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(54) Title: TELESCOPING PASSIVE DIRECT AIR CAPTURE SYSTEM AND DEVICE

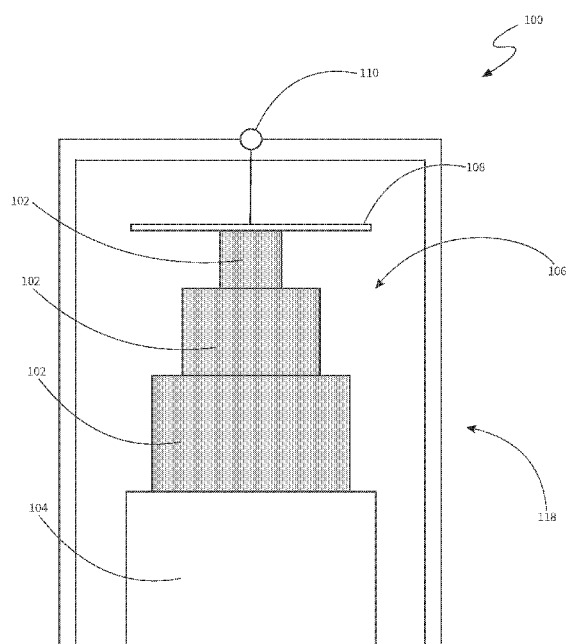


FIG. 1B

(57) Abstract: A device for passive atmospheric carbon dioxide collection comprises a vessel with an opening, a sorbent regeneration system, and a lid. Attached to the vessel is a sorbent structure featuring multiple coaxial ducts, each containing sorbent material and a central void along a shared axis. This structure transitions between a collection configuration—where the ducts extend through the vessel's opening, exposing the sorbent material to airflow for CO₂ capture and a release configuration, where the ducts nest within each other inside the vessel, allowing the regeneration system to release the captured CO₂, forming an enriched gas. An expansion mechanism facilitates movement between these configurations. The device may include features such as ducts made of sorbent material, permeable duct sections for airflow, directional vanes to enhance CO₂ capture, and a microcontroller with sensors to optimize operation.

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TELESCOPING PASSIVE DIRECT AIR CAPTURE SYSTEM AND DEVICE

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. provisional patent application
5 63/599,518, filed November 15, 2023 titled “Telescoping Passive Direct Air Capture
Device,” the entirety of the disclosure of which is hereby incorporated by this reference.

TECHNICAL FIELD

[0002] Aspects of this document relate generally to the capture of atmospheric
10 carbon dioxide.

BACKGROUND

[0003] The need for technologies to remove carbon dioxide from ambient air has
been well established. In addition to conservation, reduced-carbon processes, and on-site
15 capture efforts, a significant amount of carbon dioxide will need to be removed from the
atmosphere to avoid a looming climate change crisis.

[0004] Capture of carbon dioxide from ambient air at an affordable price could
become a critical tool in managing the anthropogenic carbon cycle. Air capture technology
would greatly enhance the options for developing the world’s energy infrastructure and would
20 be a major asset in the fight against climate change. Combined with a carbon dioxide (CO₂)
storage technology, air capture of CO₂ could compensate for CO₂ emissions from any source,
without requiring changes to the existing infrastructure and without requiring proximity to the
point of emission. Air capture technology makes it possible for existing infrastructures to live
out their natural life spans, and it permits the continued use of carbon-based fuels in distributed
25 and mobile applications, for example in the transportation sector. With air capture technology,
it is possible to continue the use of liquid hydrocarbon fuels while eliminating their climate
impact.

[0005] However, in order to have any meaningful impact on the environment, air
capture technology will need to be adopted on a large scale. Since the carbon dioxide in the
30 ambient air is very dilute, atmospheric CO₂ collectors can quickly overrun a tight energy budget
for drawing in and processing air in bulk. While there are some air capture solutions that are

resource-efficient enough to operate within this tight energy budget, such efficiencies often come at the cost of complicated designs that are expensive to make and difficult to maintain. Conventional carbon dioxide collection systems often exhibit the unfortunate combination of being costly and fragile.

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SUMMARY

[0006] According to one aspect, a device for passive collection of atmospheric carbon dioxide includes a vessel having an opening and a sorbent regeneration system, and a lid. The device also includes a sorbent structure coupled to the vessel and having a plurality of ducts that are coaxial, each duct having a sorbent material and having a central void running along a central axis shared by the plurality of ducts. The sorbent structure is movable between a collection configuration and a release configuration. The device also includes an expansion mechanism coupled to the sorbent structure and configured to move the sorbent structure between the collection configuration and the release configuration. The collection configuration includes the sorbent structure telescoping out through the opening of the vessel such that at least some of the ducts are outside the vessel and exposed to an airflow such that the sorbent material of the sorbent structure captures atmospheric carbon dioxide. The release configuration includes the plurality of ducts nested within each other and the sorbent structure sufficiently enclosed inside the vessel by the lid that the sorbent regeneration system may operate on the sorbent material to release captured carbon dioxide from the sorbent material and form an enriched gas within the vessel.

[0007] Particular embodiments may comprise one or more of the following features. Each duct of the plurality of ducts may be composed of the sorbent material. The sorbent material may be a porous membrane. Each duct of the sorbent structure may include a frame on which the sorbent material is mounted. At least part of each duct of the plurality of ducts may be permeable, such that air flows over an outer surface of the duct, an inner surface of the duct facing the central void, and through the duct between the outer surface and the inner surface. The lid may be fixedly coupled to the sorbent structure, such that the lid and sorbent structure move together as the sorbent structure is moving between the collection configuration and release configuration. The lid may be releasably coupled to the sorbent structure and able to separate from the sorbent structure such that air can flow through and out of the central void of the sorbent structure. The lid may be fixedly coupled to the sorbent structure and may include a central aperture. The vessel may include a plug positioned such that when the sorbent structure is in the release configuration, the plug is inside of and sealing the central aperture

of the lid. The collection configuration may include the plurality of ducts being spread out along the central axis such that the ducts are separated from each other along the central axis. Neighboring ducts may make contact with each other when the sorbent structure is in the collection configuration. Each duct of the plurality of ducts may include a narrow end and a wide end distal to the narrow end. For each pair of neighboring ducts having an inner duct that nests within an outer duct when the sorbent structure is in the release configuration, the collection configuration may include the wide end of the inner duct stuck inside the narrow end of the outer duct such that the inner duct and outer duct have an overlap when the sorbent structure is in the collection configuration. For each pair of neighboring ducts having an inner duct that nests within an outer duct when the sorbent structure is in the release configuration, the collection configuration may include an overlap between the inner duct and the outer duct when the sorbent structure is in the collection configuration. A largest duct of the plurality of ducts may be located further from the vessel than a smallest duct of the plurality of ducts when the sorbent structure is in the collection configuration. Each duct may have a height. The plurality of ducts may include at least two different heights. The device may further include a microcontroller communicatively coupled to the expansion mechanism and at least one sensor. The microcontroller may be configured to adjust the overlap between neighboring ducts while the sorbent structure is in the collection configuration based on data received from the at least one sensor. The device may further include a microcontroller communicatively coupled to the expansion mechanism and at least one sensor. The microcontroller may be configured to adjust how many ducts are lifted out of the vessel when moving into the collection configuration based on data received from the at least one sensor. At least one of the sorbent regeneration system and the expansion mechanism may be located within the central void. The vessel may be annular such that at least a portion of the central void of a smallest duct is occupied by the vessel when the sorbent structure is in the release configuration. Each duct may include a plurality of directional vanes to enhance carbon dioxide capture by inducing turbulence. The directional vanes may be positioned within the central void of the ducts. Each duct may further include a plurality of channels passing through the duct perpendicular to the central axis. The directional vanes may be positioned within the channels of the ducts. The expansion mechanism may be outside of the plurality of ducts, and pulls the sorbent structure away from the vessel and into the collection configuration. The expansion mechanism may be inside of the central void of the plurality of ducts, and pushes the sorbent structure away from the vessel and into the collection configuration. Each pair of neighboring ducts may include a threading on one duct of the pair of ducts that is engaged by the other of the pair of ducts, such that the

sorbent structure moves between the collection configuration and the release configuration through rotation of the ducts by the expansion mechanism. Each duct of the plurality of ducts may include an outer perimeter and an inner perimeter, with the inner perimeter and the outer perimeter sized and shaped such that the ducts can nest within each other. The outer perimeters of the plurality of ducts may include at least two cross-sectional shapes. The outer perimeters of the plurality of ducts may be non-circular. The lid may include a lip that extends down along the vessel when the lid is enclosing the sorbent structure inside the vessel. The lid may be slidably coupled to one of a largest duct and a smallest duct through a plurality of rods fixedly coupled to the one of the largest duct and the smallest duct such that the sorbent structure is suspended from the lid by the plurality of rods when in the collection configuration. The lid may include a protrusion extending out of the lid towards the central void, the protrusion being conical and sized to be received inside the central void when the sorbent structure is in the release configuration. Each duct of the plurality of ducts may have a wall thickness. A ratio between a radius of the plurality of ducts and the wall thickness of a duct may be between 1:3 and 1:200. The ratio between the radius of the plurality of ducts and the wall thickness of one duct may be between 1:10 and 1:30. A sum of the wall thickness of each duct of the plurality of ducts may be between 20% and 80% of the radius of the plurality of ducts. The sum of the wall thickness of each duct of the plurality of ducts may be between 1/3 and 2/3 of the radius of the plurality of ducts. The vessel may include a plurality of nozzles pointing into the central void and in fluidic communication with the sorbent regeneration system. Each duct of the plurality of ducts may include a cavity having at least one window, each window spanned by a mesh. The cavity may contain the sorbent material.

[0008] According to another aspect of the disclosure, a system for passive collection of atmospheric carbon dioxide includes at least one passive collection cluster, each passive collection cluster having at least two passive collection devices. Each passive collection device includes a vessel having an opening and a sorbent regeneration system, and a lid. Each device also includes a sorbent structure coupled to the vessel and having a plurality of ducts that are coaxial, each duct having a sorbent material and having a central void running along a central axis shared by the plurality of ducts. The sorbent structure is movable between a collection configuration and a release configuration. Each device also includes an expansion mechanism coupled to the sorbent structure and configured to move the sorbent structure between the collection configuration and the release configuration. For each passive collection device, the collection configuration includes the sorbent structure telescoping out through the opening of the vessel such that at least some of the ducts are outside the vessel and exposed to

an airflow such that the sorbent material of the sorbent structure captures atmospheric carbon dioxide. For each passive collection device, the release configuration includes the plurality of ducts nested within each other and the sorbent structure sufficiently enclosed inside the vessel by the lid that the sorbent regeneration system may operate on the sorbent material to release captured carbon dioxide from the sorbent material and form an enriched gas within the vessel.

[0009] Particular embodiments may comprise one or more of the following features. The at least two passive collection devices of each cluster may share one expansion mechanism. The vessel of each passive collection device in a cluster may be in fluid communication, such that the enriched gas of one collection device may be swept through the vessel of a neighboring passive collection device. The system may further include a control system communicatively coupled to each passive collection cluster and configured to drive the expansion mechanism to move the sorbent structure of at least one passive collection device between the collection configuration and the release configuration. The control system may be configured to operate the passive collection devices in series to product a continuous product stream of enriched gas.

[0010] According to yet another aspect of the disclosure, a device for passive collection of atmospheric carbon dioxide includes a vessel having an opening and a sorbent regeneration system. The device also includes a sorbent structure coupled to the vessel and having a plurality of ducts that are coaxial, each duct having a sorbent material, a wall thickness, a wide end, a narrow end distal to the wide end, and having a central void running along a central axis shared by the plurality of ducts. The sorbent structure is movable between a collection configuration and a release configuration. The device also includes a lid releasably coupled to the sorbent structure and able to separate from the sorbent structure such that air can flow through and out of the central void of the sorbent structure. The device includes an expansion mechanism coupled to the sorbent structure and configured to move the sorbent structure between the collection configuration and the release configuration. The collection configuration includes the sorbent structure telescoping out through the opening of the vessel such that at least some of the ducts are outside the vessel and exposed to an airflow such that the sorbent material of the sorbent structure captures atmospheric carbon dioxide. The release configuration includes the plurality of ducts nested within each other and the sorbent structure sufficiently enclosed inside the vessel by the lid that the sorbent regeneration system may operate on the sorbent material to release captured carbon dioxide from the sorbent material and form an enriched gas within the vessel. For each pair of neighboring ducts having an inner duct that nests within an outer duct when the sorbent structure is in the release configuration,

the collection configuration includes the neighboring ducts in contact with each other, with the wide end of the inner duct stuck inside the narrow end of the outer duct such that the inner duct and outer duct have an overlap when the sorbent structure is in the collection configuration. A ratio between a radius of the plurality of ducts and the wall thickness of a duct is between 1:10 and 1:30. A sum of the wall thickness of each duct of the plurality of ducts is between 1/3 and 2/3 of the radius of the plurality of ducts.

[0011] Particular embodiments may comprise one or more of the following features. Each duct of the plurality of ducts may be composed of the sorbent material. The sorbent material may be a porous membrane. Each duct of the sorbent structure may include a frame on which the sorbent material may be mounted. At least part of each duct of the plurality of ducts may be permeable, such that air flows over an outer surface of the duct, an inner surface of the duct facing the central void, and through the duct between the outer surface and the inner surface. For each pair of neighboring ducts having an inner duct that nests within an outer duct when the sorbent structure is in the release configuration, the collection configuration may include an overlap between the inner duct and the outer duct when the sorbent structure is in the collection configuration. A largest duct of the plurality of ducts may be located further from the vessel than a smallest duct of the plurality of ducts when the sorbent structure is in the collection configuration. Each duct may have a height. The plurality of ducts may include at least two different heights. The device may further include a microcontroller communicatively coupled to the expansion mechanism and at least one sensor. The microcontroller may be configured to adjust the overlap between neighboring ducts while the sorbent structure is in the collection configuration based on data received from the at least one sensor. The device may further include a microcontroller communicatively coupled to the expansion mechanism and at least one sensor. The microcontroller may be configured to adjust how many ducts are lifted out of the vessel when moving into the collection configuration based on data received from the at least one sensor. At least one of the sorbent regeneration system and the expansion mechanism may be located within the central void. The vessel may be annular such that at least a portion of the central void of a smallest duct is occupied by the vessel when the sorbent structure is in the release configuration. Each duct may include a plurality of directional vanes to enhance carbon dioxide capture by inducing turbulence. The directional vanes may be positioned within the central void of the ducts. Each duct further may include a plurality of channels passing through the duct perpendicular to the central axis, wherein the directional vanes are positioned within the channels of the ducts. The expansion mechanism may be outside of the plurality of ducts, and pulls the sorbent structure away from

the vessel and into the collection configuration. The expansion mechanism may be inside of the central void of the plurality of ducts, and pushes the sorbent structure away from the vessel and into the collection configuration. Each pair of neighboring ducts may include a threading on one duct of the pair of ducts that is engaged by the other of the pair of ducts, such that the sorbent structure moves between the collection configuration and the release configuration through rotation of the ducts by the expansion mechanism. Each duct of the plurality of ducts may include an outer perimeter and an inner perimeter, with the inner perimeter and the outer perimeter sized and shaped such that the ducts can nest within each other. The outer perimeters of the plurality of ducts may include at least two cross-sectional shapes. The outer perimeters of the plurality of ducts may be non-circular. The lid may include a lip that extends down along the vessel when the lid is enclosing the sorbent structure inside the vessel. The lid may be slidably coupled to one of a largest duct and a smallest duct through a plurality of rods fixedly coupled to the one of the largest duct and the smallest duct such that the sorbent structure is suspended from the lid by the plurality of rods when in the collection configuration. The lid may include a protrusion extending out of the lid towards the central void, the protrusion being conical and sized to be received inside the central void when the sorbent structure is in the release configuration. The vessel may include a plurality of nozzles pointing into the central void and in fluidic communication with the sorbent regeneration system. Each duct of the plurality of ducts may include a cavity having at least one window, each window spanned by a mesh. The cavity may contain the sorbent material.

[0012] The foregoing and other aspects, features, and advantages will be apparent to those artisans of ordinary skill in the art from the DESCRIPTION and DRAWINGS, and from the CLAIMS.

[0013] Aspects and applications of the disclosure are described in the drawings and the detailed description below. Unless specifically noted, it is intended that the words and phrases in the specification and the claims be given their plain, ordinary, and accustomed meaning to those of ordinary skill in the applicable arts. The inventor is fully aware that they can be their own lexicographers if desired. The inventor expressly elects, as its own lexicographer, to use only the plain and ordinary meaning of terms in the specification and claims unless clearly stated otherwise and then further, expressly set forth the “special” definition of that term and explain how it differs from the plain and ordinary meaning. Absent such clear statements of intent to apply a “special” definition, it is the inventor’s intent and desire that the simple, plain and ordinary meaning to the terms be applied to the interpretation of the specification and claims.

[0014] The word “exemplary,” “example,” or various forms thereof are used herein to mean serving as an example, instance, or illustration. Any aspect or design described herein as “exemplary” or as an “example” is not necessarily to be construed as preferred or advantageous over other aspects or designs. Furthermore, examples are provided solely for purposes of clarity and understanding and are not meant to limit or restrict the disclosed subject matter or relevant portions of this disclosure in any manner. It is to be appreciated that a myriad of additional or alternate examples of varying scope could have been presented but have been omitted for purposes of brevity.

[0015] The inventor is also aware of the normal precepts of English grammar. Thus, if a noun, term, or phrase is intended to be further characterized, specified, or narrowed in some way, then such noun, term, or phrase will expressly include additional adjectives, descriptive terms, or other modifiers in accordance with the normal precepts of English grammar. Absent the use of such adjectives, descriptive terms, or modifiers, it is the intent that such nouns, terms, or phrases be given their plain, and ordinary English meaning to those skilled in the applicable arts as set forth above.

[0016] Further, the inventor is fully informed of the standards and application of the special provisions of 35 U.S.C. § 112(f). Thus, the use of the words “function,” “means” or “step” in the Detailed Description or Description of the Drawings or claims is not intended to somehow indicate a desire to invoke the special provisions of 35 U.S.C. § 112(f), to define the invention. To the contrary, if the provisions of 35 U.S.C. § 112(f) are sought to be invoked to define the inventions, the claims will specifically and expressly state the exact phrases “means for” or “step for”, and will also recite the word “function” (i.e., will state “means for performing the function of [insert function]”), without also reciting in such phrases any structure, material or act in support of the function. Thus, even when the claims recite a “means for performing the function of . . .” or “step for performing the function of . . .,” if the claims also recite any structure, material or acts in support of that means or step, or that perform the recited function, then it is the clear intention of the inventors not to invoke the provisions of 35 U.S.C. § 112(f). Moreover, even if the provisions of 35 U.S.C. § 112(f) are invoked to define the claimed aspects, it is intended that these aspects not be limited only to the specific structure, material or acts that are described in the preferred embodiments, but in addition, include any and all structures, materials or acts that perform the claimed function as described in alternative embodiments or forms of the disclosure, or that are well known present or later-developed, equivalent structures, material or acts for performing the claimed function.

[0017] This disclosure, its aspects and implementations, are not limited to the specific material types, components, methods, or other examples disclosed herein. Many additional material types, components, methods, and procedures known in the art are contemplated for use with particular implementations from this disclosure. Accordingly, for
5 example, although particular implementations are disclosed, such implementations and implementing components may comprise any components, models, types, materials, versions, quantities, and/or the like as is known in the art for such systems and implementing components, consistent with the intended operation.

[0018] Finally, while this disclosure includes a number of embodiments in many
10 different forms, there is shown in the drawings and will herein be described in detail particular embodiments with the understanding that the present disclosure is to be considered as an exemplification of the principles of the disclosed methods and systems, and is not intended to limit the broad aspect of the disclosed concepts to the embodiments illustrated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The disclosure will hereinafter be described in conjunction with the appended drawings, where like designations denote like elements, and:

[0021] FIGs. 1A, 1B, and 1C are perspective, side, and top views of a telescoping
5 direct air capture (tDAC) device, respectively;

[0022] FIGs. 1D and 1E are cross sectional views of the tDAC device of FIGs. 1A-1C in the collection and release configurations, respectively;

[0023] FIGs. 2A and 2B are schematic cross sectional views of a tDAC device in the collection and release configurations, respectively;

10 [0024] FIGs. 3A and 3B are cross sectional views of a tDAC device with an internal expansion mechanism in the collection and release configurations, respectively;

[0025] FIG. 4A is a cross sectional view of a tDAC device with a lid having a protrusion;

[0026] FIG. 4B is a cross sectional view of a tDAC device with a lid having a lip;

15 [0027] FIGs. 4C and 4D are cross sectional views of a tDAC device with a sorbent structure suspended by rods in the collection and release configurations, respectively;

[0028] FIGs. 5A and 5B are cross sectional views of a tDAC device with a central aperture and a stationary plug in the collection and release configurations, respectively;

[0029] FIG. 6 is a cross sectional view of a tDAC device with threading;

20 [0030] FIGs. 7A and 7B are top views of different sets of ducts;

[0031] FIGs. 8A and 8B are cross sectional views of a tDAC device with overlapping ducts in the collection and release configurations, respectively;

[0032] FIG. 8C is a cross sectional views of a different tDAC device with overlapping ducts in the collection configuration;

25 [0033] FIG. 9 is a top cross sectional view of a duct having channels;

[0034] FIG. 10 is a top view of a permeable duct;

[0035] FIGs. 11A and 11B are side and cross sectional views of a duct with a filled cavity;

[0036] FIG. 12 is a cross sectional view of a tDAC device having an annular vessel
30 in the release configuration; and

[0037] FIGs. 13A and 13B are top and side views of a tDAC system.

DETAILED DESCRIPTION

[0038] The need for technologies to remove carbon dioxide from ambient air has been well established. In addition to conservation, reduced-carbon processes, and on-site capture efforts, a significant amount of carbon dioxide will need to be removed from the atmosphere to avoid a looming climate change crisis.

5 [0039] Capture of carbon dioxide from ambient air at an affordable price could become a critical tool in managing the anthropogenic carbon cycle. Air capture technology would greatly enhance the options for developing the world's energy infrastructure and would be a major asset in the fight against climate change. Combined with a carbon dioxide (CO₂) storage technology, air capture of CO₂ could compensate for CO₂ emissions from any source,
10 without requiring changes to the existing infrastructure and without requiring proximity to the point of emission. Air capture technology makes it possible for existing infrastructures to live out their natural life spans, and it permits the continued use of carbon-based fuels in distributed and mobile applications, for example in the transportation sector. With air capture technology, it is possible to continue the use of liquid hydrocarbon fuels while eliminating their climate
15 impact.

[0040] However, in order to have any meaningful impact on the environment, air capture technology will need to be adopted on a large scale. Since the carbon dioxide in the ambient air is very dilute, atmospheric CO₂ collectors can quickly overrun a tight energy budget for drawing in and processing air in bulk. While there are some air capture solutions that are
20 resource-efficient enough to operate within this tight energy budget, such efficiencies often come at the cost of complicated designs that are expensive to make and difficult to maintain. Conventional carbon dioxide collection systems often exhibit the unfortunate combination of being costly and fragile.

[0041] Contemplated herein is a telescoping passive direct air capture (DAC)
25 device and system that is able to strike a balance between resource-efficient operation and cost-effective implementation. The contemplated device, hereinafter referred to as a "telescoping DAC device" or "tDAC device" utilizes a sorbent structure whose geometry comprises a series of coaxial ducts. These coaxial ducts are sized and arranged such that they may be nested within each other while the sorbent is being regenerated within a closed vessel, and then
30 telescope out along their shared axis for exposure to ambient air flows, according to various embodiments. This arrangement provides the advantages of a sorbent structure that exposes a large surface area during collection that is then retracted into a small volume for regeneration (i.e., resource-efficient operation), as well as a simple architecture that is inexpensive to manufacture and service (i.e., cost-effective implementation).

[0042] The contemplated tDAC device is able to be adapted for use with a variety of sorbent materials and tuned for efficient operation in various environments. As will be discussed below, the contemplated tDAC device may be implemented with coaxial ducts having a wide range of cross-sectional shapes and sizes, some better adapted for particular implementation environments than others.

[0043] The basic premise of the tDAC contemplated herein is a device that can cycle between a capture or collection configuration and a harvest or release configuration. In the collection configuration, the tDAC exposes ambient air to sorbent material that can bind CO₂, with the sorbent material spread apart to facilitate air contact. In the release configuration, that sorbent material (and the structure that holds it) is compacted into a reduced space for regeneration of the sorbent and collection of the released CO₂. The contemplated tDAC device comprises sorbent structures whose nested geometry facilitates and enhances both capture and harvest operations. It should be noted that while this disclosure discusses the geometry of the sorbent structure at length in the context of these two configurations, the examples provided should not be interpreted to limit the choice of sorbents, the means of moving the sorbent structure, or the means of regeneration.

[0044] Additionally, while the following discussion is done entirely in the context of capturing atmospheric carbon dioxide, those skilled in the art will recognize that CO₂ capture devices and methods may often be adapted for other applications. According to various embodiments, the contemplated tDAC device and system may be adapted for use with scales, sorbents, and regeneration methods beyond those chosen for use with ambient air flows of dilute carbon dioxide.

[0045] FIGs. 1A-1E are various views of a non-limiting example of a telescoping direct air capture (tDAC) device 100. Specifically, FIGs. 1A, 1B, and 1C are perspective, side, and top views of a non-limiting example of a tDAC device 100, respectively. FIGs. 1D and 1E are cross sectional views of the tDAC device 100 of FIGs. 1A-1C in the collection configuration 118 and the release configuration 130 configurations, respectively.

[0046] As shown, the tDAC device 100 comprises a vessel 104, a sorbent structure 106, a lid 108, and an expansion mechanism 110. Each will be discussed, in turn. The sorbent structure 106 is coupled to the vessel 104 and includes a plurality of coaxial ducts 102, each comprising a sorbent material 116.

[0047] In the context of the present description and the claims that follow, a duct 102 is a structure comprising one or more sorbent materials 116 that has a hollow space or central void 122 passing along the shared central axis 120 inside of which another duct 102

may fit (except for the smallest or innermost duct 102 of the plurality of ducts 102). Embodiments of the duct 102 having a circular cross section may be described as a tube or a pipe. In some embodiments, a duct may have a discontinuity in its cross sectional shape (e.g., a u- or c-shaped cross section, etc.). In other embodiments, a duct may be limited to continuous
5 perimeters such as circles, polygons, and the like. The central voids 122 of the ducts 102, taken together, may be referred to as the central void 122 of the sorbent structure 106.

[0048] An important feature described in this disclosure is the ability of the plurality of ducts 102 to nest inside of each other. Each duct 102 is sized to fit into another larger duct 102 and/or receive a smaller duct 102 to be nested within. The duct 102 itself may
10 have various constructions, which will be discussed further in the context of FIGs. 7A-11B, below.

[0049] Each duct 102 comprises at least one sorbent material 116 to capture the atmospheric carbon dioxide and later release it inside the vessel 104. One of the advantages of the contemplated tDAC device 100 is that it is adaptable for use with sorbent materials 116 in
15 a variety of forms including, but not limited to, sheets, membranes, beads, powders, structures, and the like.

[0050] In some embodiments, the duct 102 may be a hollow monolith, formed from a sorbent material 116. In other embodiments the sorbent material 116 may be a porous membrane. In still other embodiments, the duct 102 may comprise a frame 124, providing a
20 form upon which a sorbent material 116 (e.g., sheets, ribbons, mesh packets of sorbent particles, membranes, etc.) may be mounted. For example, in some embodiments, this duct 102 frame 124 might be structured in an open manner providing a means of stretching sheets of sorbent over a frame 124 for a lightweight duct 102.

[0051] In some embodiments, the duct 102 may be composed entirely of a sorbent
25 material 116. In other embodiments, the duct 102 may be hollow and ventilated such that a sorbent material 116 within is exposed to airflow. See, for example, FIGs. 11A and 11B, which will be discussed in greater detail, below.

[0052] In still other embodiments, the duct 102 may be a solid structure having surfaces configured to contain liquid sorbents (e.g., liquid filling pores in the duct structure, etc.). The ducts 102 may have sorbent on the exterior, the interior, or both. Ducts 102 may
30 have sorbent throughout the duct 102, such that the duct 102 is structured from sorbent. According to various embodiments, the ducts 102 may be constructed such that air may pass through the walls of the duct 102, in addition to over the inner and outer surfaces. See, for example, FIG. 10.

[0053] The tDAC device 100 contemplated herein is adaptable for use with any sorbent material 116 that can take on these forms. The specific sorbent material 116 used can depend on a number of factors including cost, device size, use environment (e.g., typical humidity, temperature, wind speed, volatility of weather, sunlight exposure, etc.), preferred regeneration scheme (e.g., heat, moisture, vacuum, etc.), desired form factor for ducts 102, and the like.

[0054] The tDAC device 100 comprises a vessel 104 and a lid 108. In the context of the present description and the claims that follow, the vessel 104 is a container that can hold the sorbent structure 106 when in the release configuration 130 and that can be sufficiently closed (e.g., with a lid 108, etc.) such that a sorbent regeneration system 202 may operate on the enclosed sorbent material 116 (e.g., introduction of moisture, heat, evacuation, etc.). According to various embodiments, the vessel 104 has solid sides and an opening 114. In some embodiments, the vessel 104 also has a solid bottom. In other embodiments, the bottom may also be able to open, allowing air to flow up from the bottom during collection, or allowing easier access for maintenance.

[0055] The smaller the vessel 104, the less regeneration medium is needed to regenerate the sorbent material 116. According to various embodiments, the vessel 104 is shaped similar to the ducts 102 to minimize volume while still permitting circulation within. In some embodiments, this also includes having an annular shape, which will be discussed further in the context of FIG. 12, below.

[0056] According to various embodiments, the lid 108 is configured to seal the vessel 104 sufficient to operate the sorbent regeneration system 202 on the enclosed sorbent structure 106. In some embodiments, the lid 108 may separate from the vessel 104, while in other embodiments, the lid 108 may be movably coupled to the vessel 104 (e.g., hinged, sliding, etc.).

[0057] In other embodiments, the lid 108 may be fixedly coupled to the sorbent structure 106, such that the lid 108 and sorbent structure 106 move together as the sorbent structure 106 is cycling between the collection configuration 118 and release configuration 130. As an option, in some embodiments, the lid 108 may be able to open and close in the middle, or to be raised over the top duct 102, to allow air flow for the “chimney” effect. The lid 108 will be discussed further in the context of FIGs. 4A-4D

[0058] According to various embodiments, the tDAC device 100 uses materials that tend not to expand and contract unduly during operation, and that are also light weight. This includes low-cost materials such as polymer-based materials as well as more expensive

materials such as metals. Advantageous over more complicated capture devices, the tDAC device 100 can be mass produced, manufactured at a scale to further reduce the cost.

[0059] The scale of the ducts 102 of the contemplated tDAC device 100 may vary from embodiment to embodiment. Manufacturing and operational considerations may influence the best size for a particular use case. In some embodiments, the tDAC device 100 may be “human scale”, for ease of operation. However, smaller sized devices can reduce the impact of the failure of one device and allow for easier replacement. Smaller device can also be easier to fabricate, assemble, ship and operate.

[0060] The tDAC device 100 includes an expansion mechanism 110 coupled to the sorbent structure 106. The expansion mechanism 110 is driven to raise and lower the sorbent structure 106, moving it between the collection configuration 118 and the release configuration 130, according to various embodiments. The tDAC device 100 may be adapted for use with a variety of actuating devices and methods including, but not limited to, linear actuators (see FIGs. 3A and 3B) and rotational actuators (see FIGs. 1A-1E and FIG. 6). The expansion mechanism 110 may be powered using any form known in the art such as electric, pneumatic, hydraulic, and the like.

[0061] In some embodiments, the expansion mechanism 110 may use a "pull" mechanism, where the sorbent structure 106 is pulled upward from the vessel 104 by an external (i.e., outside of the ducts 102) application of force (e.g., a motor and a cable). As an option, the expansion mechanism 110 may be mounted on, or otherwise utilize, a support structure 112 (e.g., a gantry, frame, etc.), as shown in FIGs. 1A-1E. According to various embodiments, the expansion mechanism 110 may also comprise additional structure to provide stability to the sorbent structure 106, to prevent damage due to weather or other external forces.

[0062] In other embodiments, the expansion mechanism 110 may use an internal "push" mechanism. See, for example, FIGs. 3A and 3B. Internal expansion mechanisms 110 will be discussed in greater detail in the context of FIGs. 3A and 3B, below. It should be noted, however, that these discussions are not exhaustive. Those skilled in the art will recognize that there are diverse ways to expand/contract a structure, whether through pushing, pulling, or some other means, to which the tDAC device 100 contemplated herein may be adapted.

[0063] FIGs. 1D and 1E are cross sectional views of the tDAC device 100 of FIGs. 1A-1C in the collection configuration 118 and the release configuration 130 configurations, respectively. The sorbent structure 106 is movable between a collection configuration 118 and a release configuration 130. In the context of the present description and the claims that follow, the collection configuration 118 of the sorbent structure 106 includes the sorbent structure 106

telescoping out through the opening 114 of the vessel 104 such that at least some of the ducts 102 are outside the vessel 104 and exposed to an airflow such that the sorbent material 116 of the sorbent structure 106 captures atmospheric carbon dioxide. In the release configuration 130, these ducts 102 are nested inside of each other within the harvest vessel 104, minimizing the total volume occupied. The release configuration 130 will be discussed further in the context of FIG. 1E, below.

[0064] During exposure to the air while in the collection configuration 118, these ducts 102 are pulled apart along their shared central axis 120, so as to drastically increase the exposure to air flow over or through the walls of the ducts 102. When in the collection configuration 118, the total volume enclosed by the ducts 102 is substantially equal to the sum of all individual duct 102 volumes, according to some embodiments. When in the release configuration 130, the total volume is substantially equal to that of the duct 102 with the largest diameter (i.e., the outermost duct 102 when nested). In some embodiments, this nested geometry makes it possible to increase the density of sorbent in an enclosed volume by an order of magnitude when moving from the collection configuration 118 to the release configuration 130.

[0065] Each duct 102 has a central void 122 (i.e., the hollow part). Together, the ducts 102 form a central air column which may also be referred to as the central void 122. FIG. 1D shows the central void 122 as an unsupported column that is larger for successive ducts 102 when in the collection configuration 118. In other embodiments, the central void 122 may be further defined with support structure and/or devices associated with the function of the tDAC device 100, such as the expansion mechanism 110 and/or the sorbent regeneration system 202 (e.g., steam generators, vacuum pumps, compressors, etc.). In some embodiments, the central void 122 may be accessible from the outside of the vessel 104.

[0066] The central void 122 runs along the shared central axis 120 of the ducts 102 and provides additional air flow to encourage further interaction between the air and the sorbent material 116. In some embodiments where the top of the central void 122 is open, a chimney effect may be harnessed to further improve air flow. As an option, in some embodiments, small vanes could be mounted in this space to enhance air flow and turbulence.

[0067] According to various embodiments, the inner most duct 102 still has a diameter that is substantially larger than its wall thickness 128, resulting in a set of nested ducts 102 whose combined wall thickness 128 does not reach the center of the vessel 104. In other words, the central void 122 exists in both configurations. The ducts 102 are thin walled in the sense that the radial thickness of the wall material (i.e., the wall thickness 128) is significantly

smaller than the overall radius 126 (i.e., the outer radius of the outermost duct 102). For example, the ratio of wall thickness 128 to outer radius 126 of the duct 102 could be in the range of 1 : 3, to 1 : 200, with a preferred range between 1 : 10 to 1 : 30, in some embodiments. For very large inner diameters, an even smaller aspect ratio between wall thickness 128 and radius 126 may be implemented, in some embodiments.

[0068] The nested ducts 102 can be thought of as a single duct 102 with a thickness that is substantially equal to the sum of all individual wall thicknesses 128. For this structure the total wall thickness 128 is still smaller than the radius 126, but it is likely to be a substantial fraction of the total, (i.e., between 20 and 80% of the full radius 126). In some embodiments, the sum of the wall thickness 128 of each duct 102 may be on the order of half a radius 126, with a preferred total thickness being between 1/3 and 2/3 of a radius 126, in other embodiments.

[0069] FIG. 1E shows the non-limiting example of the tDAC device 100 from FIGs. 1A-1D with the sorbent structure 106 in the release configuration 130. In the context of the present description and the claims that follow, the release configuration 130 comprises the plurality of ducts 102 nested within each other and the sorbent structure 106 sufficiently enclosed inside the vessel 104 by the lid 108 that a sorbent regeneration system may operate on the sorbent material 116 of the ducts 102 to release captured carbon dioxide from the sorbent material 116 and form an enriched gas within the vessel 104.

[0070] The ducts 102 are sized and arranged such that they may nest inside each other during regeneration. As shown, when the ducts 102 are nested within each other, they have spaces between them to allow the flow of air or moisture for harvest and regeneration, in addition to the central void 122 down the center. Minimizing the gap between the outside of one duct 102 and the inside of the next larger duct 102 can reduce the overall volume of the vessel 104. In practice, the width of this gap is chosen such as to facilitate smooth motion of the duct 102 either while rotating along the axis or moving in the axial direction.

[0071] The size of the gap between ducts 102 is chosen by balancing two characteristics that vary from embodiment to embodiment. The smaller the gap, the more material can be regenerated in a smaller volume. However, tight gaps also mean both the material and mechanical function are technically more sophisticated, and often more expensive to build and maintain. While tighter tolerance (i.e., smaller gap space) will increase capture, the tighter gap will have a penalty of increased cost, both in capital cost and in operating costs. Advantageously, the contemplated design may be adapted for practical, efficient use in a

constantly changing market where the cost and sophistication of the technology is changing, along with the value of captured carbon.

[0072] It is important to note that while in some embodiments, including the non-limiting examples shown in the Figures herein, the central axis 120 of the ducts 102 is aligned with the vertical direction, in other embodiments the axis may have a different orientation. For example, in some embodiments the central axis 120 is aligned horizontally (e.g., ducts 102 sliding horizontally on rails, etc.) or in any other direction that may be dictated by local considerations (e.g., the slope of a hillside, etc.).

[0073] FIGs. 2A and 2B are schematic cross sectional views of a non-limiting example of a tDAC device 100 in the collection configuration 118 and the release configuration 130 configurations, respectively. As shown, the tDAC device 100 comprises a sorbent regeneration system 202. The exact nature of the sorbent regeneration system 202 will depend on the sorbent material 116 being used and how its capture/release cycle is driven (e.g., moisture, heat, pressure, etc.). In some embodiments the sorbent regeneration system 202, or at least part of it, may be located outside the vessel 104. In other embodiments, including the non-limiting example shown in FIGs. 2A and 2B, the sorbent regeneration system 202 may be located within the vessel 104. As previously discussed, this is similar to the expansion mechanism 110. According to some embodiments, at least one of the sorbent regeneration system 202 and the expansion mechanism 110 is located within the central void 122. An internal "push" expansion mechanism 110 will be discussed in the context of FIGs. 3A and 3B, below.

[0074] In operation, the tDAC device 100 captures atmospheric carbon dioxide 206 by extending the sorbent structure 106 into the collection configuration 118, exposing it to air flows. The telescoping design of the sorbent structure 106 allows for enhanced exposure of the sorbent to the air. Once laden with carbon dioxide 206, the sorbent structure 106 is retracted into the vessel 104 such that the ducts 102 nest within each other. The nesting of the ducts 102 either occurs inside the vessel 104, or alternatively it happens right before the ducts 102 enter the vessel 104. The lid 108 encloses the sorbent structure 106 (i.e., the nested ducts 102) inside the vessel 104, where the sorbent regeneration system 202 acts upon the sorbent materials 116 (e.g., steam is introduced through nozzles, etc.). The CO₂ is released into the vessel 104, forming an enriched gas 204 that is removed as a product stream for other uses.

[0075] In some embodiments, the sorbent structure 106 is exposed to ambient airflows 200 such as wind, greatly reducing the energy usage associated with moving air

mechanically. In other embodiments, the air flow may be enhanced with blowers and/or guide structures to direct more air to the sorbent ducts 102.

[0076] It should be noted that, with the exception of FIGs. 8A-8C, all of the non-limiting examples shown in the Figures are depicted with the sorbent structure 106 having three ducts 102. The number of ducts 102 in a sorbent structure 106 may vary from embodiment to embodiment.

[0077] In some embodiments, the number of ducts 102 lifted out of the vessel 104 may vary depending upon external factors. For example, in one embodiment, some of the ducts 102 may be left in the shelter of the vessel 104 during times of high winds, and more ducts 102 may be pulled out in times of low wind, to prevent damage.

[0078] In some embodiments, the number of ducts 102 being exposed when the sorbent structure 106 is in the collection configuration 118 may be modified manually by a technician. In other embodiments, the number of ducts 102 being exposed may be modified automatically, based on current ambient conditions. According to various embodiments, the tDAC device 100 may comprise a microcontroller 210 communicatively coupled to the expansion mechanism 110 and at least one sensor 208 (e.g., thermometer, anemometer, barometer, light sensor, etc.). The microcontroller 210 may be configured to adjust how many ducts 102 are lifted out of the vessel 104 when moving into the collection configuration 118 based on data received from the sensor(s) 208, allowing the tDAC device 100 to adjust itself dynamically as the ambient conditions change. This can keep the tDAC device 100 within certain boundaries that ensure efficiency while also being able to reduce the likelihood of damage and downtime.

[0079] In some embodiments, the collection configuration 118 includes the ducts 102 being completely separated from each other. See, for example, FIGs. 3A and 3B. In other embodiments, the collection configuration 118 may include some degree of overlap between neighboring ducts 102. There are some situations where being able to modify this overlap may be beneficial.

[0080] In some embodiments the relative position of the ducts 102 while in the collection configuration 118 can be externally controlled such that ducts 102 will partially overlap in collection mode and the degree of overlap can be controlled. The ability to modify the duct overlap may be used to adjust to different wind conditions. In some embodiments, the overlap may be modified manually by a technician.

[0081] In other embodiments, the overlap between ducts 102 in the collection configuration 118 may be modified automatically, based on current ambient conditions.

According to various embodiments, the tDAC device 100 may comprise a microcontroller 210 communicatively coupled to the expansion mechanism 110 or some other actuator, and at least one sensor 208 (e.g., anemometer, etc.). The microcontroller 210 may be configured to adjust the amount of overlap between ducts 102 while in the collection configuration 118, based on data received from the sensor(s) 208. In some embodiments, the overlap may be modified while the sorbent structure 106 is in the collection configuration 118. In other embodiments, the overlap may be modified when the sorbent structure 106 is moving into the collection configuration 118 from the release configuration 130, and may be modified again in the next cycle.

[0082] The height of the sorbent structure 106 during collection and the effective thickness of the duct wall can be manipulated with this control over the degree of duct 102 overlap. At low wind speeds it is advantageous to limit the wall thickness 128 and extend to full height. At high wind speeds operation with a thicker wall layer is possible, and it is advantageous to operate at less than full height to minimize the wind forces acting on the sorbent structure 106. By controlling the degree of overlap between the ducts 102, one can extend the window of operation as wind speeds change. Minimal or no overlap extends the window of operation to low wind speeds. Greater overlap allows operation at high wind speeds which at full extension could topple or otherwise damage the device 100.

[0083] In one embodiment, the duct 102 overlap can be controlled through a locking mechanism that prevents a pair of ducts 102 from separating. An actuator may remove a pin that unlocks the connection, allowing the two duct 102 sections to separate until they reach maximum extension. If the outer duct 102 slides down, a lip on the bottom of the inner duct 102 would prevent the two sections from completely separating. In this and other embodiments, it may be possible to double the effective wall thickness 128 while shortening the sorbent structure 106 by a factor of two. Other embodiments may comprise different or additional mechanisms.

[0084] In some embodiments, the ducts 102 may all be the same height 212. In other embodiments, the ducts 102 may have differing heights 212, to facilitate flow within the vessel 104 during regeneration. As a specific example, in one embodiment the height 212 of the ducts 102 may increase moving from the inner duct 102 to the outer duct 102, as shown in FIG. 2B.

[0085] FIGs. 3A and 3B are cross sectional views of a non-limiting example of a tDAC device 100 with an internal "push" expansion mechanism 110 in the collection configuration 118 and the release configuration 130 configurations, respectively. As

previously discussed, the ducts 102 making up the sorbent structure 106 form a central void 122 along their shared central axis 120. In some embodiments, this central void 122 may comprise an internal structure. In some embodiments, this may simply provide additional strength to the sorbent structure 106 when elongated and exposed to wind. In other
5 embodiments, including the non-limiting examples shown in FIGs. 3A and 3B, the central void 122 may include an expansion mechanism 110 that pushes the sorbent structure 106 away from the vessel 104 and into the collection configuration 118.

[0086] According to various embodiments, an internal expansion mechanism 110 may be pneumatic (e.g., hydraulic lift or piston, etc.), electric (e.g., actuators, etc.), and the
10 like. These "push" mechanisms have the advantage of being out of the way and protected from outdoor exposure. However, they may also be more difficult to reach for servicing. Advantageously, they can also give additional structural support to the ducts 102 when elongated, according to various embodiments.

[0087] In some embodiments, including the non-limiting example shown in FIG.
15 3A, the collection configuration 118 comprises the plurality of ducts 102 being spread out along the central axis 120 such that the ducts 102 are separated from each other, allowing air to flow around all surfaces of each duct 102. In other embodiments, the ducts 102 may be coupled to each other, such that the sorbent structure 106 is elongated and spread out when in the collection configuration 118, but the ducts 102 are not entirely separated. See, for example,
20 the tDAC devices 100 shown in FIGs. 8A-8C, where the collection configuration 118 includes overlapping ducts 102. In some embodiments, the coupled ducts 102 may overlap in the collection configuration 118, while in other embodiments, they may be separated from each other yet remain coupled to each other (e.g., to facilitate the movement between the collection configuration 118 and the release configuration 130, to provide stability, etc.).

[0088] In some embodiments, the ducts 102 may be held in place by outside support
25 structures, while in other embodiments they may be attached to each other in a manner that prevents them from being separated. These linkages could hold the ducts 102 together in the collection configuration 118, but still allow the ducts 102 to nest when in the release configuration 130. For example, in one embodiment, the next inner duct 102 may hang from
30 the outer duct 102 when in the collection configuration 118, creating a superstructure that is slightly conical with the tip hanging down. In the nested shapes all ducts 102 may all rest on the same floor. In another embodiment, the larger diameter duct 102 could hang down from the smaller diameter duct 102 creating a structure that has a smaller diameter toward is apex.

[0089] In some embodiments, including the non-limiting example shown in FIG. 3A, the top of the sorbent structure 106 when in the collection configuration 118 may be the largest duct 300 (i.e., the outermost duct). In other embodiments, including the non-limiting example shown in FIG. 2A, the top of the sorbent structure 106 (i.e., the duct 102 furthest from the vessel 104) when in the collection configuration 118 may be the smallest duct 302 (i.e., the innermost duct).

[0090] In some embodiments, the lid 108 may be fixedly coupled to the sorbent structure 106 (e.g. the top duct 102 in the collection configuration 118, etc.). The lid 108 may be permanently attached (e.g., welded, bolted, etc.) such that the lid 108 and sorbent structure 106 move together as the sorbent structure 106 is moving between the collection configuration 118 and release configuration 130. Such a permanent mounting would be an advantage over lids 108 that separate from the sorbent structure 106, as it would be easier to mount and easier to maintain. In the cases where the top duct 102 is the largest, it also simplifies the creation of a good seal when in the release configuration 130. It can ensure a permanent seal for most of the ducts 102, minimizing the regeneration loss if the outer seal between the vessel 104 and the lid 108 is compromised or degraded.

[0091] FIGs. 4A-4D show cross sectional views of various non-limiting examples of releasable lids 108. In the context of the present description and the claims that follow, a releasable lid is a lid 108 that can be moved independent from the sorbent structure 106 instead of being fixedly coupled to the sorbent structure 106 like the non-limiting example shown in FIGs. 3A and 3B. It should be noted that some of the features of the releasable lids 108 discussed below may be adapted for use in fixedly coupled lids and hybrid lids.

[0092] One benefit of using a releasable lid is that it is able to separate from the sorbent structure 106 such that air can flow through and out of the central voids 122 of the plurality of ducts 102. This "chimney effect" increases the air flow. Wind flowing over the outside of the ducts 102 will create a pressure variation along its surfaces resulting in air being sucked in at some places and pushed out at others. Careful designs can exploit such behavior.

[0093] In other embodiments, a semi-passive design may use natural airflow 200 or convection whenever it is available but augment these flows with blowers whenever the air is essentially stagnant. The disadvantage to the separable lid 108 is that there is more opportunity for seal failure between the lid 108 and the vessel 104, a problem whose solution may increase the cost to make and operate the device.

[0094] FIG. 4A is a cross sectional view of a non-limiting example of a tDAC device 100 with a lid 108 having a protrusion 400. According to various embodiments, this

protrusion 400 extends out of the lid 108 towards the central void 122, and is sized to be received inside the central void 122 when the sorbent structure 106 is in the release configuration 130. It may be shaped such that as the lid 108 is lowered, the protrusion 400 (e.g., triangle, rounded pyramid, conical, etc.) would facilitate aligning the lid 108, which may help with consistently forming a seal between the lid 108 and the vessel 104. The protrusion 400 might also be designed to serve as a baffle to direct airflow 200 both during capture and during harvest.

[0095] FIG. 4B is a cross sectional view of a non-limiting example of a tDAC device 100 with a lid 108 having a lip 402 that extends down along the vessel 104 when the lid 108 is enclosing the sorbent structure 106 inside the vessel 104. The seal between the lid 108 and the vessel 104 has a large impact on the overall efficiency of the device. A bad seal could result in wasted regeneration resources (e.g., water, heat, energy, etc.), and lost carbon dioxide 206 as it is released in the vessel 104. The use of lips 402 or other structures that provide additional interface surfaces between the lid 108 and the vessel 104 may enhance the seal without significantly increasing the cost.

[0096] FIGs. 4C and 4D are cross sectional views of a non-limiting example of a tDAC device 100 with a sorbent structure 106 suspended by rods 404, shown in the collection configuration 118 and the release configuration 130 configurations respectively. As shown, the lid 108 is still attached to the top duct 102, but is also separable. The lid 108 is slidably coupled to the sorbent structure 106 through a plurality of rods 404 fixedly coupled to the sorbent structure 106 such that it is suspended from the lid 108 by the rods 404 when in the collection configuration 118. This permits a gap between the duct 102 and the lid 108 and allows air flow across the top of the duct 102 that may lead to the chimney effect, and its accompanying benefits. The non-limiting example shown in FIG. 4C and 4D has the larger duct 102 at the top. It should be noted that this design would work equally well with the reverse, with the smaller duct 102 at the top.

[0097] FIGs. 5A and 5B are cross sectional views of a non-limiting example of a tDAC device 100 with a central aperture 500 and a stationary plug 502, shown in the collection configuration 118 and the release configuration 130 configurations respectively. This lid architecture combines the advantages of both the separable and the fixed lids discussed above. As shown, the lid 108 is fixedly coupled to the sorbent structure 106 (e.g., the top duct 102), providing the advantages of that permanent seal. However, the lid 108 also has a central aperture 500, allowing air to pass over and through, creating the chimney effect and the additional interaction between the air and the sorbent material 116 of the ducts 102.

[0098] When lowered into the release configuration 130, the central aperture 500 in the lid 108 is closed by a plug 502 that is permanently mounted to the vessel 104. Like the lids 108 with the protrusion 400, this will help guide the lid 108 into position. Additionally, the seal between the lid 108 (at the central aperture 500) and the plug 502 is easier to secure because of the shape of the plug 502 acting with gravity, according to various embodiments.

[0099] In some embodiments, there may be a geared or threaded interaction between neighboring ducts 102, such that rotating or twisting the sorbent structure 106 causes it to elongate into the collection configuration 118 or contract into the release configuration 130. FIG. 6 is a cross sectional view of a non-limiting example of a tDAC device 100 with threading 600. Each pair of neighboring ducts 102 has a threading 600 on one duct 102 that is engaged by the other duct 102 (i.e., a link 602 running between the threads), such that the sorbent structure 106 moves between the collection configuration 118 and the release configuration 130 through rotation of the ducts 102 by the expansion mechanism 110.

[00100] FIGs. 7A and 7B are top views of two non-limiting examples of a set of ducts 102. According to various embodiments, each duct 102 has an outer perimeter 702 and an inner perimeter 704. In some embodiments, these two perimeters may have the same shapes 700, with the outer perimeter 702 larger than the inner perimeter 704. In other embodiments, these two perimeters may have different shapes 700, with the inner perimeter 704 shaped and sized to permit nesting with a duct 102 having a matching outer perimeter 702. In other words, in some embodiments, the plurality of ducts 102 may all have the same shape 700, just different scales, while in other embodiments the ducts 102 may have two or more different shapes 700, which may be advantageous in certain use cases.

[00101] Although all of the examples previously shown and discussed have comprised ducts 102 having circular cross sections (normal to the axis), it should be noted that in other embodiments, the ducts 102 may have other shapes. It is possible to choose similar geometries that may be more easily constructed or are better suited to local environments. Non-circular designs used in some embodiments do not have the freedom to rotate the various sections against each other. Nevertheless, replacing the circular shape with, for example, a lower order polygon shape (e.g., hexagon, square, triangle, etc.) introduces a reduced symmetry that may be useful in some environments. For example, if the wind velocity is strongly biased toward one direction, it may be useful to have the ducts 102 of the sorbent structure 106 wider in the direction of the wind. Ducts 102 having elliptical or rectangular cross-sections may be suitable.

[00102] In some embodiments, the ducts 102 may have a cross-sectional shape 700 that changes along the central axis 120. These changes may be with respect to size (e.g., see the conical nesting ducts 102 of FIGs. 8A-8C), or orientation (e.g., a spiral duct 102, etc.). In other embodiments, the ducts 102 may be shaped such as to take advantage of the airflow 200 generated by neighboring structures. In some implementations of a system of tDAC devices 100, multiple devices are expected to operate in close proximity to each other. This may include aerodynamic structures that take advantage of higher speed flow through passages between such objects. A system of tDAC devices 100 will be discussed further in the context of FIGs. 13A and 13B, below.

[00103] FIGs. 8A and 8B are cross sectional views of a non-limiting example of a tDAC device 100 with overlapping ducts 102 in the collection configuration 118 and the release configuration 130 configurations, respectively. FIG. 8C is a cross sectional views of another non-limiting example of a tDAC device 100 with overlapping ducts 102 in the collection configuration 118. In some embodiments, the ducts 102 are arranged such that they do not touch in either configuration.

[00104] In other embodiments, neighboring ducts 102 (i.e., a pair of sequential ducts 102 having an inner duct 806 that nests within an outer duct 808 when the sorbent structure 106 is in the release configuration 130) may make contact with each other when in the collection configuration 118. For example, in some embodiments, the width of the ducts 102 at one end (i.e., the wide end 804) is larger than the width at the other end (i.e., the narrow end 802), for both inner and outer perimeters.

[00105] When nested, gravity will pull the wide end 804 of the inner duct 806 stuck inside the narrow end 802 of the outer duct 808 below it such that the inner duct 806 and outer duct 808 have an overlap 810 when the sorbent structure 106 is in the collection configuration 118. In such embodiments, the slight overlap 810 between the inner duct 806 and the outer duct 808 results in a collection configuration 118 where there are no spaces between ducts 102. In other embodiments, this may also be accomplished with inward and outward facing lips on each duct 102 that mate when pulled into the collection configuration 118.

[00106] Airflow 200 during capture and harvest is a significant factor for tDAC device 100 efficiency. In some embodiments, airflow directional elements may be incorporated, to increase the opportunities to capture CO₂ and harvest CO₂. These might be vanes, guides, scoops, or other directional influencing devices and structures attached to the device 100 or separate from the device 100 and independent.

[00107] FIG. 9 is a top cross sectional view of a non-limiting example of a duct 102 having channels 902. In some embodiments, said directional influencing structures may be incorporated into the structure of the ducts 102. The duct 102 in FIG. 9 has been sliced in half to demonstrate the internal structure. As shown, the duct 102 has a plurality of channels 902 passing through the duct 102 perpendicular to the central axis 120, and within those channels 902 (and within the central void 122) there are small directional vanes 900. These directional vanes 900 induce turbulence and direct the air flow. The introduction of additional turbulence will increase the interaction between the sorbent material 116 and the airflow 200. It should be noted that this architecture may be limited to use in special circumstances, as the cost for all of the extra engineered material might be too costly for most capture sites.

[00108] According to various embodiments, the duct 102 walls are permeable, to some degree, to radial air flow. Exemplary duct 102 structures include, but are not limited to, honeycomb-like structures, monoliths, perforated ducts 102, and the like. FIG. 10 is a top view of a non-limiting example of a duct 102 that is permeable (or at least a part 1004 of the duct 102 is permeable), such that air flows over an outer surface 1000 of the duct 102, an inner surface 1002 of the duct 102 facing the central void 122, and through the walls of the duct 102 between the outer surface 1000 and the inner surface 1002.

[00109] FIGs. 11A and 11B are side and cross sectional views of a non-limiting example of a duct 102 that is also permeable, having a sorbent-filled cavity 1100. As previously discussed, in some embodiments the duct 102 may comprise a framework or other structure that is configured to hold or give form to sorbent materials 116. In some embodiments, the ducts 102 may be perforated to allow air to flow through the walls. Here, the duct 102 has a hollow cavity 1100 with at least one window 1104. Each window 1104 is spanned by a mesh 1102 or similar material that permits air flow but will retain the sorbent material 116 contained inside the cavity 1100. Some sorbents material 116 are limited to being used in the form of beads or powder, due to their mechanical properties. Such a material may be implemented in a duct 102 having a cavity 1100, which may allow for refilling or replacement of the sorbent material 116 when necessary, without having to replace the rest of the duct 102.

[00110] According to various embodiments, the vessel 104 is shaped similar to the ducts 102 to minimize wasted volume while still permitting fluidic circulation within. In some embodiments, this also includes having an annular shape, such that the air column in the center of the ducts 102 (i.e., the central void 122) is not entirely empty, but rather is partially filled with vessel 104 wall.

[00111] In the context of the present description and the claims that follow, a vessel 104 is annular when at least a portion of the central void 122 of the smallest duct 302 is occupied by the vessel 104 (i.e., vessel wall) when the sorbent structure 106 is in the release configuration 130. In some embodiments, this may leave an empty space beneath the vessel 104. In other embodiments, including the non-limiting example shown in FIG. 12, that space may be utilized for other elements of the tDAC device 100, including but not limited to the sorbent regeneration system 202 and/or the expansion mechanism 110.

[00112] FIG. 12 is a cross sectional view of a non-limiting example of a tDAC device 100 having an annular vessel 104 in the release configuration 130. Like the non-limiting example shown in FIG. 2A, the sorbent regeneration system 202 is positioned within the central void 122 (i.e., located within the innermost or smallest duct 302). However, unlike that embodiment, here the sorbent regeneration system 202 (or at least the majority of it) is also outside the vessel 104. The only space taken up inside the vessel 104 by the sorbent regeneration system 202 is a plurality of nozzles 1200 pointing into the central void 122 and in fluidic communication with the sorbent regeneration system 202. These nozzles 1200 can be used to introduce steam to the vessel 104 to regenerate the sorbent material 116 and release the captured carbon dioxide 206. Advantageously, the use of an annular vessel 104 and positioning the sorbent regeneration system 202 within the central void 122 but outside the vessel 104 also makes it easier to access for maintenance and repair, according to various embodiments.

[00113] According to various embodiments, the tDAC device 100 may be mounted on a skids 1310 for ease of fabrication, shipping and operation. In some embodiments, multiple tDAC devices 100 may be mounted on a single skid 1310.

[00114] In some embodiments, multiple tDAC devices 100 may be operated together as a system, advantageously sharing infrastructure (e.g., product stream transport, skids, regeneration media, power, expansion mechanisms, storage, etc.). FIGs. 13A and 13B show top and side views of a non-limiting example of a tDAC system 1300. As shown, each skid 1310 comprises three tDAC devices 100 sharing a single expansion mechanism 110 attached to a support structure 112. This can be referred to as a cluster 1302. In the context of the present description and the claims that follow, a cluster 1302 comprises at least two tDAC devices 100 that share some elements or infrastructure. This lowers costs and increases efficiency, according to various embodiments.

[00115] The clusters 1302 that make up this "farm" (i.e. tDAC system 1300) may be spaced apart to facilitate access to every cluster 1302 and their tDAC devices 100, in some embodiments. In other embodiments, the spacing and arrangement of the clusters 1302 within

a tDAC system 1300 may also be chosen to capitalize on particular air flows or other environmental factors.

[00116] As a specific, non-limiting example of sharing within a cluster 1302, in some embodiments the tDAC devices 100 within a cluster 1302 may utilize the same expansion mechanism 110, as shown in FIGs. 13A and 13B. In some embodiments, this sharing may mean that all of the tDAC devices 100 of that cluster 1302 move between the collection configuration 118 and the release configuration 130 at the same time. In other embodiments, each tDAC device 100 of the cluster 1302 may be able to make independent use of the same expansion mechanism 110 (e.g., a single rotary actuator functionally coupled to three different cables that can be independently engaged or disengaged, etc.).

[00117] The cooperation between tDAC devices 100 of the same cluster 1302 moving between configurations may extend beyond using the same expansion mechanism 110. In some embodiments, tDAC devices 100 of the same cluster 1302 may be coupled to each other such that when the sorbent structure 106 of one device is moving upward into the collection configuration 118, the sorbent structure 106 of another device is moving down into the release configuration 130, allowing the weight of the descending sorbent structure 106 to assist in lifting the rising sorbent structure 106. This counter balancing would further reduce the power needed for operation. It is worth noting that in some cases identical sorbent structures 106 may have different weights depending on where each is at in the capture/release cycle (e.g., a moisture swing sorbent structure 106 may be heavier due to water immediately after finishing regeneration than the same sorbent structure 106 after drying out in the airflow 200, etc.).

[00118] The sharing of resources and infrastructure can extend beyond intra-cluster cooperation. In some embodiments, clusters 1302 such as the skid-mounted clusters 1302 shown in FIGs. 13A and 13B, can be coupled together to share resources and/or coordinate production. In some embodiments, the vessels 104 of each tDAC device 100 in the same cluster 1302 are connected and in fluid communication with each other, such that the enriched gas 204 of one device may be swept through the vessel 104 of a neighboring passive collection device 1306, facilitating the harvesting of the enriched gas 204. Each cluster 1302 may further be put in fluid communication with infrastructure for consolidating the enriched gas 204 provided by each cluster 1302. For example, in some embodiments, the clusters 1302 may send their enriched gas 204 to the same storage tank 1312 as a single, combined product stream 1308. In other embodiments, that combined product stream 1308 may be upgraded, compressed, sequestered, used as feedstock, or otherwise utilized. Other shared structures may include

scoops or vanes for directing airflows 200, as well as stabilizing structures to strengthen the sorbent structures 106 when extended.

[00119] In some embodiments, a system 1300 comprising a plurality of tDAC devices 100 may be operated such that a continuous product stream 1308 is produced by staggering the devices 100 in their collection/release cycles to ensure that at least one device 100 or cluster 1302 is always in the release phase of its cycle. According to various embodiments, this may be automated using a shared control system 1304 communicatively coupled to each tDAC device 100 or each cluster 1302. The control system 1304 is configured to drive the expansion mechanism(s) 110 to move the single or multiple sorbent structures 106 between the collection configuration 118 and the release configuration 130 in series, to produce a continuous product stream 1308 of enriched gas 204.

[00120] Wide adoption of carbon capture technology is going to require it to be economically beneficial, beyond the incentive to improve the environment. The capture of CO₂ needs to be accomplished ideally at under \$100/tonne. Design for ease of operation and lower energy costs is an essential part of achieving this objective.

[00121] Various embodiments have different features that further accomplish this goal. In some embodiments, the majority of the equipment that may need to be serviced is located at no more than 10 feet above grade. The valves, motors and other equipment is located so that it is easily accessible to technicians and has clearance for removal and replacement. In some embodiments, the vessel 104 might be at a height to allow for operational personal and vehicular equipment to remain below the level of capture (i.e., raised ducts).

[00122] The disclosed implementations are not confined to the specific components detailed herein; any components compatible with the operation of a telescoping passive direct air capture system may be employed. For instance, while certain systems, methods, and devices for carbon dioxide capture and release are described, components of any shape, size, type, material, or quantity suitable for the intended function may be utilized. References to particular implementations are illustrative, and various modifications can be made without departing from the core principles, allowing application to other gas capture devices, whether passive or active.

CLAIMS

What is claimed is:

1. A device for passive collection of atmospheric carbon dioxide, comprising:
 - a vessel comprising an opening and a sorbent regeneration system;
 - 5 a lid;
 - a sorbent structure coupled to the vessel and comprising a plurality of ducts that are coaxial, each duct comprising a sorbent material and having a central void running along a central axis shared by the plurality of ducts, the sorbent structure being movable between a collection configuration and a release configuration; and
 - 10 an expansion mechanism coupled to the sorbent structure and configured to move the sorbent structure between the collection configuration and the release configuration;
 - wherein the collection configuration comprises the sorbent structure telescoping out through the opening of the vessel such that at least some of the ducts are outside the vessel and exposed to an airflow such that the sorbent material of the sorbent structure
 - 15 captures atmospheric carbon dioxide;
 - wherein the release configuration comprises the plurality of ducts nested within each other and the sorbent structure sufficiently enclosed inside the vessel by the lid that the sorbent regeneration system may operate on the sorbent material to release captured carbon dioxide from the sorbent material and form an enriched gas within
 - 20 the vessel.
2. The device of claim 1, wherein each duct of the plurality of ducts is composed of the sorbent material.
- 25 3. The device of claim 2, wherein the sorbent material is a porous membrane.
4. The device of claim 1, wherein each duct of the sorbent structure comprises a frame on which the sorbent material is mounted.
- 30 5. The device of claim 1, wherein at least part of each duct of the plurality of ducts is permeable, such that air flows over an outer surface of the duct, an inner surface of the duct facing the central void, and through the duct between the outer surface and the inner surface.

6. The device of claim 1, wherein the lid is fixedly coupled to the sorbent structure, such that the lid and sorbent structure move together as the sorbent structure is moving between the collection configuration and release configuration.
- 5 7. The device of claim 1, wherein the lid is releasably coupled to the sorbent structure and able to separate from the sorbent structure such that air can flow through and out of the central void of the sorbent structure.
8. The device of claim 1:
10 wherein the lid is fixedly coupled to the sorbent structure and comprises a central aperture;
wherein the vessel comprises a plug positioned such that when the sorbent structure is in the release configuration, the plug is inside of and sealing the central aperture of the lid.
- 15 9. The device of claim 1, wherein the collection configuration comprises the plurality of ducts being spread out along the central axis such that the ducts are separated from each other along the central axis.
- 20 10. The device of claim 1, wherein neighboring ducts make contact with each other when the sorbent structure is in the collection configuration.
11. The device of claim 10:
wherein each duct of the plurality of ducts comprises a narrow end and a wide end distal
25 to the narrow end;
wherein, for each pair of neighboring ducts having an inner duct that nests within an outer duct when the sorbent structure is in the release configuration, the collection configuration comprises the wide end of the inner duct stuck inside the narrow end of the outer duct such that the inner duct and outer duct have an overlap when the
30 sorbent structure is in the collection configuration.
12. The device of claim 1, wherein for each pair of neighboring ducts having an inner duct that nests within an outer duct when the sorbent structure is in the release configuration,

the collection configuration comprises an overlap between the inner duct and the outer duct when the sorbent structure is in the collection configuration.

13. The device of claim 1, wherein a largest duct of the plurality of ducts is located further
5 from the vessel than a smallest duct of the plurality of ducts when the sorbent structure is in the collection configuration.

14. The device of claim 1, wherein each duct has a height, and wherein the plurality of ducts
10 comprises at least two different heights.

15. The device of claim 12, further comprising:
a microcontroller communicatively coupled to the expansion mechanism and at least one
sensor;
wherein the microcontroller is configured to adjust the overlap between neighboring ducts
15 while the sorbent structure is in the collection configuration based on data received from the at least one sensor.

16. The device of claim 1, further comprising:
a microcontroller communicatively coupled to the expansion mechanism and at least one
20 sensor;
wherein the microcontroller is configured to adjust how many ducts are lifted out of the vessel when moving into the collection configuration based on data received from the at least one sensor.

25 17. The device of claim 1, wherein at least one of the sorbent regeneration system and the expansion mechanism is located within the central void.

18. The device of claim 1, wherein the vessel is annular such that at least a portion of the
30 central void of a smallest duct is occupied by the vessel when the sorbent structure is in the release configuration.

19. The device of claim 1, wherein each duct comprises a plurality of directional vanes to enhance carbon dioxide capture by inducing turbulence.

20. The device of claim 19, wherein the directional vanes are positioned within the central void of the ducts.

21. The device of claim 19, wherein each duct further comprises a plurality of channels passing through the duct perpendicular to the central axis, wherein the directional vanes are positioned within the channels of the ducts.

22. The device of claim 1, wherein the expansion mechanism is outside of the plurality of ducts, and pulls the sorbent structure away from the vessel and into the collection configuration.

23. The device of claim 1, wherein the expansion mechanism is inside of the central void of the plurality of ducts, and pushes the sorbent structure away from the vessel and into the collection configuration.

24. The device of claim 1, wherein each pair of neighboring ducts comprises a threading on one duct of the pair of ducts that is engaged by the other of the pair of ducts, such that the sorbent structure moves between the collection configuration and the release configuration through rotation of the ducts by the expansion mechanism.

25. The device of claim 1, wherein each duct of the plurality of ducts comprises an outer perimeter and an inner perimeter, with the inner perimeter and the outer perimeter sized and shaped such that the ducts can nest within each other.

26. The device of claim 25, wherein the outer perimeters of the plurality of ducts comprise at least two cross-sectional shapes.

27. The device of claim 25, wherein the outer perimeters of the plurality of ducts are non-circular.

28. The device of claim 1, wherein the lid comprises a lip that extends down along the vessel when the lid is enclosing the sorbent structure inside the vessel.

29. The device of claim 1, wherein the lid is slidably coupled to one of a largest duct and a smallest duct through a plurality of rods fixedly coupled to the one of the largest duct and the smallest duct such that the sorbent structure is suspended from the lid by the plurality of rods when in the collection configuration.

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30. The device of claim 1, wherein the lid comprises a protrusion extending out of the lid towards the central void, the protrusion being conical and sized to be received inside the central void when the sorbent structure is in the release configuration.

10 31. The device of claim 1, wherein each duct of the plurality of ducts has a wall thickness, and wherein a ratio between a radius of the plurality of ducts and the wall thickness of a duct is between 1:3 and 1:200.

15 32. The device of claim 31, wherein the ratio between the radius of the plurality of ducts and the wall thickness of one duct is between 1:10 and 1:30.

33. The device of claim 31, wherein a sum of the wall thickness of each duct of the plurality of ducts is between 20% and 80% of the radius of the plurality of ducts.

20 34. The device of claim 33, wherein the sum of the wall thickness of each duct of the plurality of ducts is between $\frac{1}{3}$ and $\frac{2}{3}$ of the radius of the plurality of ducts.

35. The device of claim 18, wherein the vessel comprises a plurality of nozzles pointing into the central void and in fluidic communication with the sorbent regeneration system.

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36. The device of claim 1:
wherein each duct of the plurality of ducts comprises a cavity having at least one window,
each window spanned by a mesh;
wherein the cavity contains the sorbent material.

30

37. A system for passive collection of atmospheric carbon dioxide, comprising:
at least one passive collection cluster, each passive collection cluster comprising at least two passive collection devices, each passive collection device comprising:
a vessel comprising an opening and a sorbent regeneration system;

a lid;
a sorbent structure coupled to the vessel and comprising a plurality of ducts that are
coaxial, each duct comprising a sorbent material and having a central void running
along a central axis shared by the plurality of ducts, the sorbent structure being
5 movable between a collection configuration and a release configuration; and
an expansion mechanism coupled to the sorbent structure and configured to move the
sorbent structure between the collection configuration and the release configuration;
wherein, for each passive collection device, the collection configuration comprises the
sorbent structure telescoping out through the opening of the vessel such that at least
10 some of the ducts are outside the vessel and exposed to an airflow such that the
sorbent material of the sorbent structure captures atmospheric carbon dioxide; and
wherein, for each passive collection device, the release configuration comprises the
plurality of ducts nested within each other and the sorbent structure sufficiently
enclosed inside the vessel by the lid that the sorbent regeneration system may operate
15 on the sorbent material to release captured carbon dioxide from the sorbent material
and form an enriched gas within the vessel.

38. The system of claim 37, wherein the at least two passive collection devices of each
cluster share one expansion mechanism.

39. The system of claim 37, wherein the vessel of each passive collection device in a cluster
is in fluid communication, such that the enriched gas of one collection device may be
swept through the vessel of a neighboring passive collection device.

40. The system of claim 37, further comprising:
a control system communicatively coupled to each passive collection cluster and
configured to drive the expansion mechanism to move the sorbent structure of at least
one passive collection device between the collection configuration and the release
configuration;
25 wherein the control system is configured to operate the passive collection devices in
series to product a continuous product stream of enriched gas.

41. A device for passive collection of atmospheric carbon dioxide, comprising:
a vessel comprising an opening and a sorbent regeneration system;

a sorbent structure coupled to the vessel and comprising a plurality of ducts that are coaxial, each duct comprising a sorbent material, a wall thickness, a wide end, a narrow end distal to the wide end, and having a central void running along a central axis shared by the plurality of ducts, the sorbent structure being movable between a collection configuration and a release configuration;

a lid releasably coupled to the sorbent structure and able to separate from the sorbent structure such that air can flow through and out of the central void of the sorbent structure; and

an expansion mechanism coupled to the sorbent structure and configured to move the sorbent structure between the collection configuration and the release configuration; wherein the collection configuration comprises the sorbent structure telescoping out through the opening of the vessel such that at least some of the ducts are outside the vessel and exposed to an airflow such that the sorbent material of the sorbent structure captures atmospheric carbon dioxide; and

wherein the release configuration comprises the plurality of ducts nested within each other and the sorbent structure sufficiently enclosed inside the vessel by the lid that the sorbent regeneration system may operate on the sorbent material to release captured carbon dioxide from the sorbent material and form an enriched gas within the vessel;

wherein, for each pair of neighboring ducts having an inner duct that nests within an outer duct when the sorbent structure is in the release configuration, the collection configuration comprises the neighboring ducts in contact with each other, with the wide end of the inner duct stuck inside the narrow end of the outer duct such that the inner duct and outer duct have an overlap when the sorbent structure is in the collection configuration;

wherein a ratio between a radius of the plurality of ducts and the wall thickness of a duct is between 1:10 and 1:30;

wherein a sum of the wall thickness of each duct of the plurality of ducts is between $\frac{1}{3}$ and $\frac{2}{3}$ of the radius of the plurality of ducts.

42. The device of claim 41, wherein each duct of the plurality of ducts is composed of the sorbent material.

43. The device of claim 42, wherein the sorbent material is a porous membrane.

44. The device of claim 41, wherein each duct of the sorbent structure comprises a frame on which the sorbent material is mounted.
- 5 45. The device of claim 41, wherein at least part of each duct of the plurality of ducts is permeable, such that air flows over an outer surface of the duct, an inner surface of the duct facing the central void, and through the duct between the outer surface and the inner surface.
- 10 46. The device of claim 41, wherein for each pair of neighboring ducts having an inner duct that nests within an outer duct when the sorbent structure is in the release configuration, the collection configuration comprises an overlap between the inner duct and the outer duct when the sorbent structure is in the collection configuration.
- 15 47. The device of claim 41, wherein a largest duct of the plurality of ducts is located further from the vessel than a smallest duct of the plurality of ducts when the sorbent structure is in the collection configuration.
48. The device of claim 41, wherein each duct has a height, and wherein the plurality of
20 ducts comprises at least two different heights.
49. The device of claim 46, further comprising:
a microcontroller communicatively coupled to the expansion mechanism and at least one
sensor;
25 wherein the microcontroller is configured to adjust the overlap between neighboring ducts while the sorbent structure is in the collection configuration based on data received from the at least one sensor.
50. The device of claim 41, further comprising:
30 a microcontroller communicatively coupled to the expansion mechanism and at least one
sensor;
wherein the microcontroller is configured to adjust how many ducts are lifted out of the vessel when moving into the collection configuration based on data received from the at least one sensor.

51. The device of claim 41, wherein at least one of the sorbent regeneration system and the expansion mechanism is located within the central void.
- 5 52. The device of claim 41, wherein the vessel is annular such that at least a portion of the central void of a smallest duct is occupied by the vessel when the sorbent structure is in the release configuration.
- 10 53. The device of claim 41, wherein each duct comprises a plurality of directional vanes to enhance carbon dioxide capture by inducing turbulence.
54. The device of claim 53, wherein the directional vanes are positioned within the central void of the ducts.
- 15 55. The device of claim 53, wherein each duct further comprises a plurality of channels passing through the duct perpendicular to the central axis, wherein the directional vanes are positioned within the channels of the ducts.
- 20 56. The device of claim 41, wherein the expansion mechanism is outside of the plurality of ducts, and pulls the sorbent structure away from the vessel and into the collection configuration.
- 25 57. The device of claim 41, wherein the expansion mechanism is inside of the central void of the plurality of ducts, and pushes the sorbent structure away from the vessel and into the collection configuration.
- 30 58. The device of claim 41, wherein each pair of neighboring ducts comprises a threading on one duct of the pair of ducts that is engaged by the other of the pair of ducts, such that the sorbent structure moves between the collection configuration and the release configuration through rotation of the ducts by the expansion mechanism.
59. The device of claim 41, wherein each duct of the plurality of ducts comprises an outer perimeter and an inner perimeter, with the inner perimeter and the outer perimeter sized and shaped such that the ducts can nest within each other.

60. The device of claim 59, wherein the outer perimeters of the plurality of ducts comprise at least two cross-sectional shapes.

5 61. The device of claim 59, wherein the outer perimeters of the plurality of ducts are non-circular.

62. The device of claim 41, wherein the lid comprises a lip that extends down along the vessel when the lid is enclosing the sorbent structure inside the vessel.

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63. The device of claim 41, wherein the lid is slidably coupled to one of a largest duct and a smallest duct through a plurality of rods fixedly coupled to the one of the largest duct and the smallest duct such that the sorbent structure is suspended from the lid by the plurality of rods when in the collection configuration.

15

64. The device of claim 41, wherein the lid comprises a protrusion extending out of the lid towards the central void, the protrusion being conical and sized to be received inside the central void when the sorbent structure is in the release configuration.

20 65. The device of claim 52, wherein the vessel comprises a plurality of nozzles pointing into the central void and in fluidic communication with the sorbent regeneration system.

66. The device of claim 41:
wherein each duct of the plurality of ducts comprises a cavity having at least one window,
25 each window spanned by a mesh;
wherein the cavity contains the sorbent material.

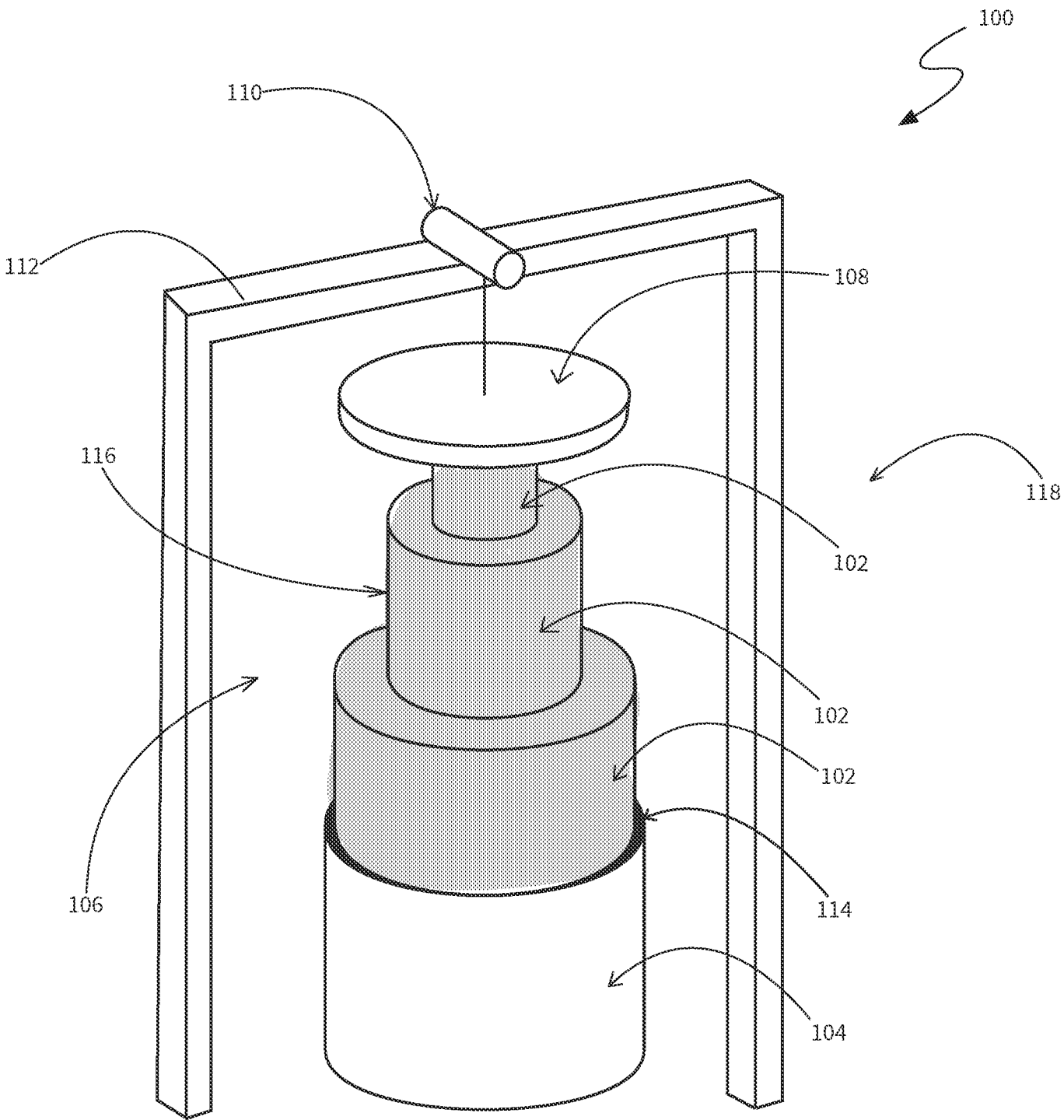


FIG. 1A

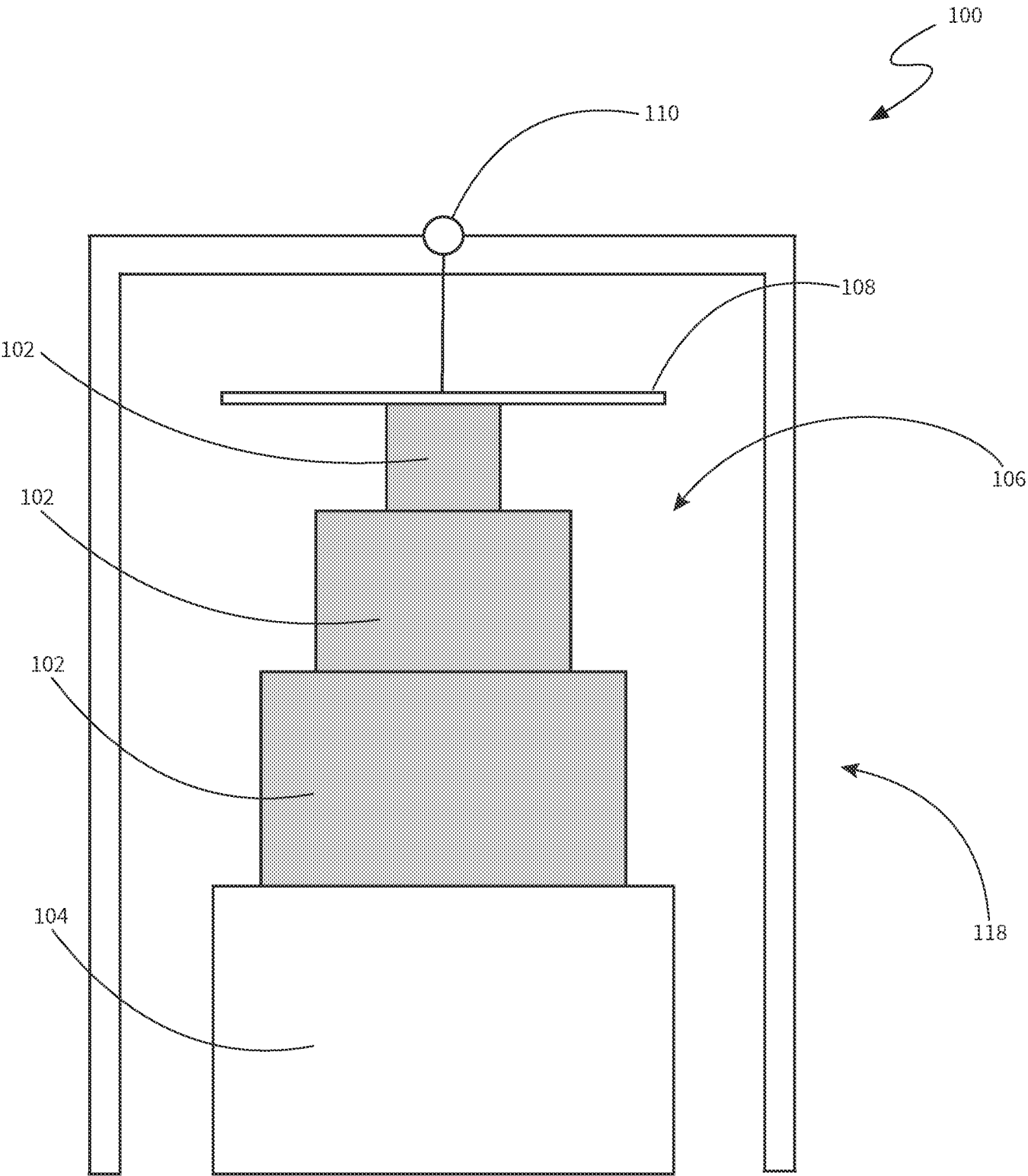


FIG. 1B

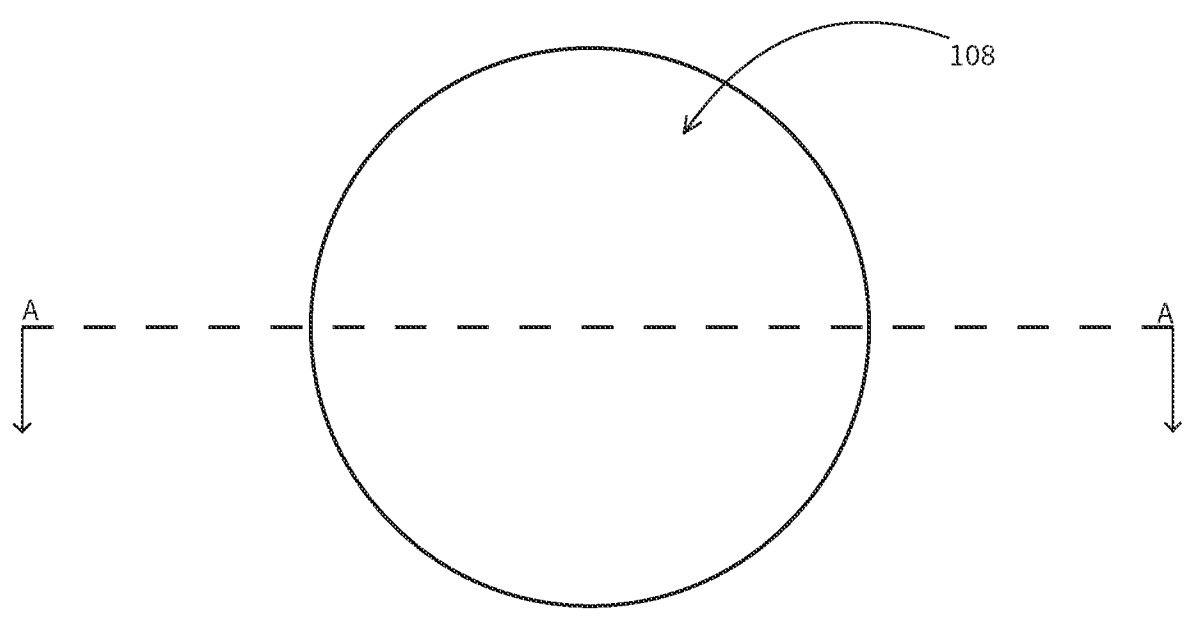


FIG. 1C

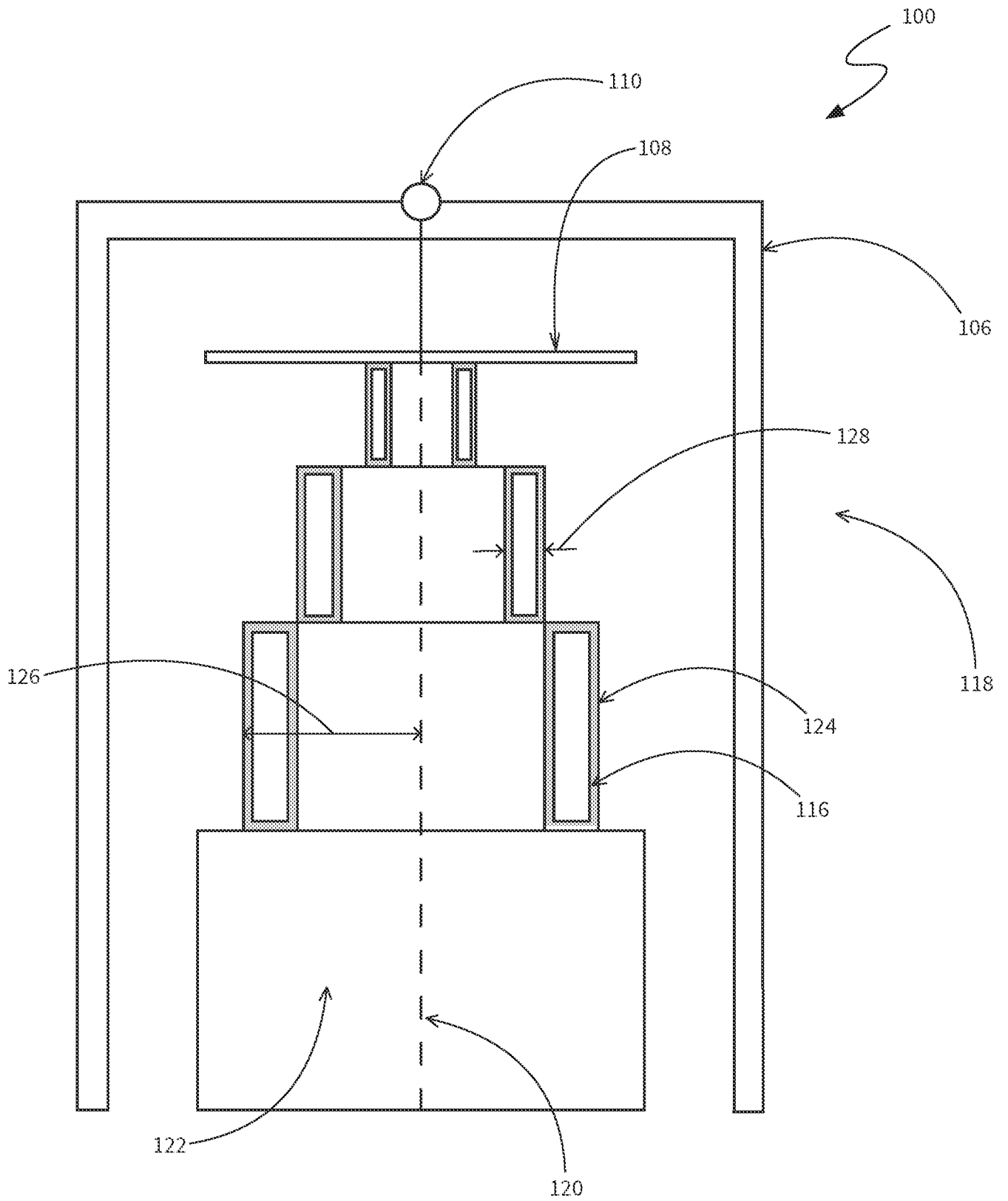


FIG. 1D

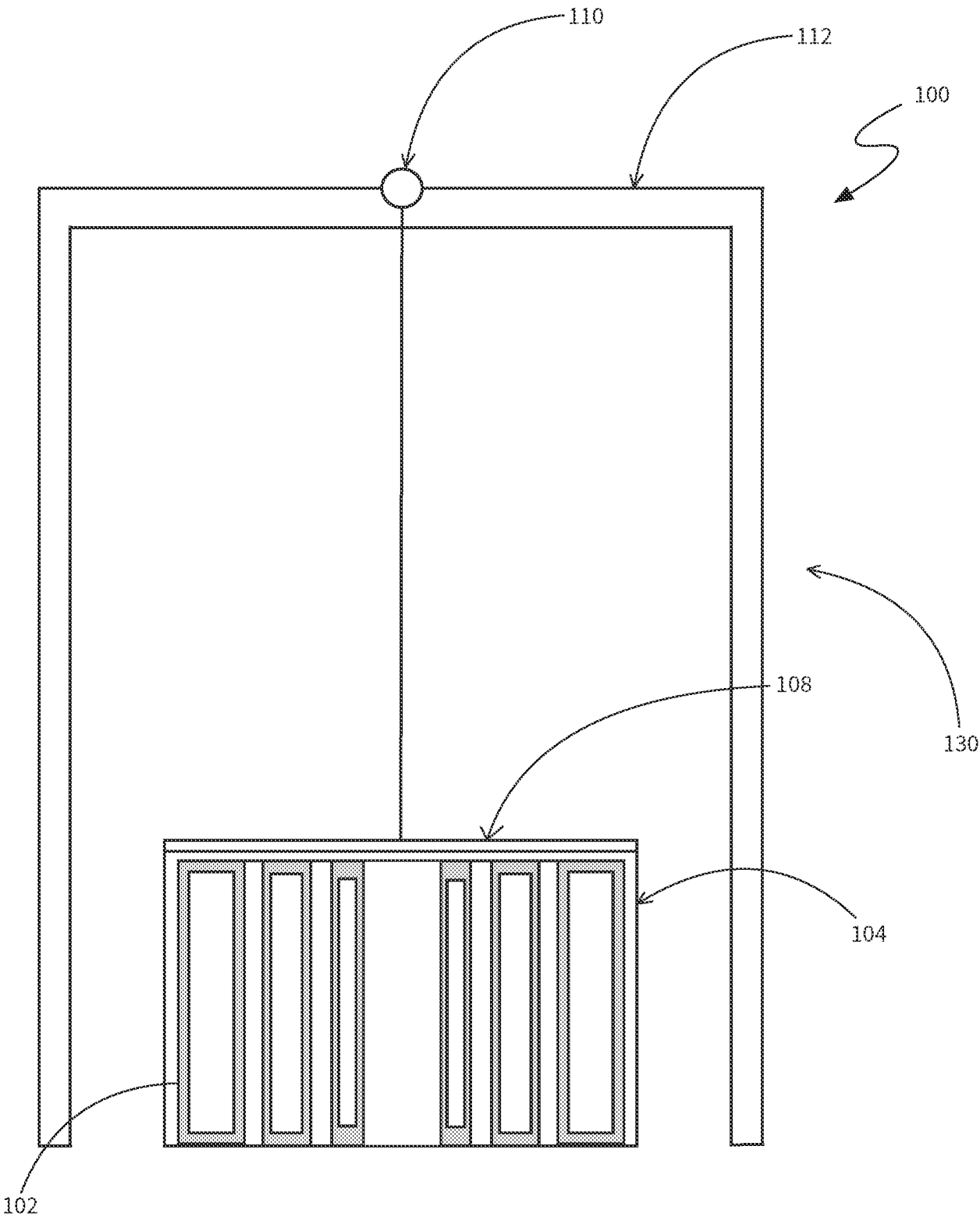


FIG. 1E

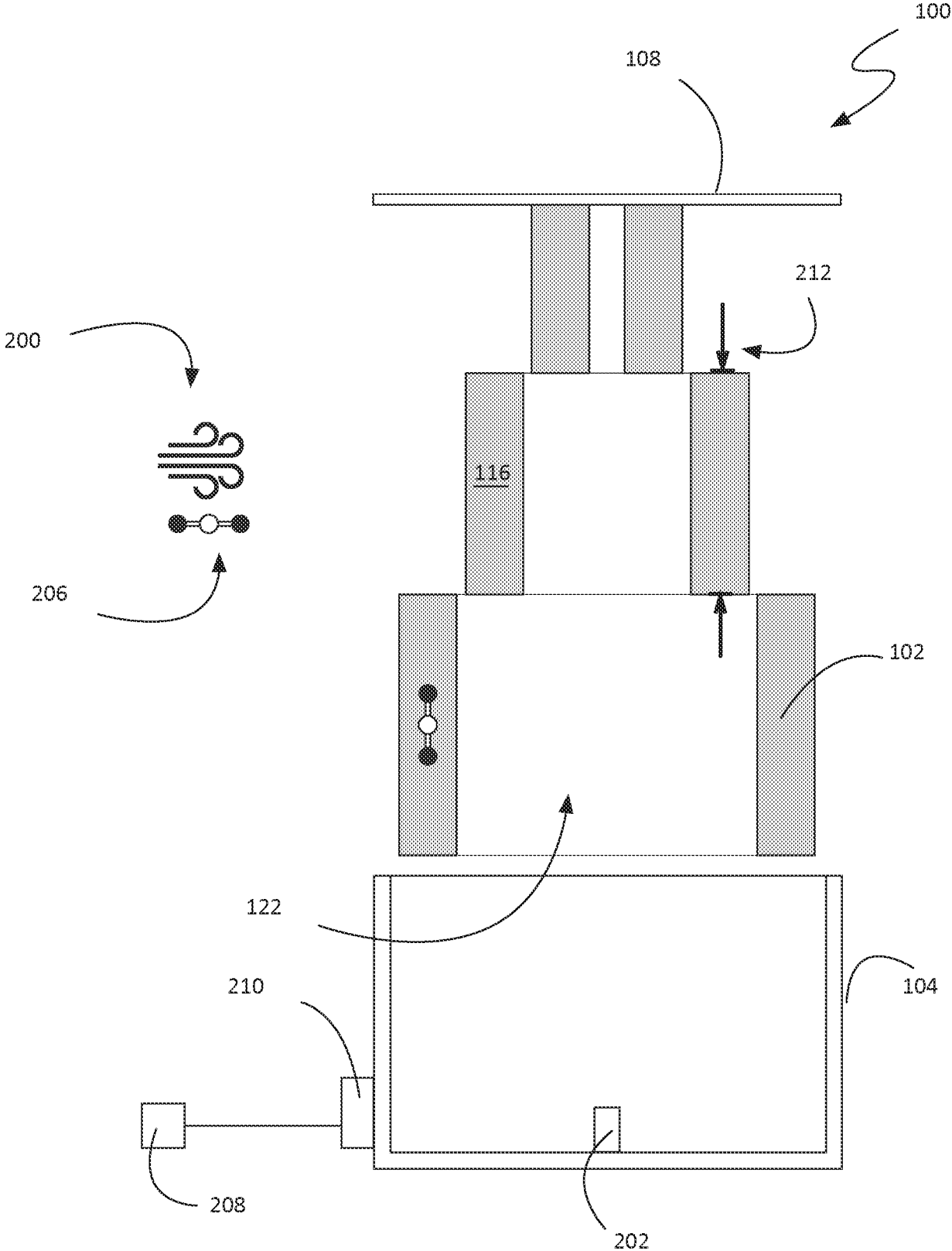


FIG. 2A

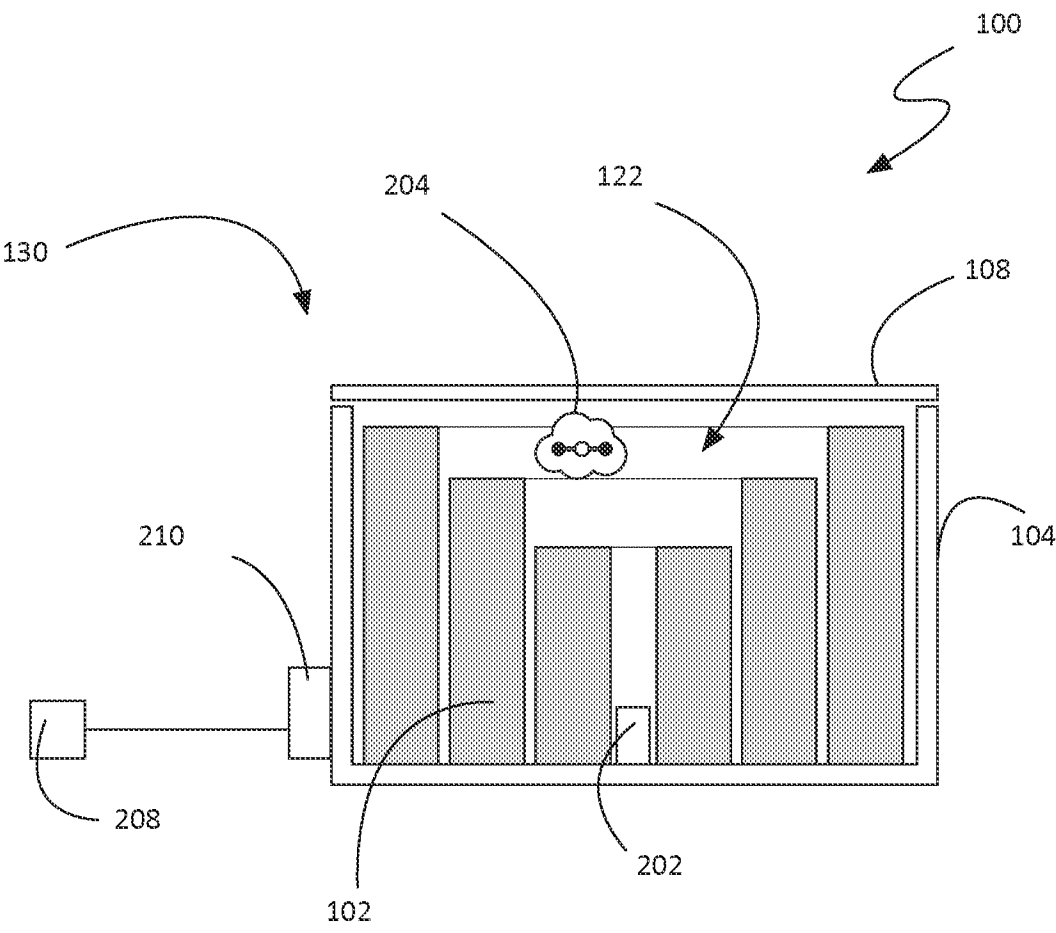


FIG. 2B

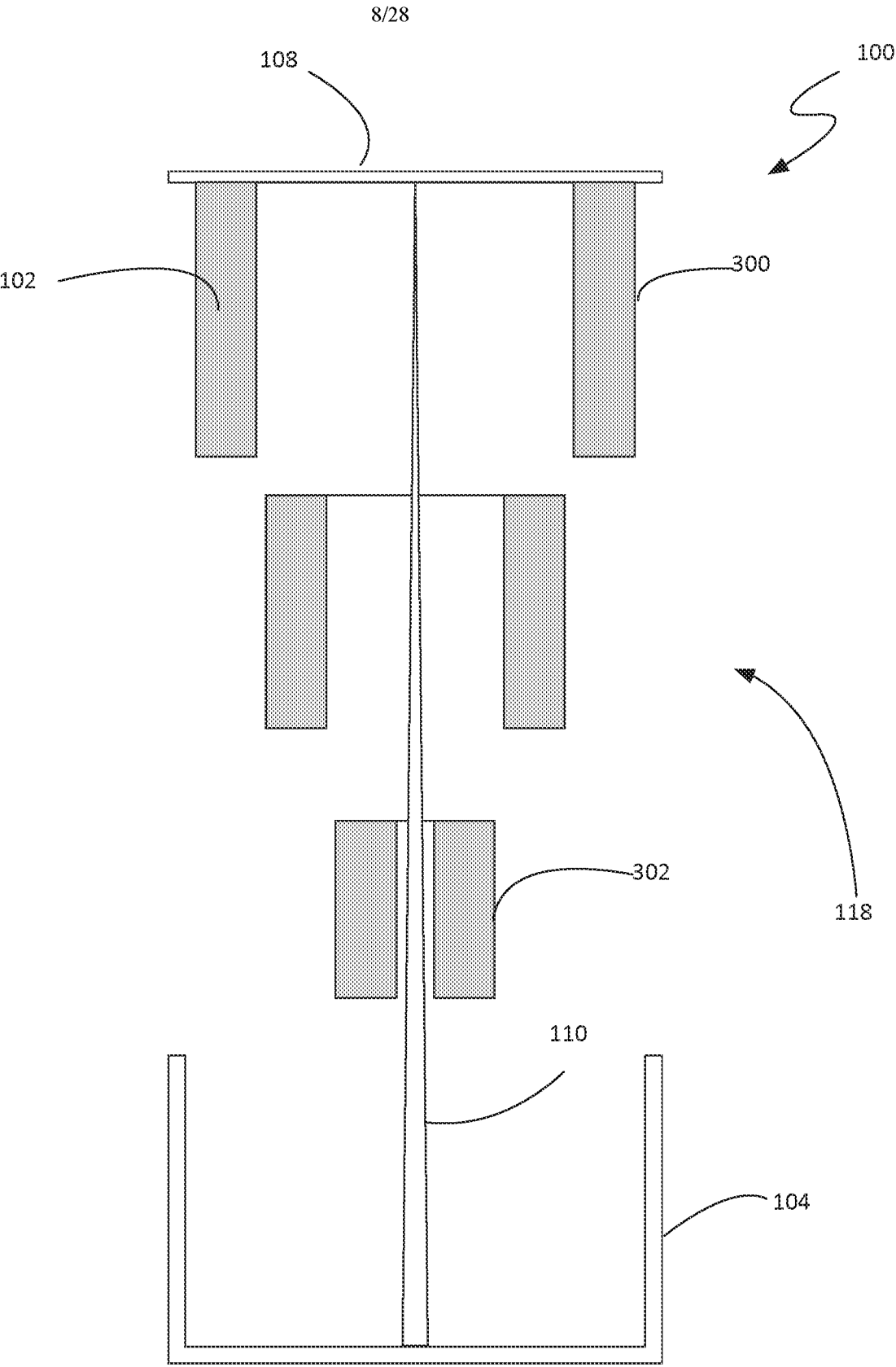


FIG. 3A

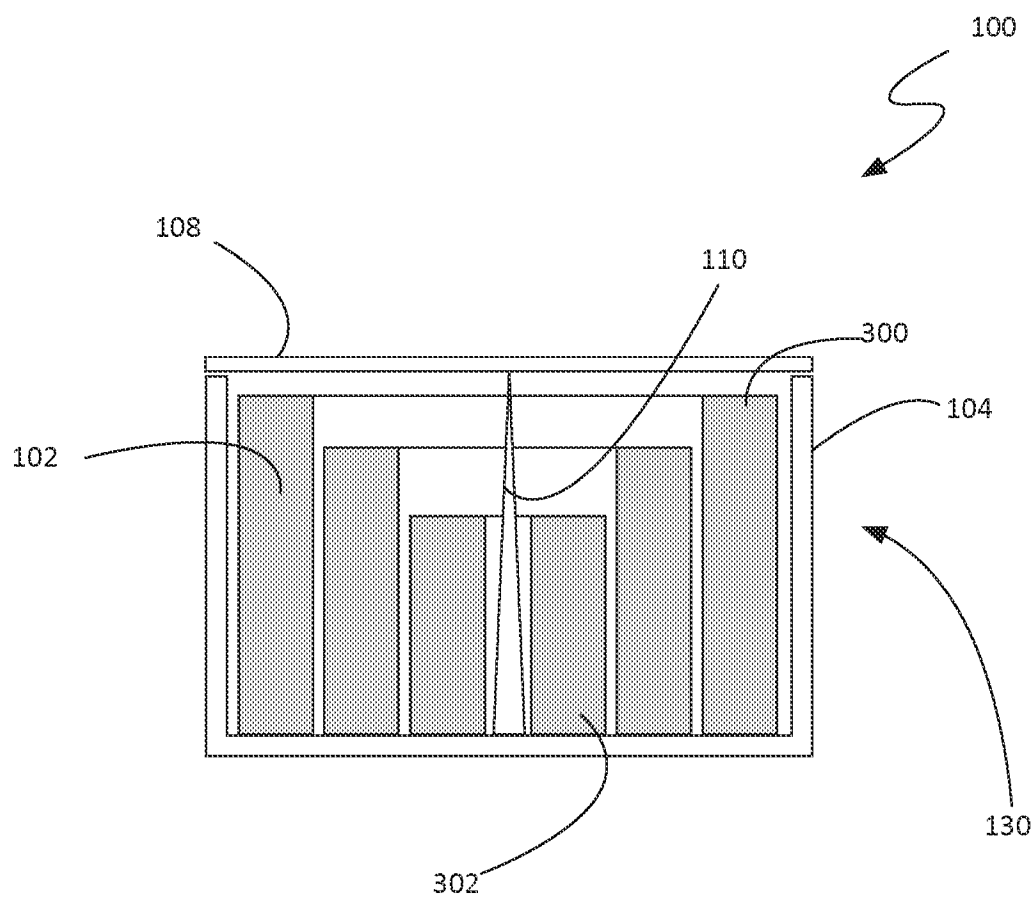


FIG. 3B

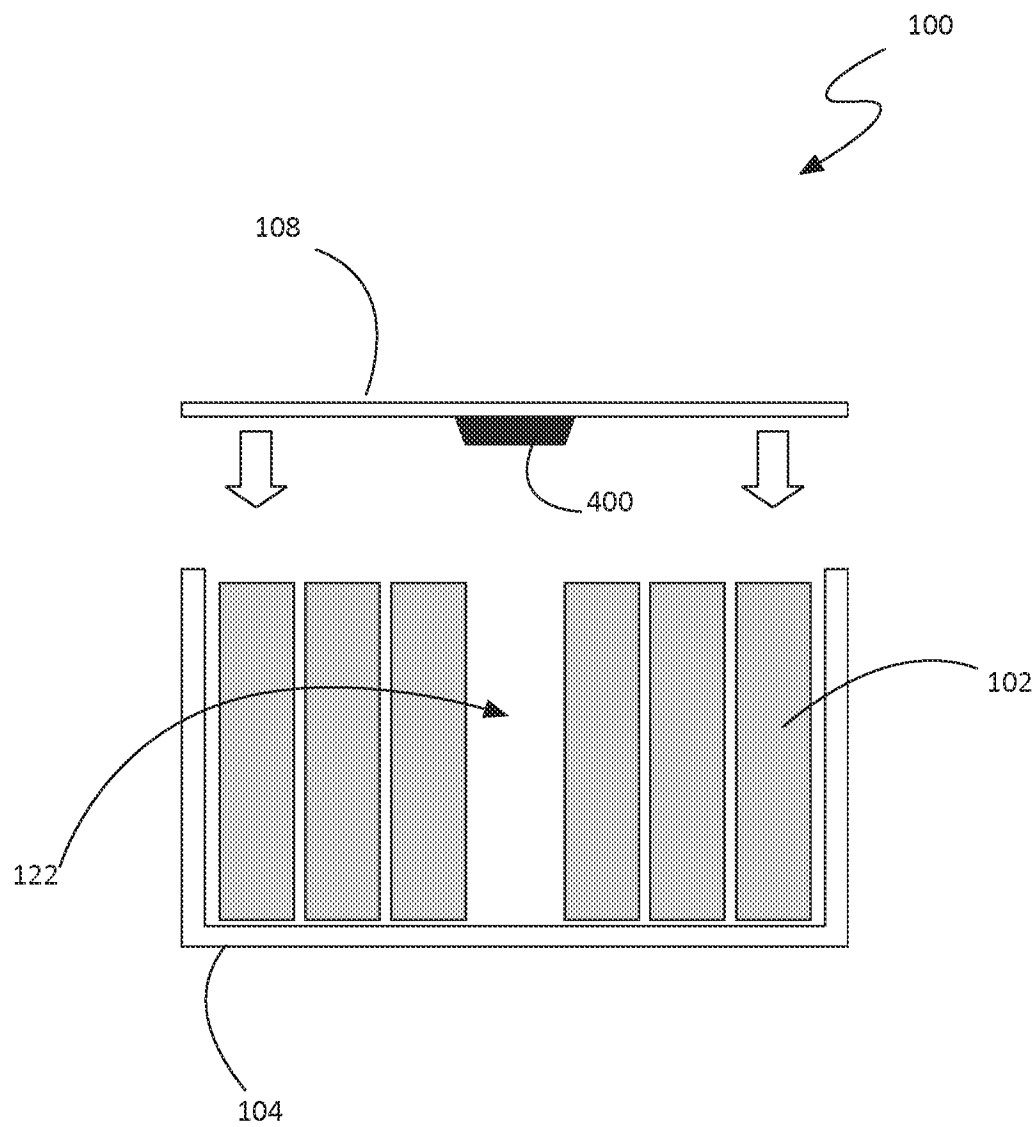


FIG. 4A

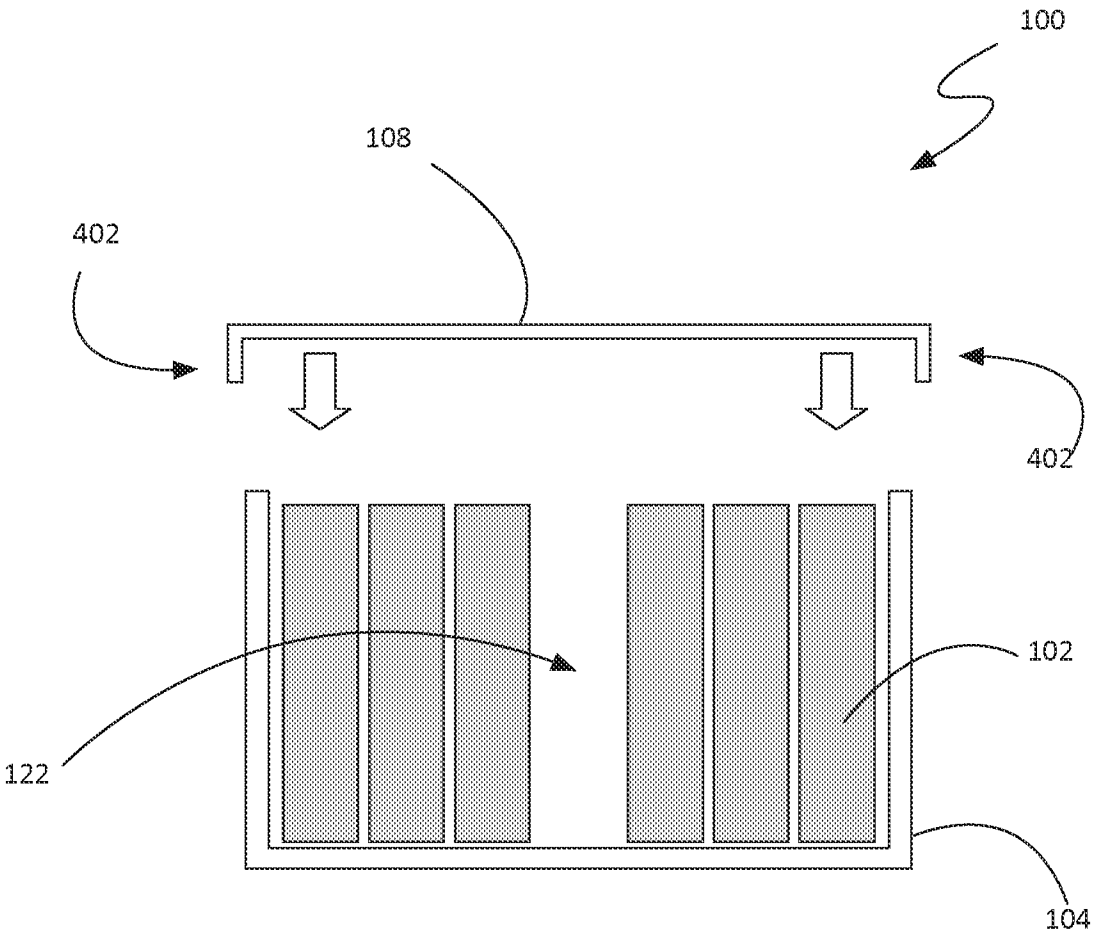


FIG. 4B

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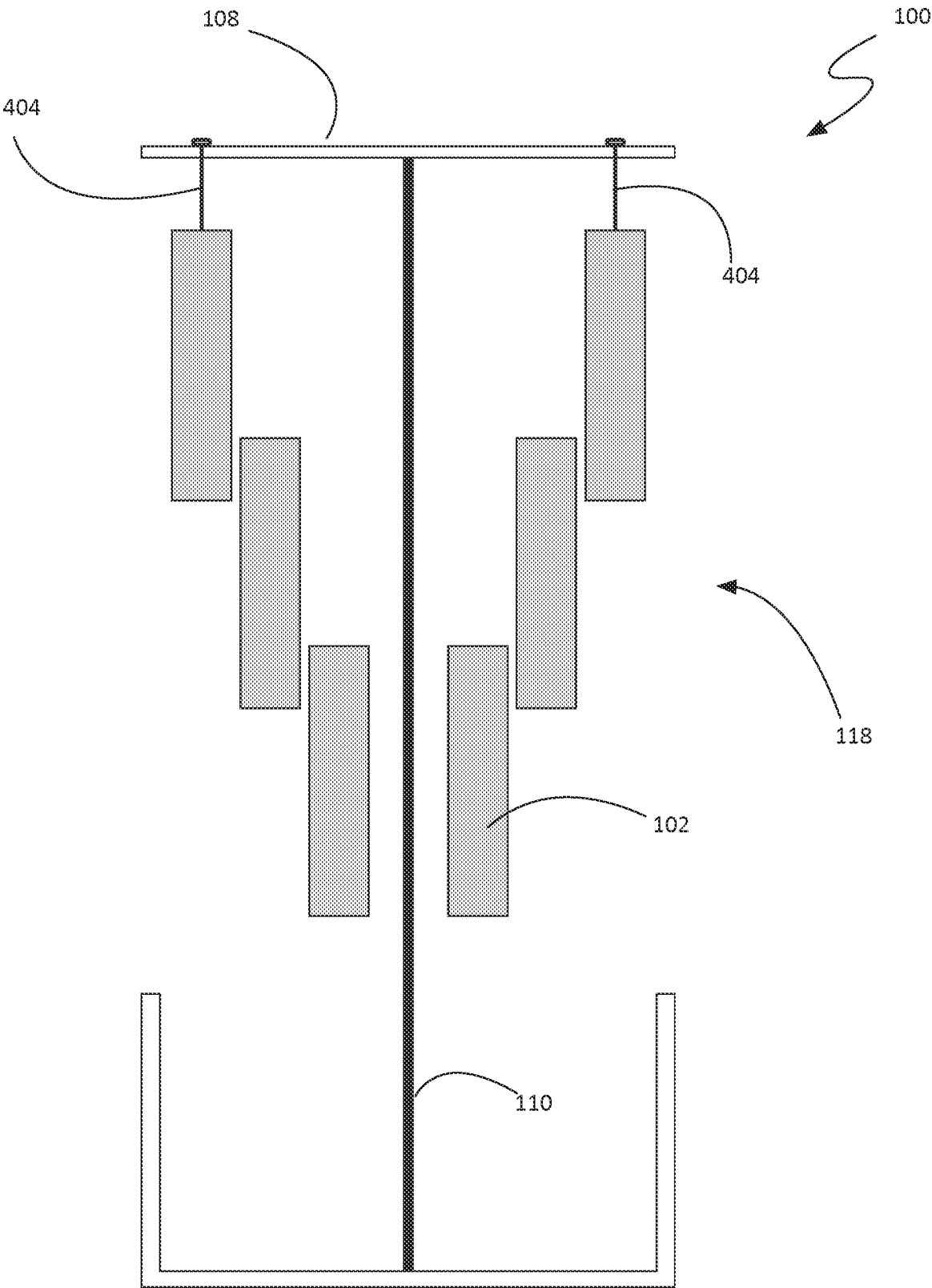


FIG. 4C

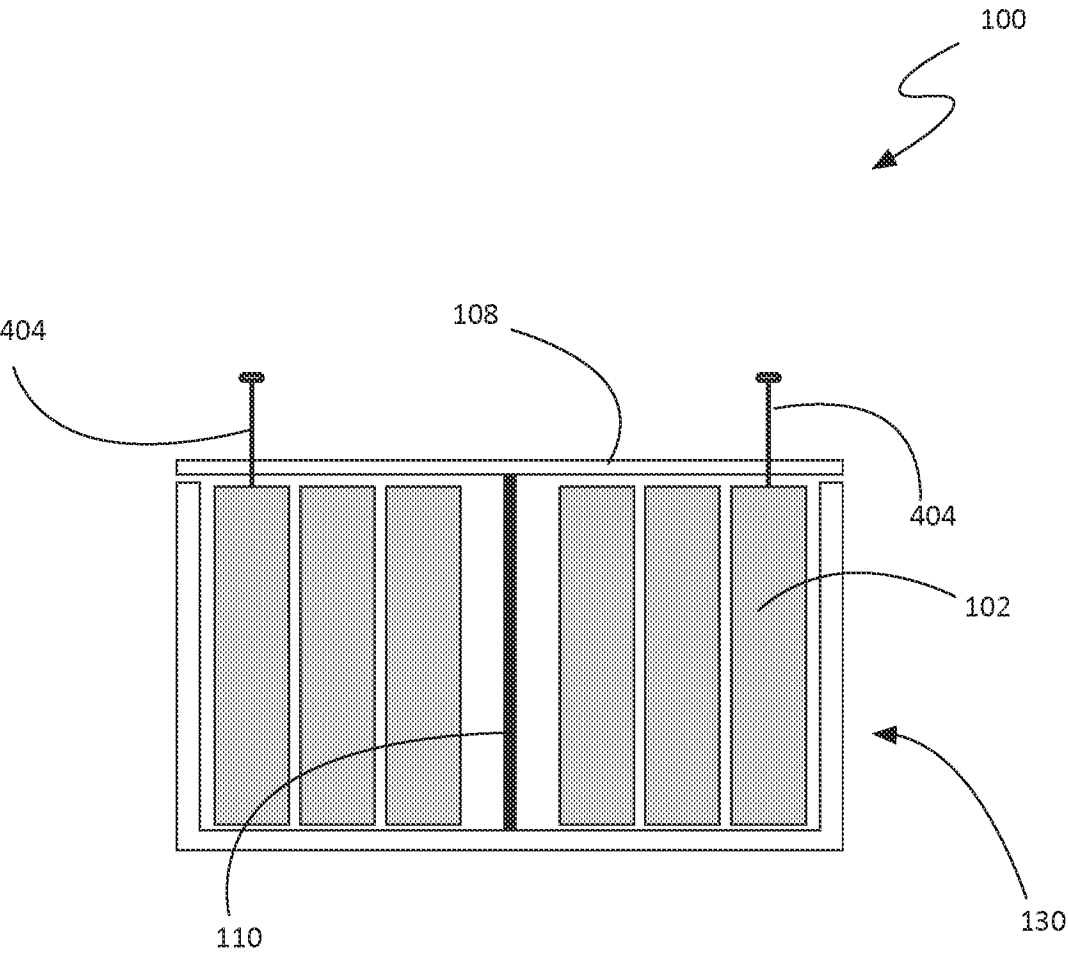


FIG. 4D

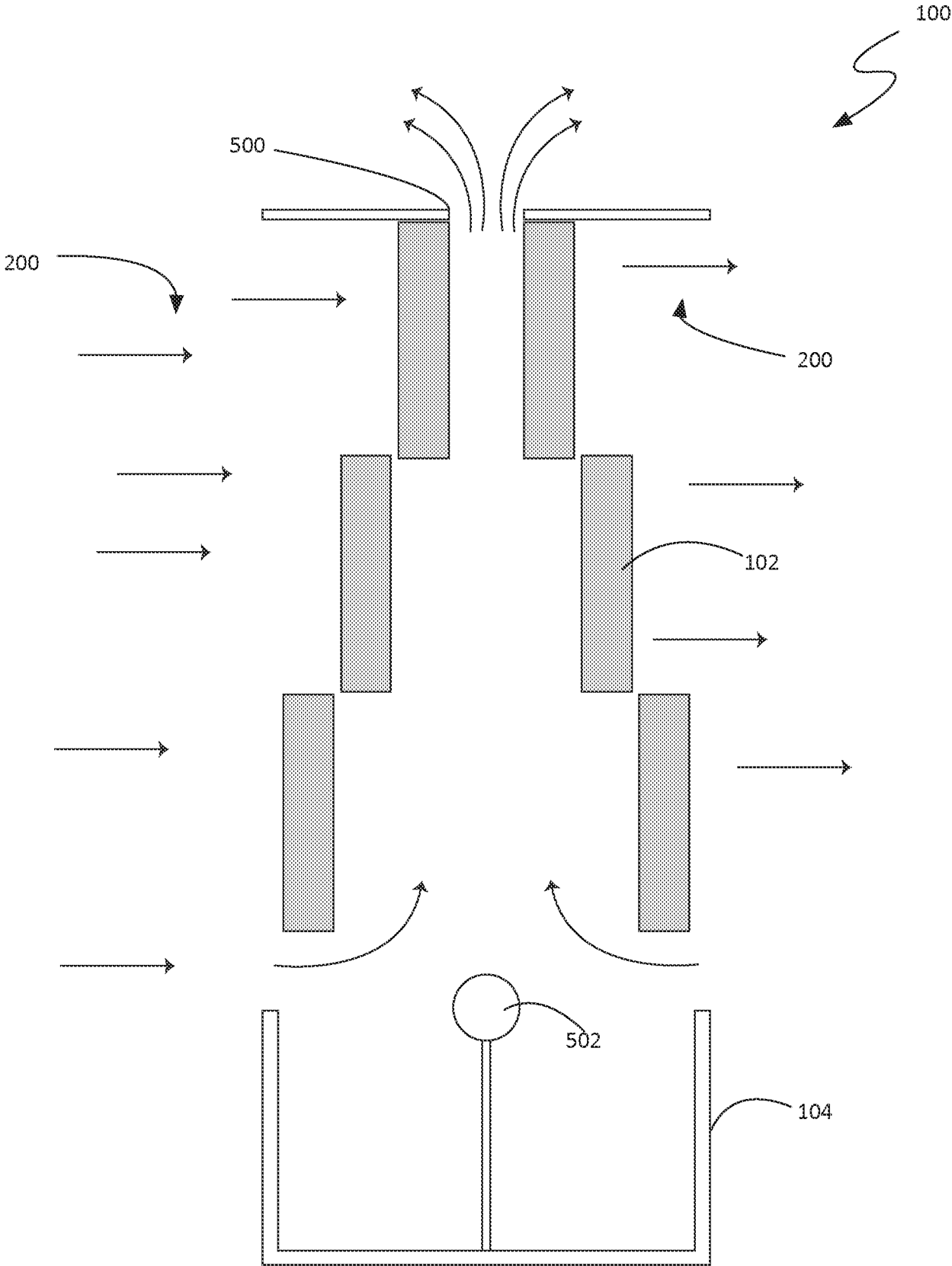


FIG. 5A

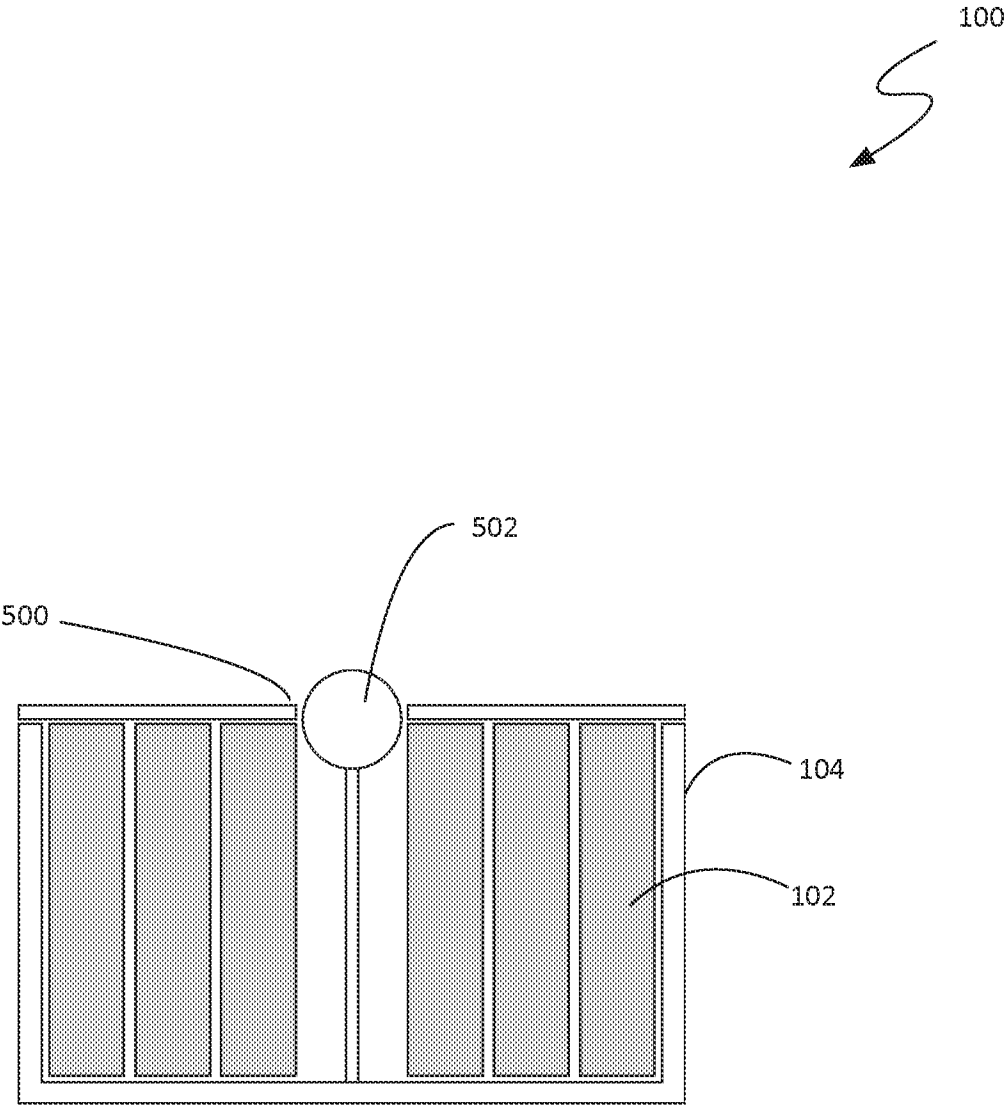


FIG. 5B

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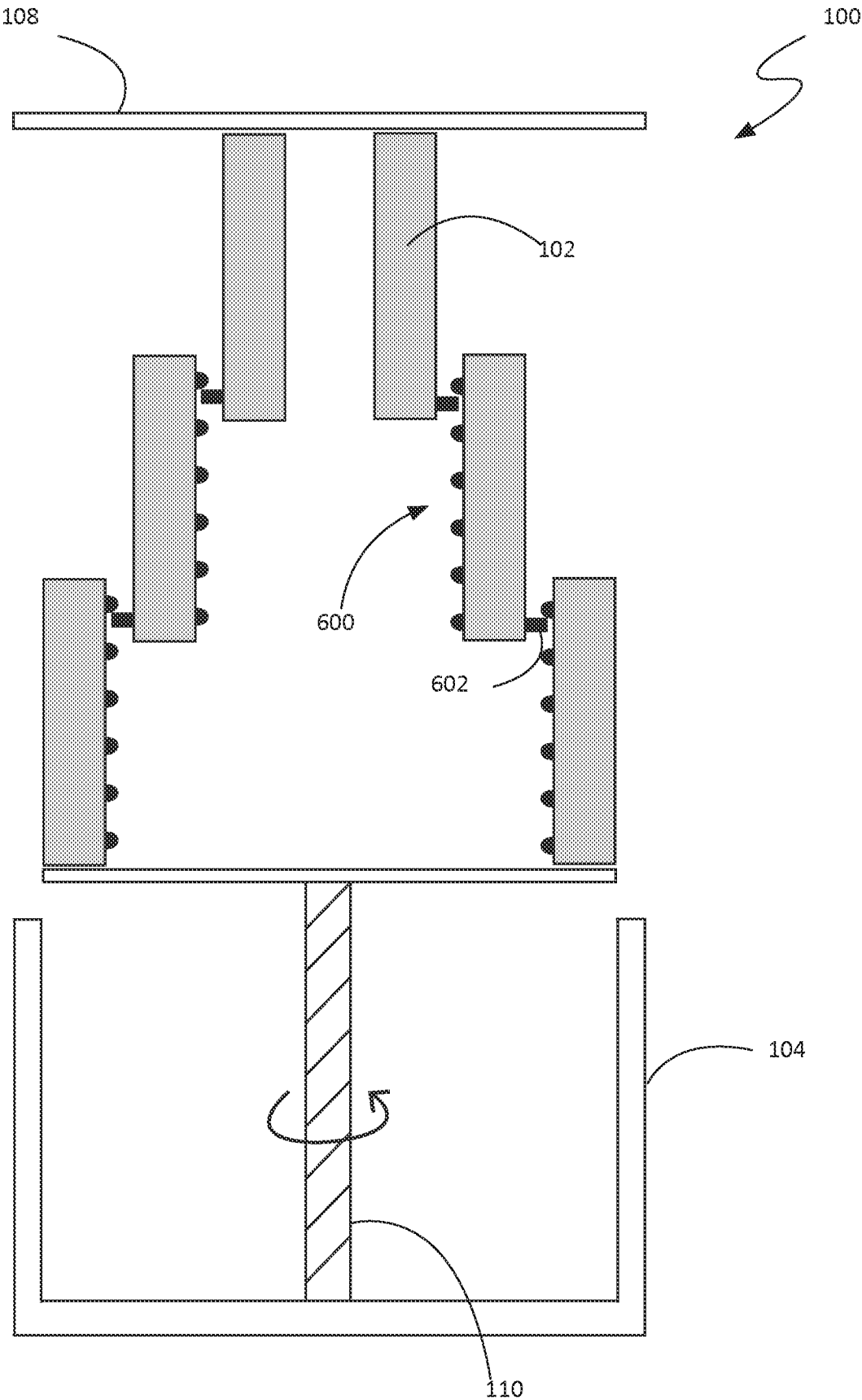


FIG. 6

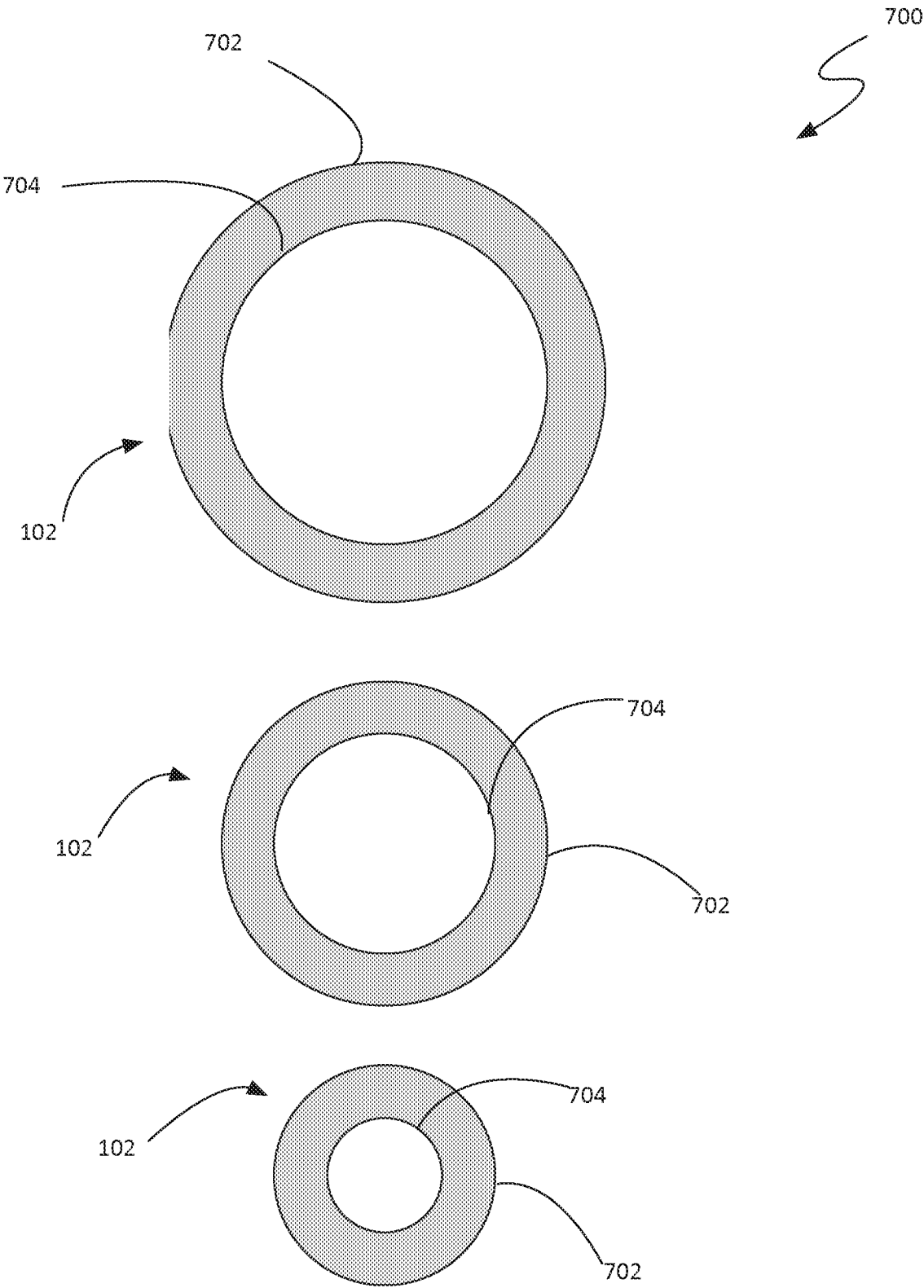


FIG. 7A

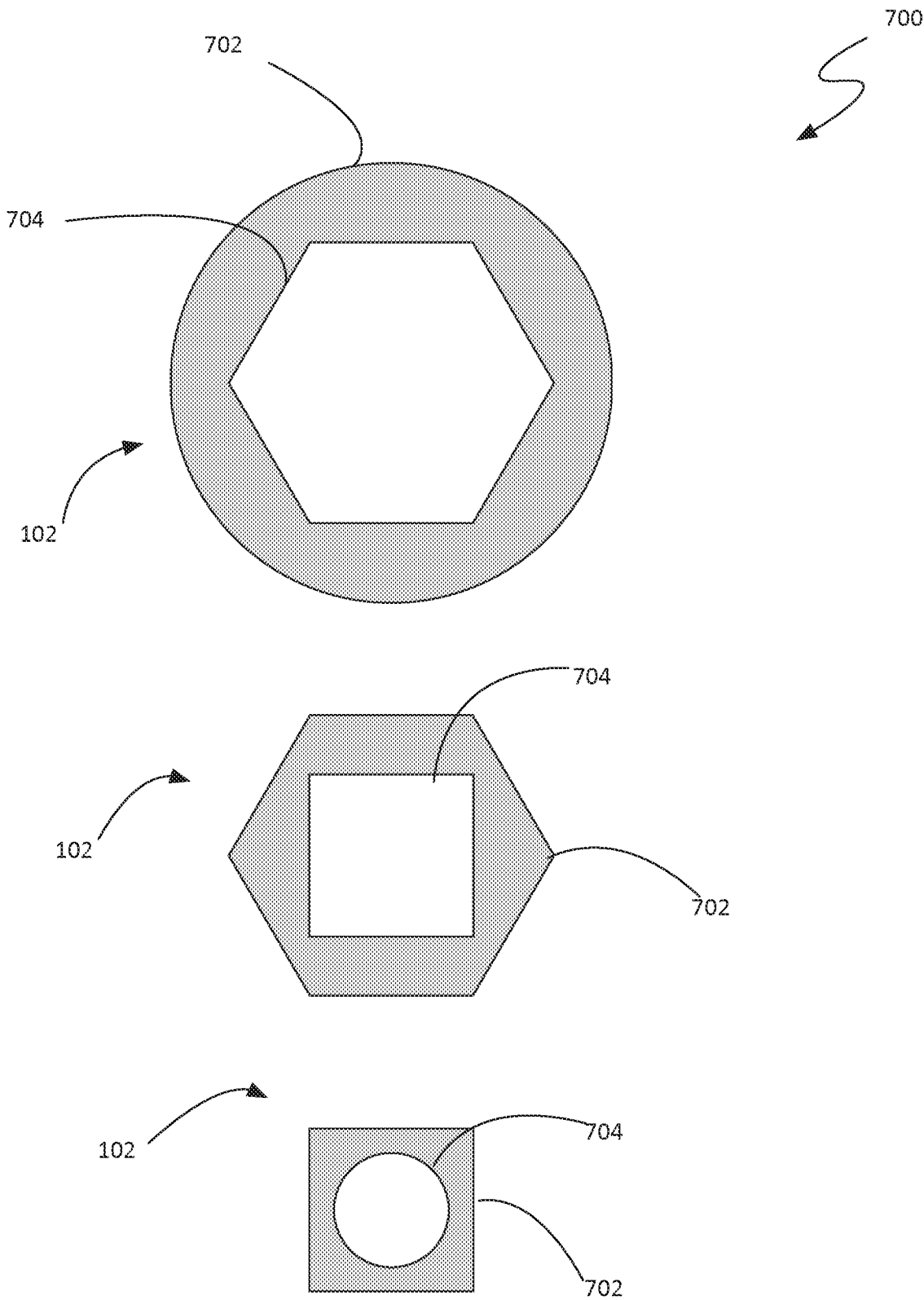


FIG. 7B

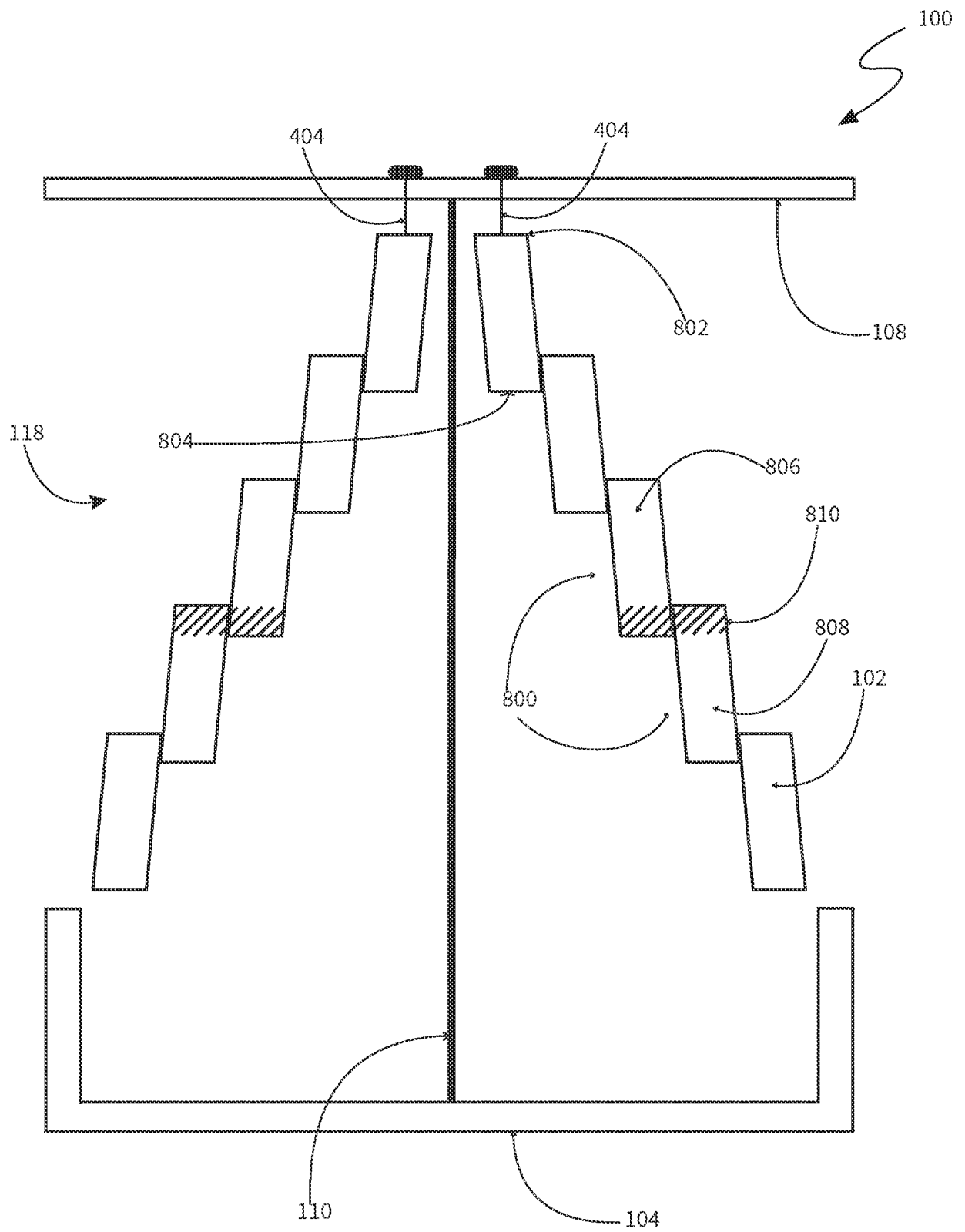


FIG. 8A

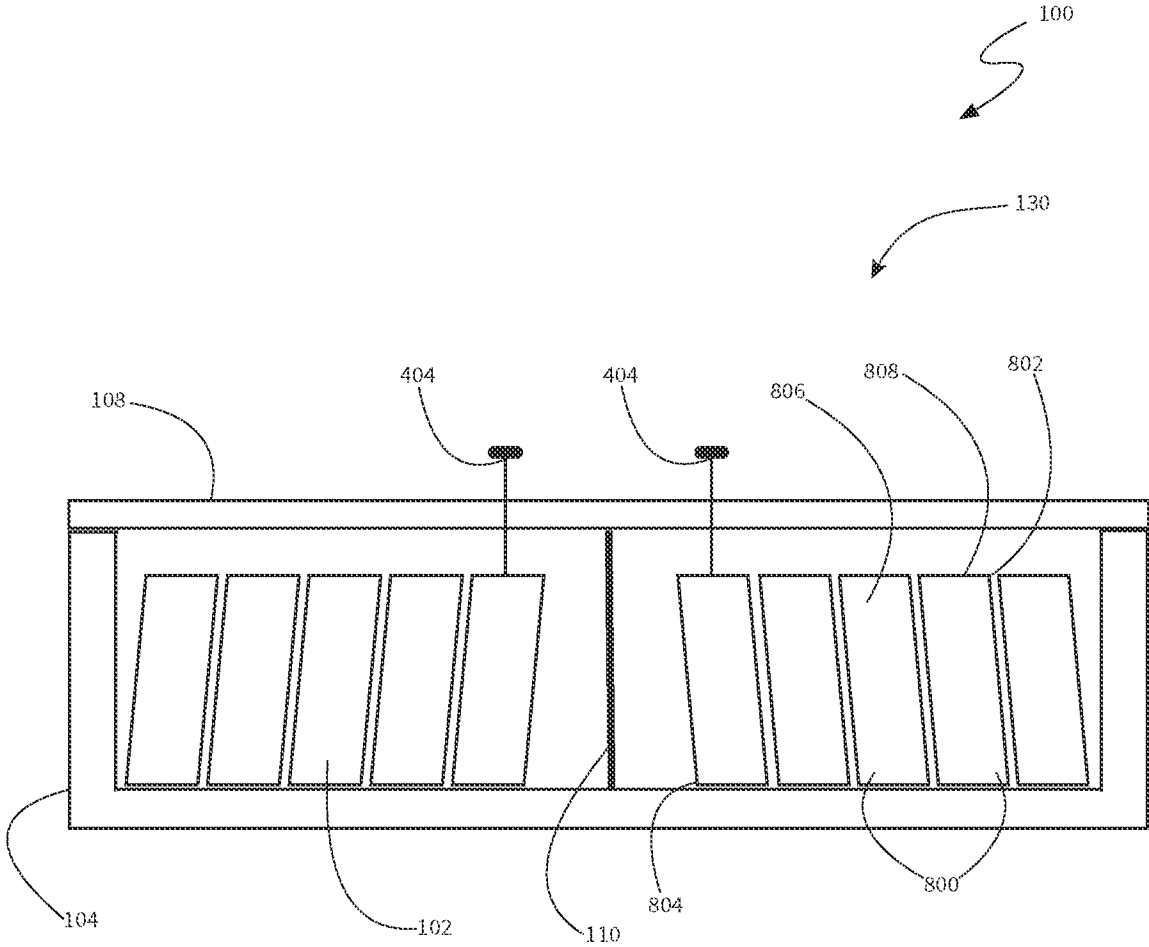


FIG. 8B

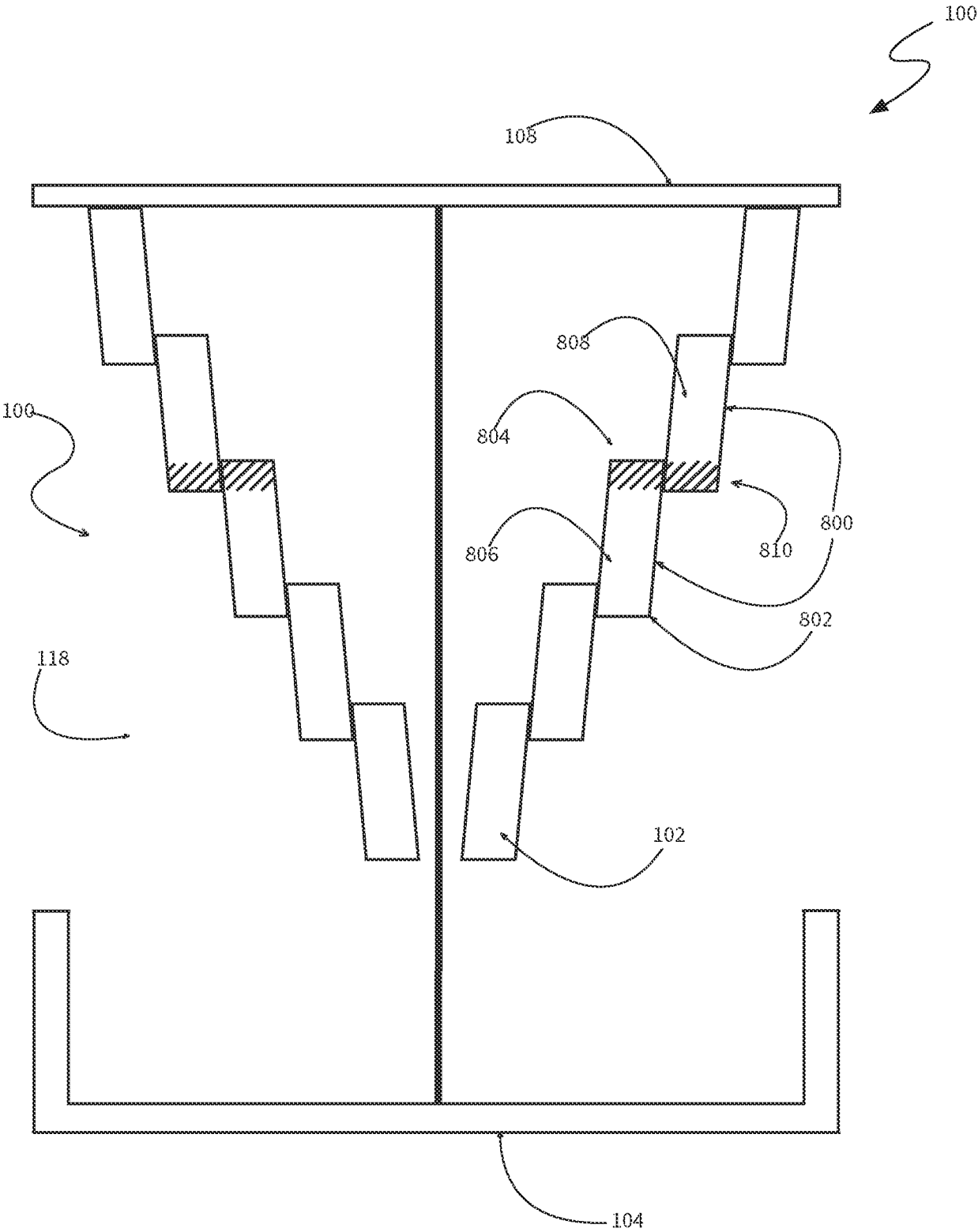


FIG. 8C

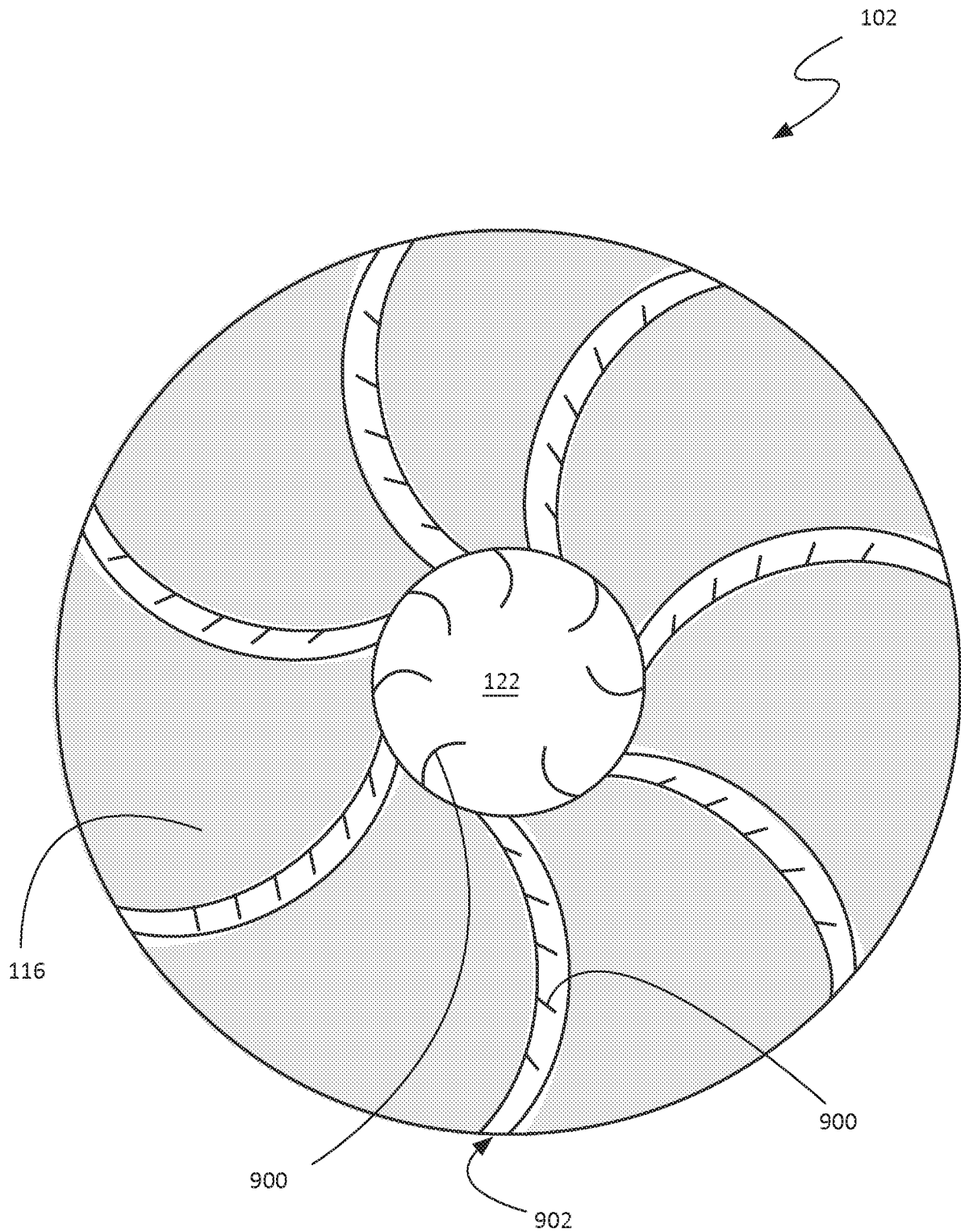


FIG. 9

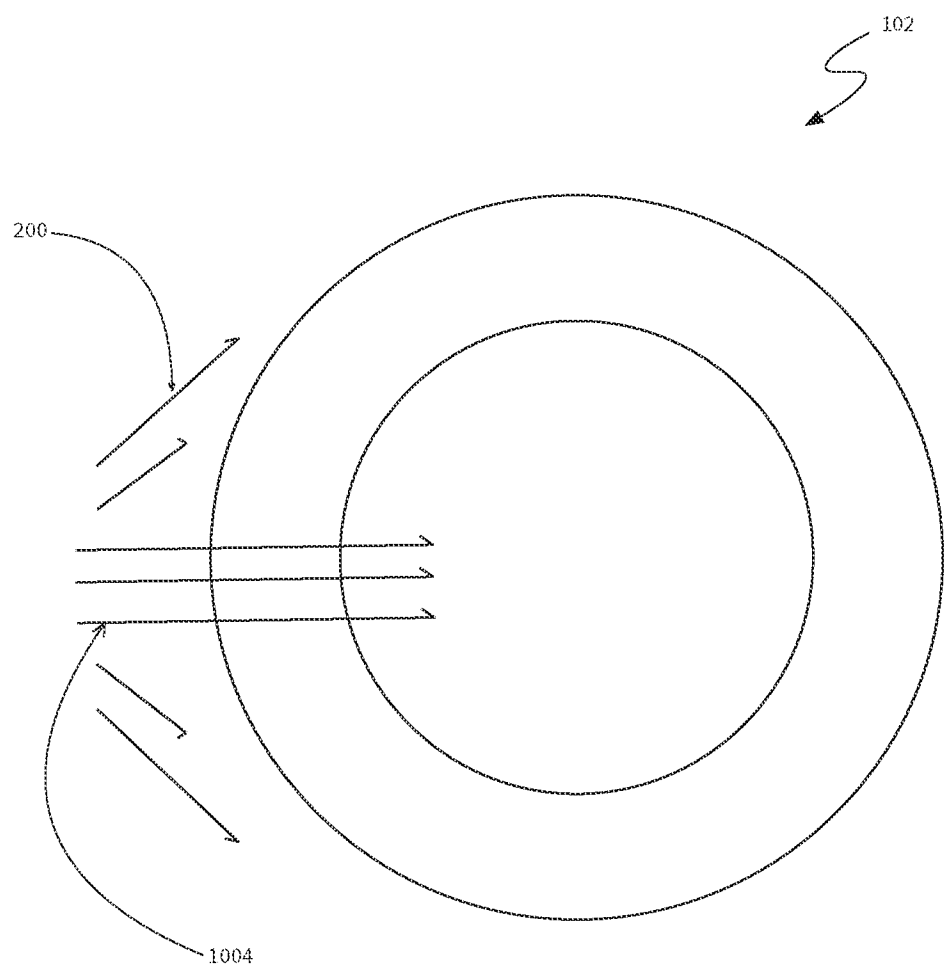


FIG. 10

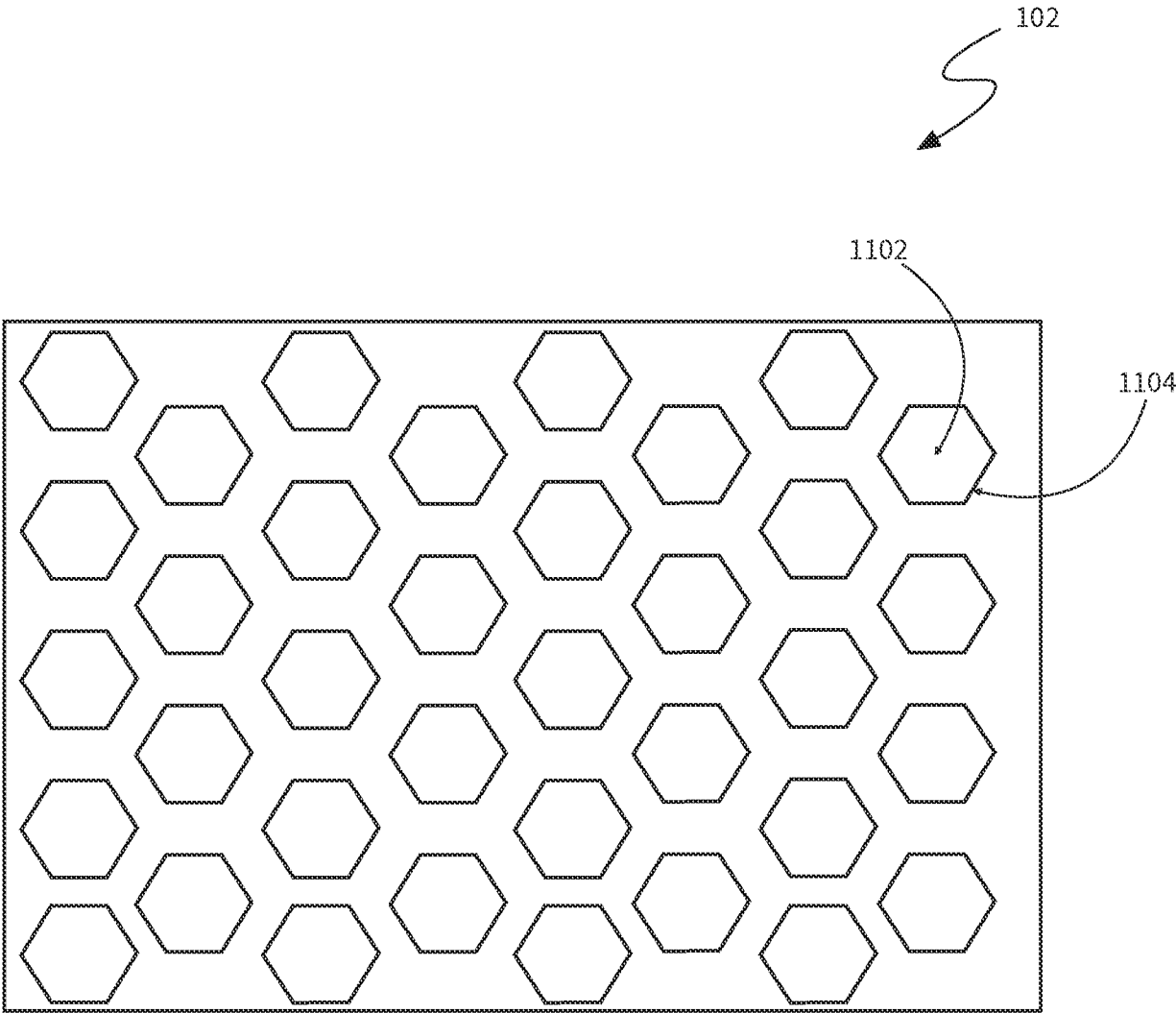


FIG. 11A

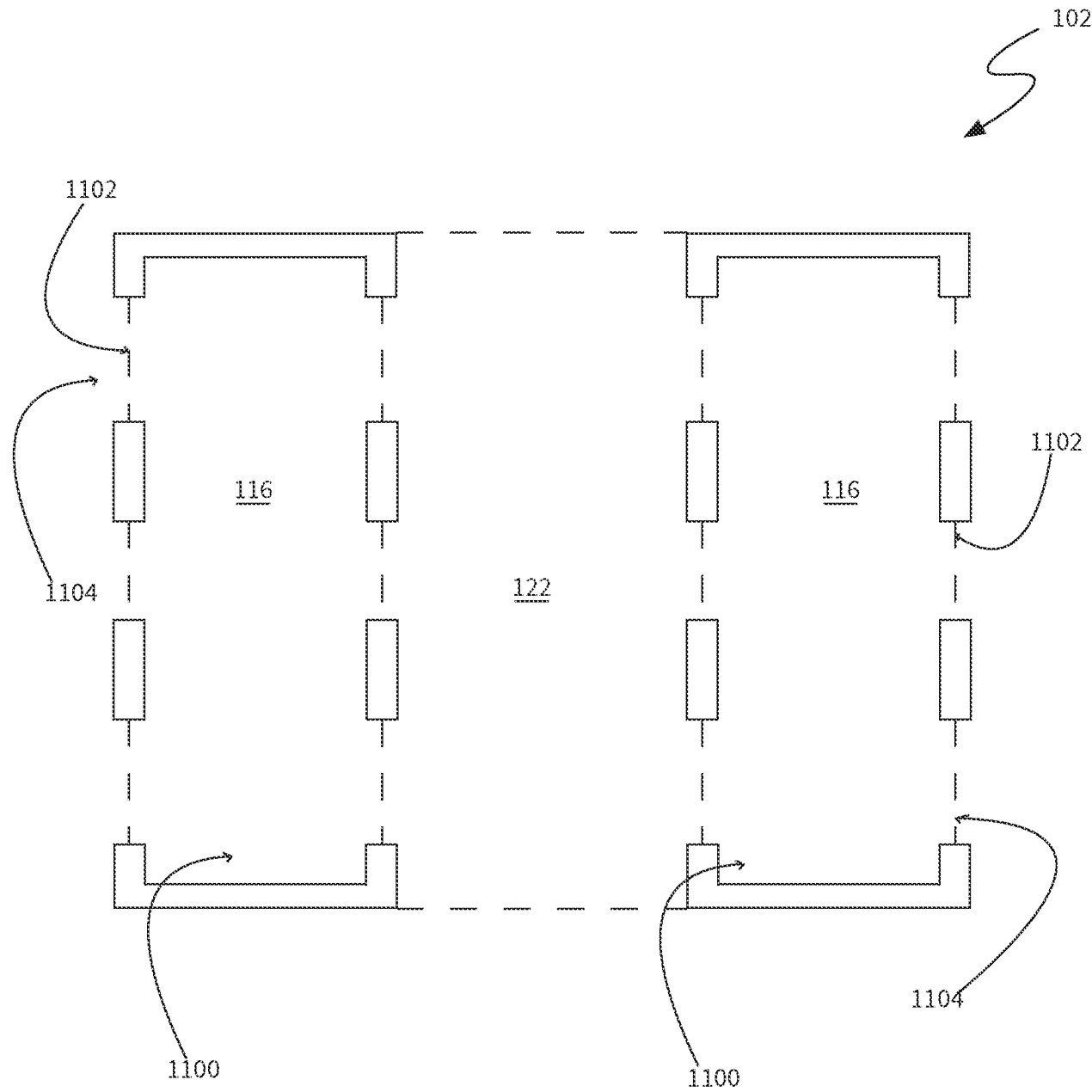


FIG. 11B

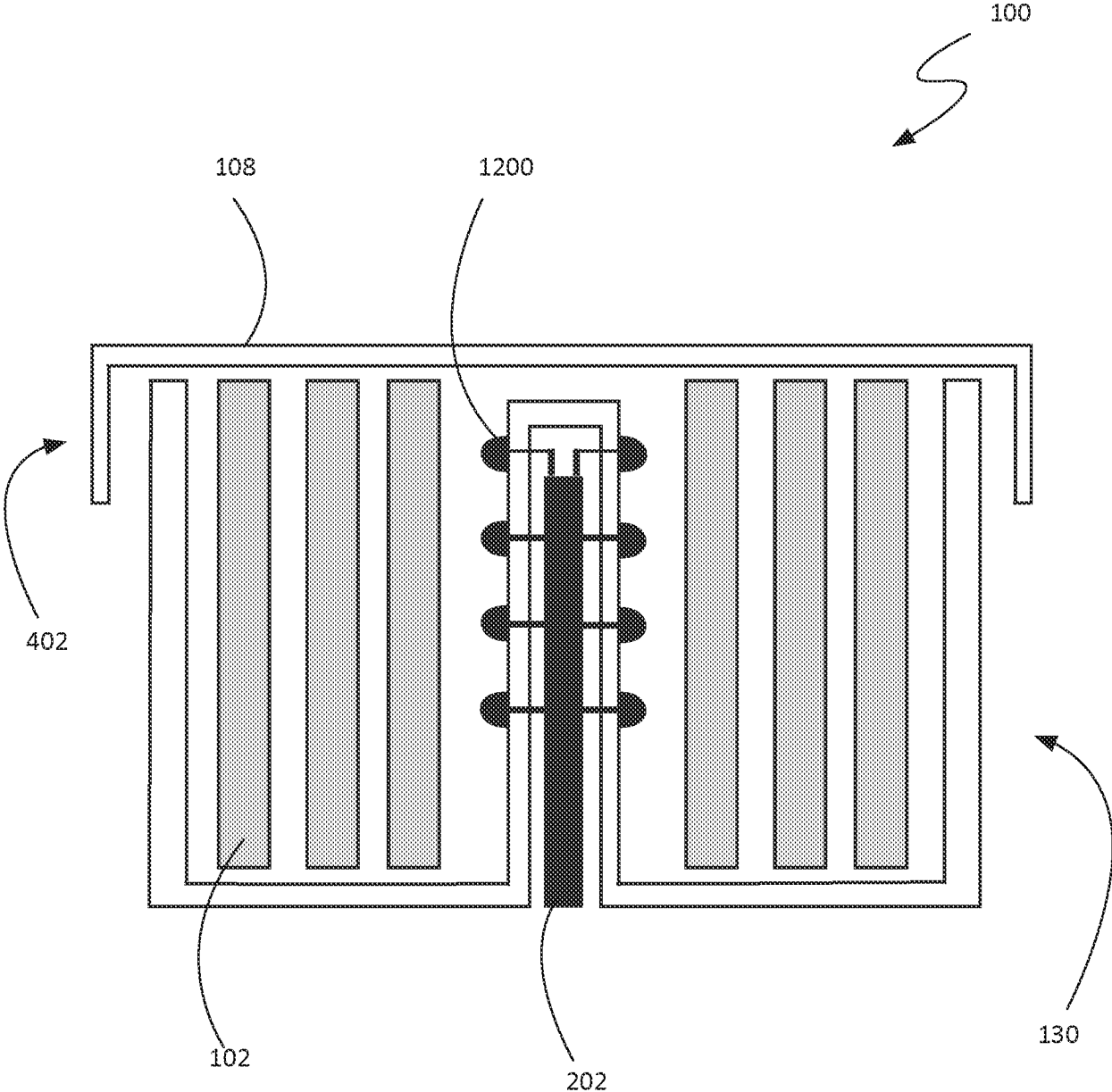


FIG. 12

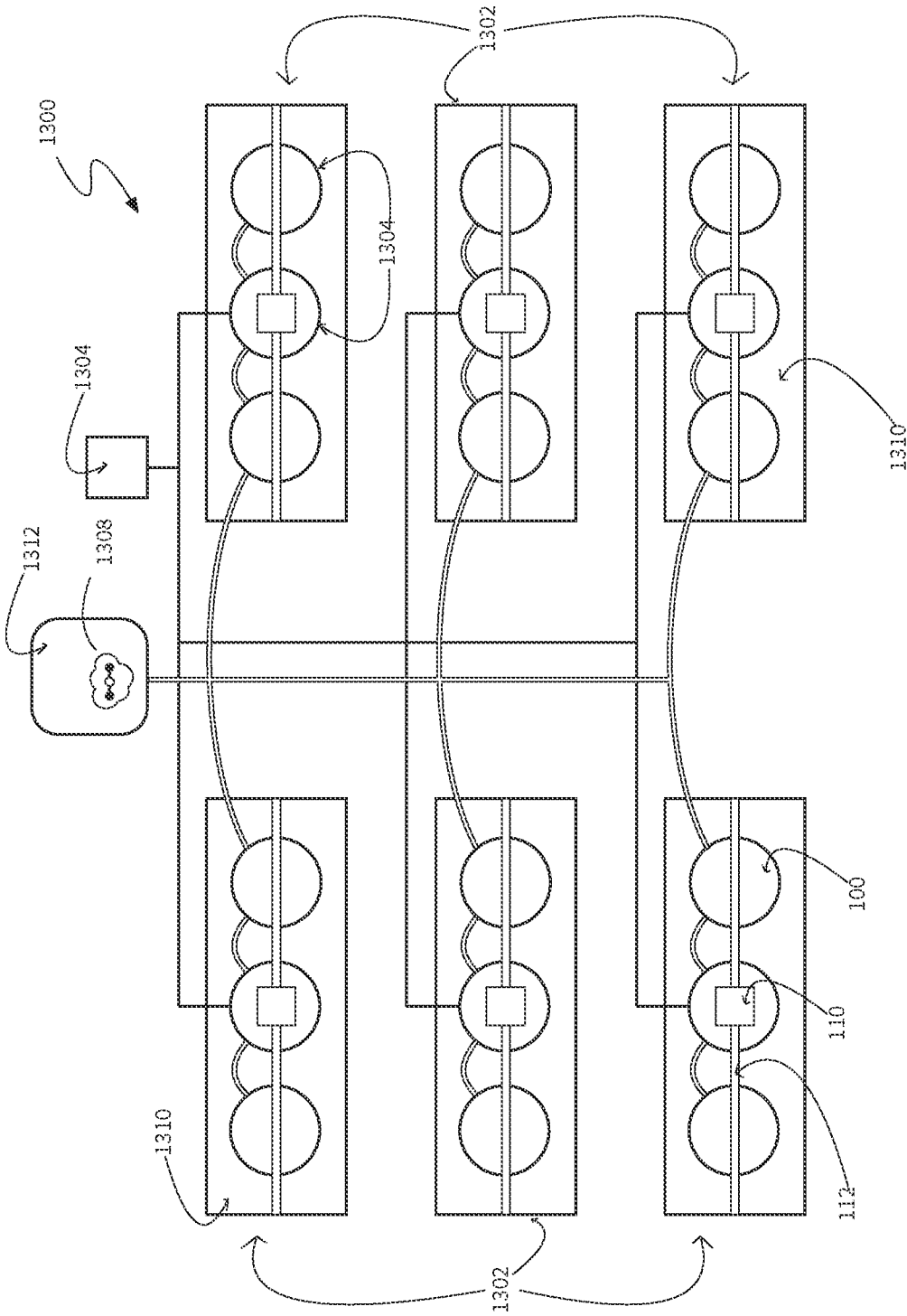


FIG. 13A

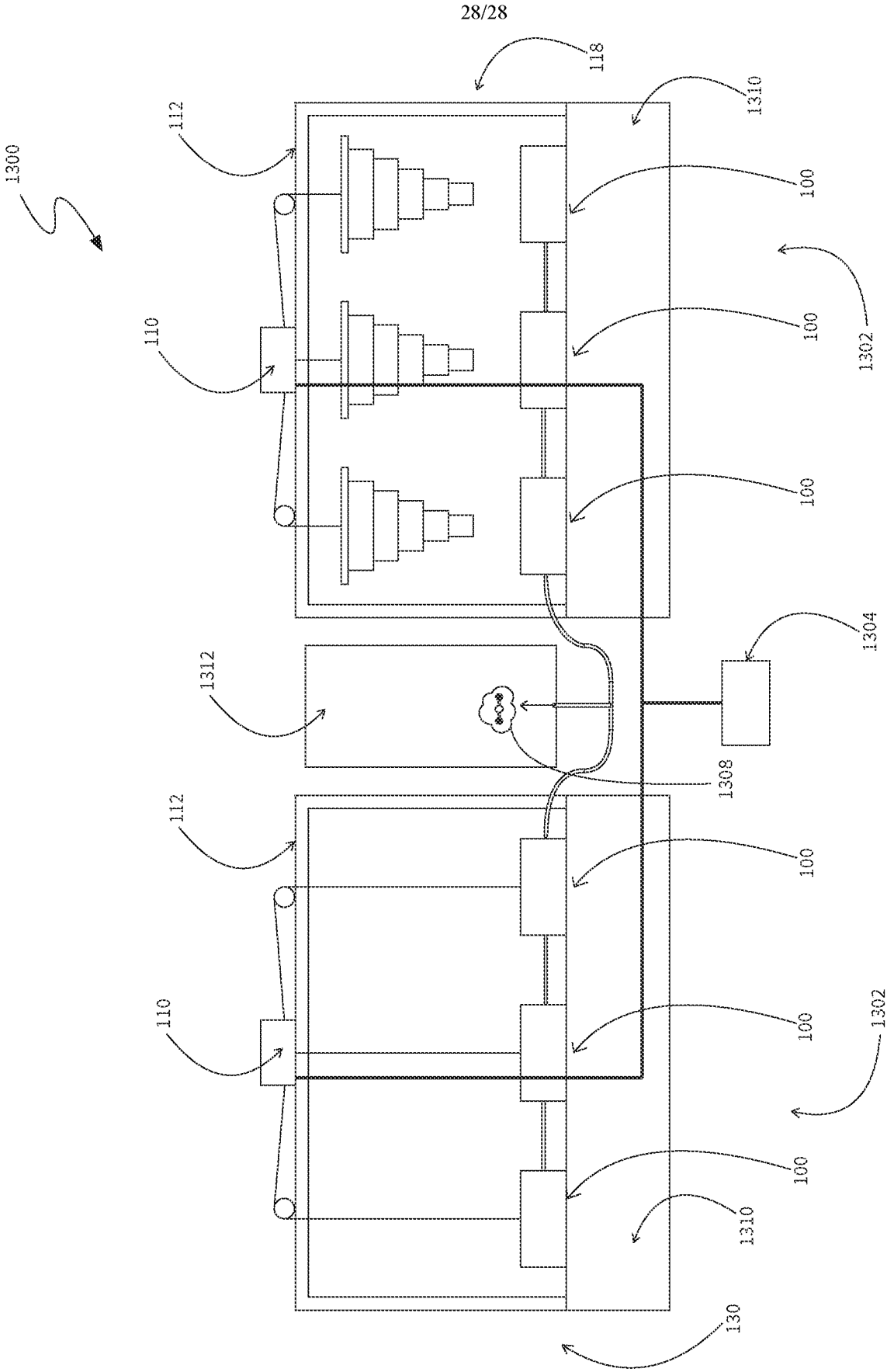


FIG. 13B

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/056300

A. CLASSIFICATION OF SUBJECT MATTERIPC: **A61M 16/22** (2025.01); **B01D 53/04** (2025.01); **B01J 20/34** (2025.01)CPC: **A61M 16/22**; **B01D 53/0423**; **B01J 20/34**; **B01D 2253/34**

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)

See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2022/115785 A1 (ARIZONA BOARD OF REGENTS ON BEHALF OF ARIZONA STATE UNIVERSITY) 02 June 2022 (02.06.2022) entire document	1-66
A	WO 2022/115773 A1 (ARIZONA BOARD OF REGENTS ON BEHALF OF ARIZONA STATE UNIVERSITY) 02 June 2022 (02.06.2022) entire document	1-66
A	US 2022/0152547 A1 (HANGZHOU OXYGEN PLANT GROUP CO. LTD.) 19 May 2022 (19.05.2022) entire document	1-66
A	US 4,801,308 A (KEEFER) 31 January 1989 (31.01.1989) entire document	1-66
A	US 2018/0313296 A1 (THERMOLIFT INC.) 01 November 2018 (01.11.2018) entire document	1-66



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See patent family annex.

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“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

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“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

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Date of mailing of the international search report

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