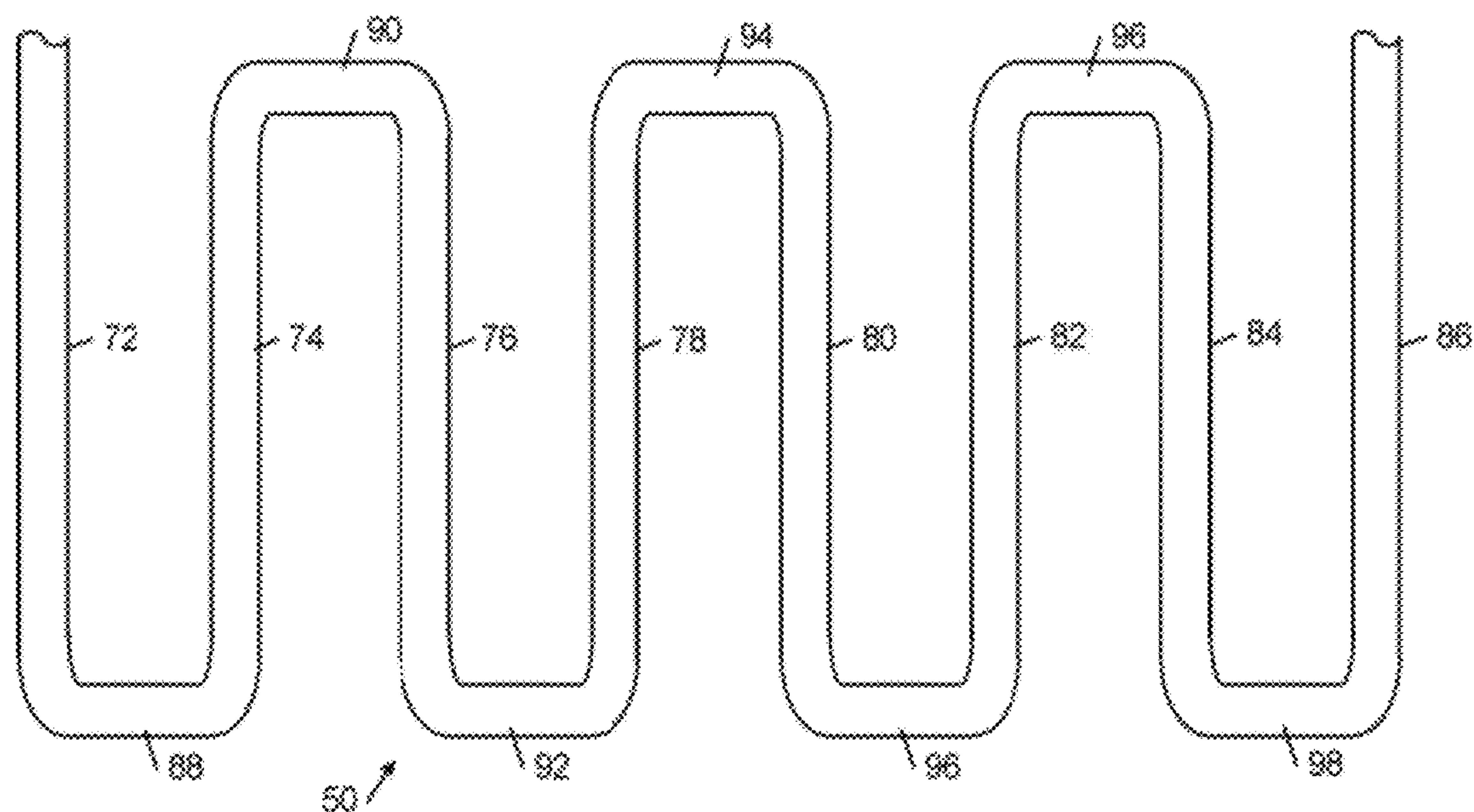


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(19) **United States**(12) **Patent Application Publication**
Conley(10) **Pub. No.: US 2012/0312295 A1**(43) **Pub. Date: Dec. 13, 2012**(54) **SOLAR THERMAL COLLECTION
APPARATUS AND METHODS***F24J 2/12* (2006.01)*F24J 2/48* (2006.01)(76) Inventor: **Gary D. Conley**, Saratoga, CA
(US)(52) **U.S. Cl. 126/652; 126/694; 126/676; 126/663;
29/890.033**(21) Appl. No.: **13/155,602**(22) Filed: **Jun. 8, 2011****Publication Classification**(51) **Int. Cl.***F24J 2/05* (2006.01)*B21D 53/06* (2006.01)*F24J 2/24* (2006.01)(57) **ABSTRACT**

A solar thermal collector includes a receptacle and a fluid conduit. The receptacle is evacuated to a subatmospheric pressure. The receptacle includes a window and a reflector facing the window. The window and the reflector are exposed to the subatmospheric pressure in the receptacle. The fluid conduit extends through the receptacle between the window and the reflector. The reflector concentrates solar radiation passing through the window onto the fluid conduit.



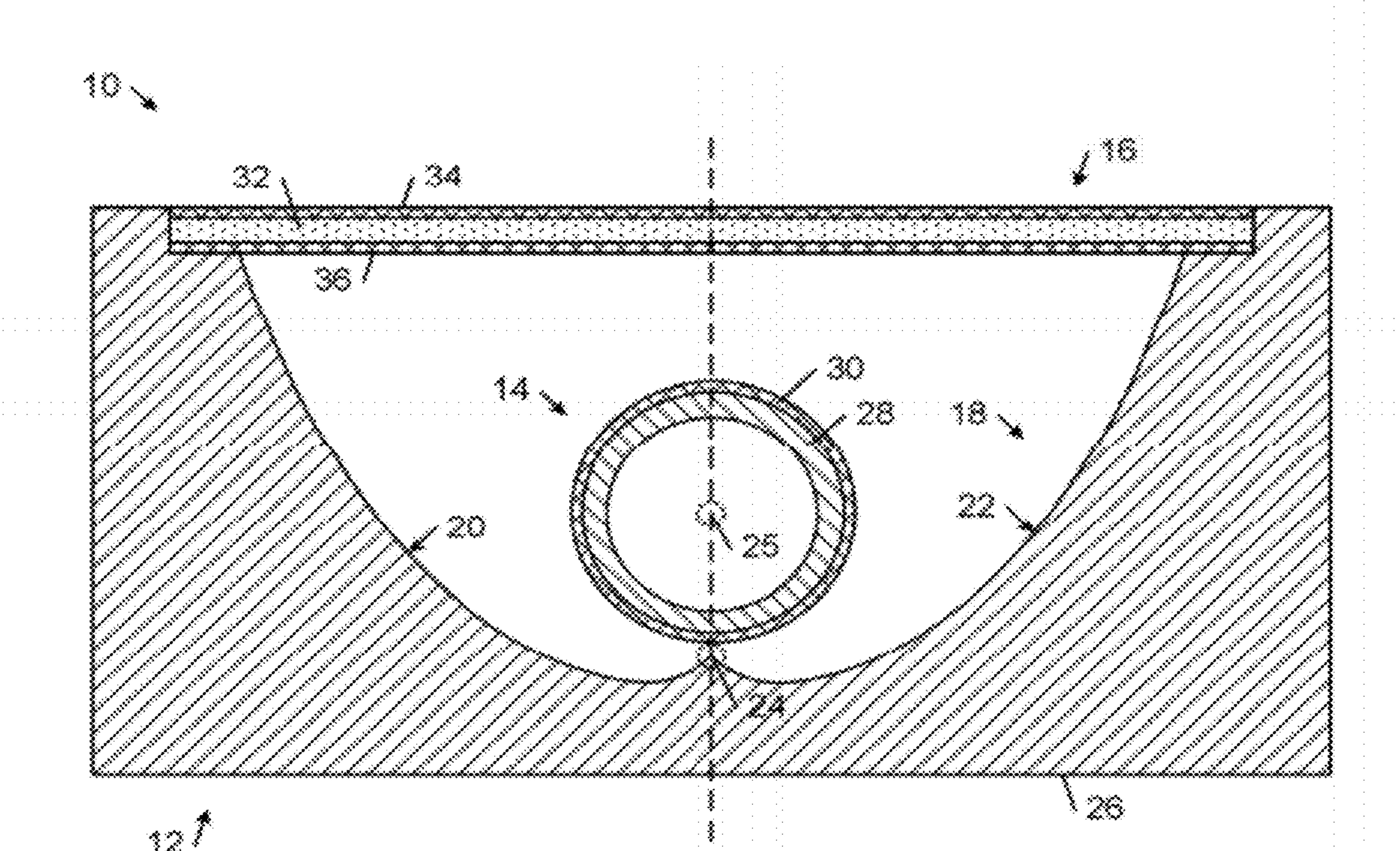


FIG. 1A

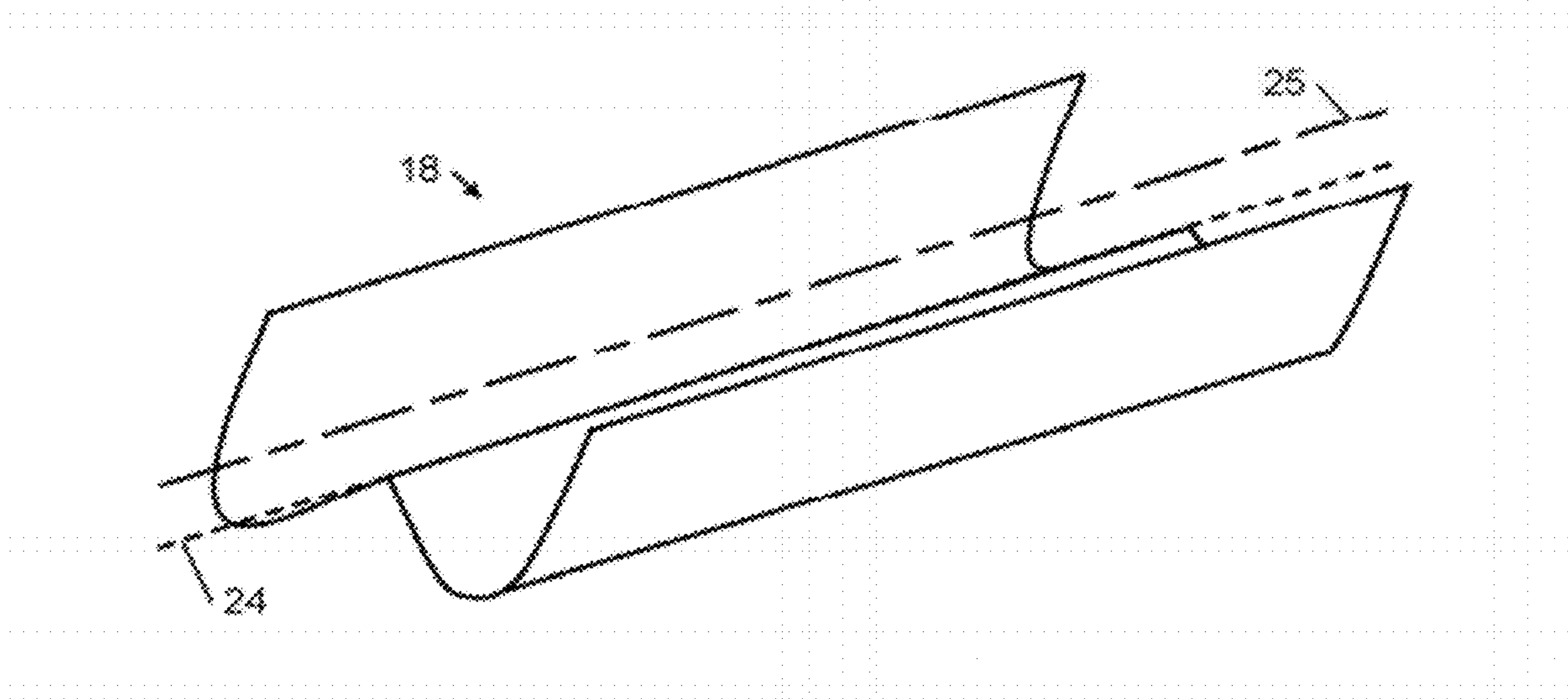


FIG. 1B

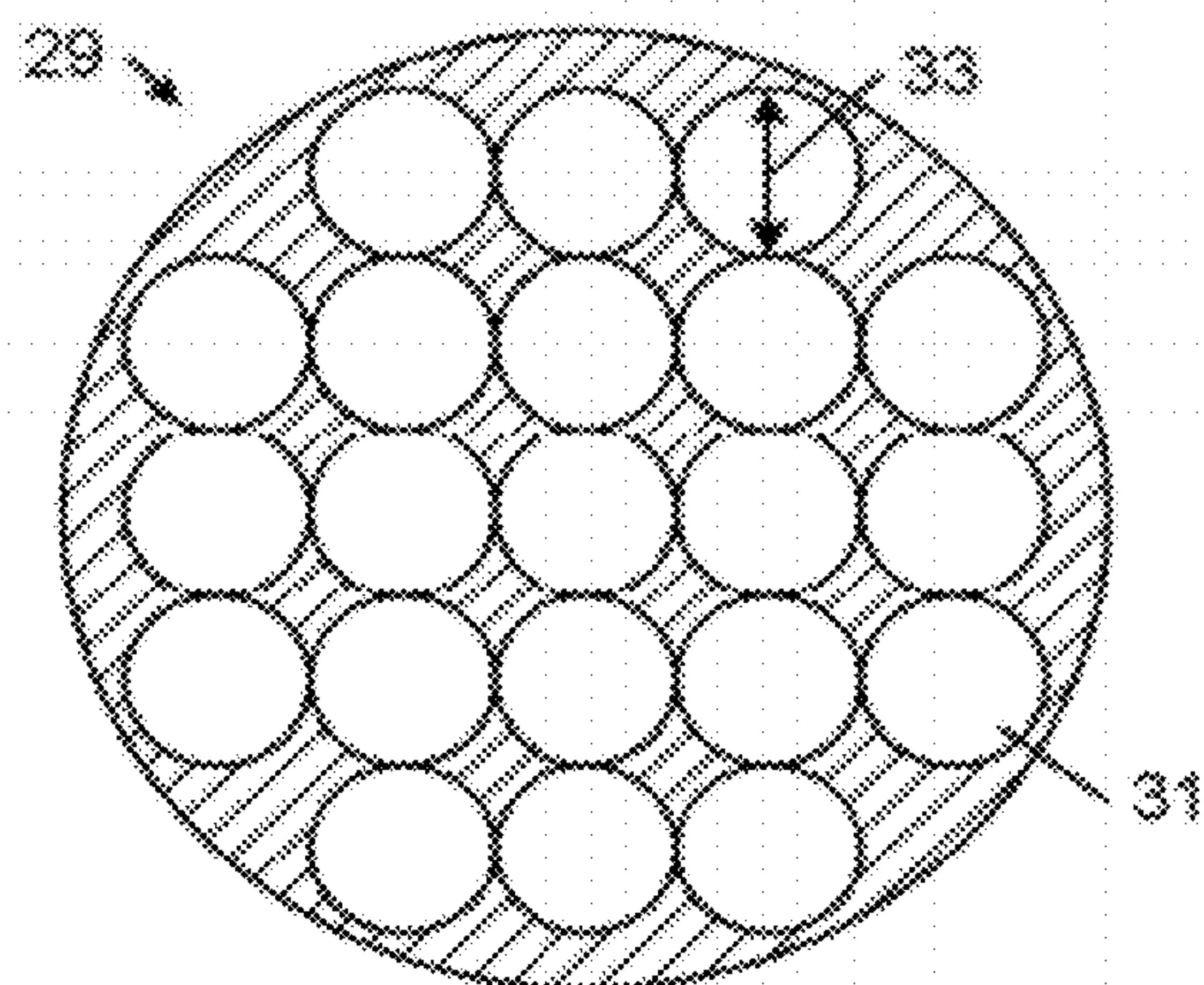


FIG. 2

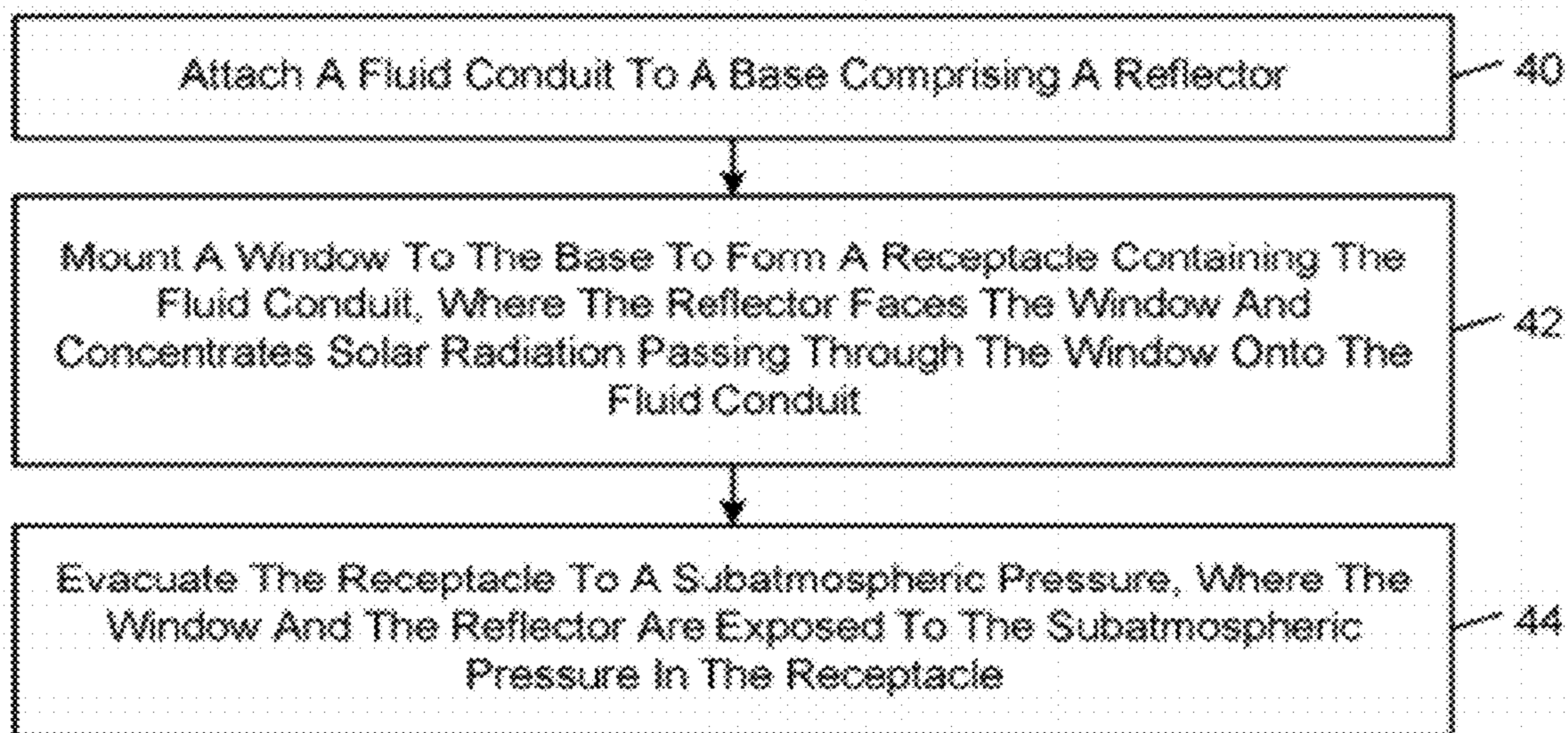


FIG. 3

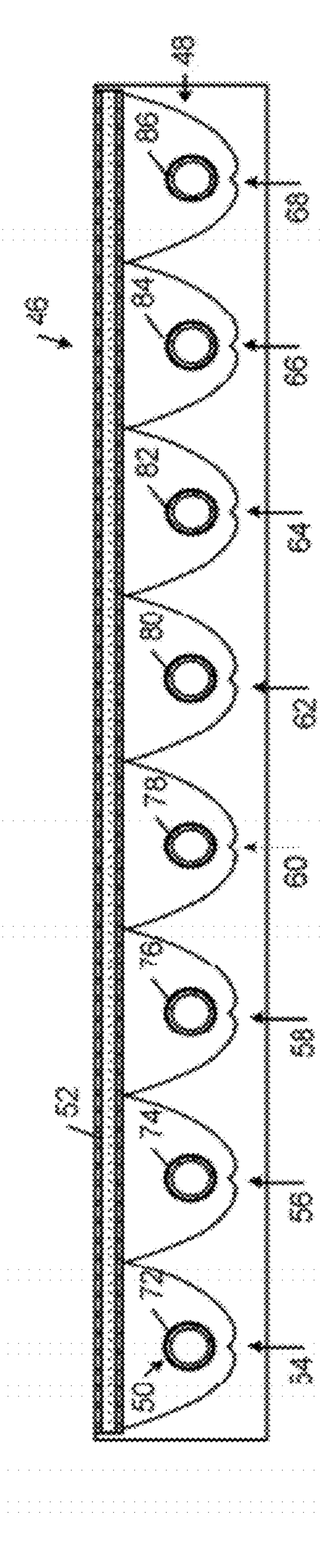


FIG. 4A

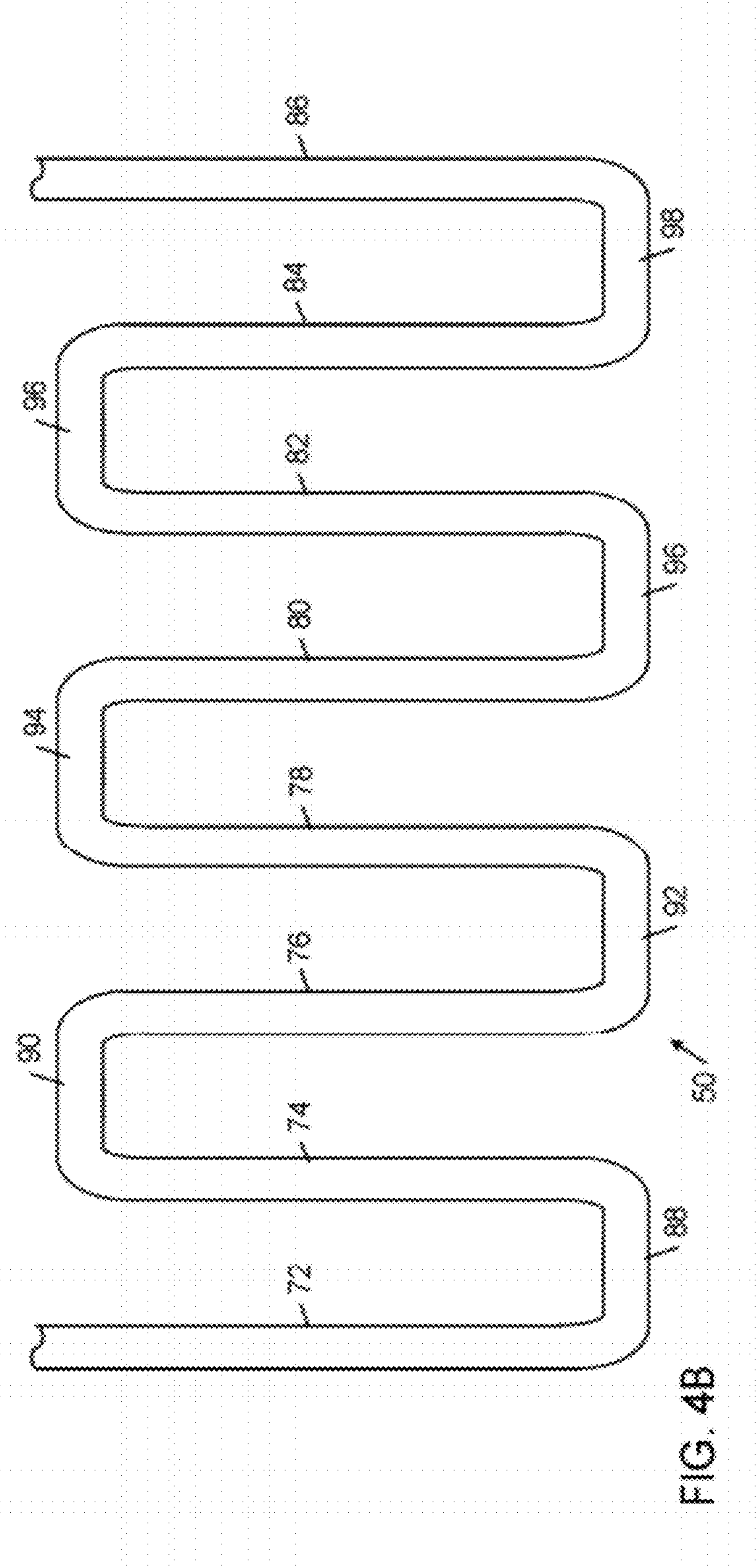


FIG. 4B

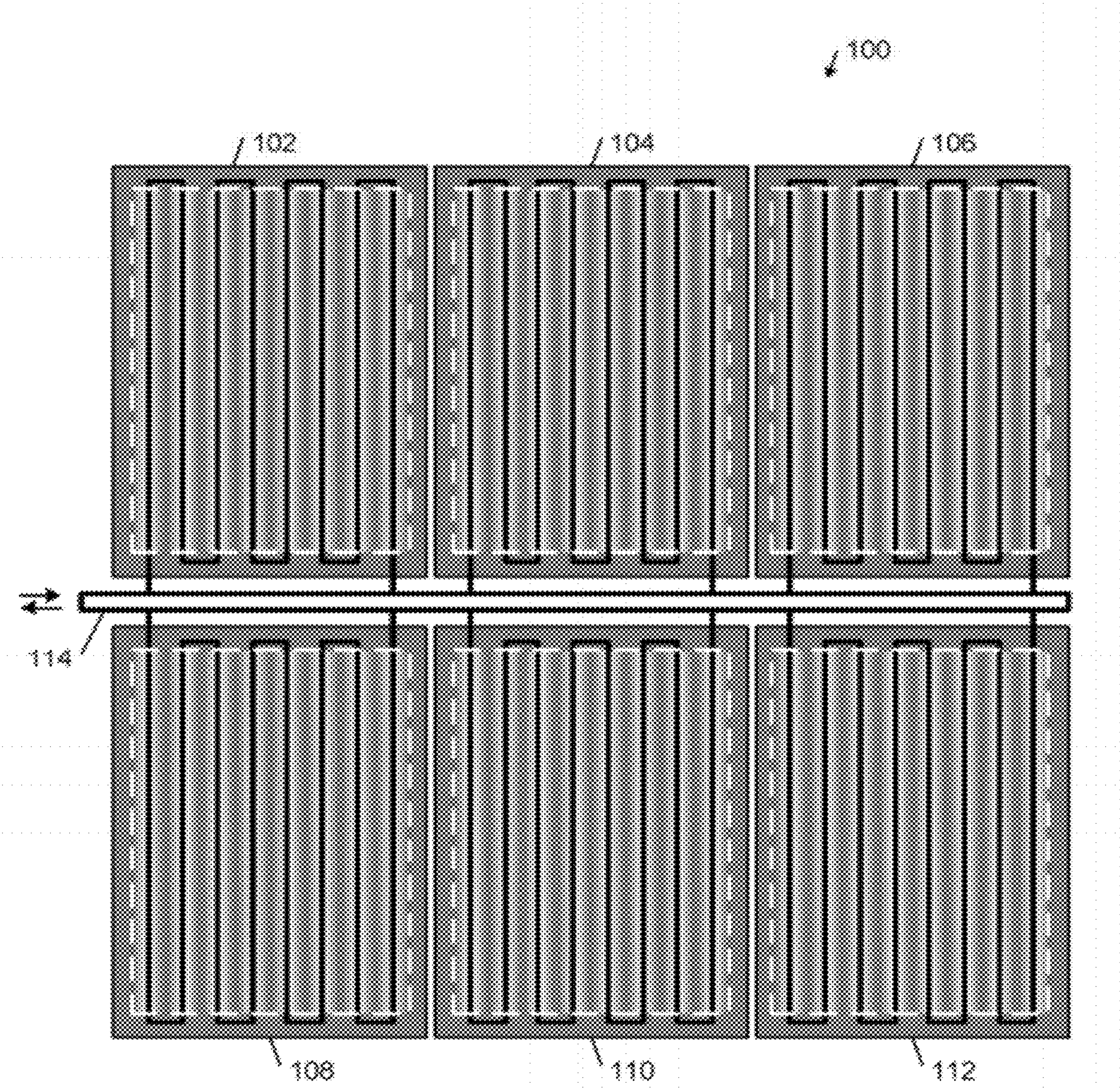


FIG. 5

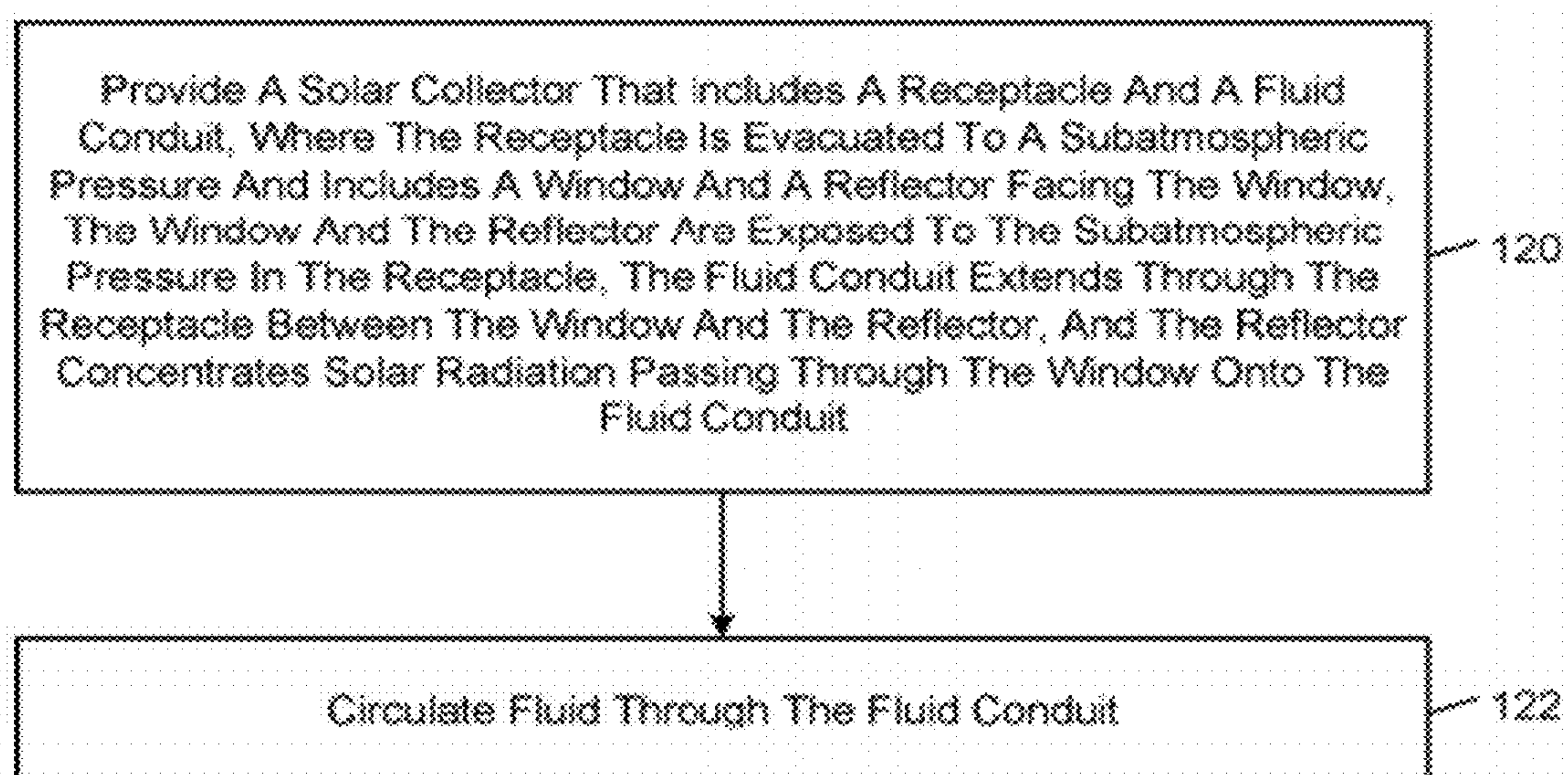


FIG. 6

SOLAR THERMAL COLLECTION APPARATUS AND METHODS

BACKGROUND

[0001] Solar thermal collectors collect heat by absorbing solar radiation. Solar thermal collectors come in a variety of different types, including flat-plate collectors, evacuated tubes, and solar concentrating collectors. A flat plate solar thermal collector has a broad flat plate solar radiation absorber, whereas an evacuated tube collector contains an absorber within an evacuated tube. A concentrating collector includes a reflector that focuses radiant energy onto a localized solar radiation absorber. In both cases, the solar radiation absorber converts the solar radiation into heat energy that typically is transferred to a circulating heat transfer fluid. Solar thermal collectors may be incorporated into stationary installations or into installations that track solar azimuthal position.

DESCRIPTION OF DRAWINGS

[0002] FIG. 1A is a diagrammatic cross-sectional view of an example of a solar thermal collector.

[0003] FIG. 1B is a diagrammatic perspective view of an example of a reflector.

[0004] FIG. 2 is a diagrammatic cross-sectional view of an example of a fluid conduit.

[0005] FIG. 3 is a flow diagram of an example of a method of manufacturing a solar thermal collector.

[0006] FIG. 4A is a diagrammatic cross-sectional view of an example of a solar thermal collector.

[0007] FIG. 4B is a diagrammatic top view of an example of a fluid conduit.

[0008] FIG. 5 is a diagrammatic top view of an example of a solar thermal collector.

[0009] FIG. 6 is a flow diagram of an example of a method of using a solar thermal collector.

DETAILED DESCRIPTION

[0010] In the following description, like reference numbers are used to identify like elements. Furthermore, the drawings are intended to illustrate major features of exemplary embodiments in a diagrammatic manner. The drawings are not intended to depict every feature of actual embodiments nor relative dimensions of the depicted elements, and are not drawn to scale.

[0011] At least some of the examples that are described herein provide solar collection apparatus and methods that reduce manufacturing costs, improve reliability, and improve efficiency through the incorporation of a reflector and a fluid conduit into an evacuated receptacle. These examples eliminate the plurality of individual evacuated glass tubes that typically are used in prior solar panel designs to contain the absorber elements. In this way, these examples are able to achieve low convective losses while avoiding the increased manufacturing complexity and cost associated with such evacuated tube based solar thermal collectors. At least some of these examples may be assembled with substantially fewer fluid connections as compared to evacuated-tube-based solar thermal collectors, which require a fluid connection for each tube. By reducing the number of fluid connections and their associated convective losses, the operating performance of these examples are expected to be higher than evacuated tube based solar thermal collectors. In addition, by containing the

fluid connections within the evacuated space, these examples enable convective losses and insulation requirements to be significantly reduced.

[0012] FIG. 1A shows an example of a solar thermal collector **10** that includes a receptacle **12** and a fluid conduit **14** (also referred to as an absorber). The receptacle **12** is evacuated to a subatmospheric pressure and includes a window **16** and a reflector **18** facing the window. The window **16** and the reflector **18** are exposed to the subatmospheric pressure in the receptacle **12**. The fluid conduit **14** extends through the receptacle **12** between the window **16** and the reflector **18**. The reflector **12** concentrates solar radiation passing through the window **16** onto the fluid conduit **14**. In some examples the fluid conduit **14** defines a generally cylindrical flow path with a circular cross-section.

[0013] The reflector **18** may be any type of reflector that concentrates incoming solar radiation onto the fluid conduit **14**, including imaging solar concentrators (e.g., cylindrical and parabolic concentrators) and non-imaging solar concentrators that use non-imaging optics geometries to concentrate solar radiation onto the fluid conduit **14**. In the illustrated example, the reflector **18** includes a pair of concave radiation-reflective surface portions **20**, **22** that meet along a longitudinal axis **24** (represented by the center of the dashed circle) in a longitudinal plane about which the concave radiation-reflective surface portions **20**, **22** are symmetrical. In other examples, the concave radiation-reflective surface portions are asymmetrically offset on opposite sides of the longitudinal plane. In some examples, the pair of concave surface portions form a non-imaging concentrator collector (NICC) trough (see FIG. 1B). In these examples, the concave surface portions are curved with respective parabolic profiles that are inclined at the same angle with respect to the longitudinal plane and focus incoming solar radiation to a common confocal solar concentration line **25** that lies in the longitudinal plane and is parallel to the longitudinal axis **24**, as shown in FIG. 1B.

[0014] In the illustrated embodiment, the reflector **18** is integrally incorporated into a base **26** of the receptacle **12**. In some examples, the base **26** is a unitary metal structure that comprises the reflector **18**. The unitary metal structure may be formed, for example, by a metal extrusion process (e.g., an aluminum extrusion process) or a metal stamping process (e.g., a steel stamping process). In other examples, the base **26** is an extruded or molded plastic piece and the reflector **18** is made of a metal (e.g., an aluminum or silver film) that is bonded to the plastic base. In some examples, a getter (e.g., a zirconium based getter) is applied to the reflector **18** in order to capture gases that outgas from or leakage into the receptacle **12** and thereby prevent oxidation of the receptacle (which can serve as a source of emissive loss) after the receptacle **12** has been sealed and evacuated.

[0015] The fluid conduit **14** extends adjacent the reflector **18** along the confocal solar concentration line **25** of the reflector **18**. The fluid conduit **14** may be any type of structure through which a heat transfer fluid (e.g., air, water, oil such as synthetic paraffin oil, and super critical carbon dioxide) can be circulated. In some examples, the fluid conduit **14** is a hollow cylindrical metal tube **28** (e.g., an aluminum or copper tube) that includes an outer surface and an inner surface. In the illustrated example, the outer surface of the fluid conduit **14** carries a solar radiation absorbent coating **30**. The coating **30** typically includes a solar selective absorbent layer (e.g., aluminum nitride, metal-aluminum nitride cermets, or tita-

niun oxide layer) and, optionally, one or more additional layers, including an overlying antireflection layer that passes solar radiation to the radiation absorbent layer with minimal reflections and an underlying stabilizing layer under the radiation absorbent layer. In some examples, the solar radiation absorbent coating 30 targets maximum absorption of solar thermal energy and rejects solar spectra outside this range, while maintaining an ideal emissivity of less than 6% at 180° Celsius. In some examples, the inner surface of the fluid conduit 14 is textured with surface features that disturb the flow of fluid through the fluid conduit 14 to reduce laminar flow and increase heat transfer to the circulating fluid. In some of these examples, the textured inner surface of the fluid conduit 14 is formed by creating patterns (e.g., helical patterns) of ribs and grooves in the inner surface of the fluid conduit using a knurling tool.

[0016] FIG. 2 shows an example 29 of the fluid conduit 14 that includes multiple separate fluid channels 31 for concurrently conveying fluid through the receptacle 12. This example has particular utility for circulating heat transfer fluids at high pressure (e.g., 10^3 pounds per square inch (PSI) or 6.89×10^3 kilopascals (kPa), or higher), such as supercritical, carbon dioxide (i.e., carbon dioxide at a temperature and pressure greater than or equal to its critical temperature and pressure). In some examples, each of the fluid channels 31 has a respective channel diameter 33 between 0.75 millimeter and 0.25 millimeter. In one example, each of the plurality of fluid channels 31 has a channel diameter of 0.5 ± 0.01 millimeter. In some examples, the fluid channels 31 form a matrix of parallel microchannels in a tubular structure. In some of these examples, the channels may be formed in a solid aluminum tube by electrochemical oxidation as described in Delendik et al., "Aluminium oxide microchannel plates," Nuclear Physics B—Proceedings Supplements, Volume 125, pages 394-399 (September 2003). In other examples, the fluid channels 31 may be formed by etching away sacrificial fillers (e.g., sacrificial wires) that are embedded in a tubular aluminum substrate.

[0017] Referring back to FIG. 1A, the window 16 passes solar radiation to the reflector 18. In the illustrated example, the window 16 includes a tempered glass substrate 32 that has a top surface carrying a top antireflective coating 34 and a bottom surface carrying a bottom antireflective coating 36. The antireflective coatings 34, 36 may be any of a variety of different types of antireflective coatings including, for example, porous antireflective coatings and textured multi-layer sol-gel antireflective coatings. The antireflective coatings 34, 36 reduce Fresnel losses and, together with the far-angle performance of non-imaging concentrator design of the reflector 18, mitigate blue-shift and Brewster angle losses (whereby an increase in the amount of reflected light due to the increased incident angle reduces performance) resulting from the presence of the window 16.

[0018] In the illustrated example, the base 26 of the receptacle 12 includes a peripheral groove 38 into which the window 16 is recessed such that the bottom edges of the window 16 are supported by the foot of the groove and the top edges of the window are flush with the top surface of the base 26. The window 16 is mounted to the base 26 with a connection that maintains the subatmospheric pressure in the receptacle 12. In examples in which the base is formed of a metal (e.g., aluminum) and the window 16 is formed of glass, the connection between the window 16 and the base 26 may include a glass-to-metal seal (e.g., a solder based seal or a laser

weldable glass or ceramic seal) that maintains the subatmospheric pressure in the receptacle 12.

[0019] FIG. 3 shows an example of a method of manufacturing the solar thermal collector 10.

[0020] In accordance with the method of FIG. 3, the fluid conduit 14 is attached to the base 26 (FIG. 3, block 40). In some examples, the fluid conduit 14 is supported at opposite ends of the reflector 18 by respective support structures in the base 26 such that the fluid conduit is suspended over the reflector 18. In some of these examples, one or more struts may be added to the reflector 18 to provide additional support for the fluid conduit 14 along the length of the reflector 18.

[0021] The window 16 is mounted to the base 26 to form the receptacle 12 containing the fluid conduit 14, where the reflector 18 faces the window 16 and concentrates solar radiation passing through the window onto the fluid conduit 14 (FIG. 3, block 42). As explained above, the window 16 is mounted to the base 26 with a connection that is capable of maintaining a subatmospheric pressure in the receptacle 12.

[0022] The receptacle 12 is evacuated to a subatmospheric pressure, where the window 16 and the reflector 18 are exposed to the subatmospheric pressure in the receptacle 12 (FIG. 3, block 44). In some examples the reflector 18 is evacuated to a pressure of about 10^{-3} pascal (Pa). In some examples, before the receptacle 12 is evacuated, the receptacle 12 is purged of air using an inert gas (e.g., argon) in order to reduce convective losses.

[0023] FIG. 4A shows an example of a solar thermal collector 46 that includes a reflector 48, an example 50 of the fluid conduit 14, and an example 52 of the window 16.

[0024] The reflector 48 includes an array of reflector elements 54, 56, 58, 60, 62, 64, 66, 68 each of which corresponds to the reflector 18 described above. In the illustrated example, each of the reflector elements 54-68 is formed from a respective pair of concave radiation-reflective surface portions, the concave radiation-reflective surface portions of each reflector element 54-68 meet along a respective longitudinal axis in a respective longitudinal plane about which the concave radiation-reflective surface portions are either symmetrically or asymmetrically disposed, and the respective longitudinal axes are parallel. Each reflector element 54-68 concentrates radiation passing through the window onto a different respective section of the fluid conduit 50.

[0025] Referring to FIG. 4B, the fluid conduit 50 includes parallel linear segments 72, 74, 76, 78, 80, 82, 84, 86 each of which extends adjacent a respective one of the reflector elements 54, 56, 58, 60, 62, 64, 66, 68 along a respective direction in a respective one of the longitudinal planes that is parallel to the respective longitudinal axis. The fluid conduit 50 also includes curved segments 88, 90, 92, 94, 96, 98 that interconnect the linear segments 72, 74, 76, 78, 80, 82, 84, 86 to define a serpentine fluid flow path adjacent the reflector 48.

[0026] Referring back to FIG. 4A, the window 52 corresponds to the window 16 described above. In this example, the side walls of the reflector elements 54-68 provide distributed support along the width of the window 52 (e.g., every 39 millimeters in some examples). This support enables the thickness of the window 52 to be reduced. In some examples, the window 52 is formed of a tempered glass substrate that has a thickness in the range of 1.5 to 3 millimeters.

[0027] FIG. 5 shows a top view an example of a solar thermal collector 100 that includes a set of six panels 102, 104, 106, 108, 110, 112 each of which corresponds to the solar thermal collector 46 (see FIG. 4A), where the respective

reflectors **48** are demarcated by the dashed boxes. The terminal ends of each of the fluid conduits **50** are connected to a manifold **114**. The manifold and the fluid conduits **50** of the panels **102-112** together define a recirculating fluid path for a heat exchange fluid. In some examples, the manifold is integrated into the panels, which avoids the need to provide separate insulation for the manifold.

[0028] Table 1 below shows a comparison of the relative sizes of components of an exemplary evacuated-tube-based solar thermal collector and an exemplary tubeless solar thermal collector of the type shown in FIG. 1A. As shown in Table 1, the elimination of evacuated tubes, allows the dimensions of the reflector and the absorber in tubeless solar thermal collector to be significantly reduced. This feature enables the thickness of the window **52** to be reduced significantly as compared to tube-based designs, thereby reducing the losses and weight associated with thicker windows.

TABLE 1

	Evacuated Tube Based Solar Thermal Collector	Tubeless Solar Thermal Collector
Orientation	North-South	North-South
Acceptance Angle [Degrees]	~60	~60
Concentration	1.152	1.152
Reflector Height [mm]	108.01	19.079
Reflector Width [mm]	202.63	39.80
Tube	Viessmann	none
Absorber Diameter [mm]	56	11
Tube Diameter [mm]	65	N/A
Panel height	192	25

[0029] In some examples, the solar panel array shown in FIG. 5 is part of a fixed solar thermal installation. In some of these examples, the solar panel array is mounted at a fixed angle in a North/South configuration in which the longitudinal axes of the reflectors are fixed vertically at a tilt equal to latitude facing the sun perpendicular to its solar noon position. In other ones of these examples, the solar panel array is mounted at a fixed angle in an East/West configuration in which the longitudinal axes of the reflectors are similarly fixed but in a horizontal fashion. Such an installation is advantageous in that it does not require any mechanical tracking because the non-imaging optical relationship between the reflectors and the fluid conduits provides an acceptance angle of up to $\pm 60^\circ$ while concentrating between 1.05 and 1.08 times the collected energy onto the solar radiation absorbing fluid conduits.

[0030] FIG. 6 shows an example of a method of using a solar thermal collector.

[0031] In accordance with the method of FIG. 6, a solar thermal collector is provided (FIG. 6, block **120**). The solar thermal collector includes a receptacle that is evacuated to a subatmospheric pressure and a fluid conduit. The receptacle includes a window and the reflector faces the window. The window and the reflector are exposed to the subatmospheric pressure in the receptacle. The fluid conduit extends through the receptacle between the window and the reflector. The reflector concentrates solar radiation passing through the window onto the fluid conduit.

[0032] Fluid is circulated through the fluid conduit (FIG. 6, block **122**). In some examples, the fluid conduit includes a plurality of fluid channels for conveying the fluid, and the fluid is circulated through the plurality of fluid channels concurrently. In some examples, the fluid includes super-critical

carbon dioxide, which allows for more compact thermal collector designs and improves the solar thermal collection efficiency with no adverse environmental impact. In these examples, each of the fluid channels typically has a respective inner diameter between 0.75 millimeter and 0.25 millimeter. **[0033]** Other embodiments are within the scope of the claims.

1. A solar thermal collector, comprising
a receptacle evacuated to a subatmospheric pressure and comprising a window and a reflector facing the window, wherein the window and the reflector are exposed to the subatmospheric pressure in the receptacle; and
a fluid conduit extending through the receptacle between the window and the reflector, wherein the reflector concentrates solar radiation passing through the window onto the fluid conduit.
2. The solar thermal collector of claim 1, wherein the reflector comprises a pair of concave radiation-reflective surface portions that meet along a longitudinal axis in a longitudinal plane.
3. The solar thermal collector of claim 2, wherein the fluid conduit extends adjacent the reflector along a direction in the longitudinal plane that is parallel to the longitudinal axis.
4. The solar thermal collector of claim 1, wherein the reflector comprises a plurality of reflector elements each comprising a respective pair of concave radiation-reflective surface portions, the concave radiation-reflective surface portions of each reflector element meet along a respective longitudinal axis in a respective longitudinal plane, and the respective longitudinal axes are parallel.
5. The solar thermal collector of claim 4, wherein the fluid conduit comprises parallel linear segments each of which extends adjacent a respective one of the reflector elements along a respective direction in a respective one of the longitudinal planes that is parallel to the respective longitudinal axis.
6. The solar thermal collector of claim 5, wherein the fluid conduit comprises curved segments that interconnect the parallel linear segments to define a serpentine fluid flow path adjacent the reflector.
7. The solar thermal collector of claim 4, wherein each reflector element concentrates radiation passing through the window onto different respective sections of the fluid conduit.
8. The solar thermal collector of claim 1, wherein the receptacle comprises a base, and the window is mounted to the base with a connection that maintains the subatmospheric pressure in the receptacle.
9. The solar thermal collector of claim 8, wherein the base integrally incorporates the reflector.
10. The solar thermal collector of claim 9, wherein the base is a unitary metal structure that comprises the reflector.
11. The solar thermal collector of claim 10, wherein the window is formed of glass, and further comprising between the window and the base a glass-to-metal seal that maintains the subatmospheric pressure in the receptacle.
12. The solar thermal collector of claim 9, wherein the base is plastic and the reflector is bonded to the plastic base.
13. The solar thermal collector of claim 1, wherein the window comprises an antireflective coating.
14. The solar thermal collector of claim 13, wherein the antireflective coating is porous.
15. The solar thermal collector of claim 1, wherein the window comprises first and second parallel surfaces each of which is coated with a respective antireflective coating.

16. The solar thermal collector of claim **1**, wherein the fluid conduit comprises an outer surface carrying a radiation-absorbent coating, and an inner surface exposed for contact with fluid flowing through the fluid conduit.

17. The solar thermal collector of claim **1**, wherein the fluid conduit comprises an outer surface, and a textured inner surface exposed for contact with fluid flowing through the fluid conduit.

18. The solar thermal collector of claim **1**, wherein the fluid conduit comprises a plurality of fluid channels for conveying fluid.

19. The solar thermal collector of claim **18**, wherein each of the fluid channels has a respective inner diameter between 0.75 millimeter and 0.25 millimeter.

20. A method of manufacturing a solar thermal collector, comprising
attaching a fluid conduit to a base comprising a reflector;
mounting a window to the base to form a receptacle containing the fluid conduit, wherein the reflector faces the window and concentrates solar radiation passing through the window onto the fluid conduit; and
evacuating the receptacle to a subatmospheric pressure, wherein the window and the reflector are exposed to the subatmospheric pressure in the receptacle.

21. The method of claim **20**, wherein the reflector comprises a plurality of reflector elements each comprising a respective pair of concave radiation-reflective surface portions, the concave radiation-reflective surface portions of each reflector element meet along a respective longitudinal axis in a respective longitudinal plane, and the respective longitudinal axes are parallel.

22. The method of claim **21**, wherein each reflector element concentrates radiation passing through the window onto a different respective section of the fluid conduit.

23. The method of claim **20**, wherein the receptacle comprises a base, and the mounting comprises attaching the window to the base with a connection that maintains the subatmospheric pressure in the receptacle.

24. The method of claim **20**, wherein the base is a unitary metal structure that comprises the reflector, the window is formed of glass, and the mounting comprises forming between the window and the base a glass-to-metal seal that maintains the subatmospheric pressure in the receptacle.

25. The solar thermal collector of claim **20**, wherein the fluid conduit comprises a plurality of fluid channels for conveying fluid.

26. The method of claim **20**, further comprising purging the receptacle with an inert gas before evacuating the receptacle.

27. A solar collection method, comprising
providing a solar thermal collector comprising
a receptacle evacuated to a subatmospheric pressure and comprising a window and a reflector facing the window, wherein the window and the reflector are exposed to the subatmospheric pressure in the receptacle, and
a fluid conduit extending through the receptacle between the window and the reflector, wherein the reflector concentrates solar radiation passing through the window onto the fluid conduit; and
circulating fluid through the fluid conduit.

28. The method of claim **27**, wherein the fluid comprises super-critical carbon dioxide.

29. The method of claim **28**, wherein the fluid conduit comprises a plurality of fluid channels for conveying the fluid.

30. The method of claim **29**, wherein each of the fluid channels has a respective inner diameter between 0.75 millimeter and 0.25 millimeter.

* * * * *