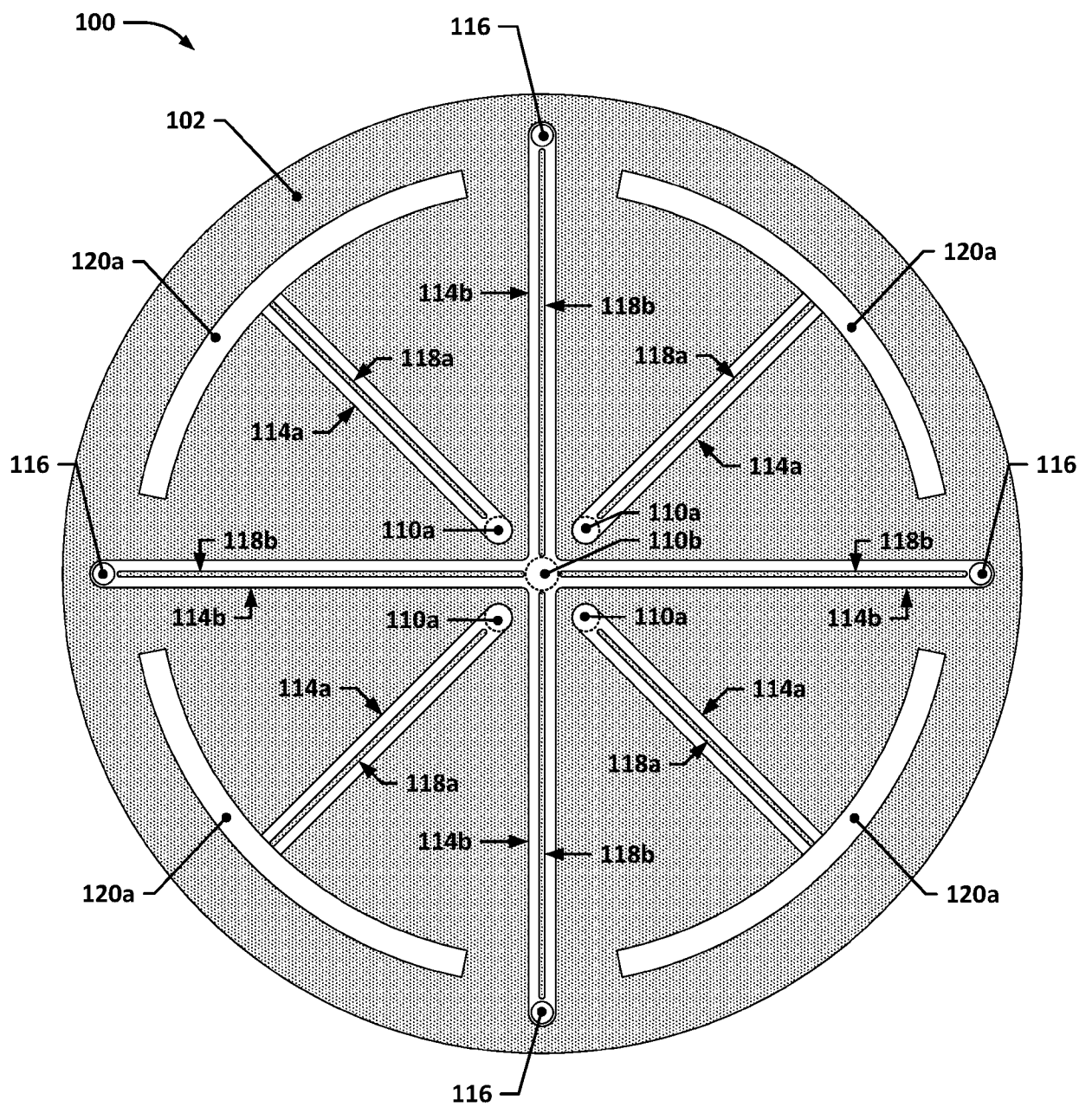


FIG. 6

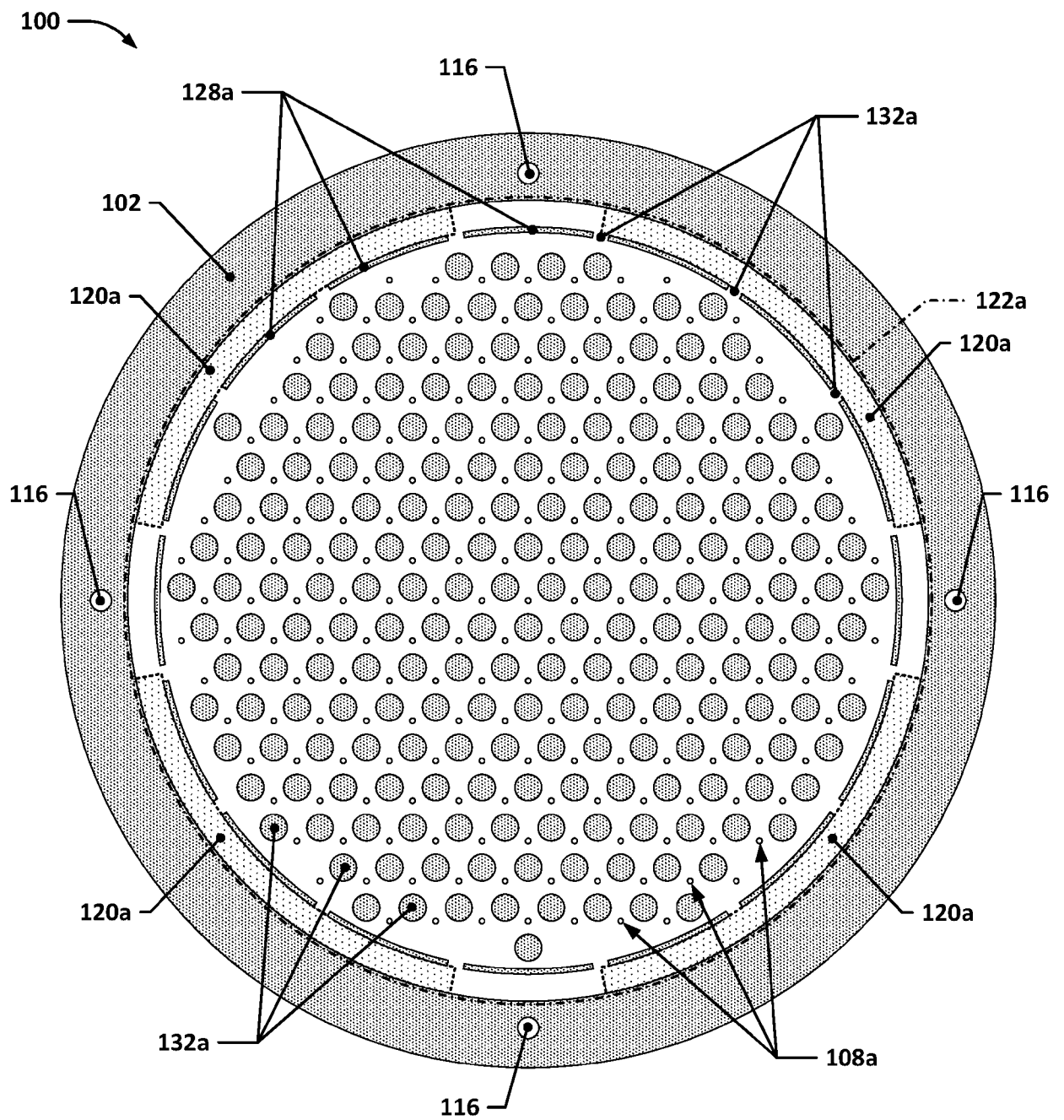


FIG. 7

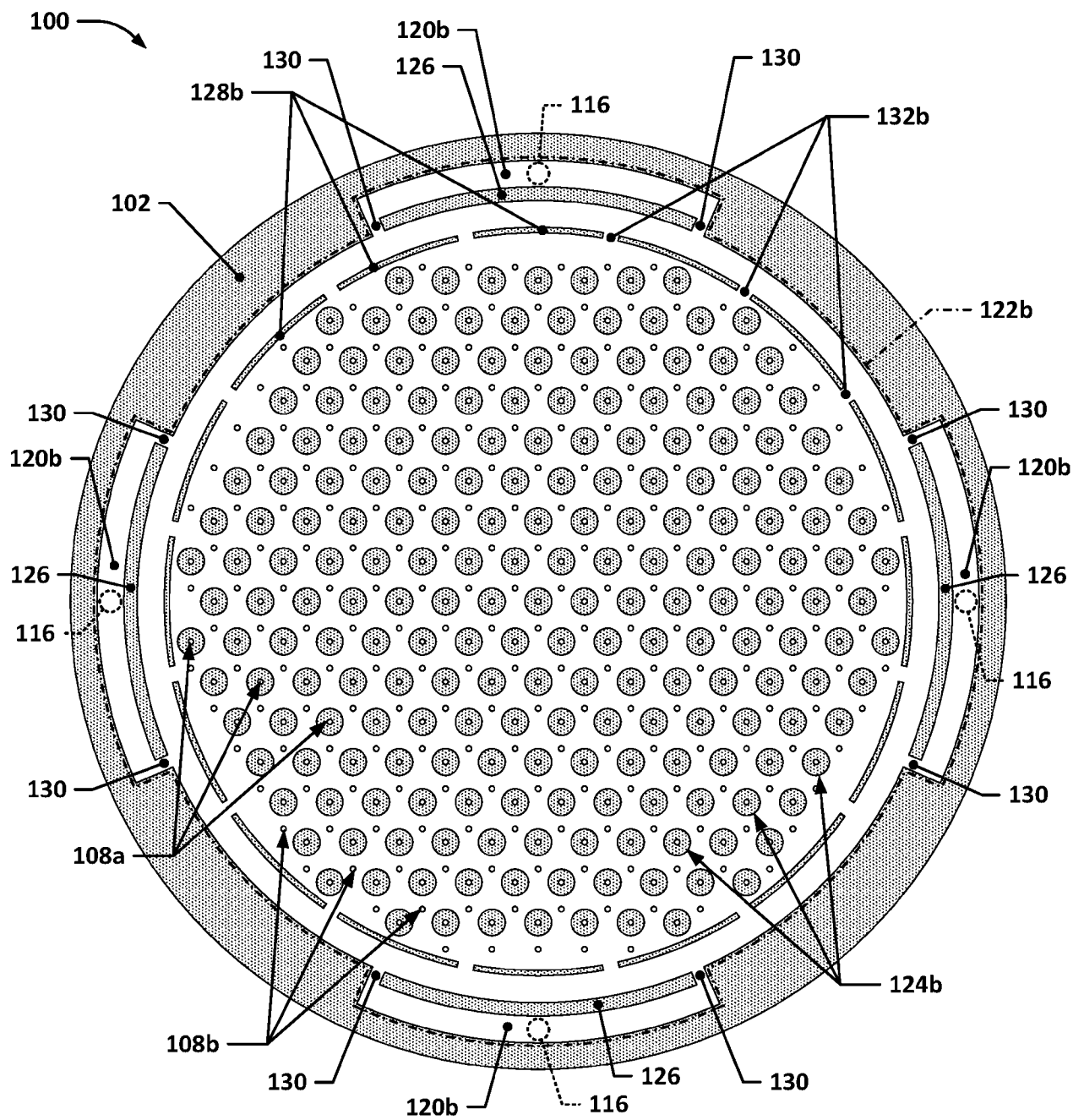


FIG. 8

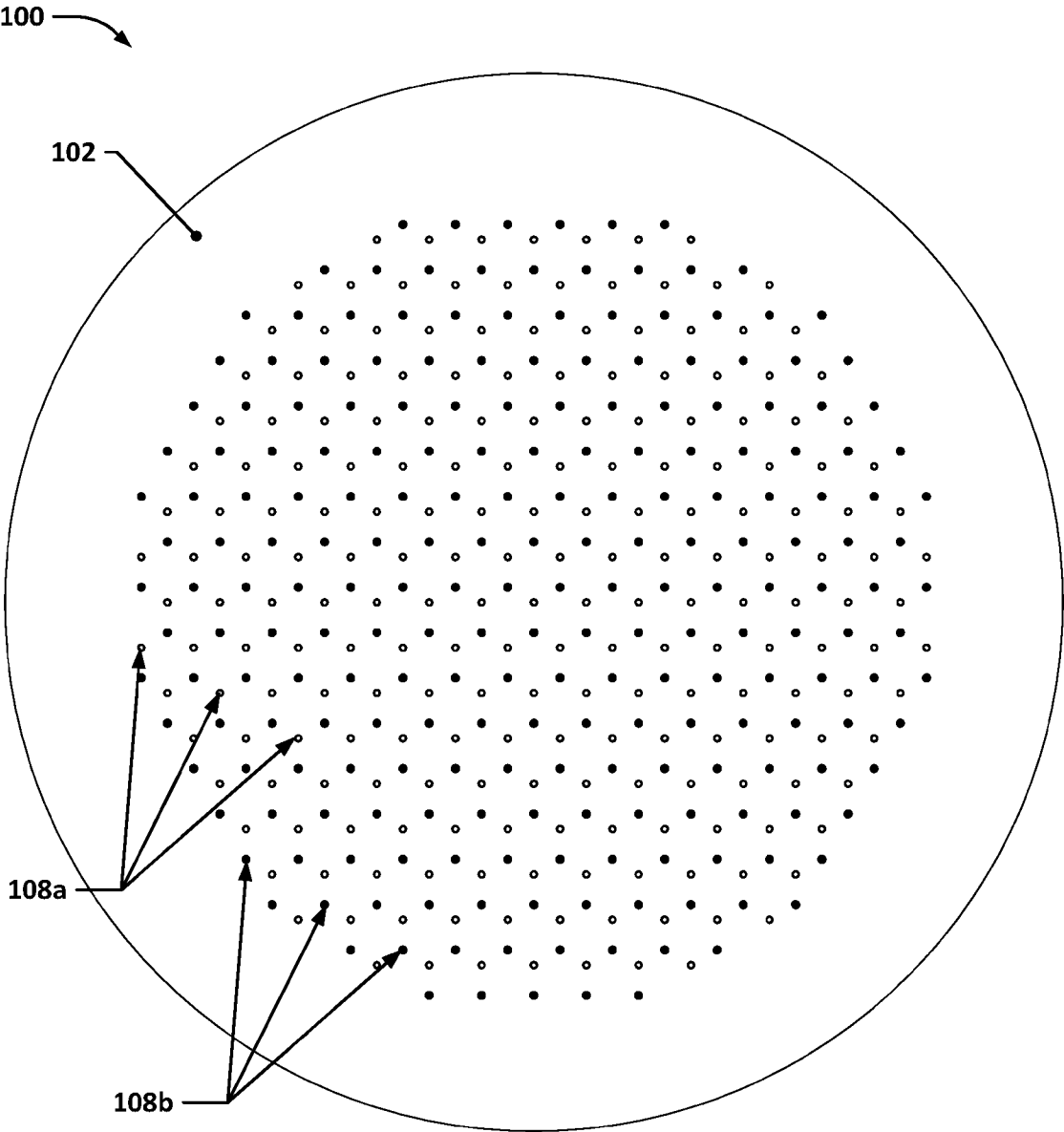


FIG. 9

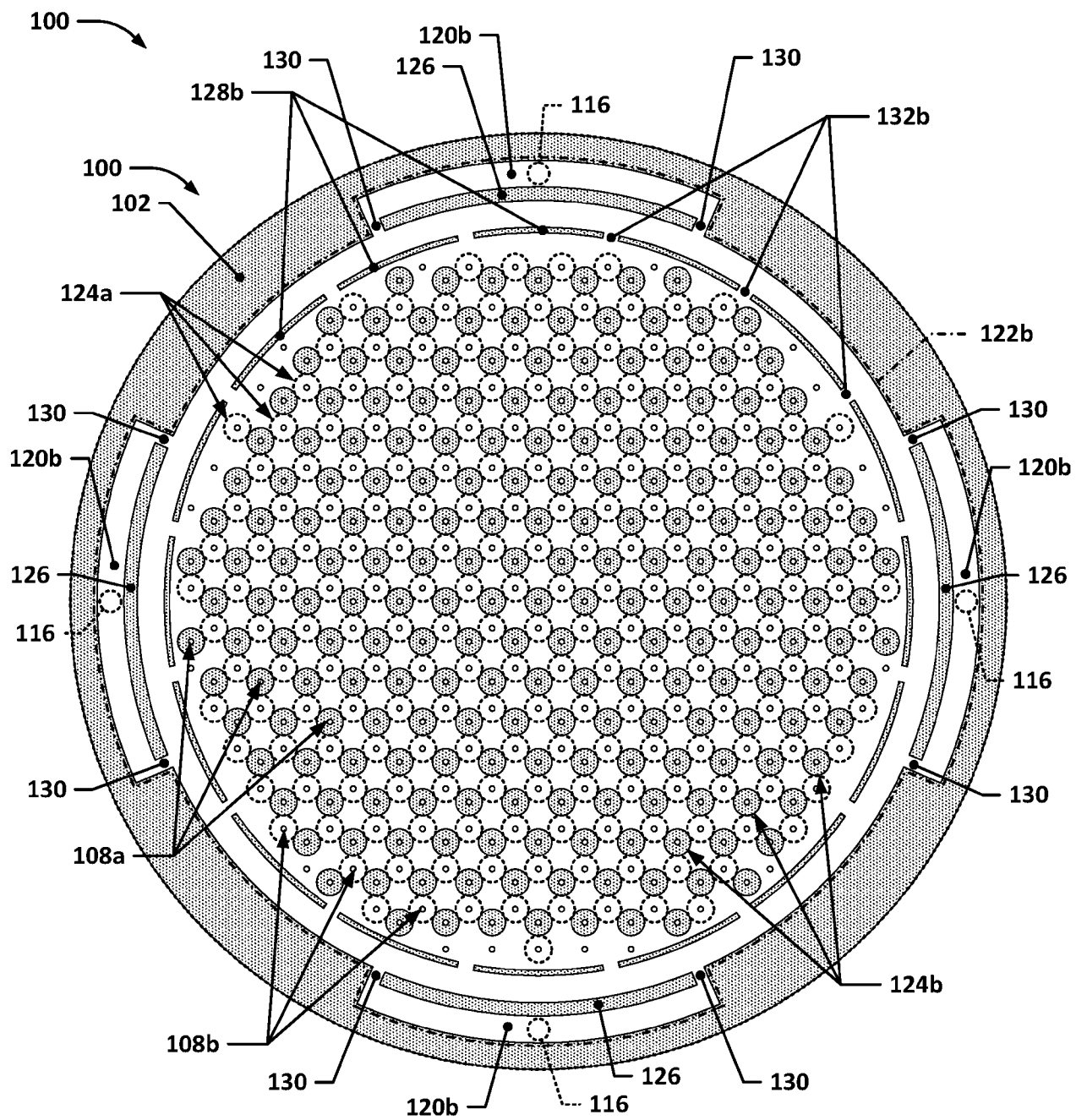


FIG. 10

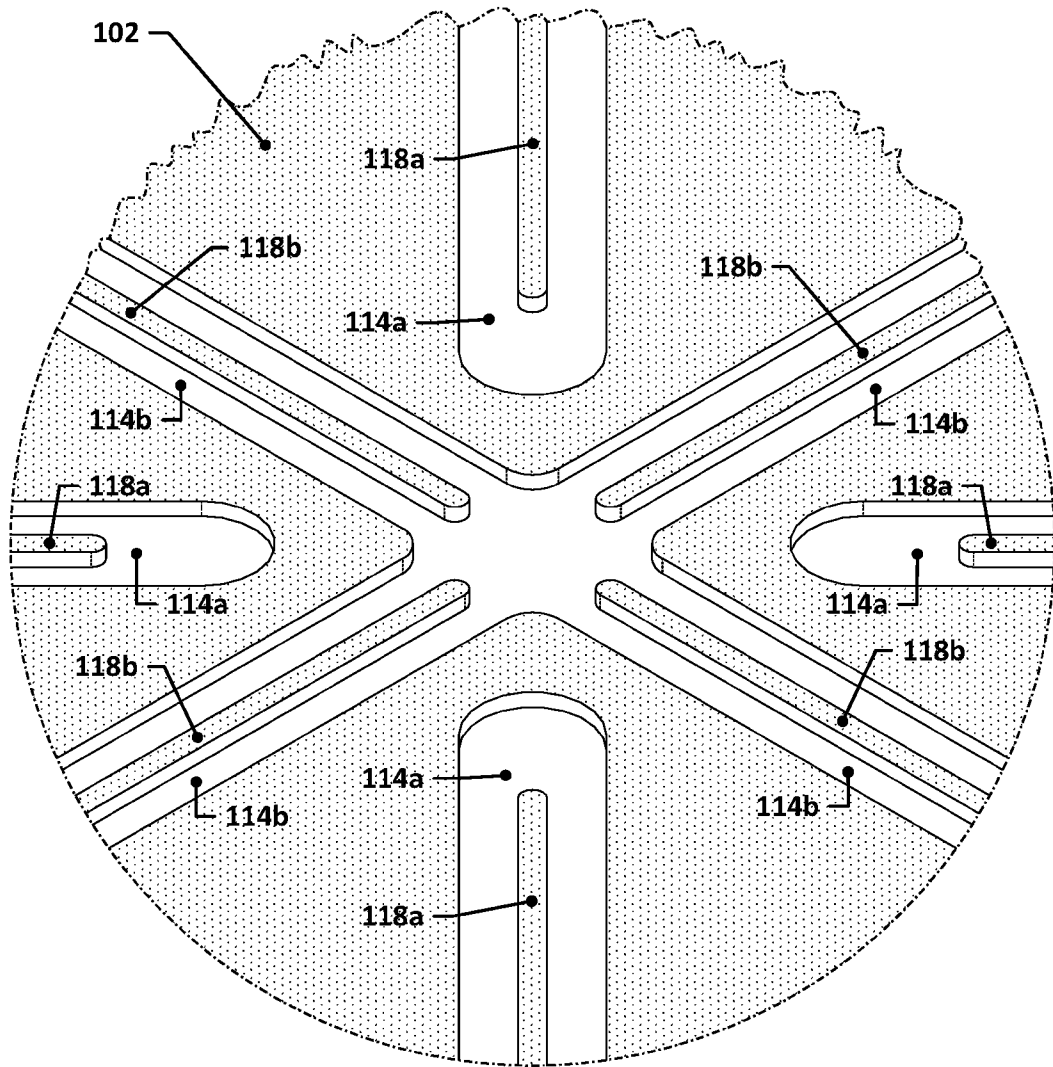


FIG. 11

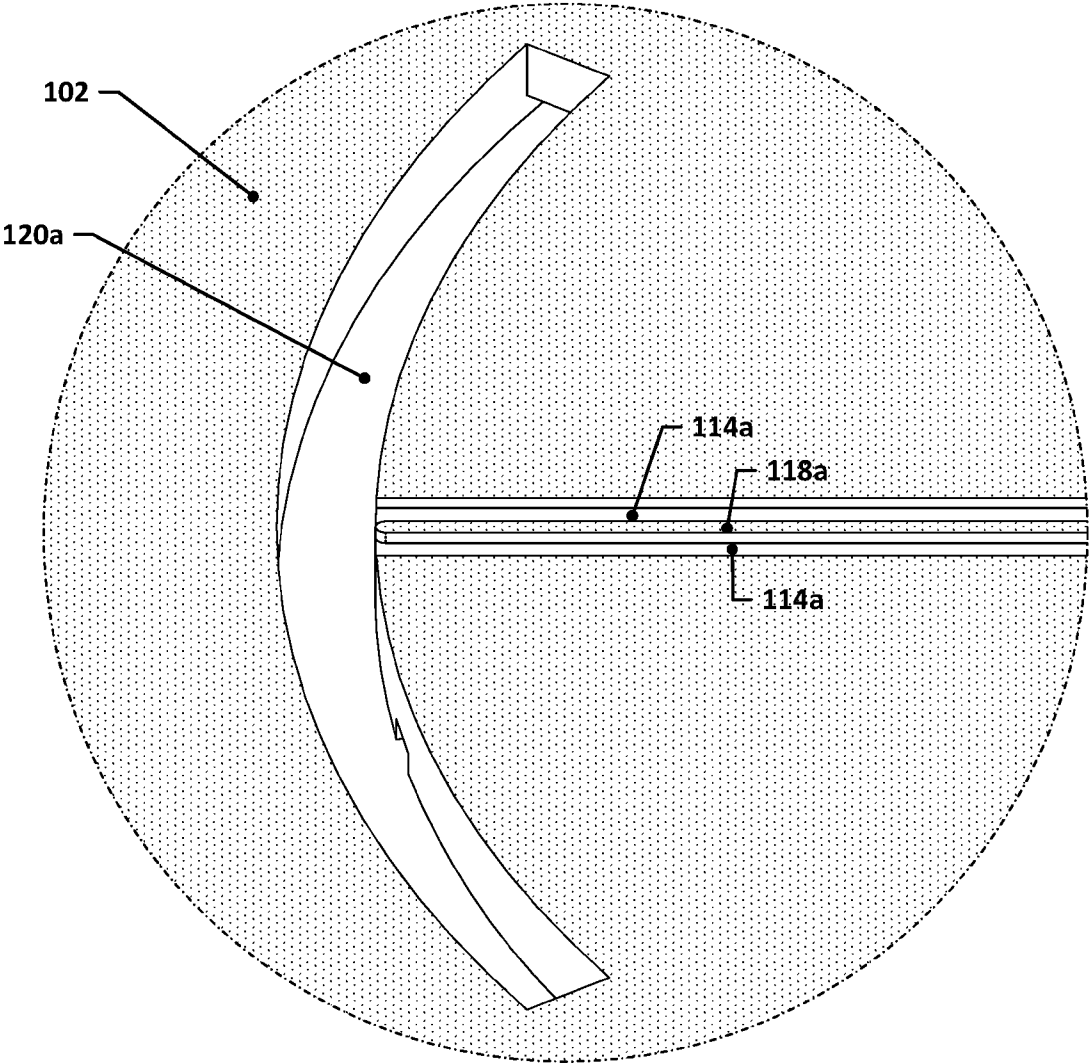


FIG. 12

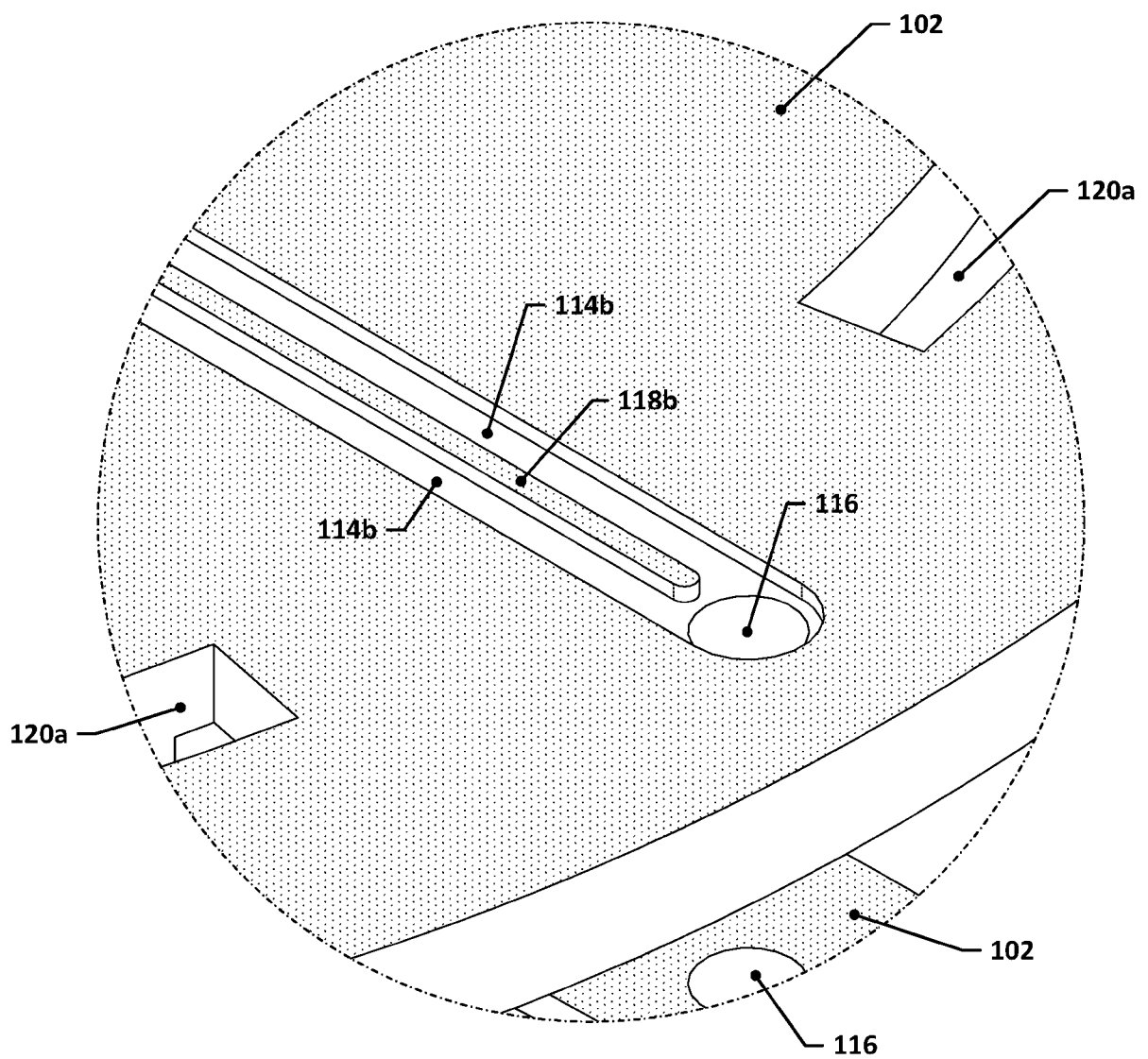


FIG. 13

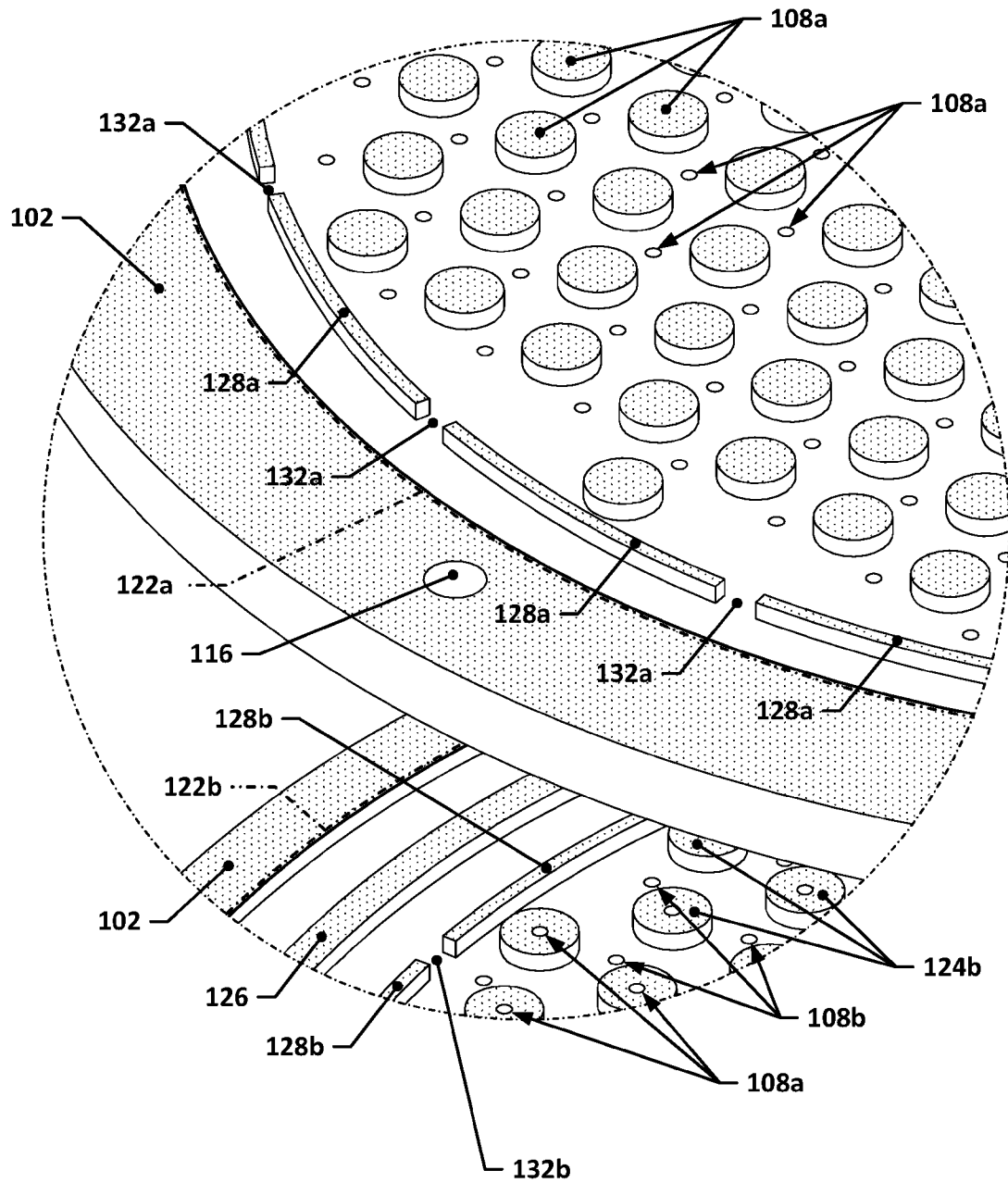


FIG. 14

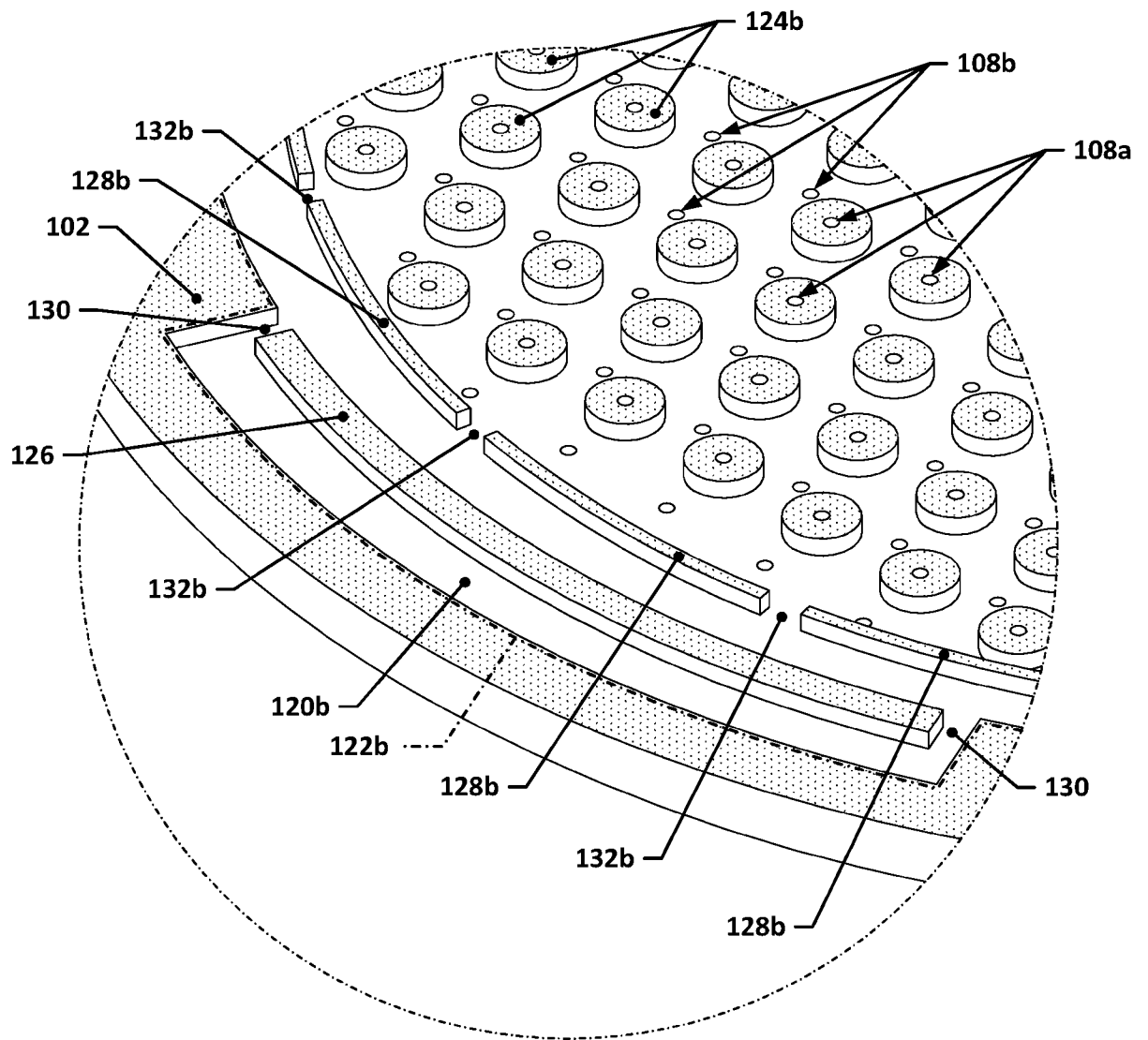


FIG. 15

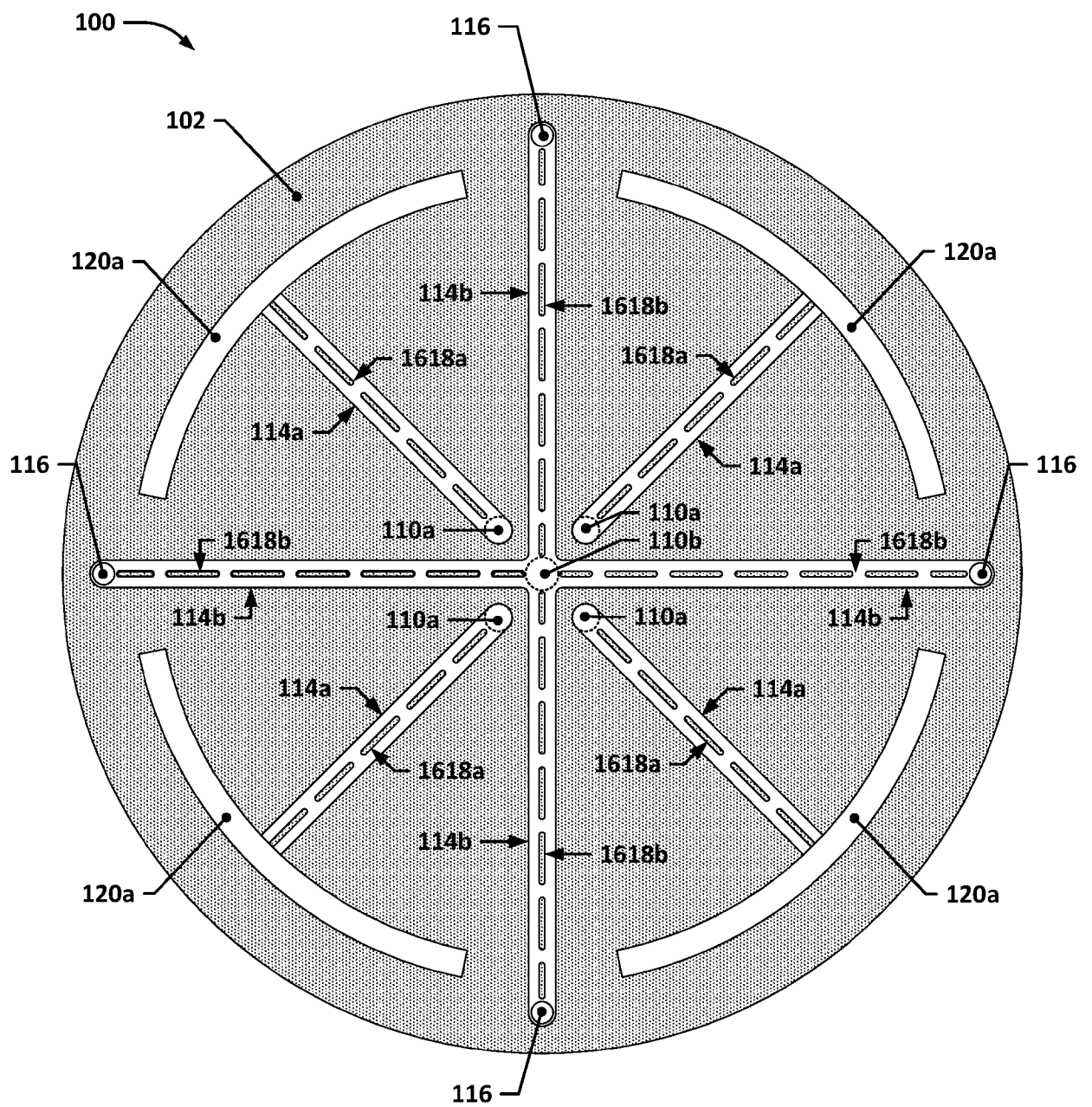


FIG. 16

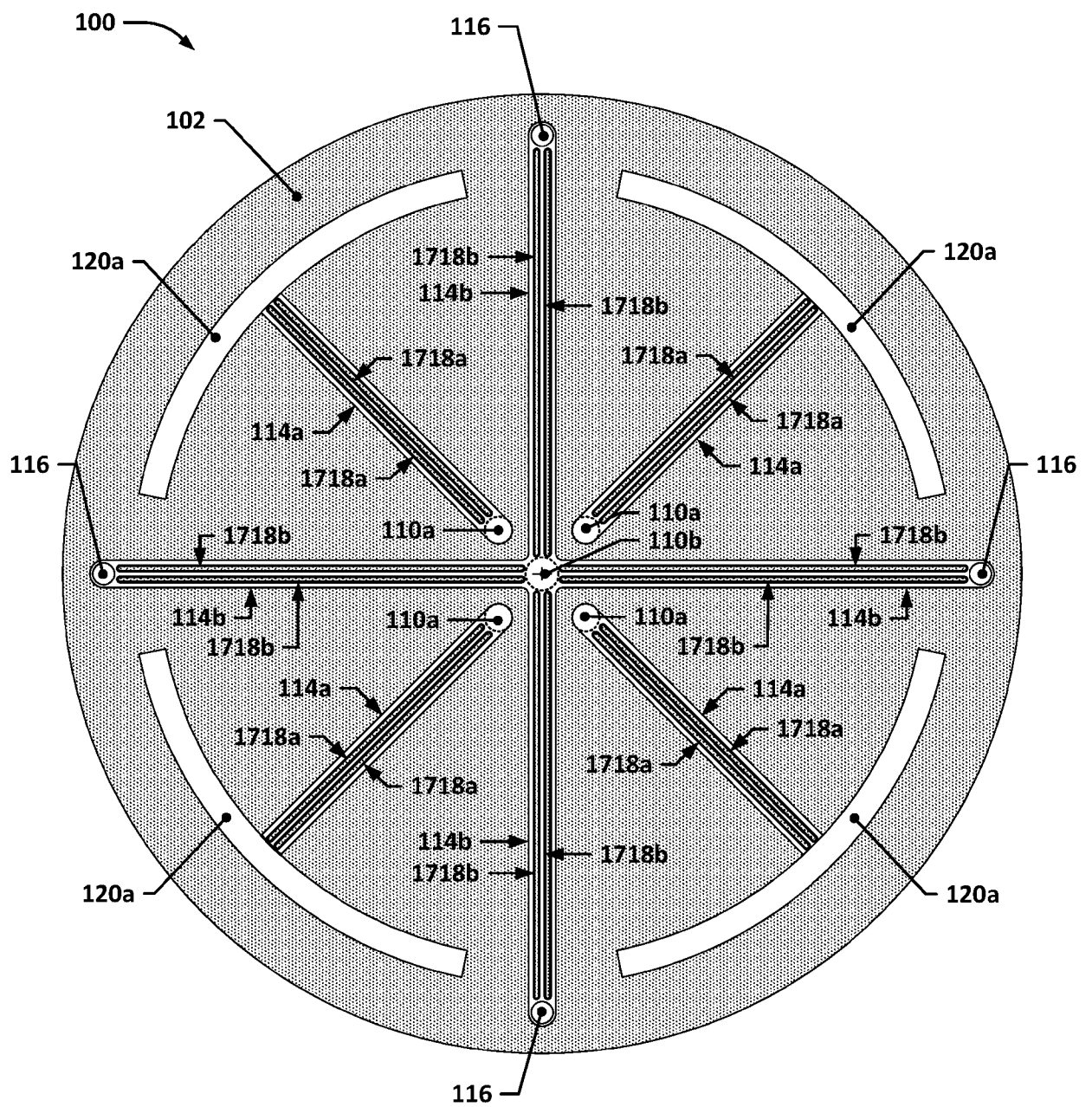


FIG. 17

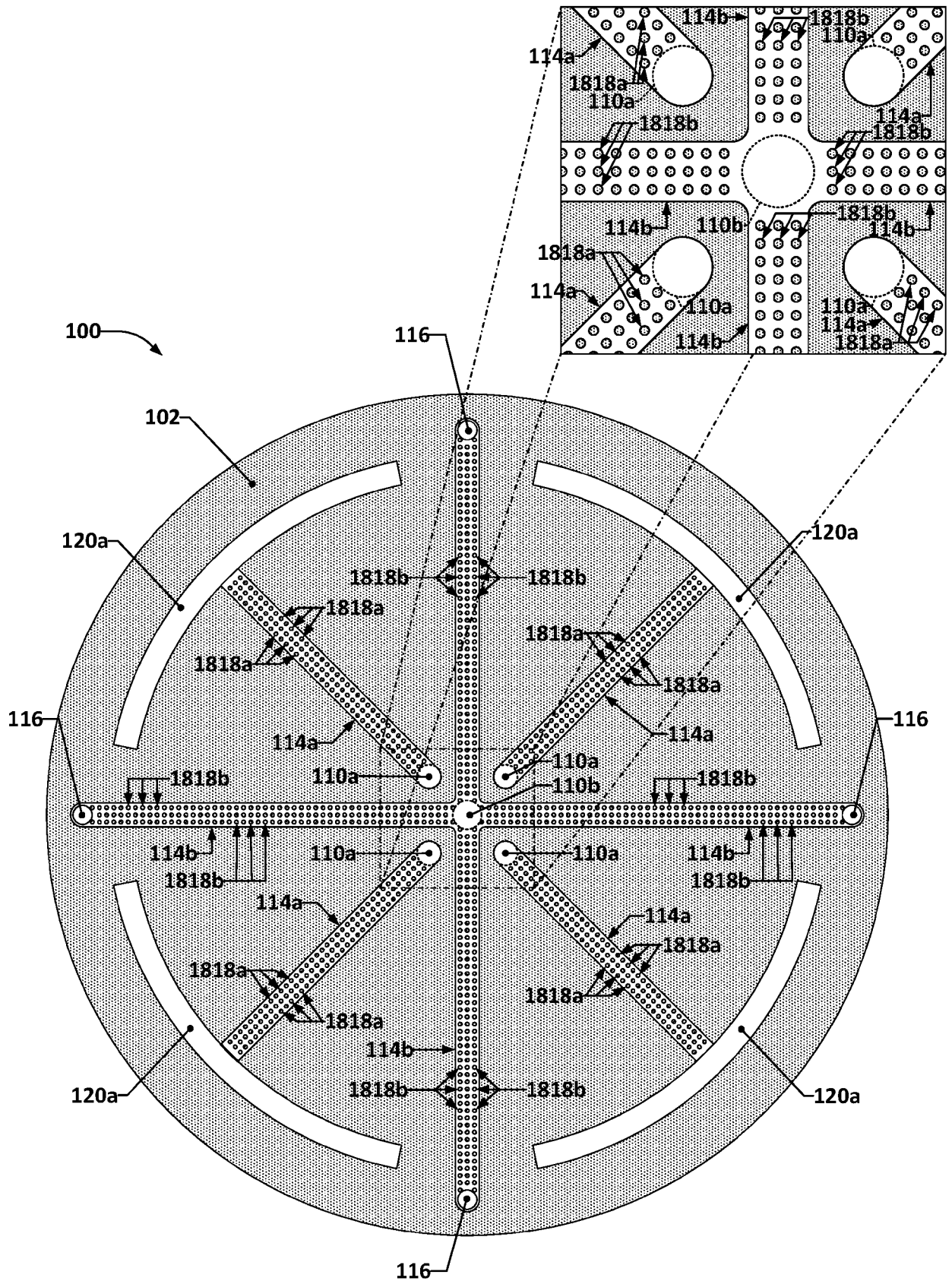


FIG. 18

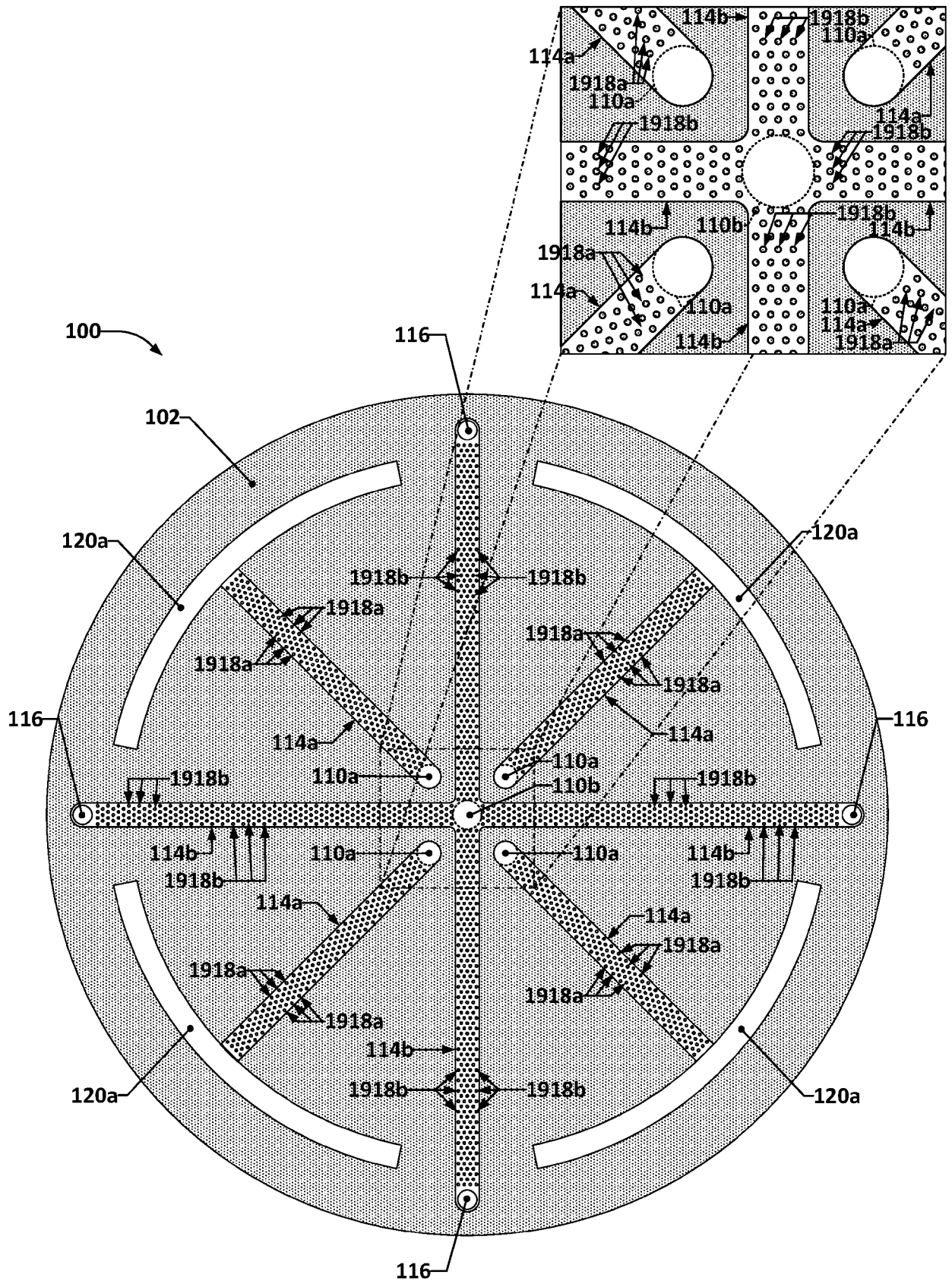


FIG. 19

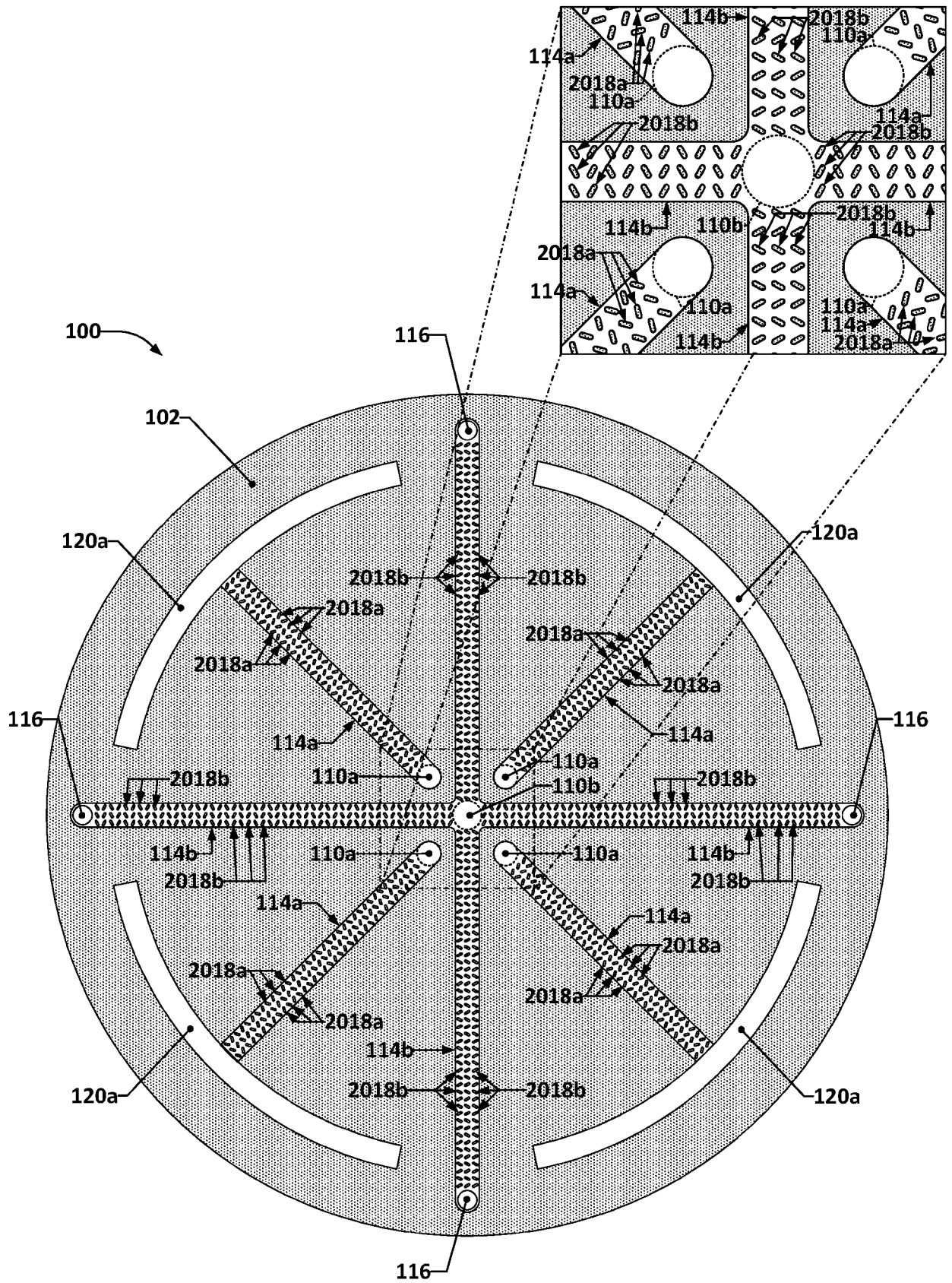


FIG. 20

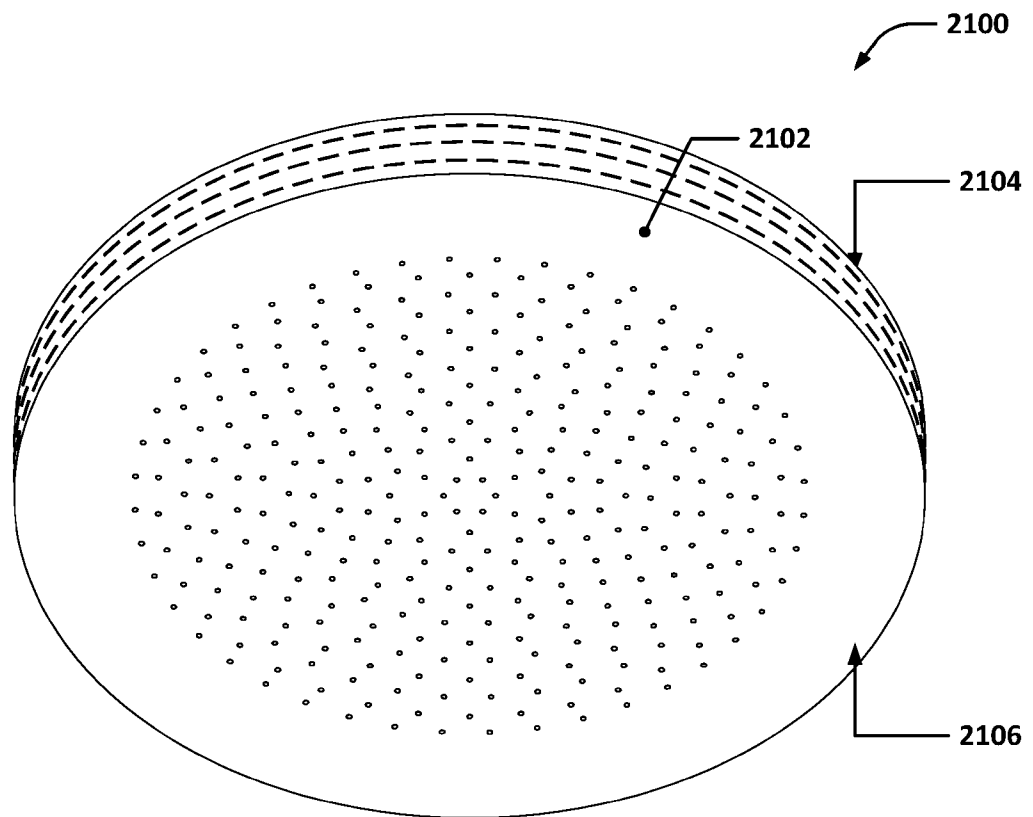


FIG. 21

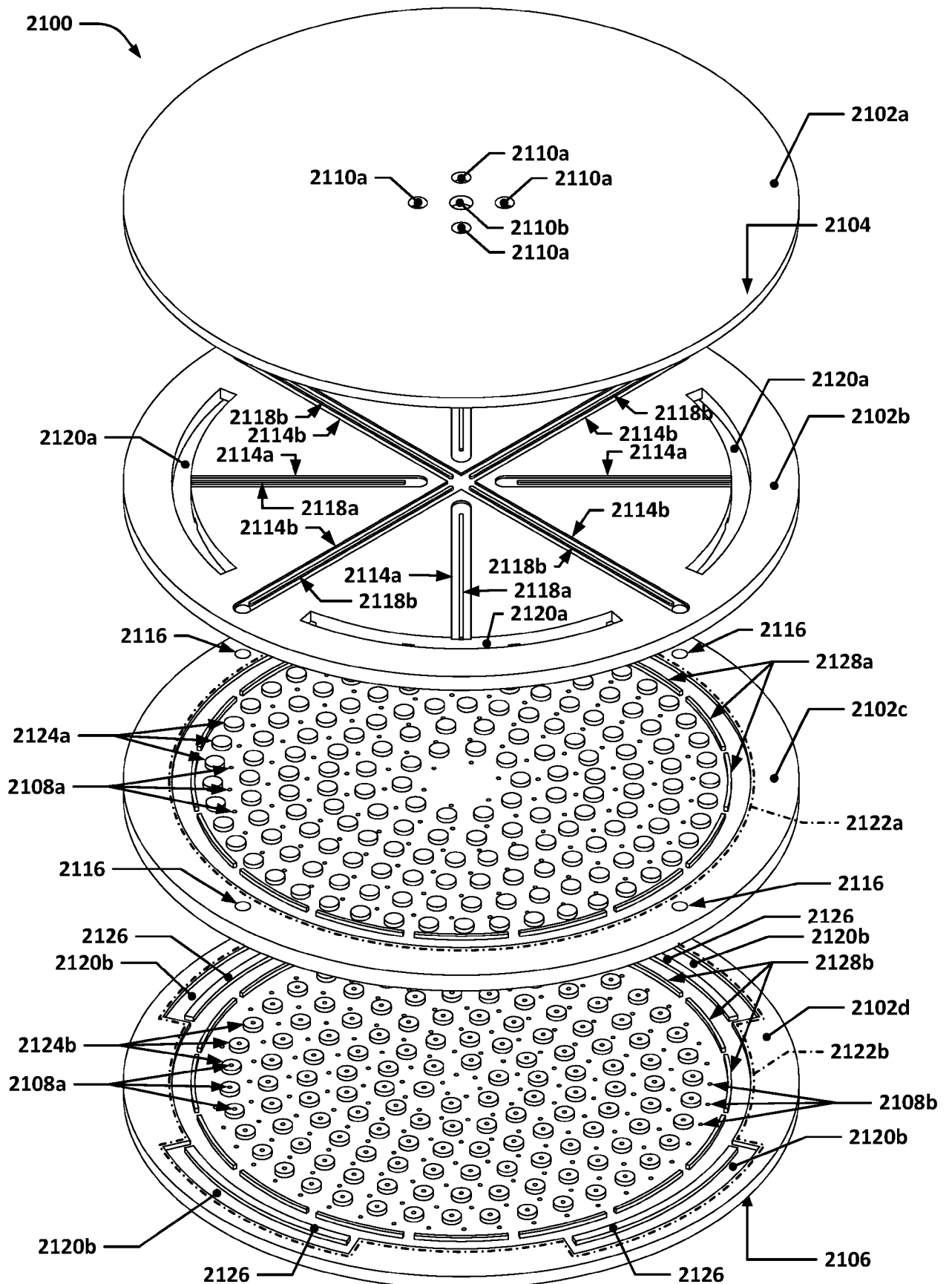


FIG. 22

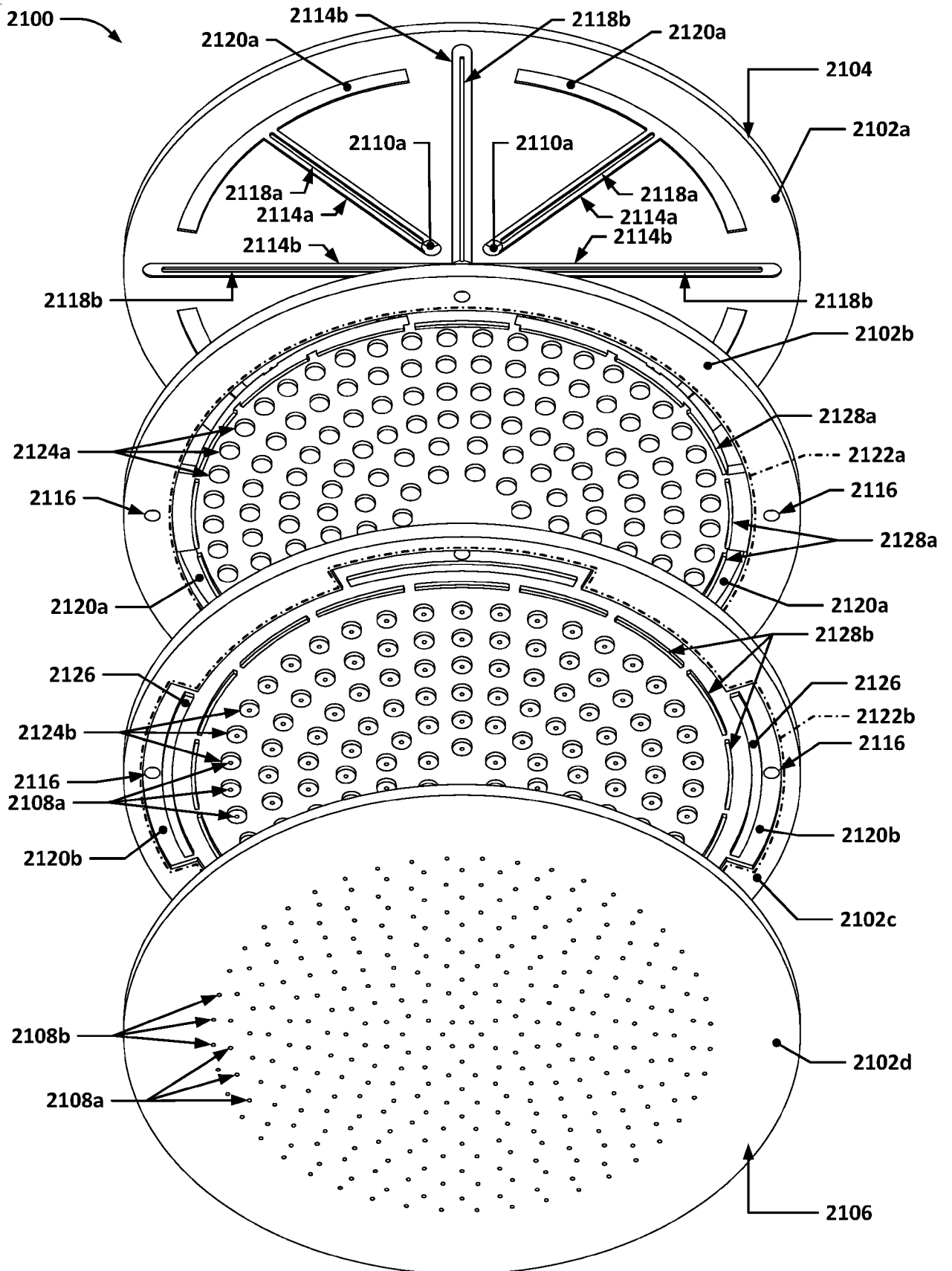


FIG. 29

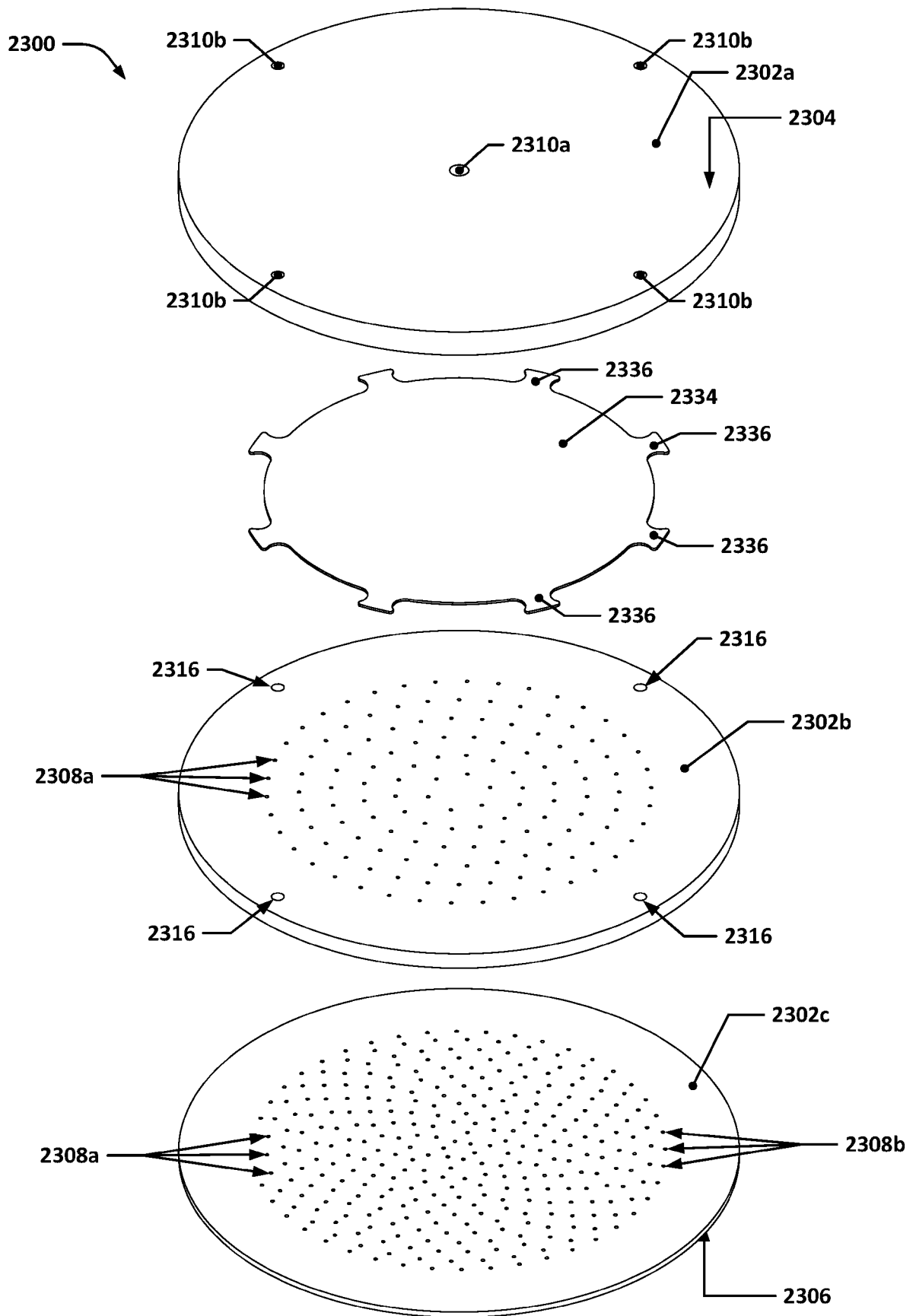


FIG. 23

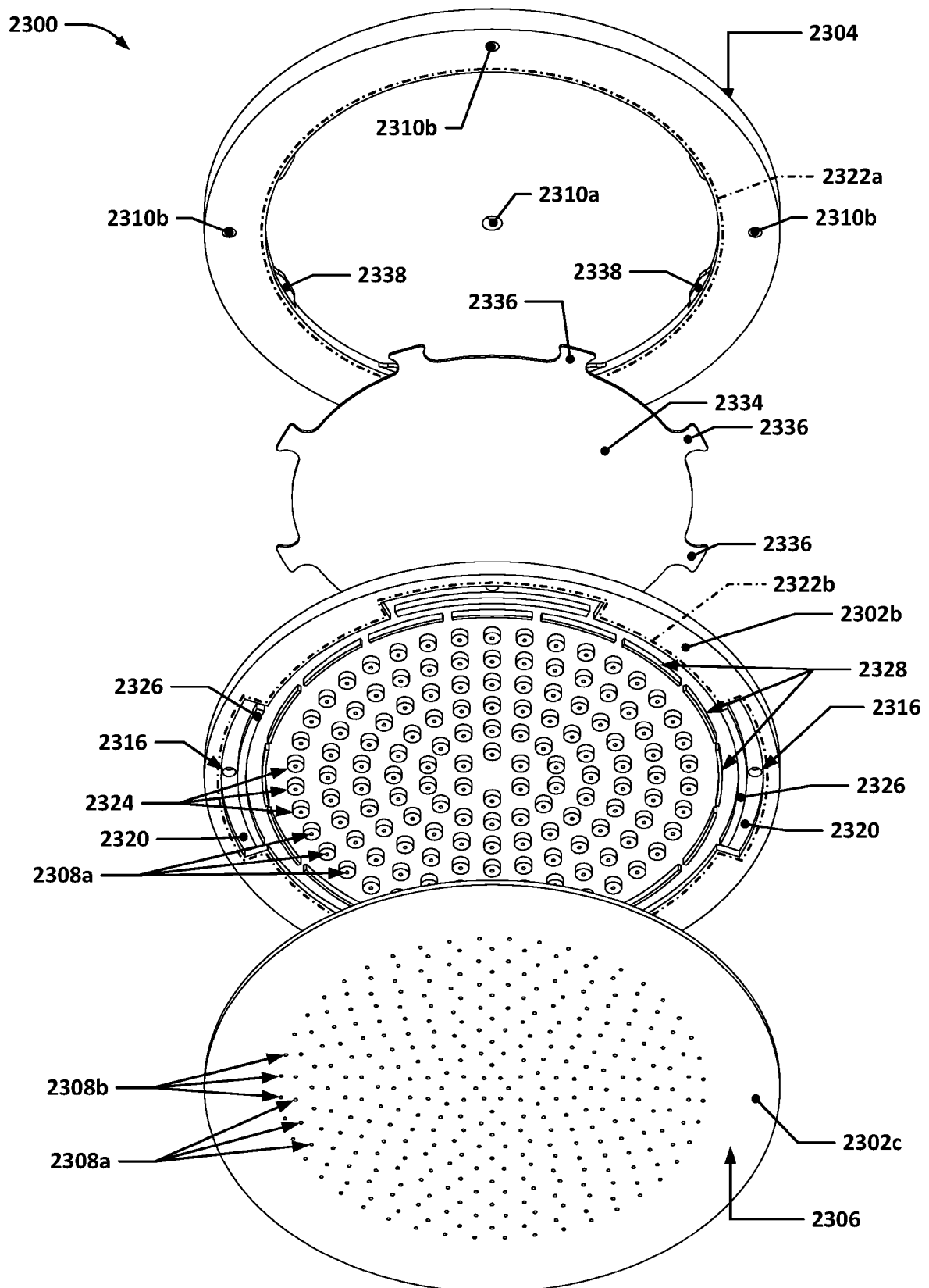


FIG. 24

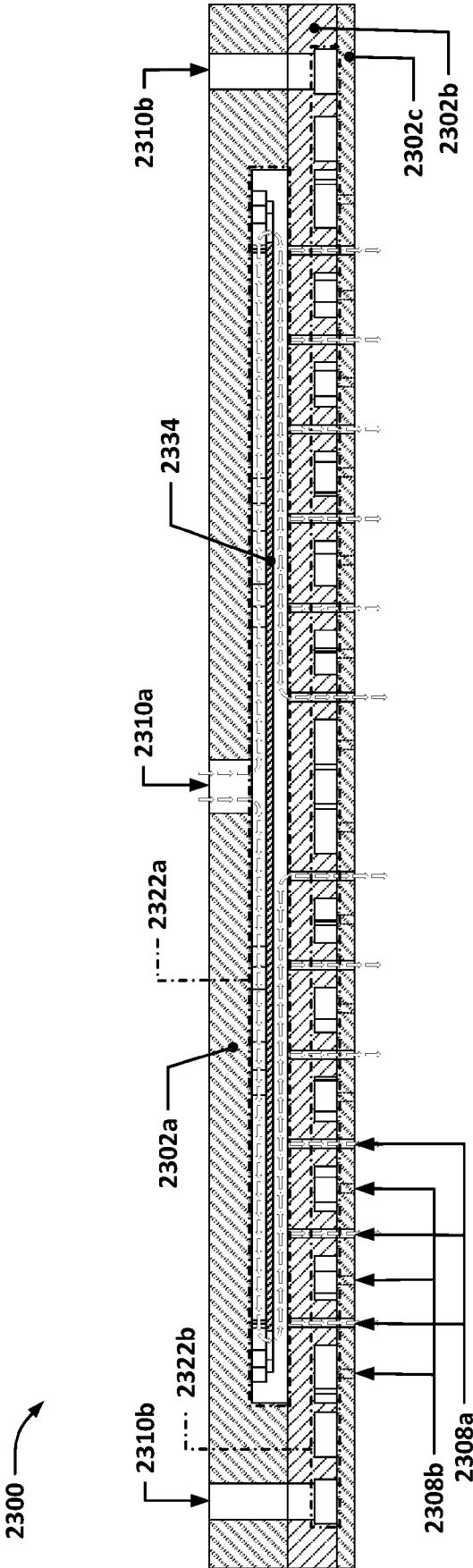


FIG. 25

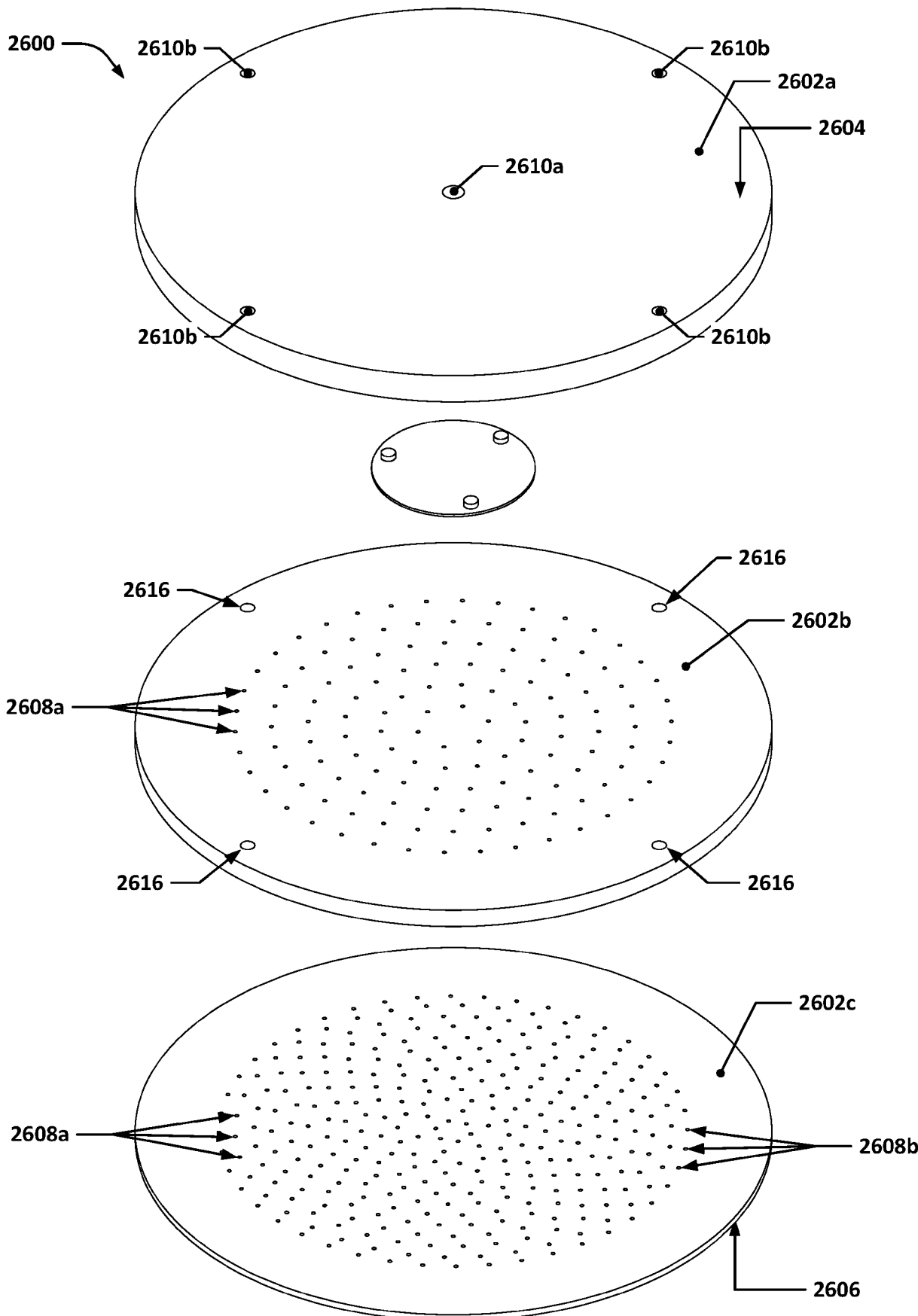


FIG. 26

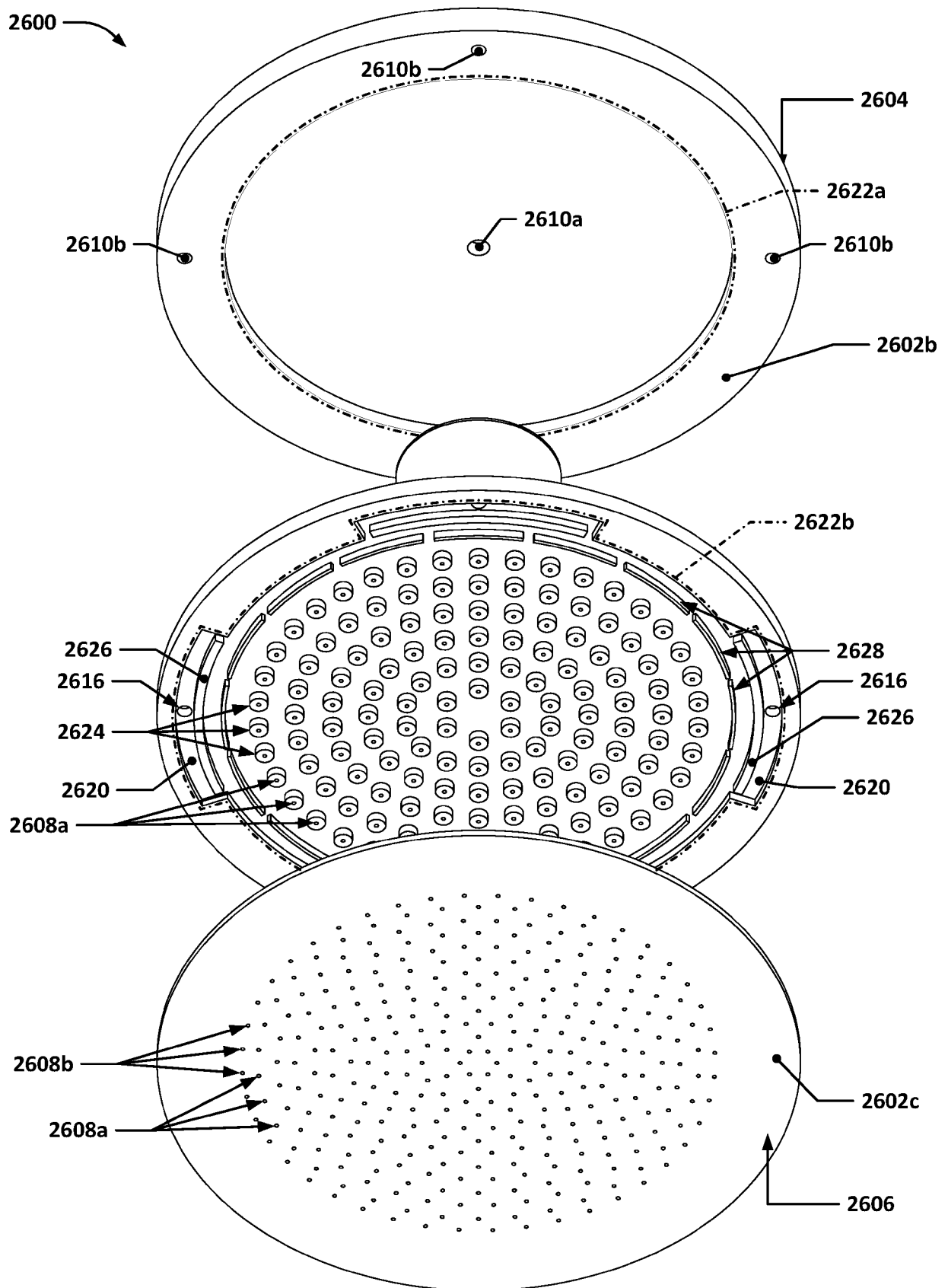


FIG. 27

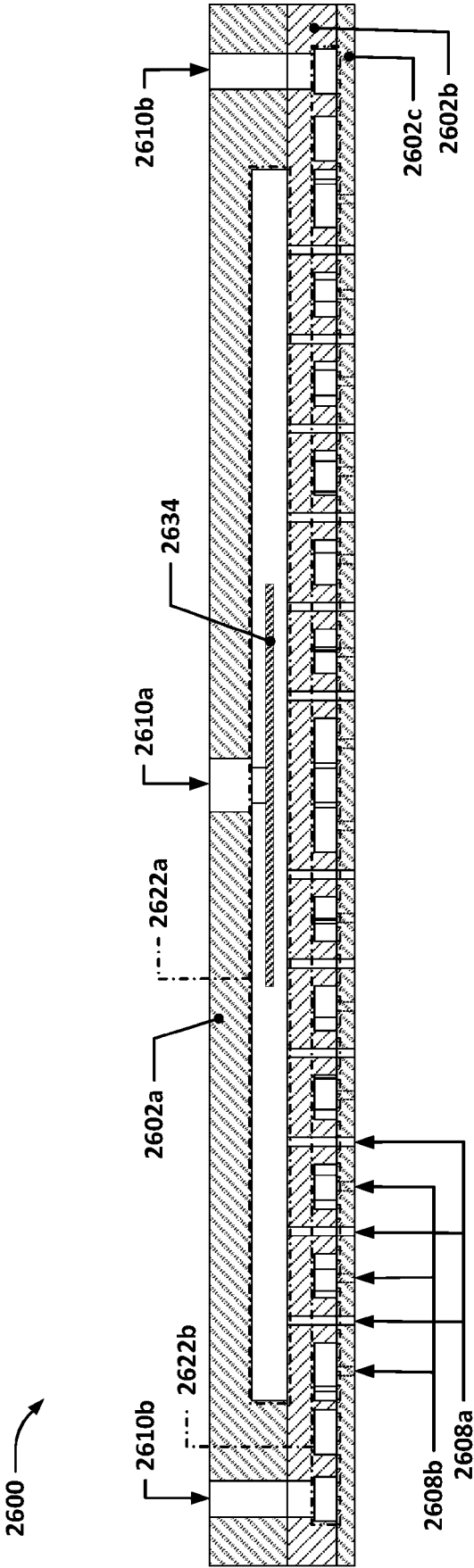


FIG. 28

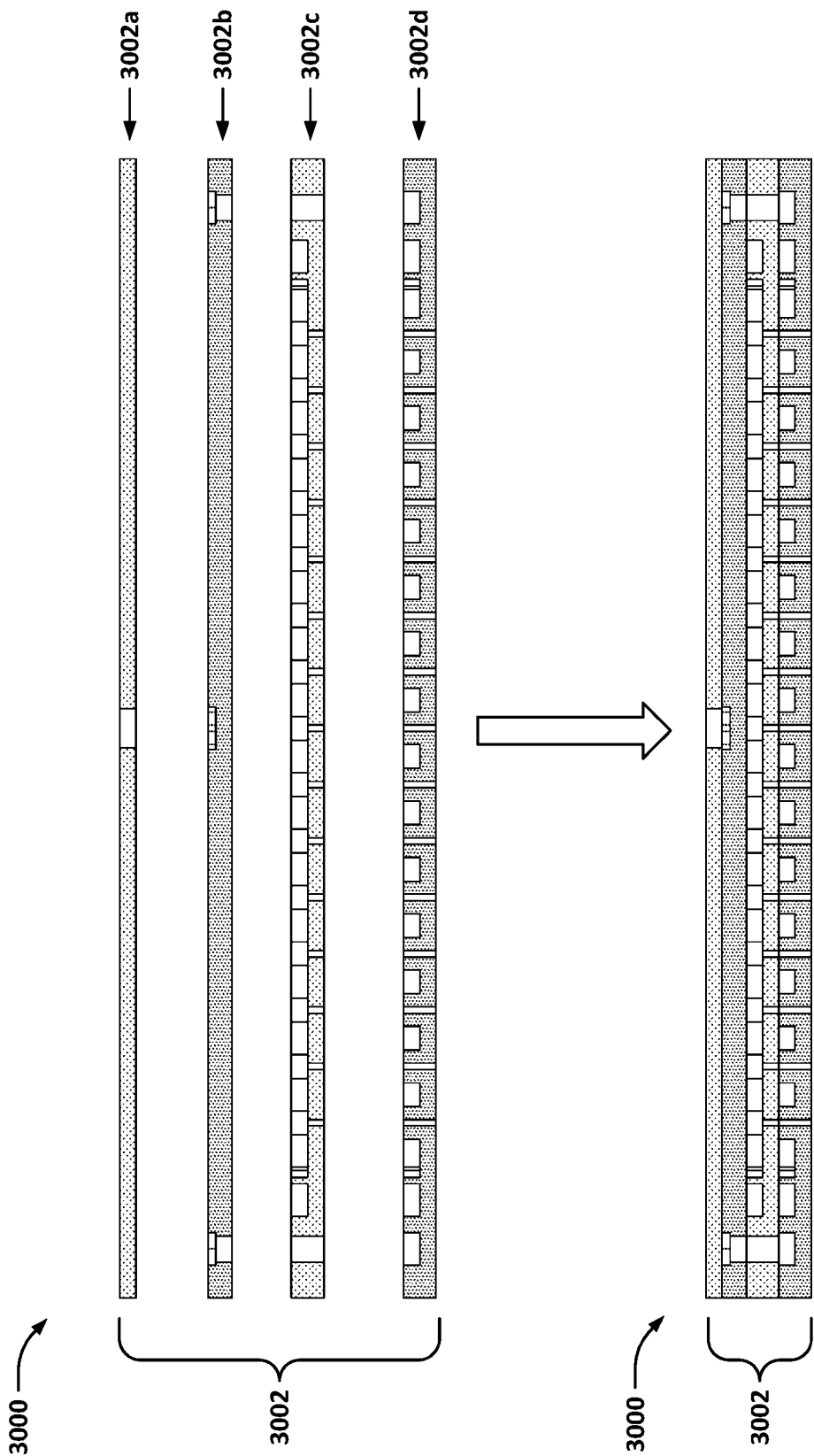


FIG. 30

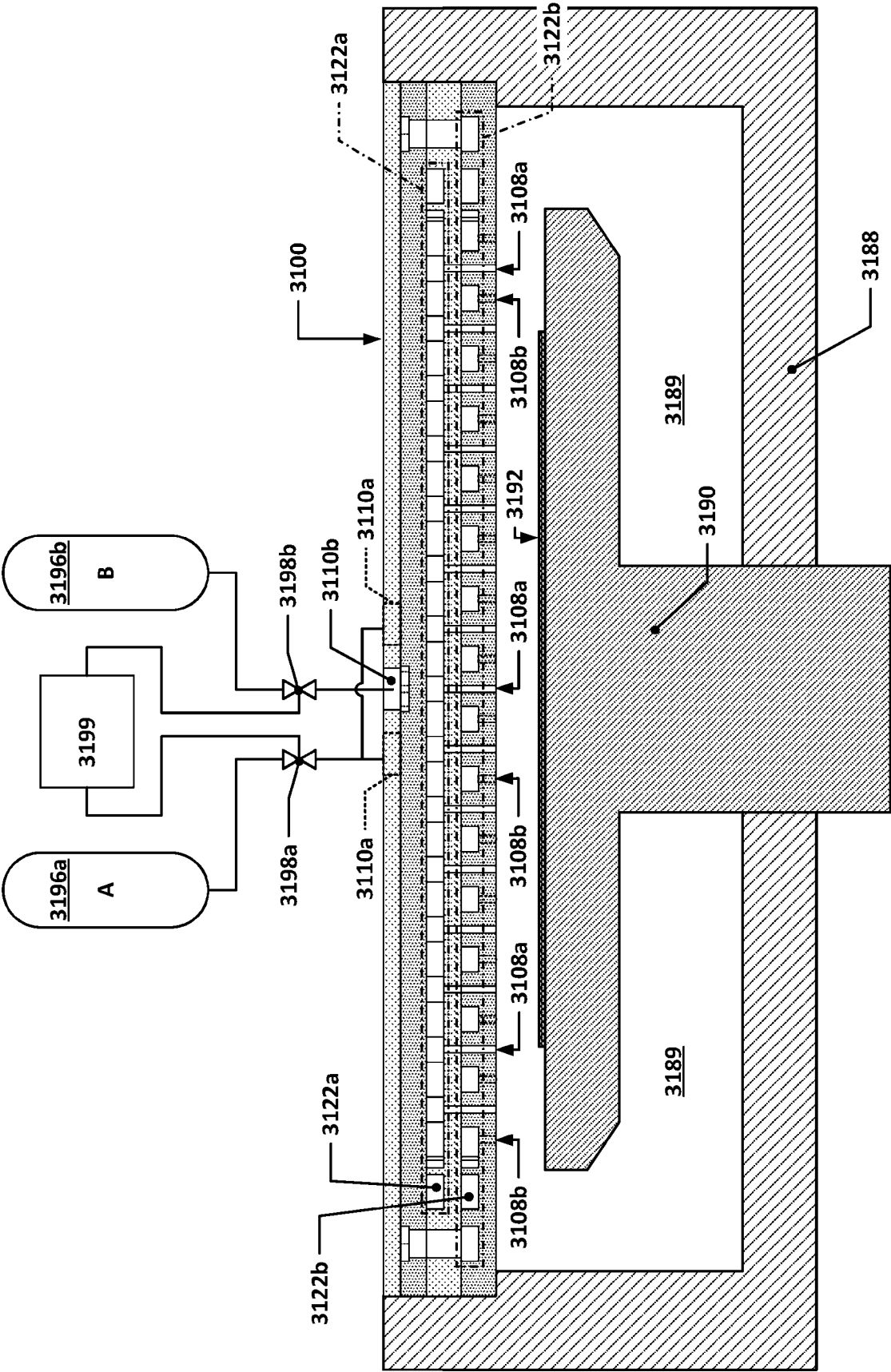


FIG. 31

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/037723

A. CLASSIFICATION OF SUBJECT MATTER H01J 37/32(2006.01)i; C23C 16/455(2006.01)i According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H01J 37/32(2006.01); B05B 1/00(2006.01); B05B 1/18(2006.01); C23C 16/455(2006.01); H01L 21/48(2006.01); H01L 21/67(2006.01) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Korean utility models and applications for utility models Japanese utility models and applications for utility models Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) eKOMPASS(KIPO internal) & Keywords: semiconductor, shower head, plenum, pillar, port, gas, inlet		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016-0348242 A1 (LAM RESEARCH CORPORATION) 01 December 2016 (2016-12-01) paragraphs [0003]-[0066]; and figures 1-12	1-8,23-24
A		9-22
Y	US 2019-0032211 A1 (LAM RESEARCH CORPORATION) 31 January 2019 (2019-01-31) paragraph [0038]; and figures 7-10	1-8,23-24
Y	US 2023-0140263 A1 (LAM RESEARCH CORPORATION) 04 May 2023 (2023-05-04) paragraphs [0261]-[0265]; and figures 44-47	3-7
A	WO 2021-076527 A1 (LAM RESEARCH CORPORATION) 22 April 2021 (2021-04-22) paragraphs [0045]-[0049]; and figures 5-11	1-24
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: “A” document defining the general state of the art which is not considered to be of particular relevance “D” document cited by the applicant in the international application “E” earlier application or patent but published on or after the international filing date “L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) “O” document referring to an oral disclosure, use, exhibition or other means “P” document published prior to the international filing date but later than the priority date claimed “T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention “X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone “Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art “&” document member of the same patent family		
Date of the actual completion of the international search 31 October 2024		Date of mailing of the international search report 01 November 2024
Name and mailing address of the ISA/KR Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon 35208, Republic of Korea Facsimile No. +82-42-481-8578		Authorized officer LEE, Kang Ha Telephone No. +82-42-481-5687

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/037723

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: **25-26**
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/037723

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	WO 2024-059684 A1 (LAM RESEARCH CORPORATION) 21 March 2024 (2024-03-21) paragraphs [0238]-[0251]; and figures 59-63 *The above document is a publication of the earlier application whose priority has been claimed in this international application.	1-2,8,24

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/US2024/037723

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2016-0348242	A1	01 December 2016	CN	106191814	A	07 December 2016
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				KR	10-2511464	B1	16 March 2023
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				TW	I835740	B	21 March 2024
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				WO	2019-023429	A3	28 February 2019
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				JP	2023-020804	A	09 February 2023
				KR	10-2023-0018969	A	07 February 2023
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				EP	4046182	A1	24 August 2022
				EP	4046182	A4	13 December 2023
				JP	2022-551152	A	07 December 2022
				KR	10-2022-0067002	A	24 May 2022
				KR	10-2500928	B1	16 February 2023
				TW	202129688	A	01 August 2021
WO	2024-059684	A1	21 March 2024	None			