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(54) **APPARATUS AND METHODS FOR WARMING AND COOLING BODIES**

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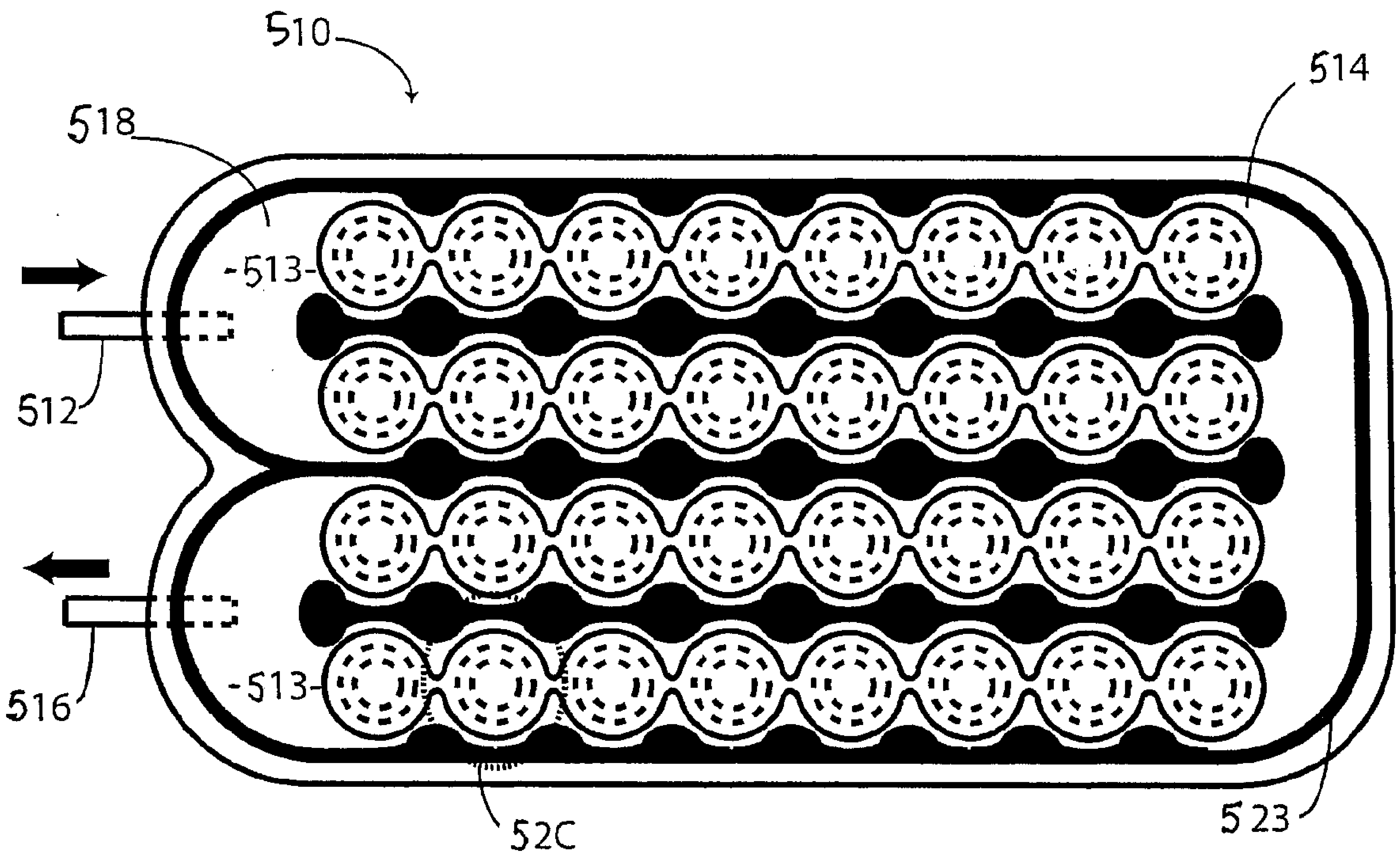
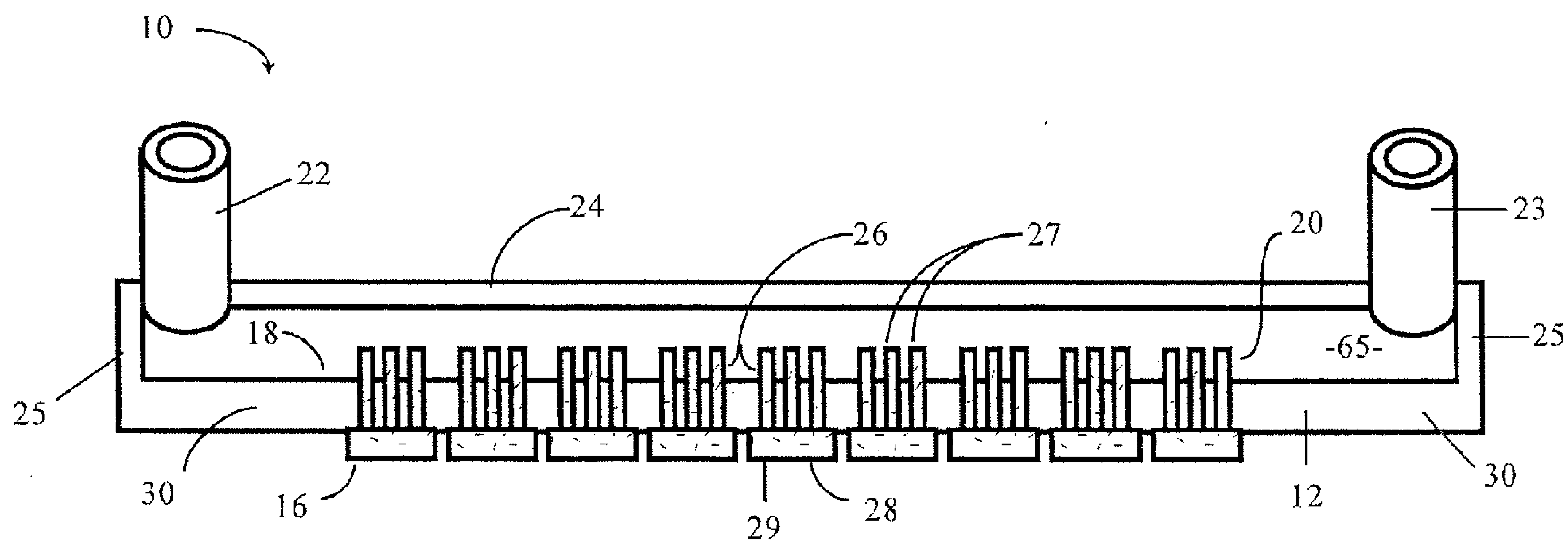
(57) **ABSTRACT**

A flexible heat exchanger is suitable for heating or cooling living subjects or objects. The heat exchanger has a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet. A flexible heat exchange plate that is essentially impermeable to the heat exchange fluid is penetrated by substantially rigid thermally-conductive members. The members provide paths of high thermal conductivity through the plate. The heat exchange fluid may be water.





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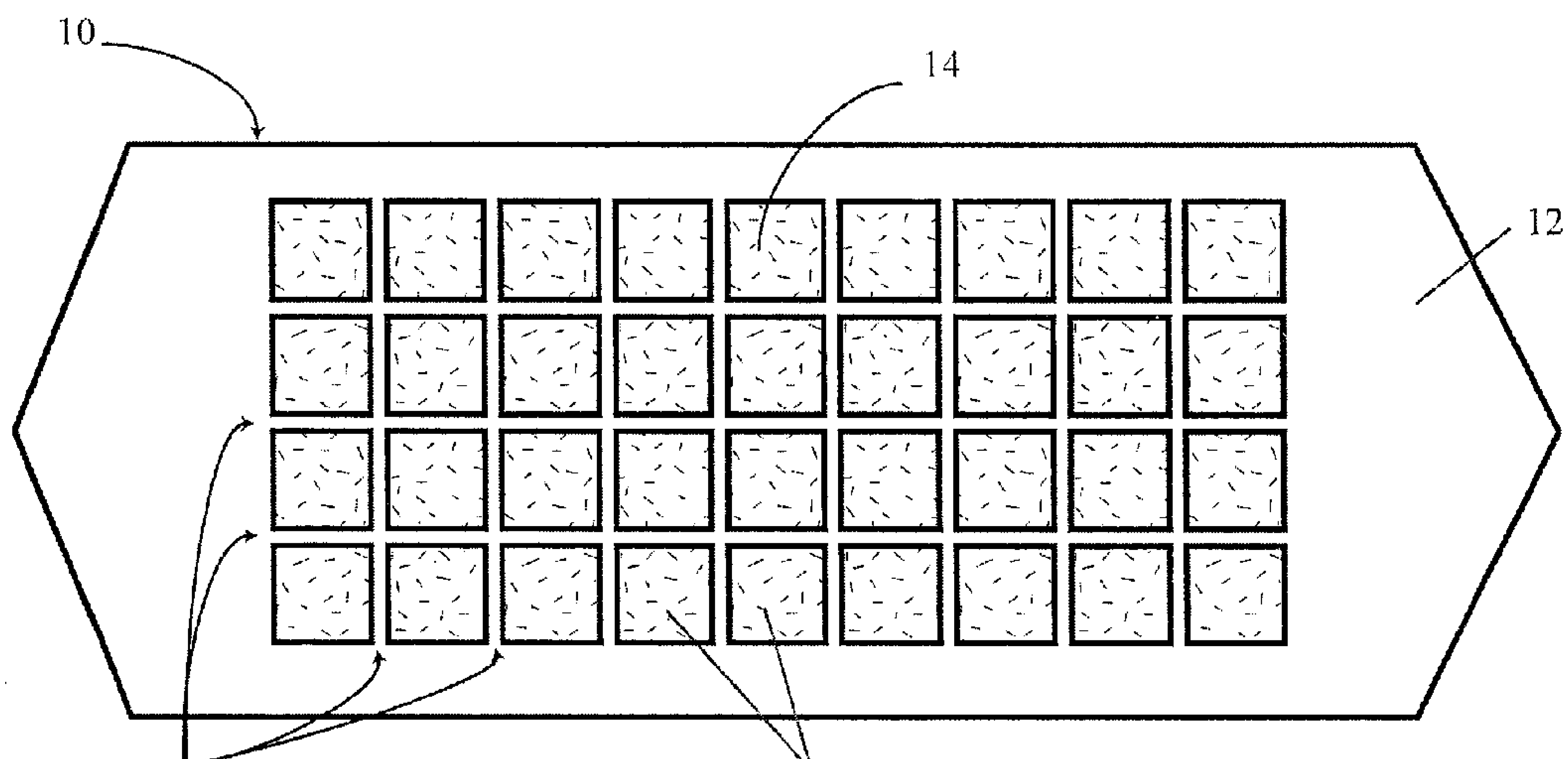

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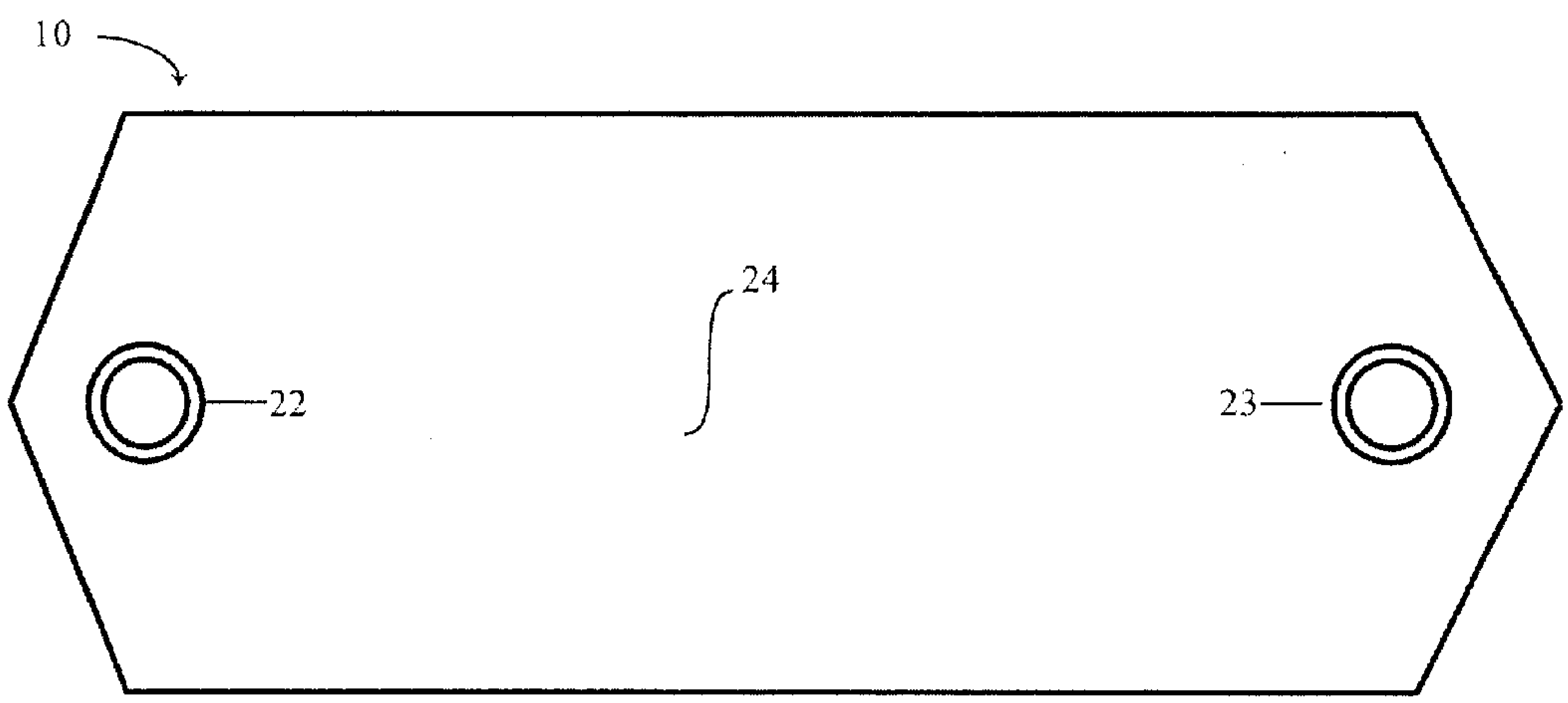

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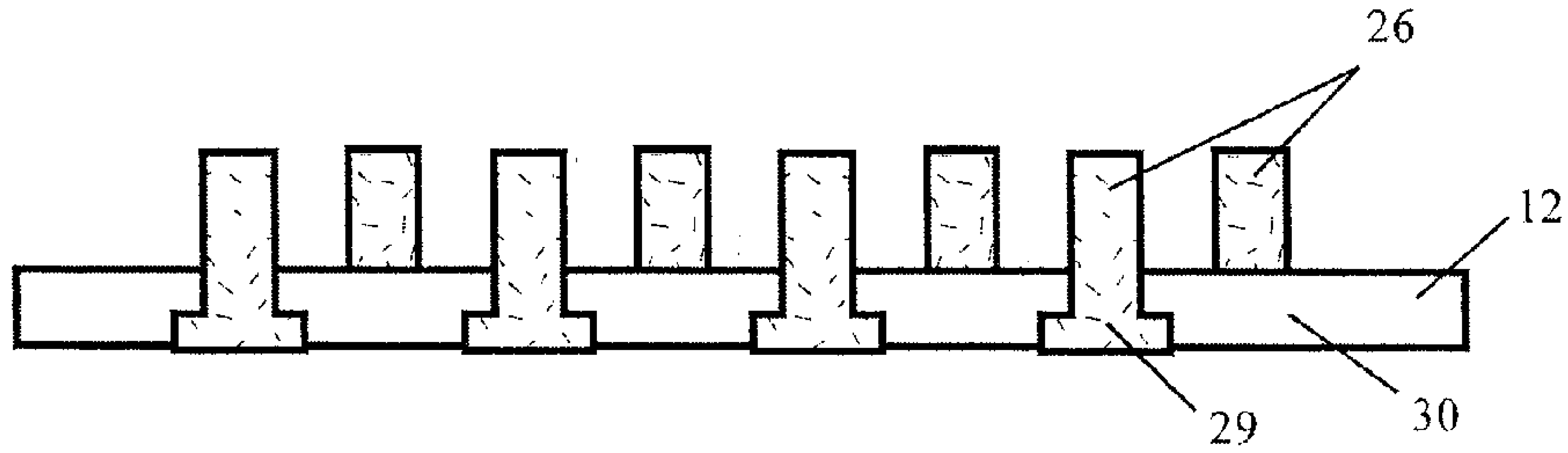

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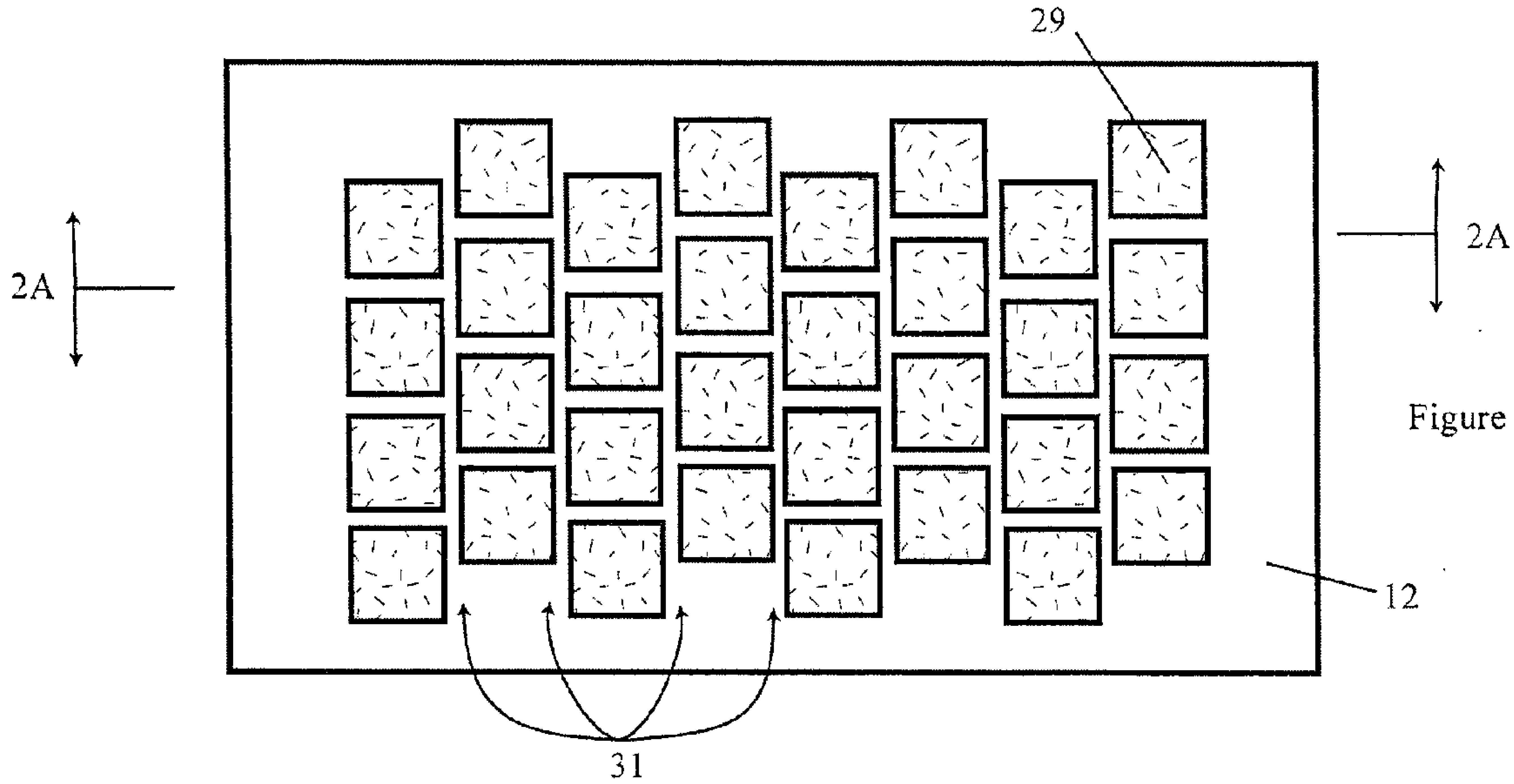

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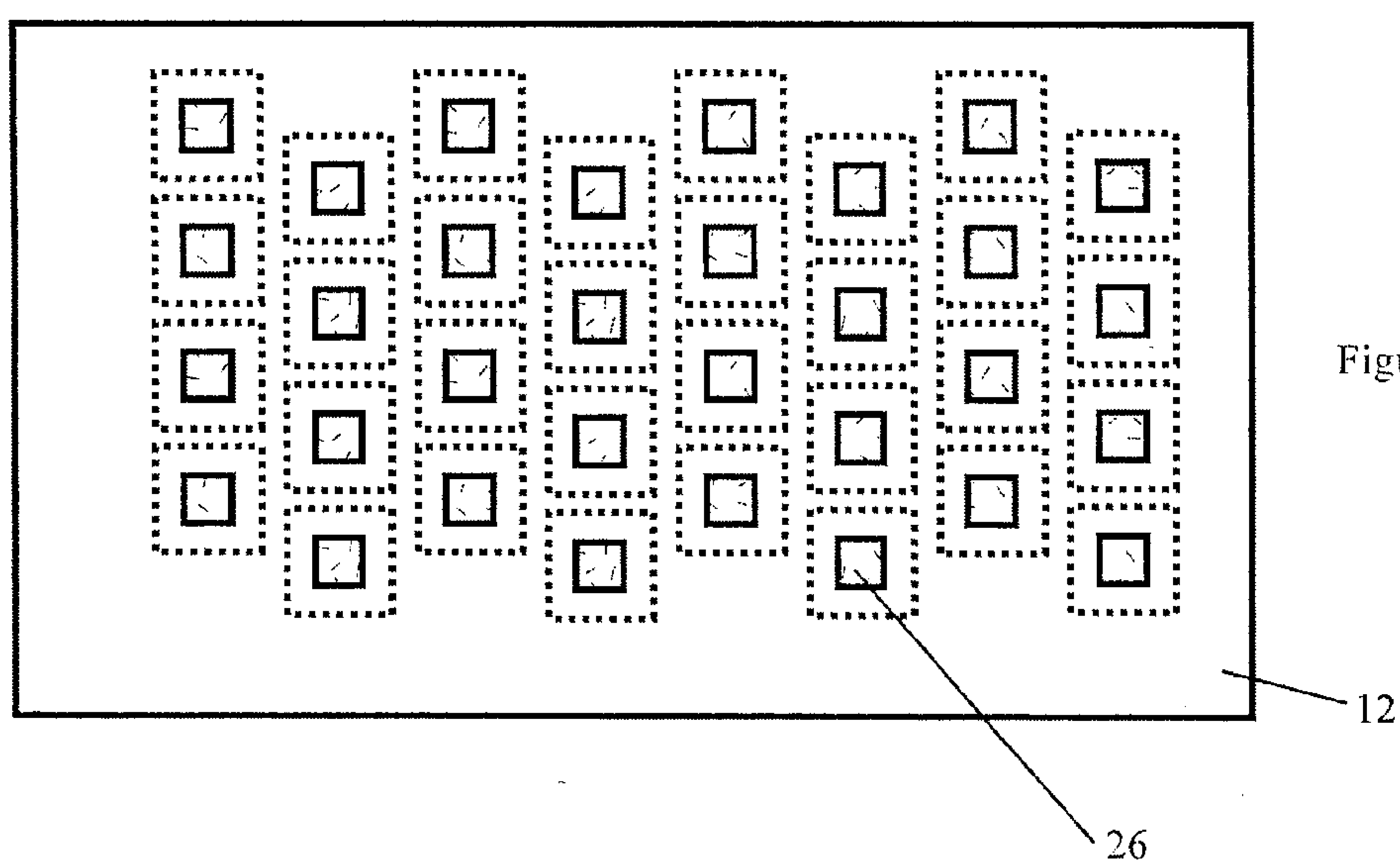

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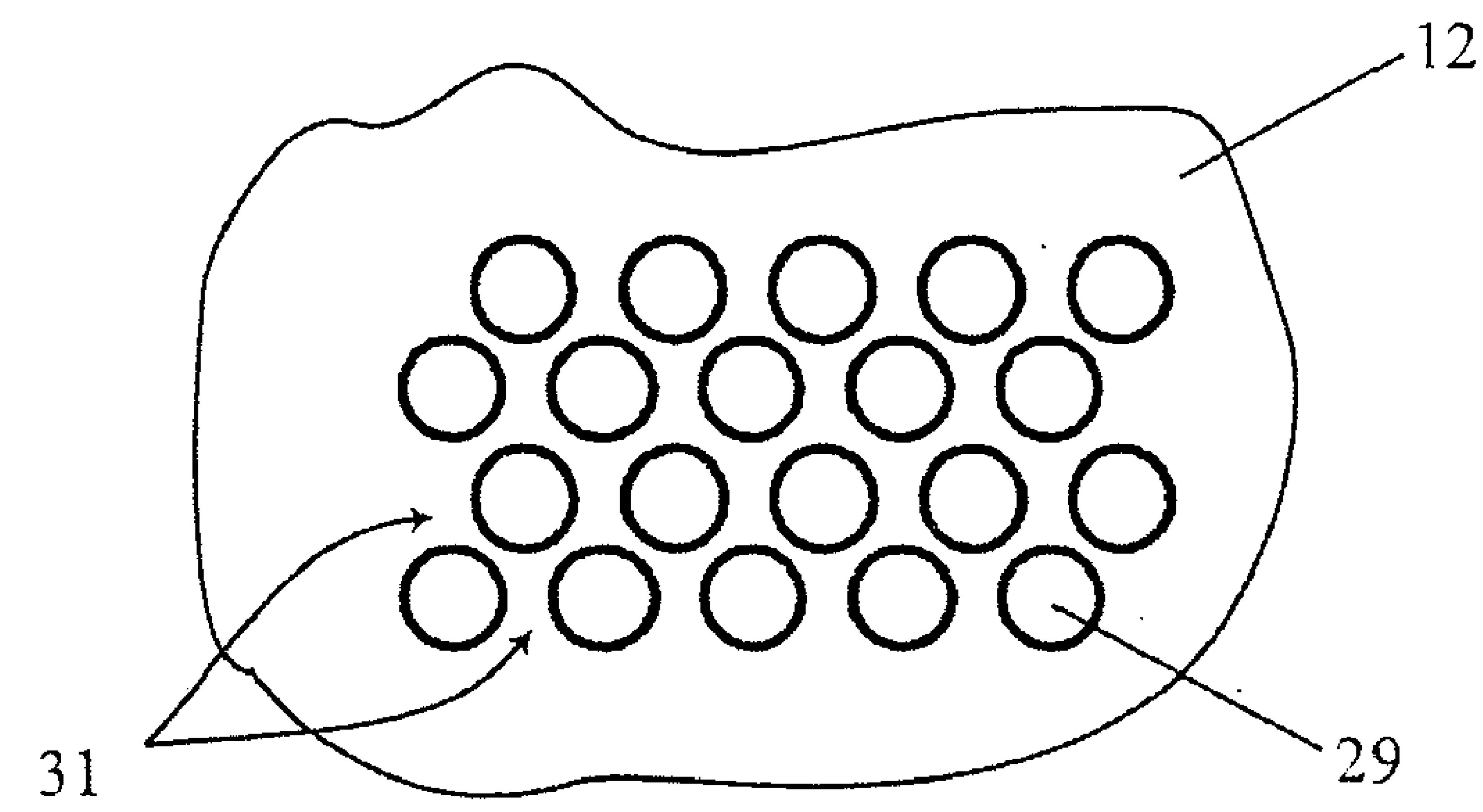

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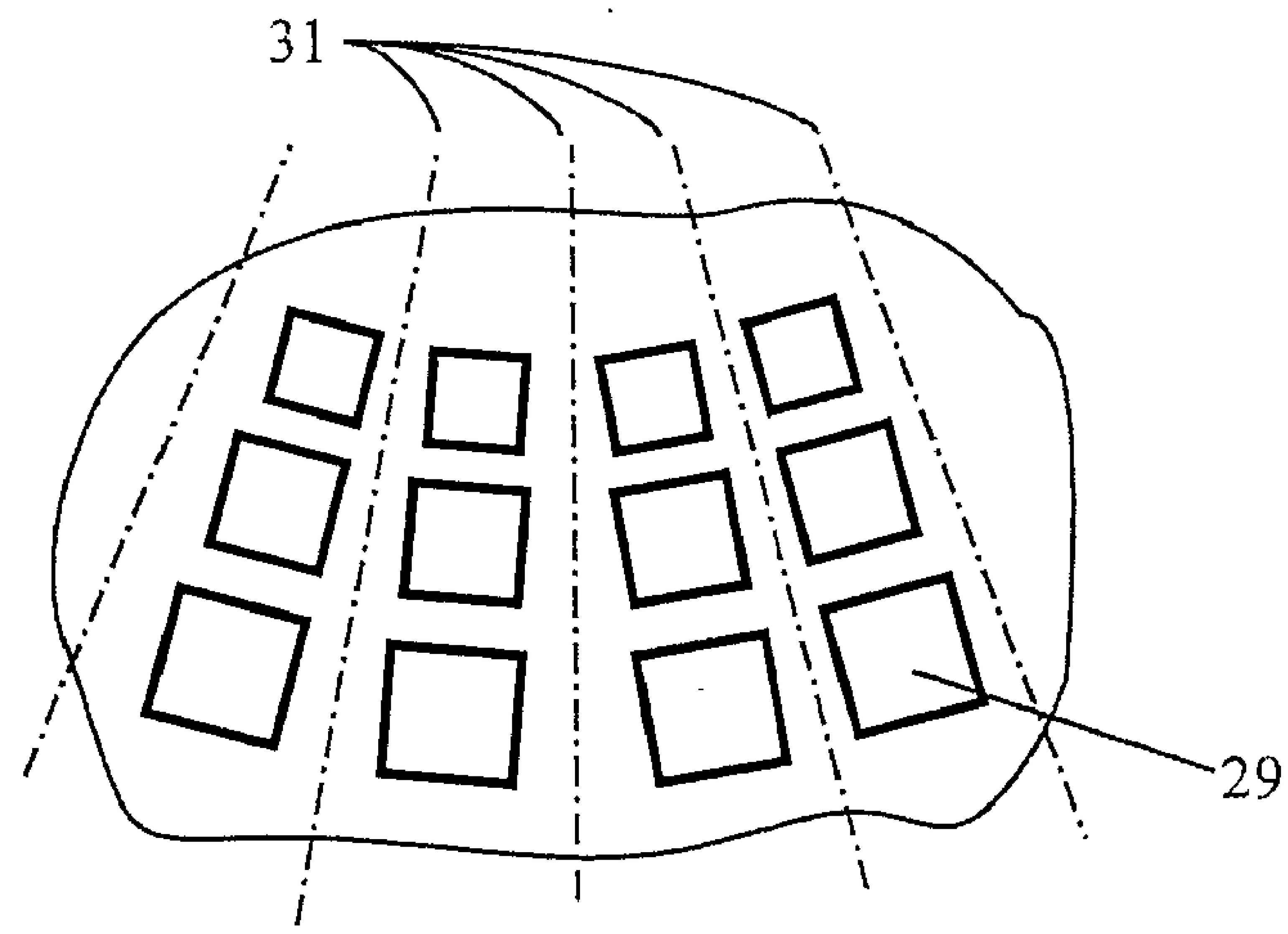

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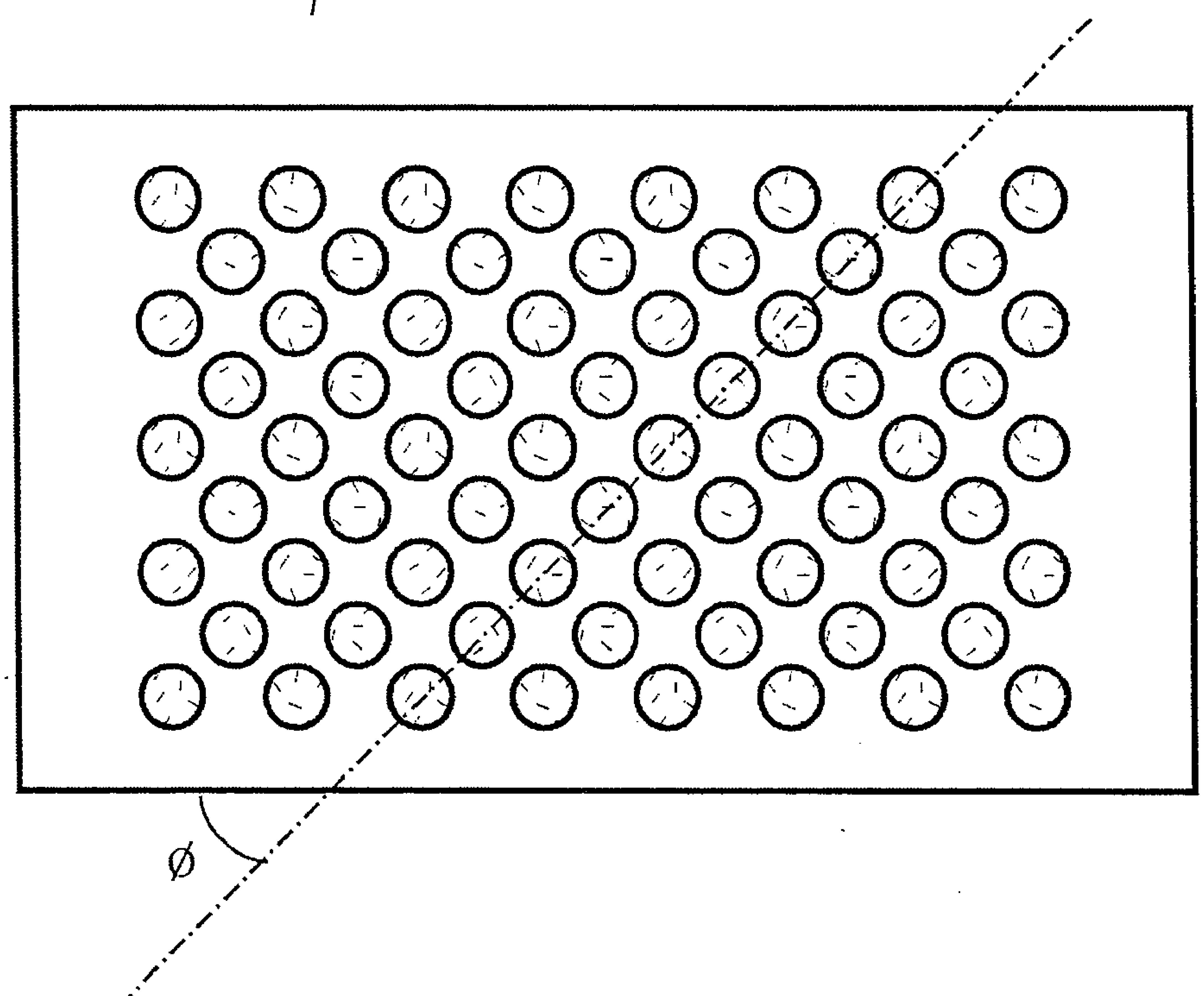

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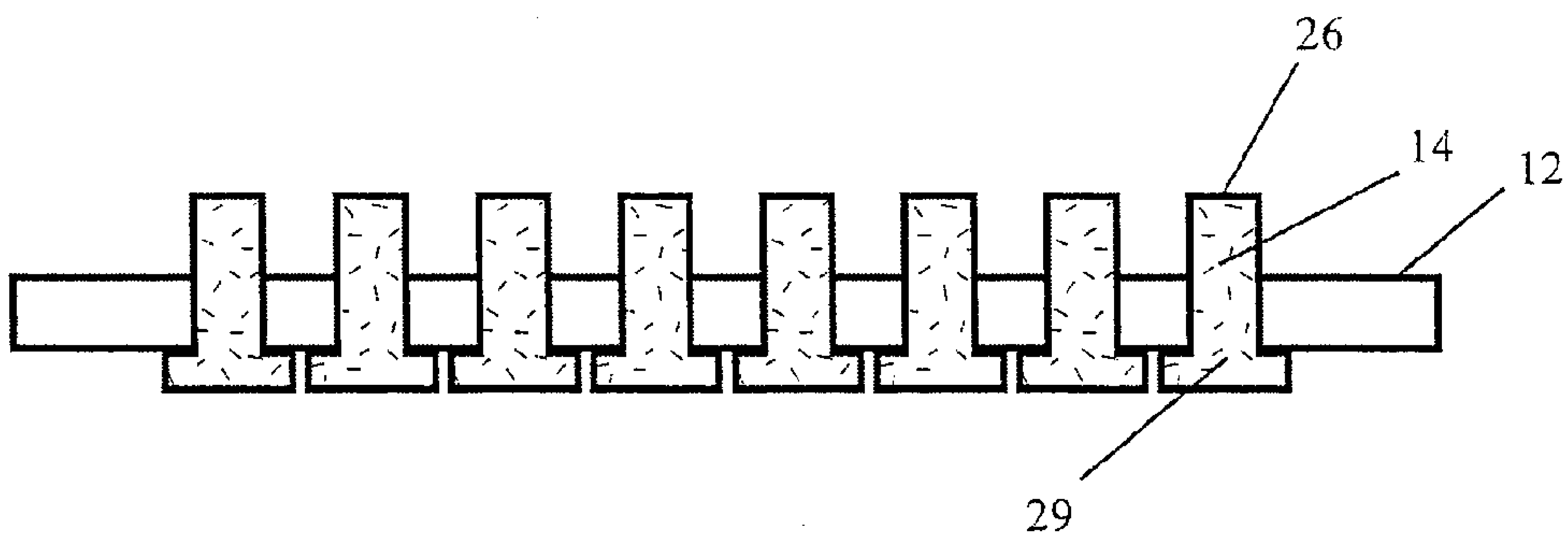

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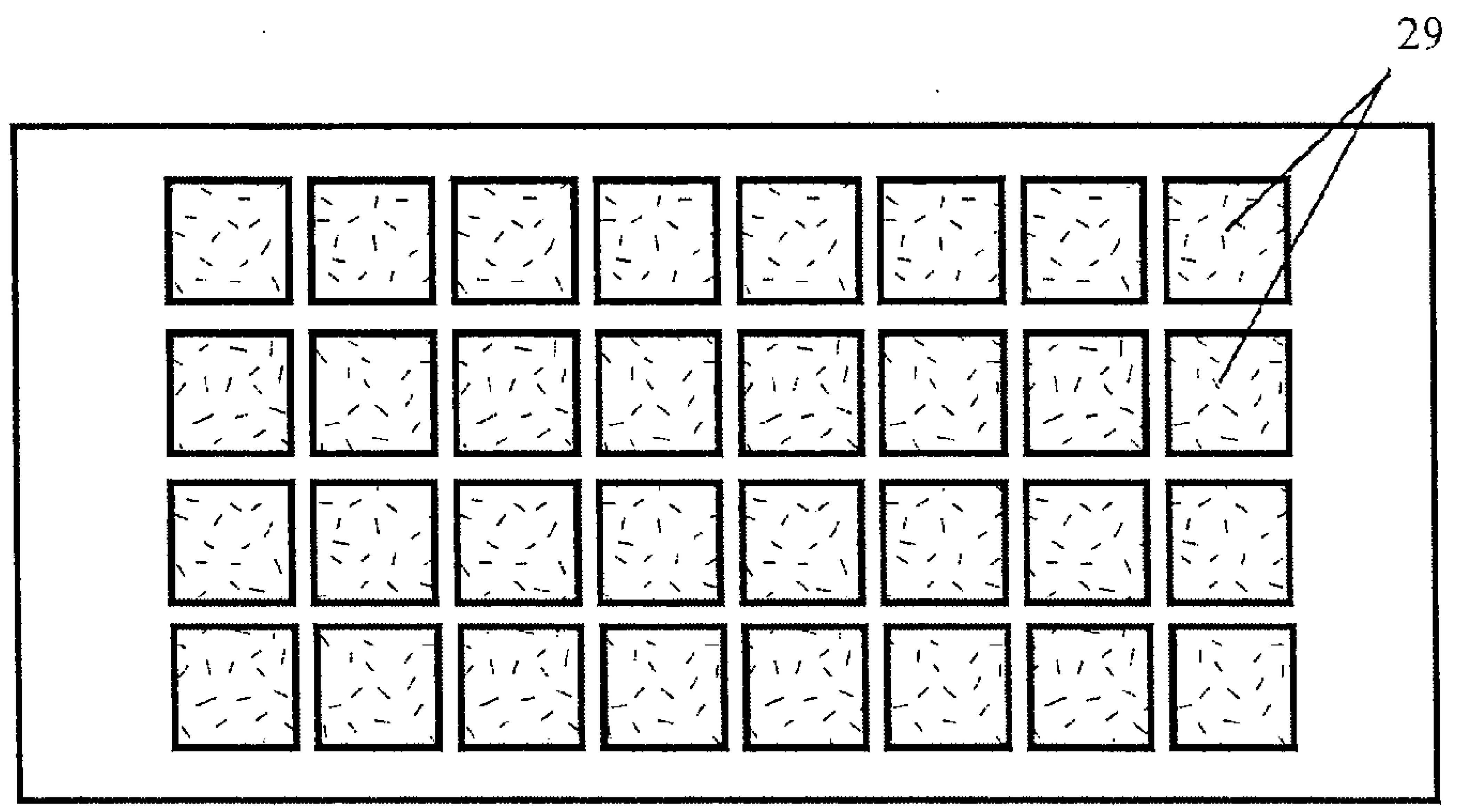

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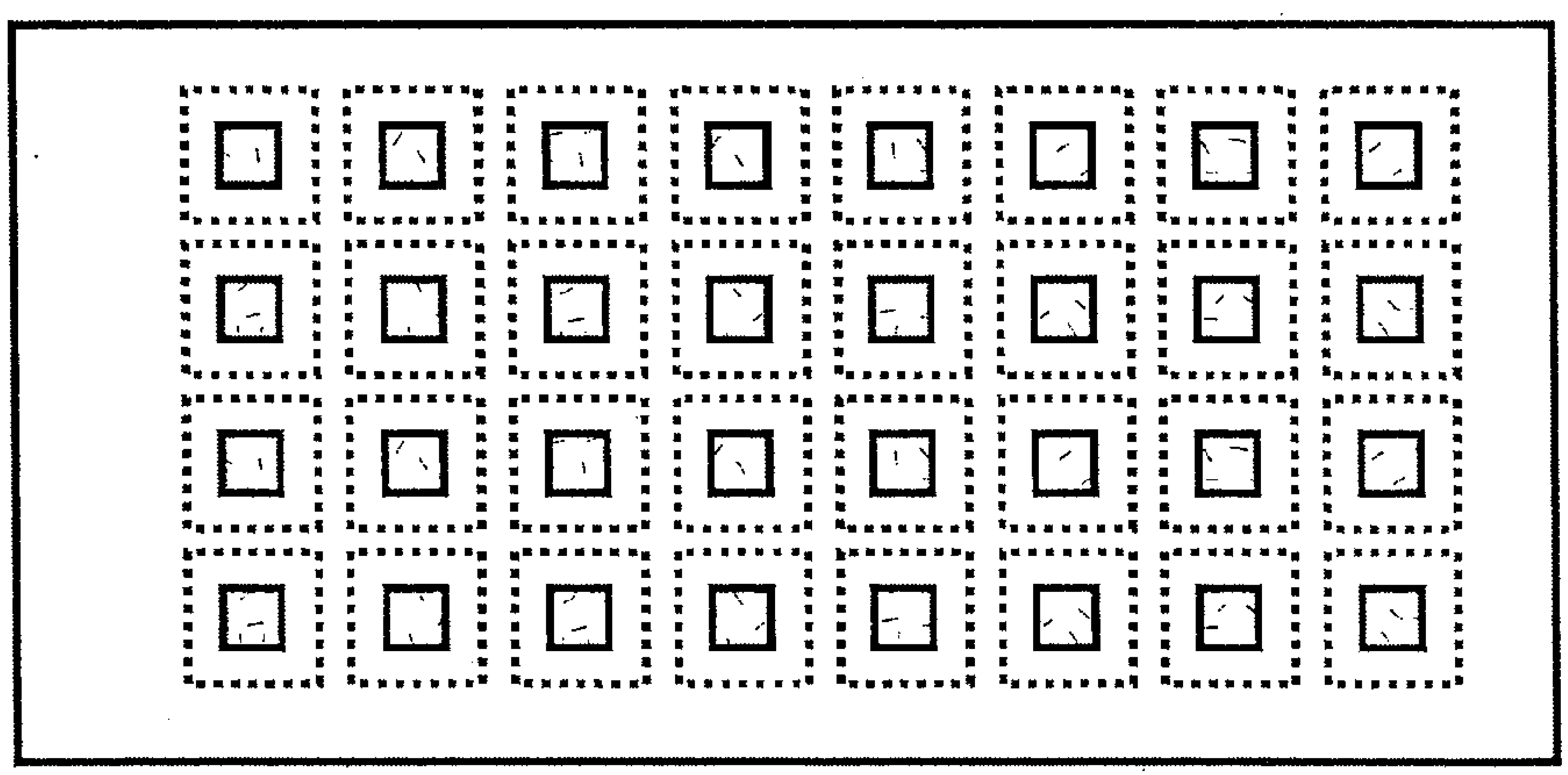

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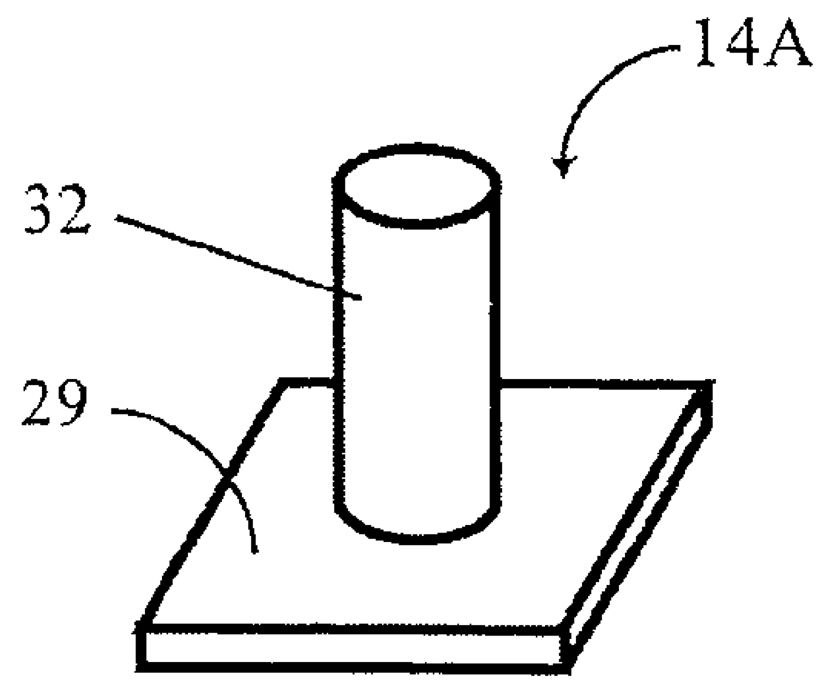

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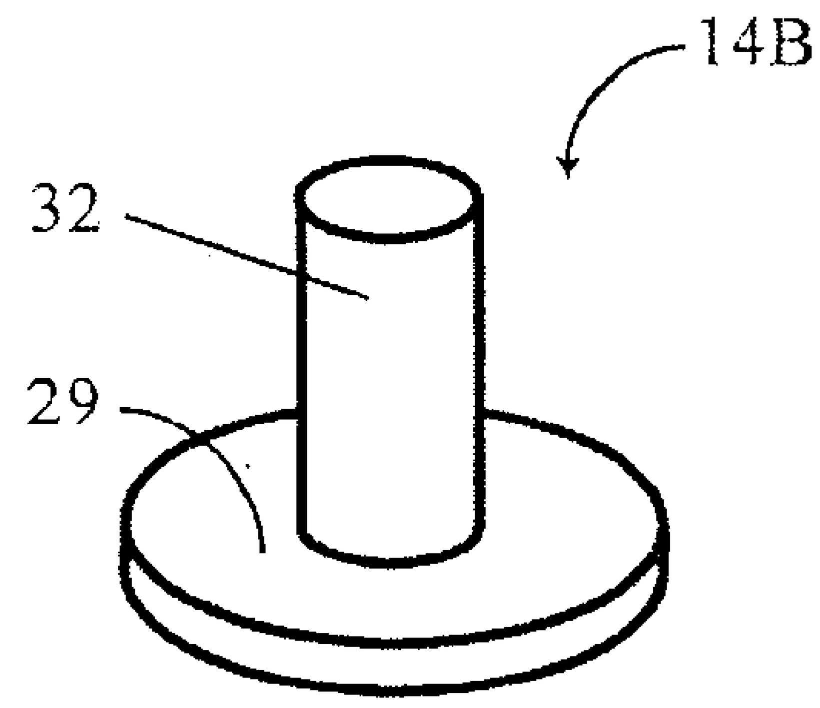

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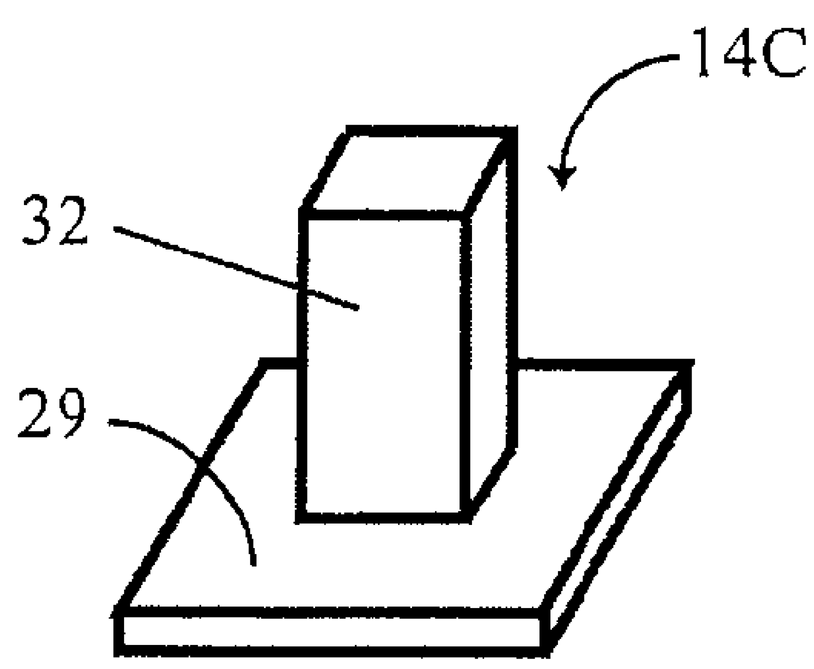

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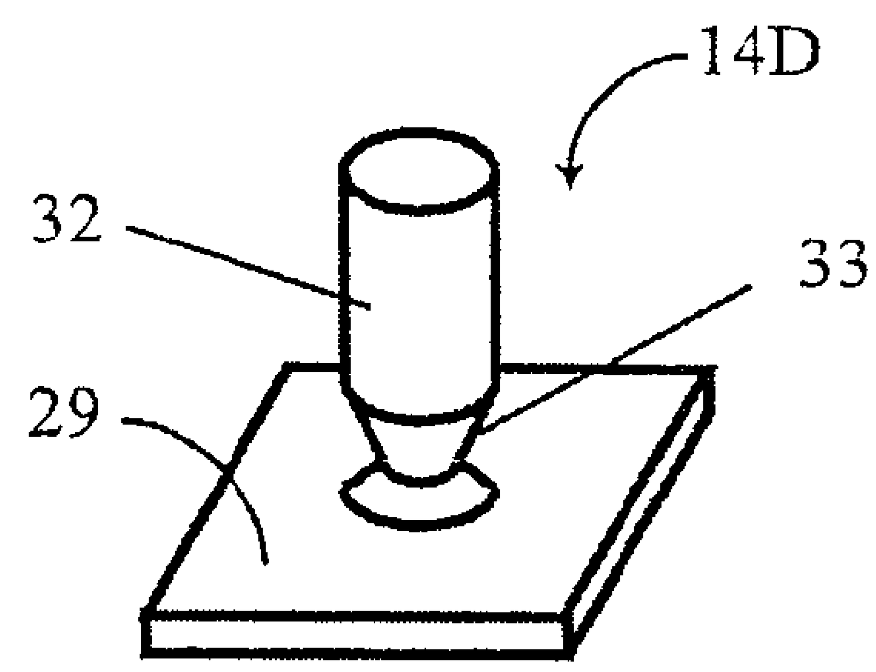

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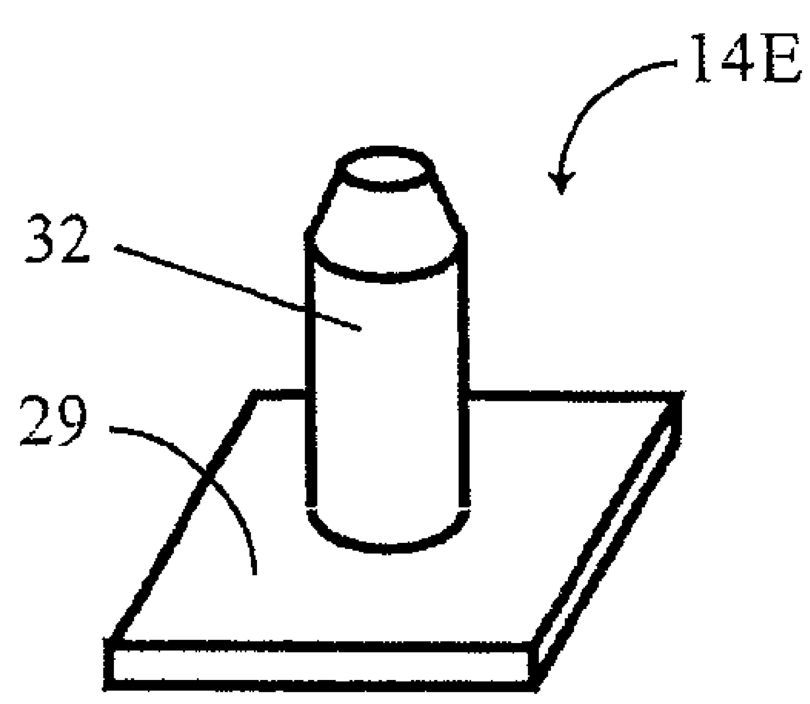

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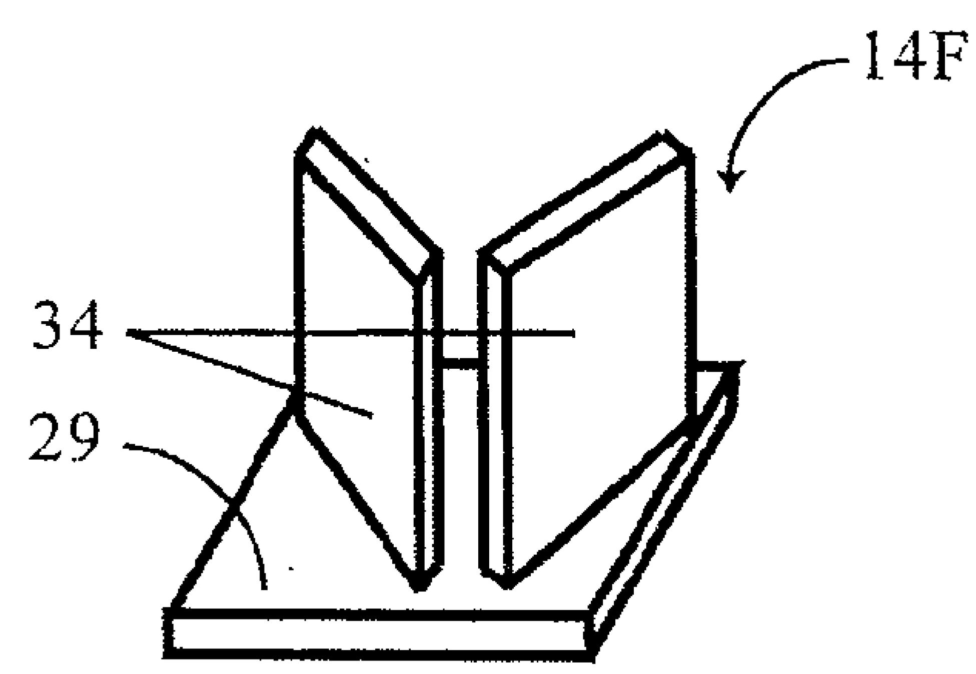

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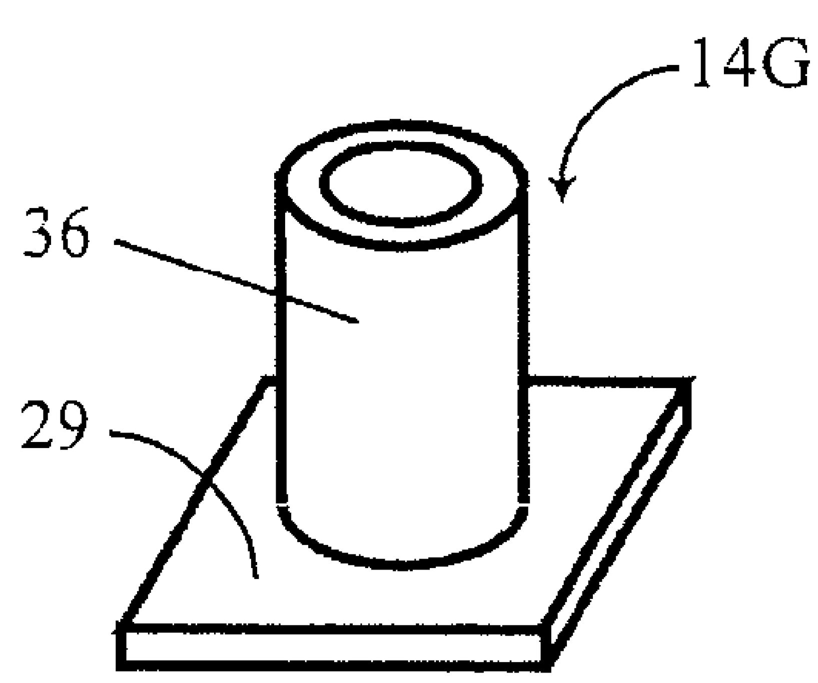

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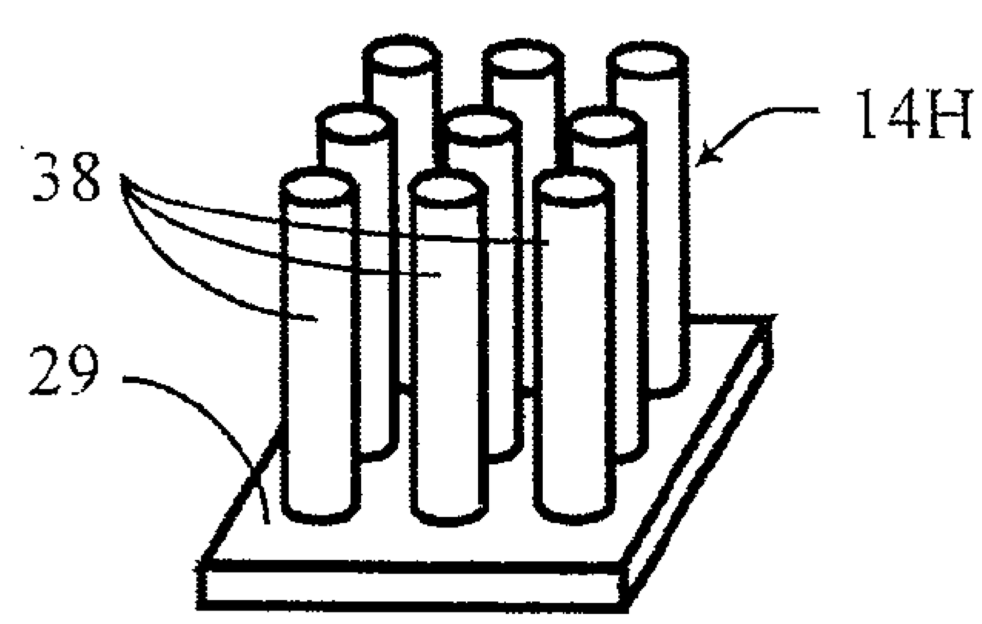

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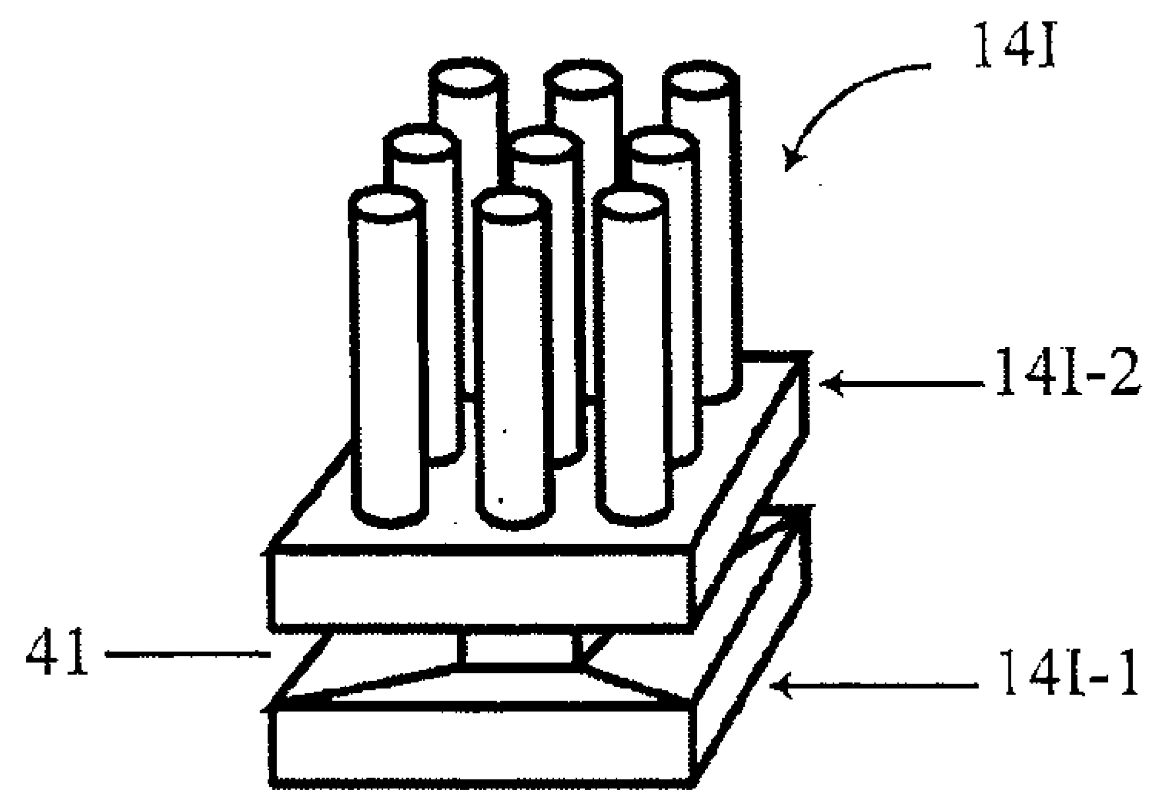

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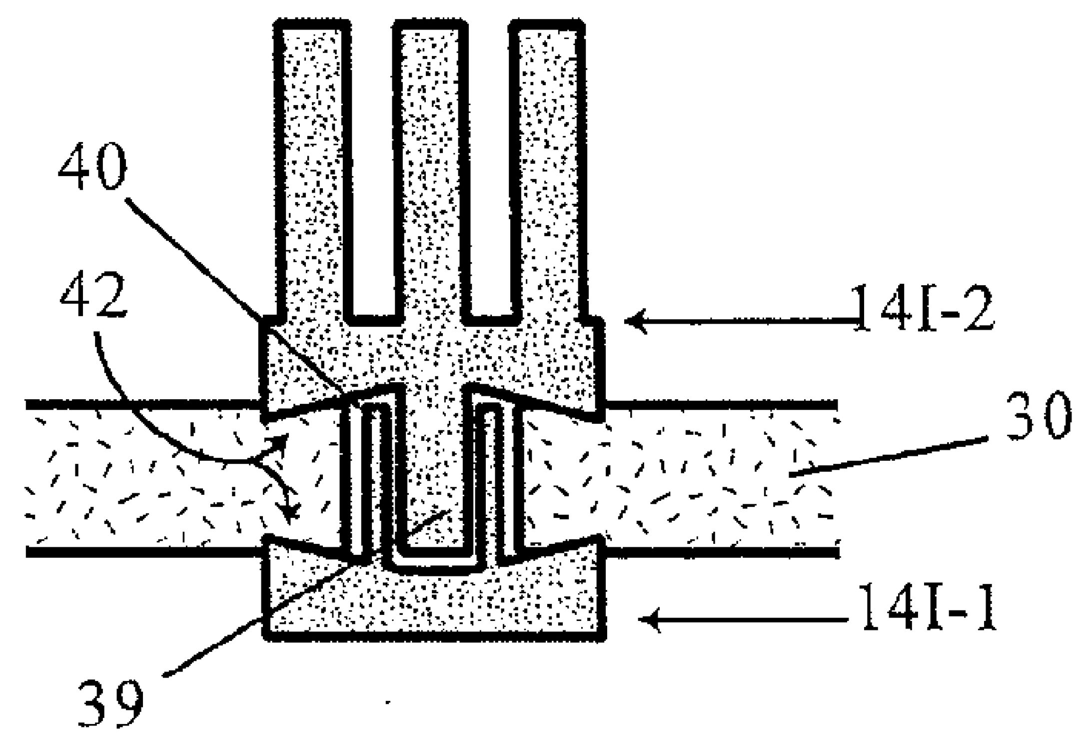

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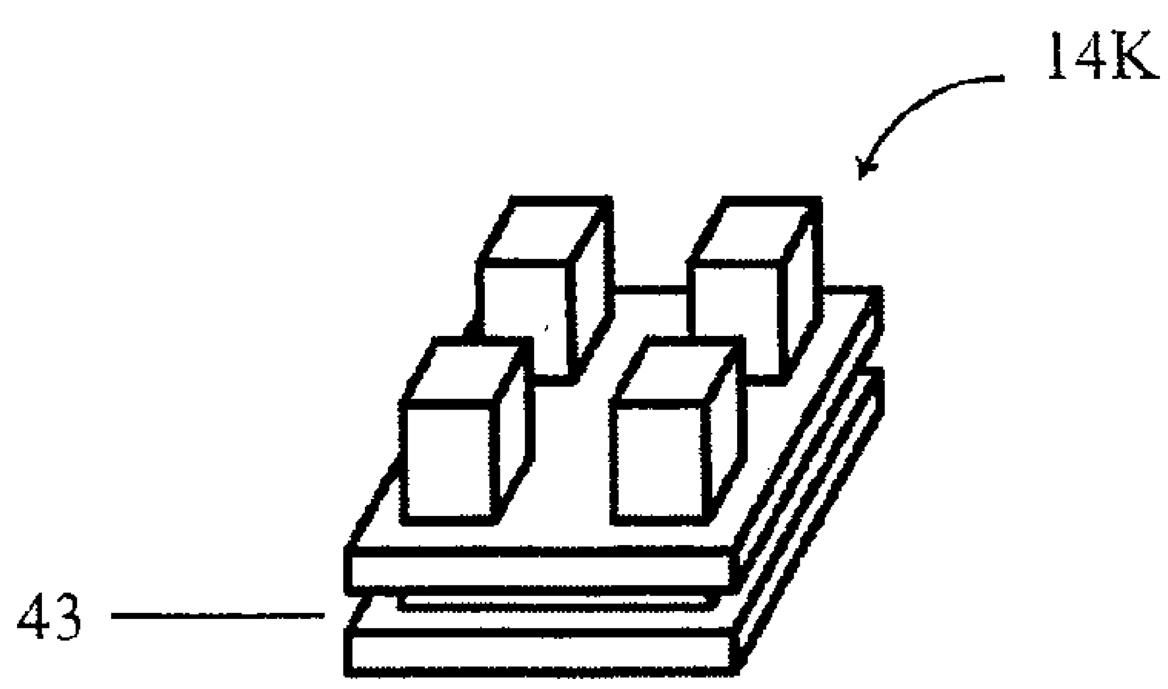

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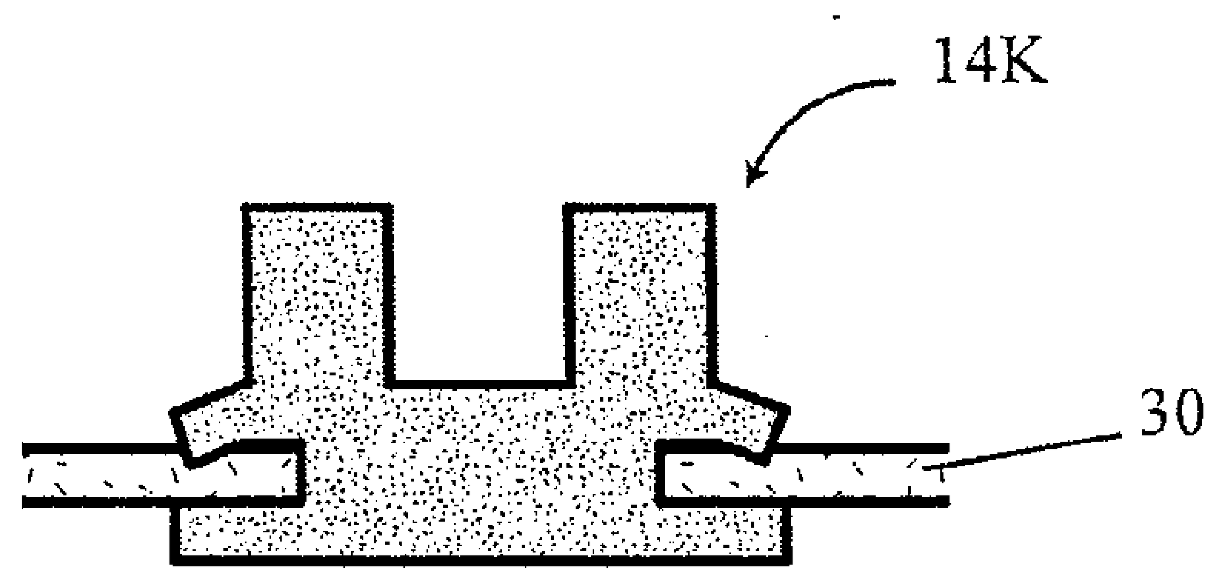

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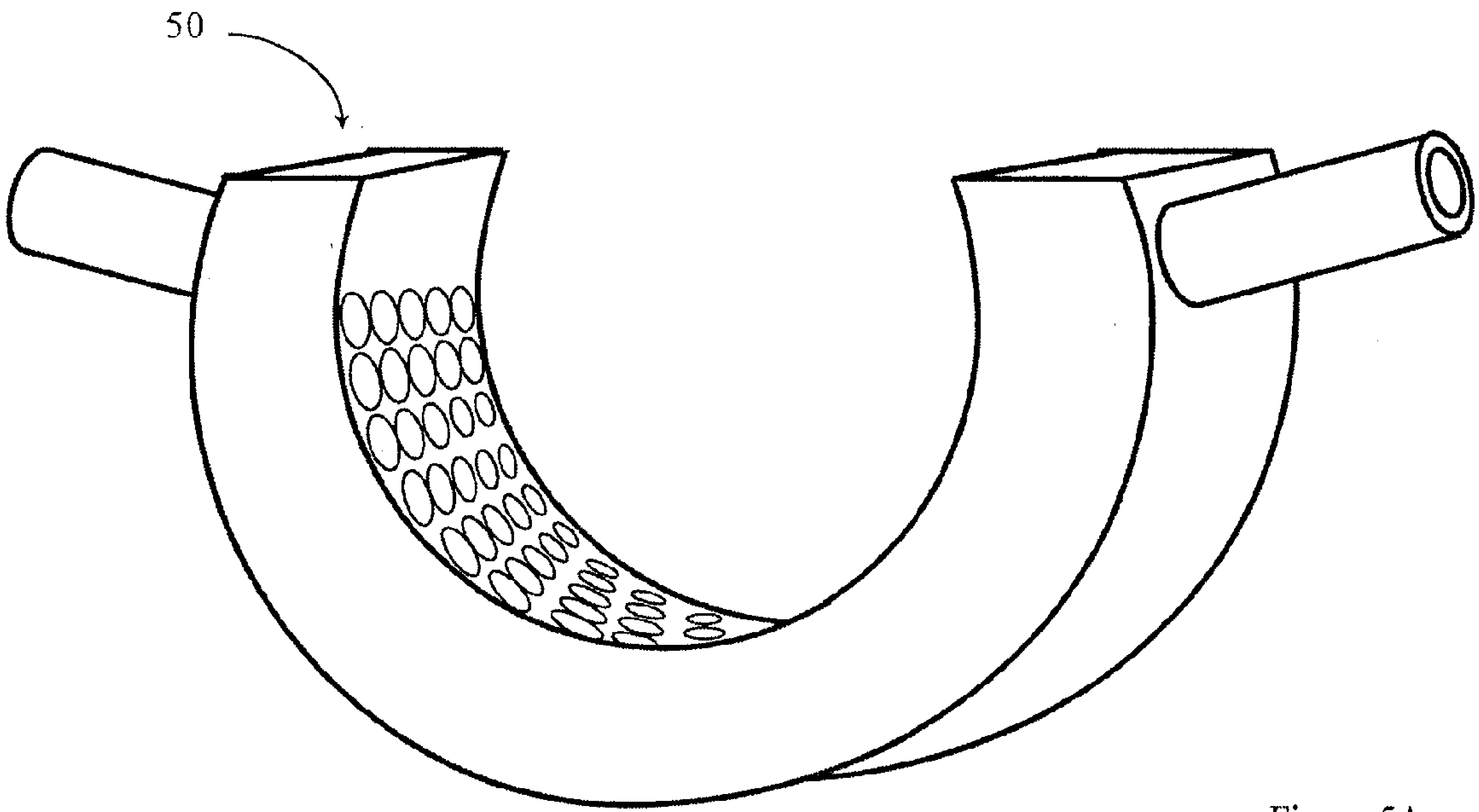

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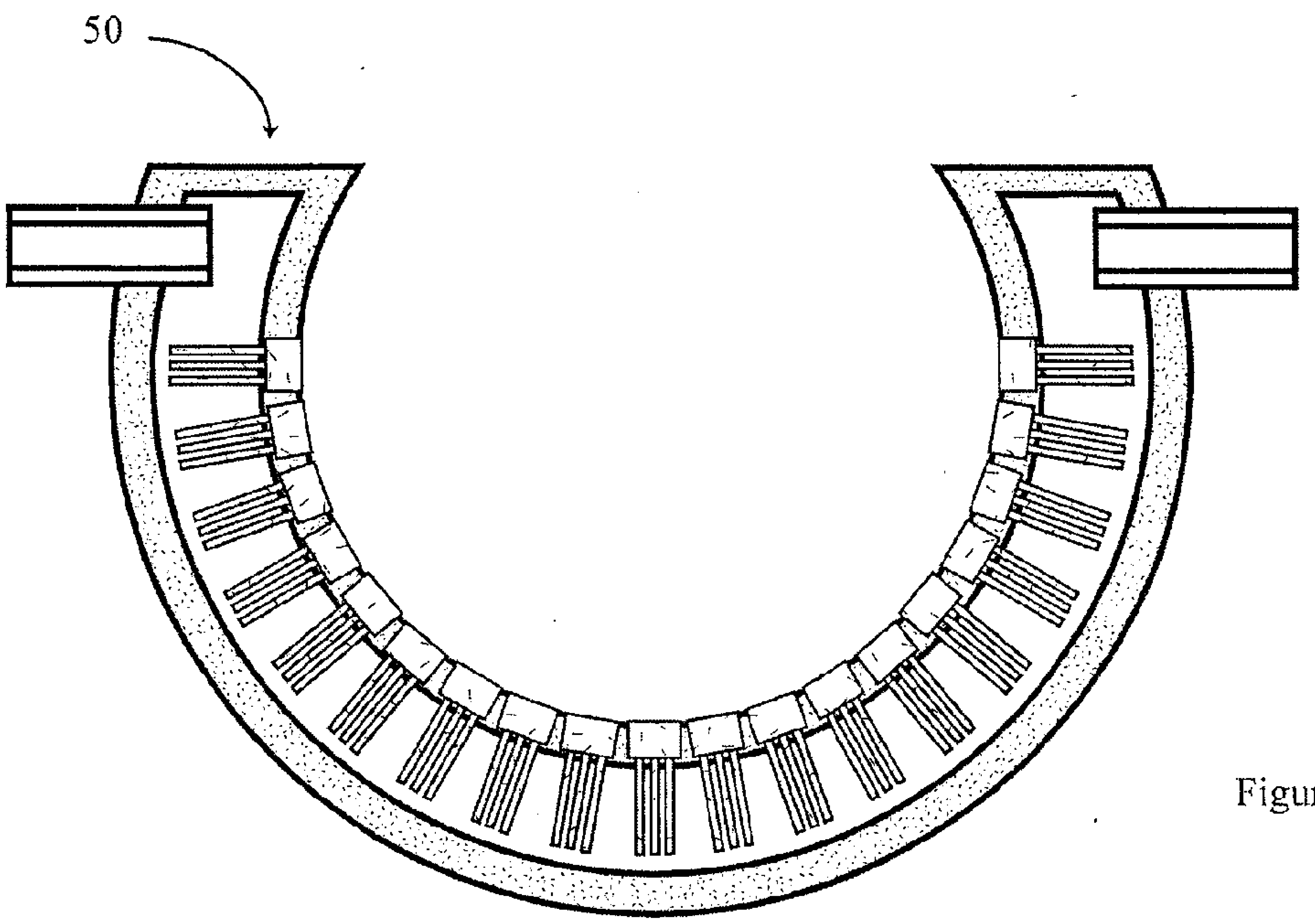

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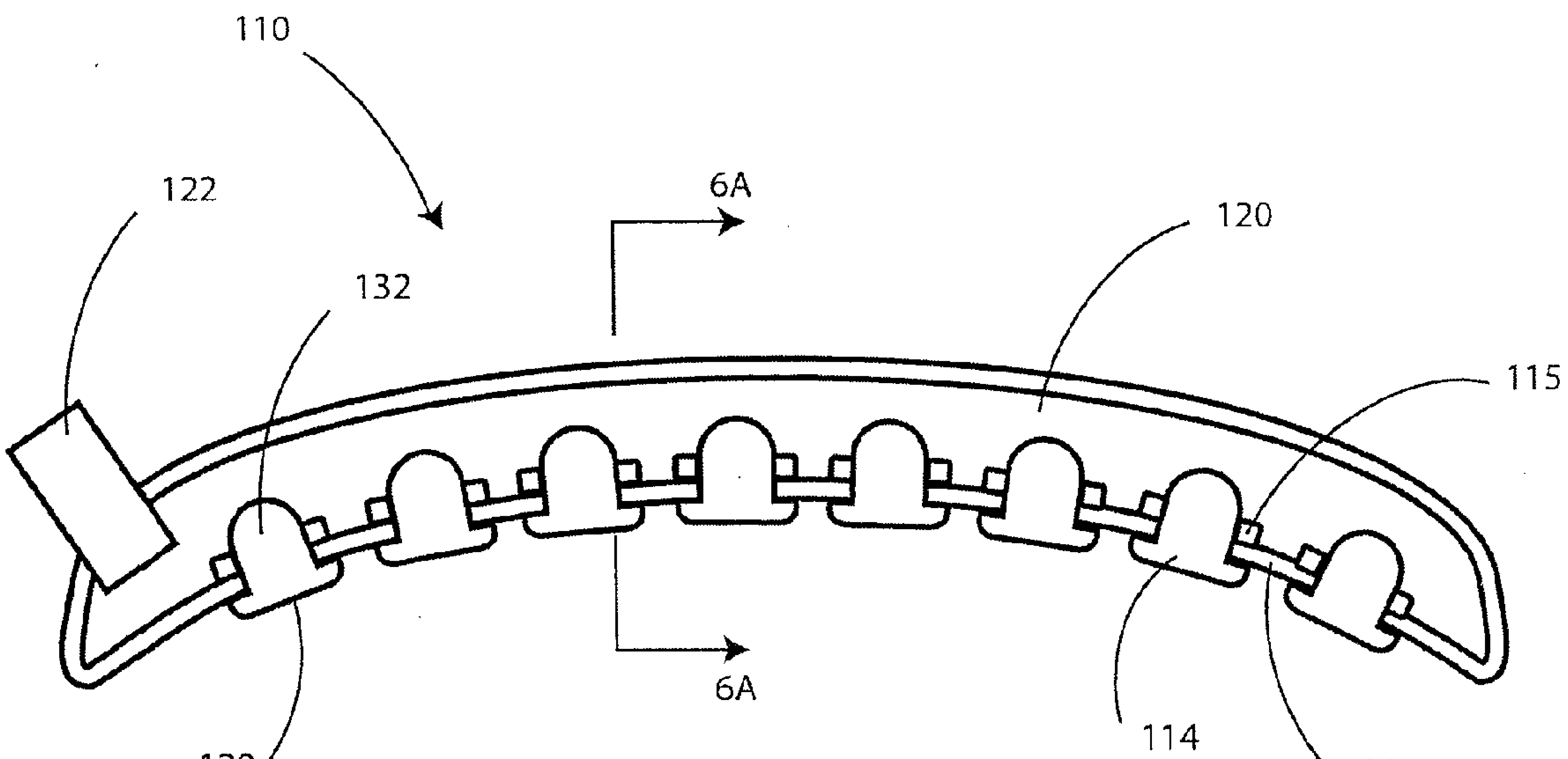

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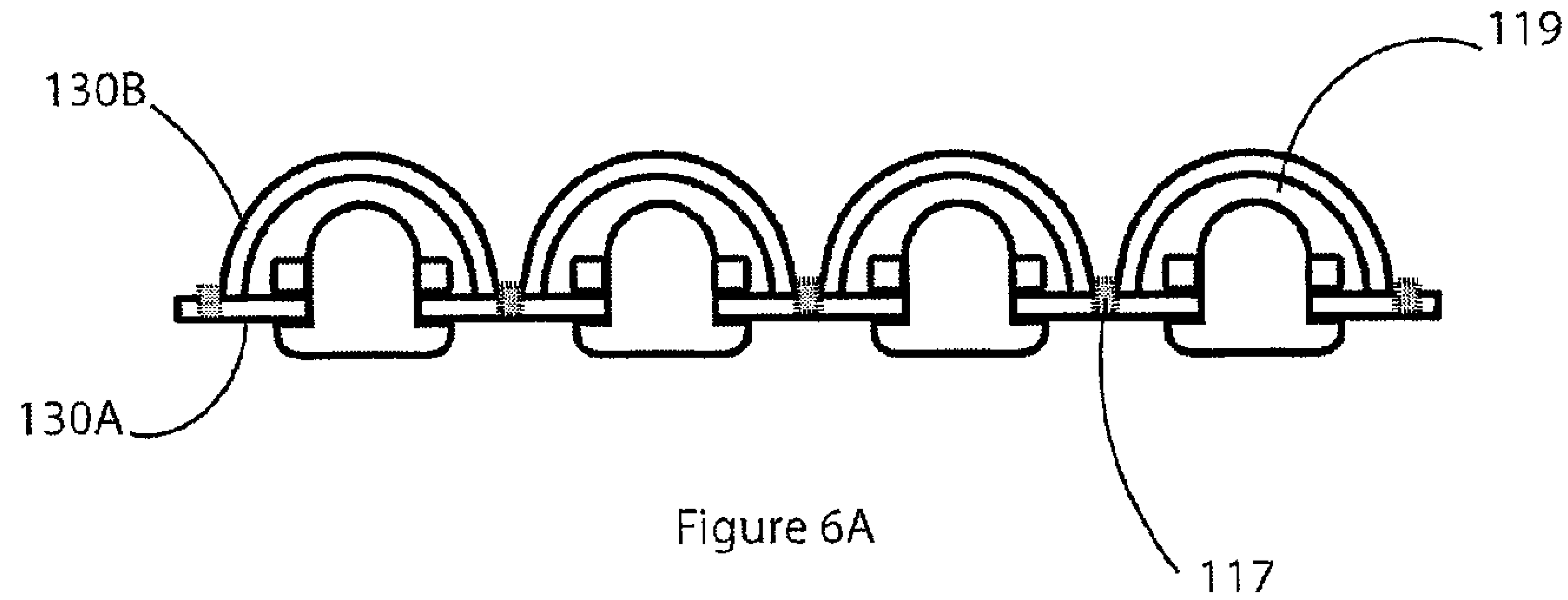

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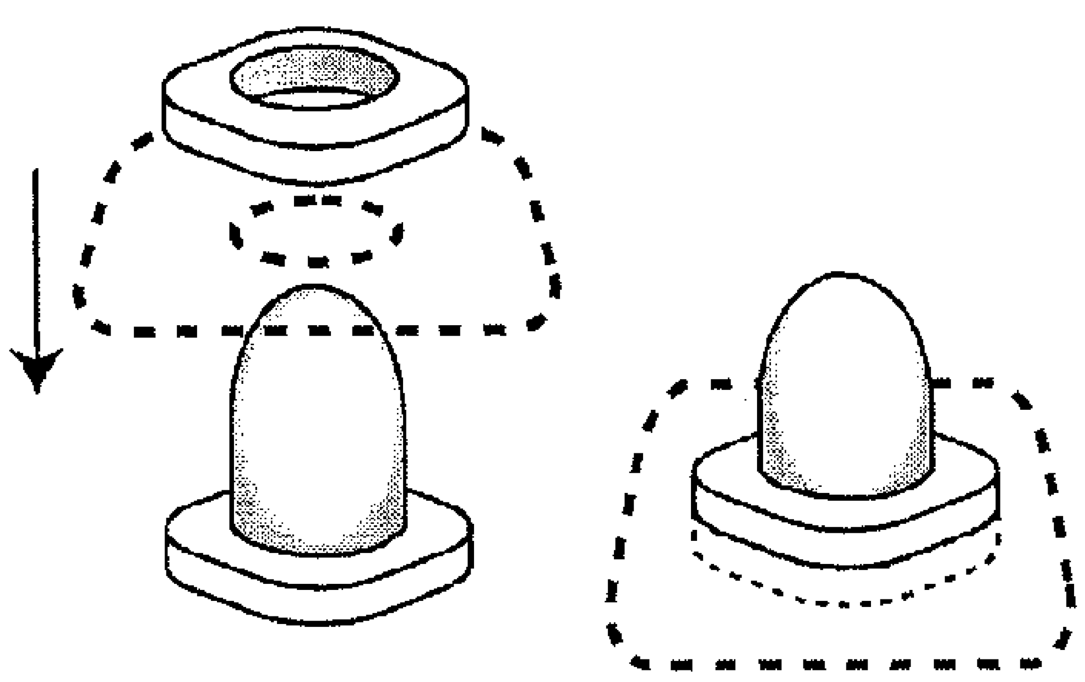

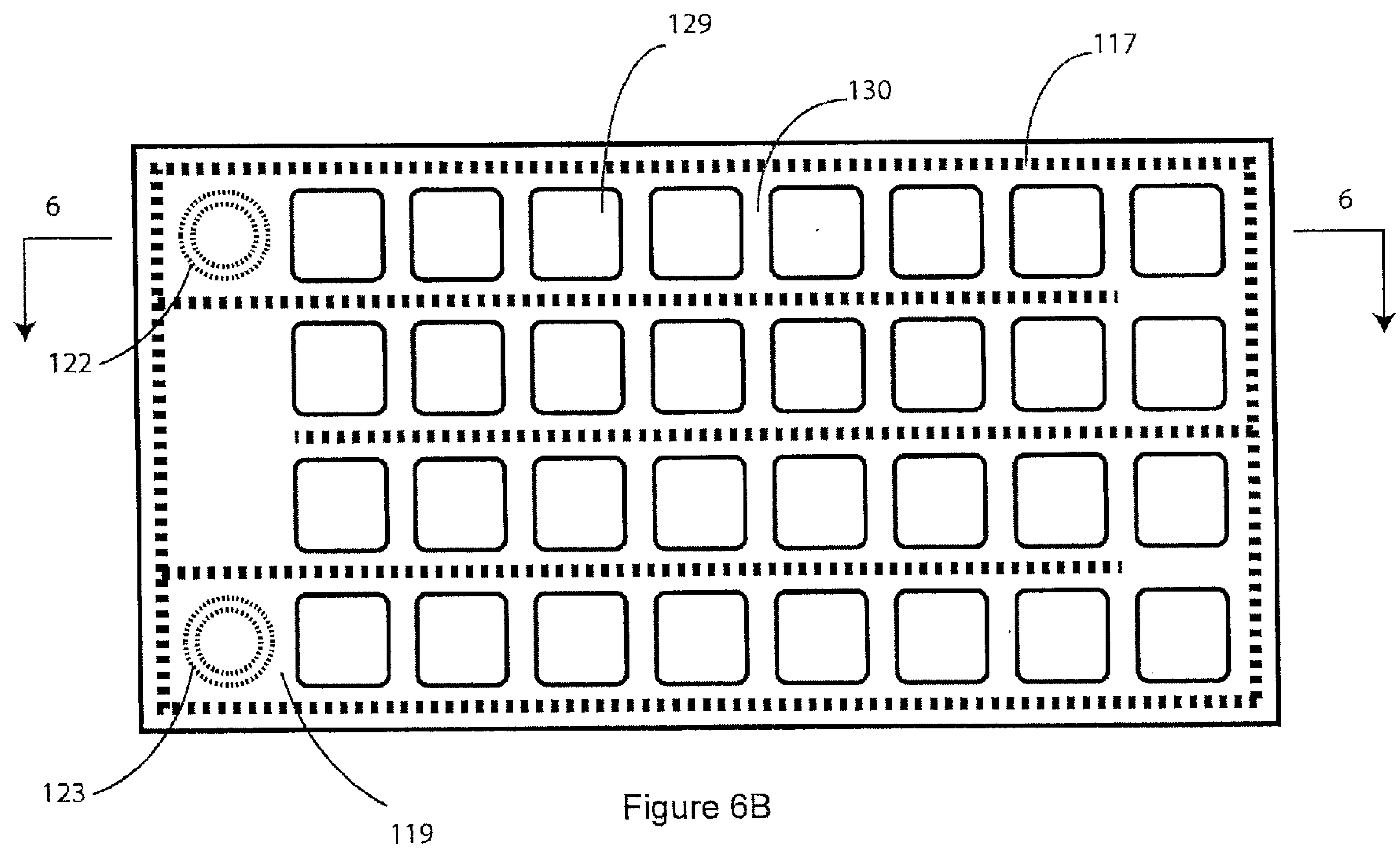

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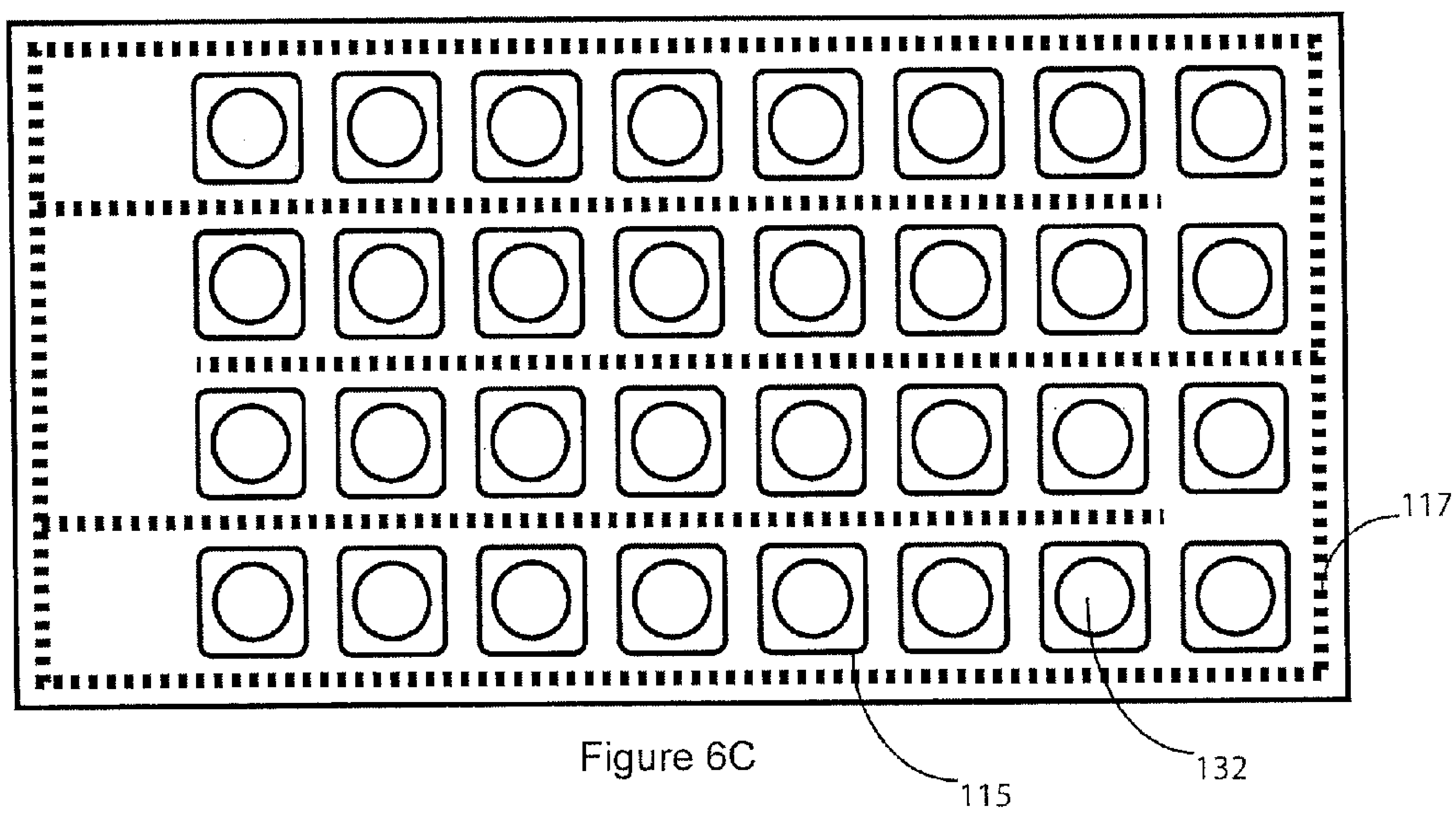

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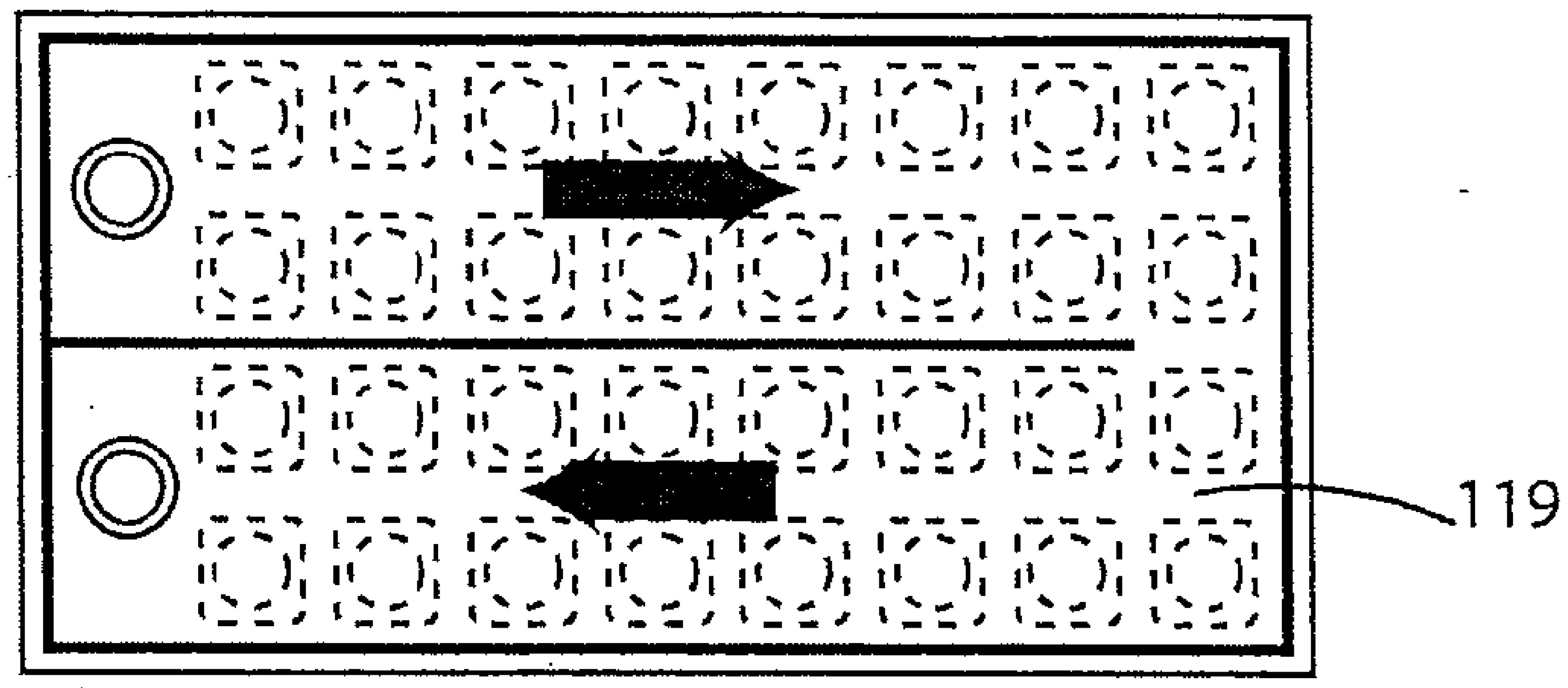

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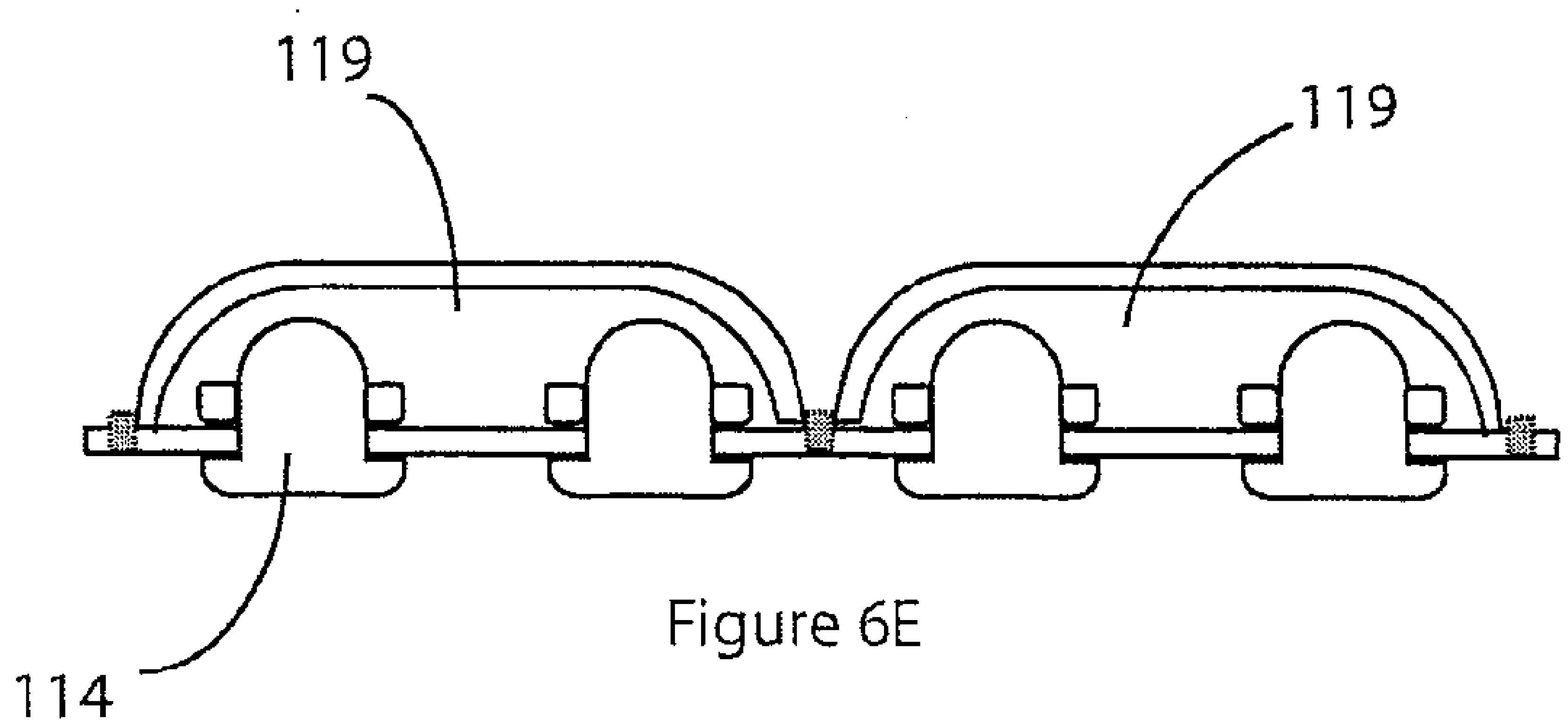

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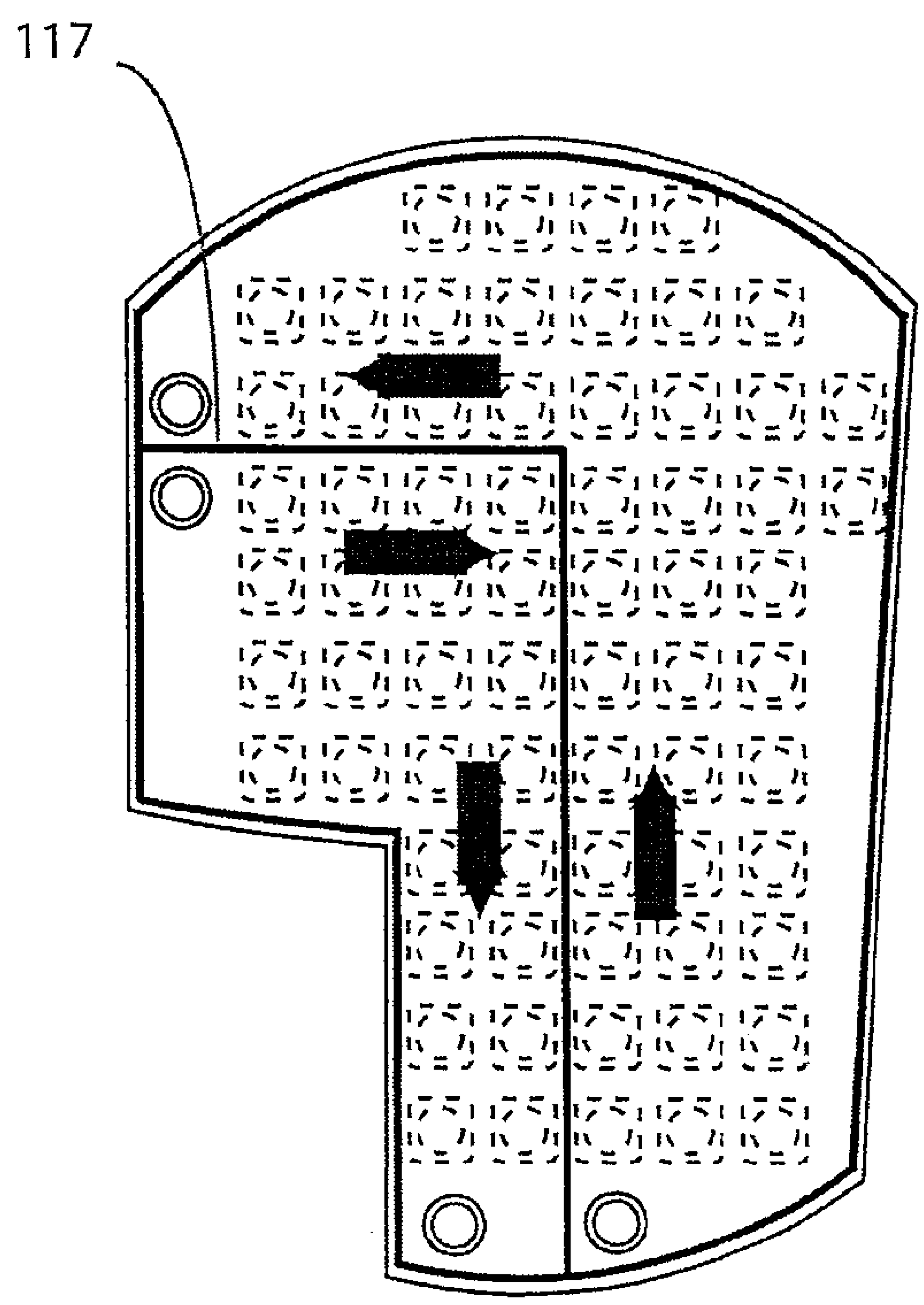

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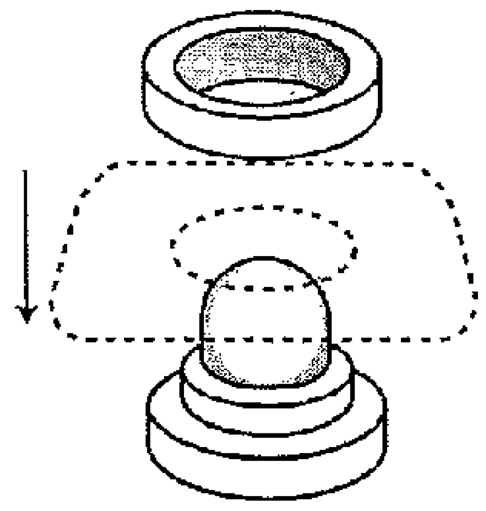

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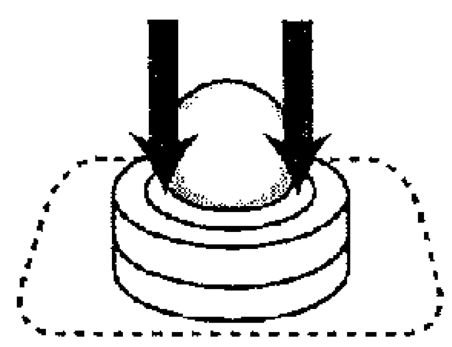

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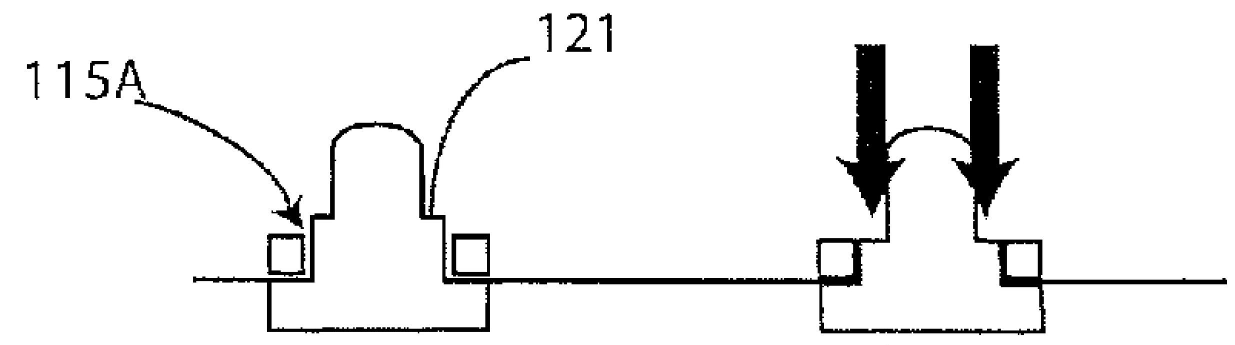


Figure 7A-1 Figure 7B-1

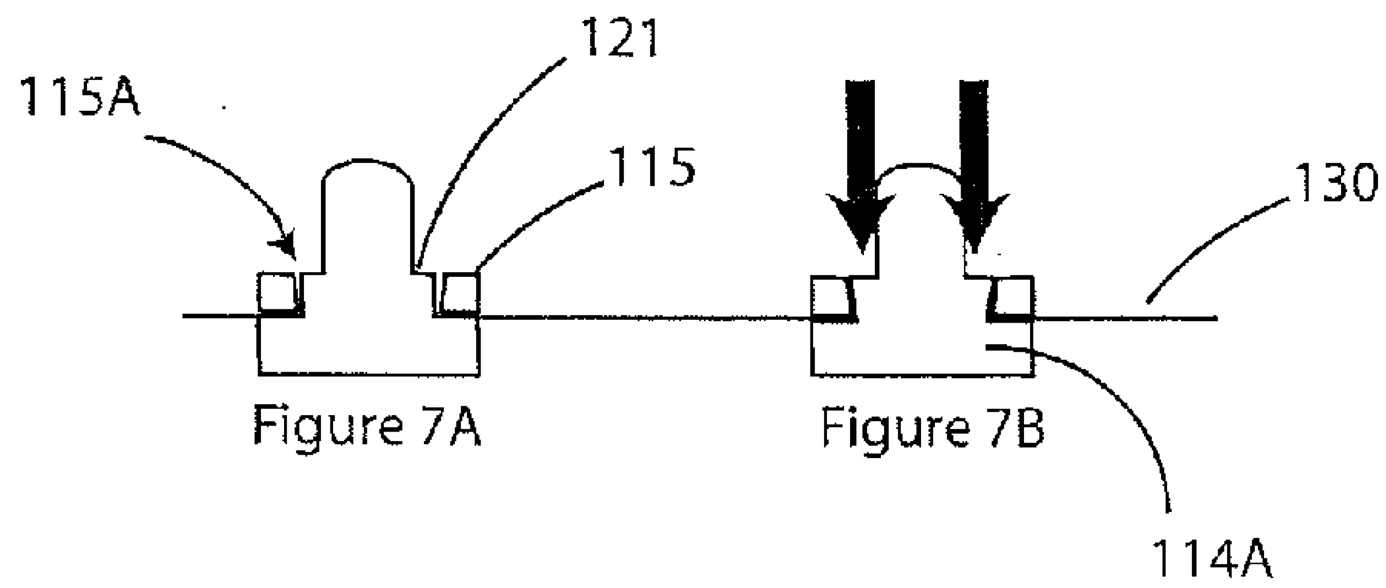
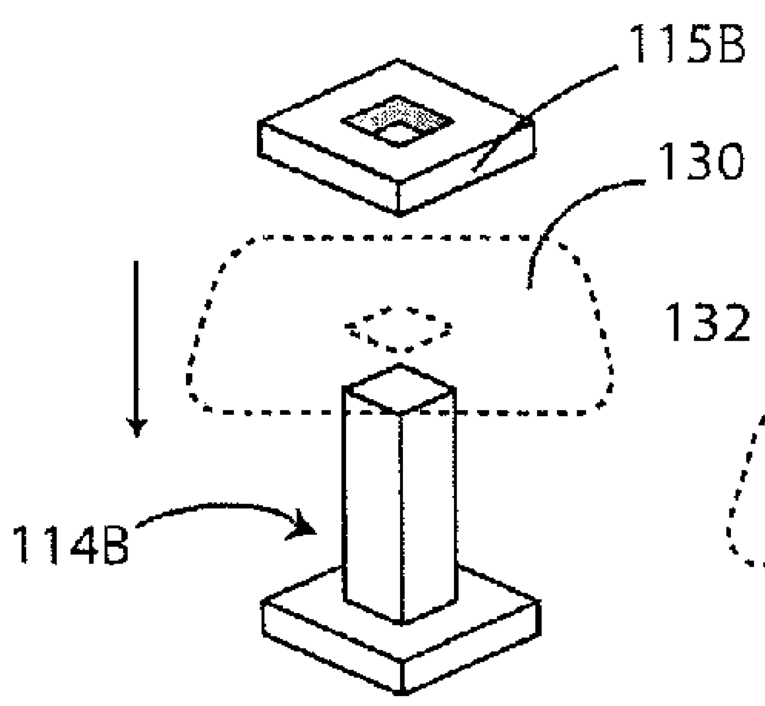


Figure 7A Figure 7B



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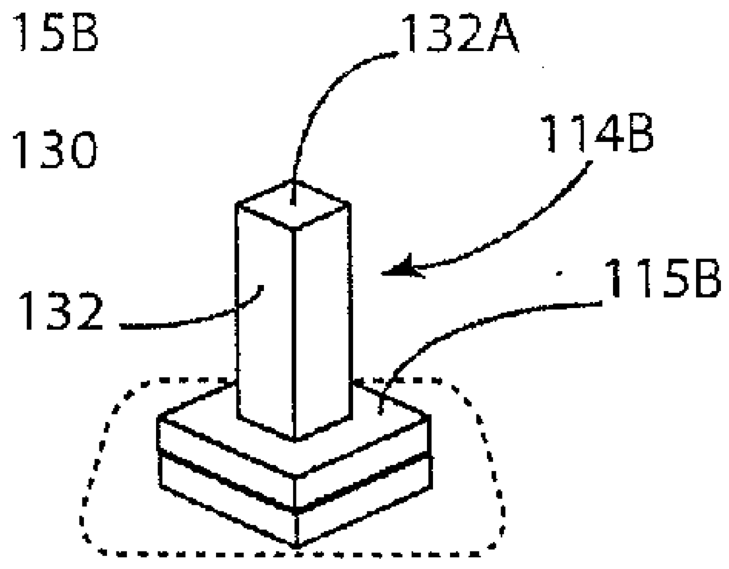

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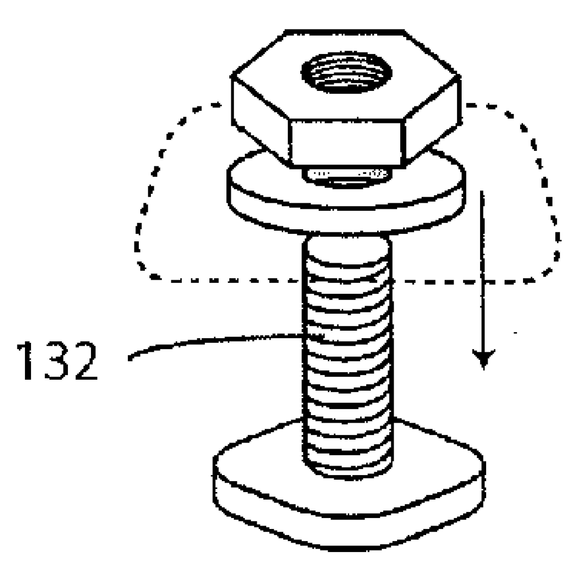

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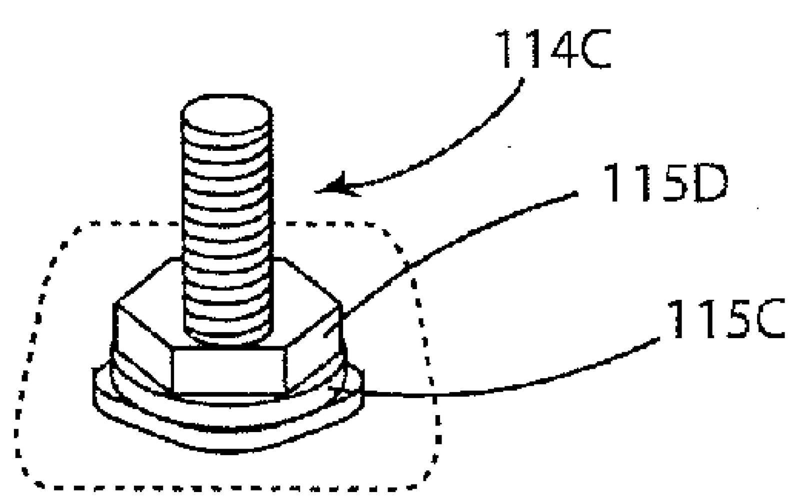

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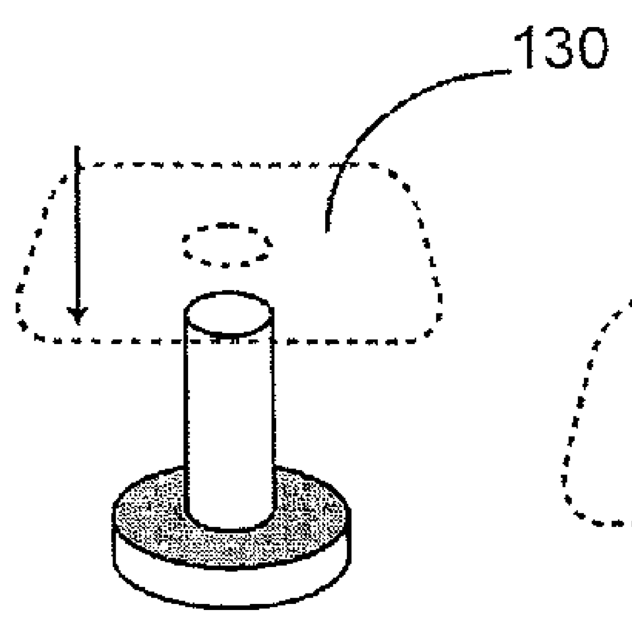

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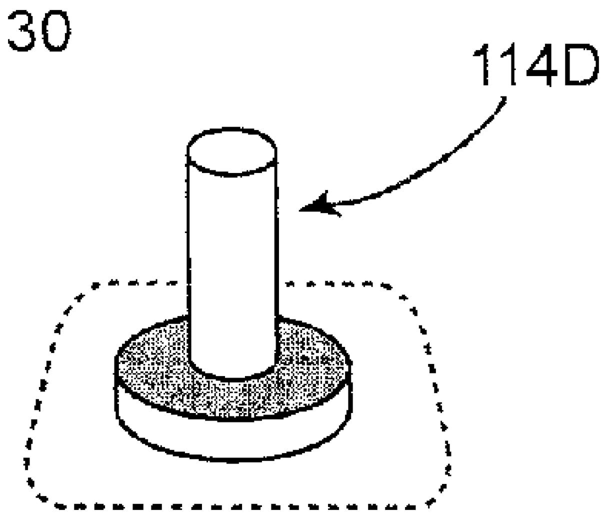

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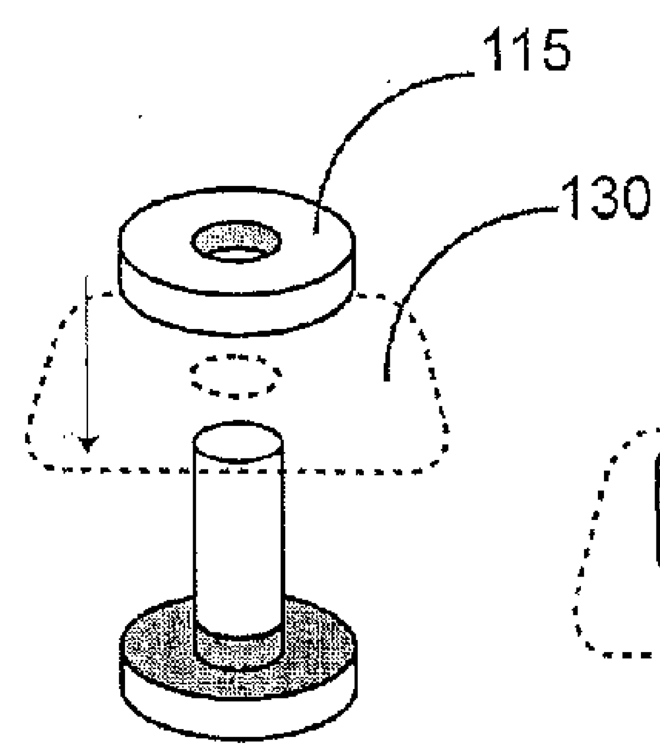

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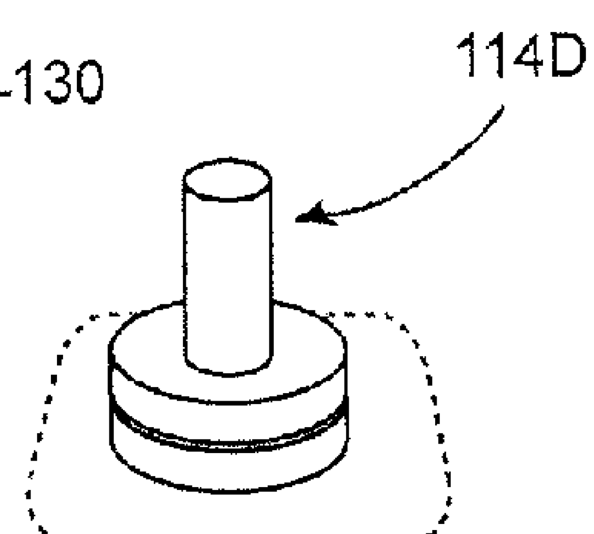

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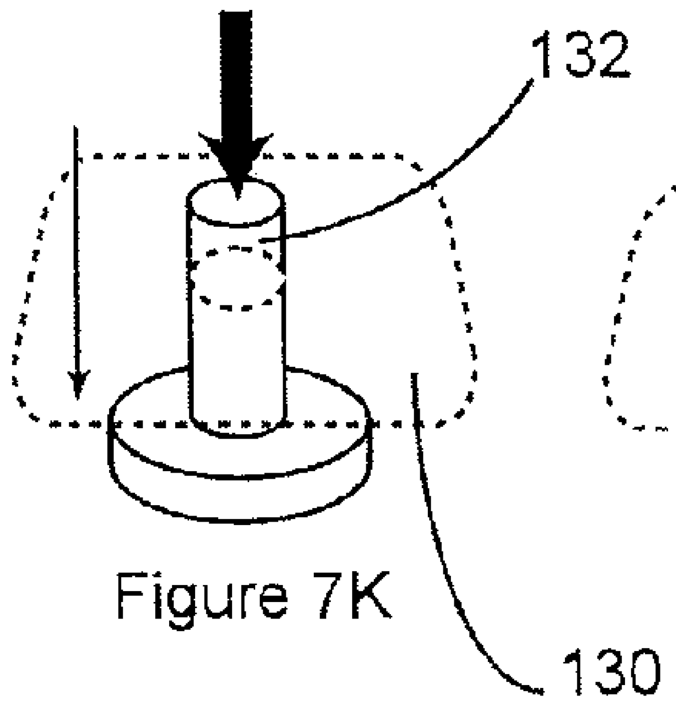

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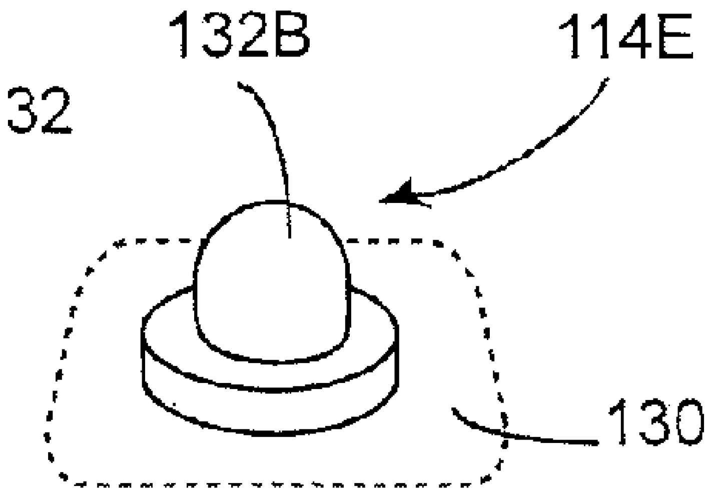

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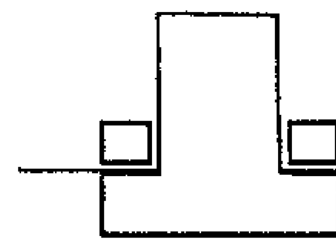

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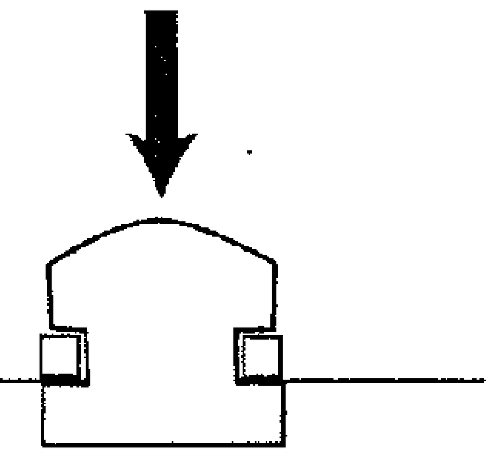

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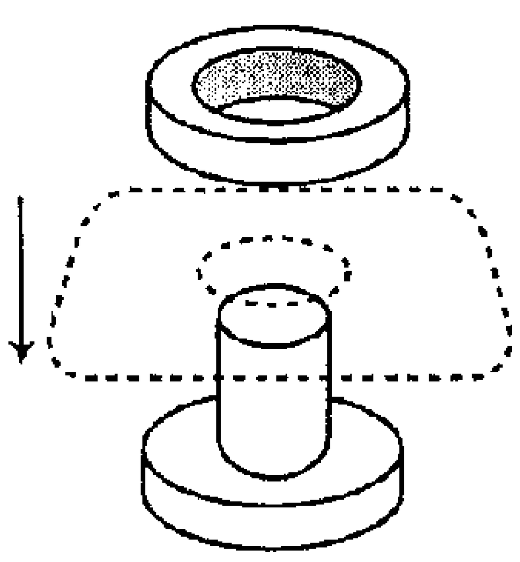

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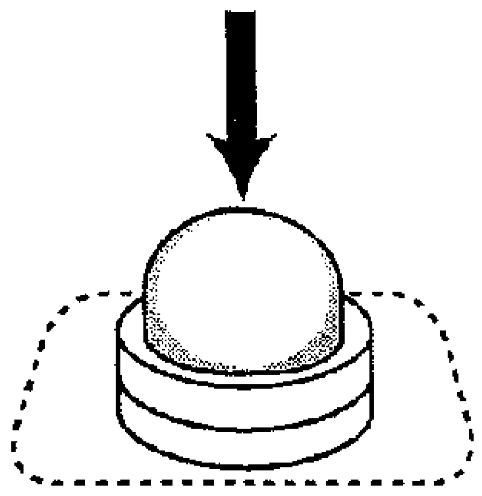

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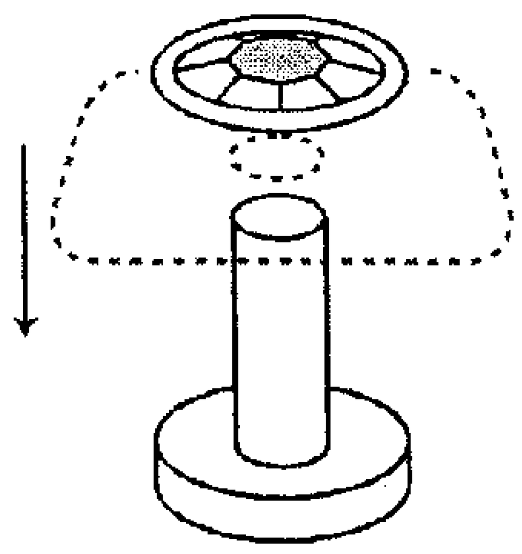

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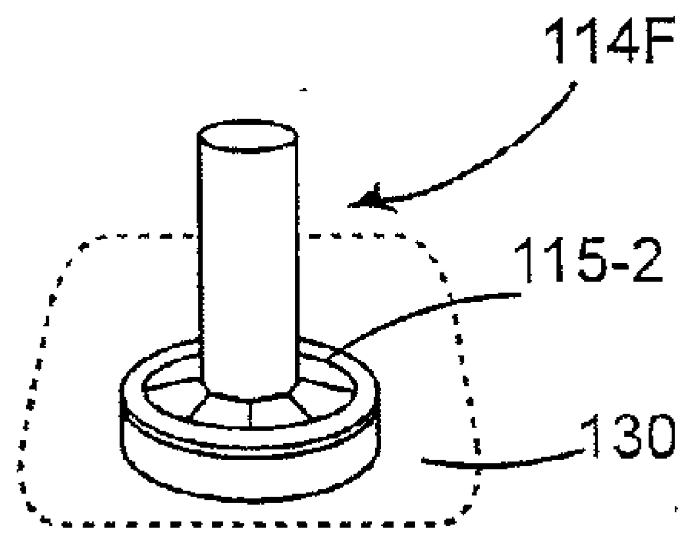

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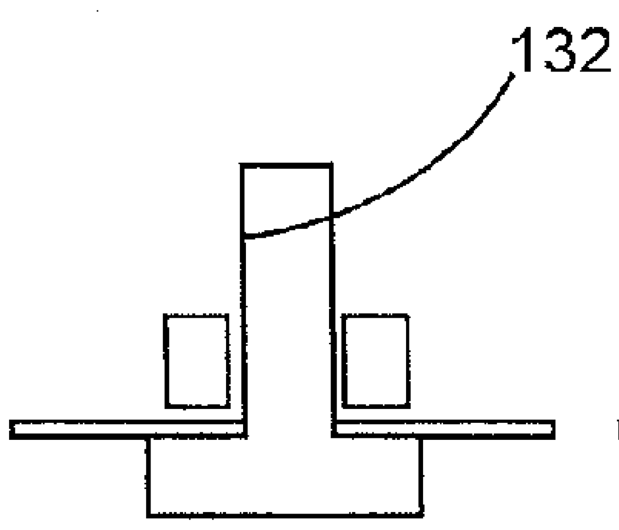

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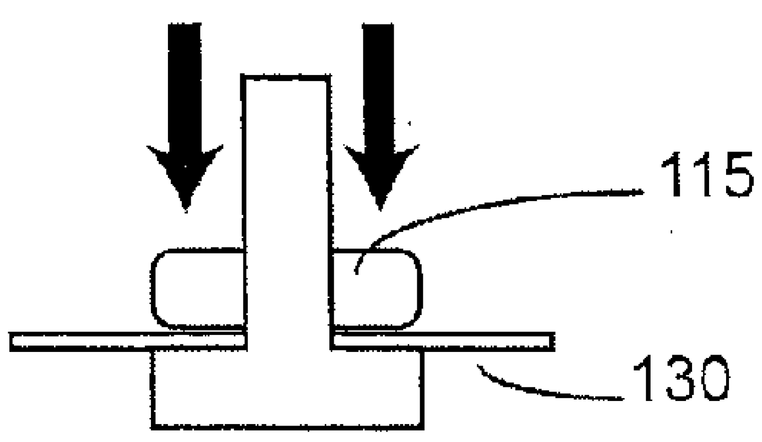

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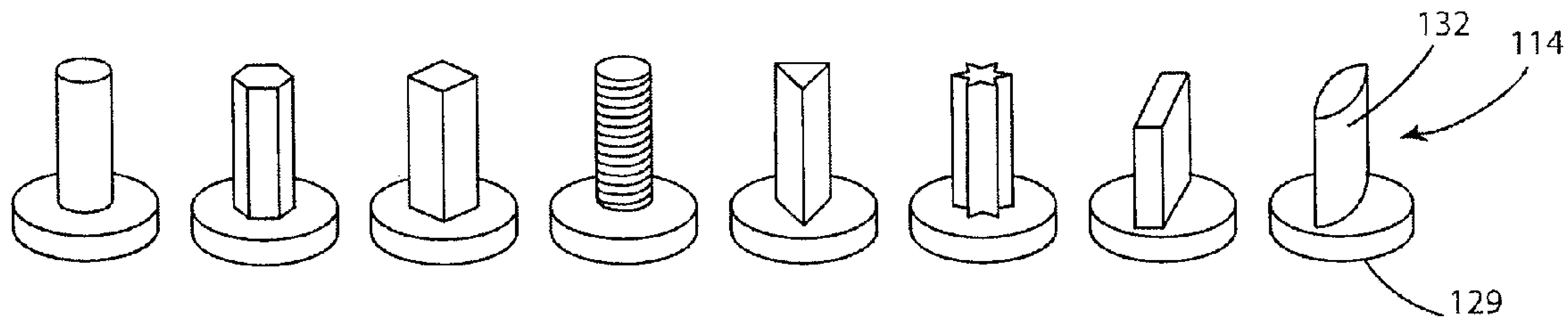

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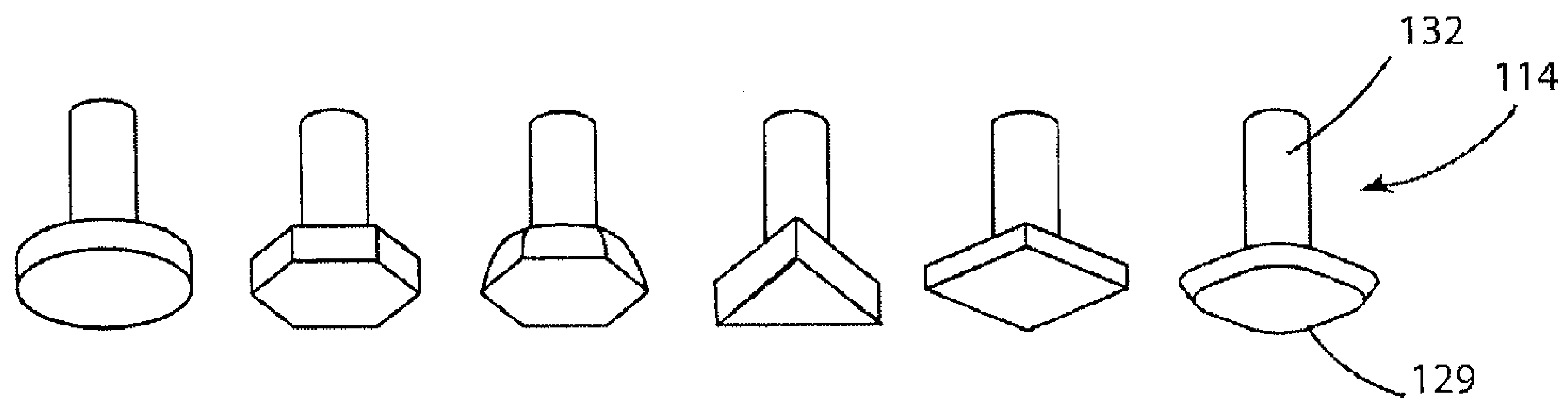

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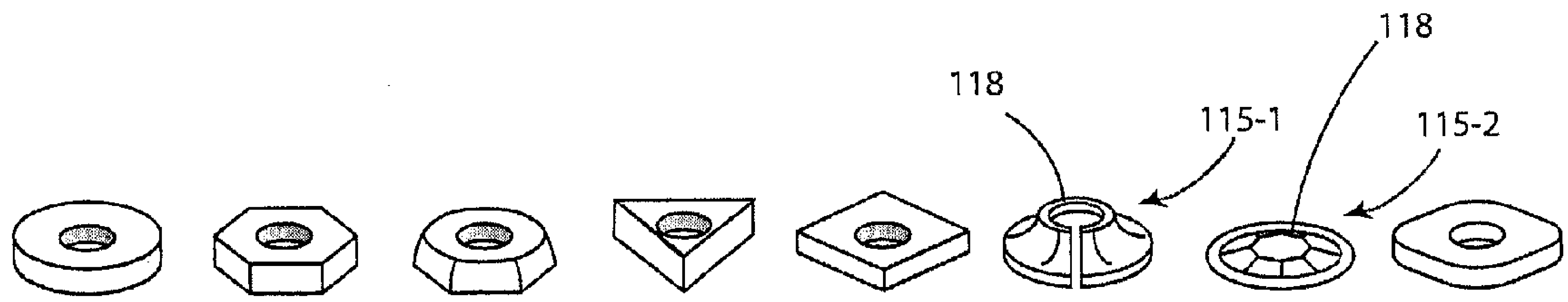

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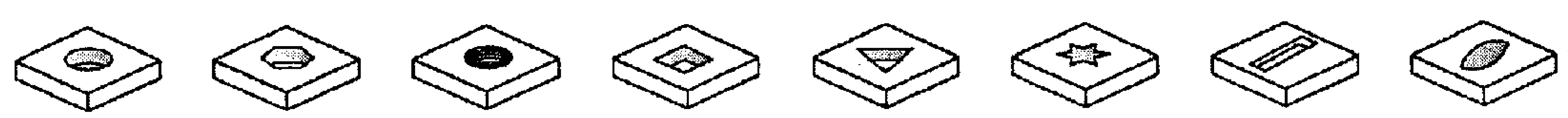

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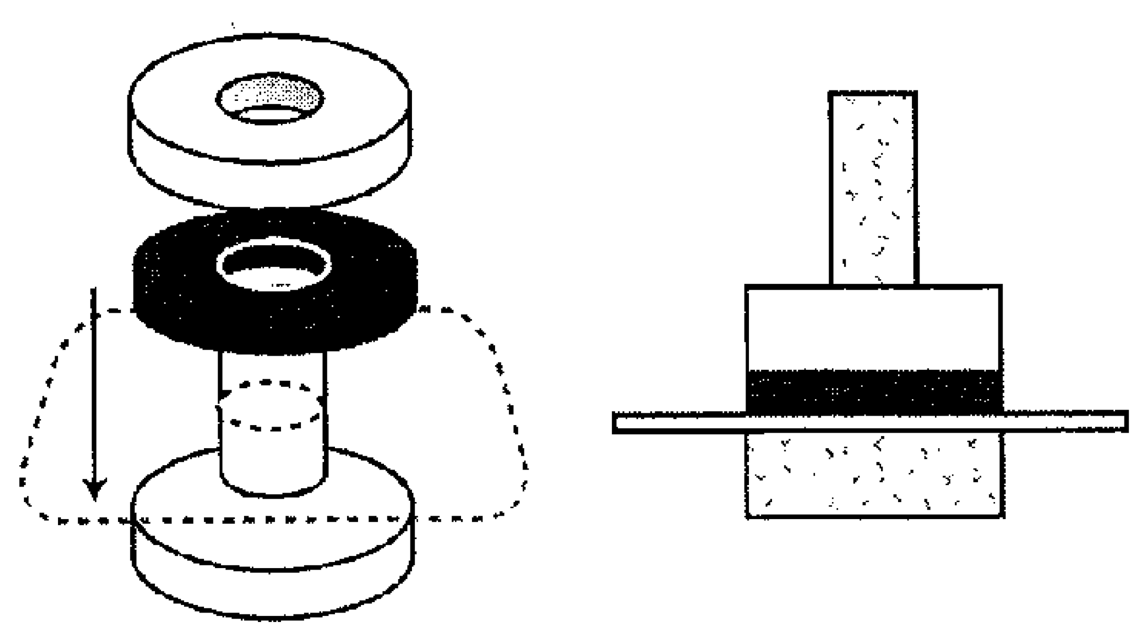

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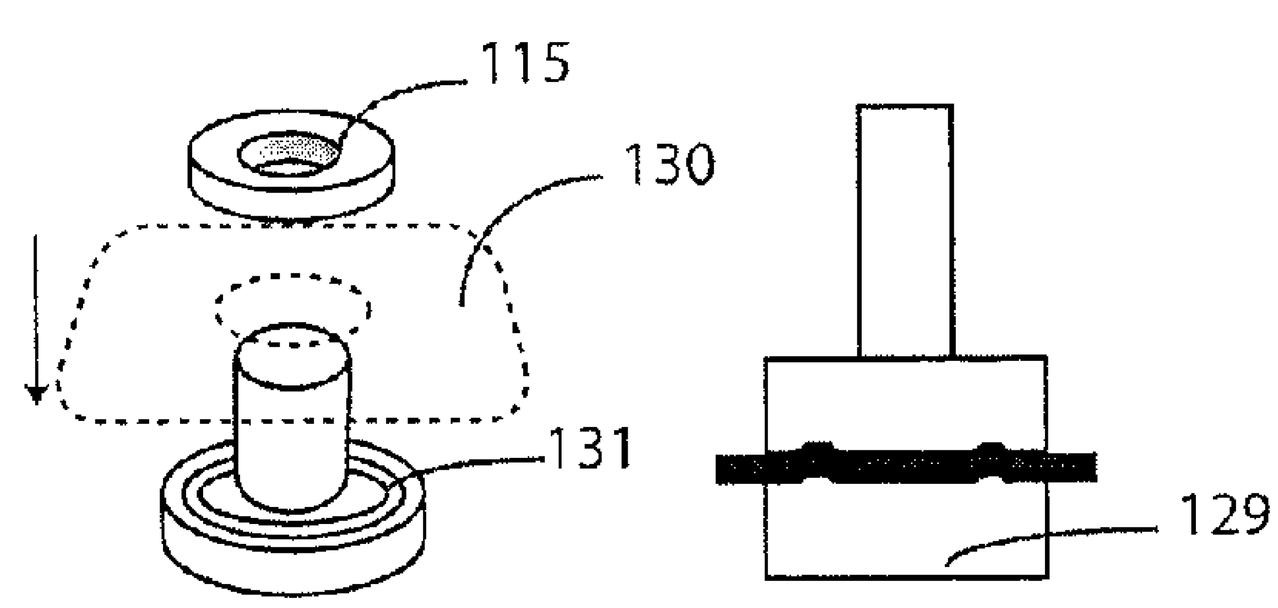

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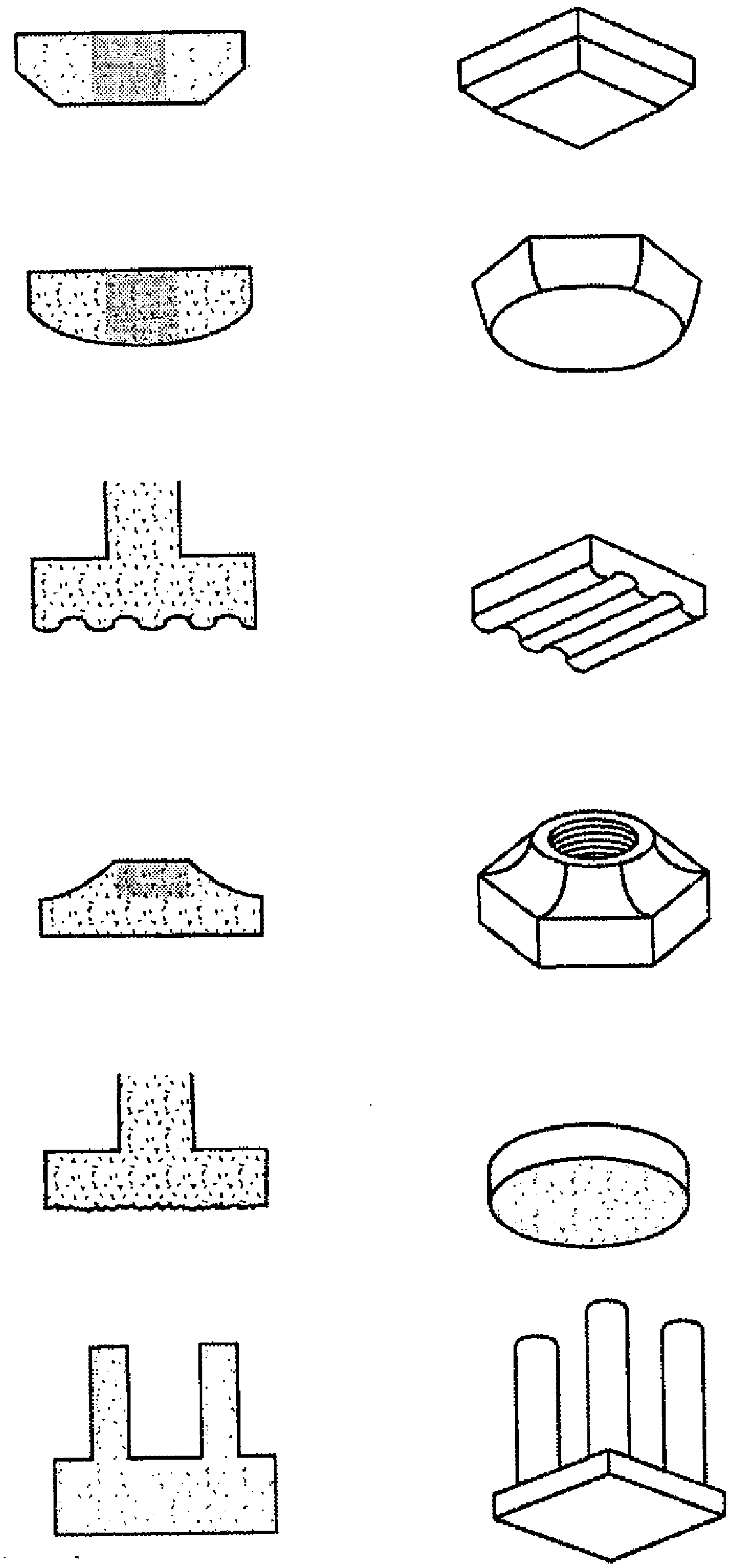

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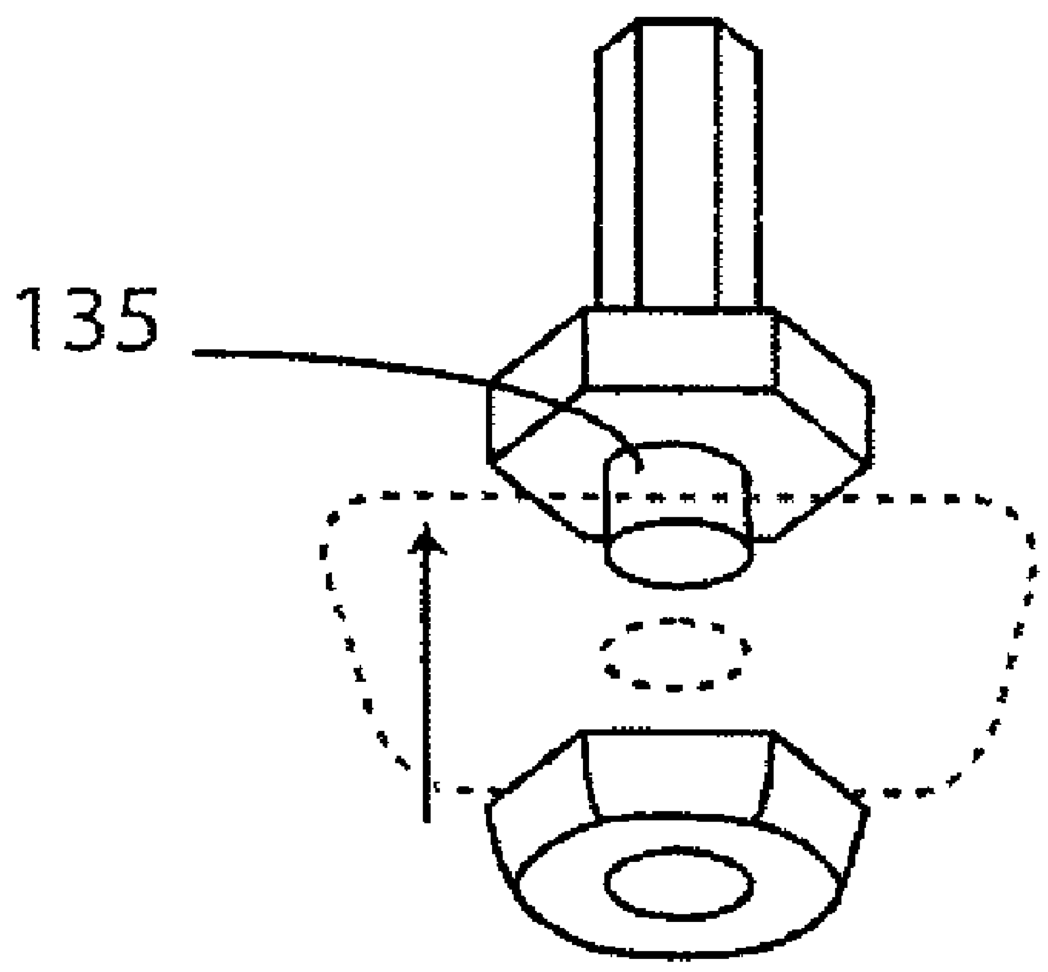
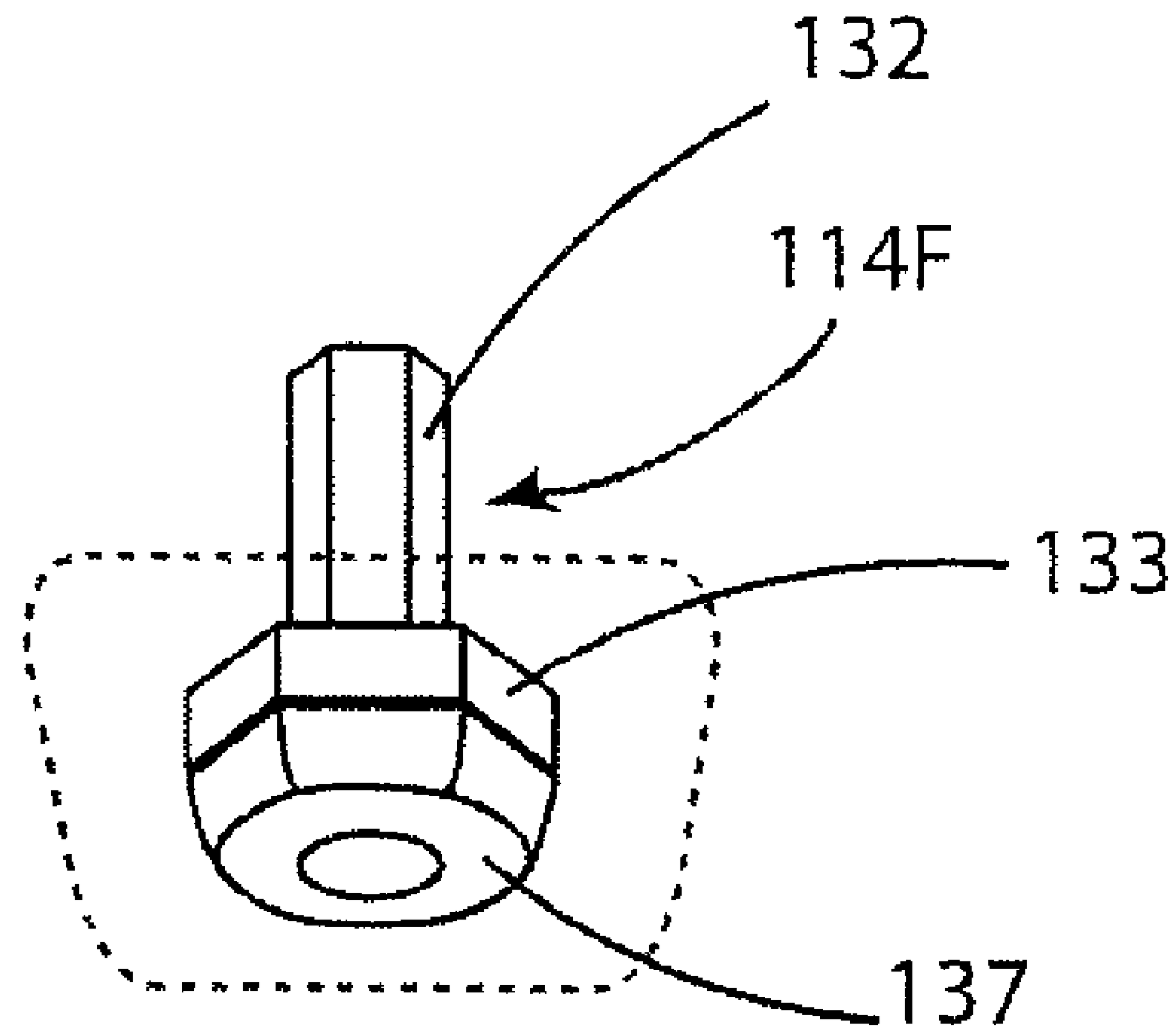


Figure 9A



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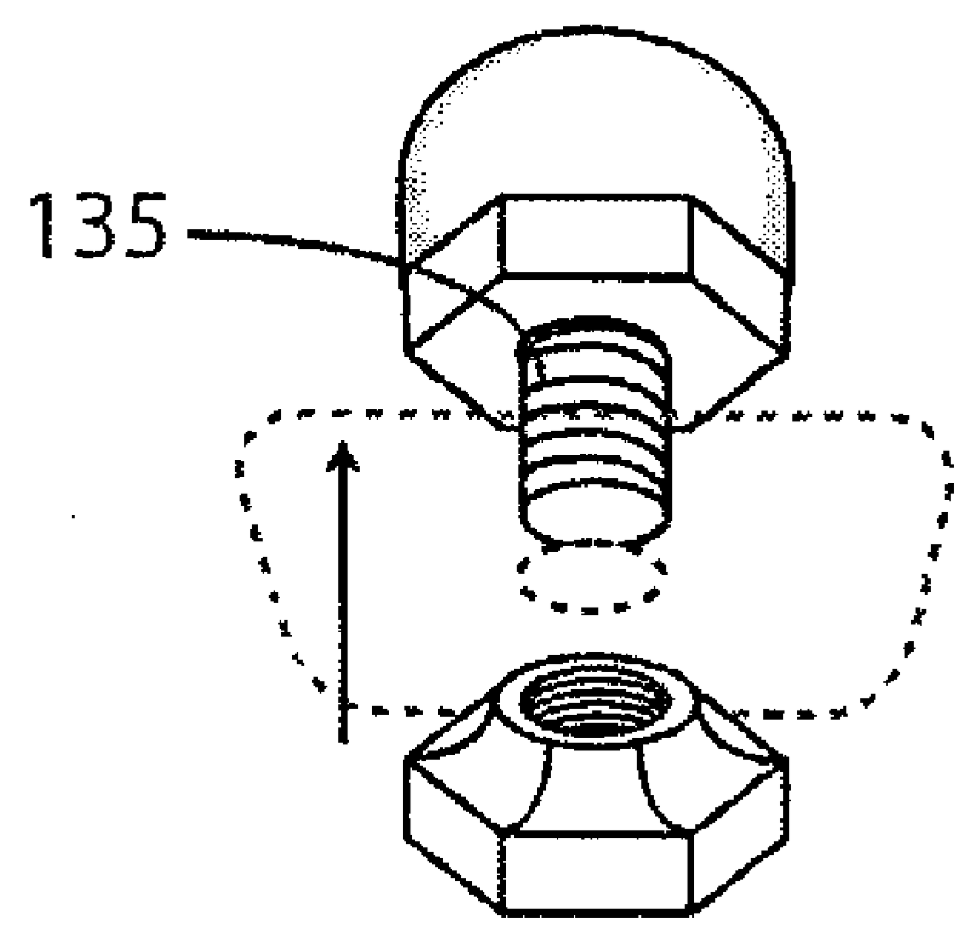

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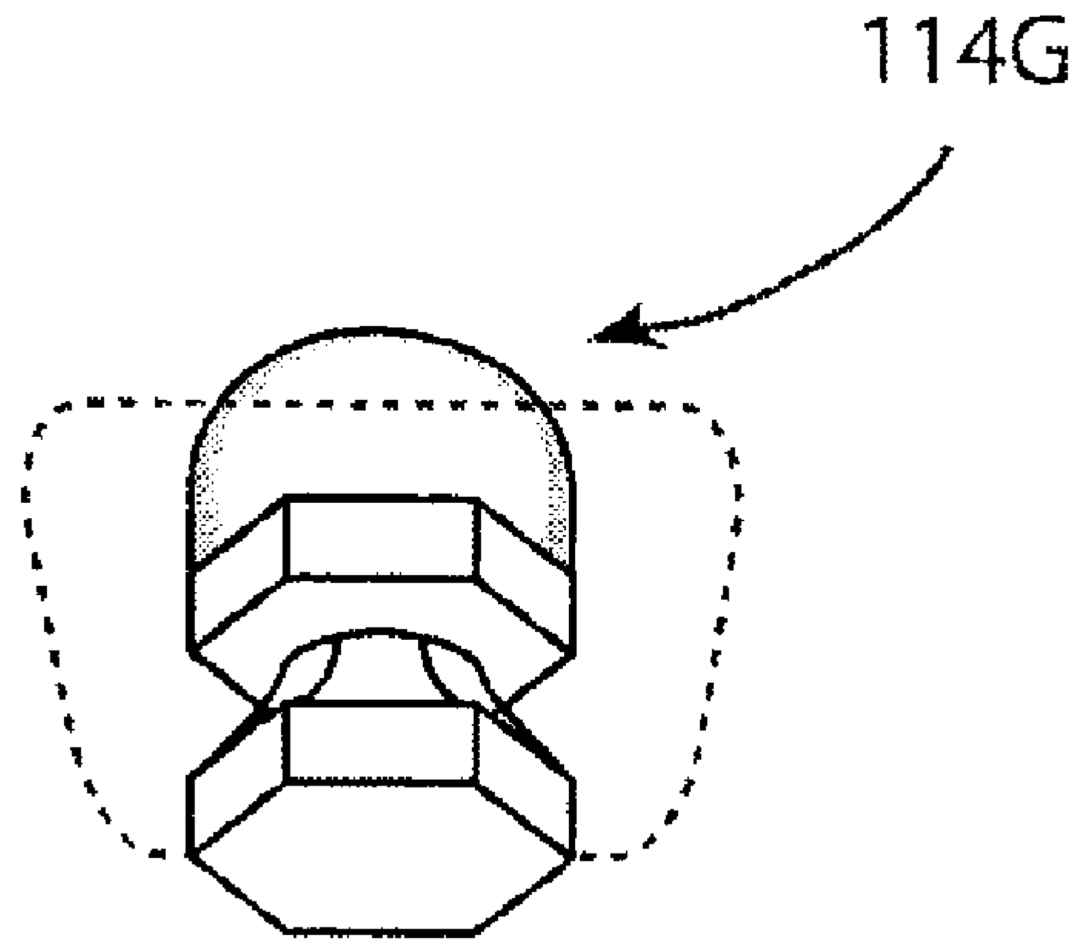

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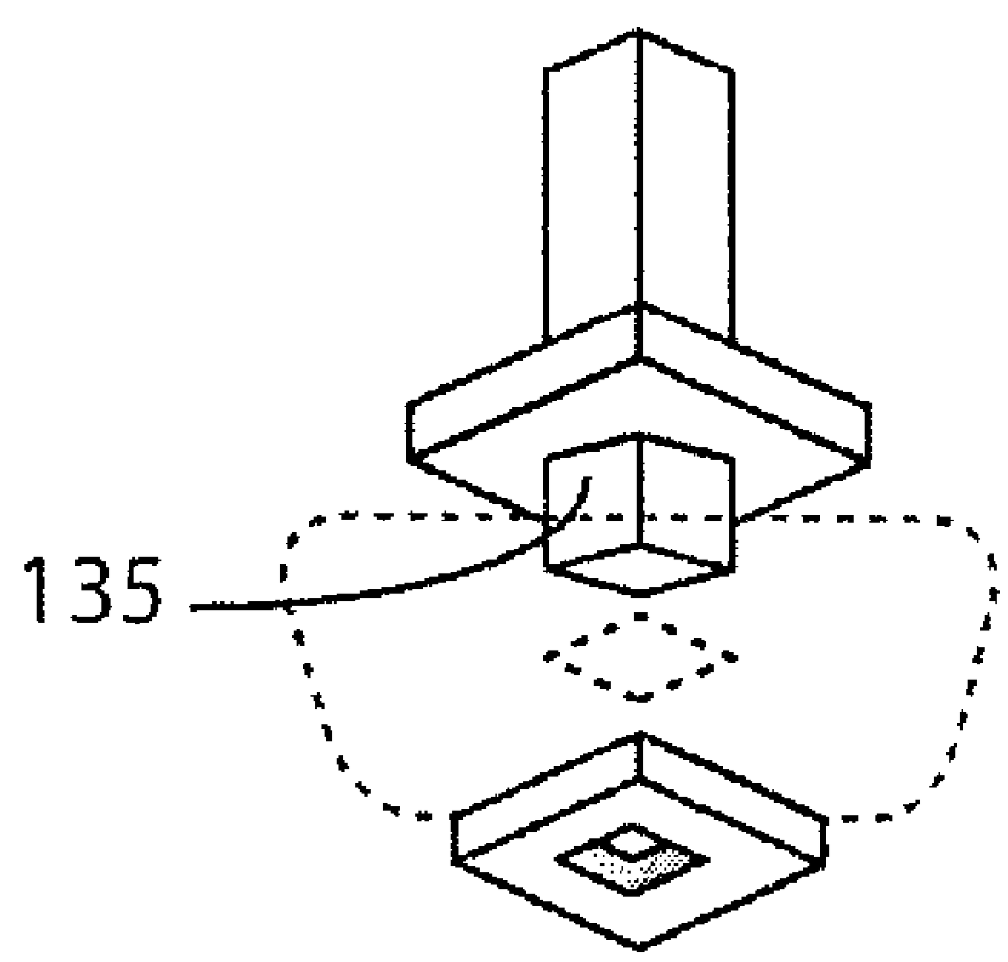


Figure 9E

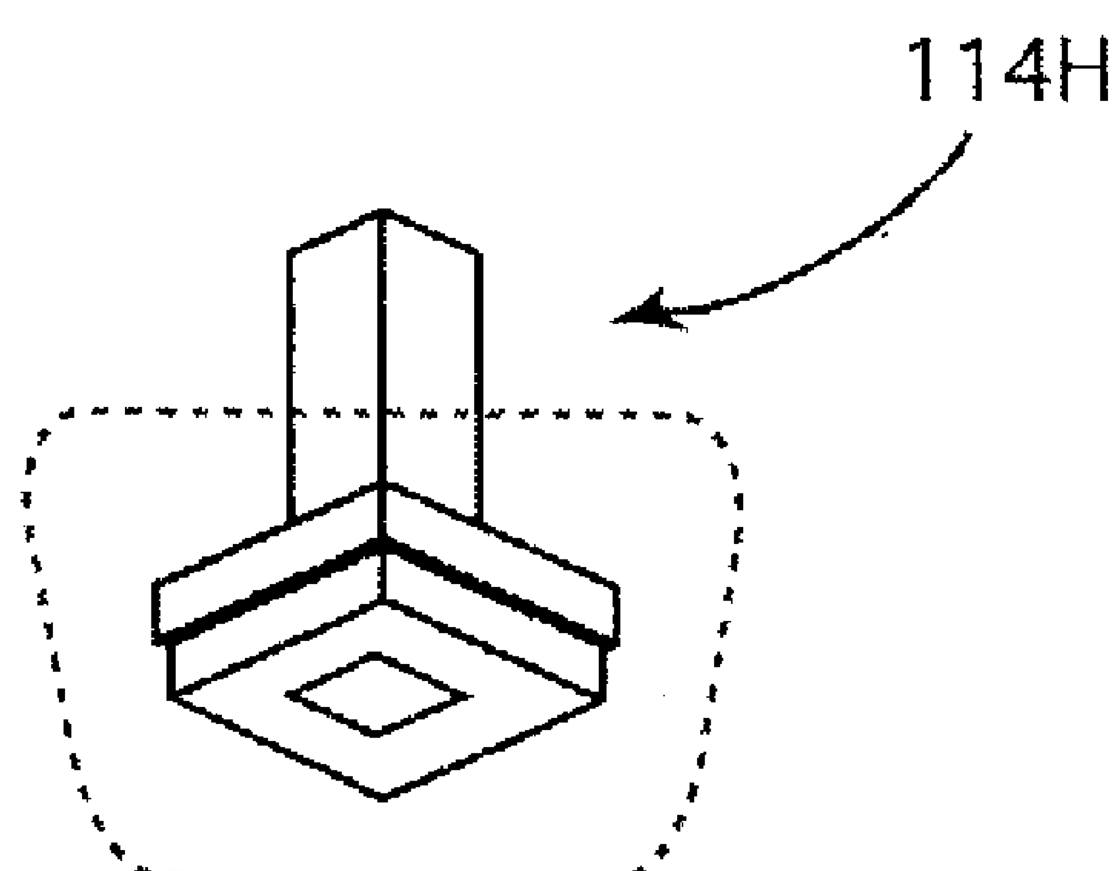


Figure 9F

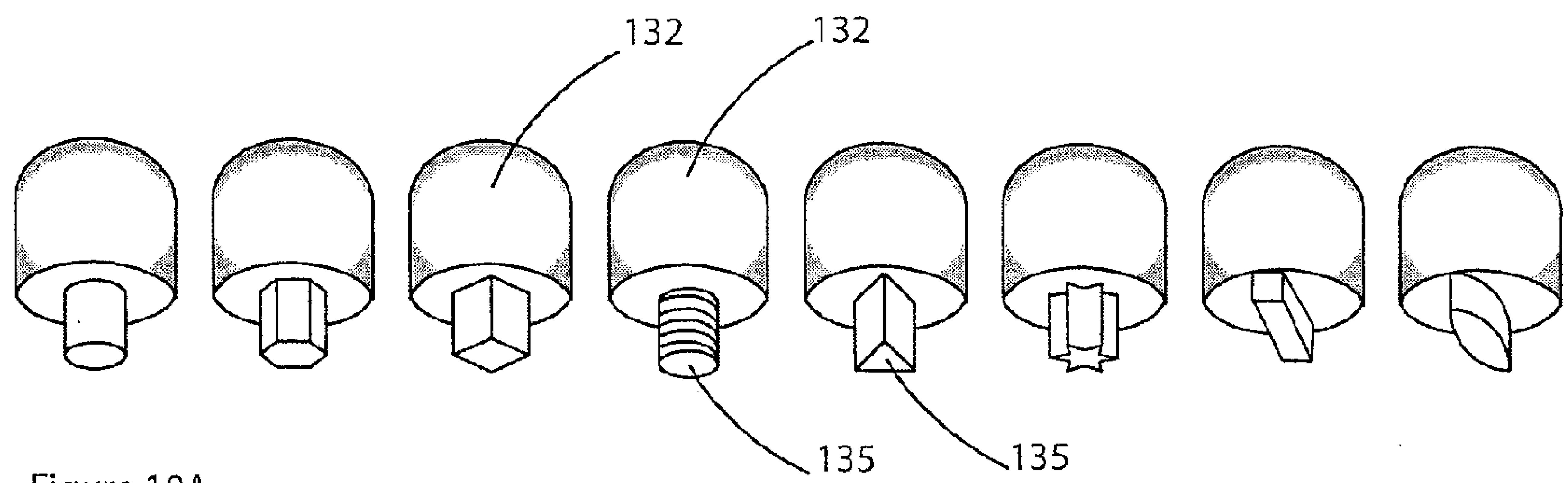


Figure 10A

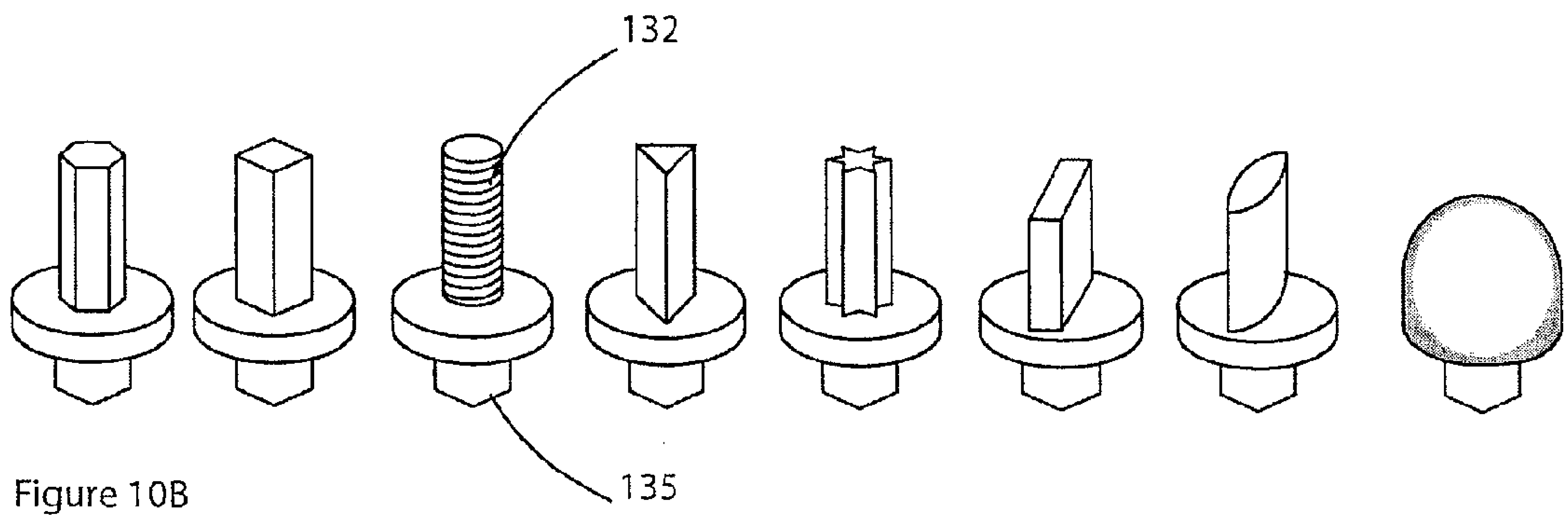


Figure 10B

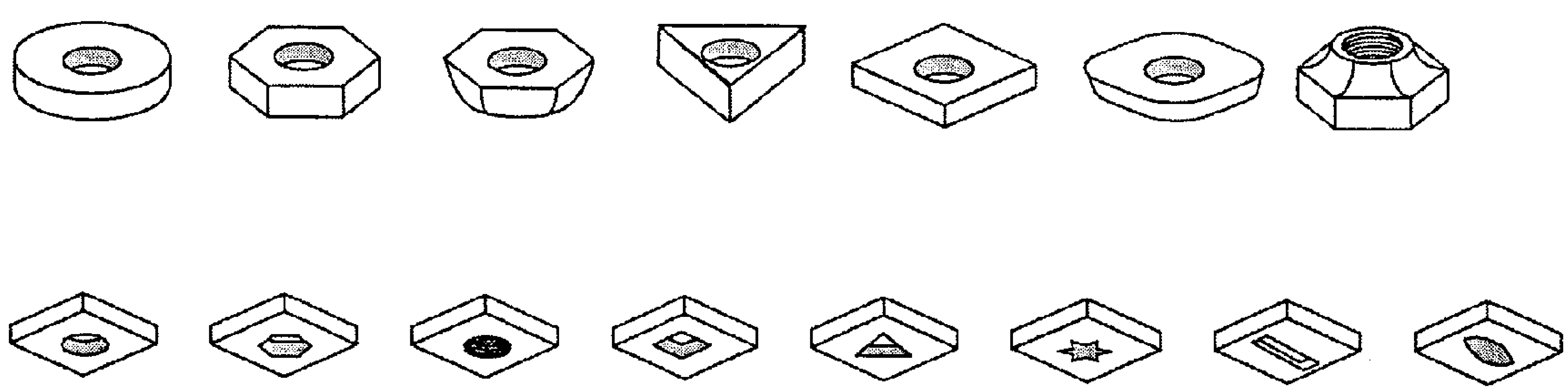
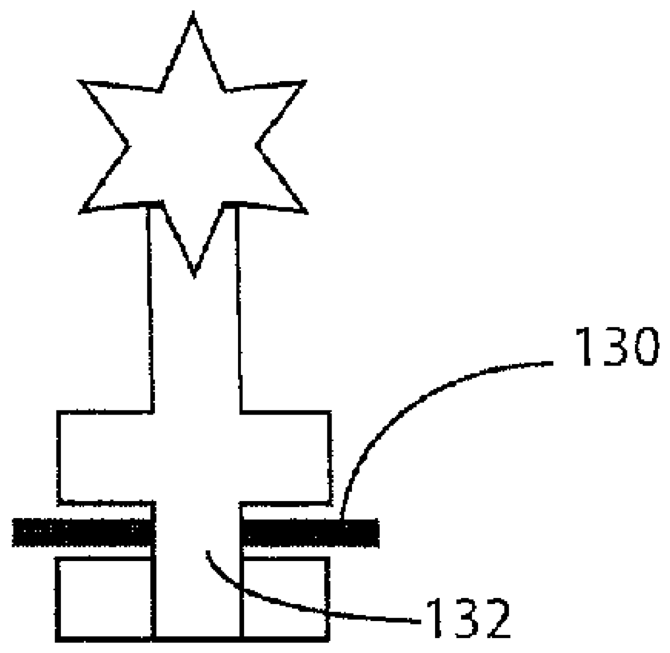


Figure 10C



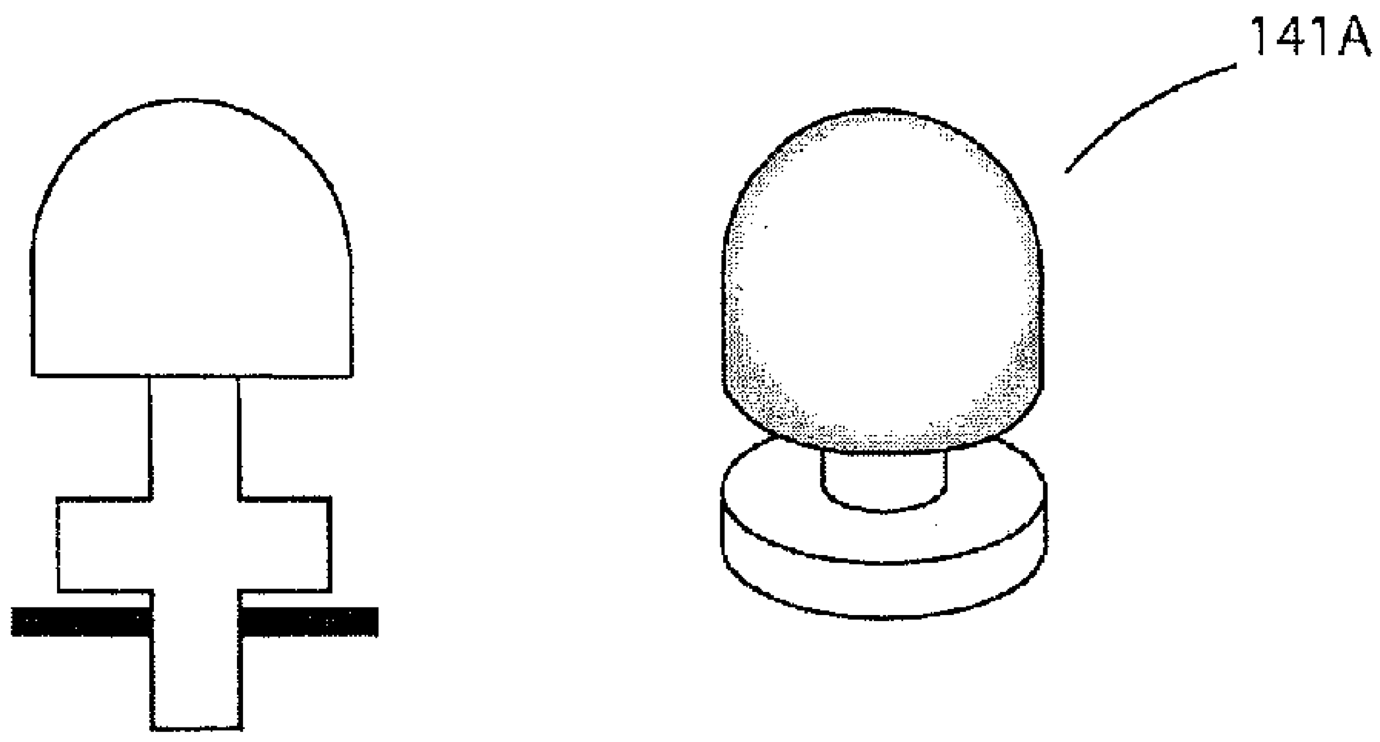


Figure 11A

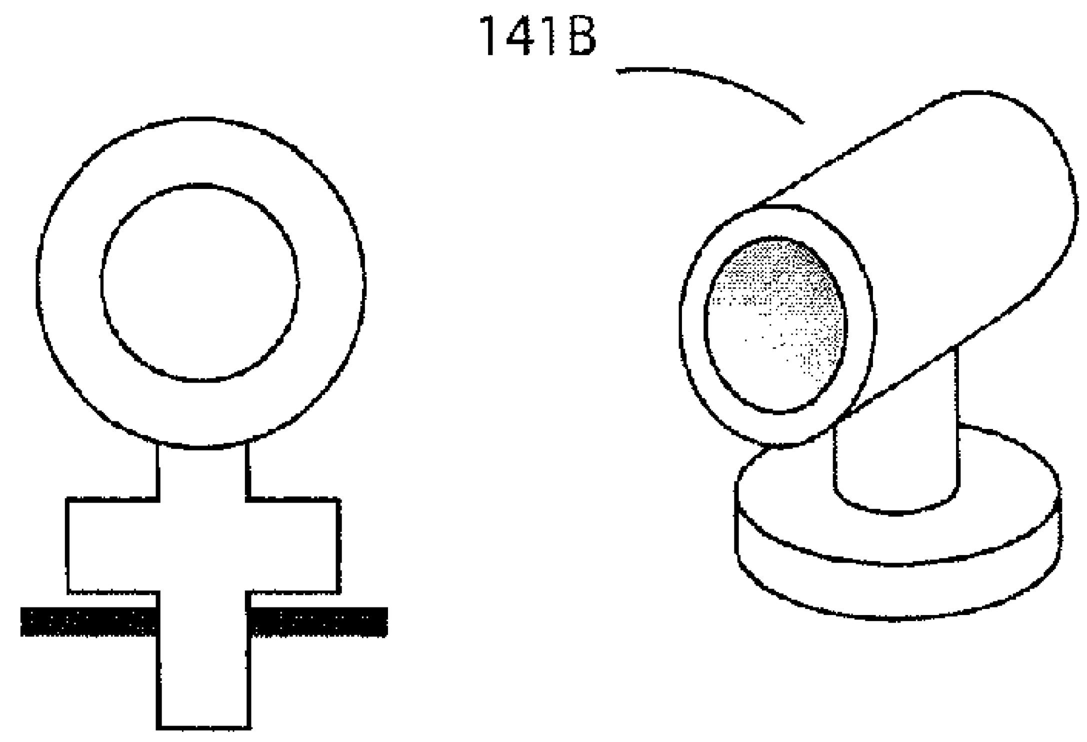


Figure 11B

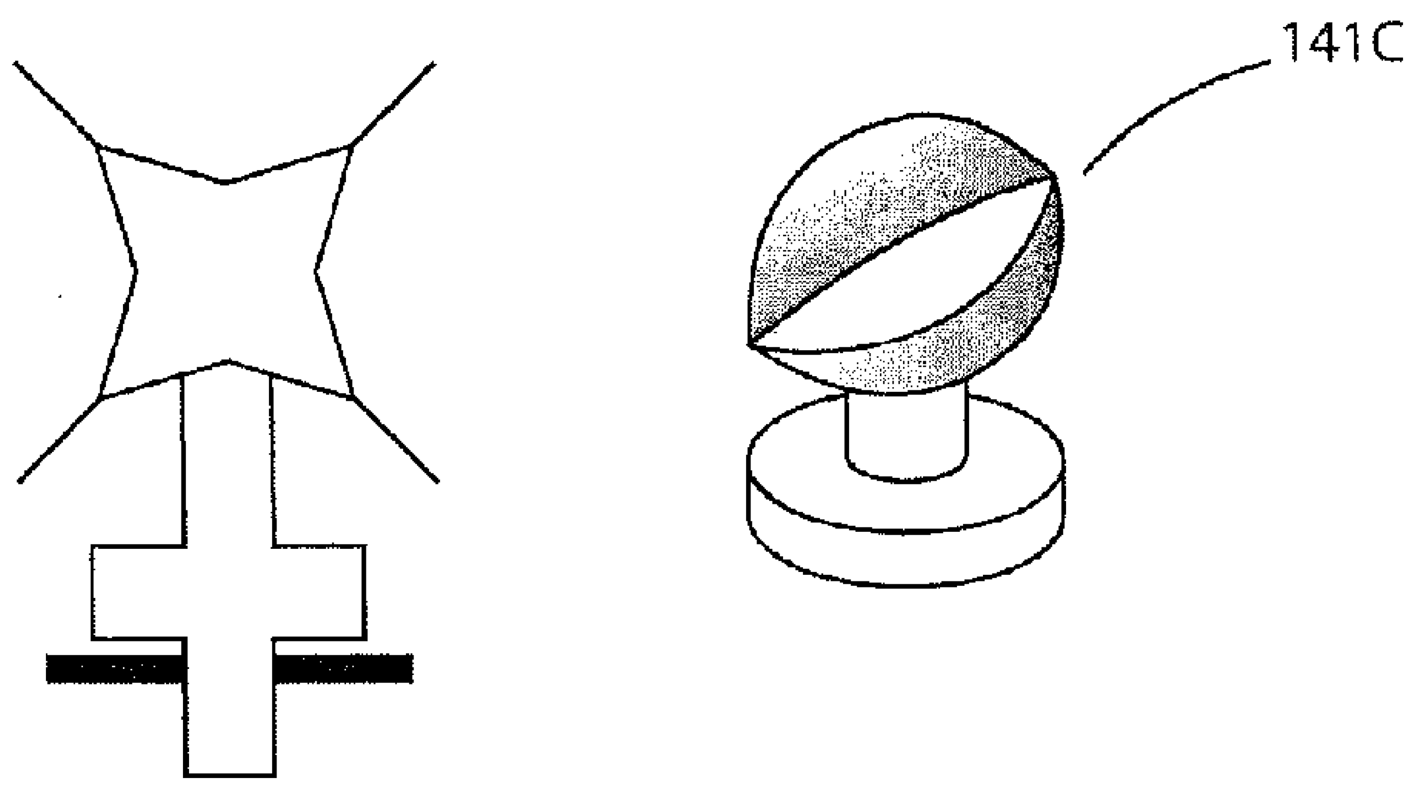


Figure 11C

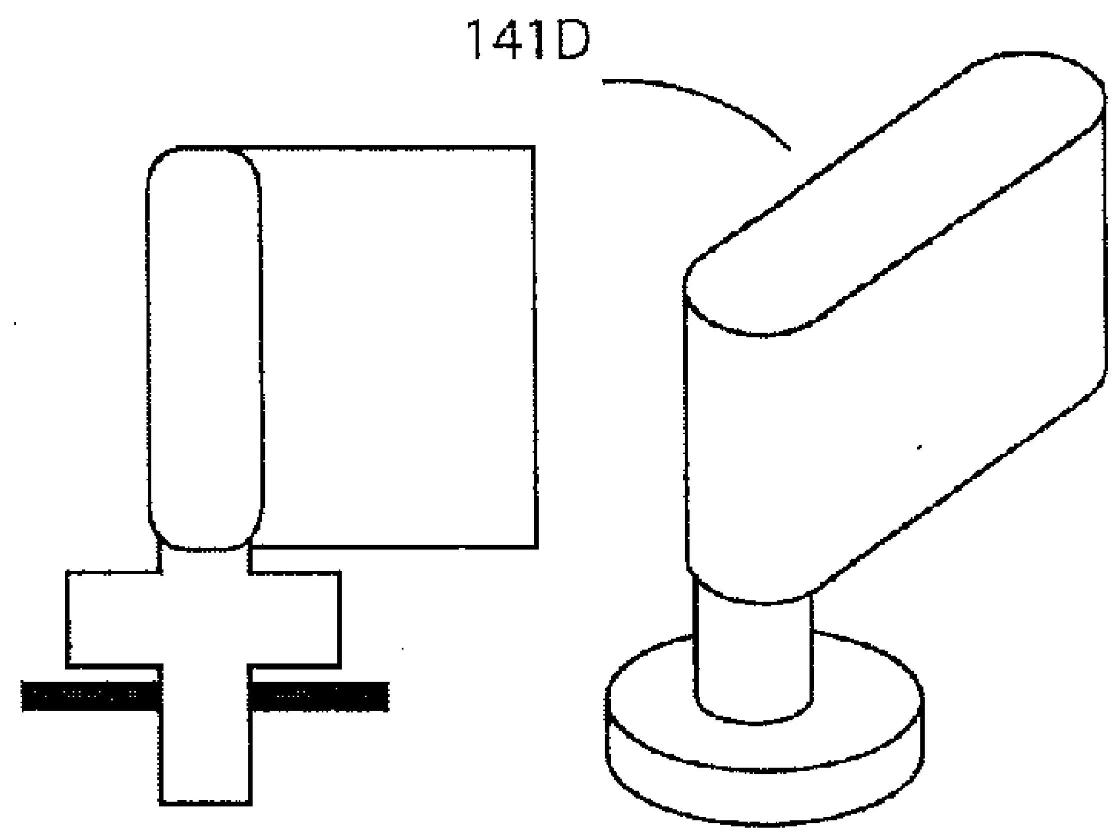


Figure 11D

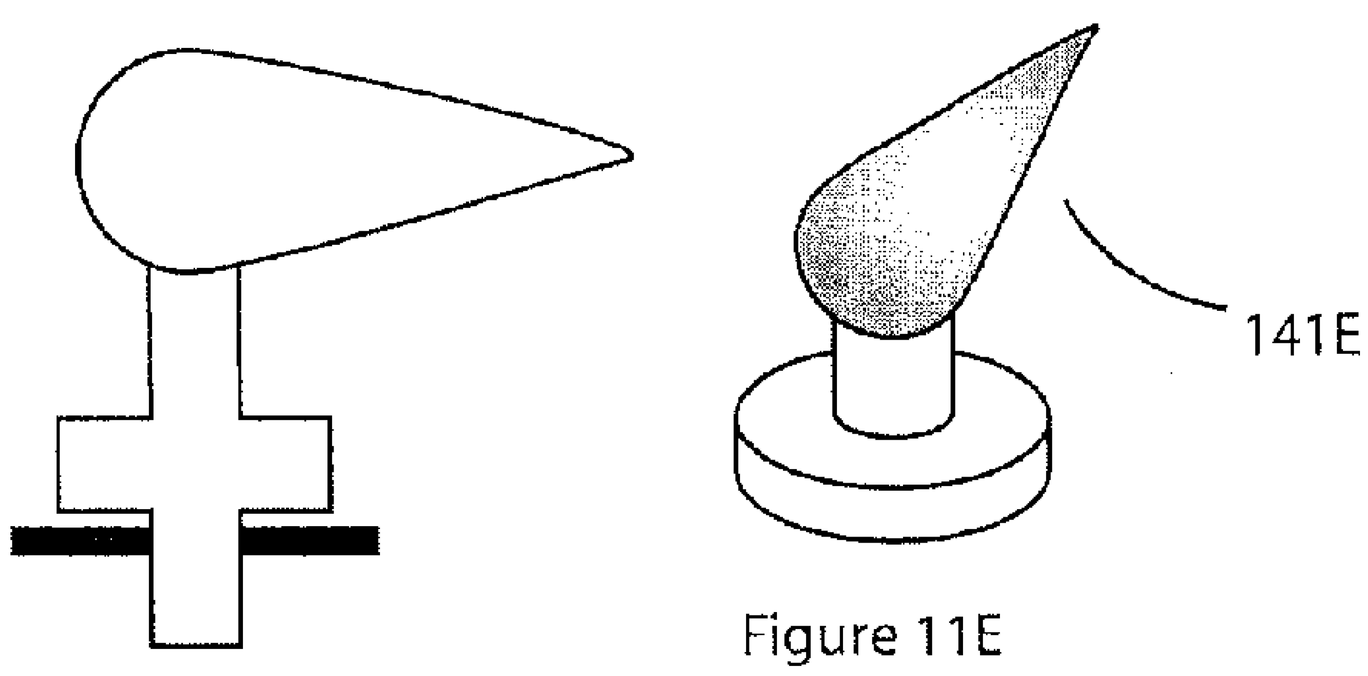


Figure 11E

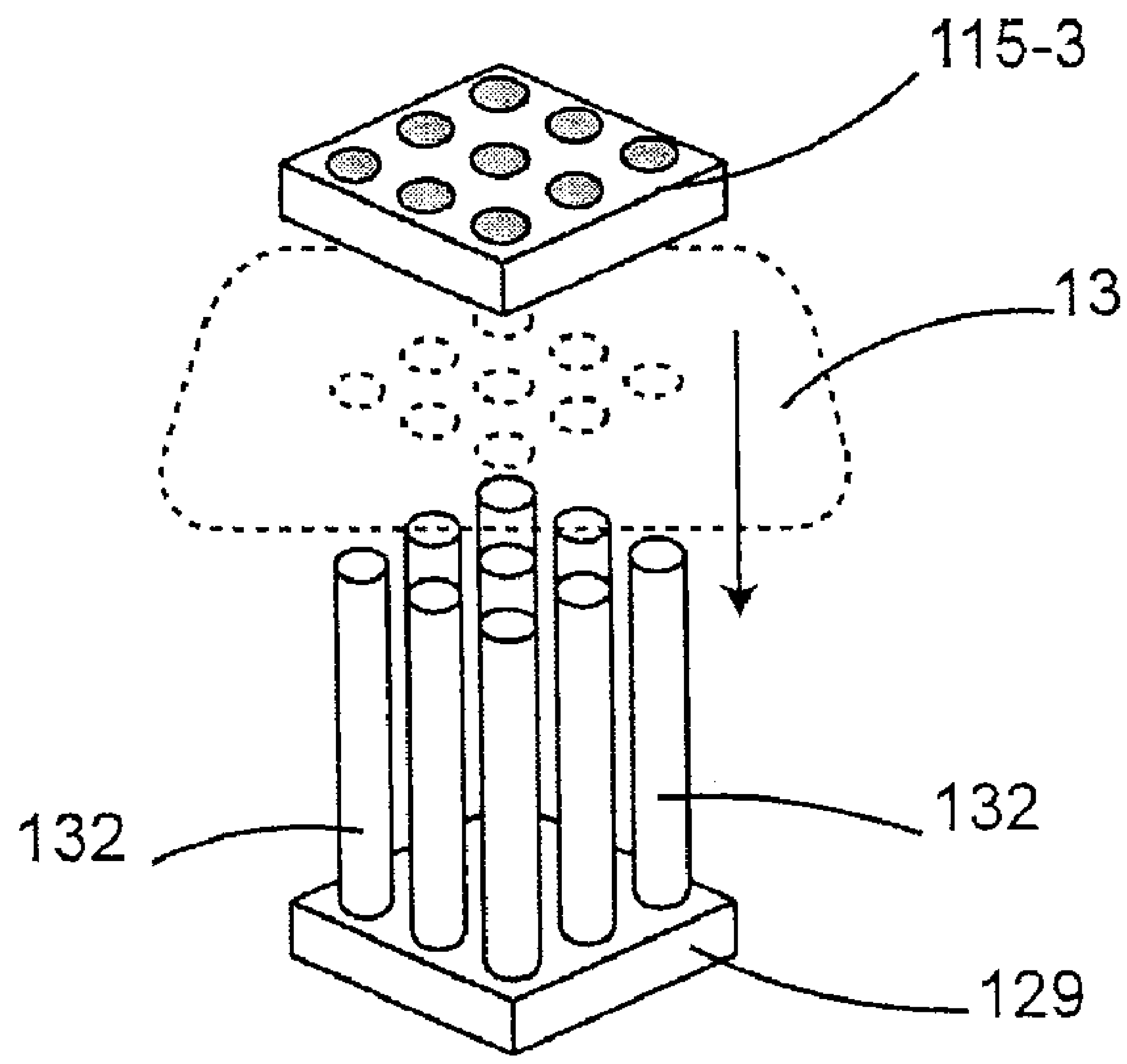


Figure 12A

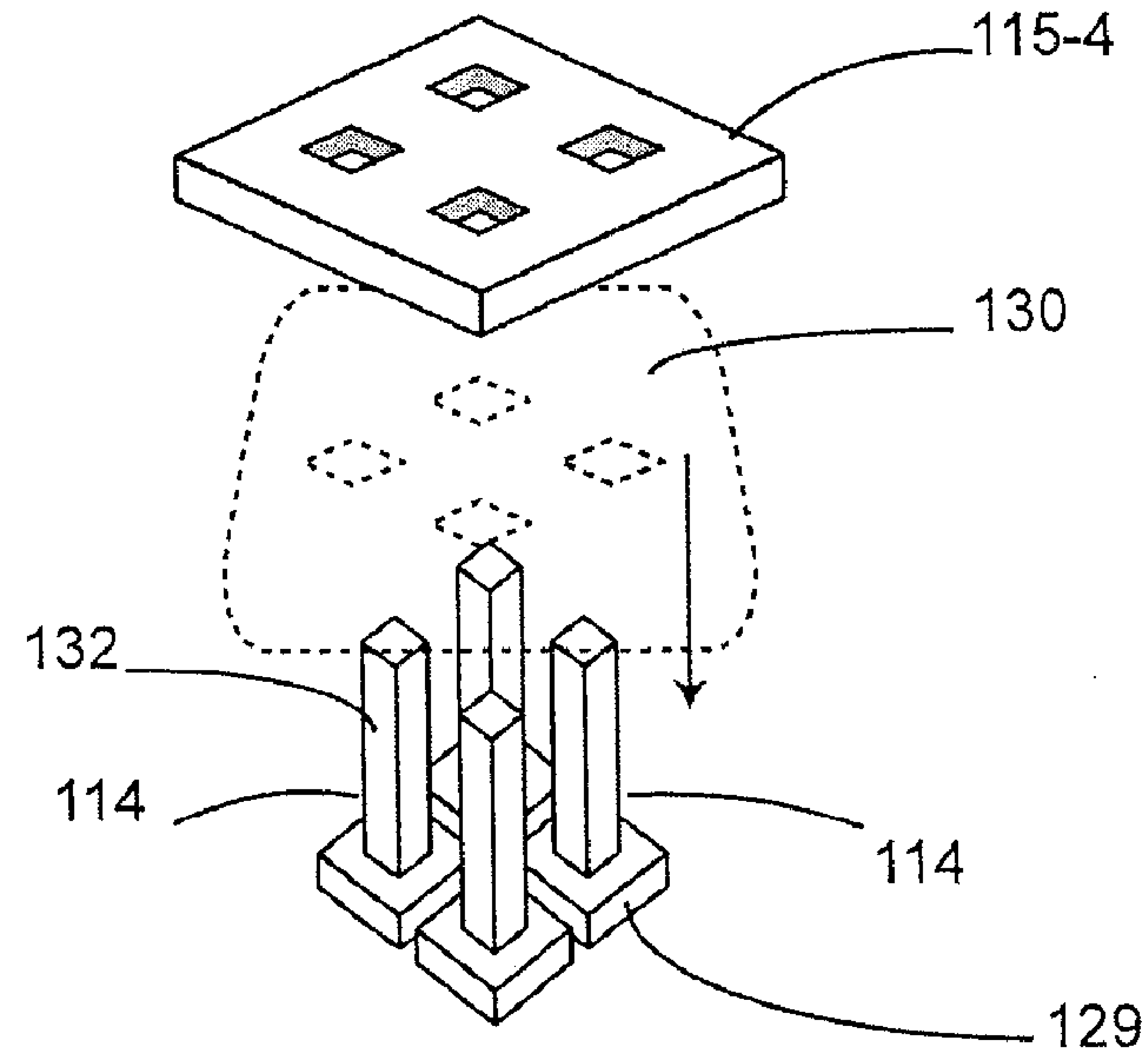


Figure 12B

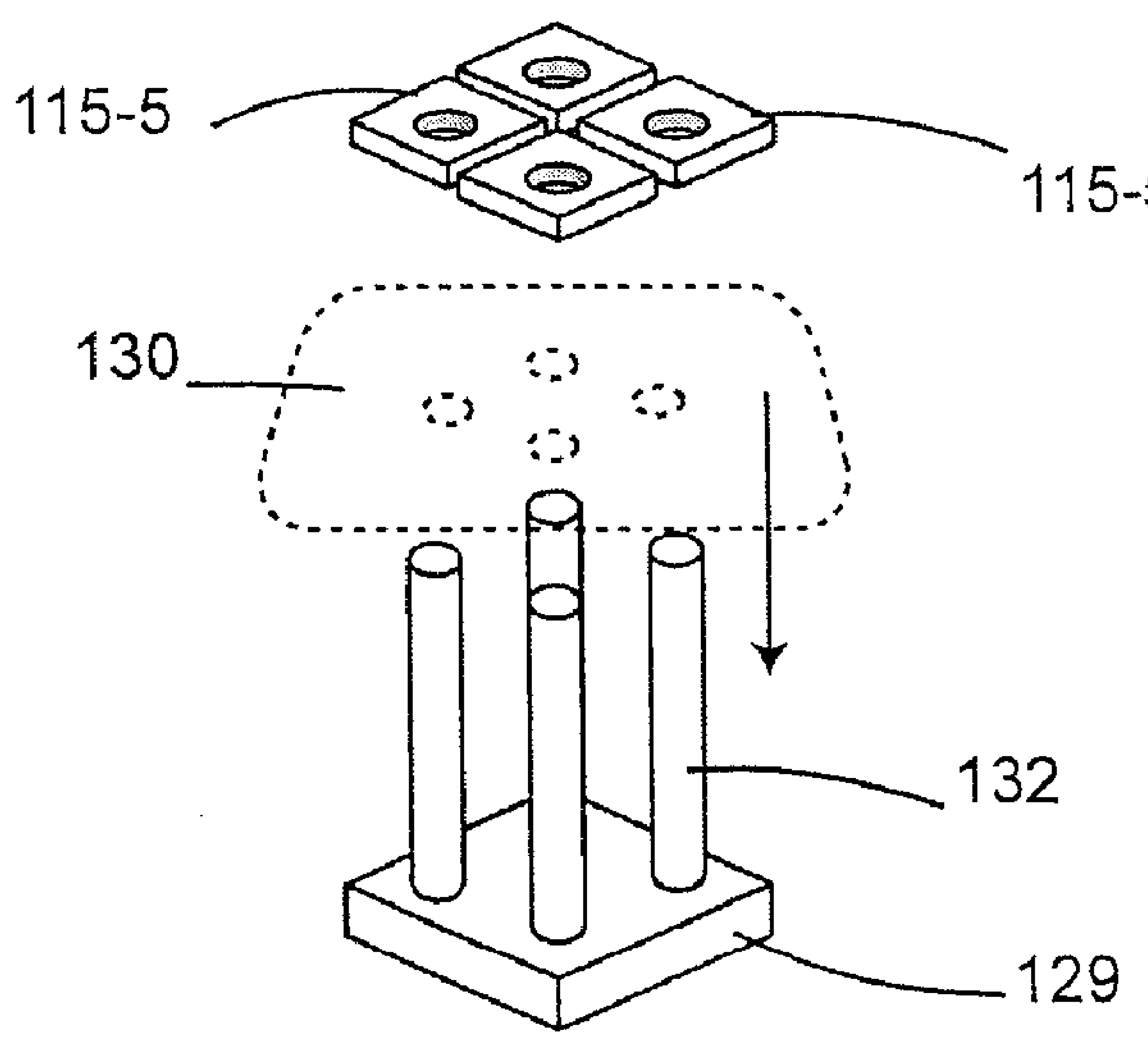


Figure 12C

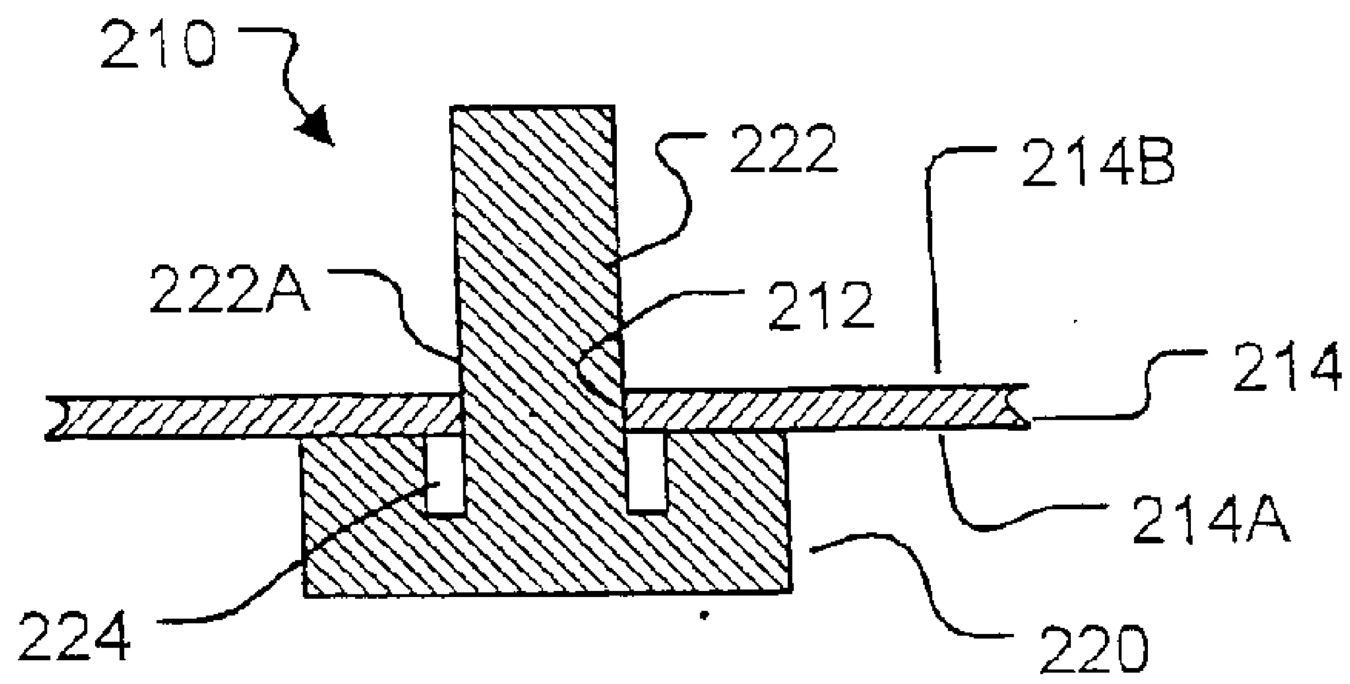


FIGURE 13

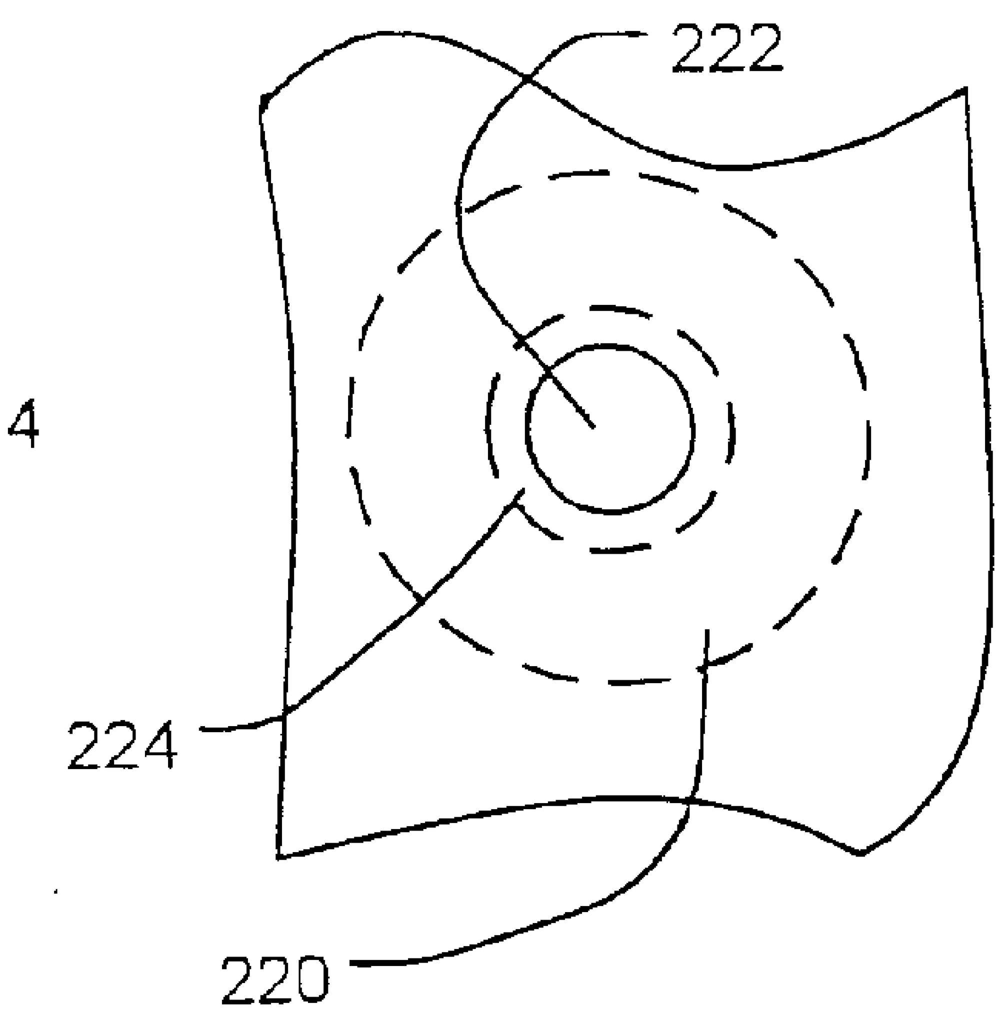


FIGURE 13A

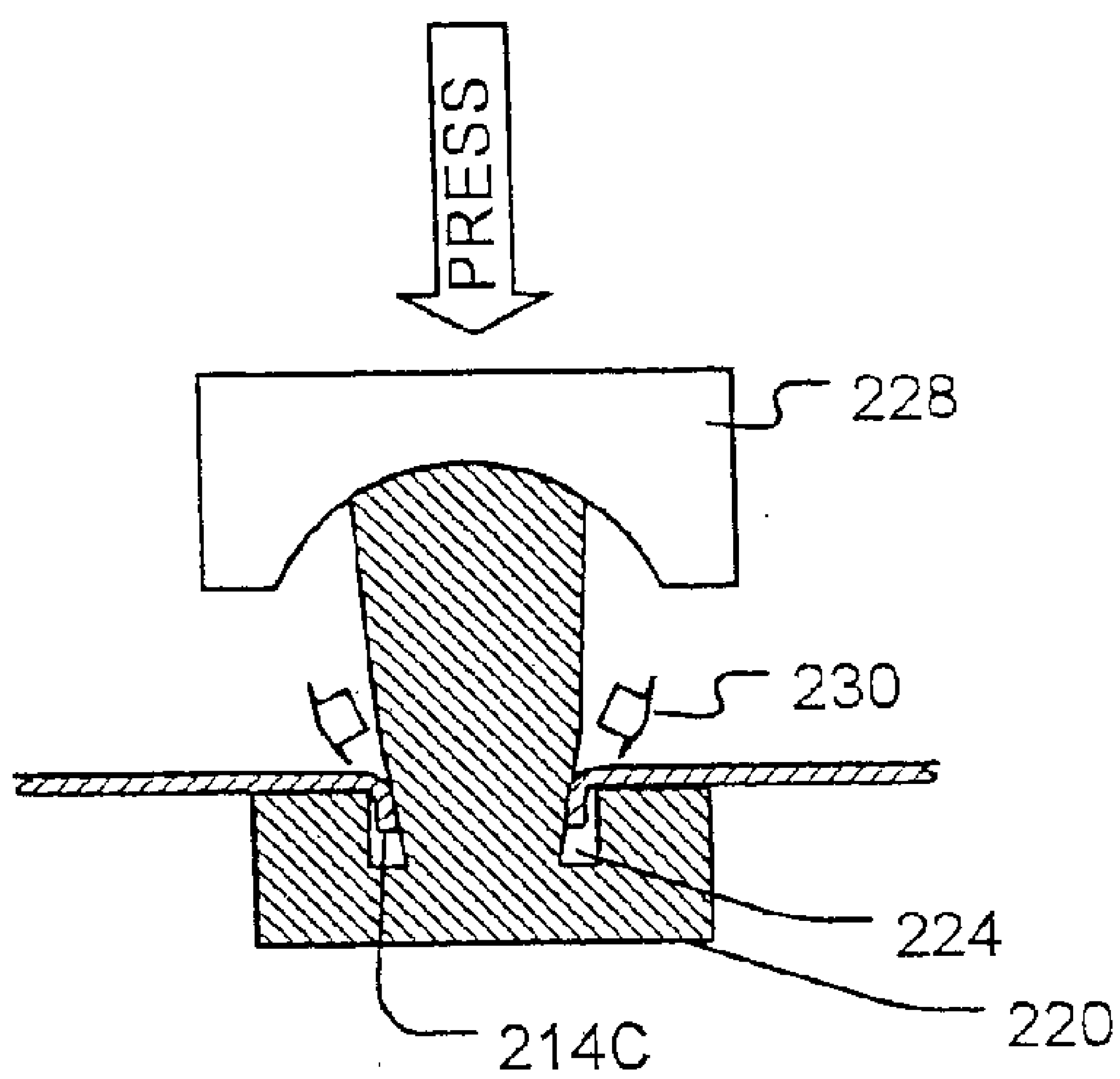


FIGURE 14

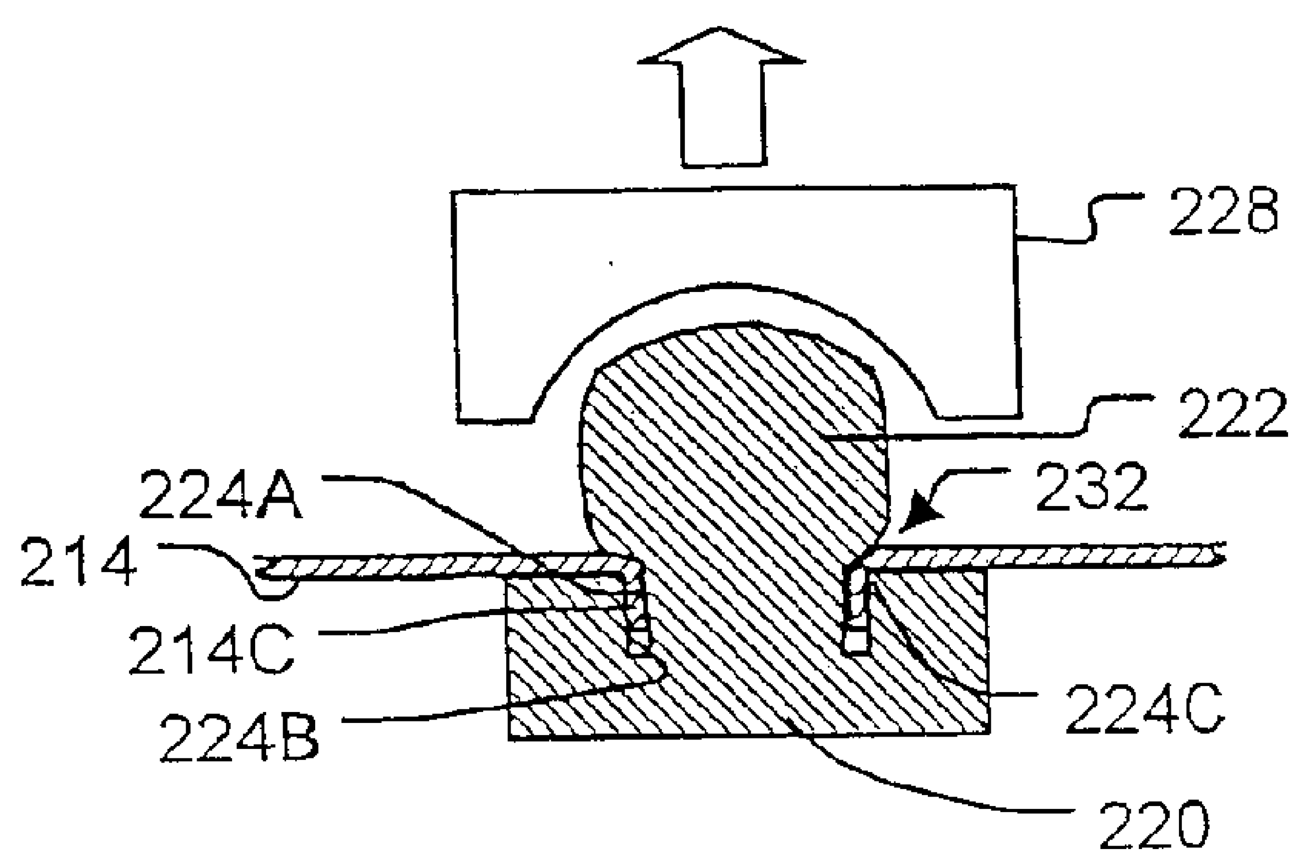


FIGURE 15

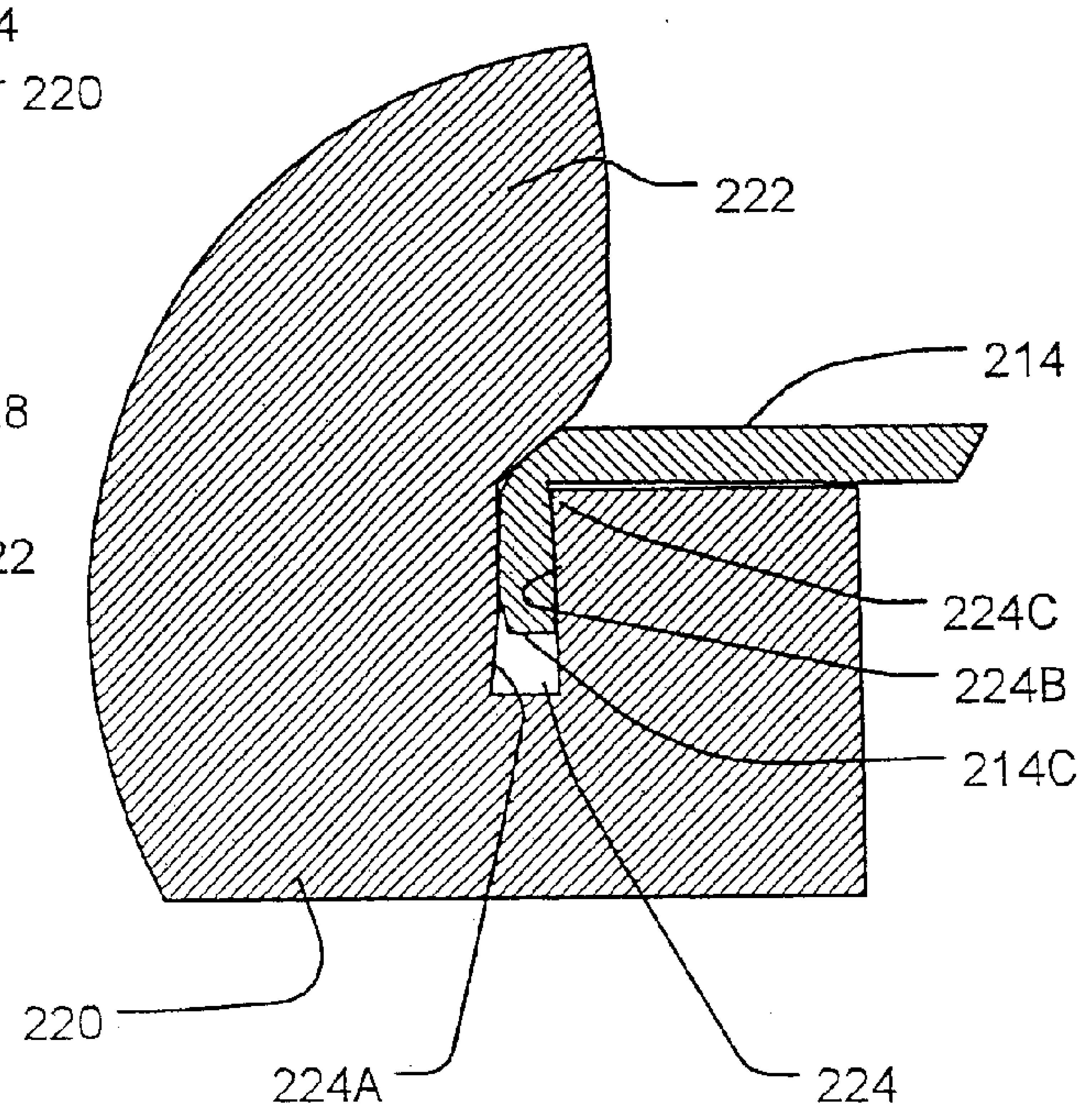


FIGURE 15A

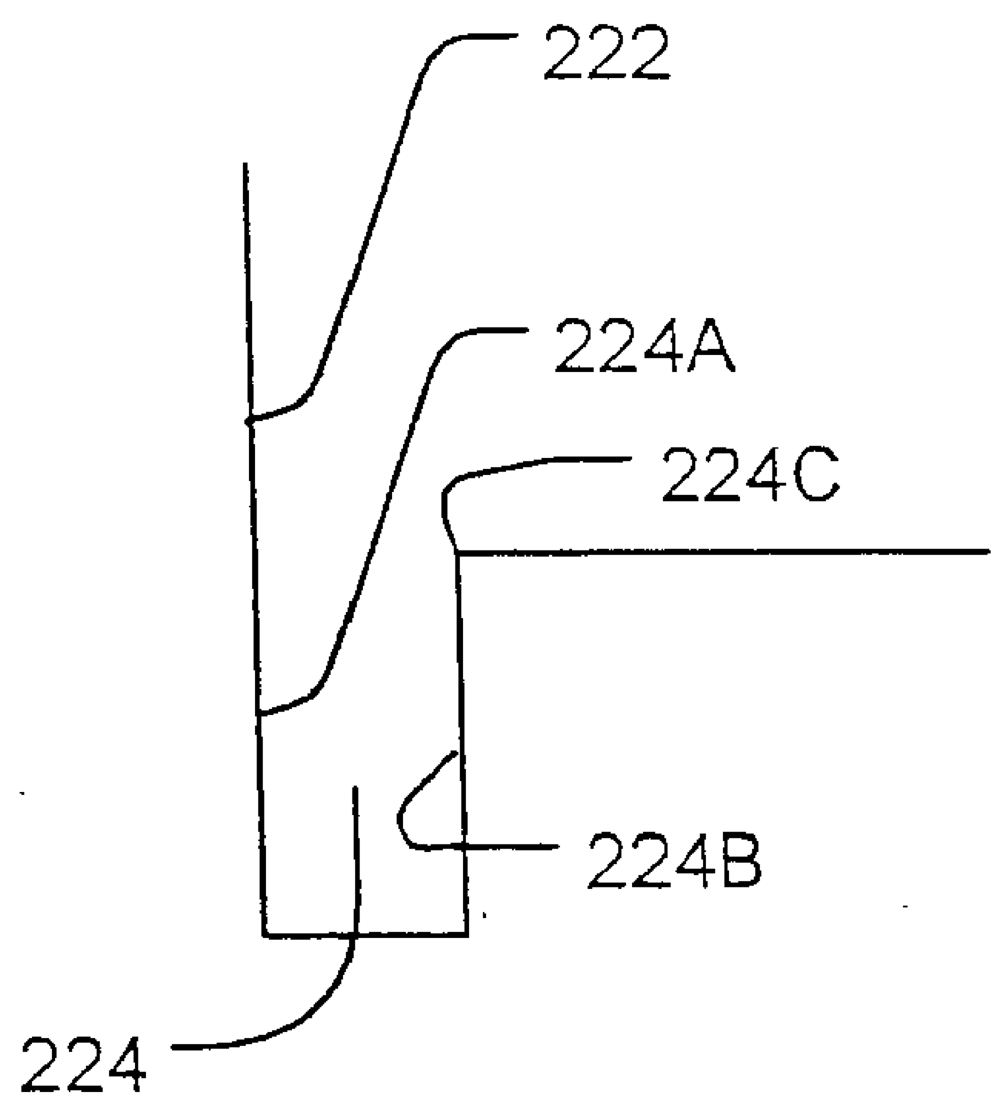


FIGURE 16A

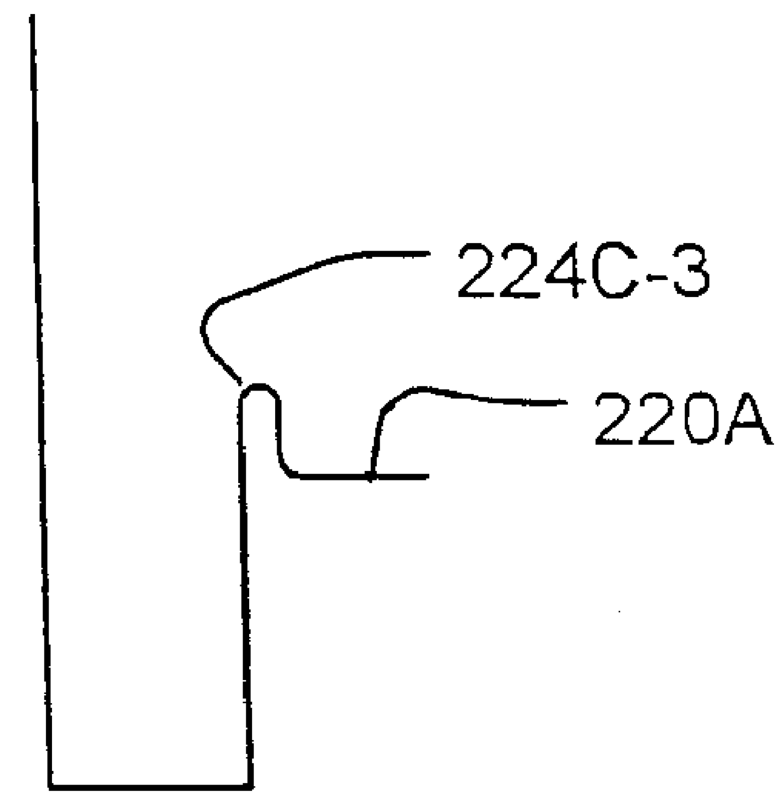


FIGURE 16D

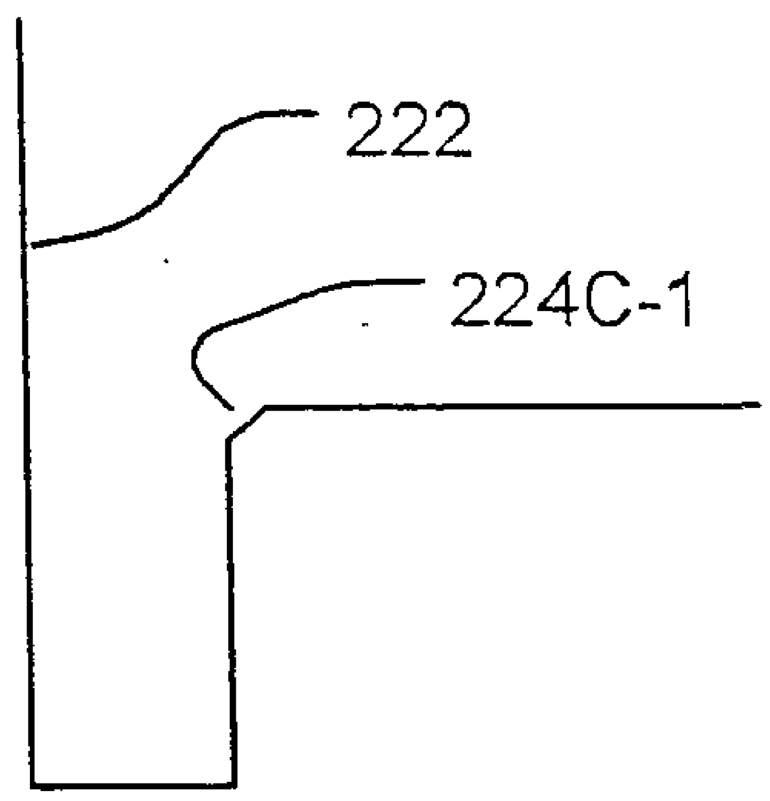


FIGURE 16B

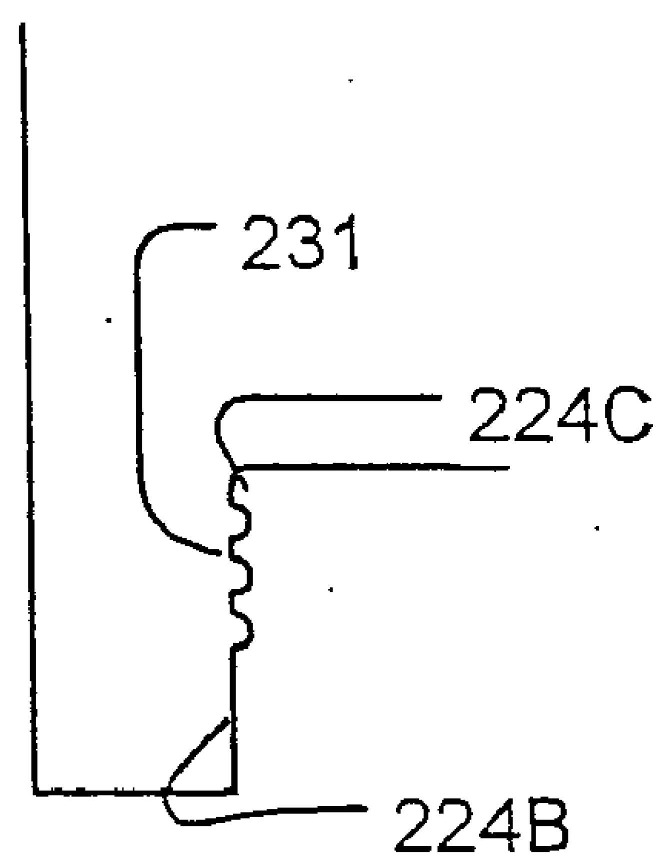


FIGURE 16E

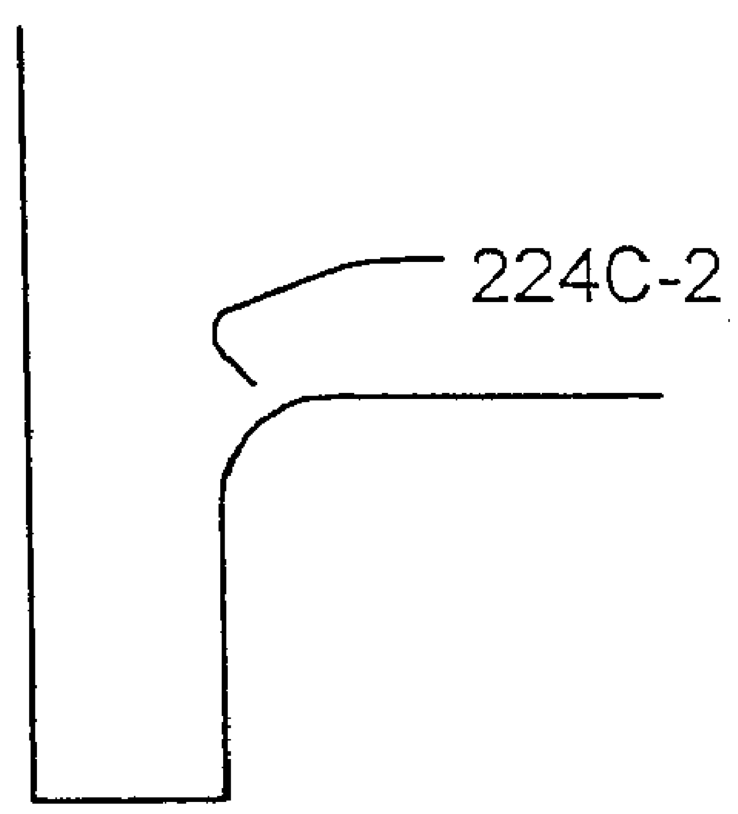


FIGURE 16C

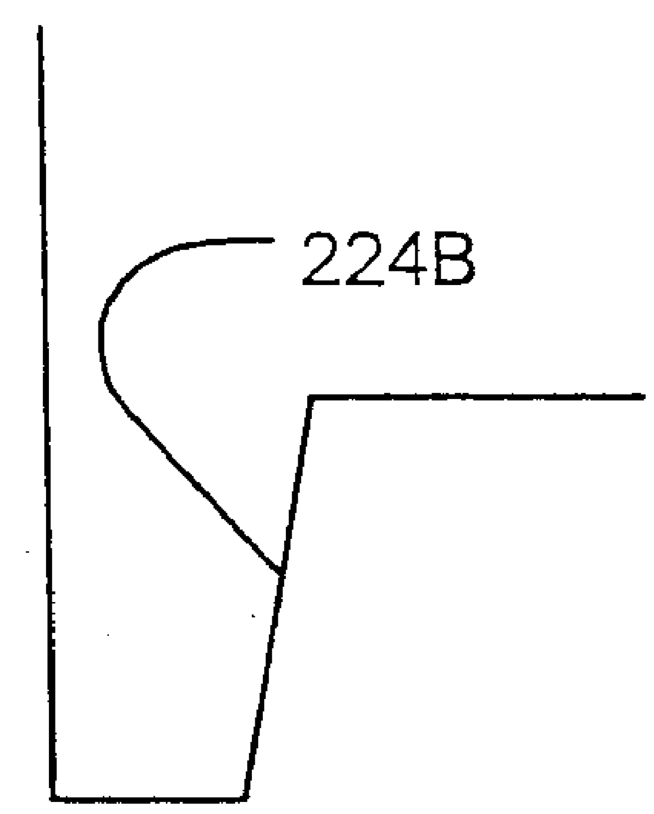


FIGURE 16F

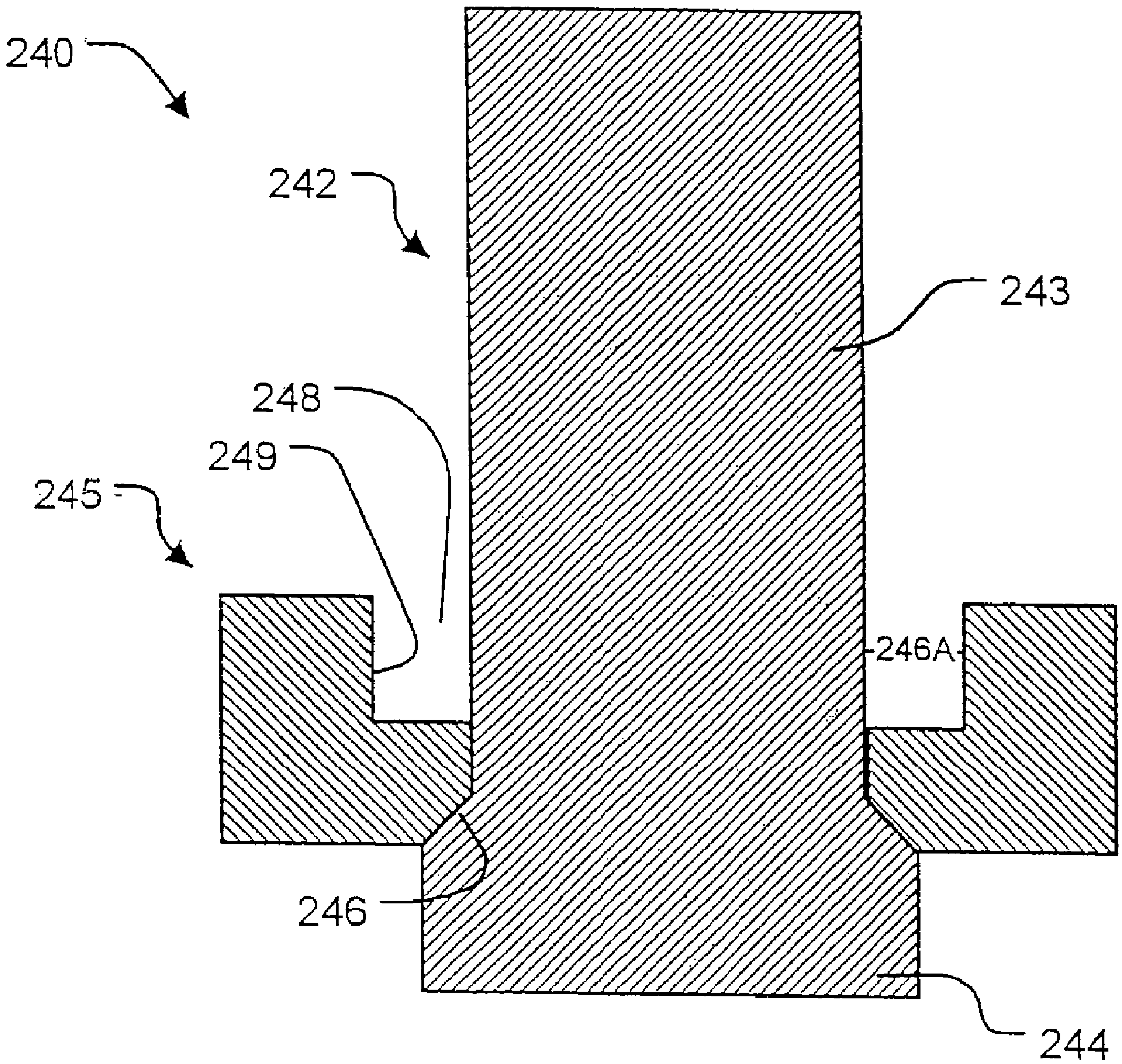


FIGURE 17

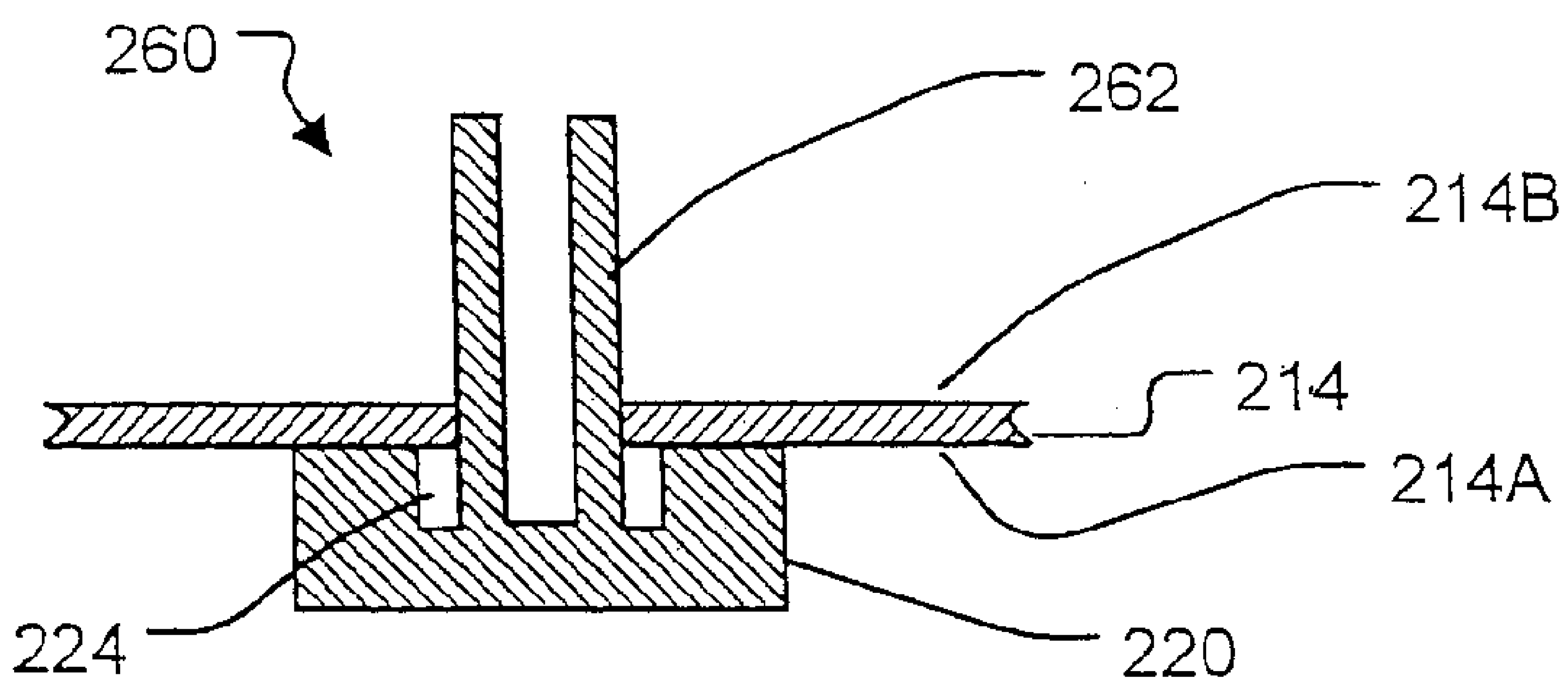


FIGURE 18A

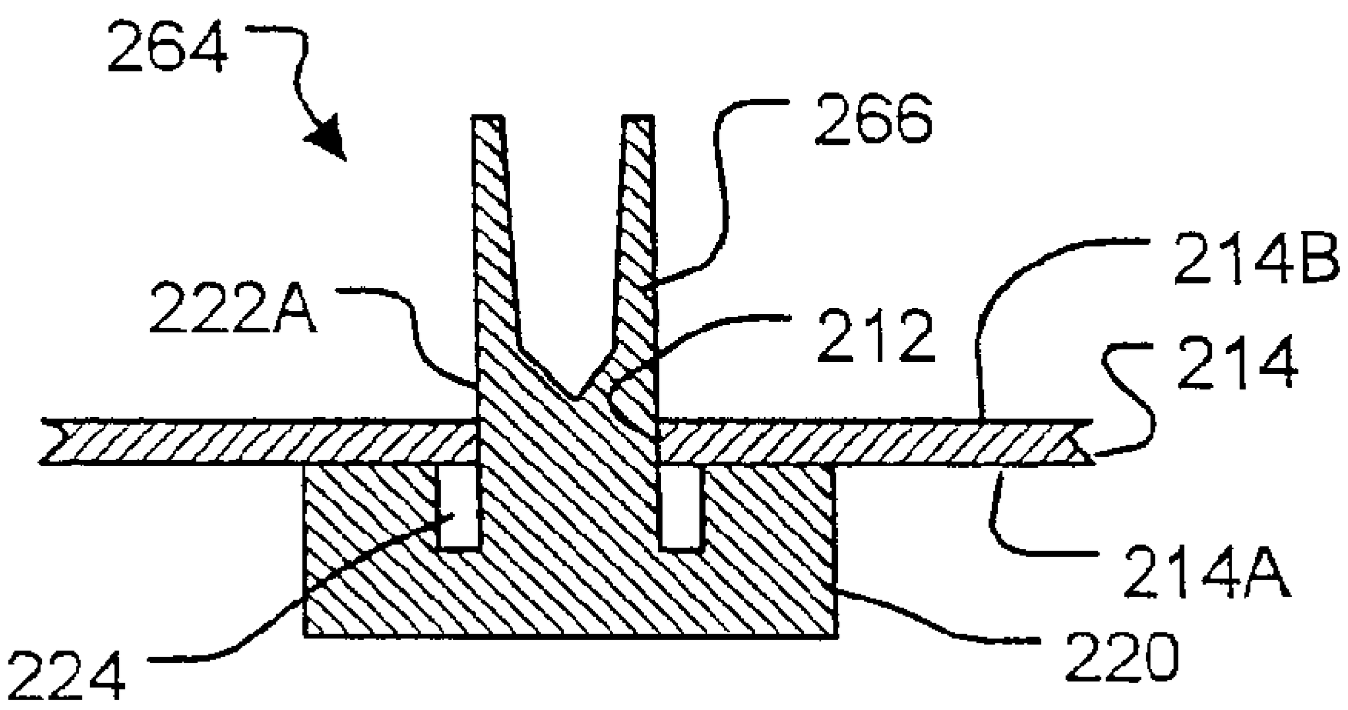


FIGURE 18B

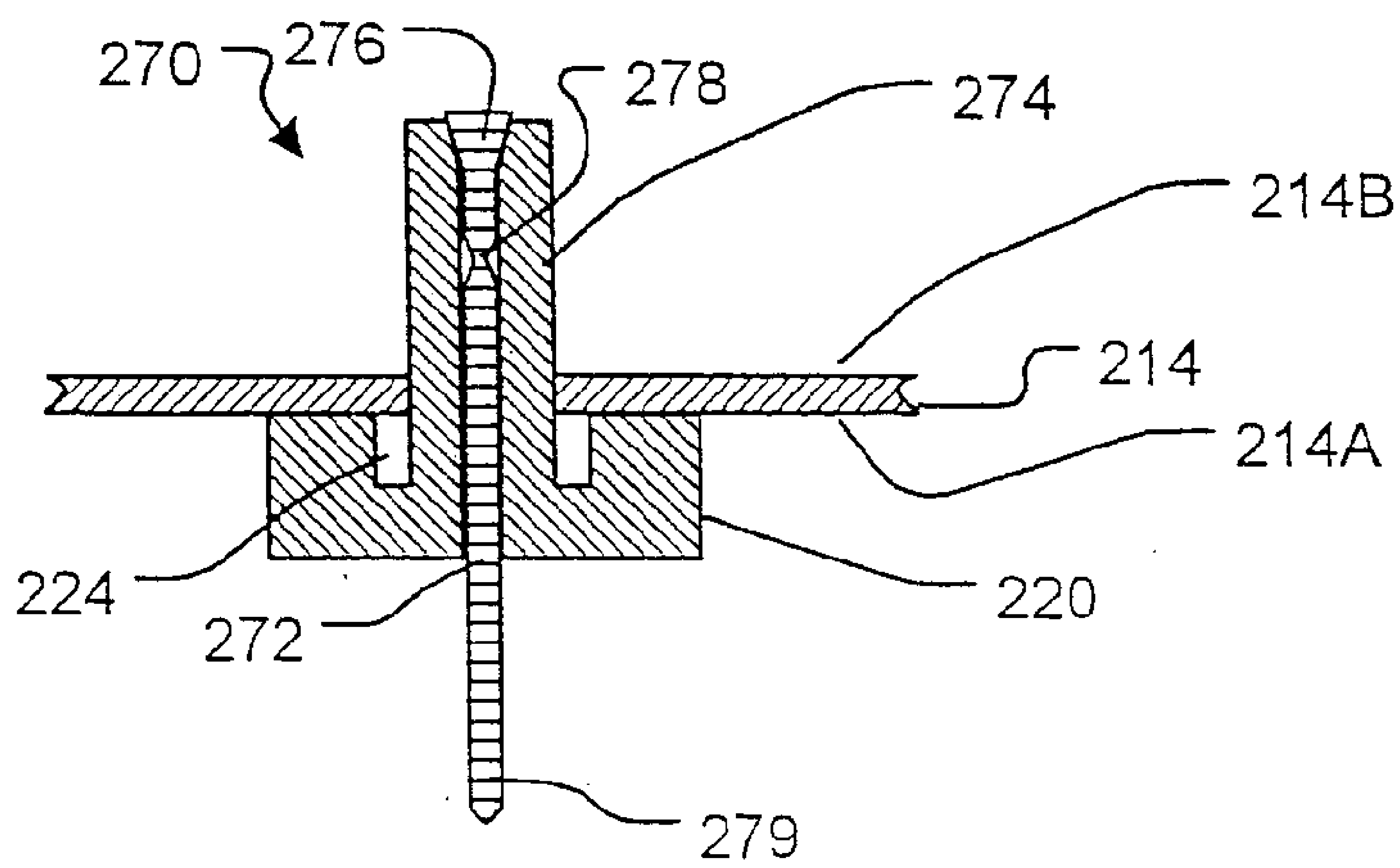


FIGURE 18C

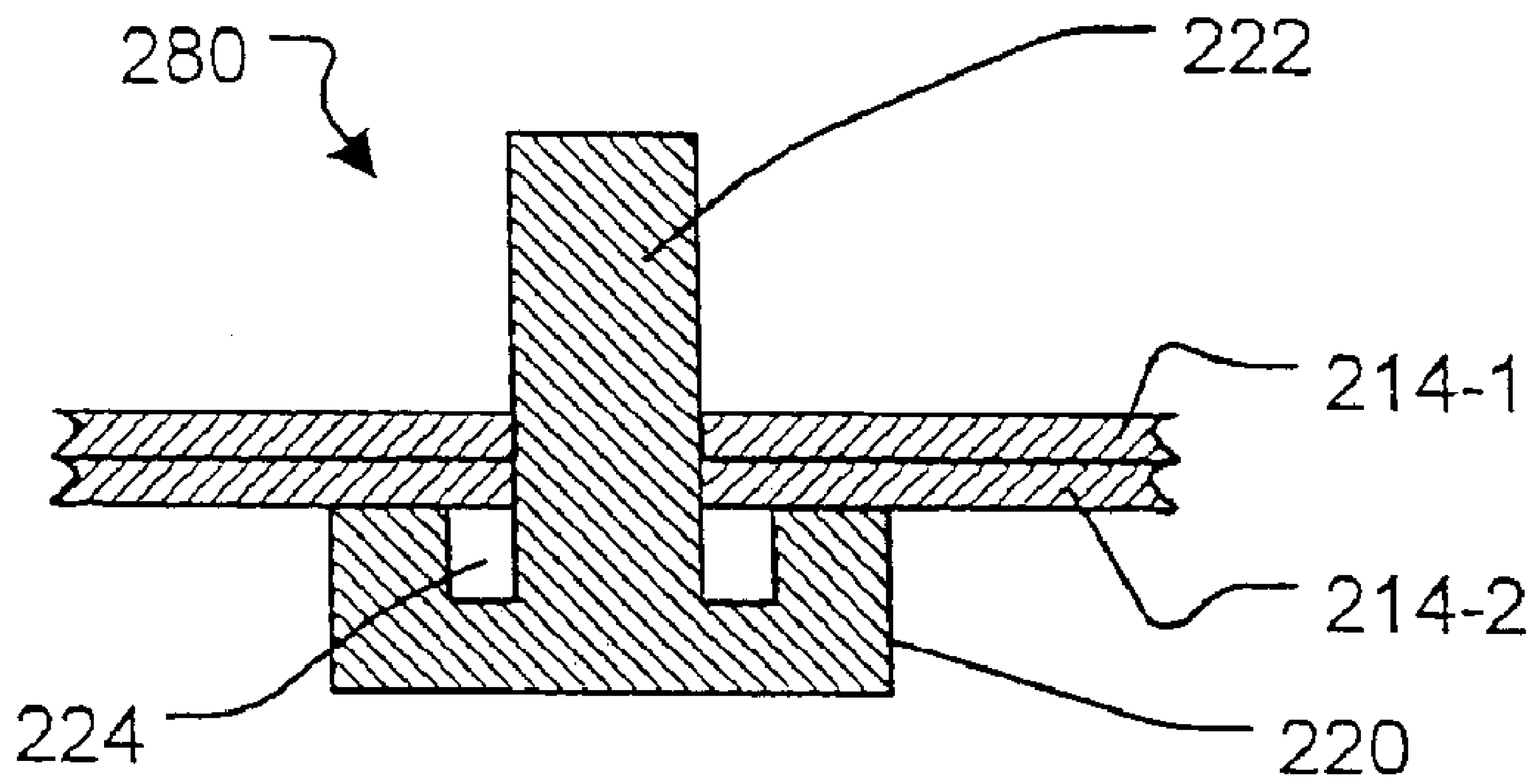


FIGURE 19A

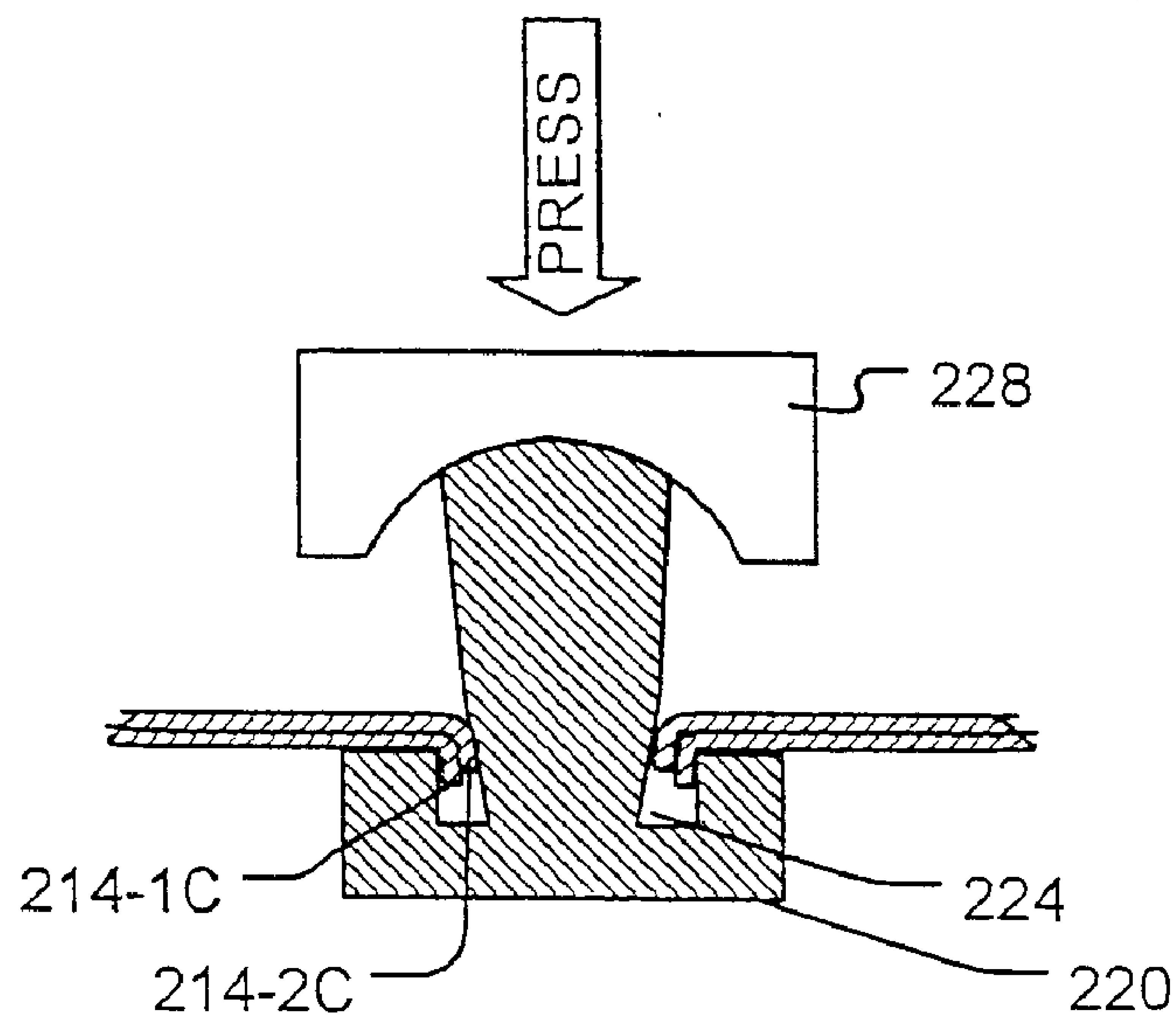


FIGURE 19B

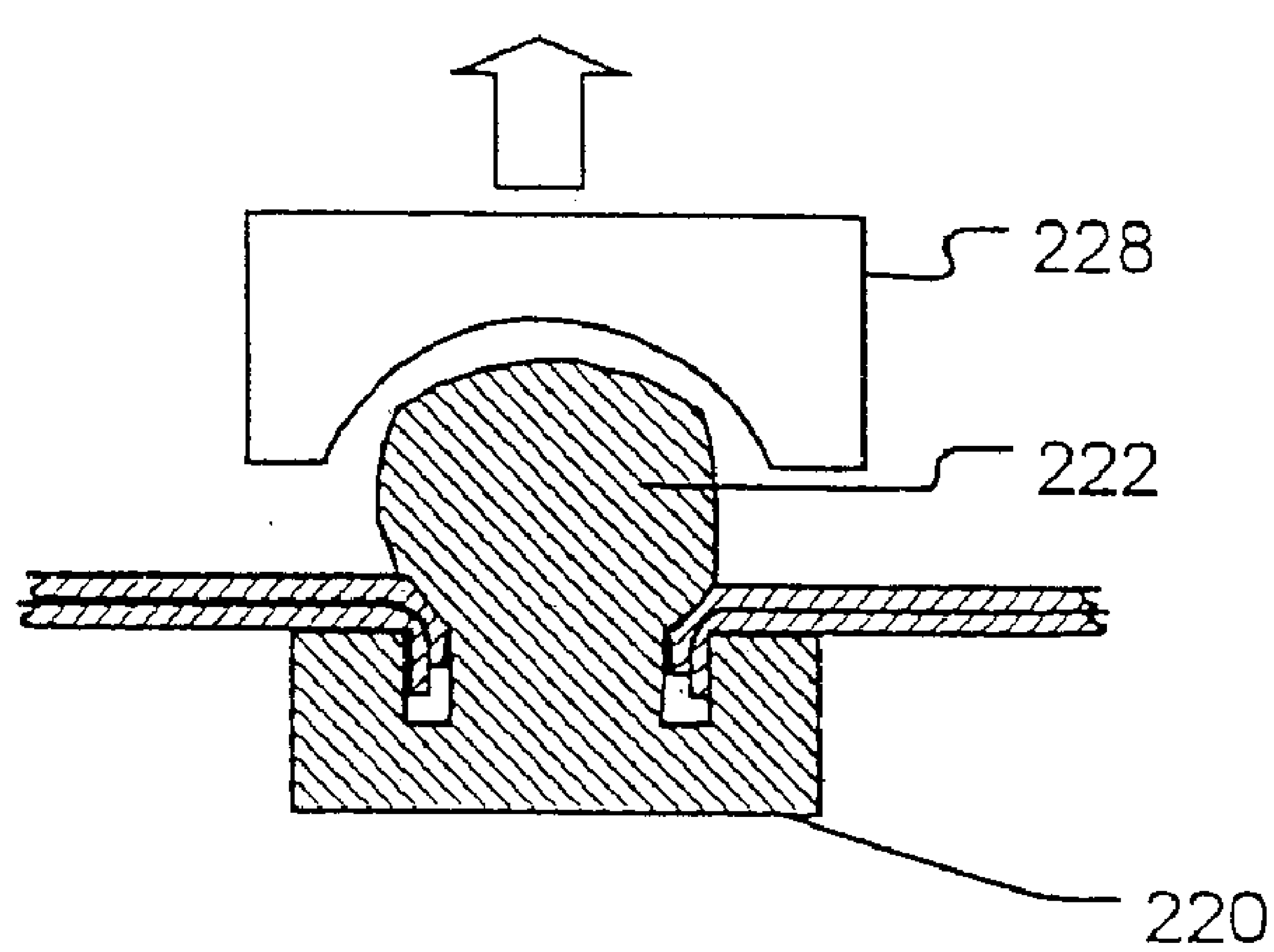


FIGURE 19C

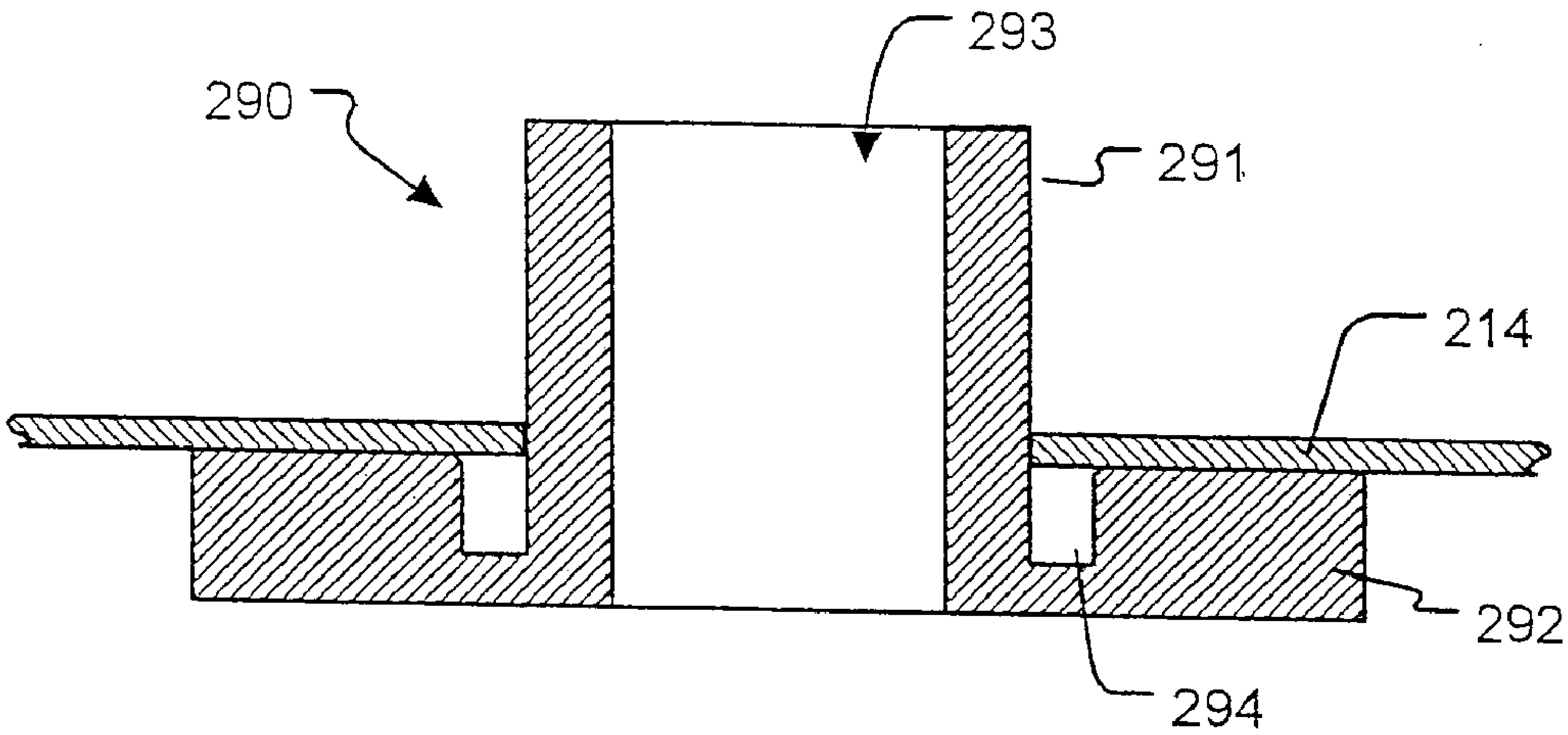


FIGURE 20A

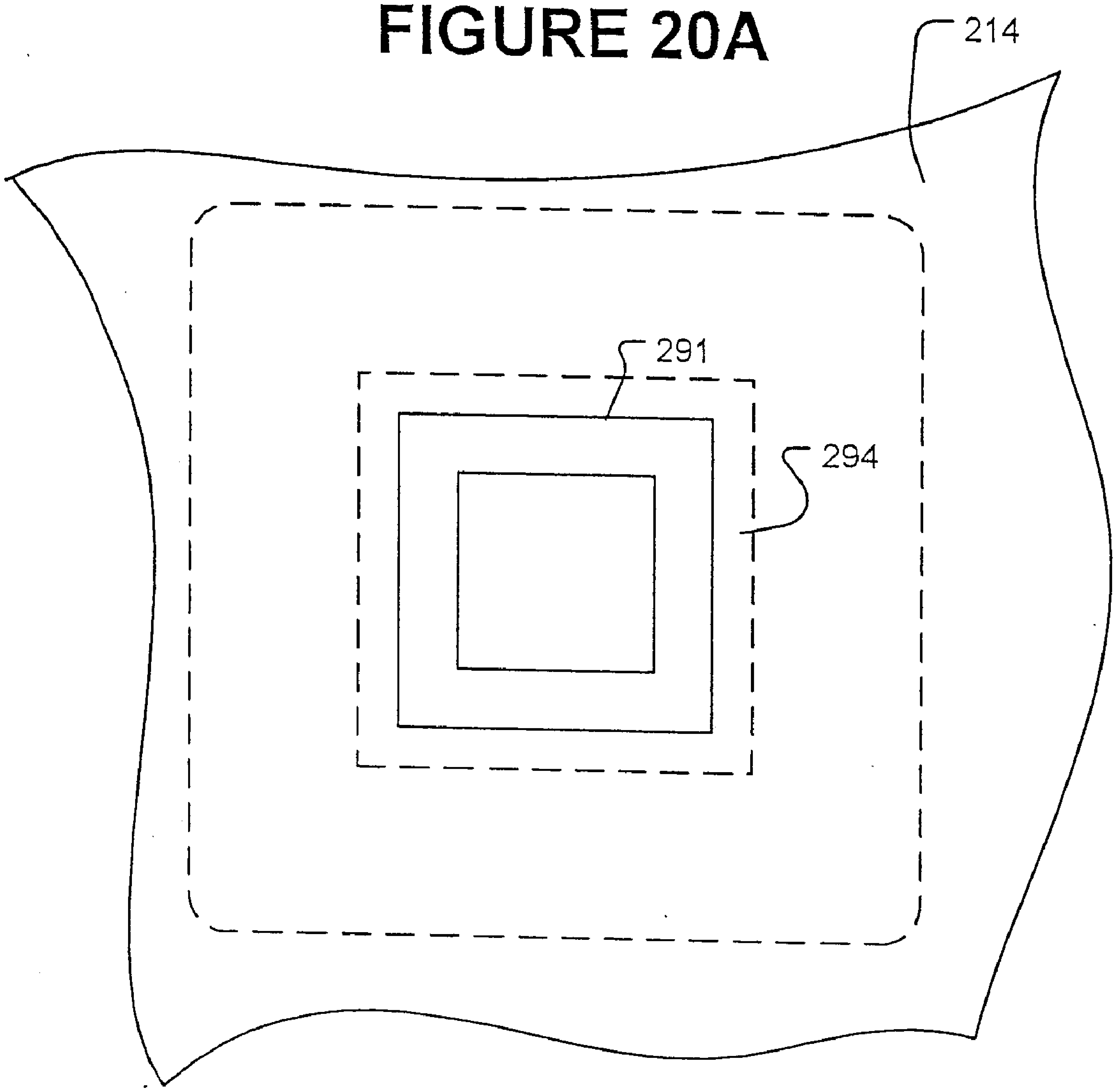


FIGURE 20B

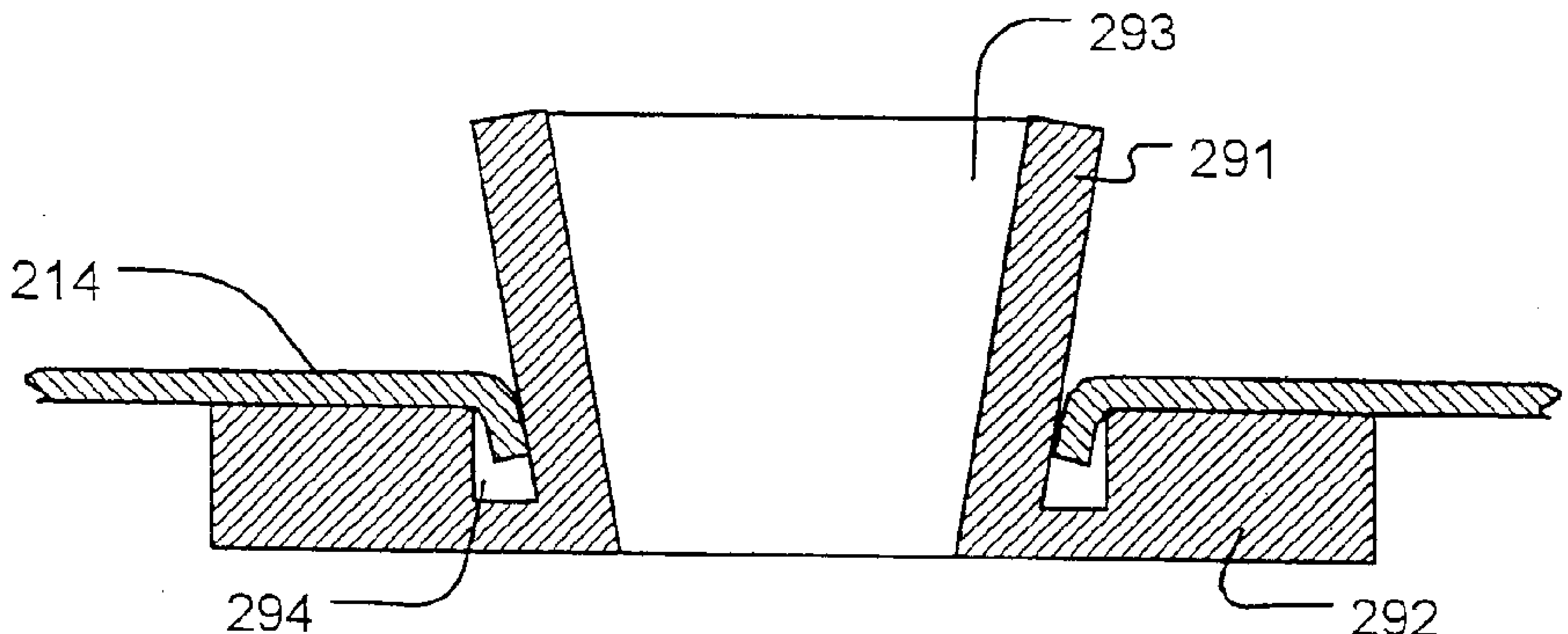


FIGURE 20C

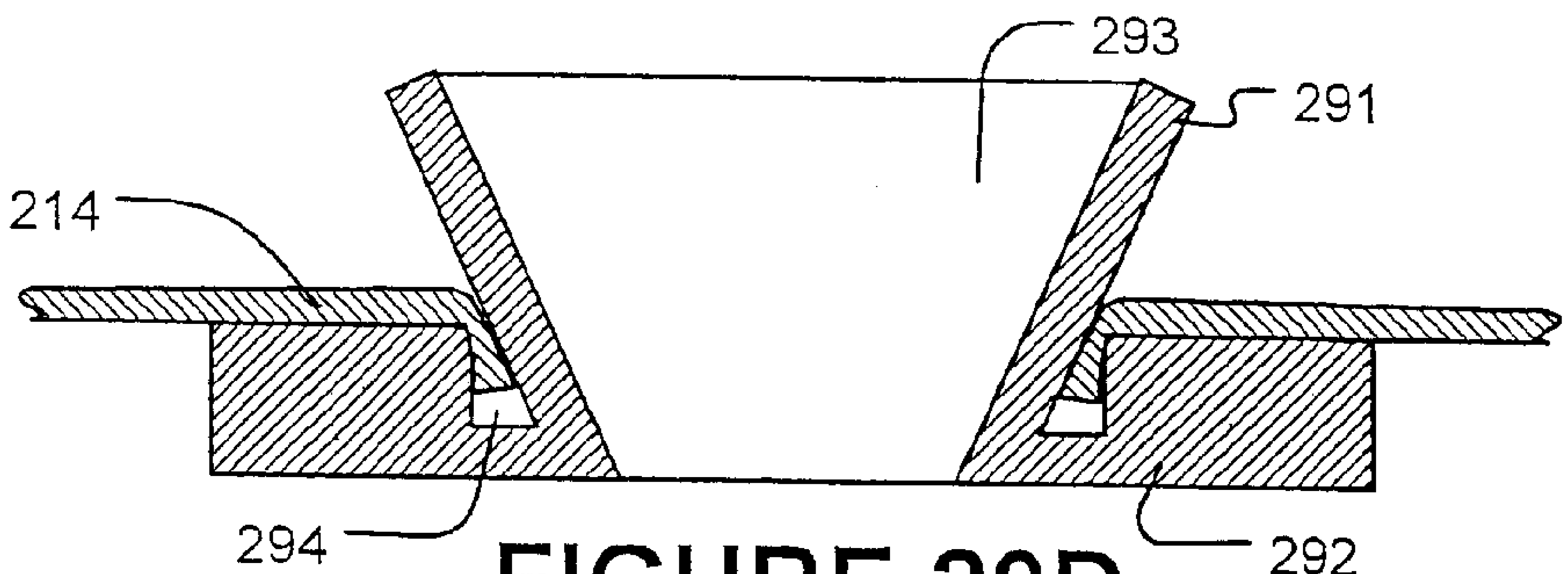


FIGURE 20D

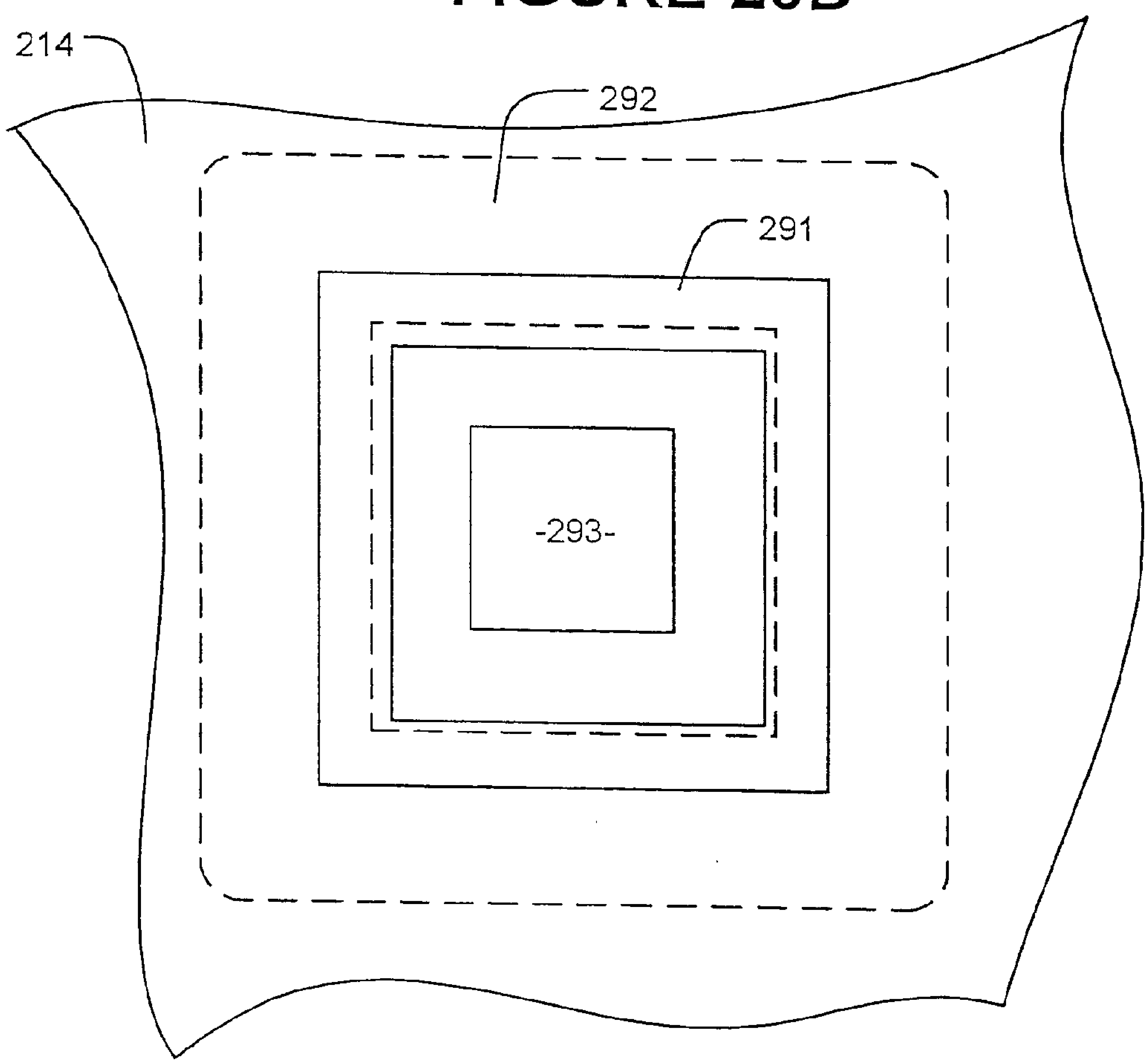


FIGURE 20E

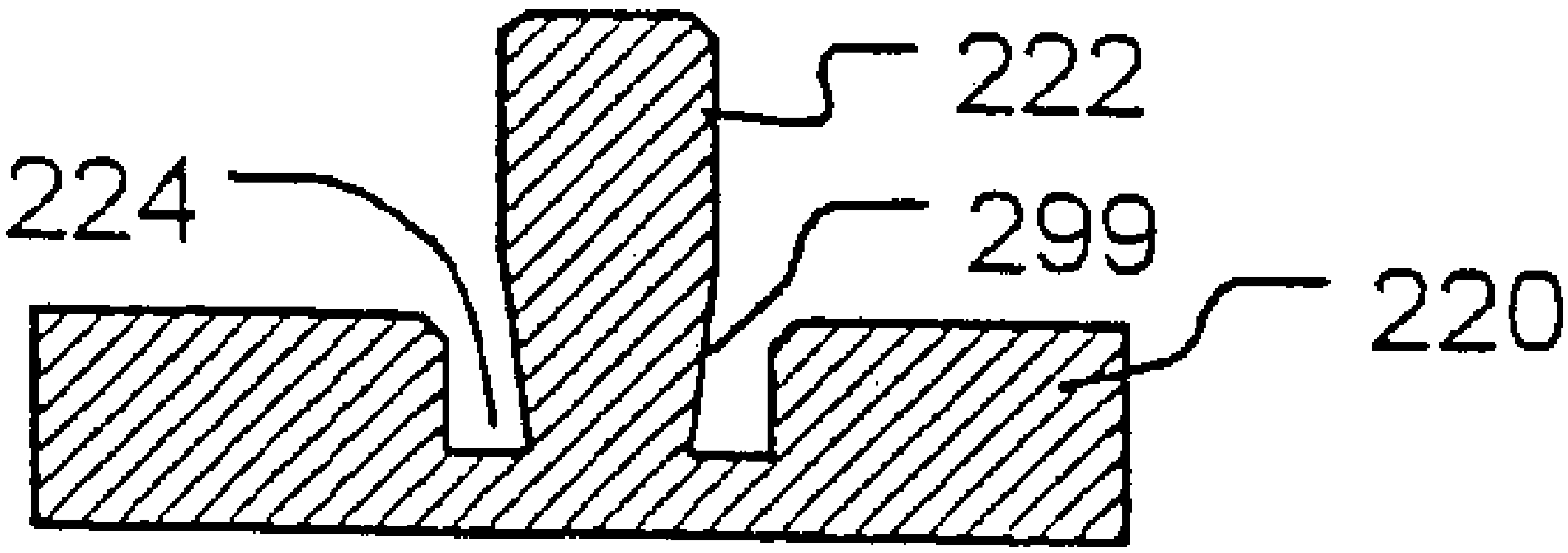


FIGURE 21

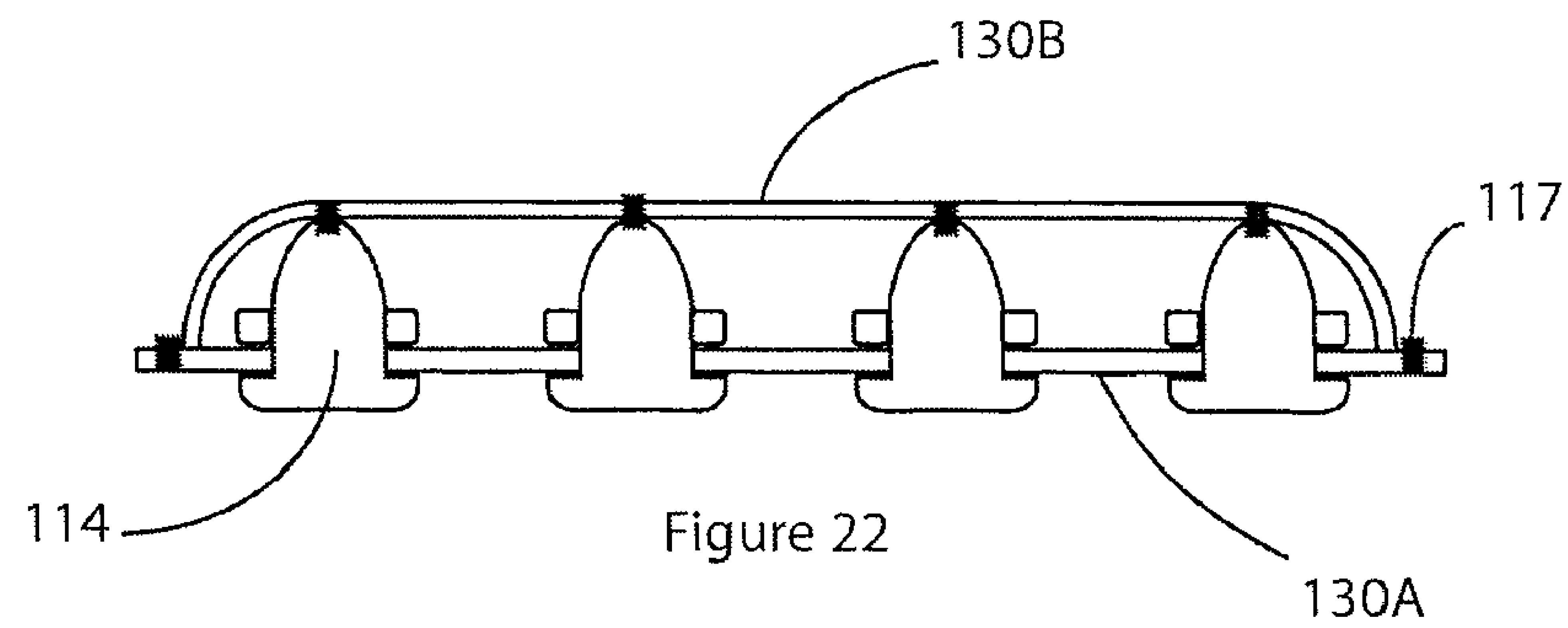


Figure 22

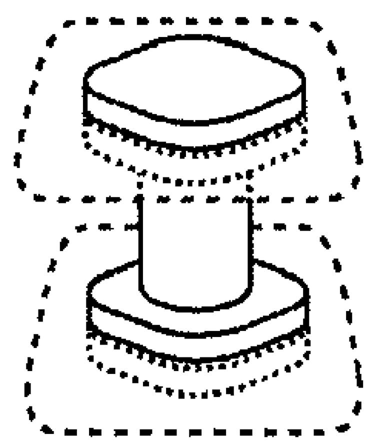


Figure 22A

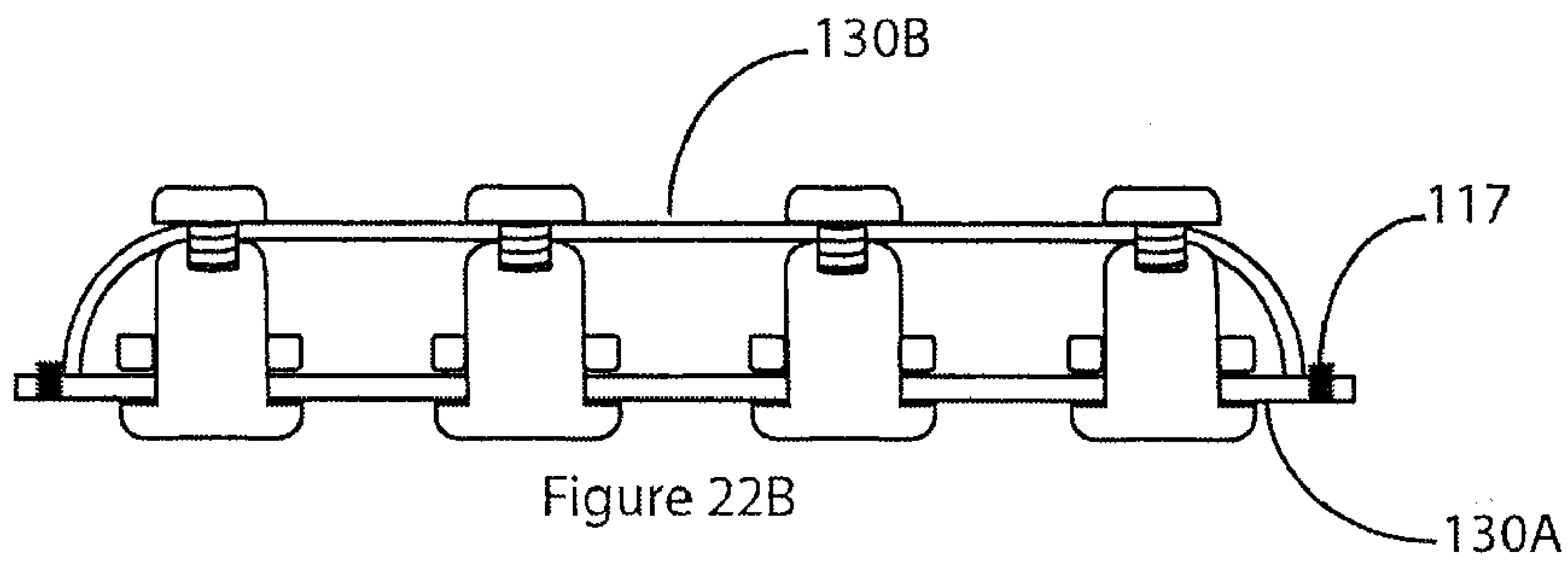


Figure 22B

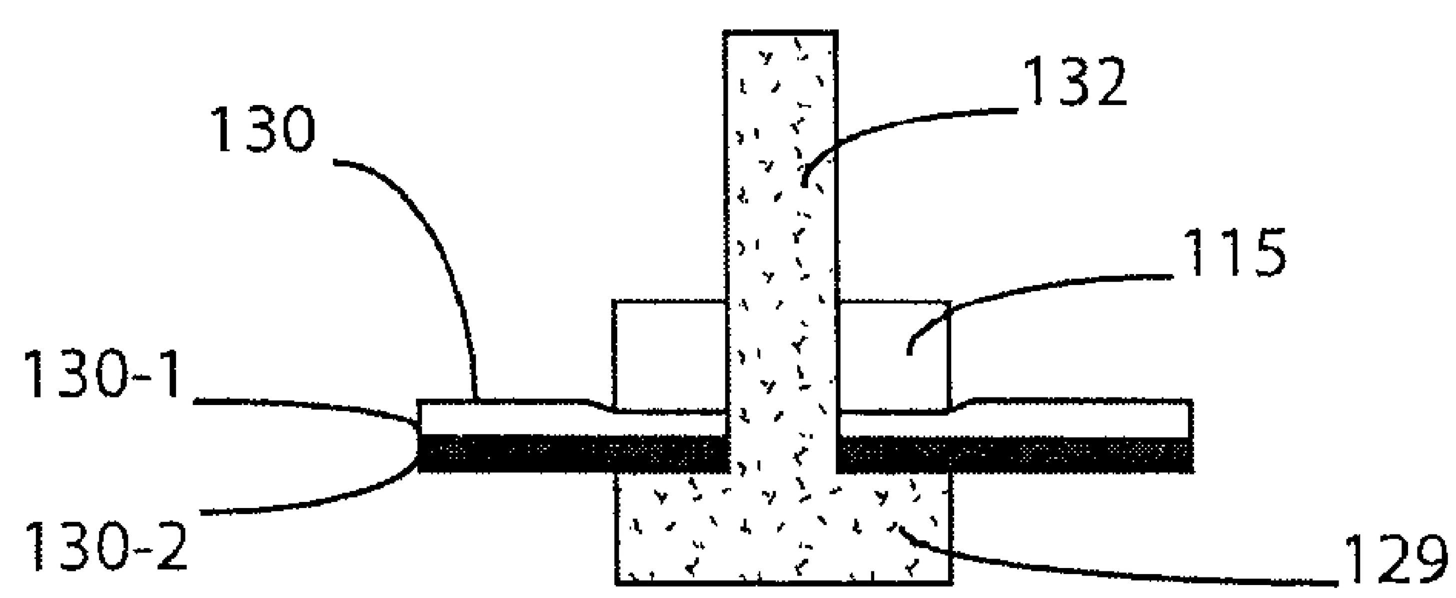


Figure 23A

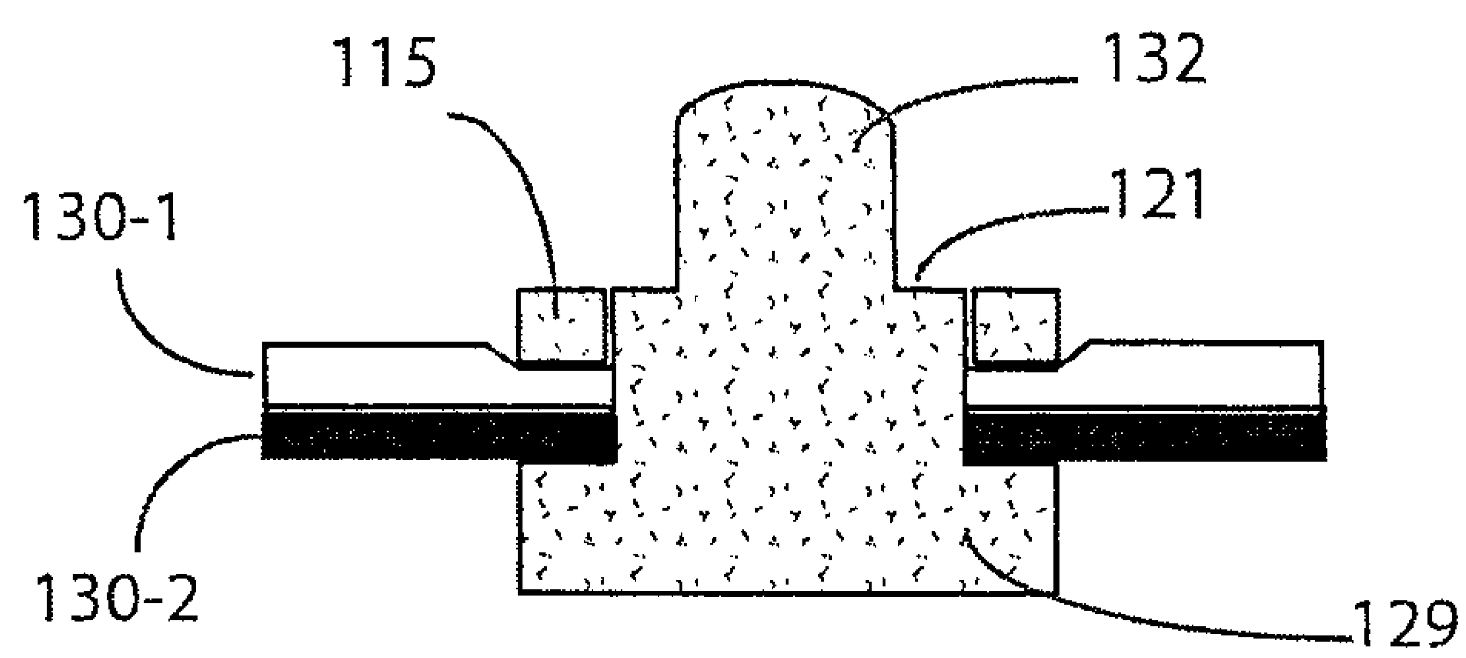


Figure 23B

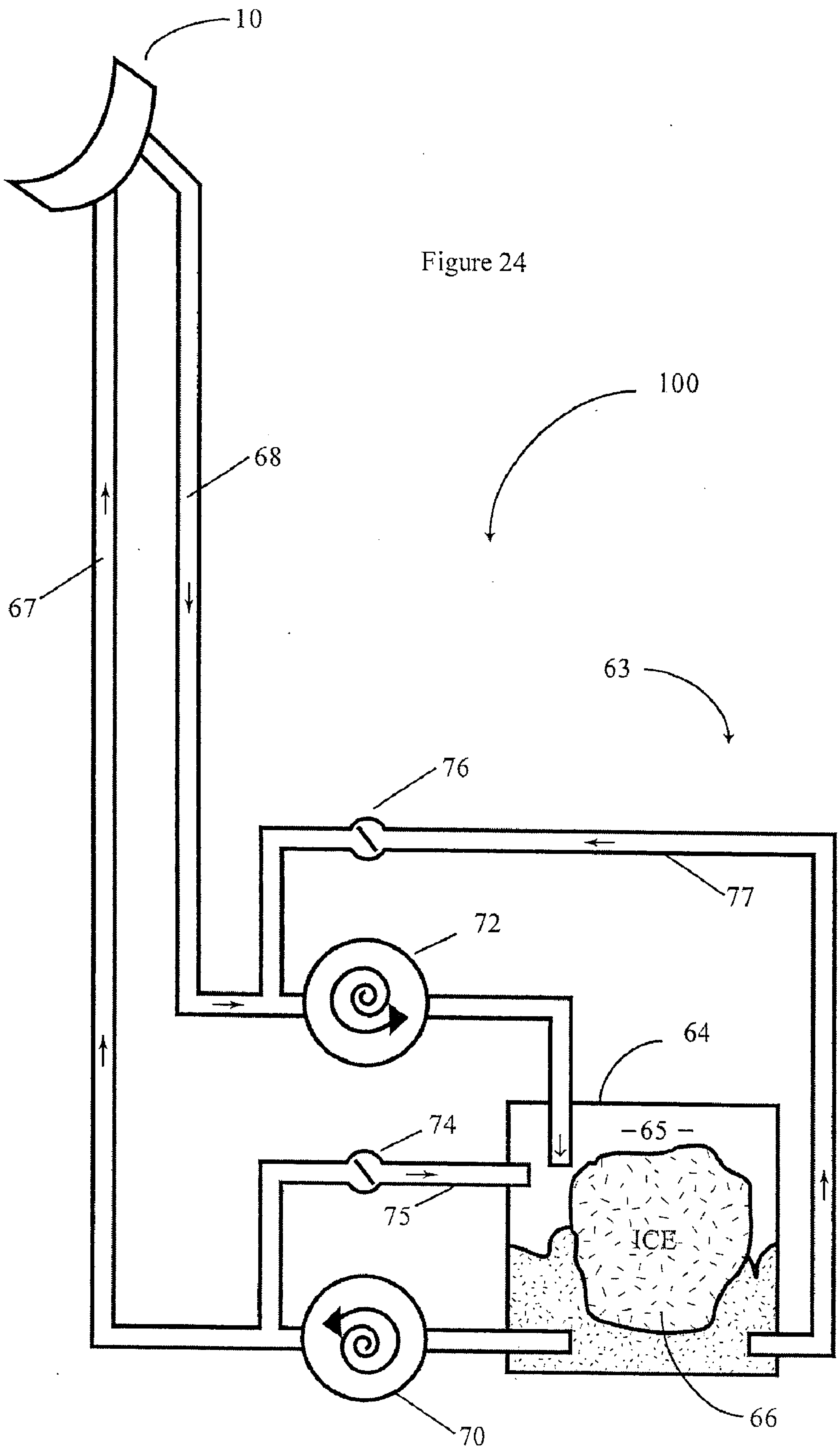
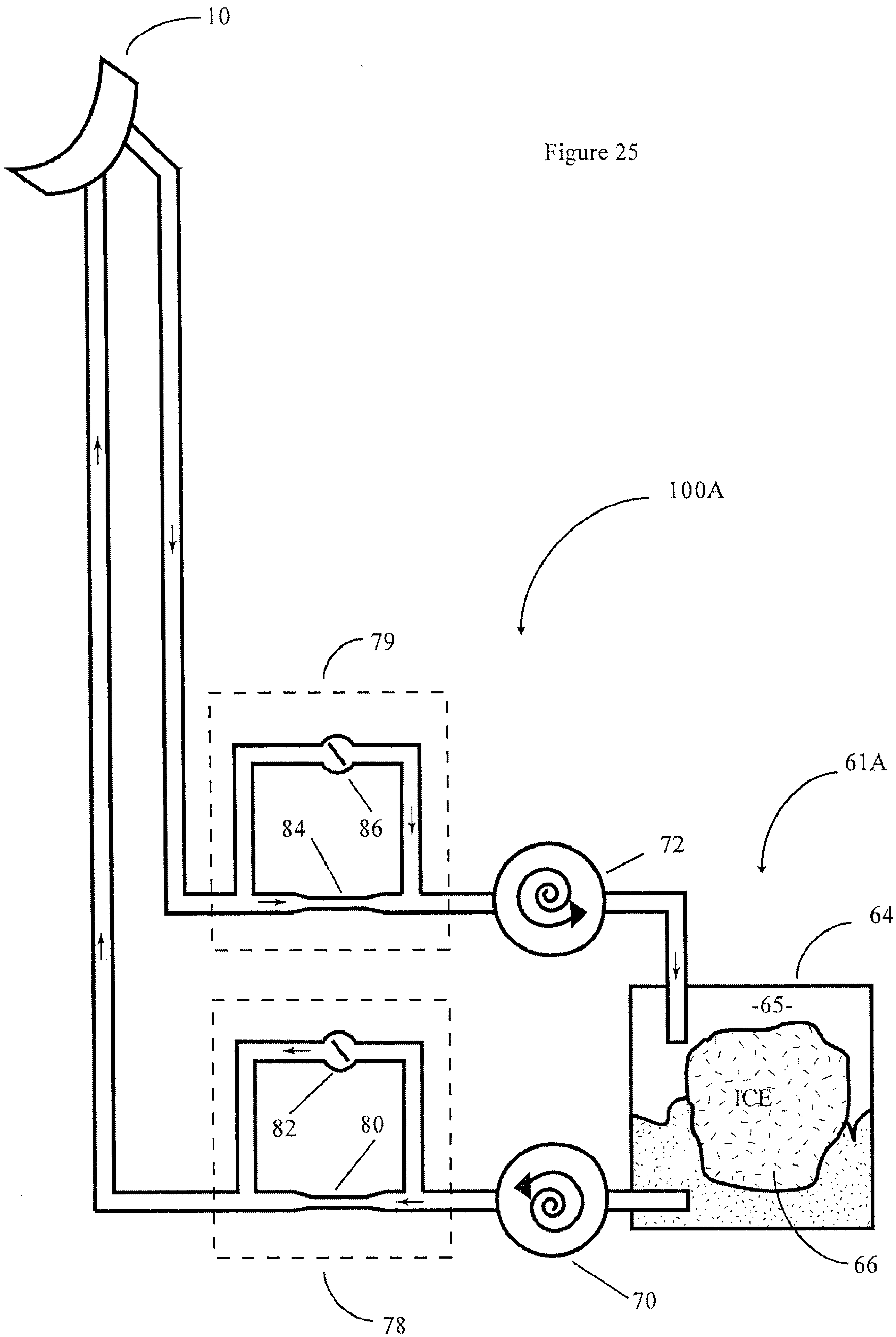


Figure 24


10
Figure 25
100A
79
84
86
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61A
64
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ICE
82
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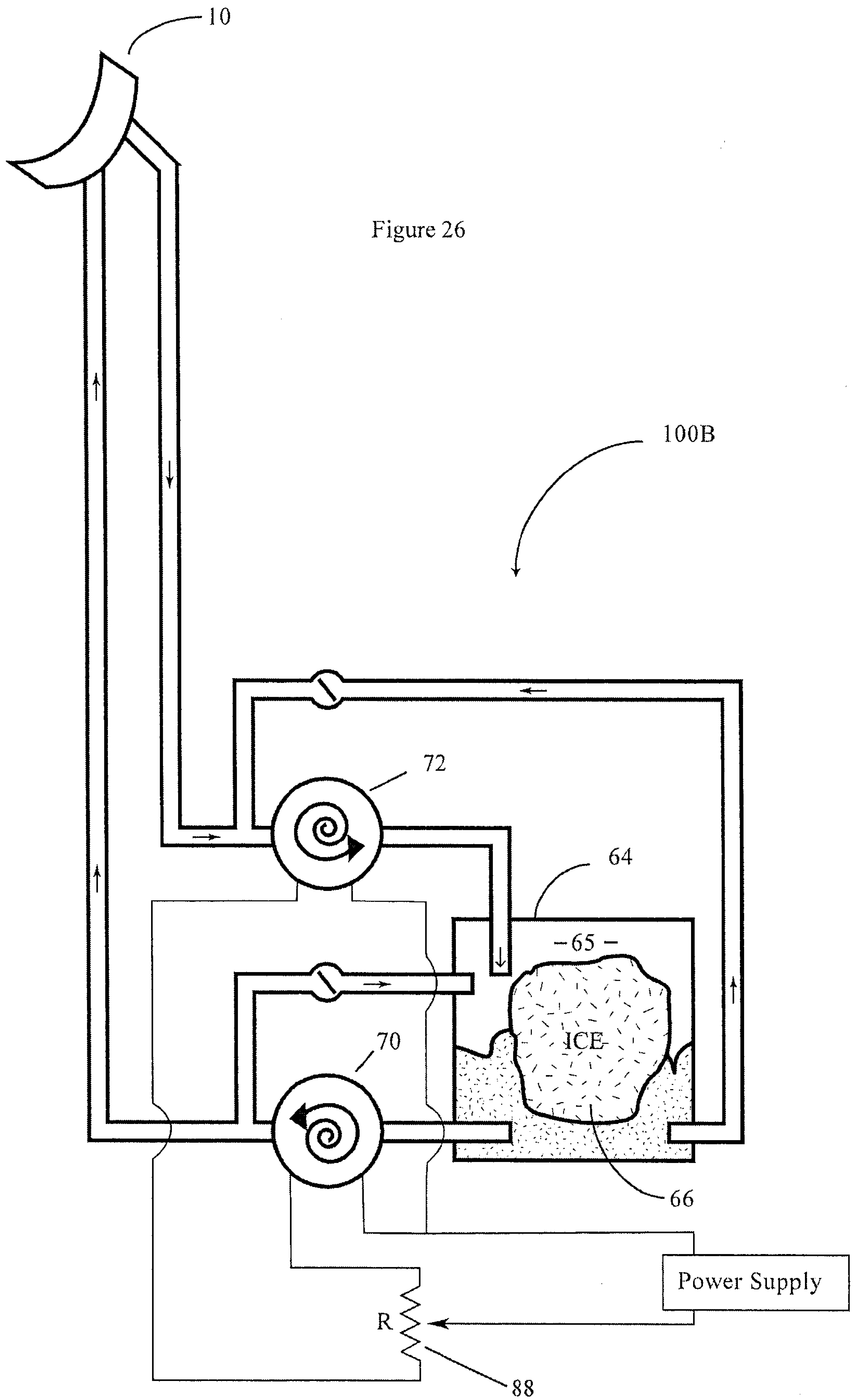
70
78

Figure 26



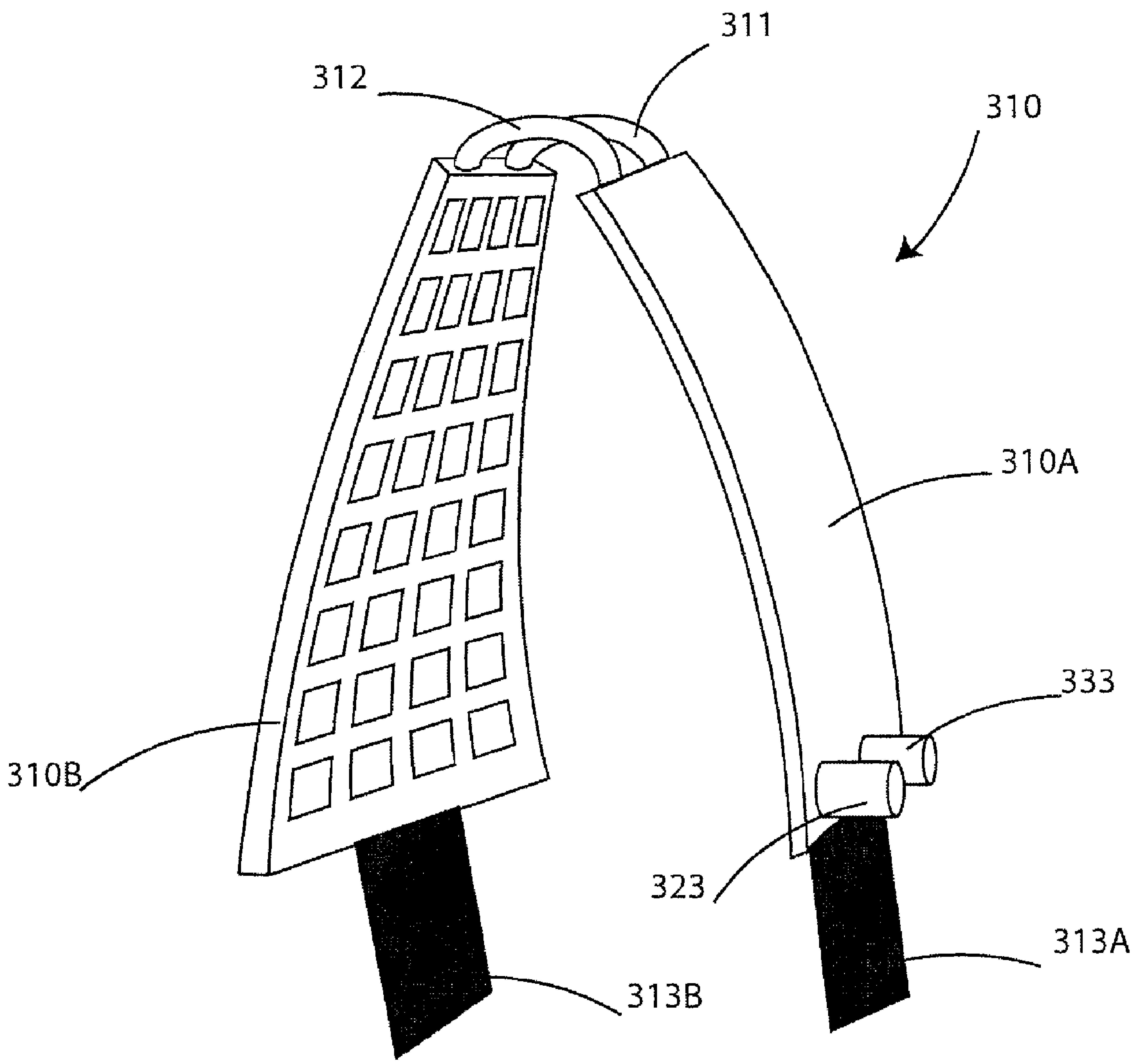


Figure 27

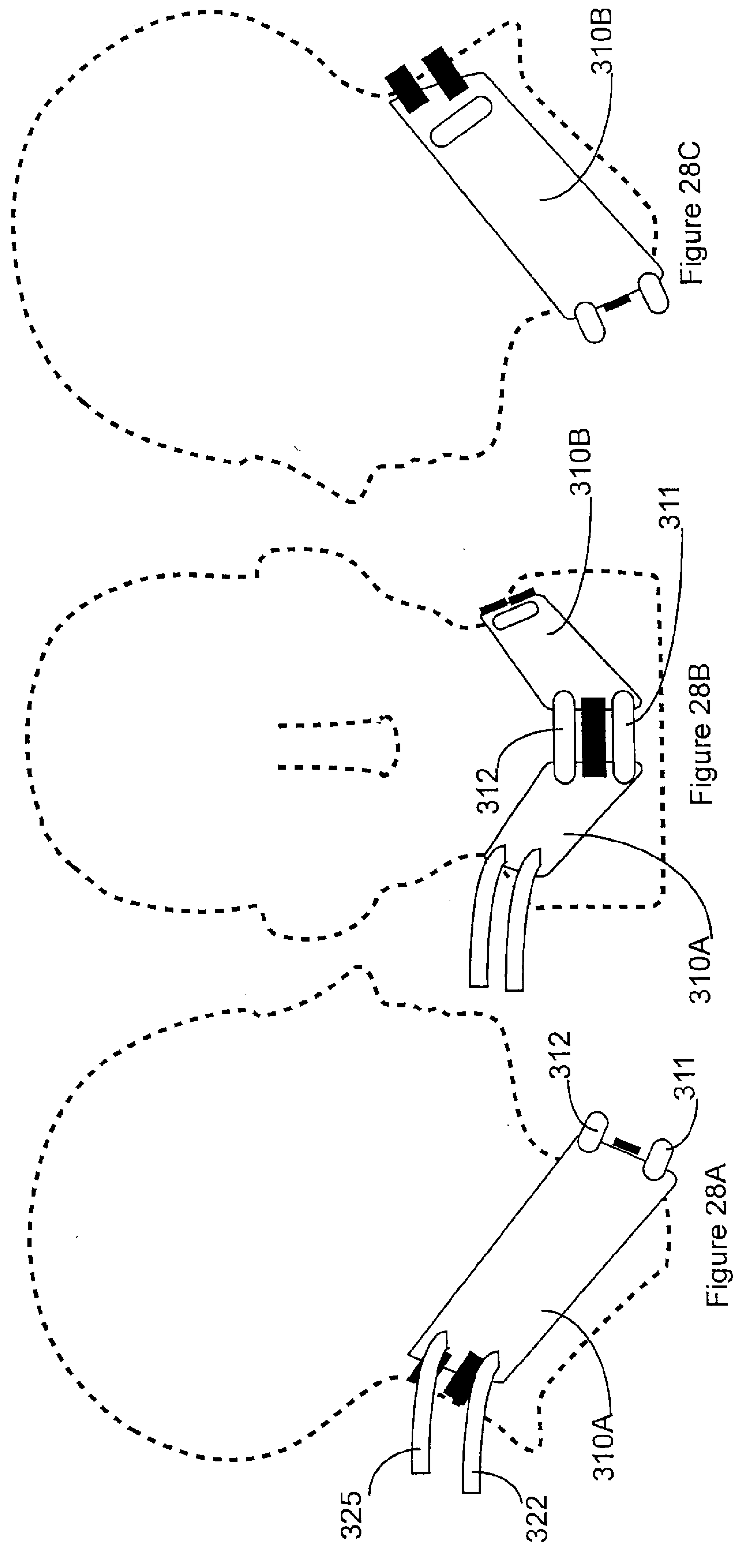


Figure 28C
Figure 28B
Figure 28A

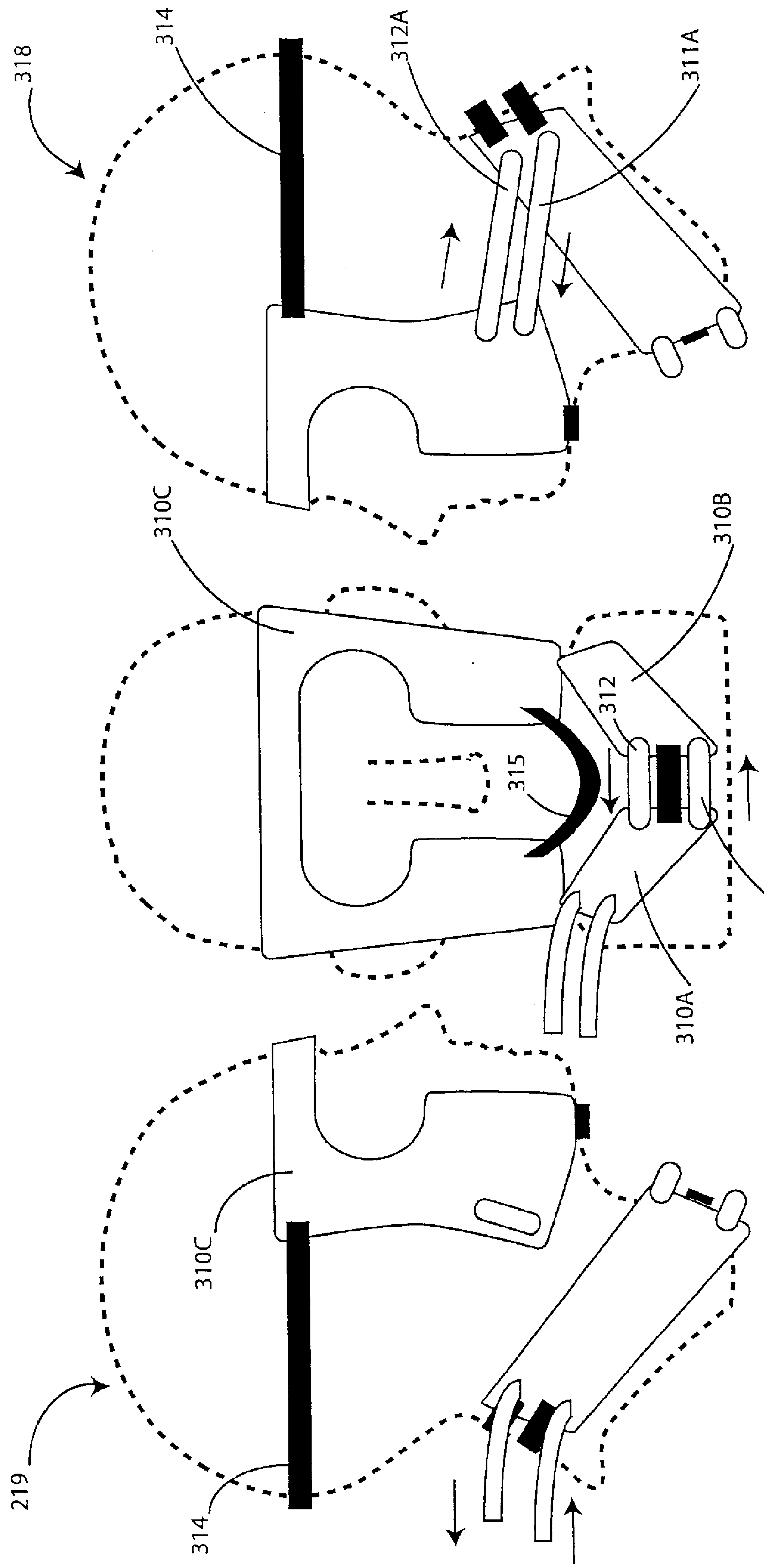


Figure 29C

Figure 29B

Figure 29A

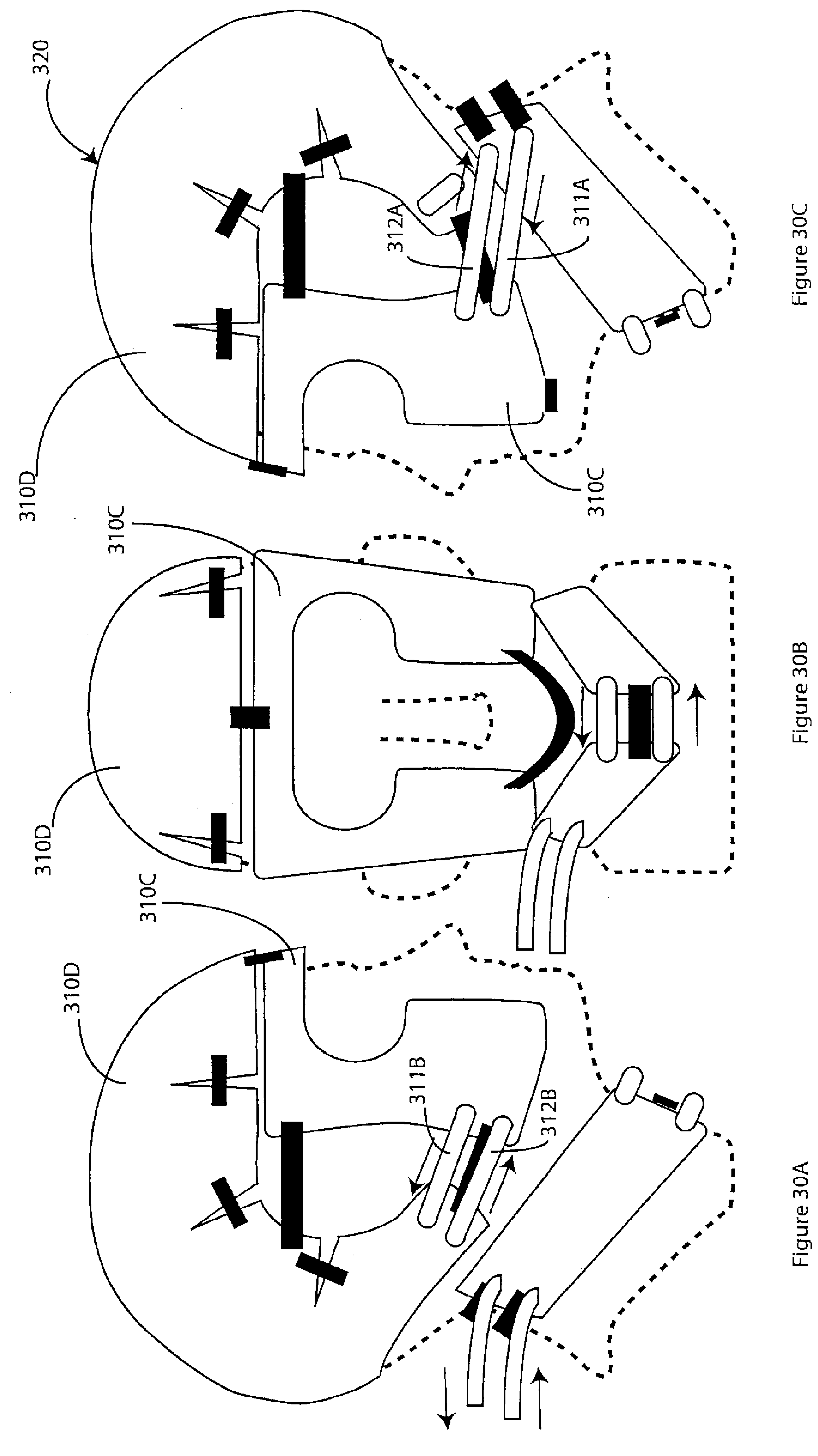


Figure 30C

Figure 30B

Figure 30A

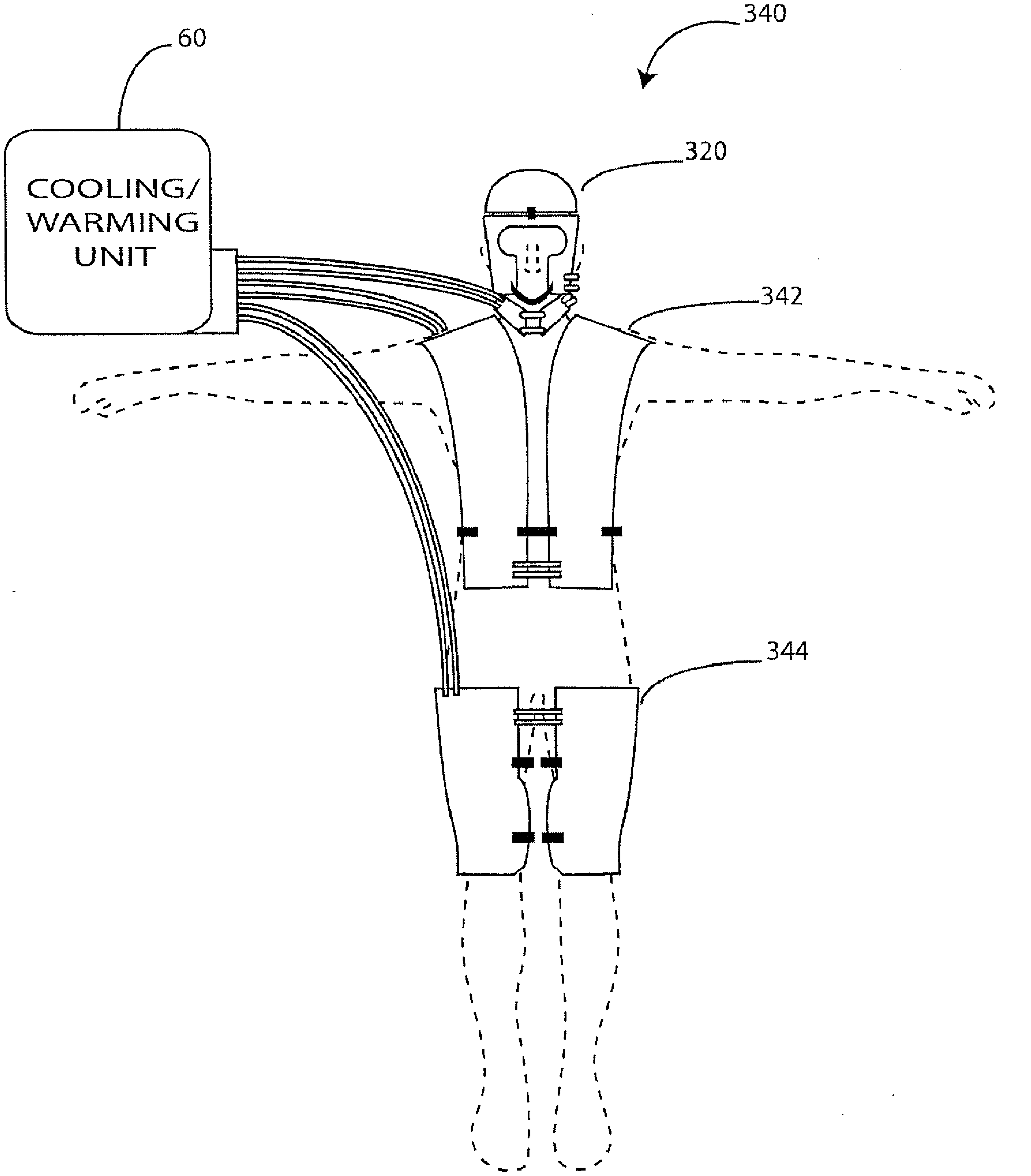


Figure 31

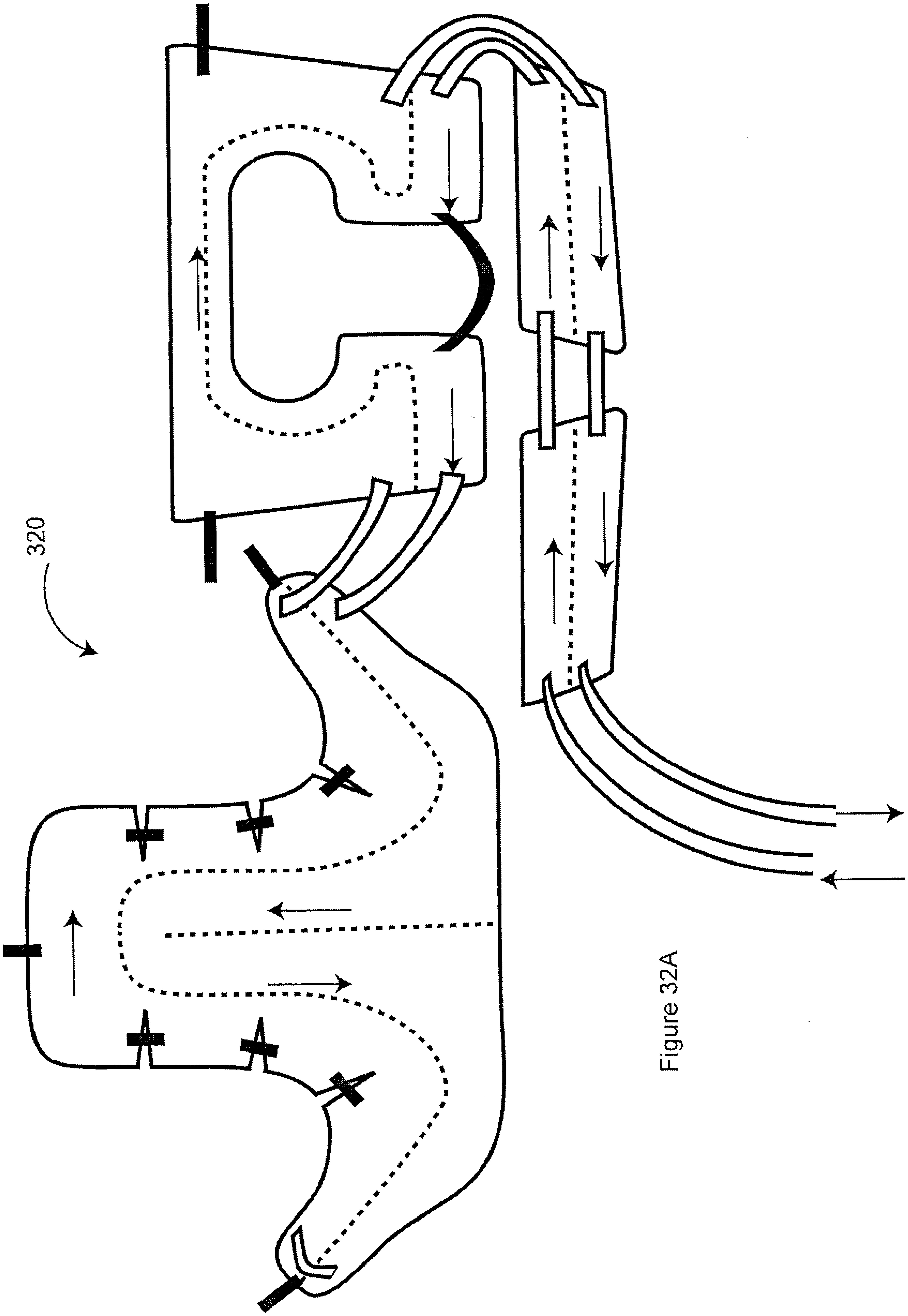


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Figure 32A

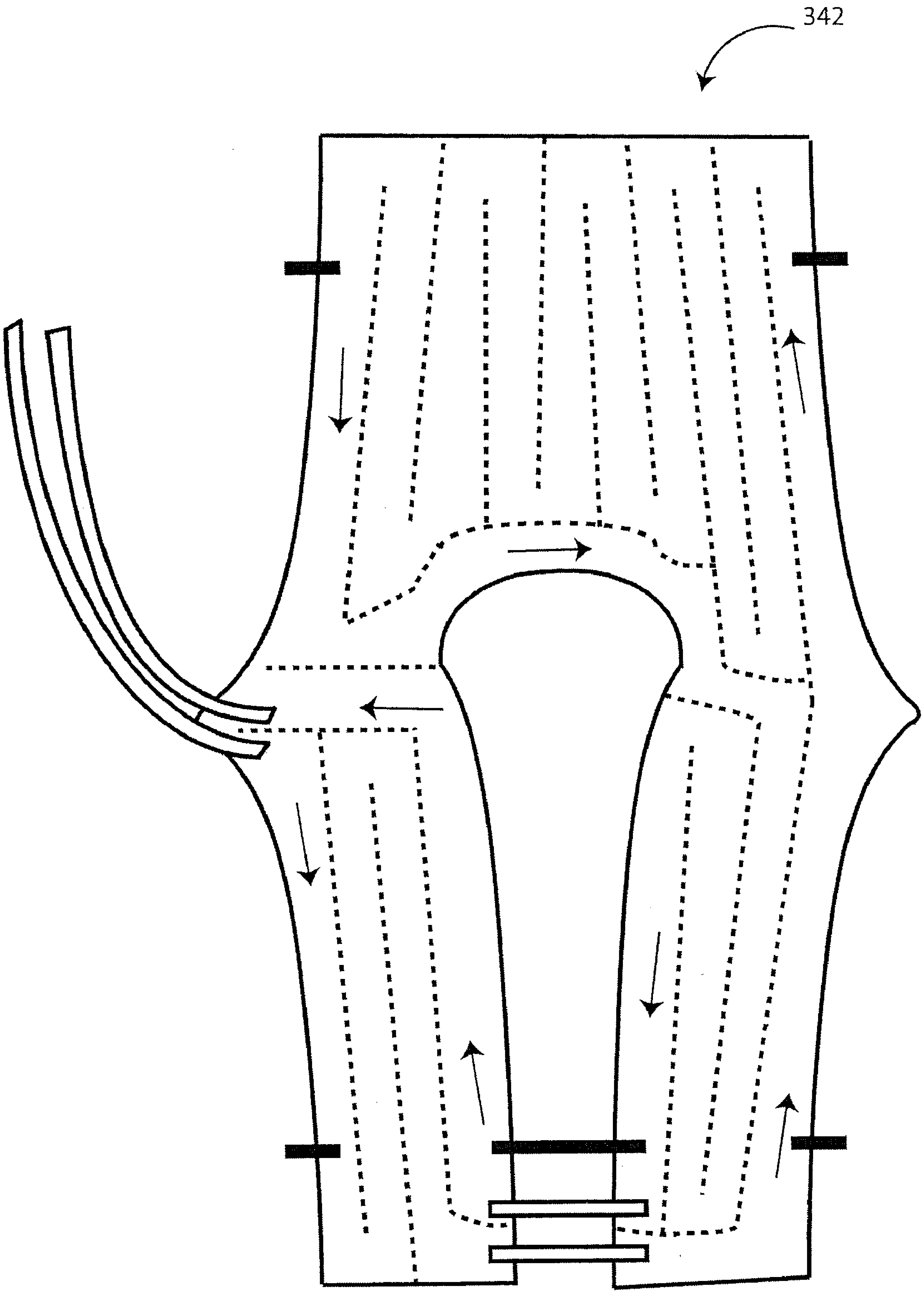


Figure 32B

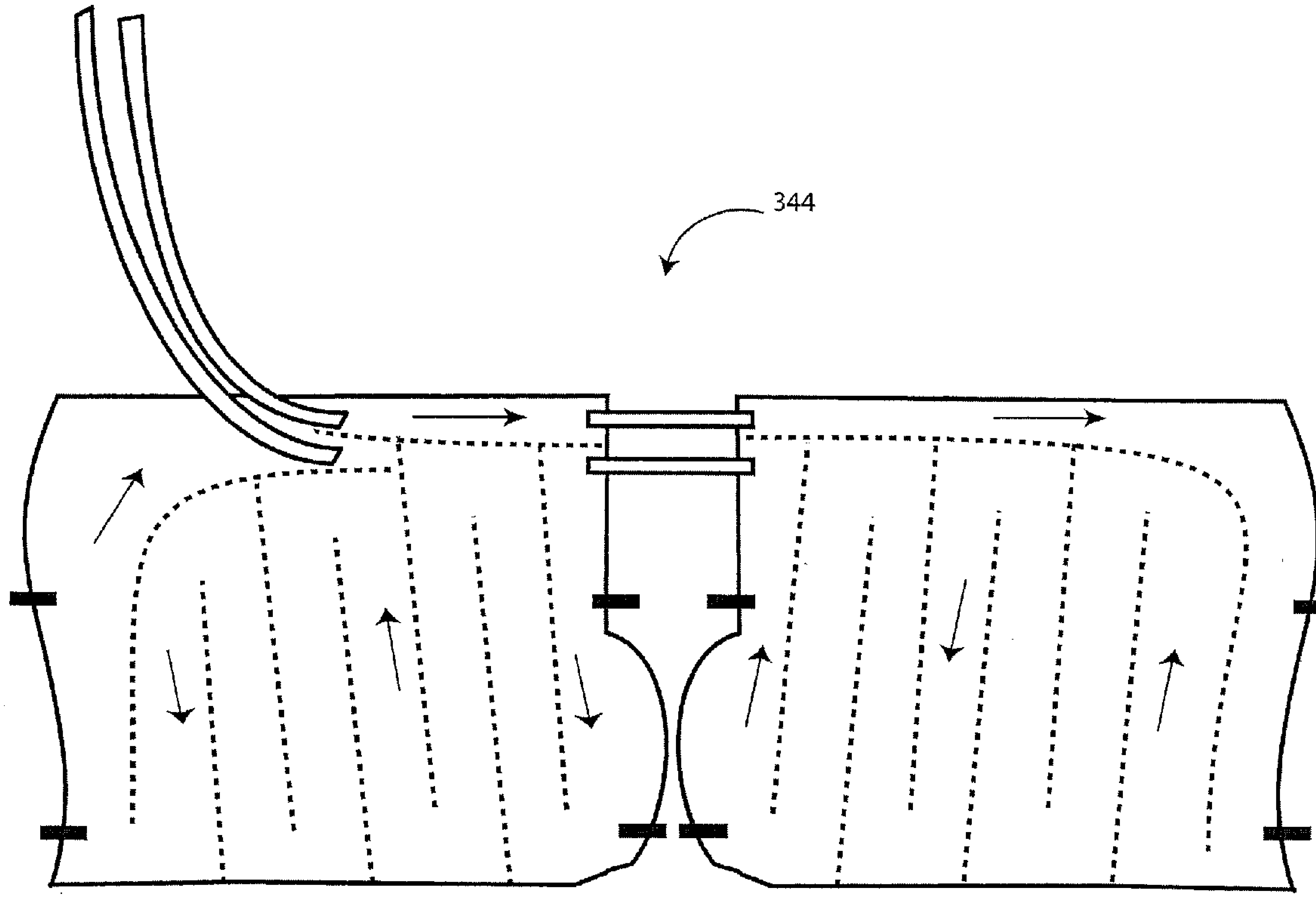


Figure 32C

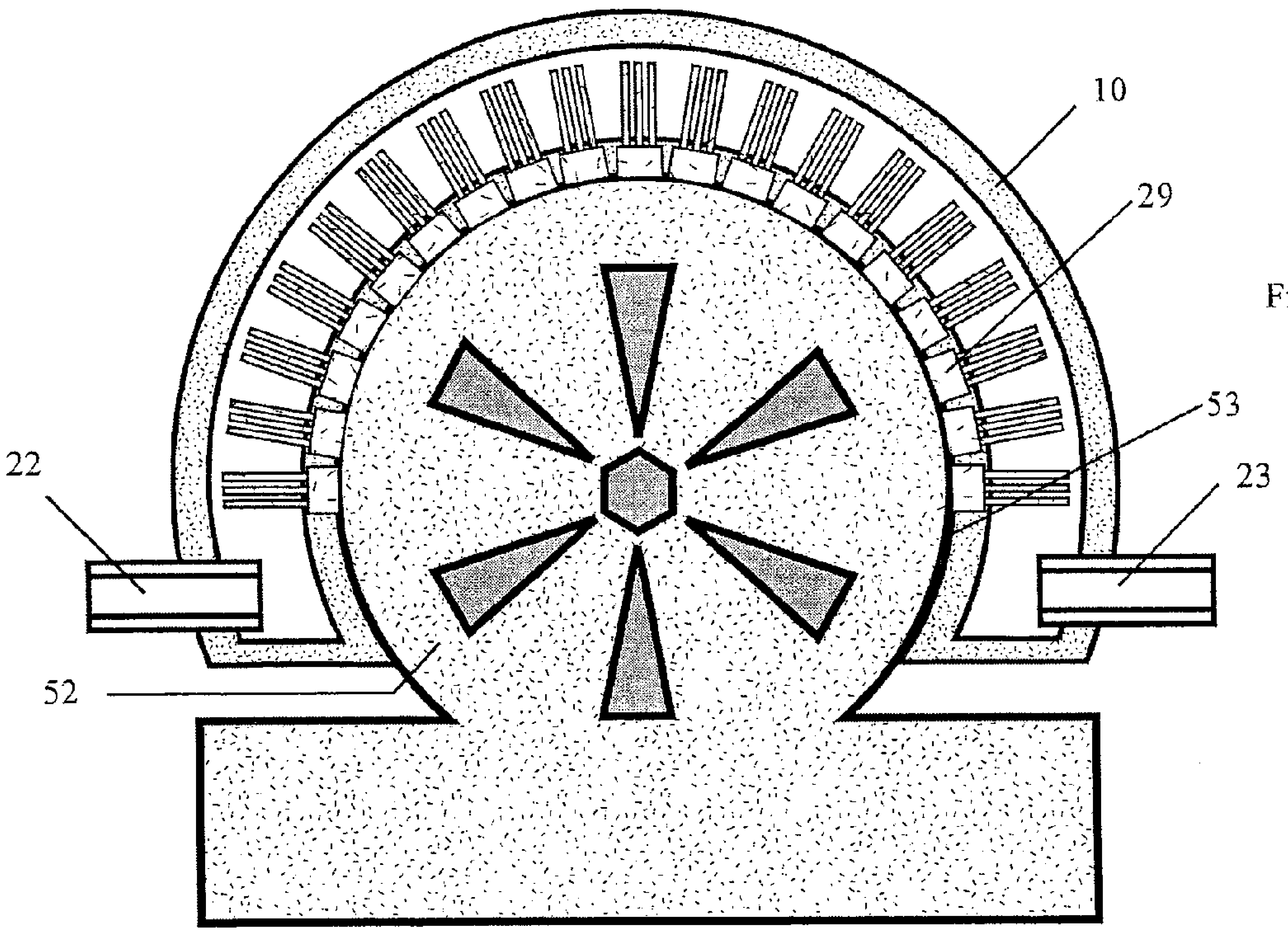


Figure 33A

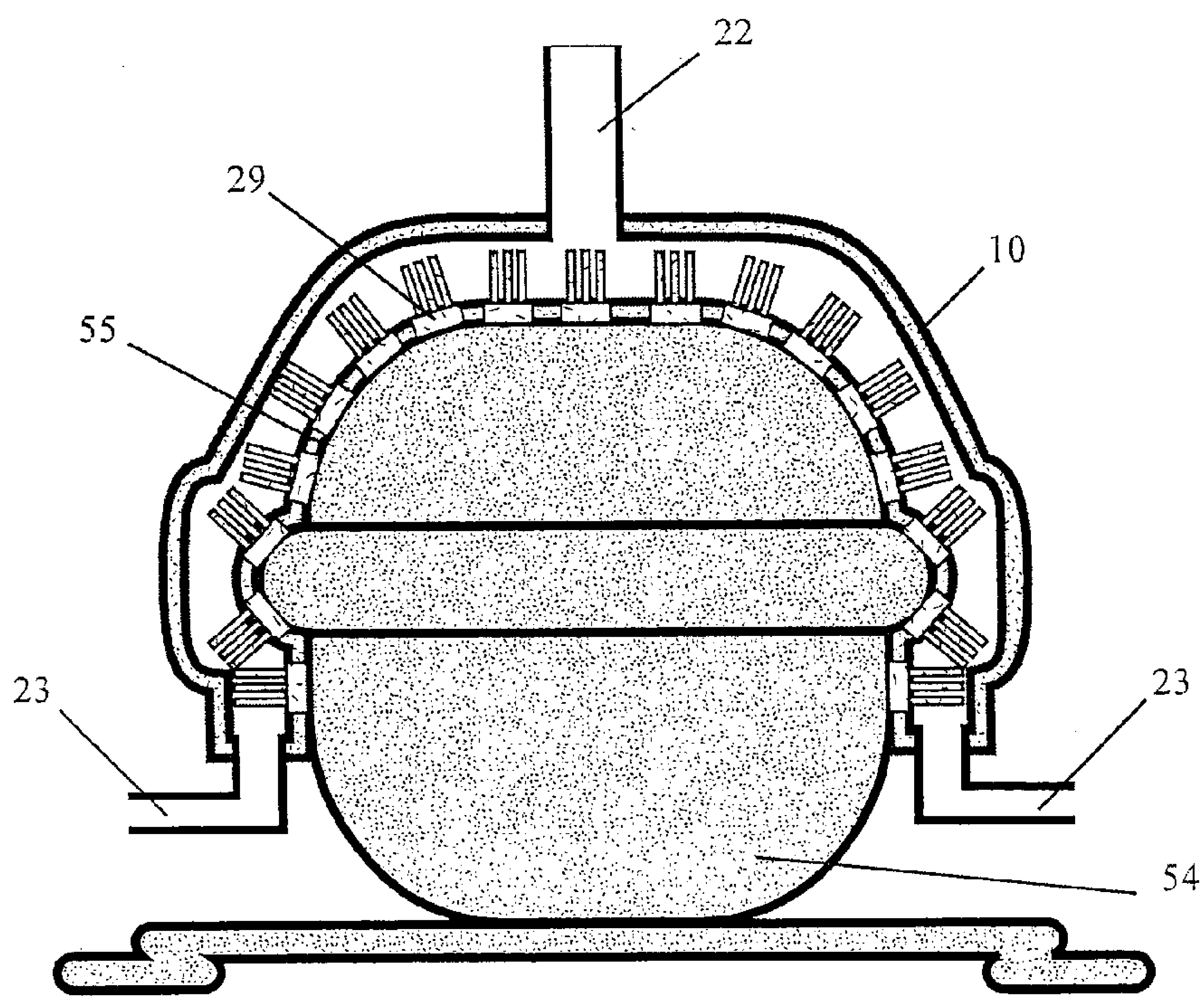


Figure 33B

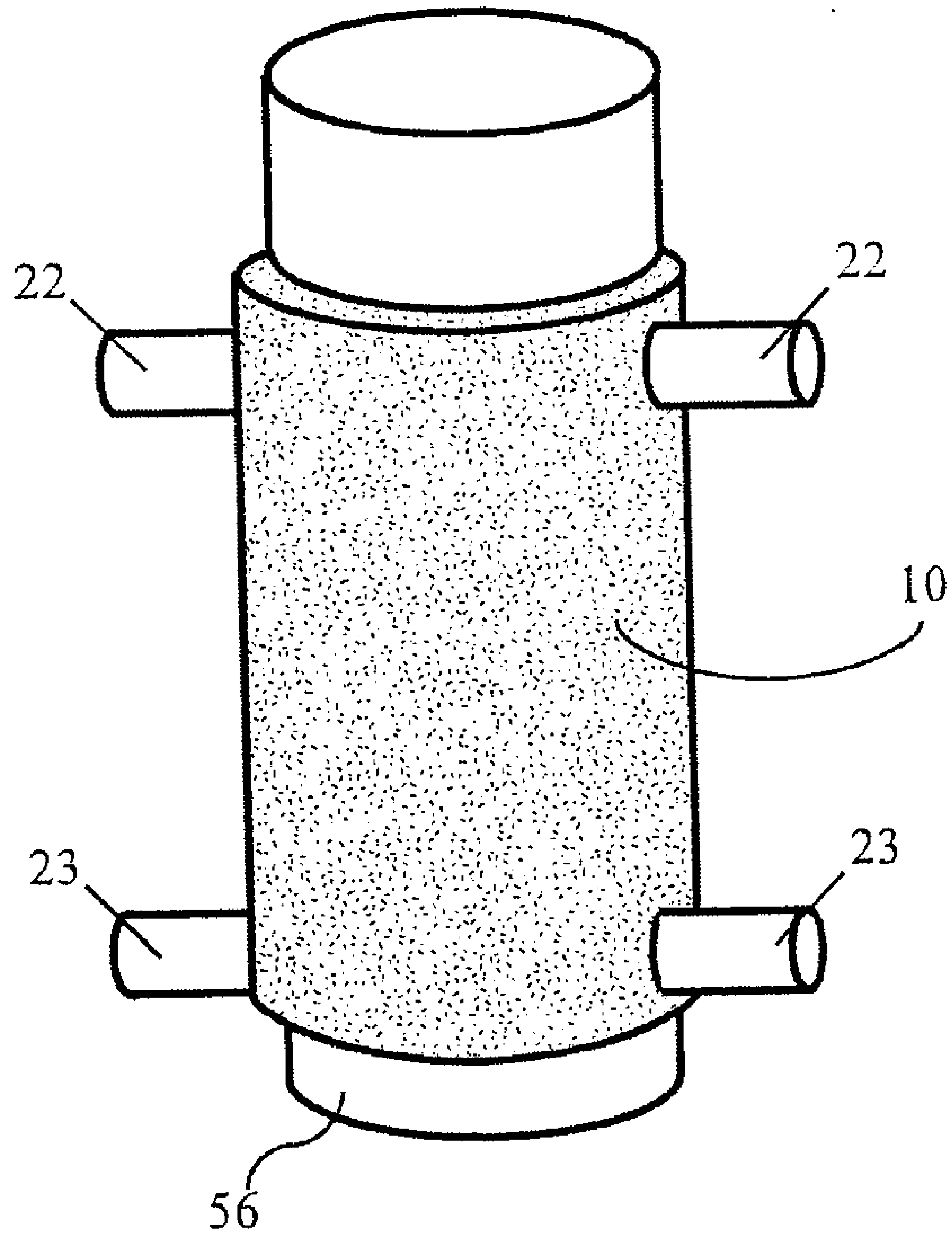


Figure 33C

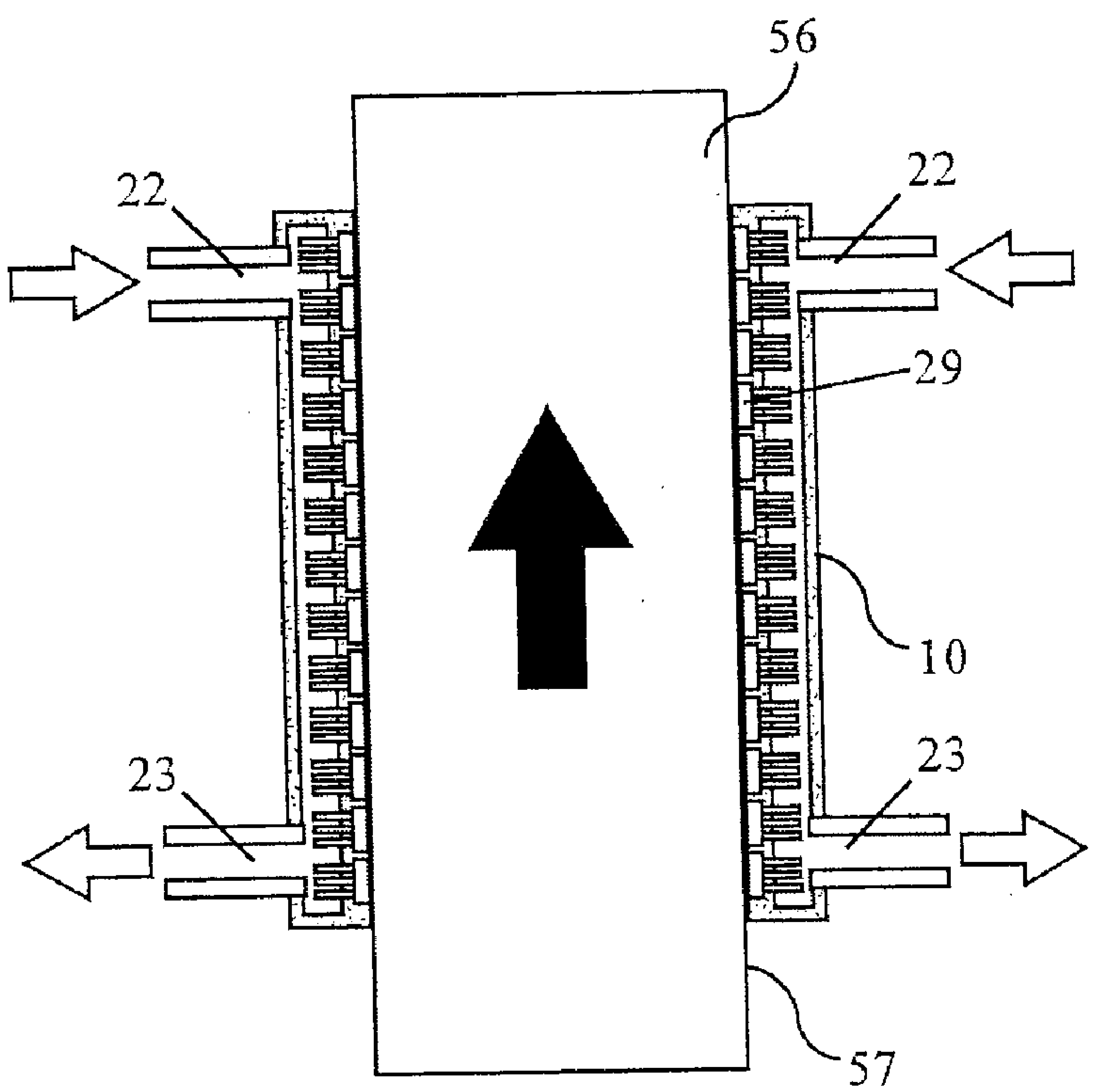


Figure 33D

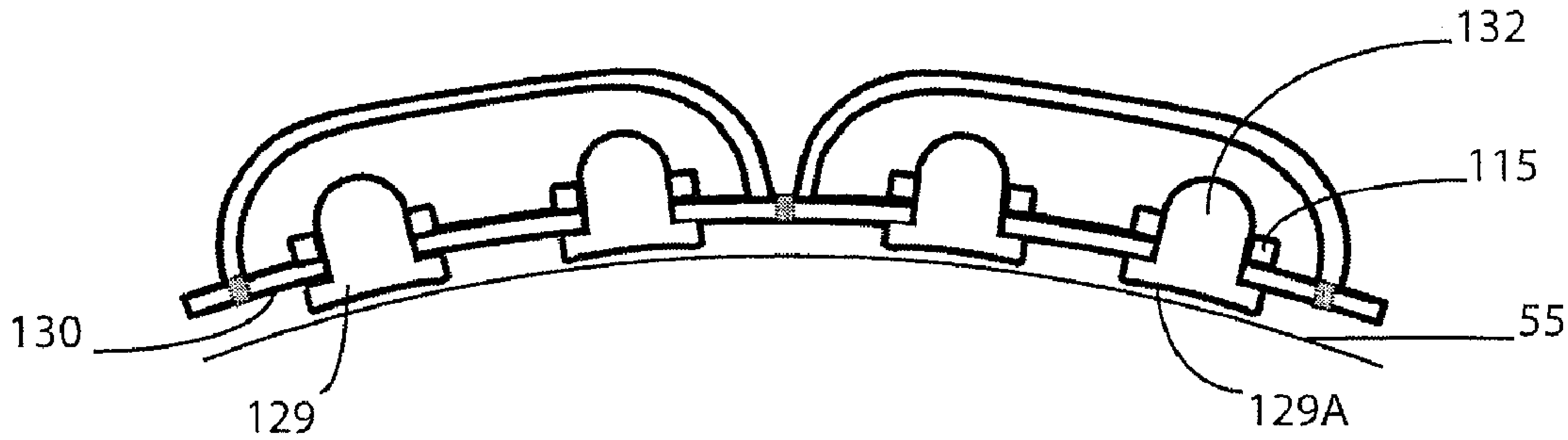


Figure 33E

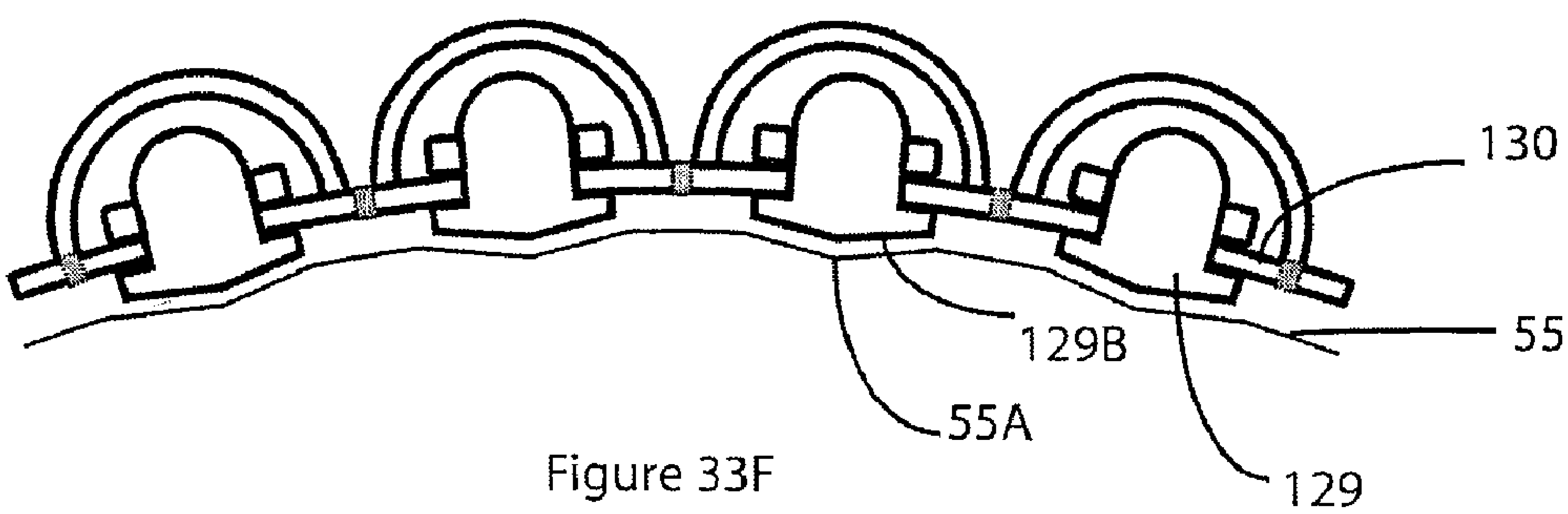


Figure 33F

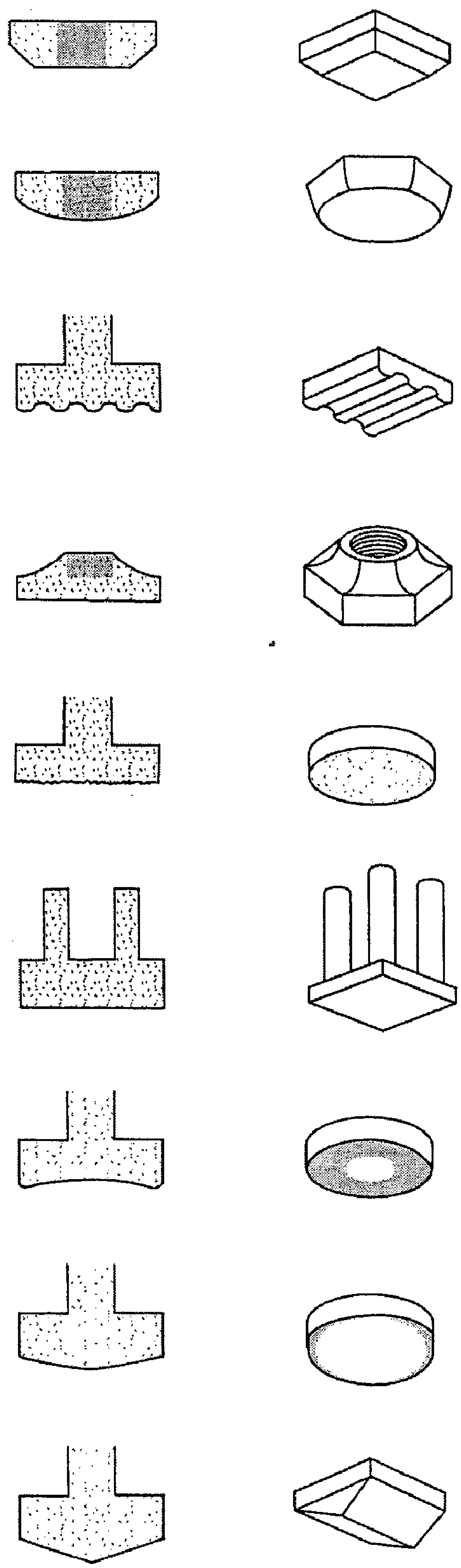


Figure 33G

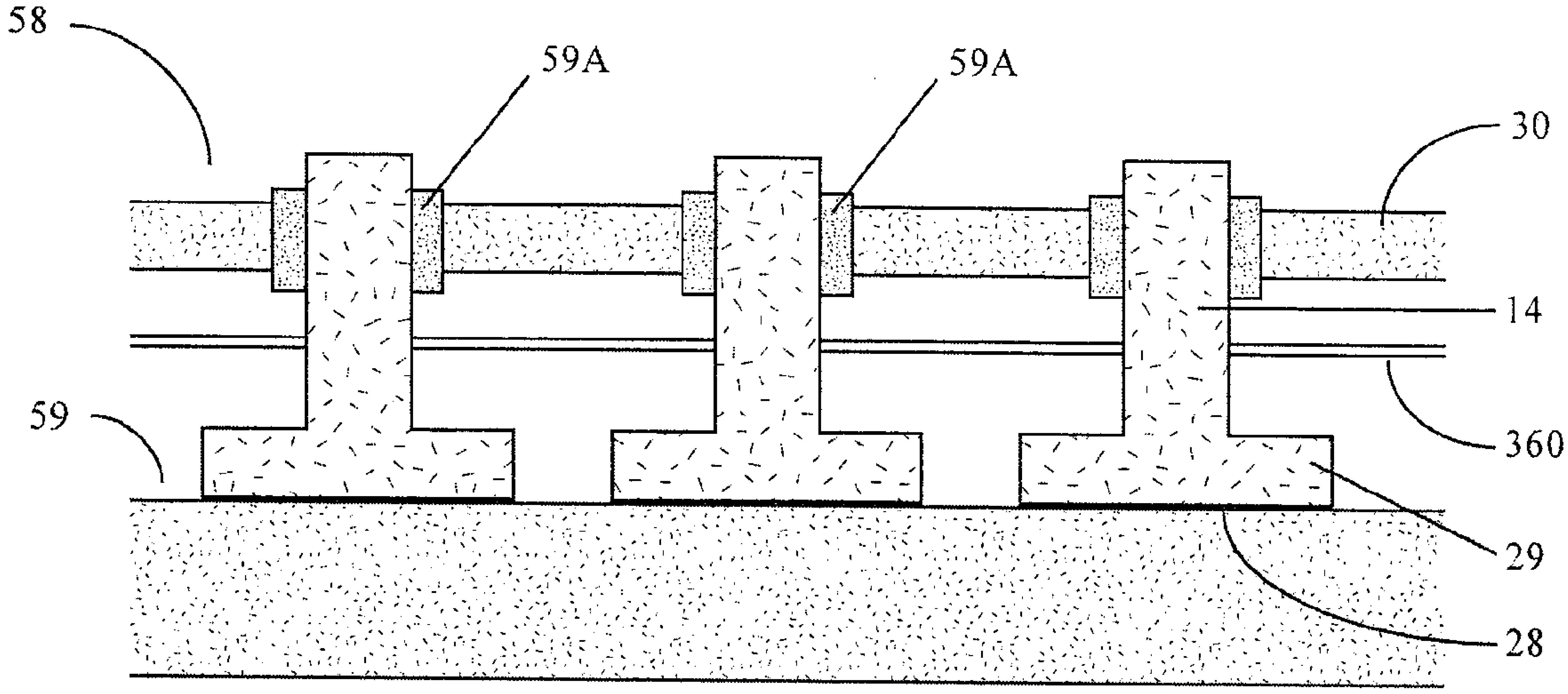


Figure 34

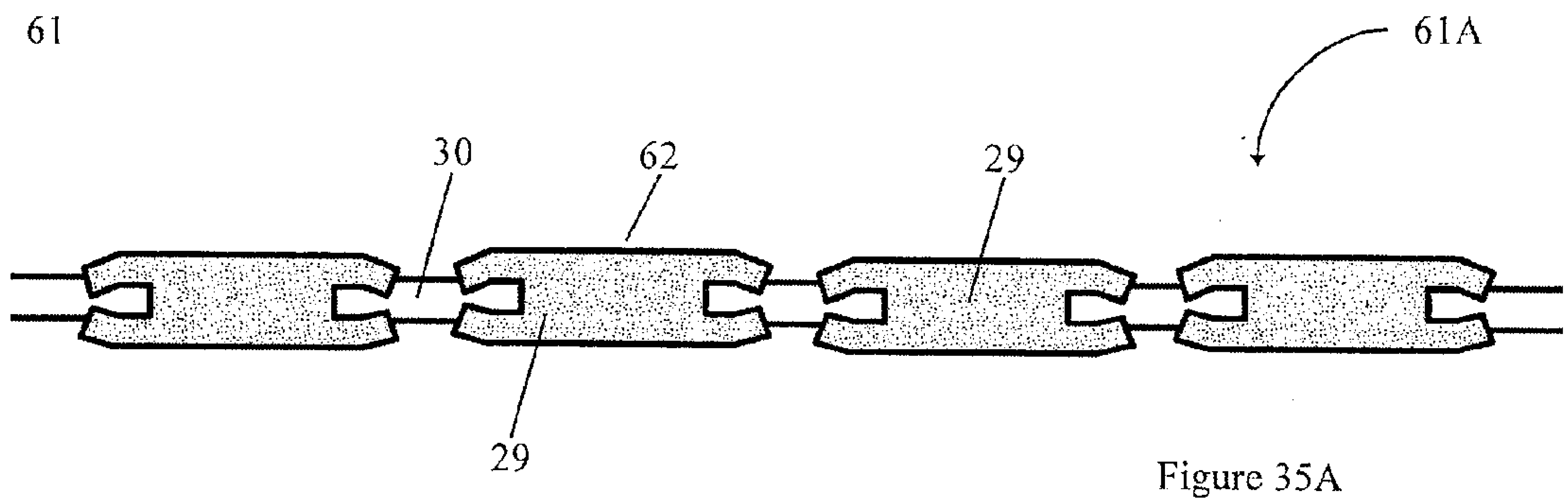


Figure 35A

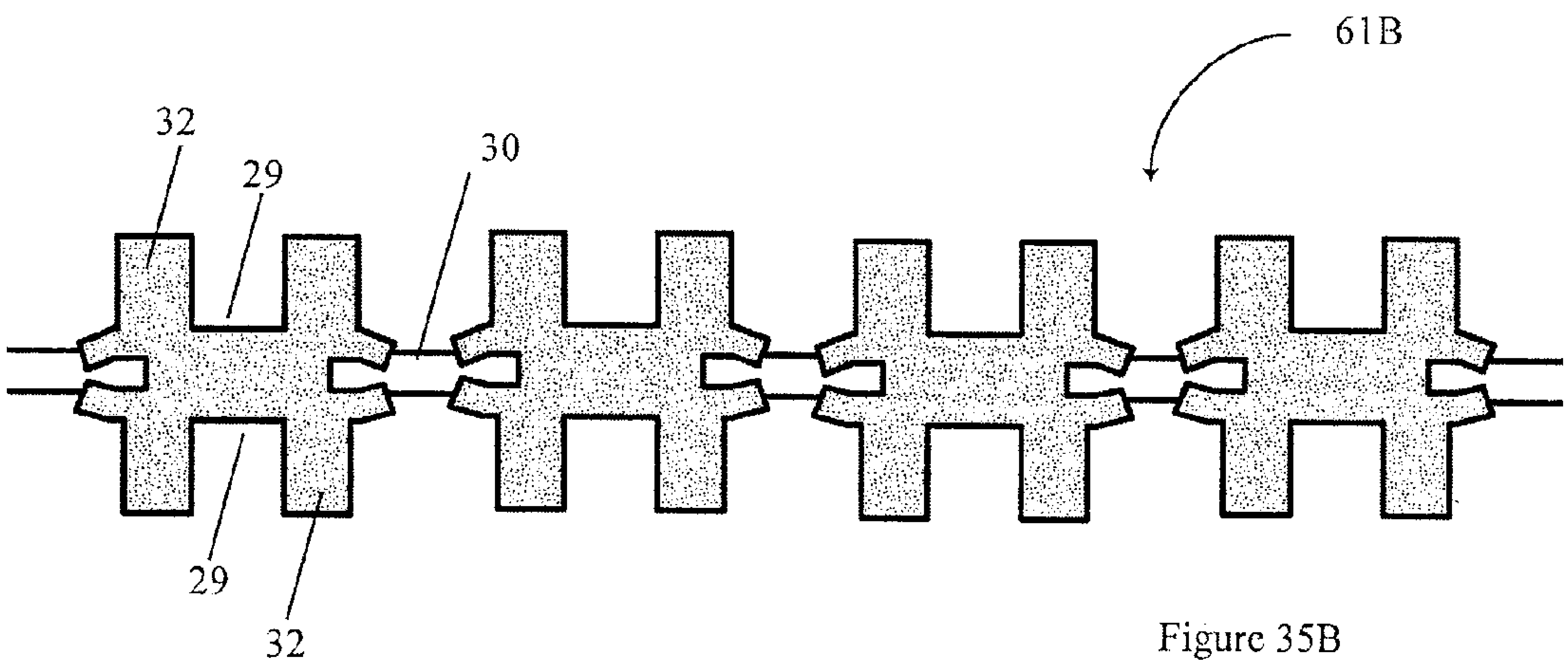


Figure 35B

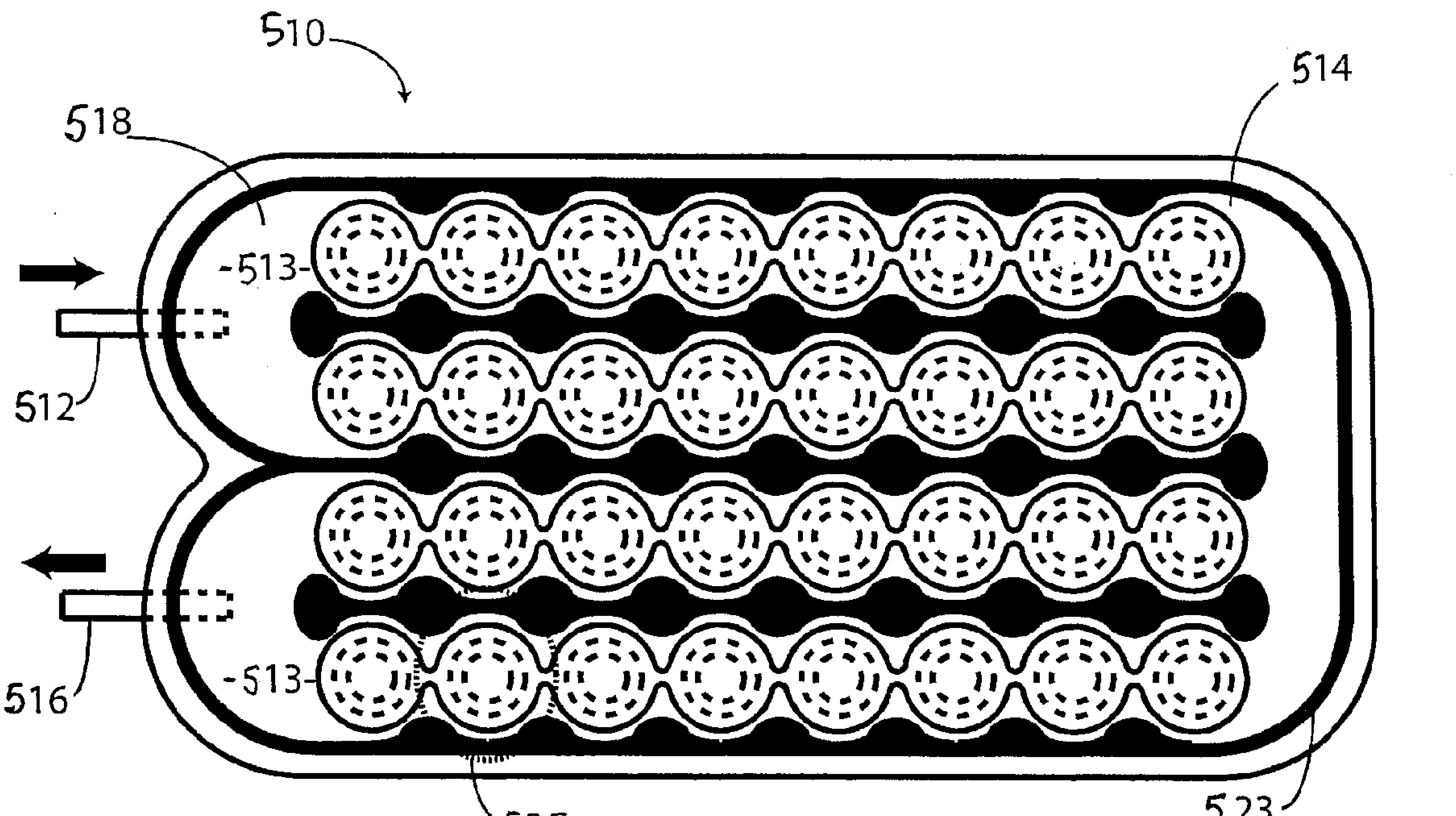


Figure 36A

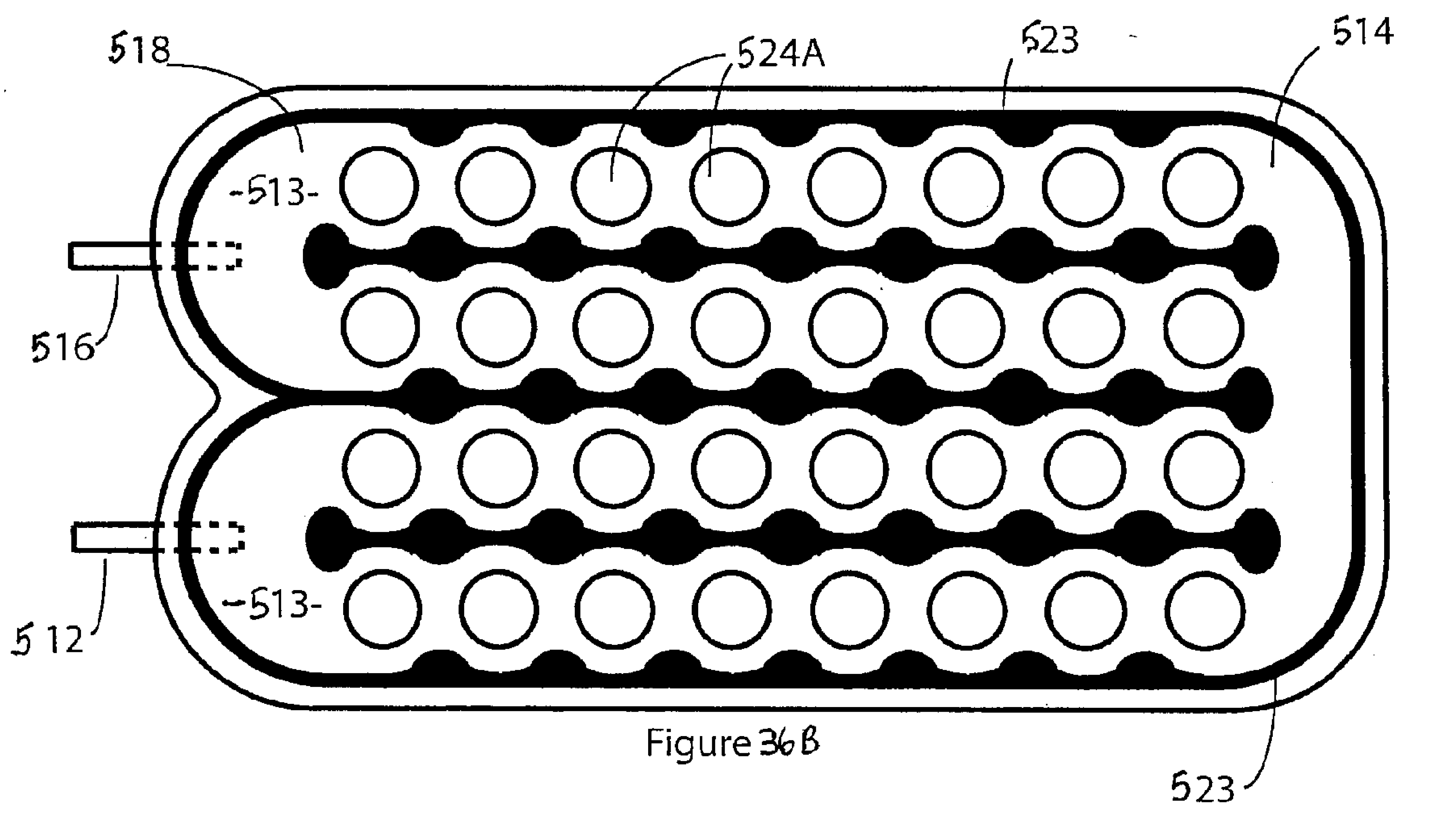


Figure 36B

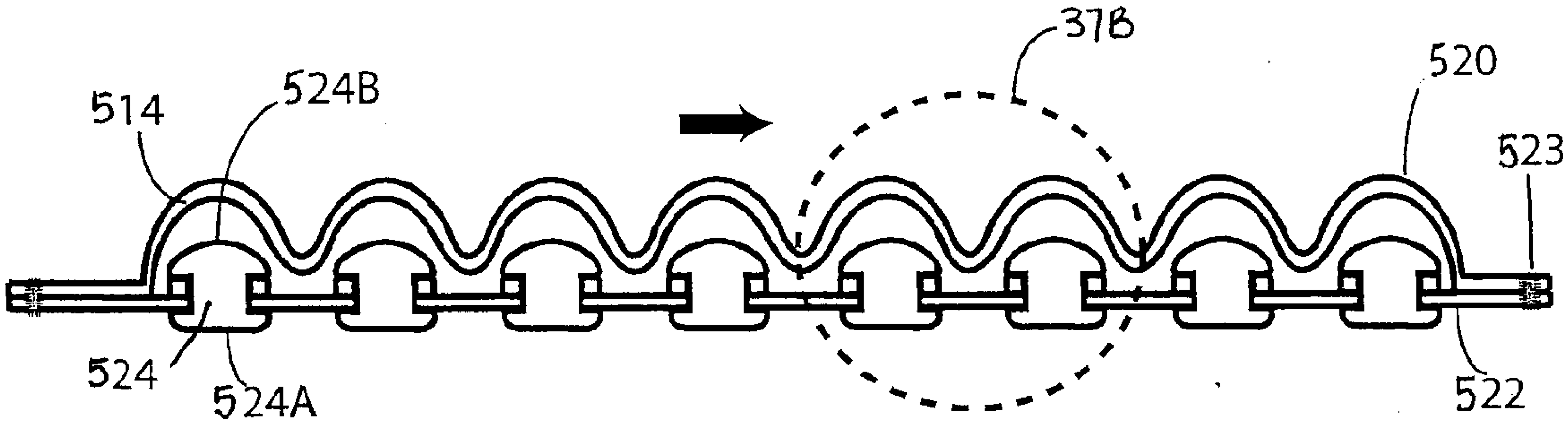


Figure 37A

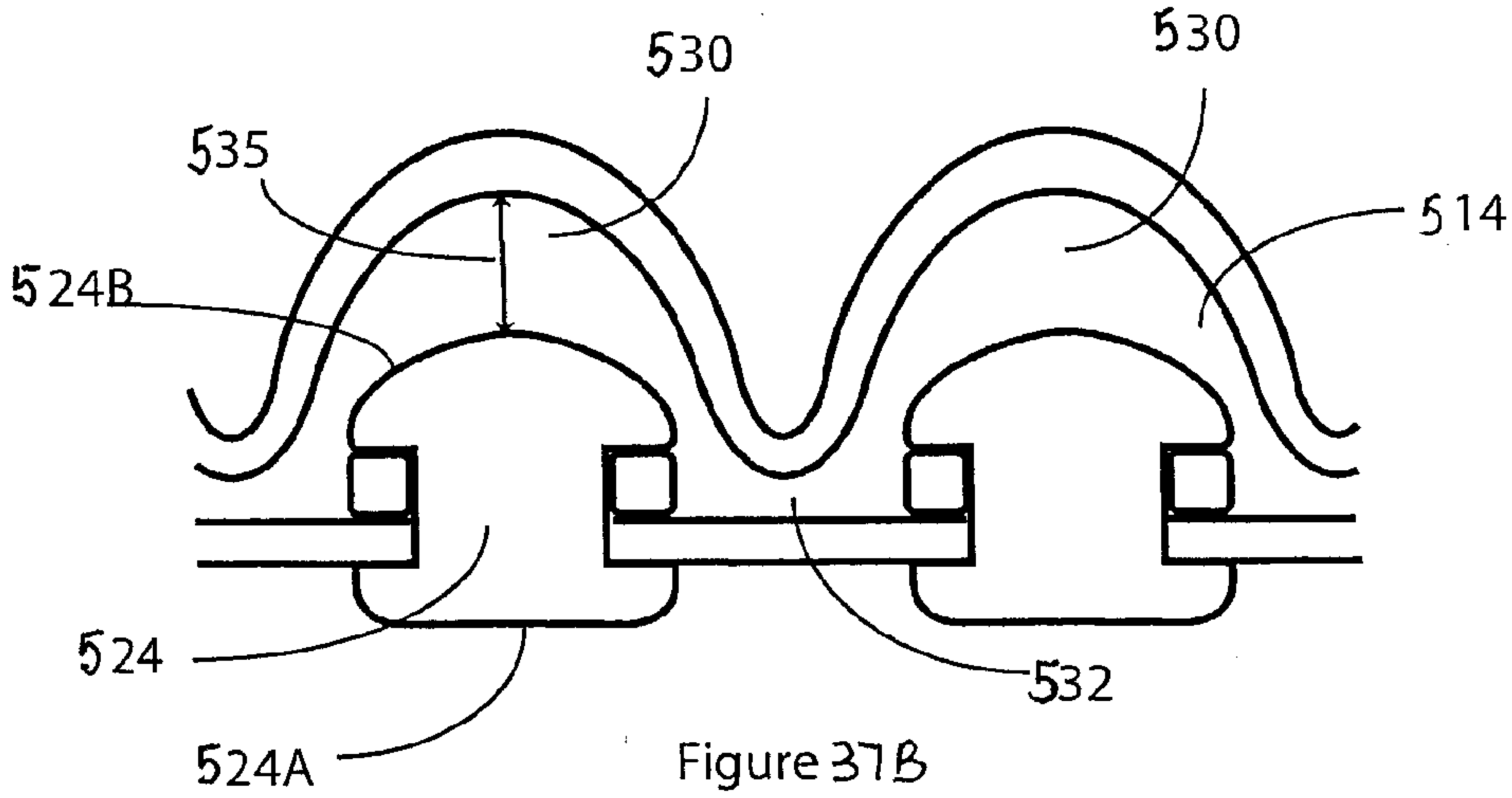


Figure 37B

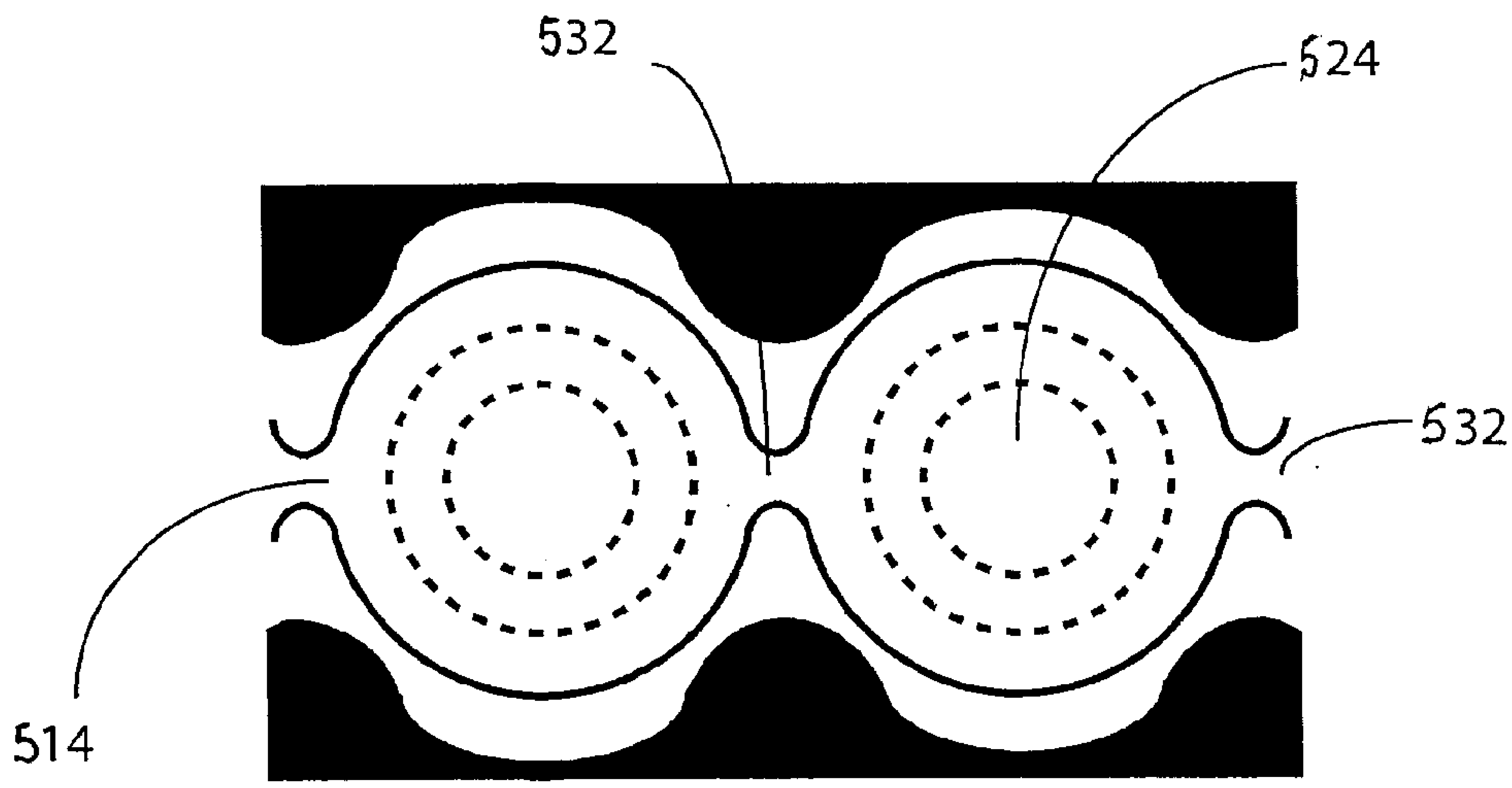


Figure 37C

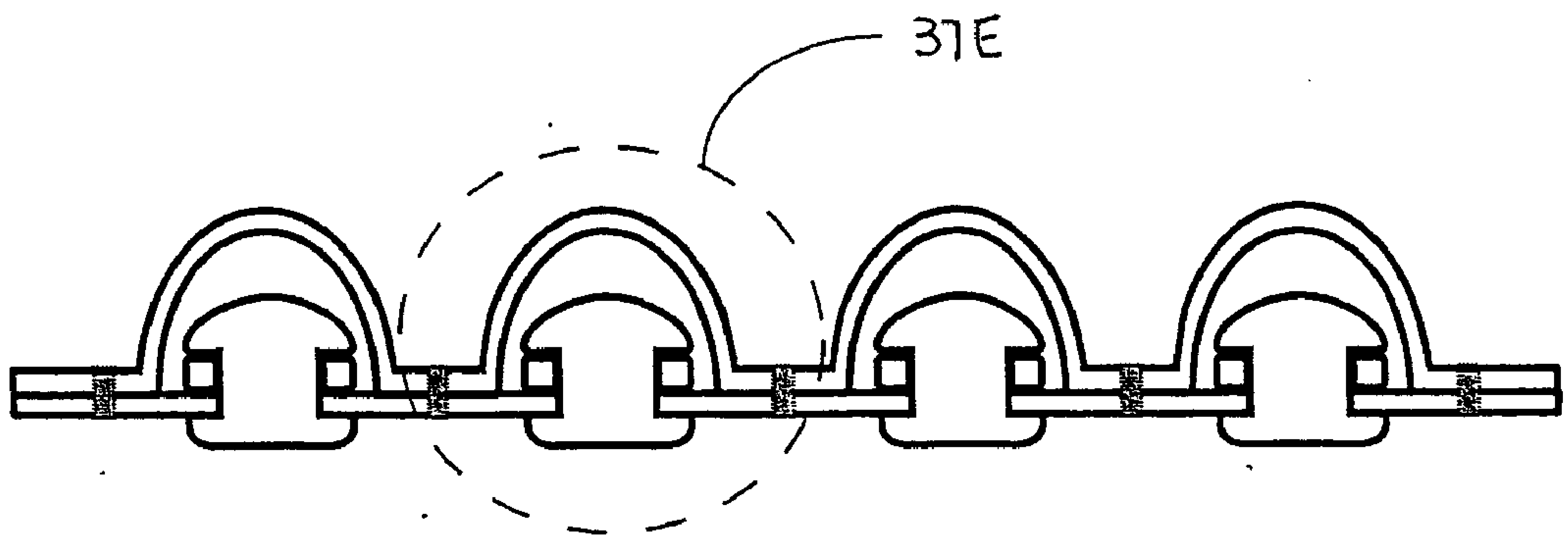


Figure 37D

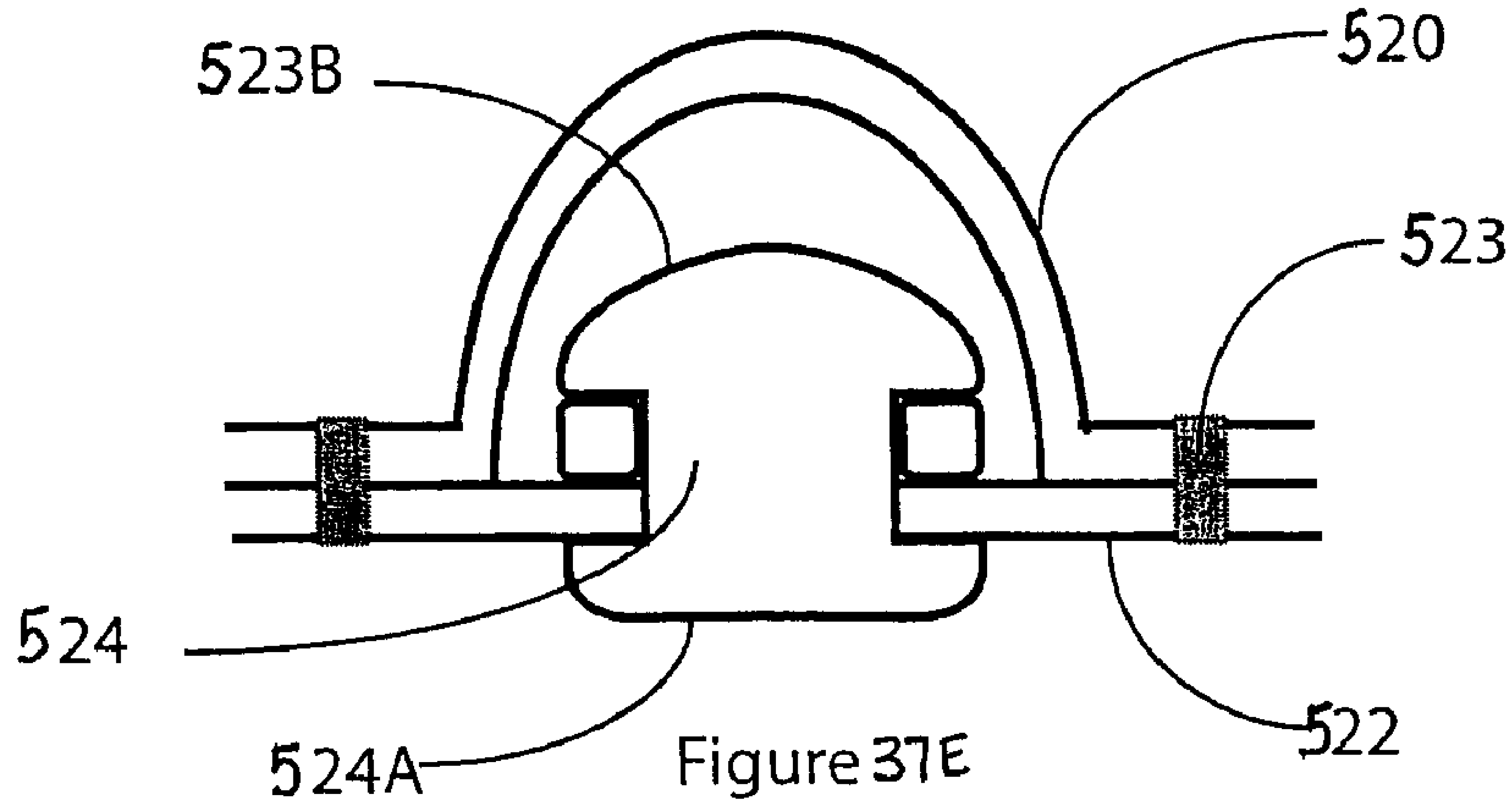


Figure 37E

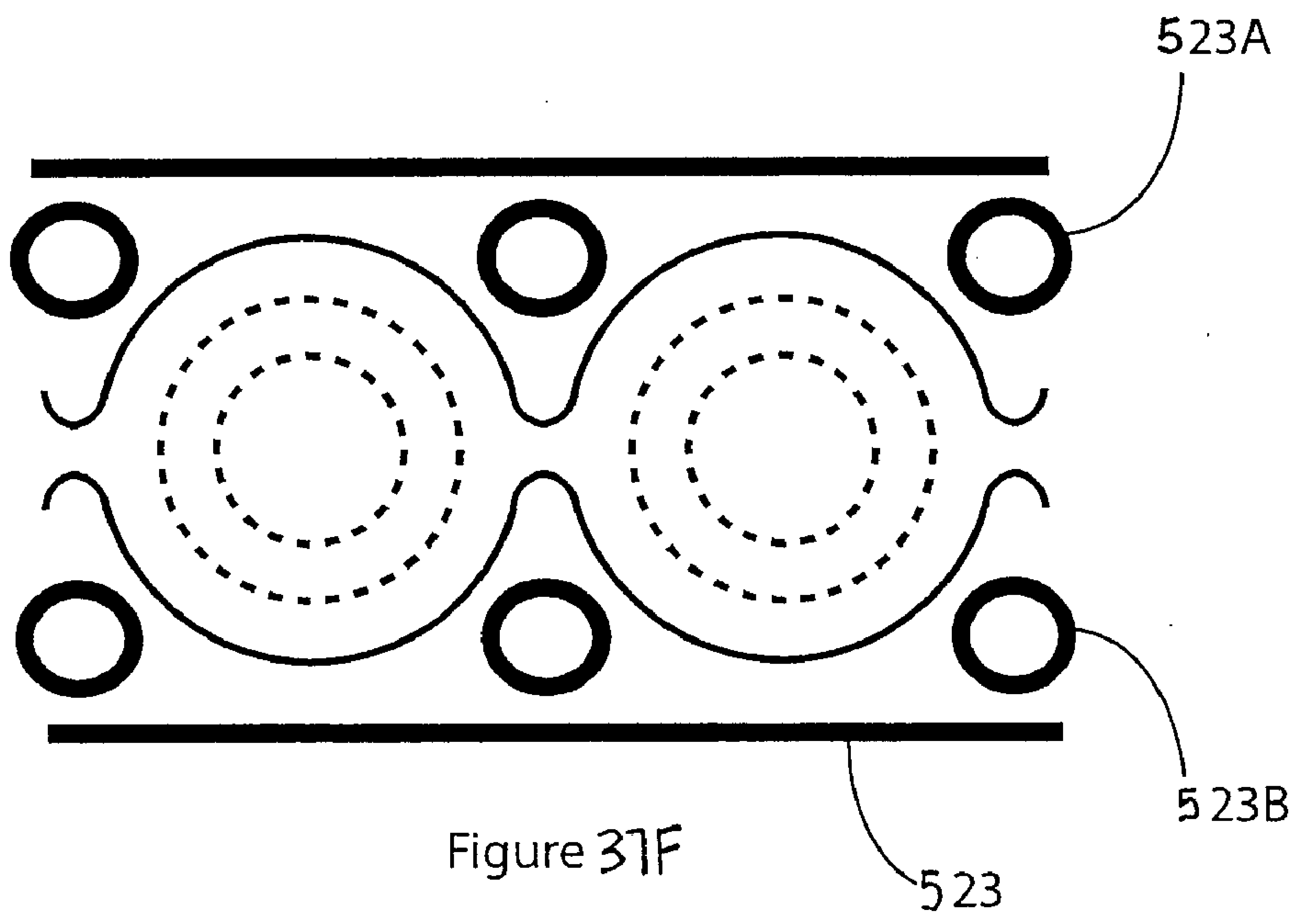


Figure 37F

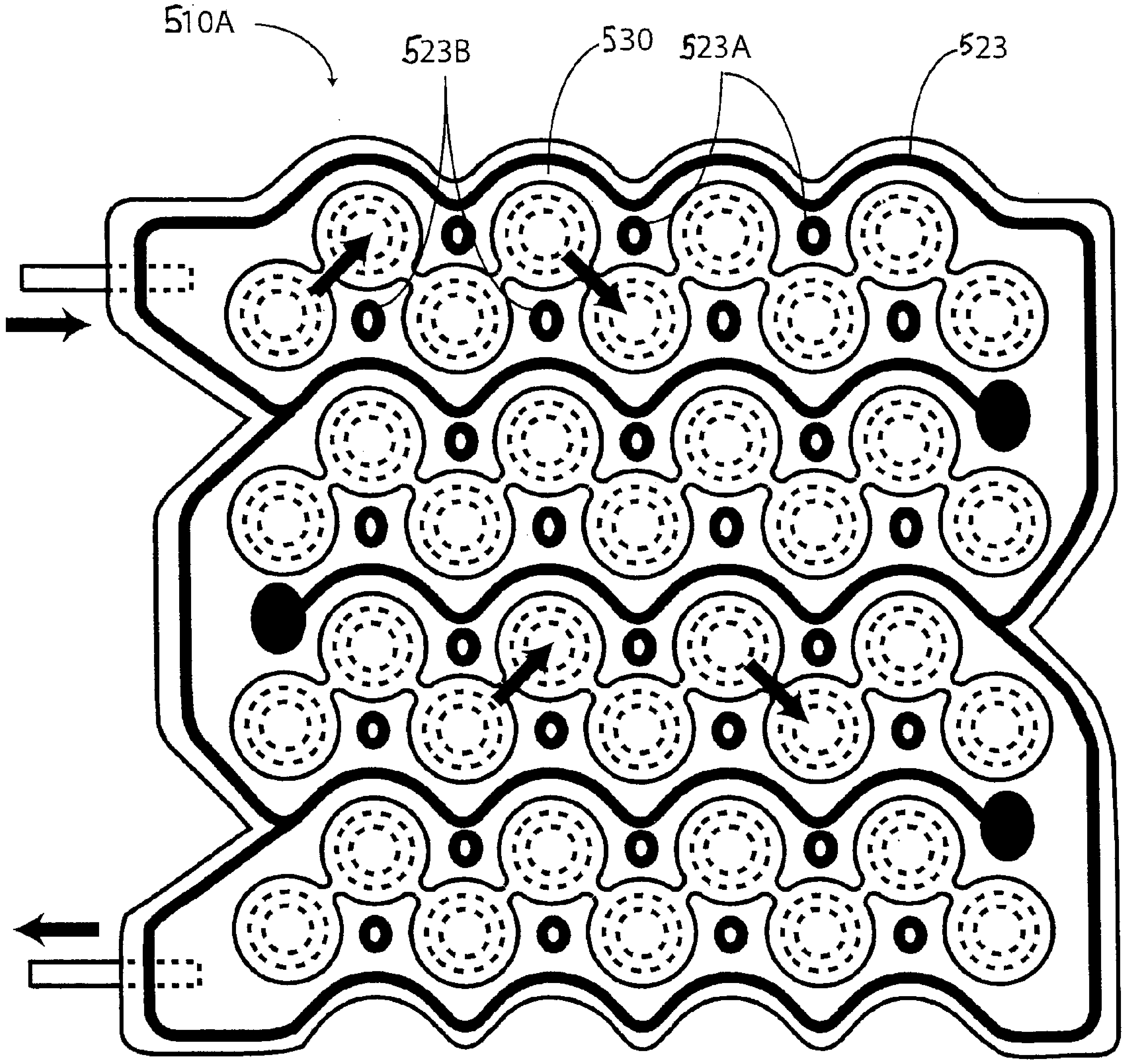


Figure 37G

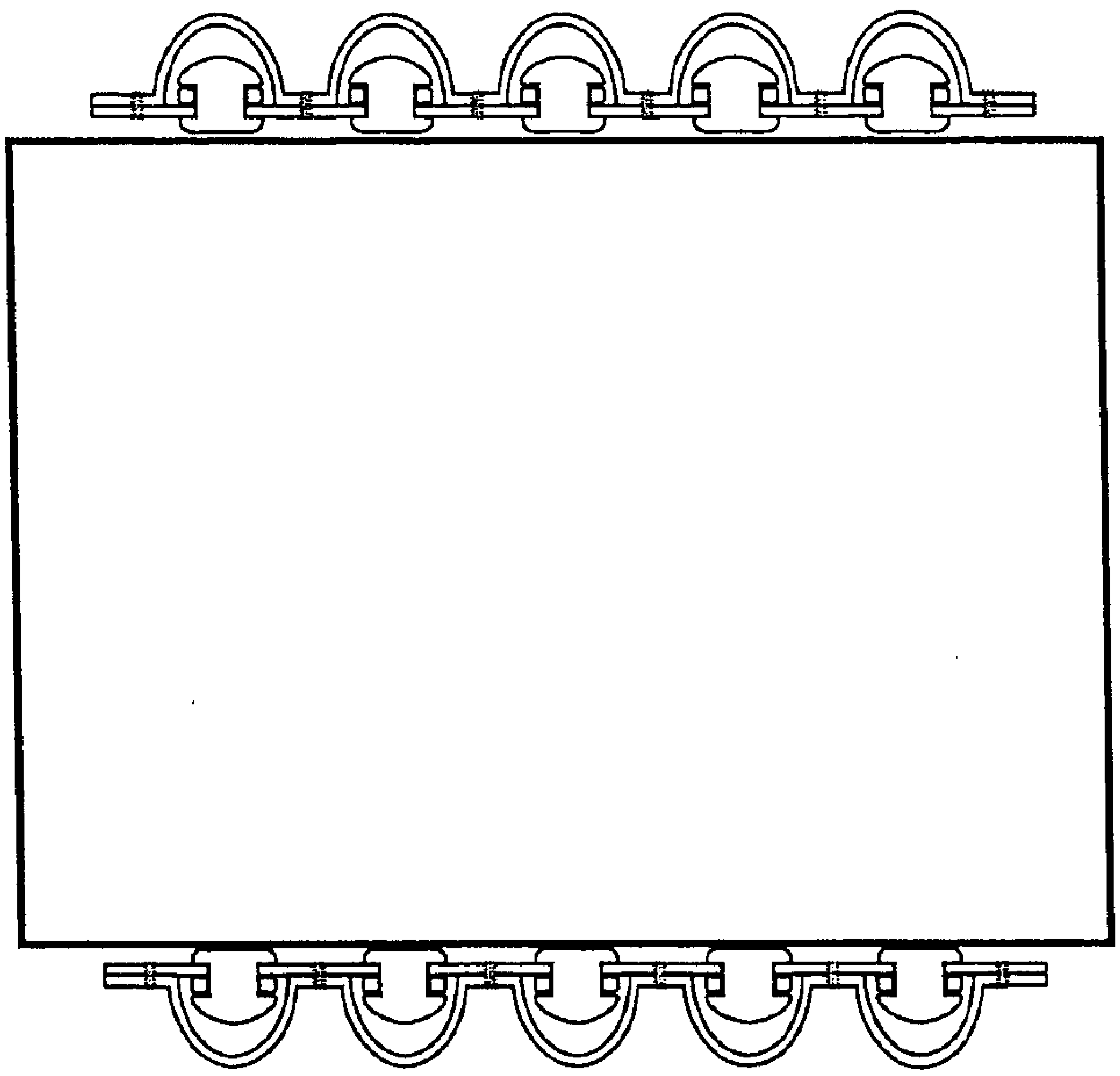


Figure 38 B

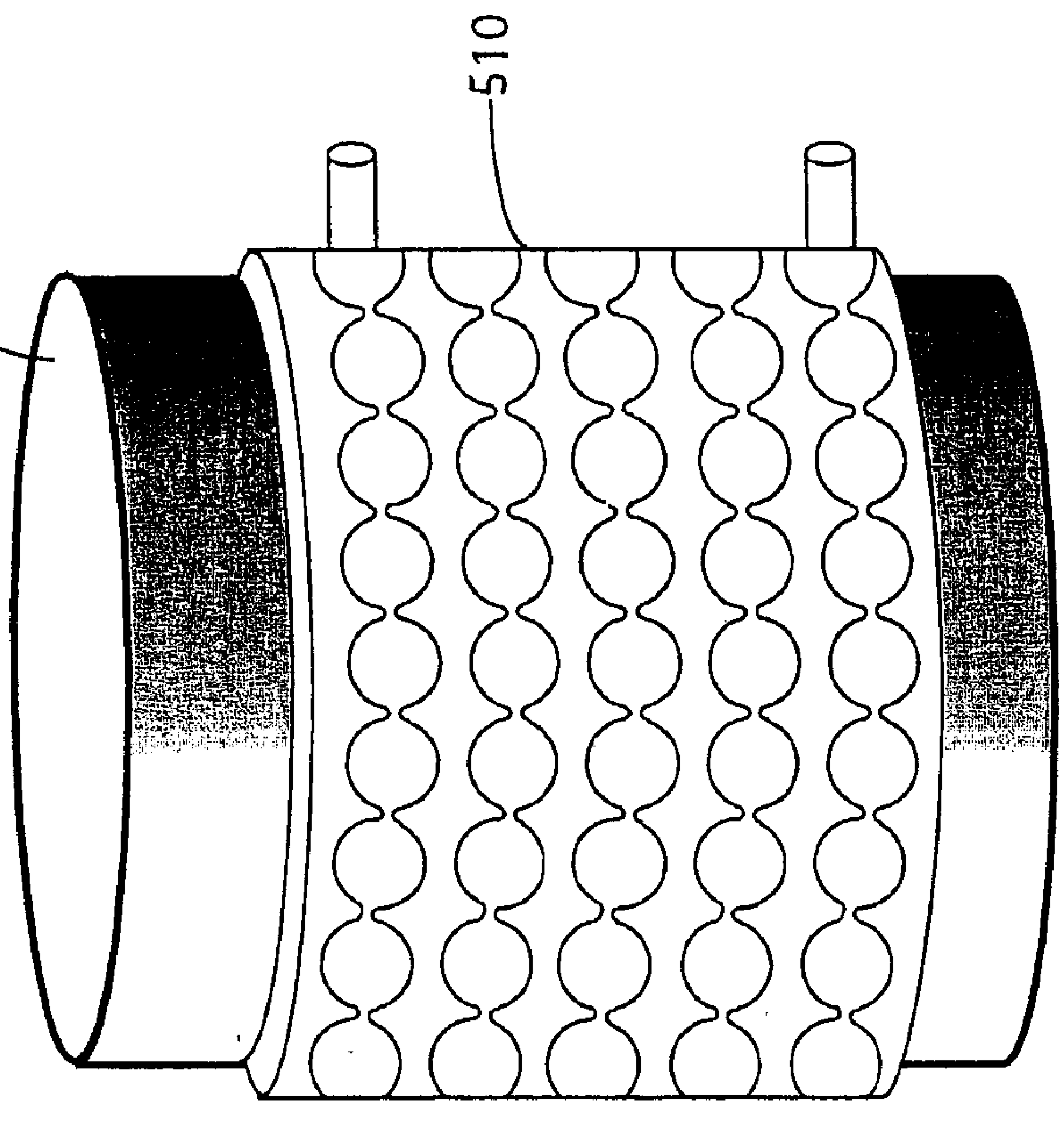


Figure 38 A

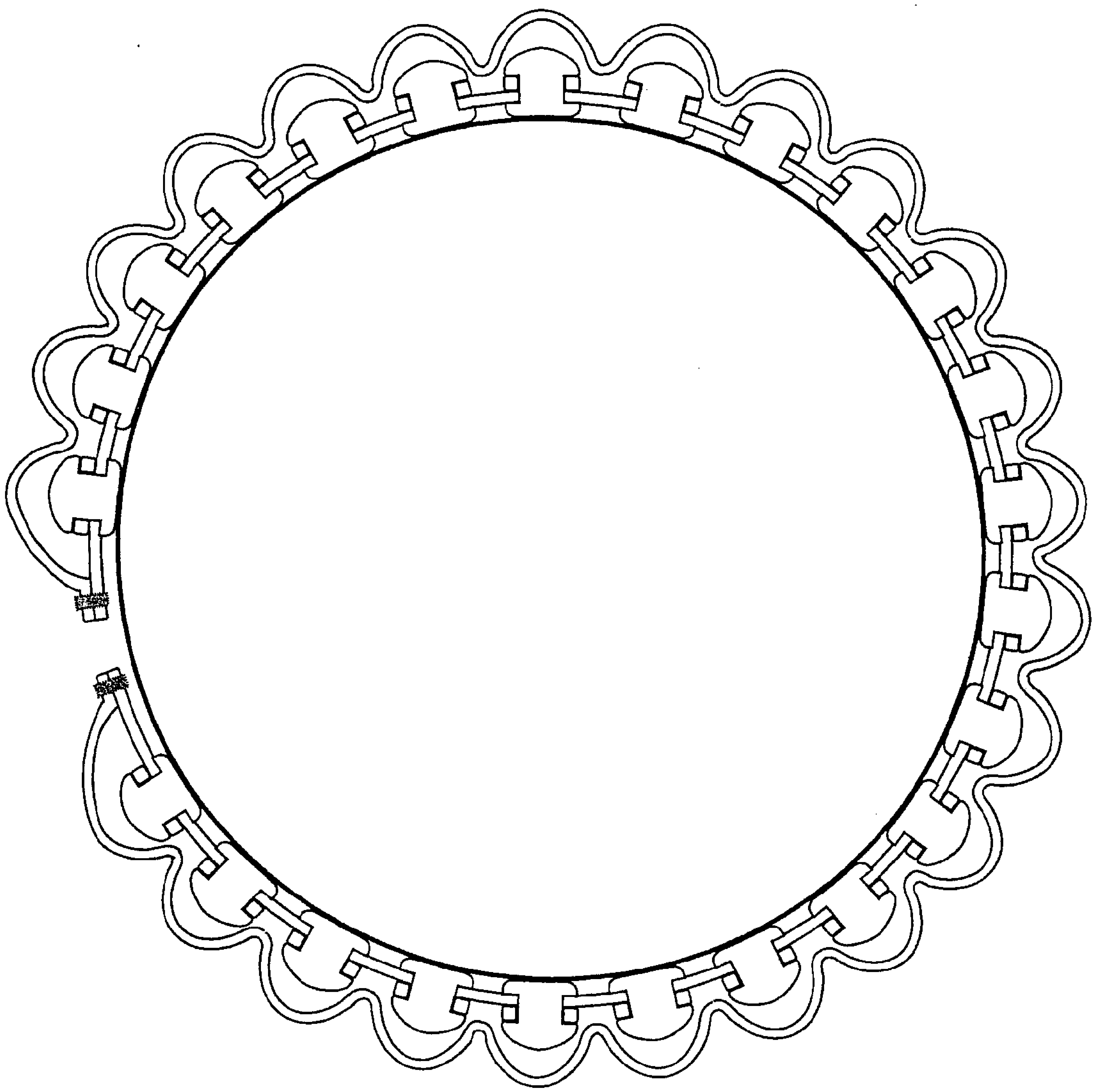


Figure 38C

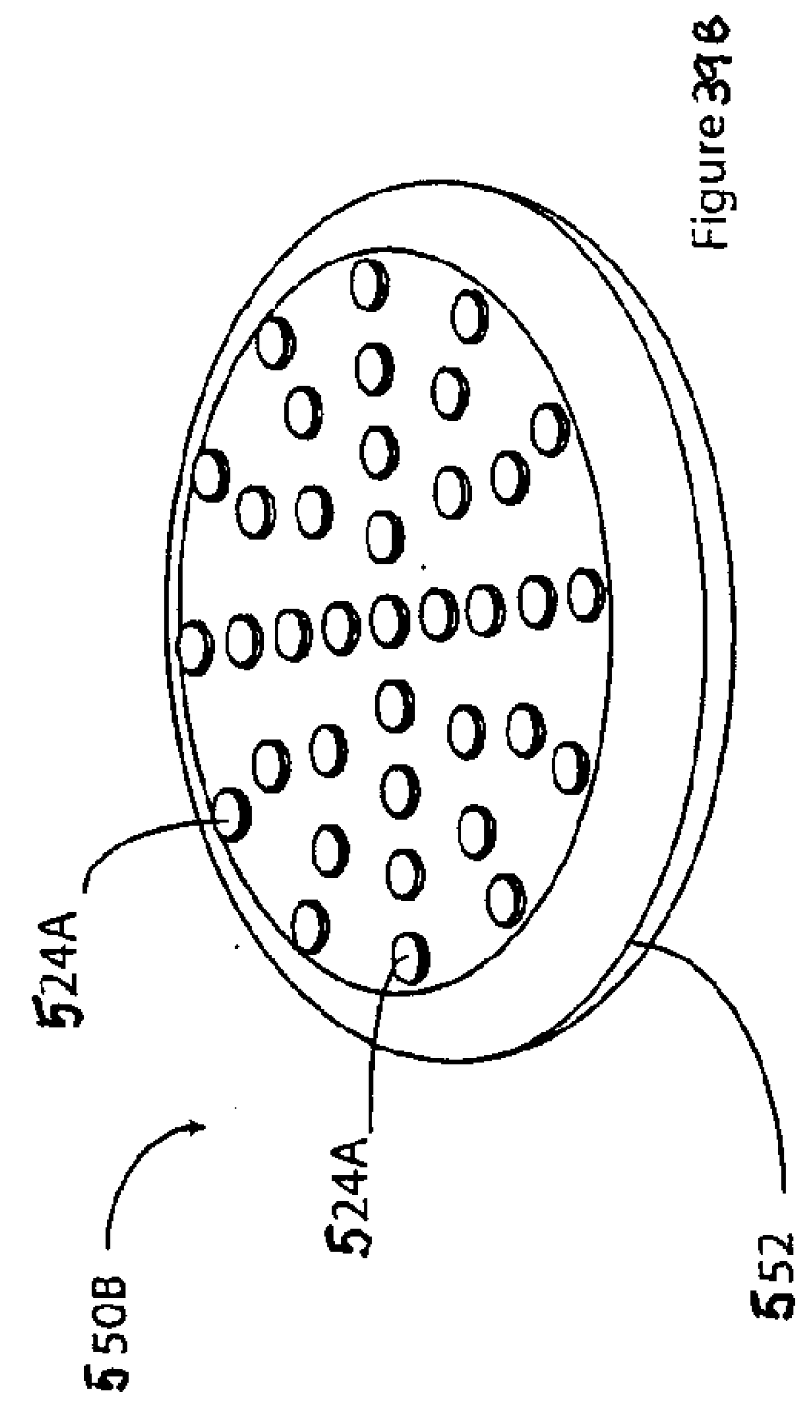


Figure 39B

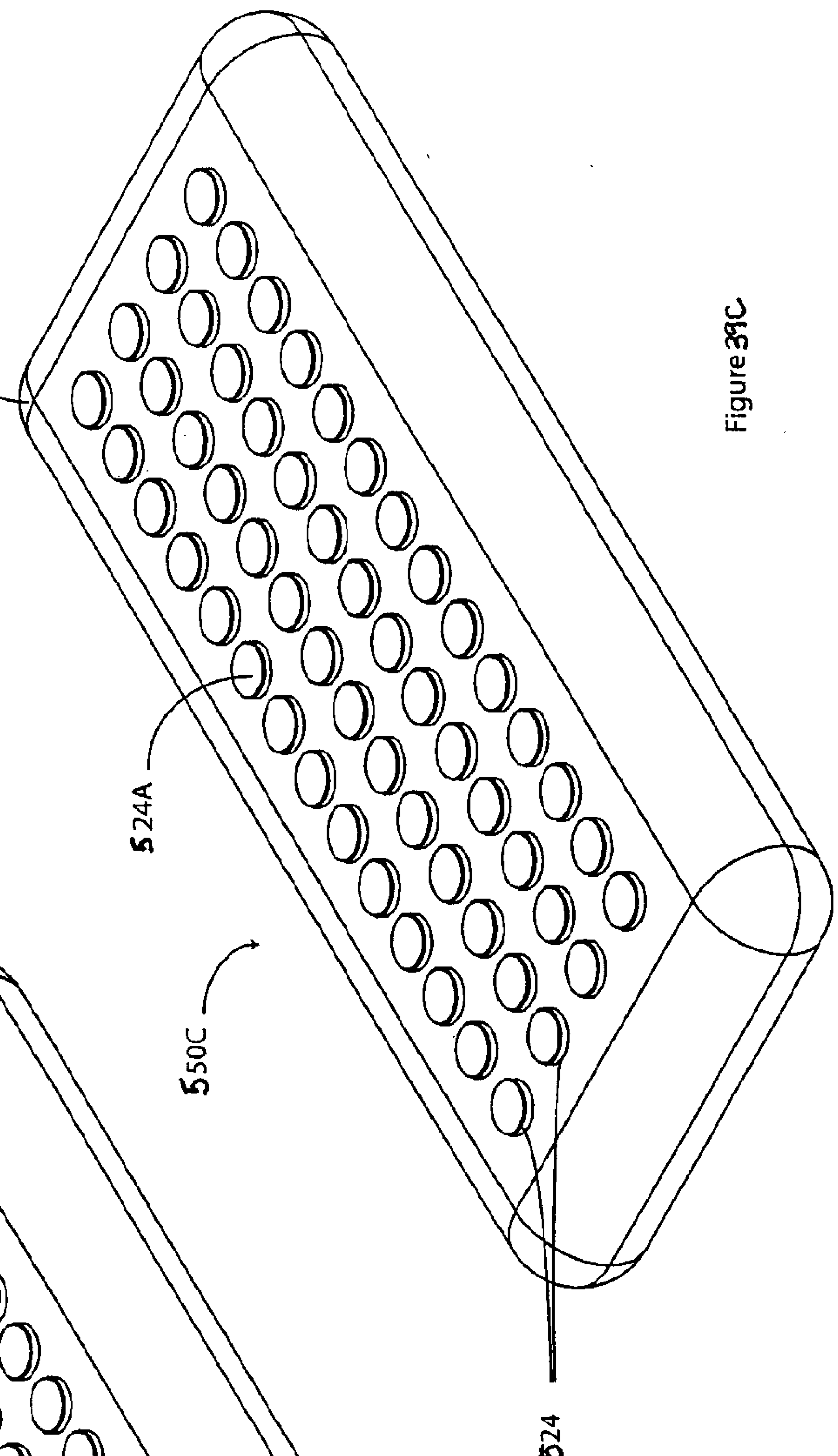


Figure 39C

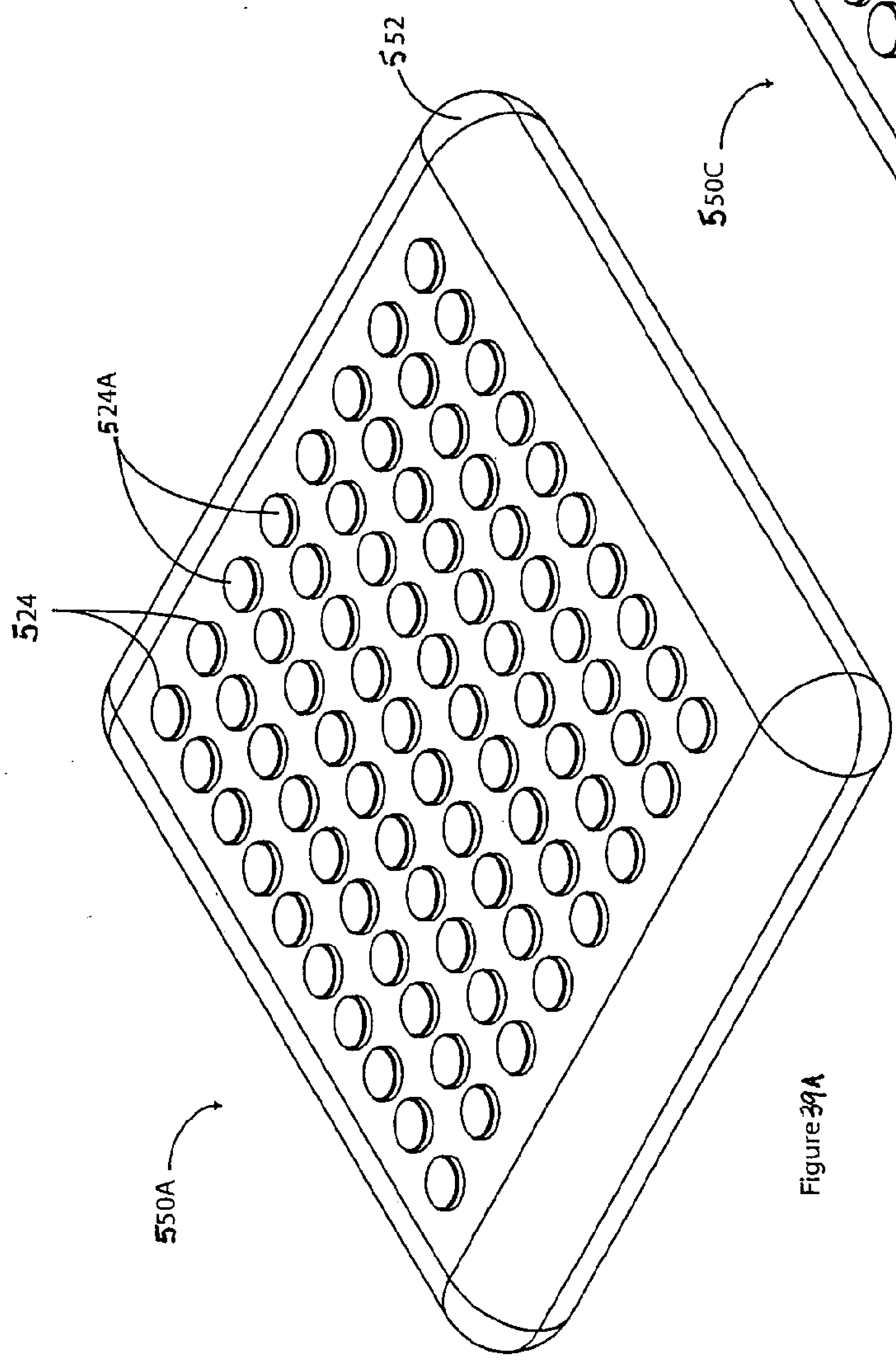


Figure 39A

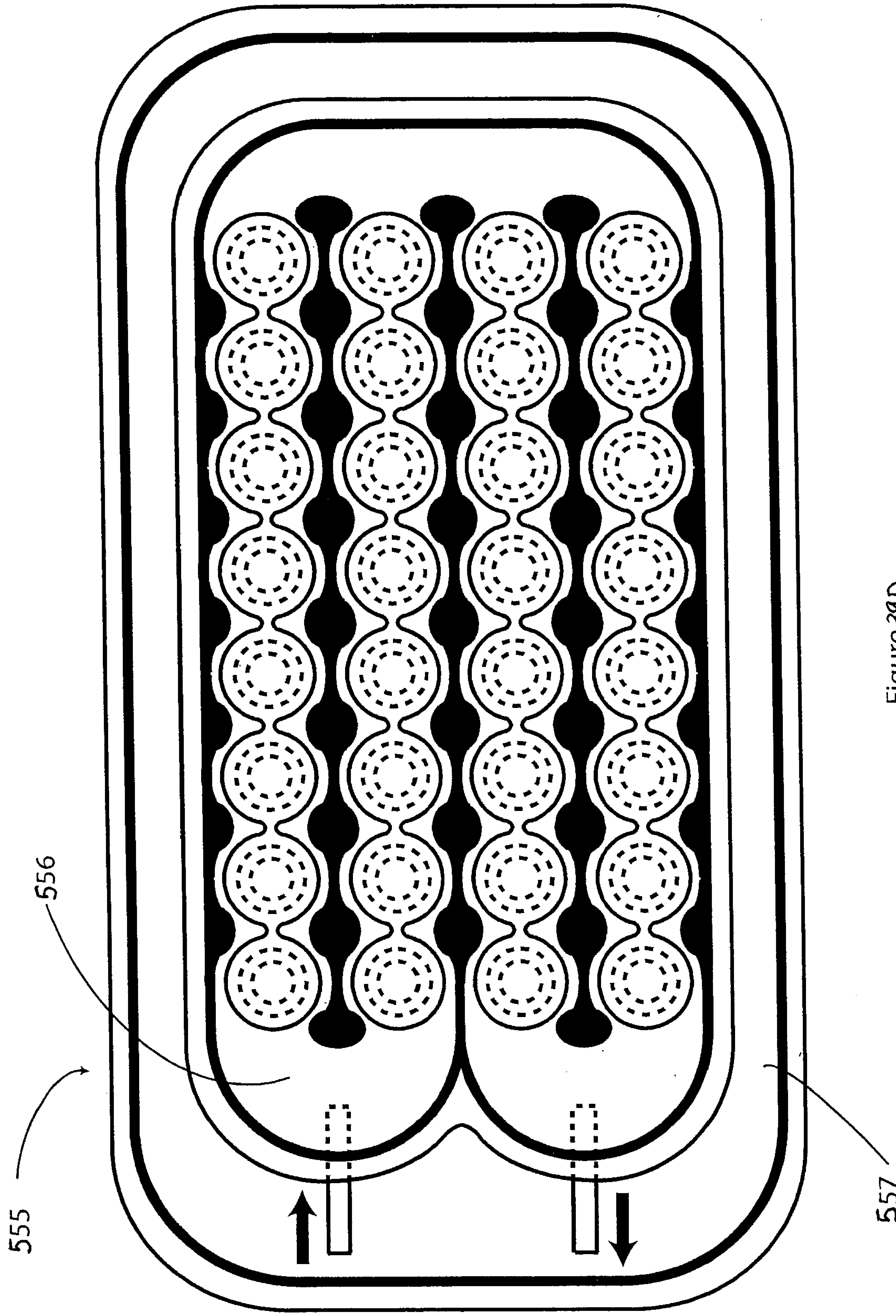


Figure 39D

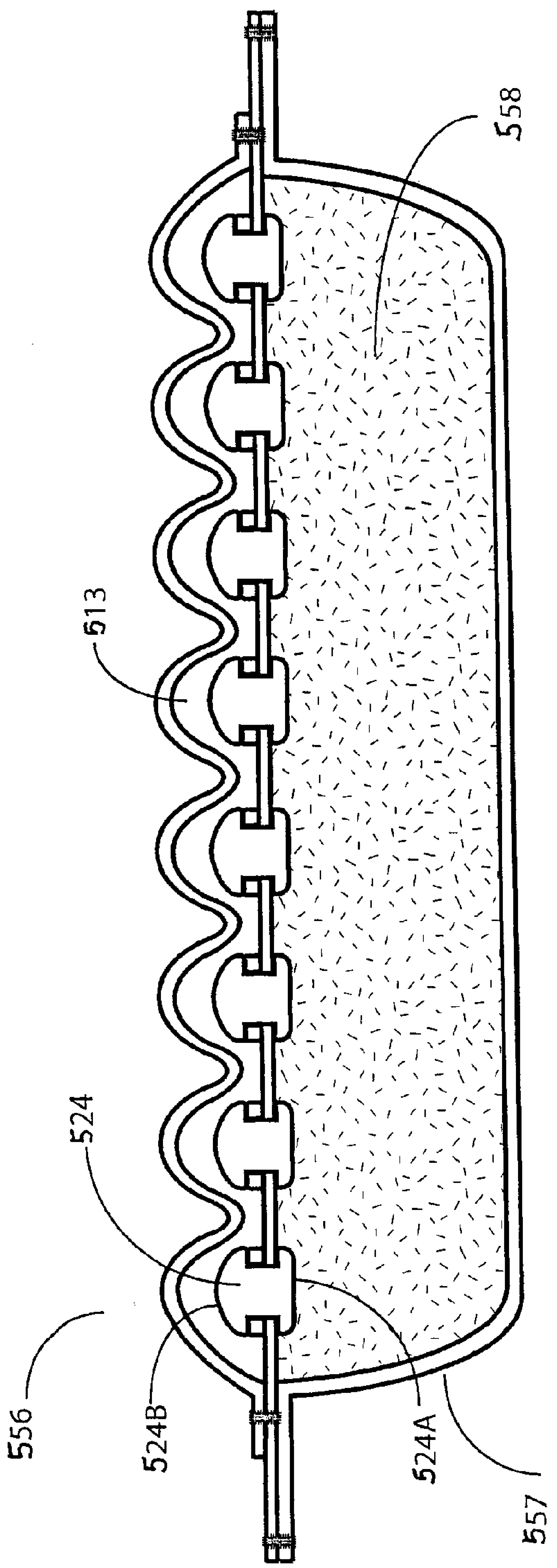


Figure 39E

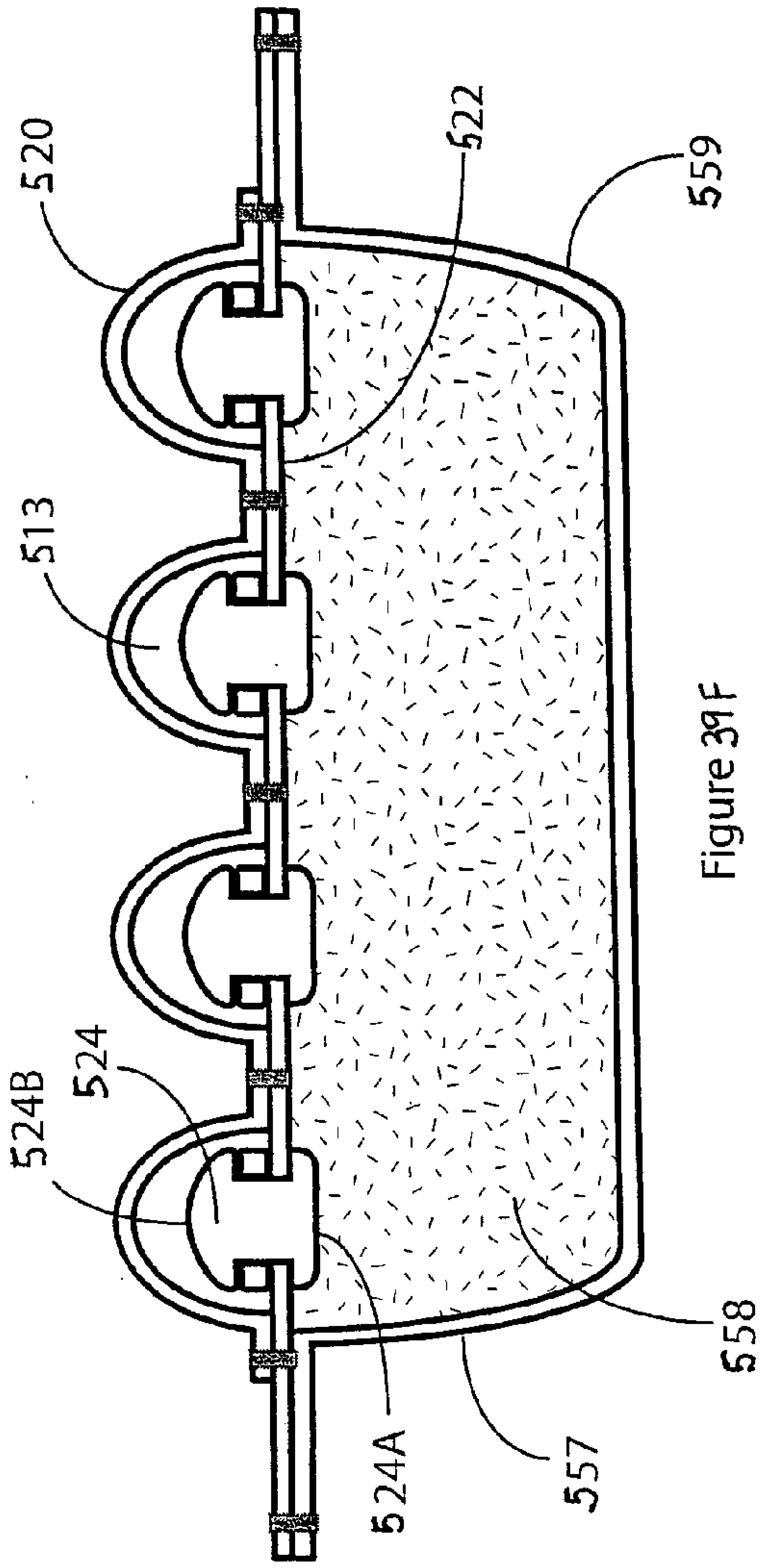


Figure 39F

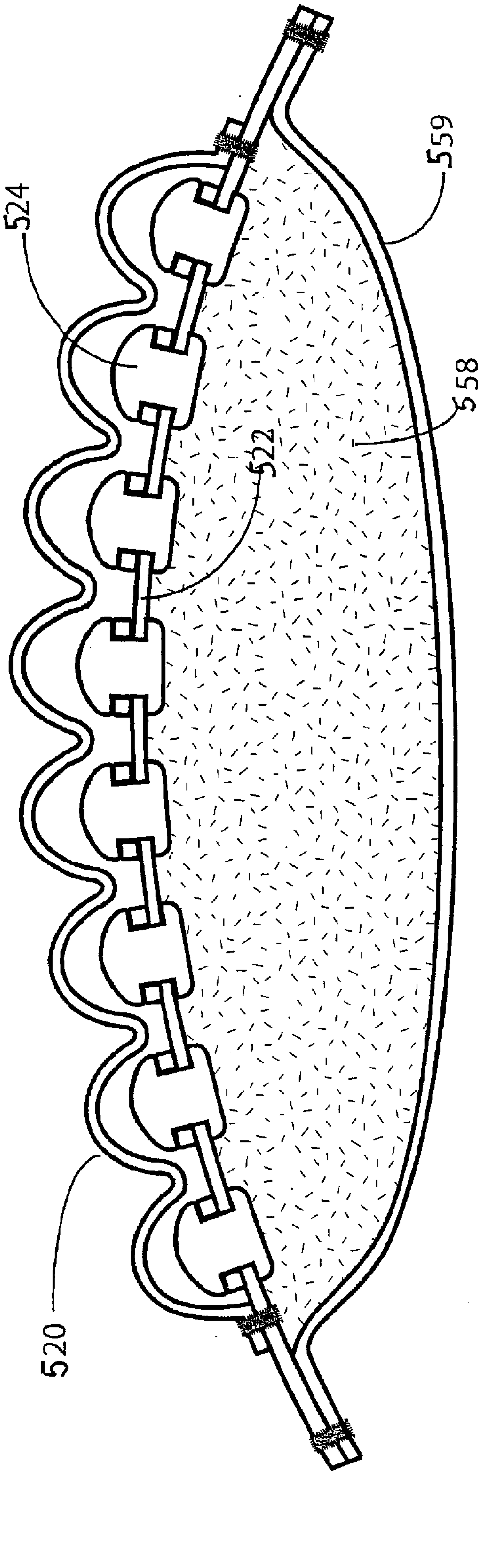


Figure 39G

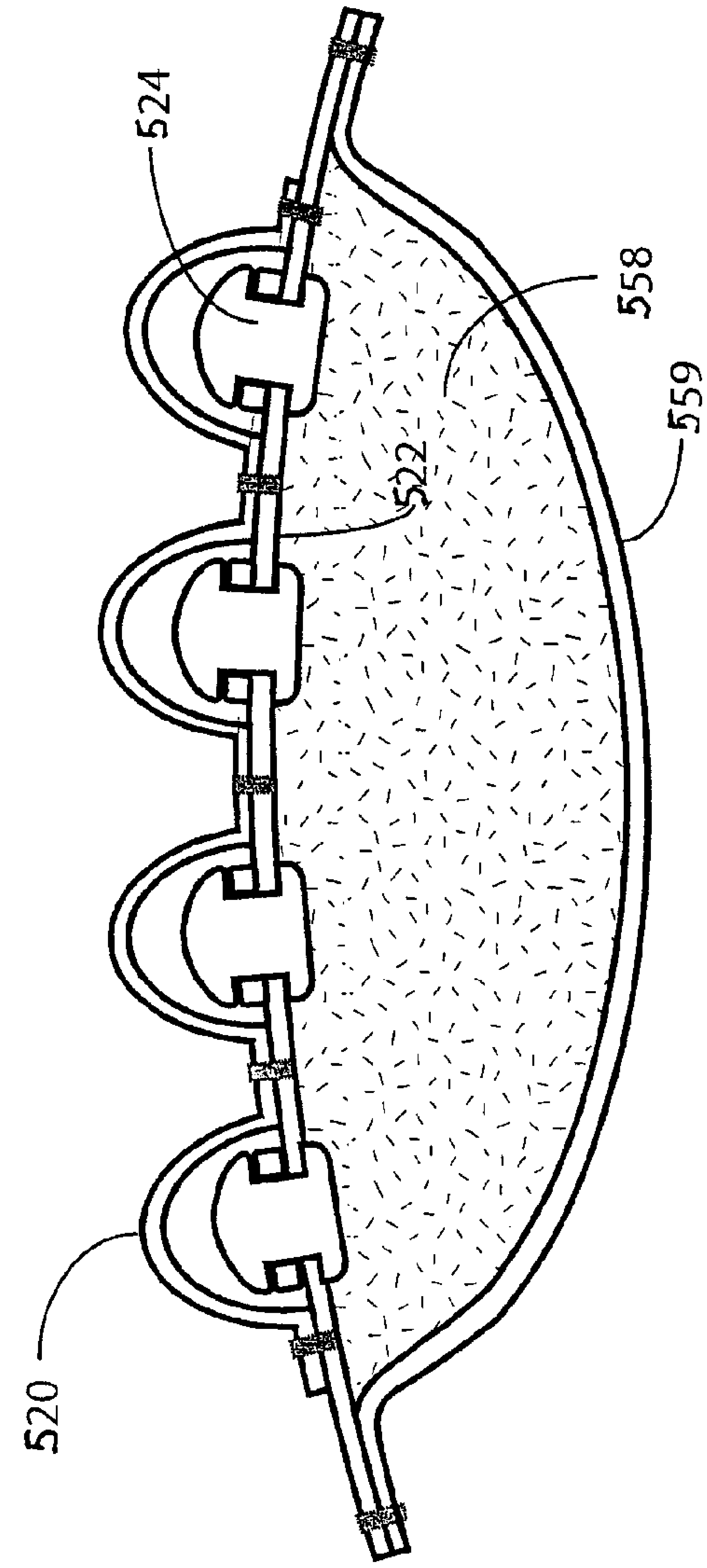


Figure 39H

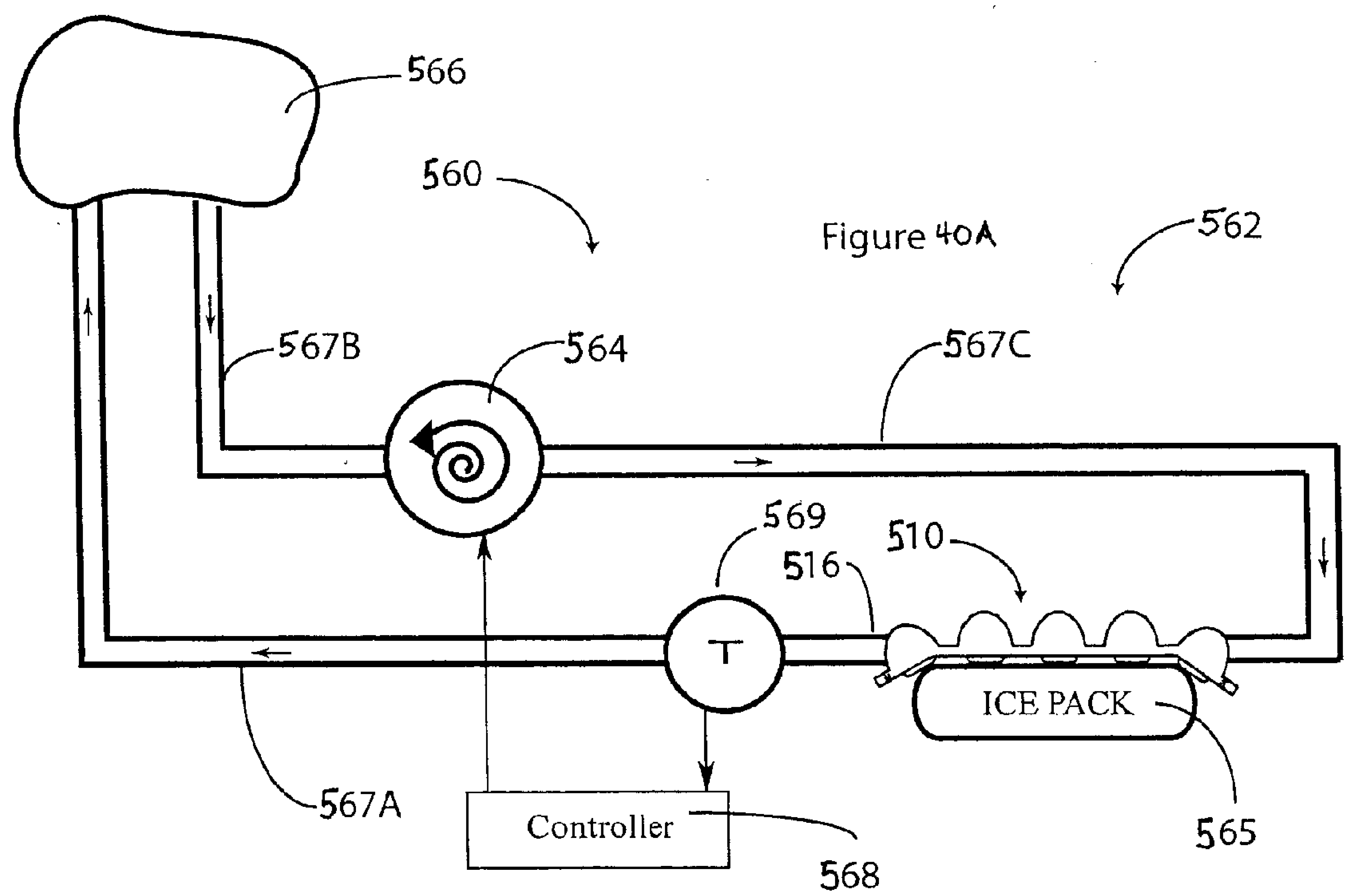


Figure 40A

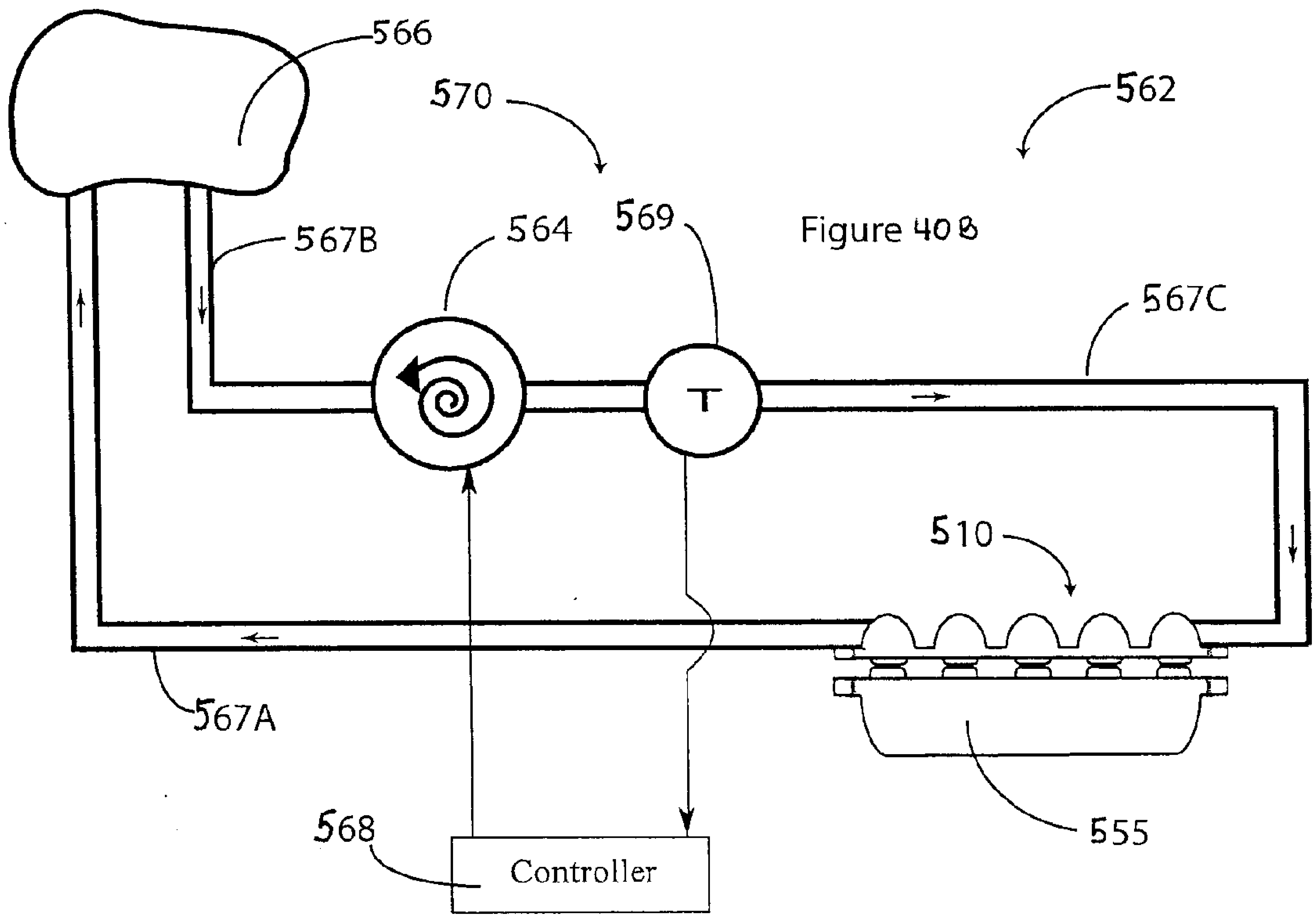


Figure 40B

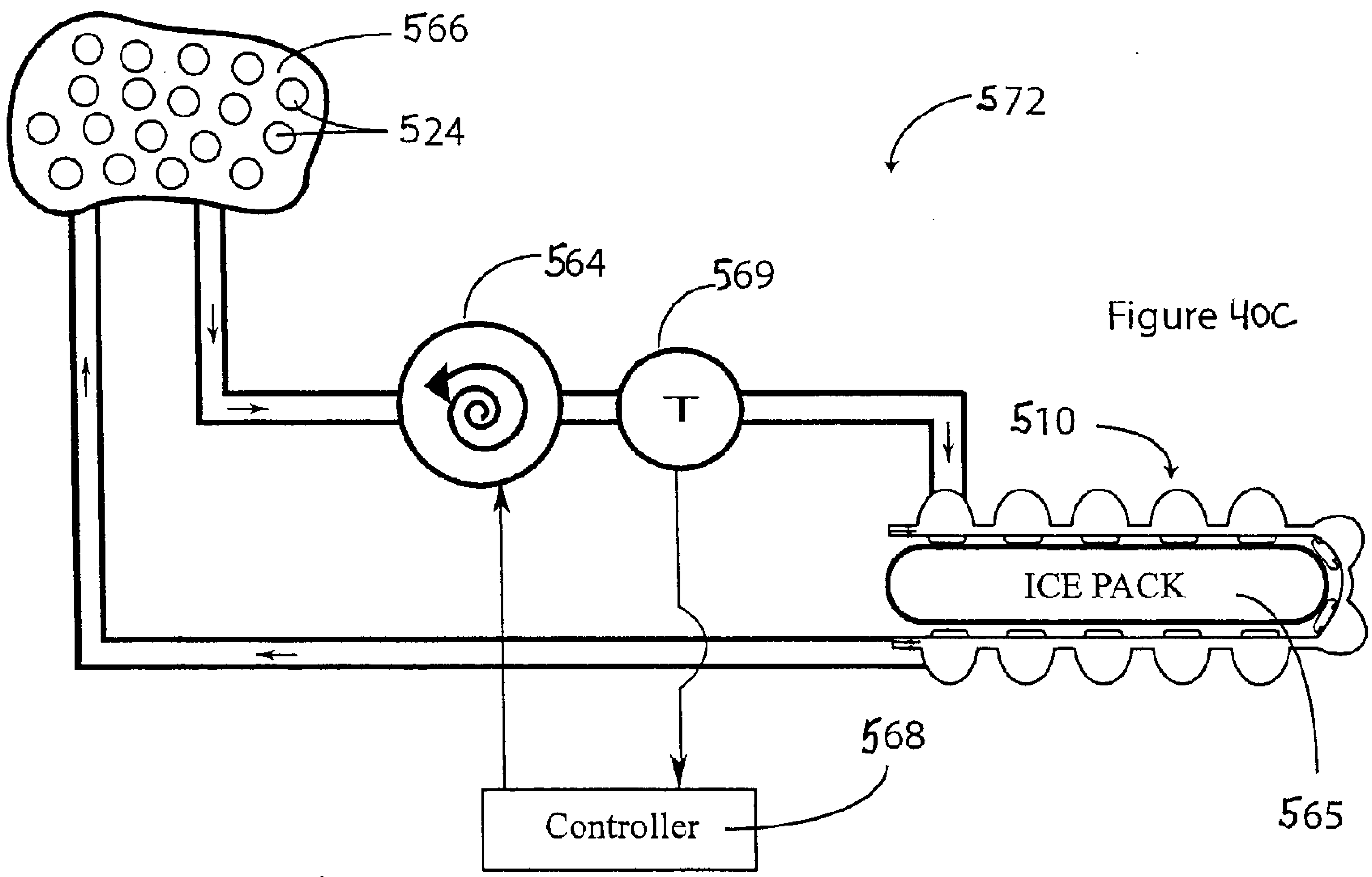


Figure 40C

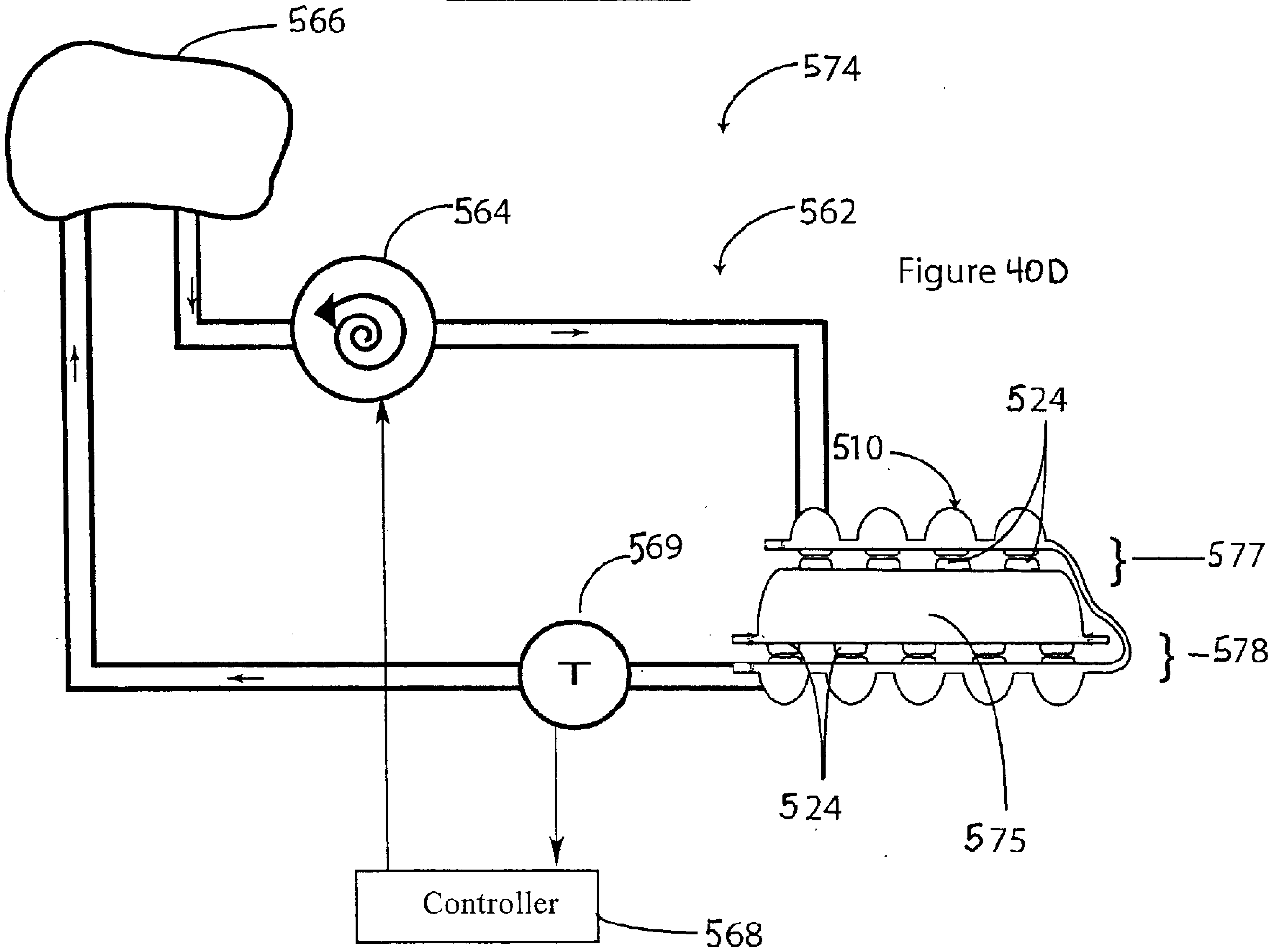


Figure 40D

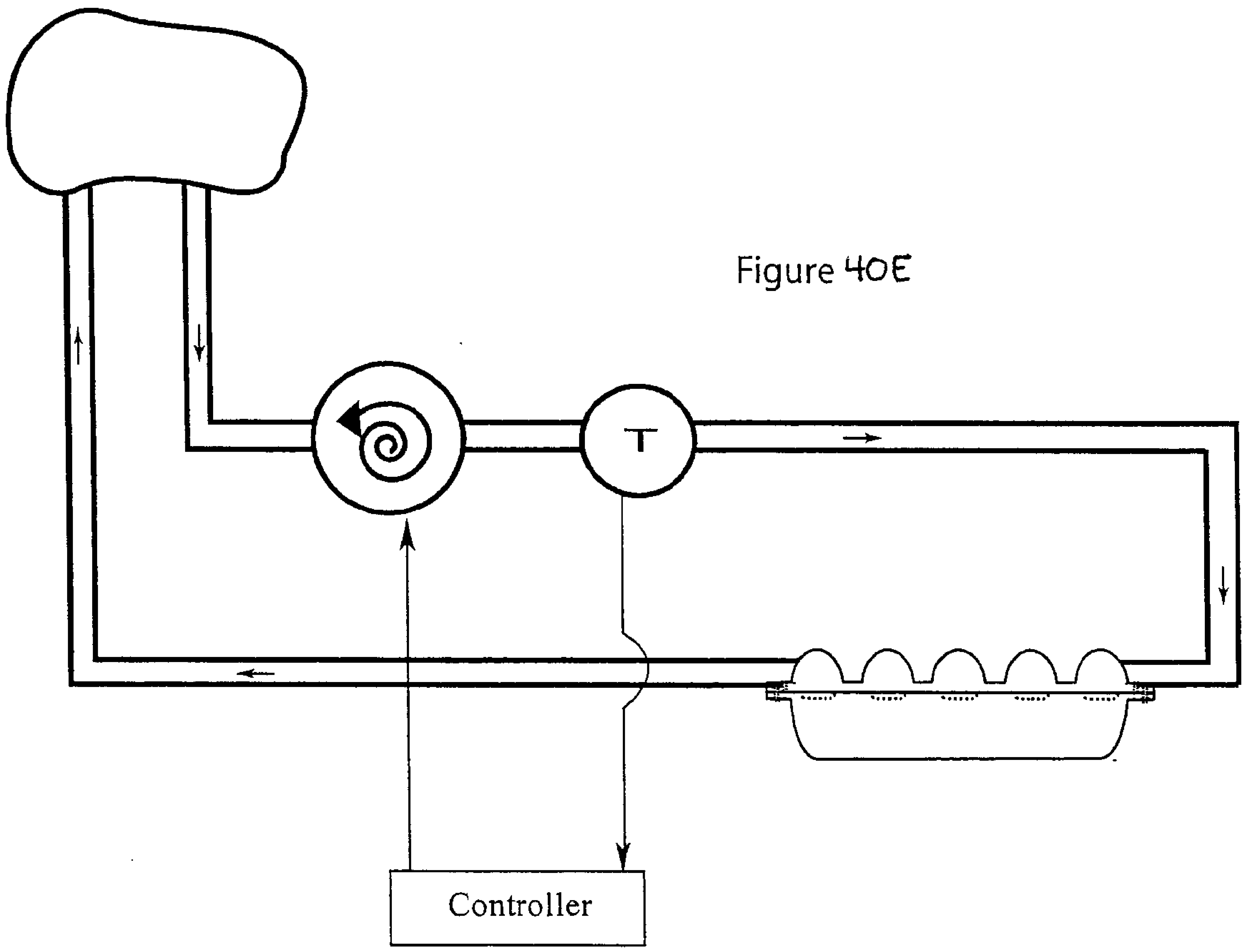


Figure 40E

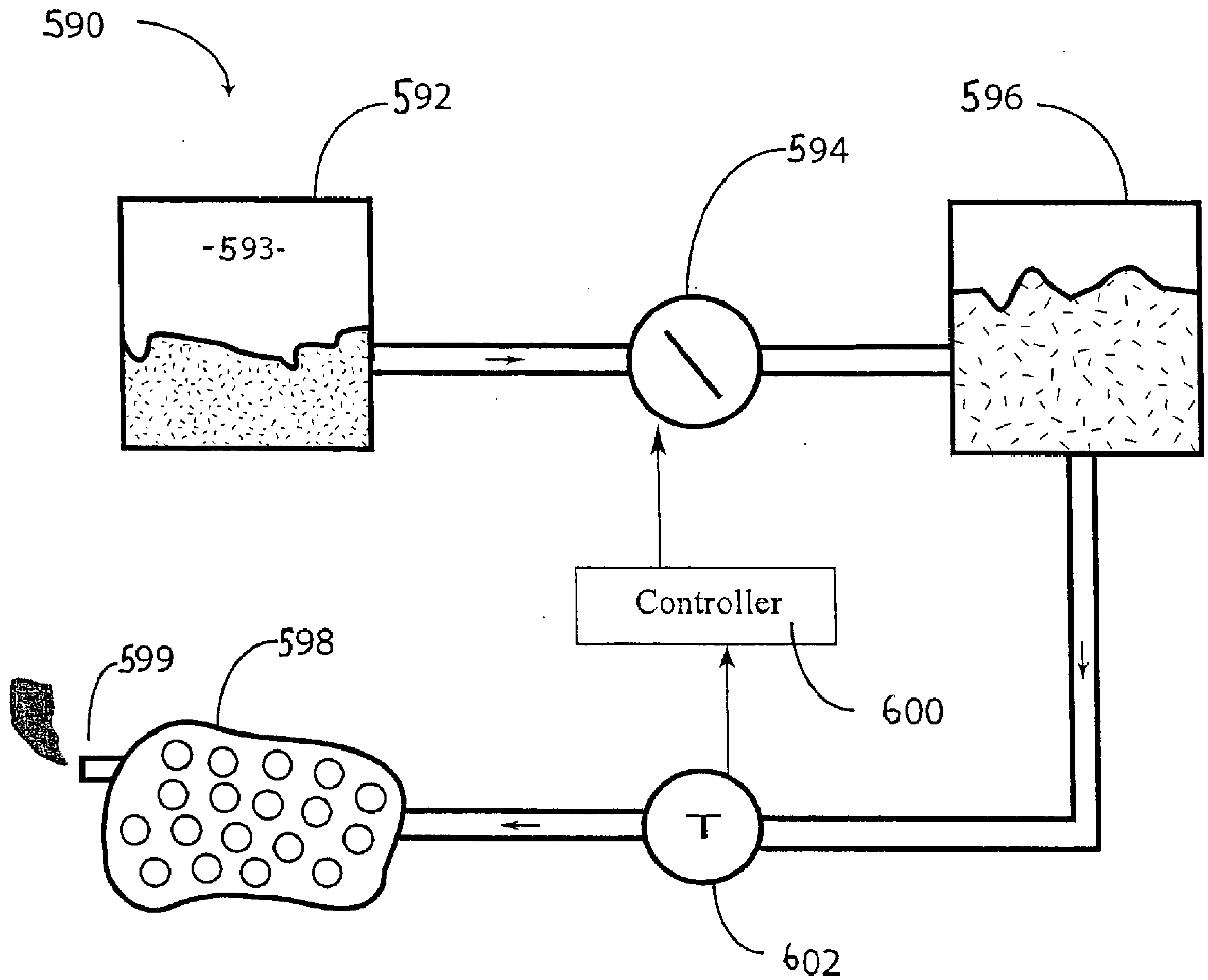
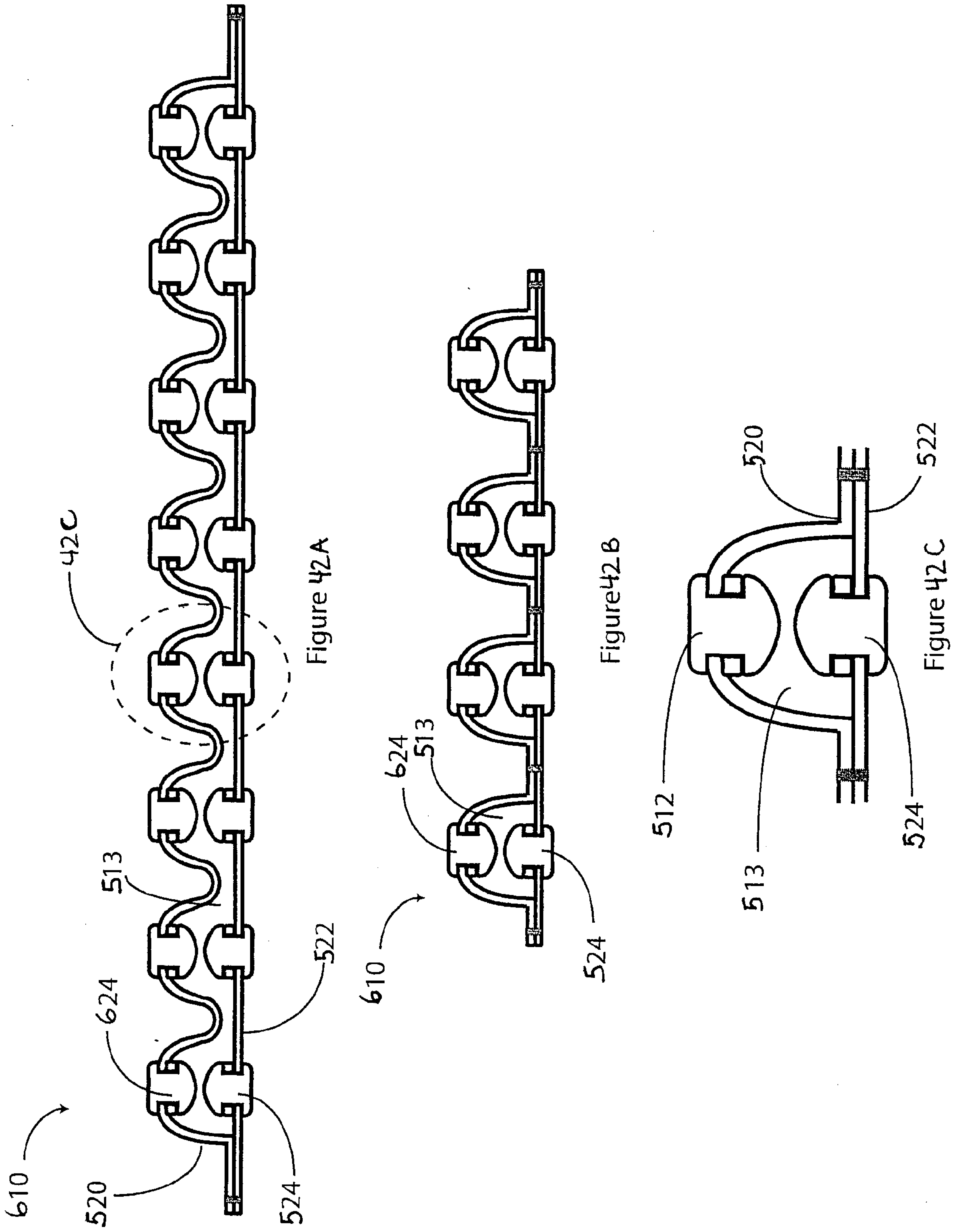


Figure 41


42C
Figure 42A
513
624
522
610
520
524
Figure 42B
624
513
610
524
Figure 42C
520
522
512
513
524

APPARATUS AND METHODS FOR WARMING AND COOLING BODIES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of PCT patent application No. PCT/CA2004/001660 filed on 22 Sep. 2004 which is a continuation-in-part of U.S. application Ser. No. 10/665,073 filed on 22 Sep., 2003 and entitled FLEXIBLE HEAT EXCHANGERS FOR MEDICAL COOLING AND WARMING APPLICATIONS, Ser. No. 10/665,074 filed on 22 Sep., 2003 and entitled FLEXIBLE HEAT EXCHANGERS pursuant to 35 U.S.C. § 120. PCT patent application No. PCT/CA2004/001660 also claims the benefit of U.S. patent application 60/565,517 filed on 27 Apr. 2004 and entitled FLEXIBLE HEAT EXCHANGERS, 60/565,537 filed on 27 Apr. 2004 and entitled FLEXIBLE HEAT EXCHANGERS FOR MEDICAL COOLING AND WARMING APPLICATIONS, and 60/580,356 filed on 18 Jun. 2004 and entitled METHOD AND APPARATUS FOR AFFIXING THROUGH MEMBER IN MEMBRANE, all of which are hereby incorporated by reference herein. This application claims the benefit of U.S. application No. 60/663,267 filed on 21 Mar. 2005 pursuant to 35 U.S.C. § 119.

TECHNICAL FIELD

[0002] The invention relates to heat exchangers. The invention has particular application to heat exchangers for use in warming or cooling living subjects. The invention may be applied to cooling the brains or other body parts of living subjects. The apparatus and methods generally provide a heat exchange fluid, which is a liquid in some embodiments and a gas in other embodiments, that passes through a heat exchanger to exchange heat with a body to be warmed or cooled.

BACKGROUND

[0003] It has been discovered that quickly inducing hypothermia can significantly improve the recovery prospects of patients who suffer global ischemic brain injury secondary to cardiac arrest and probably focal ischemic brain injury from thrombotic or embolic causes. The latter is referred to as an ischemic stroke. Some trials have placed global and focal ischemic brain damaged victims in whole-body cooling chambers or devices. Intra vascular devices are used for whole body cooling and, secondarily, brain cooling. Such chambers or devices are unwieldy and can be intimidating for the patient. Fletcher, U.S. Pat. No. 6,511,502 discloses methods for cooling a subject's brain by applying heat exchangers to the neck of the subject adjacent the subject's carotid arteries. The heat exchangers cool blood flowing to the subject's brain.

[0004] In various other areas of medicine it is desirable to cool or warm body parts. For example, U.S. Pat. Nos. 4,138,743; 5,916,242; 4,566,455; 4,750,493; 4,763,866; 4,020,963; 5,190,032; 5,486,204; 5,643,336; 5,897,581; 5,913,855; 5,057,964; and 6,030,412 relate to cooling or warming body.

[0005] Various types of heat exchanger exist. Air cooled heat sinks are structures which take heat from an object and dissipate the heat into ambient air. Such heat sinks typically consist of a finned piece of thermally-conductive material having a face which can be placed in thermal contact with an object, such as an electronic component, to be cooled. Some heat sinks are equipped with fans located to flow air past the fins to improve the rate at which heat is dissipated.

[0006] U.S. Pat. No. 6,549,411 B1 discloses a flexible heat sink that can be attached to a generally flat surface of an object. The heat sink can flex to conform to the surface of the object to achieve improved contact with the object, and hence increase the efficiency of heat transfer between the heat sink and the object. U.S. Pat. No. 6,367,541 B2 discloses a heat sink that can be attached to multiple electronic chips which have different heights. The heat sink dissipates heat from the chips into ambient air. The devices disclosed in these patents are not suitable for heating or cooling living subjects.

[0007] U.S. Pat. No. 5,368,093 discloses a flexible bag filled with thermal transfer fluid useful for thawing frozen foods. U.S. Pat. No. 4,910,978 discloses a flexible pack containing a gel. The pack can be cooled and applied to a patient for cold therapy. The pack conforms to surface contours of the patient's body. These devices have limited cooling capacities.

[0008] More sophisticated heat exchangers use a heat exchange fluid such as a cooling or heating liquid instead of ambient air to carry heat away from or provide heat to an object to be cooled or heated. Golden, U.S. Pat. No. 4,864,176 discloses a thermal bandage. The bandage includes a conforming member adapted to be placed against the skin. A thermal pack includes a chamber through which fluid can be circulated. The thermal pack is separated from the conforming member by a thermally-conductive surface. U.S. Pat. No. 5,757,615 discloses a flexible heat exchanger with circulating water as coolant for cooling a notebook computer. U.S. Pat. No. 5,643,336 discloses a flexible heating or cooling pad with circulating fluid for therapeutically treating the orbital, frontal, nasal and peri-oral regions of a patient's head. U.S. Pat. No. 6,551,347 B1 discloses a flexible heat exchange structure having fluid-conducting channels formed between two layers of flexible material for heat/cold and pressure therapy. U.S. Pat. Nos. 6,197,045 B1 and 6,375,674 B1 disclose a flexible medical pad with an adhesive surface for adhering the pad to the skin of a patient. U.S. Pat. No. 6,030,412 discloses a flexible enveloping member for enveloping a head, neck, and upper back of a mammal for cooling the brain of the mammal suffering a brain injury. All of these heat exchangers require heat to pass through a layer of some flexible material such as rubber, a thermoplastic, or a flexible plastic such as polyurethane. In addition, heat is exchanged between the surface of the flexible material and circulating fluid. Water is the most commonly used circulating fluid.

[0009] Rubber and flexible plastics are poor conductors of heat. To provide a high heat transfer efficiency in a flexible heat exchanger in which heat is transferred across a layer of rubber or plastic the layer must be very thin. This makes such heat exchangers prone to damage. In addition, water is a poor heat conductor. Heat exchange between the flexible material and water is largely dependent on convection. Water flowing over a relatively flat surface will often not result in efficient heat exchange.

[0010] U.S. Pat. No. 3,825,063 discloses a heat exchanger having metal screens of fine mesh with internal plastic barriers that at least partly penetrate the screens. The screens are stacked to provide transverse heat conduction relative to longitudinal flow paths. U.S. Pat. No. 4,403,653 discloses a heat transfer panel comprising a woven wire mesh core embedded in a layer of plastic material. The mesh and closure layer extend in the same longitudinal direction. U.S. Pat. No. 5,660,917 discloses a sheet with electrically insulating thermal conductors embedded in it. The apparatus disclosed in those patents is not adapted for warming or cooling living subjects.

[0011] There remains a need for heat exchangers suitable for warming or cooling living subjects via the surface of the subjects' skin. There is a particular need for such heat exchangers that provide a high ratio of heat-transfer capacity to skin contact area. There is also a need for heat exchangers which can be used in practising the methods described in Fletcher, U.S. Pat. No. 6,511,502 and which avoid at least some disadvantages of prior heat exchangers. In some fields there remains a need for heat exchangers capable of providing high heat transfer rates between the heat exchangers and objects that are not flat, are vibrating or are otherwise difficult to interface to. There is a particular need for such heat exchangers which have high ratio of heat-transfer capacity to contact area.

SUMMARY OF THE INVENTION

[0012] The invention relates to heat exchangers and has many aspects which may be combined or, in some cases, exploited individually. One aspect of the invention provides a flexible heat exchanger comprising a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet and a flexible sheet essentially impermeable to the heat exchange fluid. The sheet carries a plurality of substantially-rigid members. Each of the members comprises an exposed thermally-conductive surface on a thermally-conductive first body on an outside of the sheet and having a thermally-conductive portion extending from the thermally-conductive first body, through the sheet, and into the volume. Each of the plurality of members comprising opposed gripping surfaces held firmly against opposed sides of the sheet.

[0013] Another aspect of the invention provides a flexible heat exchanger comprising a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet. The volume has a flexible wall essentially impermeable to the heat exchange fluid. The wall carries a plurality of substantially-rigid members. Each of the members comprising a thermally-conductive surface on an outside of the wall and has a thermally-conductive portion extending from the thermally-conductive surface, through the wall and into the volume. The thermally-conducting surface is supported at a location spaced outwardly apart from an outside surface of the wall.

[0014] Another aspect of the invention provides a flexible heat exchange surface for use in a heat exchanger. The flexible heat exchange surface comprises a flexible sheet essentially impermeable to the heat exchange fluid. The sheet carries a plurality of substantially-rigid members sealed to the sheet. Each of the members comprises first and second thermally-conductive bodies exposed on first and second sides of the sheet. The first and second thermally-conductive bodies are connected by a narrowed thermally-conductive portion having a cross sectional area smaller than a cross sectional area of either of the first and second bodies. The thermally-conductive portion extends through an aperture in the sheet.

[0015] Another aspect of the invention provides a flexible heat exchanger comprising a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet. The volume has a flexible wall essentially impermeable to the heat exchange fluid. The wall carries a plurality of substantially-rigid members. Each of the members comprises a thermally-conductive surface on an outside of the wall and has a thermally-conductive portion extending from the pad, through the wall and into the volume. The thermally-conducting surface is either flush with or projects outwardly from an outside surface of the wall.

[0016] Another aspect of the invention provides a method for making a heat exchange surface for use in a heat exchanger. The method comprises providing a sheet, the sheet being essentially impervious to a heat exchange fluid to be used in the heat exchanger; inserting thermally-conductive members through the sheet; and, deforming at least one end of each of the thermally-conductive members to cause the thermally-conductive member to sealingly engage the sheet.

[0017] Another aspect of the invention provides a method for cooling or warming a plurality of thermally-conductive heat exchange surfaces suitable for placement against the skin of a living subject to cool or warm the living subject. The method comprises: establishing a turbulent flow of a heat exchange fluid through a volume; allowing the heat exchange fluid to contact and exchange heat with a plurality of thermally-conductive members projecting into the volume through a flexible wall of the volume, the thermally-conductive members each in direct thermal contact with at least one of the heat exchange surfaces by way of an unbroken path of a material or materials having a thermal conductivity of at least 50 $Wm^{-1}K^{-1}$; and, allowing heat to flow between the heat exchange surfaces and the thermally-conductive members along the paths.

[0018] Another aspect of the invention provides a flexible heat exchanger for warming or cooling a living subject. The heat exchanger comprises a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet; and, a flexible heat exchange plate essentially impermeable to the heat exchange fluid, the plate comprising a plurality of substantially rigid thermally-conductive members extending through a flexible material of the plate from an outside surface of the plate into the volume, the thermally-conductive members each projecting into a volume by a distance of at least 2 mm.

[0019] Another aspect of the invention provides a flexible heat exchanger comprising a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet; and, a flexible plate essentially impermeable to the heat exchange fluid. The plate comprises an array of closely-spaced apart substantially rigid metal thermally-conductive members extending through a flexible material of the plate, substantially at right angles to inner and outer surfaces of the plate, from an outside surface of the plate into the volume wherein a total area of the thermally-conductive members exposed on the outer surface of the plate exceeds a total cross sectional area of the thermally-conductive members at a point where the cross sectional members are extending through the flexible material.

[0020] Another aspect of the invention provides apparatus for warming or cooling a living subject, the apparatus comprising a plurality of heat exchangers and a mechanism for independently regulating a supply of cooling or warming fluid circulated through each of the heat exchangers. One aspect of the invention provides a flexible heat exchanger for warming or cooling a living subject. The heat exchanger comprises a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet. A heat exchange fluid may be circulated through the volume. The heat exchanger comprises a flexible heat exchange plate essentially impermeable to the heat exchange fluid. The plate comprises a flexible fluid-impervious membrane supporting a plurality of substantially rigid thermally-conductive members. The thermally-conductive members extend through the membrane from an outside surface of the plate into the volume. Each of the thermally-conductive members comprises a body, a portion extending through the membrane from the body and a retainer member on a side of the membrane opposite to the body. The membrane is gripped between the body and the retainer member.

[0021] Another aspect of the invention provides a flexible heat exchanger. The heat exchanger comprises a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet. A heat exchange fluid, for example, water, can flow through the volume. A flexible heat exchange plate essentially impermeable to the heat exchange fluid has a plurality of substantially rigid thermally-conductive members. The thermally-conductive members extend through a flexible material of the plate from an outside surface of the plate into the volume. The thermally-conductive members conduct heat between a subject and the heat exchange fluid.

[0022] Another aspect of the invention provides systems for heating or cooling a subject. The systems have a reservoir holding heat exchange fluid and a pair of feed pumps. One feed pump is connected to deliver the heat exchange fluid to a heat exchanger. Another feed pump is connected to withdraw the heat exchange fluid from the heat exchanger. The rate at which the heat exchange fluid is introduced into the heat exchanger by the first feed pump is balanced with the rate at which fluid is withdrawn from the heat exchanger by the second feed pump to maintain a pressure within a volume in the heat exchanger within a desired range of an ambient pressure.

[0023] One aspect of the invention provides a flexible heat exchanger. The heat exchanger comprises a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet. A heat exchange fluid may be circulated through the volume. The heat exchanger comprises a flexible heat exchange plate essentially impermeable to the heat exchange fluid. The plate comprises a flexible fluid-impervious membrane supporting a plurality of substantially rigid thermally-conductive members. The thermally-conductive members extend through the membrane from an outside surface of the plate into the volume. Each of the thermally-conductive members comprises a body, a portion extending through the membrane from the body and a retainer member on a side of the membrane opposite to the body. The membrane is gripped between the body and the retainer member.

[0024] Another aspect of the invention provides a flexible heat exchanger. The heat exchanger comprises a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet. A heat exchange fluid, for example, water, can flow through the volume. A flexible heat exchange plate essentially impermeable to the heat exchange fluid has a plurality of substantially rigid thermally-conductive members. The thermally-conductive members extend through a flexible material of the plate from an outside surface of the plate into the volume. The thermally-conductive members conduct heat between a subject and the heat exchange fluid.

[0025] Another aspect of the invention provides systems for heating or cooling an object. The systems have a reservoir holding heat exchange fluid and a pair of feed pumps. One feed pump is connected to deliver the heat exchange fluid to a heat exchanger. Another feed pump is connected to withdraw the heat exchange fluid from the heat exchanger. The rate at which the heat exchange fluid is introduced into the heat exchanger by the first feed pump is balanced with the rate at which fluid is withdrawn from the heat exchanger by the second feed pump to maintain a pressure within a volume in the heat exchanger within a desired range of an ambient pressure.

[0026] Another aspect of the invention provides a heat exchanger comprising front and rear sheet portions substantially impermeable to a heat exchange fluid. The front sheet portion supports a plurality of substantially rigid thermally-conductive members extending through the front sheet portion and having inner portions projecting into a volume between the front sheet portion and the rear sheet portion. The thermally-conducting members have exposed thermally-conducting surfaces on a front side of the front sheet portion. The rear sheet portion is formed with indentations receiving each of the inner portions of the plurality of thermally-conductive members.

[0027] Other aspects of the invention provides flexible heat exchange interfaces. The interfaces have plates or membranes penetrated by substantially rigid thermally-conductive members. The thermally-conductive members have enlarged pads on at least one side of the plate or membrane. The flexible material allows the interfaces to flex while the thermally-conductive members are operative to channel heat from a higher-temperature side of the interface to a lower-temperature side of the interface.

[0028] Another aspect of the invention provides a flexible heat exchanger comprising a volume having an inlet and an outlet. The volume can receive a heat exchange fluid, for example, water or a water-based coolant. The heat exchanger includes a flexible plate. Substantially rigid thermally-conductive members extend through a flexible material of the flexible plate from an outside surface of the flexible plate into the volume.

[0029] In preferred embodiments the thermally-conductive members each have a thermal conductivity of at least 50 $Wm^{1}K^{1}$ and preferably at least 100 $Wm^{1}K^{1}$. The thermally-conductive elements may be made of materials such as aluminum, copper, gold, silver, alloys of two or more of aluminum, copper, gold, or silver with one another, alloys of one or more of aluminum, copper, gold, or silver with one or more other metals, carbon, graphite, diamond, or sapphire.

[0030] The thermally-conductive members may cover a substantial portion of the outer surface of the flexible heat exchange plate in some embodiments. For example, the thermally-conductive members may be exposed in an area of 30% or 40% or more of an area of the flexible heat exchange plate. In some embodiments, at least 50%, at least 70% or even at least 80% of an area of the flexible heat exchange plate is covered by the thermally-conductive members. Because of the very high rate at which heat can be carried through a thermally- conductive member, in some cases a coverage of 20% or even less by the thermally-conductive members is sufficient.

[0031] The flexible material of the plate sheet or membrane may comprise, for example, a suitable grade of polyurethane or other suitable thermoplastic polymer. Examples of other materials that may be suitable for use as the plate of membrane include: styrenic copolymers; suitable grades of: polyvinyl chloride (PVC); polyolefins such as polyethylene or polypropylene; styrenics such as polystyrene; polyesters such as polyethylene terephthalate (PET); polyethers such as polyetheretherketone (PEEK); polyamides (e.g. NYLON™); silicone; cellophane; cellulose acetates; natural or synthetic rubbers; ethylene-vinyl acetate; neoprene; polytetrafluoroethylene (PTFE e.g. TEFLON™); plasticized metallic films; a combination of two or more of these materials; coated or impregnated fabrics; and the like. In some embodiments the flexible material has a thermal conductivity not exceeding 5 $Wm^{-1}K^{-1}$.

[0032] A further aspect of the invention provides a temperature control system comprising a heat exchanger according to the invention, a reservoir containing a heat exchange fluid; a first feed pump connected to feed heat exchange fluid from the reservoir into the heat exchanger and a second feed pump connected to withdraw the heat exchange fluid from the heat exchanger.

[0033] Further aspects of the invention and features of specific embodiments of the invention are described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] In drawings which illustrate non-limiting embodiments of the invention:

[0035] **FIGS. 1A, 1B** and 1C are respectively a longitudinal elevational cross-section view; a top plan view and a bottom plan view of a flexible heat exchanger configured as a cooling/warming pad for a subject's neck;

[0036] **FIGS. 2A, 2B** and 2C are respectively a cross-section view; a bottom view; and a top view of the flexible heat exchange plate of a heat exchanger according to an alternative embodiment of the invention;

[0037] **FIG. 2D** is a partial view of the outside surface of a heat exchanger having thermally-conductive members arranged in a triangular array;

[0038] **FIG. 2E** is a partial view of the outside surface of a heat exchanger having thermally-conductive members arranged to provide converging lines of flexible material;

[0039] **FIG. 2F** is a view of the outside surface of a heat exchanger having thermally-conductive members arranged in a rectangular array oriented at an angle to a long axis of the heat exchanger;

[0040] **FIGS. 3A, 3B** and 3C are respectively a cross-section view; a bottom view; and a top view of the flexible heat exchange plate of a heat exchanger according to one embodiment of the invention;

[0041] **FIGS. 4A through 4L** are views of different heat conductors that can be used in heat exchangers according to different embodiments of the invention;

[0042] **FIGS. 5A and 5B** are respectively sectional and bottom views of a flexible plate of a heat exchanger according to another embodiment of the invention;

[0043] **FIG. 6** is a section through a heat exchanger according to another embodiment of the invention. **FIGS. 6A, 6B** and **6C** are respectively a cross section in the plane **6A-6A**, a bottom plan view, and a horizontal section through the heat exchanger of **FIG. 6** (with the rear membrane removed);

[0044] **FIGS. 6D**, and **6E** illustrate a heat exchanger in which a pattern of seams provides a U-shaped channel; **FIG. 6F** shows another heat exchanger in which a pattern of seams provides two separate fluid paths through the heat exchanger;

[0045] **FIGS. 7A through 7P** illustrate some alternative constructions for thermally-conductive members;

[0046] **FIG. 8A** illustrates a number of alternative configurations for a pin in a thermally-conductive member; **FIG. 8B** illustrates a number of alternative configurations for a base in a thermally-conductive member; **FIG. 8C** illustrates a number of alternative configurations for a retention member; **FIG. 8D** illustrates a thermally-conductive member having a projecting sealing ring; **FIG. 8E** shows some possible surface configurations for bases of thermally-conductive members; **FIG. 8F** shows a construction which includes a compliant washer;

[0047] **FIGS. 9A through 9F** illustrate some alternative constructions for thermally-conductive members;

[0048] **FIG. 10A** shows a few possible alternative configurations for a pin in a thermally-conductive member; **FIG. 10B** shows a few possible shapes for a pin in a thermally-conductive member; **FIG. 10C** shows a few possible configurations for retainers for thermally-conductive members of the types shown in **FIGS. 10A and 10B**;

[0049] **FIGS. 11A through 11E** illustrate extensions which may be attached to thermally-conductive members to provide enhanced thermal contact with a circulating fluid;

[0050] **FIGS. 12A through 12C** illustrate thermal conduction members according to other alternative embodiments of the invention;

[0051] **FIG. 13** is a cross section through a pin passing through a membrane before the pin is deformed to seal to the membrane;

[0052] **FIG. 13A** is a top plan view of the pin of **FIG. 13**;

[0053] **FIG. 14** is a cross section through the pin of **FIG. 13** while the pin is being deformed and the membrane is being carried into a groove on the pin;

[0054] **FIG. 15** is a cross section through the pin of **FIG. 13** after the pin has been deformed to seal to the membrane;

[0055] **FIG. 15A** is an enlarged view of one of the grooves shown in **FIG. 15**;

[0056] **FIGS. 16A, 16B**, **16**C, **16**D, **16**E and **16**F are detailed views of alternative configurations for the edge of a membrane retention groove;

[0057] **FIG. 17** illustrates a two-part through member according to an alternative embodiment of the invention;

[0058] **FIGS. 18A, 18B** and **15**C are cross sectional views of three through members according to alternative embodiments of the invention;

[0059] **FIGS. 19A, 19B** and **19**C demonstrate the use of a through member according to the invention to join together two or more thin flexible sheets;

[0060] **FIGS. 20A, 20B**, **20**C, **20**D and **20**E show a through member according to an alternative embodiment of the invention; and, **FIG. 21** shows a through member according to another alternative embodiment of the invention.

[0061] **FIGS. 22, 22A** and **22**B illustrate heat exchangers having rear sheets affixed to thermally-conductive members;

[0062] **FIGS. 23A and 23B** illustrate embodiments of the invention in which inner and outer surfaces of a membrane have different characteristics;

[0063] **FIGS. 24, 25**, and **26** are schematic views of cooling systems according to the invention;

[0064] **FIG. 27** shows a heat exchanger adapted for cooling or warming the neck of a subject;

[0065] **FIGS. 28A, 28B** and **28**C show a heat exchanger like that of **FIG. 27** in position on the neck of a subject;

[0066] **FIGS. 29A, 29B** and **29**C illustrate a heat exchanger system comprising a heat exchanger configured to fit a subject's neck and another heat exchanger configured to fit the subject's face;

[0067] **FIGS. 30A, 30B** and **30**C illustrate a heat exchanger system comprising a heat exchanger configured to fit a subject's neck, another heat exchanger configured to fit the subject's face and another heat exchanger configured to fit the subject's scalp;

[0068] **FIG. 31** illustrates a heat exchanger system having heat exchangers for warming or cooling a patient's head, torso and thighs;

[0069] **FIGS. 32A, 32B** and **32**C illustrate various heat exchangers and fluid flow paths of the heat exchanger system of **FIG. 31**;

[0070] **FIGS. 33A, 33B**, **33**C and **33**D are schematic views of heat exchangers according to embodiments of the invention being applied to cooling various objects;

[0071] **FIGS. 33E and 33F** show heat exchangers having thermally conductive members shaped to conform with a surface of an object to be cooled;

[0072] **FIG. 33G** shows thermally-conductive members having ends shaped in various ways;

[0073] **FIG. 34** illustrates a heat exchanger according to an embodiment of the invention being used to cool a high-temperature object;

[0074] **FIGS. 35A and 35B** show heat exchangers according to alternative embodiments of the invention

[0075] **FIG. 36A** is a top plan view of a heat exchange pad according to an embodiment of the invention;

[0076] **FIG. 36B** is a bottom plan view of the heat exchange pad of **FIG. 36A**;

[0077] **FIG. 37A** is a longitudinal section through the heat exchange pad of **FIG. 36A**;

[0078] **FIG. 37B** is an enlarged portion of **FIG. 37A**;

[0079] **FIG. 37C** is an enlarged portion of **FIG. 36A**;

[0080] **FIG. 37D** is a transverse section through the heat exchange pad of **FIG. 36A**;

[0081] **FIG. 37E** is an enlarged portion of **FIG. 37D**;

[0082] **FIG. 37F** is an enlarged top plan view of a heat exchanger according to an alternative embodiment of the invention;

[0083] **FIG. 37G** is a top plan view of a heat exchange pad according to another alternative embodiment of the invention;

[0084] **FIGS. 38A, 38B** and **38**C are respectively a side elevation view, an elevational cross section view, and a transverse cross section view through a heat exchange pad according to the invention wrapped around an outer surface of a cylindrical object;

[0085] **FIGS. 39A, 39B** and **39**C are isometric views of three different thermal reservoirs having integrated heat exchangers;

[0086] **FIGS. 39D, 39E** and **39**F are respectively a top plan view, a longitudinal elevational section, and a transverse elevational section of a thermal reservoir according to another embodiment of the invention;

[0087] **FIGS. 39G and 39H** are respectively a longitudinal elevational section, and a transverse elevational section of a thermal reservoir according to another embodiment of the invention;

[0088] **FIG. 40A through 40E** are schematic views illustrating cooling and heating systems according to various embodiments of the invention;

[0089] **FIG. 41** is a schematic view illustrating a cooling system that uses a gaseous heat exchange fluid; and, **FIGS. 42A, 42B** and **42**C are respectively a longitudinal section, a transverse section and an enlarged view of a portion of a transverse section of a heat exchange pad according to an alternative embodiment of the invention.

DESCRIPTION

[0090] Throughout the following description, specific details are set forth in order to provide a more thorough understanding of the invention. However, the invention may be practised without these particulars. In other instances, well known elements have not been shown or described in detail to avoid unnecessarily obscuring the invention.

Accordingly, the specification and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

[0091] One aspect of this invention relates to pads useful for transferring heat between a body and a heat exchange fluid. Where the heat exchange fluid is warmer than the body, the pad facilitates heat flow from the heat exchange fluid into the body and the pad serves to warm the body. When the heat exchange fluid is cooler than the body then the pad facilitates heat flow from the body into the heat exchange fluid and the pad serves to cool the body.

[0092] The heat exchange fluid may comprise a liquid, of which water is an example, or a gas, of which air is an example. The heat exchange fluid is provided at a suitable temperature by a suitable temperature control system.

[0093] Some embodiments of this invention provide flexible heat exchangers suitable for use in warming or cooling living subjects. Heat exchangers according to the invention have a flexible heat exchange plate. A plurality of thermal channels pass through the flexible heat exchange plate. The flexible heat exchange plate has a plurality of thermally-conductive members projecting through a flexible medium that is essentially fluid-impermeable. The thermally-conductive members provide effective means to accept heat from a higher-temperature side of the medium, channel the heat through the medium, and release the heat on a lower-temperature side of the medium.

[0094] An outer side of the flexible heat exchange plate can be brought into contact with a living subject. The thermally-conductive members contact the skin of the subject. In preferred embodiments, an inner side of the flexible heat exchange plate forms one side of a channel which carries a heat exchange fluid. Heat can be exchanged between the heat exchange fluid and the subject's skin at a high rate by way of the thermally-conductive members which extend directly from the subject's skin into the heat exchange fluid.

[0095] The thermally-conductive members may be made of any suitable thermally-conductive materials including thermally-conductive metals, for example, aluminum, copper, gold, silver, or alloys of these metals with one another and with other metals. The thermally-conductive members may also be made of non-metals which have high thermal conductivities such as carbon, suitable grades of graphite, diamond, sapphire or the like. Preferably the thermally-conductive members are made from materials having thermal conductivities, k, of at least 50 $Wm^{-1}K^{-1}$ and preferably at least 100 $Wm^{-1}K^{-1}$. All other factors being equal, it is desirable that the material from which the thermally-conductive members is made be relatively low in density to reduce the weight of heat exchangers according to the invention. Where a heat exchanger is made in a way that involves deforming the thermally-conductive members, the material of the thermally-conductive members is chosen to be malleable. For many applications, aluminum is a good choice for the material of thermally-conductive members. For many embodiments, soft 1300 series aluminum is a good choice of material for the thermally-conductive members.

[0096] The thermally-conductive members are sized and located to permit the thermally-conductive plate to be flexed sufficiently to conform substantially to a part of a body of a living subject. The thermally-conductive members are dimensioned and distributed in a manner so that the thermally-conductive members cover a large proportion of the area of the outer side of the flexible heat exchange plate. In certain embodiments of the invention a plurality of the thermally-conductive members cover more than 30% of an area of the outer side of the flexible heat exchange plate. In some embodiments 50% or more of an area of the outer side of the flexible heat exchange plate is covered by the thermally-conductive members.

[0097] In preferred embodiments of the invention a plurality of the thermally-conductive members have thermally-conductive pins, fins, bars or the like that project into the volume of a heat exchanger to form an efficient heat exchange interface with heat exchange fluid in the volume. The projecting pins, fins, bars, plates or the like that form a heat exchange interface with the fluid inside the volume of a heat exchanger may or may not be similar in shape or other physical characteristics to the pins, fins, bars, plates or the like that extend through the flexible medium to form a thermal channel through the medium.

[0098] The following example embodiments of the invention will be described in the context of cooling a living subject. Embodiments of the invention could also be applied to warming a subject. As noted below, embodiments of the invention could also be applied to heating or cooling objects in other fields.

[0099] **FIGS. 1A through 1C** show a heat exchanger **10** according to an embodiment of the invention. Heat exchanger **10** has a flexible heat exchange plate **12** penetrated by a number of thermally-conductive members **14**. Plate **12** has an outer face **16** and an inner face **18**. Heat exchanger **10** has an inside volume **20** and ports **22**, **23** by way of which a heat exchange fluid can flow through volume **20**. Volume **20** is defined on a front side by plate **12** and on a rear side by a rear wall **24**. Side walls **25** extend between plate **12** and rear wall **24**. Plate **12**, rear wall **24** and side walls **25** are all flexible so that the outer surface **16** of heat exchanger **10** can conform to the local contours of a portion of a subject's body to be cooled or heated.

[0100] Thermally-conductive members **14** pass through the material **30** of plate **12**. Inside ends **26** of thermally-conductive members **14** project into volume **20**. Ends **26** preferably project significantly into volume **20**. In the illustrated embodiment, ends **26** are cut away to provide increased surface area for heat transfer with fluid in volume **20**. Each inner end **26** comprises a number of prongs **27**. Outer faces **28** of thermally-conductive members can be placed against the skin of a subject. Outer faces **28** may be outer faces of thermally-conductive bodies (which may be called "bases") **29**. Bases **29** are separated sufficiently to permit heat exchanger **10** to flex in a desired degree but are preferably closely spaced to maximize the area of outer faces **28** that can be placed against a desired region on a subject. For example, in some embodiments, bases **29** are spaced apart from one another by spacings in the range of 0.5 mm to 5.0 mm.

[0101] In some embodiments, each base **29** has a thickness in the range of 0.5 mm to 5 mm. For example, in some embodiments base **29** has a thickness in the range of 1 mm to 2.5 mm. The size and dimensions of base **29** in the plane of plate **12** may be chosen to suit the application, and particularly depends on the contour of the object to be cooled or heated. Thermally-conductive members **14** according to some embodiments of the invention for use in cooling/warming pads for human subjects, have bases **29** having areas in the range of 1 mm^2 to 400 mm^2. For such cooling/heating pads the area is preferably in the range of 10 mm^2 to 100 mm^2.

[**0102**] Thermally-conductive members **14** may have reduced cross sectional areas in their portions inward from bases **29**. The cross-sectional area of thermally-conductive members **14** at the point that thermally-conductive members **14** emerge from material **30** on the inside face of plate **12** may, for example, be in the range of 20% to 100%, and preferably 35% to 65%, of the area of base **29**.

[**0103**] Plate **12** comprises a flexible sheet or membrane through which thermally-conductive members **14** project. The membrane may be made of a flexible material or materials **30**. Thermally-conductive members **14** have lengths sufficient to pass through material **30**. In preferred embodiments, members **14** project into volume **20**. Thermally-conductive members **14** may, for example, project into volume **20** for a distance in the range of 0 mm to 20 mm. In some embodiments intended for warming or cooling a living subject, thermally-conductive members **14** project into volume **20** for a distance in the range of 2 mm to 10 mm. In some embodiments members **14** project past material **30** by at least 3 mm. The portions of members **14** which project into volume **20** may also function as supports to maintain a minimum spacing between rear wall **24** and plate **12**.

[**0104**] It is not necessary that all thermally-conductive members **14** be identical or that all thermally-conductive members **14** have equal-sized bases **29** although it is convenient to make heat exchanger **10** with thermally-conductive members **14** substantially the same as one another.

[**0105**] Material **30** constitutes a flexible membrane through which thermally-conductive members **14** extend. In some embodiments, rear wall **24** is made of material **30**. Substantially all of heat exchanger **10**, except for thermally-conductive members **14**, may be made of the same material or materials **30**. Material **30** is preferably flexible and/or elastically stretchable. Material **30** may, for example, comprise any of a variety of suitable flexible polymers such as natural rubber, polyurethane, polypropylene, polyethylene, ethylene-vinyl acetate, polyvinyl chloride, silicone, a combination of these materials, a coated fabric, or the like. Material **30**, or portions of material **30** may optionally be loaded with particles of one or more thermally-conductive materials such as metal or graphite. However, since material **30** is not required to play a significant role in conducting heat, material **30** may be a material having a low thermal conductivity not exceeding 5 $Wm^{-1}K^{-1}$ without significantly impairing the function of heat exchanger **10**. In some embodiments, material **30** has a hardness in the range of 10 to 80 on the Shore A hardness scale.

[**0106**] One specific example embodiment of the invention is constructed as shown in **FIGS. 1A** to **1C** and is designed to be applied to the neck of a human subject to cool the subject's brain. This embodiment of heat exchanger **10** has approximately 50 thermally-conductive members **14** arranged in a rectangular array. Each member **14** has nine pins which project into volume **20**. Bases **29** have areas of about 10 mm×10 mm and thicknesses of about 2 mm. Each of the pins has a diameter of about 1.8 mm. The total length of each of the pins is about 10 mm. The thickness of material **30** in the walls of heat exchanger **10** is about 4 mm. Two short tubes of approximately 10 mm inner diameter provide inlet and outlet ports **22** and **23**. A heat exchange fluid **65** such as cold water may be circulated through volume **20**.

[**0107**] Two such heat exchangers may be dimensioned so that they can be applied to a subject's neck respectively over the left and right carotid arteries to cool the subject's brain by cooling blood flowing to the subject's brain. The heat exchangers are sufficiently flexible to conform substantially to the curvature of the subject's neck without causing unacceptable pressure spots. The heat exchangers may be held in place under a collar, such as a foam collar.

[**0108**] Plate **12** may be fabricated using any suitable process. For example, plate **12** may be made by making holes in a sheet of material **30** and inserting thermally-conductive members **14** through the holes. The holes may initially have dimensions smaller than corresponding dimensions of thermally-conductive members **14** so that material **30** seals around thermally-conductive members **14** sufficiently to prevent any significant loss of heat exchange fluid from volume **20**. Additionally, or in the alternative, a sealant, such as a suitable glue may be provided to enhance the seal between thermally-conductive members **14** and material **30**. Plate **12** may also be made by a suitable plastic manufacturing process such as thermal injection molding, reaction injection molding, compression molding, vacuum forming or casting. In this case, thermally-conductive members **14** may be molded into plate **12**.

[**0109**] The thickness of material **30** in plate **12** can be selected to provide a desired compromise between flexibility and durability. Since heat exchanger **10** does not rely on material **30** to conduct heat, it is not necessary to make material **30** extremely thin to improve heat conduction. Material **30** may, for example, have a thickness in the range of about 0.1 mm to 20 mm. In some embodiments of the invention, material **30** has a thickness in the range of 4 mm to 7 mm in plate **12**. When thermally-conductive members of types which grip material **30** from either side (as shown for example in **FIG. 4I** to **FIG. 4L** or **7**A to **7**P) are used, the thickness of material **30** may be smaller, for example, as little as about 1 mm in plate **12**.

[**0110**] Projections of material **30** or some other material may optionally extend into volume **20**. Such projections may be positioned to support wall **24** relative to plate **12**, to direct the flow of fluid **65** within volume **20** and/or to induce turbulence at selected locations in the flow of fluid **65** in order to provide enhanced thermal contact between thermally-conductive members **14** and fluid **65**.

[**0111**] Thermally-conductive members **14** may be arranged in a wide range of patterns. For example, as shown in **FIGS. 1A** to **1C** and **3A** to **3C**, members **14** may be arranged in a number of rows and columns to form a rectangular array, which could be a square array. In some embodiments, members **14** are arranged in rows or columns which are shifted relative to one another as shown in **FIGS. 2B and 2C**. This arrangement creates increased turbulence in fluid **65** flowing through volume **20** and hence increases the efficiency of heat transfer between the inside ends of thermally-conductive members **14** and fluid **65**. In some embodiments, bases **29** of members **14** are arranged in a rectangular array as illustrated, for example, in **FIG. 1**, while portions of members **14** which project into volume **20** are arranged in rows or columns which are shifted relative to one another as shown in **FIGS. 2B and 2C**. In some embodiments, members **14** are arranged in a triangular array, as shown in **FIG. 2D**.

[**0112**] Flexing of plate **12** may be facilitated by arranging members **14** to provide substantially unbroken lines **31** of material **30** extending generally parallel to one or more axes about which a user may wish to flex heat exchanger **10**. The embodiment shown in **FIG. 1B** shows two sets of lines **31** of material **30** which extend between adjacent rows and columns of members **14**. The embodiment illustrated in **FIG. 2B** has one set of parallel lines **31**. Lines **31** are not necessarily parallel to one another. For example, **FIG. 2E** illustrates an arrangement of members **14** which facilitates flexing in such a way as to conform to a portion of the surface of a cone. The array of members **14** is not necessarily aligned with any axis of heat exchanger **10**. For example, **FIG. 2F** shows the outside face of a heat exchanger wherein thermally-conductive members **14** are arranged in a rectangular array oriented at an angle, ϕ, to a long axis of the heat exchanger.

[**0113**] **FIGS. 1**A to **1**C and **2**A to **2**F illustrate heat exchangers in which faces **28** are substantially flush with material **30** on outer face **16**. This arrangement facilitates cleaning, as outer face **16** is substantially smooth. **FIGS. 3**A to **3**C illustrate an alternative embodiment of the invention wherein base **29** is not embedded in material **30**. In this embodiment faces **28** are spaced outwardly from material **30**. The embodiments illustrated in these Figures can be fabricated, for example, by inserting thermally-conductive members **14** though holes formed in a sheet of material **30**.

[**0114**] Thermally-conductive members **14** may take any of a wide variety of forms which provide the function of carrying heat in either direction between a subject on one side of the flexible plate and a heat exchange fluid **65** or other matter on an opposed side as the flexible plate that is warmer or cooler than the subject. Ideally, members **14** provide:

[**0115**] good thermal interfaces between the thermally-conductive members and the subject to be cooled or warmed;

[**0116**] good thermal channels across flexible material **30**; and

[**0117**] good thermal interfaces between the thermally-conductive members and the fluid in volume **20** of the thermal exchanger.

Some possible forms for members **14** are illustrated in **FIGS. 4A through 4L**. It is understood that these are possible forms and are included only as examples. Modifications to these examples can be made to obtain a much larger list of examples. In addition, features illustrated in these examples can be exchanged or combined partially or fully to obtain an even larger list of examples.

[**0118**] **FIG. 4A** shows a thermally-conductive member **14**A having a square base **29** and cylindrical pin **32**. Pin **32** can carry heat through material **30** and constitutes a means for channelling heat through flexible material **30** and releasing heat into (or taking heat from) fluid in volume **20** of a heat exchanger. **FIG. 4B** shows a thermally-conductive member **14**B having a circular base **29** instead of a square base. It is generally preferable that the thermally-conductive surfaces that contact a subject's skin be rounded and not have sharp corners.

[**0119**] **FIG. 4C** shows a thermally-conductive member **14**C wherein both base **29** and the pin **32** are square in cross-section (like the thermally-conductive members of **FIGS. 2**A to **2**C). **FIG. 4D** shows a thermally-conductive member **14**D similar to member **14**A except that pin **32** has a circumferential groove **33** in its part close to base **29**. Groove **33** receives extra material **30** in an injection molding or casting process to better seal member **14**D to material **30**. **FIG. 4E** shows a thermally-conductive member **14**E wherein a tip of pin **32** is tapered to facilitate insertion into a hole in a sheet of material **30**.

[**0120**] **FIG. 4F** shows a thermally-conductive member **14**F having a pair of platelike rectangular conductors **34** which serve both as thermal channels through material **30** and as structures for releasing heat into (or taking heat from) volume **20**. Conductors **34** may be arranged in a V-shape to better transfer heat to fluid flowing past plates **34**. Plate-like conductors could also be arranged in other manners such as being parallel with each other. Thermally-conductive member **14**F has the advantage in manufacturing that it can be made by cutting and folding thermally-conductive sheet material.

[**0121**] **FIG. 4G** shows a thermally-conductive element **14**G having a thermal channel portion provided by a tubular pin **36**. **FIG. 4H** shows a thermally-conductive member **14**H having multiple pins **38** extending from base **29**. Pins **38** provide multiple thermal channels extending from the same base **29** and projecting into the volume **30**. Conductive member **14**H advantageously provides increased contact area between conductive member **14**H and a heat transfer fluid **65** in volume **20**. **FIGS. 41 and 4**J show a thermally-conductive member **14**I that is designed to reduce the possibility of fluid leaking between material **30** and member **14**I. Member **14**I may be fabricated in two-pieces **14**I-**1** and **14**I-**2** that can be assembled together in a manner that provides good thermal contact between pieces **14**I-**1** and **14**I-**2**.

[**0122**] In the illustrated embodiment, one of the pieces of member **14**I has a pin **39** which is received in a corresponding socket **40** (see **FIG. 4J**) in the other piece. Pin **39** may have an interference fit in socket **40** to keep the two pieces tightly together and to provide good heat transfer between the pieces. A circumferentially extending groove **41** is defined between pieces **14**I-**1** and **14**I-**2**. Groove **41** receives material **30**. The faces of pieces **14**I-**1** and **14**I-**2** which contact material **30** may be undercut to provide ridges **42** which help to prevent fluid from leaking past member **14**I. The pieces of multi-piece thermally-conductive members may be fastened together in other ways which provide thermal contact between the pieces. For example, fastening means such as screws, rivets, or the like may be provided. **FIGS. 4K and 4L** show a thermally-conductive member **14**K that is similar to member **14**I but is an integral part. Member **14**K is designed to be cramped onto material **30**. Material **30** projects into a groove **43**. The sides of the groove **43** may be cramped together to hold material **30** around the edges of member **14**K as shown in **FIG. 4L**.

[0123] **FIGS. 5A and 5B** show a flexible fluid heat exchanger **50** which is normally curved in the absence of applied forces. Heat exchanger **50** may be used to apply heat to or to cool a substantially cylindrical object such as a subject's limb. Apart from being curved, heat exchanger **50** is similar to heat exchanger **10** of **FIGS. 1A through 1C**.

[0124] **FIGS. 6 through 14**B illustrate various embodiments of heat exchanger according to the invention in which thermally-conductive members extend through apertures in a fluid impermeable membrane and are held in place by retention members. **FIG. 6** shows a heat exchanger **110** having a volume **120** defined within a membrane **130**. Membrane **130** comprises a layer of a suitable flexible fluid-impermeable material. Membrane **130** has a thickness adequate to provide a desired strength. Membrane **130** may be thin. For example, in some embodiments, membrane **130** has a thickness of **0.010** inches or less.

[0125] Membrane **130** may comprise, for example, a suitable grade of polyurethane or other suitable thermoplastic polymer. Examples of other materials that may be suitable for use as membrane **130** include: styrenic copolymers; suitable grades of: polyvinyl chloride (PVC); polyolefins such as polyethylene or polypropylene; styrenics such as polystyrene; polyesters such as polyethylene terephthalate (PET); polyethers such as polyetheretherketone (PEEK); polyamides (e.g. NYLON™); silicone; cellophane; cellulose acetates; natural or synthetic rubbers; ethylene-vinyl acetate; neoprene; polytetrafluoroethylene (PTFE e.g. TEFLON™); plasticized metallic films; combinations of two or more of these materials; coated or impregnated fabrics; and the like.

[0126] Thermally-conductive members **114** penetrate membrane **130**. Each thermally-conductive member **114** has a pad (which may also be called a base) **129** on an outer side of membrane **130** and a pin portion **132** which projects into volume **120** and is in thermal contact with a fluid **65** in volume **120**. Base **129** may be a body formed in or attached to thermally-conductive member **114**. Thermally-conductive members **114** are held in place by retention members **115**.

[0127] As shown in **FIGS. 6A, 6B** and **6**C, membrane **130** may be affixed to itself, for example by adhesive bonding or by welding at seams **117**, to form channels **119**. In the embodiment illustrated in **FIGS. 6 through 6**C, front and rear sheets **130**A and **130**B of membrane **130** of heat exchanger **110** are joined together in a pattern which provides a single sinuous channel **119** which extends between ports **122** and **123**. Ports **122** and **123** are attached to membrane **130** with a suitable fluid-impermeable attachment means such as welding, suitable adhesive, stitching, taping, or the like. Front and rear sheets **130**A and **130**B are not necessarily equal in thickness. In some embodiments, front sheet **130**A is thicker than rear sheet **130**B.

[0128] In a currently preferred embodiment of the invention, rear sheet **130**B is vacuum formed, or otherwise shaped, to provide a dimple corresponding to each of the thermally-conductive members (e.g. **114**). Thermally-conductive members **114** project into the corresponding dimples. This can yield a structure which remains highly flexible and resistant to "ballooning" as heat exchange fluid **65** is pumped through it. With this construction the volume surrounding thermally conductive members **114** can be made small, thereby reducing the weight of the fluid-filled heat exchanger. Front and rear sheets **130**A and **130**B may be affixed together at locations which define one or channels which each have a single row of thermally-conductive members extending along the channels. The locations at which front and rear sheets **130**A and **130**B are affixed together may be just far enough apart to be on either side of the thermally-conductive members **114**. The channels may be straight, serpentine, U-shaped, or follow alternative paths as convenient for the application at hand. One can appreciate that as one moves along the centerline of one of the channels the rear sheet **130**B bumps away from the front sheet **130**A in each dimpled portion and is close to, even touching or almost touching front sheet **130**A in its portions between thermally-conductive members **114**.

[0129] In some embodiments of the invention, the heat exchanger has "drape". This means that when the heat exchanger is placed over a horizontal member, such as a thin horizontal dowel or a pencil, the overhanging parts of the heat exchanger hang down substantially vertically from the horizontal member. A heat exchanger which has drape can conform readily to the surface contours of a person or object against which it is brought.

[0130] **FIGS. 6D and 6E** illustrate a heat exchanger in which the pattern of seams **117** provides a U-shaped channel **119**. By comparing **FIGS. 6A through 6C** to **FIGS. 6D and 6E** it can be seen that the width of channel **119** may be varied. In some embodiments channel **119** is narrow and accommodates only a single row of thermally-conductive members **114**. In other embodiments, channel **119** is wider and can accommodate several thermally-conductive members **114** side-by-side. As described above, there are many variations in the placement of thermally-conductive members **114**. **FIG. 6F** shows another heat exchanger in which a pattern of seams **117** provides two separate paths through the heat exchanger. Each path has ports which provide an inlet and outlet for the path.

[0131] **FIGS. 7A and 7B** illustrate a thermally-conductive member **114**A. As shown in **FIG. 7A**, thermally-conductive member **114**A has a shoulder **121** which projects through membrane **130** and through an aperture **115**A in retention member **115**. As shown in **FIG. 7B**, shoulder **121** is deformed, for example by pressing, to firmly engage retention member **115** and to compress membrane **130** between retention member **115** and base **129**. In some embodiments, shoulder **121** initially projects past retention member **115** just far enough that it provides a good seal when pressed flush with retention member **115**. Aperture **115**A may have various profiles, for example, it may be tapered, as shown in **FIGS. 7A and 7B** or straight-sided, as shown in **FIGS. 7A-1**, 7B-1, 7A-2 and 7B-2.

[0132] **FIGS. 7C and 7D** show a thermally-conductive member **114**B. Pin **132** of thermally-conductive member **114**B has a sharp end **132**A and a cross sectional profile which matches the cross sectional profile of retention member **115**B. Thermally-conductive member **114**B does not require a pre-existing aperture in membrane **130**. Pin **132** and retention member **115**B cooperate as a punch and die. As pin **132** is pressed into the aperture in retention member **115**B through membrane **130**, the end of pin **132** punches an aperture in membrane **130** which matches the cross sectional shape of pin **132**. Pin **132** is a friction fit in the aperture of retention member **115**B.

[0133] **FIGS. 7E and 7F** illustrate an alternative thermally-conductive member **114**C wherein pin **132** is threaded and the retention member comprises a washer **115**C which is compressed against membrane **130** by a nut **115**D.

[0134] **FIGS. 7G and 7H** illustrate an alternative thermally-conductive member **114**D which is adhered to membrane **130** by a suitable adhesive. Thermally-conductive member **114**D may be used with or without a retention member as shown in **FIGS. 7G and 7H** or with a retention member as shown in **FIGS. 7I and 7J**. In some embodiments, a retention member **115** is secured to membrane **130** with a suitable adhesive.

[0135] **FIGS. 7K, 7L**, 7K-**1**, 7L-**1**, 7K-**2** and 7L-**2** illustrate alternative constructions wherein pin **132** of a thermally-conductive member **114**E is deformed and shaped into a head **132**B which bears against membrane **130**. A washer may be provided between head **132**B and membrane **130**. This configuration is the basis for a currently preferred embodiment of the invention.

[0136] In other embodiments of the invention (not shown), a part of thermally-conductive member **114** projects from an enlarged body in volume **120** through an aperture in membrane **130**. The projecting part of thermally-conductive member **114** is subsequently deformed, for example by pressing, to form an enlarged base on the outside of membrane **130**. The membrane is held between the body in volume **120** and the enlarged base.

[0137] **FIGS. 7M and 7N** illustrate a construction in which a thermally-conductive member **114**F is held against membrane **130** by a spring clip **115-2**.

[0138] **FIGS. 7O and 7P** illustrate a construction wherein a retaining member **115** is deformed, for example by pressing, to seal against pin **132** and membrane **130**.

[0139] Many variations in the design of a thermally-conductive member **114** and retention member **115** are possible within the scope of the invention. Thermally-conductive member **114** and retention member **115** may be made of the same material. If they are made from different materials then it is desirable that the coefficients of thermal expansion of the materials of thermally-conductive member **114** and retention member **115** be such that retention member **115** does not tend to loosen as a heat exchanger is used. For example, where a heat exchanger is to be used for cooling applications it is desirable that retention member **115** have a coefficient of thermal expansion that is the same as or greater than that of pin **132**.

[0140] **FIG. 8A** shows a few possible forms for pin **132**. Pin **132** may have any of a wide range of cross-sectional shapes. **FIG. 8B** shows a few possible shapes for base **129**. **FIG. 8C** shows a few possible configurations for retention member **115**. Retention members **115-1** and **115-2** are spring clips, sometimes known as push retainers. Retention members **115-1** and **115-2** have inner edge portions **118** which tightly engage pin **132**. The retention member used to retain a thermally-conductive member **114** typically has an outer profile which matches that of the base **129** of the thermally-conductive member **114** although this is not necessary. In some embodiments of the invention a compliant member, such as an **0**-ring or compliant washer is provided between retention member **115** and membrane **130**, between base **129** and membrane **130**, or both. **FIG. 8F** shows a construction which includes a compliant washer.

[0141] In some embodiments of the invention, retention member **115**, base **129**, or both have one or more narrow projecting rings **131** or grooves (**FIG. 8D**) to provide an enhanced seal with membrane **130**. **FIG. 8E** shows some possible surface configurations for bases **129**. Bases **129** may be roughened or profiled to provide increased surface area and consequentially improved thermal conductivity between bases **129** and an adjacent compliant surface, such as the surface of a subject's skin.

[0142] **FIGS. 9A through 9F** show some alternative embodiments of the invention in which thermally-conductive members have an enlarged portion within volume **120** and are held to membrane **130** by a retainer located on the outer side of membrane **130**. **FIGS. 9A and 9B** show a thermally-conductive member **114**G which comprises a pin **132** which projects into volume **120** from an enlarged portion **133**. A pin **135** extends from enlarged portion **133** through membrane **130**. Pins **132**, **135** and enlarged portion **133** are conveniently integral with one another. A retainer **137** engages pin **135** to hold thermally-conductive member **114**G in place and sealed to membrane **130**. Pin **132** may project through retainer **137**, as shown in **FIGS. 9A and 9B**. In some embodiments retainer **137** covers the end of pin **132**.

[0143] **FIGS. 9C and 9D** illustrate another thermally-conductive member **114**H in which pin **135** is threaded and retainer **137** is in the form of a nut that screws onto pin **135**. In the illustrated embodiment, the portion of retainer **137** that contacts membrane **130** is smaller than the body-contacting end of retainer **137**. This enhances the flexibility of the heat exchanger.

[0144] **FIGS. 9E and 9F** show another thermally-conductive member **114**I wherein retainer **137** is a press fit onto pin **135**.

[0145] Many variations are possible in the embodiments of the invention illustrated in **FIGS. 9A through 9F**. Pins **132** and **135** may have the same cross sectional shape, as shown in **FIGS. 9E and 9F** or may have different cross sectional shapes, as shown in **FIGS. 9A and 9B**.

[0146] **FIGS. 10A through 10C** show thermally-conductive members that may be used in embodiments like those of **FIGS. 9A through 9F**. **FIG. 10A** shows a few possible forms for pin **135**. In the embodiments of **FIG. 10A**, enlarged portion and pin **132** have the same diameter. Pin **132** may have any of a wide range of cross-sectional shapes. **FIG. 10B** shows a few possible shapes for pin **132** in thermally-conductive members which also have a pin **135**. **FIG. 10C** shows a few possible configurations for retainers **137**.

[0147] Some embodiments of the invention provide an extension on one or more of pins **132** which provides additional surface area for thermal contact with fluid **65**. The extension may be in the form of a cap affixed to the end of pin **132**. Various forms of extension are shown in **FIGS. 11A through 11E**. **FIG. 11A** shows an extension **141**A shaped generally like a mushroom cap. **FIG. 11B** shows an extension **141**B in the form of a cylinder. **FIG. 11C** shows an extension **141**C shaped generally like a football in side elevation and star-shaped in cross section. **FIG. 11D** shows a fin-shaped extension **141**D. **FIG. 11E** shows a tear-drop-shaped extension **141**A. The extensions may be made of the same class of materials as pins **132** and are in good thermal contact with pins **132**. In some embodiments, extensions are formed integrally with pins **132**.

[**0148**] **FIGS. 12A through 12C** illustrate some further alternative embodiments of the invention. As shown in **FIG. 12A**, a single base **129** may have multiple pins **132** which extend through membrane **130** and are held in place by a single retainer member **115-3**. As shown in **FIG. 12B**, multiple thermally-conductive members **114** may be held in place by a single retainer member **115-4**. As shown in **FIG. 12C**, a single base **129** having multiple pins **132** passing through membrane **130** may be held in place by multiple retainer members **115-5**.

[**0149**] FIGS. **13** to **21** show members adapted to be sealed to a membrane or other flexible material and methods for installing such members. A number of the embodiments of FIGS. **13** to **21** are suitable for use as thermally-conductive members in heat exchangers according to the invention. **FIG. 13** shows a pin **210** passing through an aperture **212** in a membrane **214**. Pin **210** has a head **220** on a first side **214**A of membrane **214**. Pin **210** has a shaft **222** which extends through aperture **212** and projects on a second side **214**B of membrane **214**. A groove **224** in head **220** extends around the base of shaft **222**. Groove **224** is wide enough to receive an edge portion **214**C of membrane **214**.

[**0150**] As shown in **FIG. 14**, shaft **222** can be deformed, for example, by compressing shaft **222** toward head **220** with a press **228**. As the deformation occurs, the material on the outside of shaft **222** in its lower portion **222**A near head **222** tends to move outwardly and downwardly as indicated by arrows **230**.

[**0151**] Edge portion **214**C of membrane **214** fits closely to shaft **222**. The deformation of lower portion **222**A of shaft **222** carries edge portion **214**C of membrane **214** into groove **224**. Continued deformation of shaft **222** moves edge portion **214**C deeper into groove **224**. Eventually the continued deformation of shaft **222** moves inner wall **224**A of groove **224** toward outer wall **224**B of groove **224** so that edge portion **214**C of membrane **214** becomes gripped between inner wall **224**A and at least a portion of outer wall **224**B as shown in **FIG. 15**. Typically membrane **214** is gripped first between inner wall **224**A and corner **224**C at which outer wall **224**B meets surface **220**A of head **220** which surrounds groove **224**.

[**0152**] It is thought that providing a smooth or even polished surface on the portion of shaft **222** contacted by the edge of a sheet **214** during deformation of shaft **222** will help the edge of sheet **214** to slide down shaft **222** into groove **224**. It is also thought that the edges of sheet **214** will be drawn most effectively into groove **224** if the edges of sheet **214** is at least somewhat elastic.

[**0153**] In some embodiments of the invention, membrane **214** is impervious to fluids and pin **210** makes a fluid-tight seal to membrane **214**. Membrane may be of any suitable flexible material. In some embodiments of the invention, membrane **214** comprises an elastic material, such as urethane. Membrane **214** could comprise any of a variety of suitable flexible sheet like materials. Some examples are polymers such as natural rubber, polyurethane, polypropylene, polyethylene, ethylene-vinyl acetate, polyvinyl chloride, silicone, a combination of these materials, fabrics, or the like.

[**0154**] Pin **222** may be of any suitable material which is sufficiently ductile to be plastically deformed by pressing, as described above. Where pin **222** is to operate as a thermally-conductive member in a heat exchanger then the material of pin **222** should be highly thermally-conductive. For example, pin **222** may be made of aluminum, copper, or another plastically deformable metal having good thermal conductivity. Other metals or materials commonly used to make blind or solid rivets could be used. Some examples of such metals include suitable steels, stainless steels; brasses; bronzes; monel (a nickel-copper alloy); and inconel (a nickel-chromium alloy). Some successful prototypes have used 1100 series aluminum having a hardness of about 32 on the Brinell hardness scale for shaft **222**. The other materials listed above typically have hardnesses in the range of about 20 and about 200 on the Brinell hardness scale. In applications in which pin **222** is not required to conduct heat, deformable plastics such as suitable grades of polyurethane, polyethylene, polypropylene, PVC or poly carbonate could also be used for shaft **222**.

[**0155**] As shown in **FIGS. 16A** to **16**F, the profile of groove **224** may be varied. It may be desirable to provide a relieved corner or "lip"**224**C where outer wall **224**B of groove **224** intersects surface **220**A of head **220**. In some embodiments of the invention the main seal between pin **210** and membrane **214** occurs at the nip **232** (**FIG. 15**) between corner **224**C and the deformed shaft **222**. Providing a relieved corner **224**C provides increased surface area in the seal and also facilitates membrane **214** being moved into groove **224**.

[**0156**] **FIG. 16A** shows a groove **224** having a sharp outside corner **214**C. **FIG. 16B** shows a groove **224** having a bevelled outside corner **214**C-**1**. **FIG. 16C** shows a groove **224** having a rounded outside corner **224**C-**2**. **FIG. 16D** shows a groove **224** wherein outside corner **224**C-**3** is elevated above the surrounding surface of face **220**A of head **220**. **FIG. 16F** shows a groove **224** having an outer wall **224**B which is inclined away from shaft **222**.

[**0157**] It is convenient, although not mandatory, to make head **220** and shaft **222** integral with one another. Head **220**, including the outer wall **224**B of groove **224** does not need to be deformable as does shaft **222**. In some embodiments, shaft **222** and head **220** could comprise separate parts which are suitably affixed to one another. An example of such a construction is depicted in **FIG. 17**.

[**0158**] **FIG. 17** shows a through-member **240** having a first part **242** which includes a plastically deformable shaft **243** having an enlarged head **244** at one end. A second part **245** has an aperture **246**. Shaft **243** projects through aperture **246**. A groove **248** is defined between shaft **243** and a wall **249** of a counterbored part **246**A of aperture **246**. Second part **245** may be made of a harder material than first part **242**.

[**0159**] **FIG. 18A** illustrates a through member **260** according to an alternative embodiment of the invention in which shaft **262** is tubular. **FIG. 18B** illustrates a through member **264** according to another alternative embodiment of the invention in which shaft **266** is semi-tubular. A tubular or semi-tubular shaft can be deformed with the application of less force than would be required to deform a solid shaft made out of the same material.

[0160] A through member may be configured as a blind rivet. **FIG. 18C** shows a through member **270** configured as one type of blind rivet. Through member **270** has an actuating stud **272** passing through a hollow shaft **274**. Actuating stud **272** has an enlarged head **276** and a weakened portion **278**. Through member **270** can be installed by pulling on the projecting shank **279** of actuating stud **272**. This causes head **276** to compress shaft **274** and to deform shaft **274** outwardly. As shaft **274** is deformed, a membrane **214** is drawn into and becomes affixed within a groove **224** as described above. Eventually enough tension can be applied to shank **279** to cause actuating stud **272** to break off at weakened portion **278**. In typical embodiments, shaft **274** is a soft deformable material such as aluminum or a suitable grade of stainless steel while stud **272** is of a harder material such as steel.

[0161] The invention could also be embodied in blind rivets of other types which have a shaft which in deforms outwardly when the blind rivet installed in a manner such that a membrane **214** or other material through which the blind rivet passes is moved into and retained in a groove by the deformation of the shaft.

[0162] A through member according to the invention may be used to join together two or more sheets of material. **FIGS. 19A, 19B** and **19C**, show the application of a through member **280** to join together two or more sheets of material. Through member **280** may be constructed and used as described above. Through member **280** is similar to the through member **210** of **FIG. 13** except that groove **224** has been made wider. In this embodiment, groove **224** is wide enough to receive edges **214-1**C and **214-2**C of each of the sheets **214-1** and **214-2** of material being joined together. Even where the sheets of material are flexible it is not necessary to provide a washer or other separate fastening component on the side of the material sheets away from head **220**. Through members according to other embodiments of the invention described herein, including the blind rivet embodiments, could also be used to attach multiple sheets of material together.

[0163] **FIGS. 20A through 20E** depict stages in the installation of a though member **290** according to an alternative embodiment of the invention. Through member **290** has a square shaft **291** extending from a head **292**. An aperture **293** extends through shaft **291**. A groove **294** extends around the base of shaft **291**. Shaft **291** passes through an aperture in a sheet **214** of a flexible material.

[0164] As shown in **FIG. 20C**, deformation of shaft **291** causes the outward faces of shaft **291** to be tapering toward groove **294**. This urges the edges of sheet **214** into groove **294**. Continued deformation of shaft **291** results in the edges of sheet **214** being captured in groove **294** between the outer face of shaft **291** and the outside corner (or "lip") of groove **294**.

[0165] Another aspect of the invention provides a method for securing a through member in a membrane. The method begins with providing a through member having a head, a shaft extending from the head and a groove surrounding the shaft. The shaft is inserted through an aperture in a membrane to which the through member is to be secured. The method continues by compressing the shaft of the through member longitudinally and thereby deforming the shaft such that an initial deformation of the shaft moves an edge portion of the membrane into the groove of the through member. The method continues by continuing to compress the shaft longitudinally until the shaft deforms sufficiently to cause the edge portion of the membrane to be gripped between an outer surface of the deformed shaft and an outer wall of the groove.

[0166] This method may be used to secure a one-piece through member securely, and in some embodiments sealingly, to a membrane or to multiple membranes or other sheet-like materials in a single operation. It is not necessary to assemble multiple pieces to provide the through member or to perform multiple operations (although the invention could be applied to through members assembled from more than one part or to methods involving additional steps). The through member may be introduced from one side of the membrane (or other sheet like material(s)) to which the through member is being affixed. It is not necessary to introduce different parts of the through member from different sides of the membrane.

[0167] Head **220** may carry or be attached to some structure which is to be attached to membrane **214**. For example, head **220** may carry a snap and membrane **214** may comprise a cover for something, an article of clothing, or the like. A through member according to the invention may be apertured. A valve, stopper or orifice for allowing air, another gas or a liquid to flow through the aperture may be provided in the aperture. A through member may have a threaded aperture capable of receiving a screw or may have a projecting stud. A through member could carry alternative structures such as electrical connectors. In some embodiments of the invention the through member is electrically conductive or has one or more electrical conductors which join electrical connectors on opposing sides of membrane **214**.

[0168] Various alterations and modifications are possible in the construction and installation of through-members as illustrated in FIGS. **13** to **20** without departing from the invention. For example:

[0169] shaft **222** is not necessarily circular, as illustrated, but could have another cross sectional shape, such as slightly elliptical or square.

[0170] where a shaft has an aperture passing all or part way through it, as shown in **FIGS. 20A through 20E**, for example, then the installation method may include pressing outwardly from within the aperture. for example, the method may include pressing a tapered pin into the aperture.

[0171] the outer surface of shaft **222** is not necessarily perpendicular to the head. For example, **FIG. 21** illustrates an embodiment wherein a lower portion **299** of a shaft **222** is tapered toward groove **224**. In this embodiment, the thickness of shaft **222** increases in the direction away from head **222**. However, if membrane **214** is elastic then membrane **214** can be pulled over shaft **222** and still contact portion **299** closely enough to be urged into groove **224** as shaft **222** is deformed.

[0172] A through member according to the invention may be attached to sheet like materials of a wide range of types including fabrics, membranes, leather, thin metal sheets (e.g. metal foils, shim stock), plastic sheets, rubberized sheets and the like.

[0173] As shown in **FIG. 22**, rear sheet **130**B of membrane **130** may be affixed to some or all of thermally-conductive members **114**. This helps to prevent "ballooning" of the heat exchanger, especially where volume **120** is large. Any suitable means may be provided to affix rear sheet **130**B to thermally-conductive members **114**. For example:

[0174] rear sheet **130**B may be glued to thermally-conductive members **114** using a suitable adhesive;

[0175] a piece of material to which rear sheet **130**B may be welded may be affixed in any suitable manner at the inner ends of thermally-conductive members **114** and rear sheet **130**B may be welded to that piece of material; or

[0176] rear sheet **130**B may be mechanically attached to thermally-conductive members **114**, for example: a screw, part of the thermally-conductive member **114** or the like may pass through an aperture in rear sheet **130**B to hold rear sheet **130**B against thermally-conductive member **114**; a portion of rear sheet **130**B may be pressed into an aperture on the end of thermally-conductive member **114**; or, a retaining member behind rear sheet **130**B may be held in place by deforming a portion of thermally-conductive member **114** in a manner similar to that illustrated in **FIGS. 7K and 7L. FIGS. 22A and 22B** show one example of a mechanical means for holding rear sheet **130**B to thermally-conductive member **114**.

[0177] In some embodiments of the invention it is desirable that the outer surface of membrane **130** have different properties than the surface of membrane **130** which faces into volume **120**. For example, where a heat exchanger is intended to warm or cool a living subject it may be desirable that the outer surface of membrane **130** be absorbent to absorb any sweat, dirt or condensation from the subject's skin. As shown in **FIG. 23A**, membrane **130** may be a two-ply membrane having different surface characteristics on its inner and outer faces.

[0178] In the embodiment of **FIG. 23B**, membrane **130** is made up of an inner fluid-impermeable layer **130-1** and an outer absorbent layer **130-2**. With this construction, it is unnecessary to make fluid-impermeable layer **130-1** of a material that is approved for contact with a subject or other item to be heated or cooled because only thermally-conductive members and outer absorbent layer **130-2** can come into contact with the subject. As an example, layer **130-2** may comprise SOFTESSE™ material available from DuPont.

[0179] Where a membrane has multiple layers, the materials of the layers may be chosen to have characteristics under compression and/or elastic characteristics which differ from one layer to the other. Such membranes may be included to advantage in embodiments of the invention in which the membrane is compressed between parts of a thermally-conductive member (as shown, for example, in **FIG. 6A** or **13** to **21**). In such embodiments of the invention, it can be desirable for the membrane to include a relatively soft fluid impermeable layer which can seal well to the thermally-conductive member. However, a single-ply membrane that is highly compressible and/or greatly compressed by a thermally-conductive member may take on a shape which is somewhat distorted in the vicinity of the thermally-conductive member. By providing a two-ply or two-layer membrane this problem can be avoided. The membrane can combine a sealing layer having good properties for sealing with a control layer. The sealing layer may be highly compressible and relatively easily stretchable. The control layer may be significantly less stretchy and less compressible than the sealing layer.

[0180] For example, the sealing layer may comprise a sheet of suitable plastic material, such as urethane, while the control layer may comprise a sheet of a woven or unwoven fabric. The fabric may be significantly less elastic than the sealing layer and, in some cases may be substantially non-elastic under the expected conditions of use of the heat exchanger. The sealing layer may be on the inside of membrane **130** facing into volume **120** in which case the sealing layer may be welded to a layer making up the back side of volume **120**.

[0181] In some embodiments of the invention the membrane has three layers, for example, a compressible elastomer sealing layer; a fabric control layer; and an outer layer of a soft absorbent material that is approved for skin contact.

[0182] A suitable circulation system may be used to circulate a heat exchange fluid through the volume **20** of one or more heat exchangers as described herein. For cooling purposes it is desirable that the temperature of circulating fluid **65** be greater than 0° C. to avoid freezing the subject's skin. The desired temperature of the circulating fluid will depend to some degree on the application and the portion of the subject's body to be treated. The desired temperature for cold therapy ranges between 0° C. and 15° C. Water has properties which make it good for use as a circulating fluid **65**.

[0183] It is generally desirable to maintain the pressure of fluid **65** in volume **20** approximately equal to the air pressure surrounding heat exchanger **10**. If the pressure within volume **20** is significantly smaller than the ambient air pressure then pressure differences across the walls of volume **20** will tend to collapse volume **20** although the projecting inside ends **26** of thermally-conductive members **14** may prevent the walls from complete collapse. If the pressure within volume **20** is significantly larger than the ambient air pressure then heat exchanger **10** will tend to balloon.

[0184] **FIG. 24** is a schematic view of a cooling system which includes a heat exchanger **10** and a fluid circulating system **60**. Circulation system **60** has an insulated reservoir **62** containing a volume of ice **64**. System **60** contains a suitable heat exchange fluid **65**, which may be liquid water. System **60** delivers fluid **65** to heat exchanger **10** through delivery conduit **66** and returns coolant to reservoir **62** through a return conduit **67**.

[0185] A first feed pump **70** upstream from heat exchanger **10** delivers fluid **65** from reservoir **62** to heat exchanger **10**. A second feed pump **72** is located downstream from heat exchanger **10**. Second feed pump **72** draws fluid **65** from heat exchanger **10** and returns the fluid to reservoir **62**. First and second feed pumps **70** and **72** are balanced so that within volume **20** of heat exchanger **10** the pressure of fluid **65** is substantially equal to the ambient air pressure.

[0186] One or more bypass valves may be provided to provide better control over fluid pressure within volume **20**.

In system **60**, an adjustable bypass valve **74** is connected between the output of first feed pump **70** and reservoir **62**. Bypass valve **74** indirectly regulates the pressure within volume **20**. When bypass valve **74** is opened, a larger proportion of fluid **65** is returned to reservoir **62** by way of bypass conduit **75** and the amount of fluid **65** flowing into heat exchanger **10** is reduced. Bypass valve **74** may be pressure-operated.

[0187] System **60** has a second bypass valve **76** connected in parallel with second feed pump **72**. When second bypass valve **76** is open, second feed pump **72** can draw fluid **65** from reservoir **62** by way of conduit **77**. Opening second bypass valve **76** increases pressure at the input of second feed pump **72** and consequently increases the pressure within volume **20**.

[0188] Many variations of system **60** are possible. Although two bypass valves are shown in **FIG. 24** for maximum flexibility, one bypass valve connected parallel with either one of pumps **70** or **72** or in parallel with heat exchanger **10** may be sufficient to permit pressure inside heat exchanger **10** to be maintained within a desired range. In addition, depending upon the construction of pumps **70** and **72** and the fluid flow properties of the circuit which includes conduits **66**, **67** and heat exchanger **10** it may be possible to maintain the fluid pressure in volume **20** within the desired range without the need for bypass valves **74** and **76**. Where bypass valves are provided it is not necessary that they be connected directly to reservoir **62** as illustrated. Other connections may be provided which have the result of maintaining pressures upstream and/or downstream from heat exchanger **10** at values which keep the pressure within volume **20** at a desired level while maintaining fluid flow through volume **20**.

[0189] In some cases it may be convenient to provide a single reservoir **62** for providing heat exchange fluid for multiple heat exchangers **10**. In such cases it is best to provide upstream and downstream pumps **70** and **72** for each heat exchanger **10**. In the alternative, suitable manifolds, such as T-connectors, could be provided to allow a number of heat exchangers **10** to be connected in parallel between a single upstream pump system and a single downstream pump system.

[0190] **FIG. 25** illustrates another fluid circulating system **60**A. In system **60**A, a first flow regulator **78** comprising a restrictor **80** and a bypass valve **82** is provided between first feed pump **70** and heat exchanger **10**. Bypass valve **82** is connected in parallel with restrictor **80**. When fluid **65** is flowing through flow regulator **78** then a pressure drop across flow regulator **78** depends upon the fluid flow rate and upon the degree to which bypass valve **82** is open.

[0191] System **60**A has a second flow regulator **79** which includes a second flow restrictor **84** and a bypass valve **86**. Bypass valve **86** is connected in parallel with restrictor **84**.

[0192] In system **60**A, bypass valves **82** and **86** are adjustable. The fluid pressure within volume **20** can be controlled by adjusting one or both of bypass valves **82** and **86**.

[0193] Some alternative embodiments of the invention lack one of flow regulators **78** and **79**. When system **60**A is connected to supply fluid **65** to a plurality of heat exchangers **10** it is preferable to provide for each heat exchanger **10** at least one adjustable flow regulator **78** or **79** located where only fluid going to or from that heat exchanger passes through the flow regulator. This permits the pressure within each heat exchanger **10** to be individually regulated. In the alternative, as described above, suitable manifolds may be provided to split the flow of fluid **65** between a number of heat exchangers **10** connected in parallel.

[0194] **FIG. 26** illustrates another fluid circulating system **60**B. In system **60**B the pressure within volume **20** of heat exchanger **10** is controlled by adjusting the rate of operation of one or both of upstream and downstream feed pumps **70** and **72**. In some embodiments of the invention a control system simultaneously increases the rate of operation of feed pump **70** and decreases the rate of operation of feed pump **72** or vice versa. The rate of operation of pumps **70** and **72** may be controlled by adjusting the rate of rotation of motors which drive the pumps, by adjusting displacements of the pumps, or the like.

[0195] In the illustrated embodiment, control is accomplished by operating a power splitter **88** (illustrated schematically by a potentiometer). Power splitter **88** can be operated to increase the speed of a motor driving pump **70** and to decrease the speed of a motor driving pump **72** or vice versa.

[0196] Systems **60**, **60**A and **60**C may be automatically controlled using any suitable control system. For example, a controller may be provided to operate bypass valves and/or control pump speeds or displacements by way of suitable actuators (not shown) as necessary to control pressure within volume **20** to stay within a desired range. Those skilled in the art are familiar with suitable controllers. The controller may, for example, comprise a suitable programmed programmable controller or a hardware controller. One or more pressure sensors and/or flow sensors (not shown) may be included to provide feedback to the controller.

[0197] Any of cooling systems **60**, **60**A and **60**B could be adapted for warming by replacing ice **64** with a suitable heating element which can be operated to raise fluid **65** in reservoir **62** to a desired temperature. Instead of ice **64**, any of systems **60**, **60**A or **60**B could cool fluid **65** by way of a refrigeration system. However, a refrigeration system large enough to provide high-rate cooling of a living person is expensive, consumes a large amount of power and is not readily portable. Ice has the advantage that melting a block of ice takes a large amount of heat. A reservoir **62** containing enough ice to apply high rate cooling to a human subject for a significant period can be small enough to be readily portable.

[0198] **FIGS. 27 through 32**C show heat exchangers incorporating thermally-conductive members **14** or **114** as described above. The heat exchangers may be used to cool or warm various body parts of a living subject. **FIG. 27** shows a heat exchanger **310** adapted for cooling or warming the neck of a subject adjacent the subject's carotid arteries. Such a heat exchanger may be used to cool blood flowing to the subject's brain. Heat exchanger **310** comprises two pads **310**A and **310**B. The pads may be attached around a subject's neck with fasteners **313**A and **313**B which may, for example, comprise complementary hook and loop fasteners such as VELCRO™. A layer of thermally-conductive gel may be provided on the pad to improve heat transfer between the subject's skin and thermally-conductive members **114**. Cooling fluid may be introduced through an inlet port **322**. The cooling fluid circulates through both of pads **310**A and **310**B before exiting at outlet port **323**. A tube **311** carries fluid from pad **310**A to pad **310**B and a return tube **312** returns fluid from pad **310**B to pad **310**A.

[**0199**] **FIGS. 28A, 28B** and **28**C show a heat exchanger **310** like that of **FIG. 27** in position on the neck of a subject.

[**0200**] As shown in **FIGS. 29A through 30C**, additional heat exchanger pads may be connected in series with heat exchanger **310** to cool or warm a larger area of the subject. **FIGS. 29A, 29B** and **29**C show a system **318** which includes a pad **310**C configured to be applied over a subject's face. Pad **310**C receives fluid from pad **310**A through tube **311**A and returns fluid to pad **310**B through tube **312**A. Pad **310**C is held in place by a head strap **314** and a chin strap **315**.

[**0201**] **FIGS. 30A, 30B** and **30**C show a head cooling and/or warming system **320** which includes a scalp pad **310**D in addition to the pads **310**A, **310**B and **310**C of the system of **FIGS. 29A through 29C**. Scalp pad **310**D is configured to conform substantially with the scalp of a subject. In the illustrated embodiment, scalp pad **310**D receives fluid from face pad **310**C by way of tube **311**B and returns fluid to face pad **310**C by way of tube **312**B.

[**0202**] **FIG. 31** illustrates a system **340** for cooling or warming multiple regions of a subject. System **340** includes a head cooling and/or warming system **320** as shown in **FIGS. 30A through 30C**, a torso cooling and/or warming system **342** and a thigh cooling and/or warming system **344**. Each of systems **320**, **342** and **344** are connected to a source **60** of a cooled (or warmed) fluid. The rate of flow of fluid through each of systems **320**, **342** and **344** may be independently regulated. In some embodiments of the invention, a controller associated with source **60** regulates the rate of fluid flow through systems **320**, **342** and **344** in response to measurements of the subject's core temperature or equivalent measurements and a target value for the subject's core temperature.

[**0203**] **FIG. 32A** illustrates a possible arrangement of fluid passages in head cooling and/or warming system **320**. **FIG. 32B** illustrates a possible arrangement of fluid passages in torso cooling and/or warming system **342**. **FIG. 32C** illustrates a possible arrangement of fluid passages in thigh cooling and/or warming system **344**. Thermally-conductive members **114** have been omitted from **FIGS. 32A through 32C** for clarity.

[**0204**] As noted above, heat exchangers according to alternative embodiments of the invention may be applied to heating or cooling objects of diverse types. For example, **FIG. 33A** shows a heat exchanger **10** being used to cool an electric motor **52**. Bases **29** of thermally-conductive members **14** contact the curved outer surface **53** of motor **52**. **FIG. 33B** shows a heat exchanger **10** being applied to cool a compressor **54** having an outer housing **55** which has a profile having compound curvature. Bases **29** contact the surface of housing **55**. Compressors having compound curves are frequently used in refrigeration and air conditioning systems. **FIG. 33C and 33D** show a heat exchanger **10** being applied to cool a pipe **56**. Bases **29** contact an outer cylindrical surface **57** of pipe **56**. Pipe **56** could be an exhaust pipe, for example.

[**0205**] Bases **29** or **129** of thermally-conductive members of heat exchangers as described herein may be shaped to better conform with a surface of an object to be warmed or cooled. For example, **FIG. 33E** shows a heat exchanger in which bases **129** of thermally-conductive members **114** are machined or otherwise shaped to provide concave faces **129**A. Faces **129**A each have a radius of curvature to match that of the cylindrical surface of a housing **55** of an object to be heated or cooled. On other embodiments (not shown), thermally-conductive members **14** or **114** may have faces shaped to provide convex surfaces of surfaces having more complex shapes to match the profile of a surface of an object to be cooled or heated. In some cases, ends of thermally-conductive members **14** or **114** may be affixed, for example, with bolts or studs, to a surface of an object to be cooled or heated.

[**0206**] An object to be heated or cooled may be specially configured to match a heat exchanger according to this invention. **FIG. 33F** shows an object to be cooled which has sockets **55**A in an outer housing **55**. A heat exchanger has thermally-conductive members **114** having bases **129** with ends **129**B inserted into and shaped to conform with sockets **55**A. A suitable thermally-conductive paste may be used to enhance thermal contact between thermally-conductive members **114** and housing **55**. **FIG. 33G** shows thermally-conductive members having ends shaped in various ways.

[**0207**] **FIG. 34** illustrates schematically a heat exchanger **58** being used to cool an object **59** having a temperature high enough that it could cause degradation of material **30**. Heat exchanger **58** is similar to heat exchanger **10** except that bases **29** are elongated so that they contact object **59** at a location spaced away from material **30**. A heat shield **360** is provided between object **59** and material **30**. Thermally-conductive members **14** pass through the heat shield. Each of thermally-conductive members **14** extends through a thermally insulating sleeve **59**A. Sleeves **59**A protect material **30** from becoming overheated through contact with members **14**. Shield **360** protects material **30** from heat radiated by object **59**.

[**0208**] Heat exchangers may also be used to transfer heat between fluids and/or between solid objects. **FIG. 35A** shows a heat exchanger **61** comprising a membrane of a material **30** penetrated by thermally-conductive members **62**. Members **62** have bodies **29** on both sides of material **30**. As shown in **FIG. 35B**, bodies **29** can optionally comprise fins, pins or other thermally-conductive elements disposed to provide improved thermal contact between the body **29** and a surrounding fluid. The heat exchanger **61**A illustrated in **FIG. 35B** has pins **32** projecting from each body **29**. Bodies **29** are larger in area than the central portions of members **14** which pass through material **30**. The edges of the bodies press against the membrane to seal any gap between the member and the membrane so that fluid will not leak from one side to the other.

[**0209**] **FIGS. 36A through 37F** show a pad **510** according to one embodiment of the invention. Pad **510** has an inlet **512** for receiving a heat exchange fluid **513**, a path **514** along which heat exchange fluid **513** can flow, and an outlet **516**. In some embodiments, heat exchange fluid **513** is recirculated along a fluidic circuit extending between a temperature controller and one or more pads **510**. For example, pad **510** may be used in one of the systems for heating or cooling a body disclosed in PCT patent application No. PCT/CA2004/001660.

[0210] Path **514** of pad **510** is defined in a chamber **518** between a back sheet **520** and a front sheet **522** that are bonded together along connection lines **523**. Connection lines **523** comprise locations along which back sheet **520** and front sheet **522** are affixed to one another by welding, a suitable adhesive, or other suitable affixation means. Thermally-conductive members **524** are disposed along path **514**. Each thermally-conductive member **524** penetrates and is sealed to front sheet **522** to prevent heat exchange fluid **513** from leaking around thermally-conductive members **524**.

[0211] Each thermally-conductive member **524** has an outer face **524**A on a front face of pad **510** and an inner face **524**B on a part of member **524** that projects into chamber **518**. Inner faces **524**B of thermally-conductive members **524** are in contact with heat exchange fluid **513**. Thermally-conductive members **524** may have, for example, any of the constructions described in the above-noted PCT application.

[0212] Rear sheet **520** is formed to provide a cup **530** coinciding with each thermally-conductive member **524**. As seen best in **FIGS. 37B and 37C**, the cross-sectional area of path **514** alternates between cups **530** in which the cross-sectional area is relatively large and constricted areas **532** between thermally-conductive members in which the cross-sectional area of path **514** is relatively small. In embodiments illustrated by **FIG. 37B**, the clearance **535** between inner face **524**B of the thermally-conductive member **524** and rear sheet **520** is greater than the clearance between rear sheet **520** and front sheet **522** in constricted area **532**. In the embodiments illustrated by **FIG. 37C**, the width of path **514** is greater in portions of path **514** adjacent a thermally-conductive member **524** than it is in its constricted portions **532**.

[0213] In some preferred embodiments front sheet **522** and rear sheet **520** are very flexible fluid-impermeable sheets such as thin sheets of polyether thermoplastic polyurethane. This material has a temperature range from −60 C to 140 C. Front sheet **522** and rear sheet **520** may also be made of other suitable materials, such as urethane, polyurethane, polyvinylchloride (PVC), rubber, silicone, or the like. Various materials suitable for use as front sheet **522** and rear sheet **520** are described in the above-noted PCT application. The material of rear sheet **520** is preferably somewhat elastic. Urethane having a thickness of approximately 0.015 inches has been found to be a satisfactory material to use for rear sheet **520**.

[0214] For some applications, the thermal characteristics of the materials are important. For example, some polyvinylchloride materials become quite brittle at temperatures below 5° C. Ethylvinylacetate can also become undesirably rigid at low temperatures. Such materials would not be optimum choices for front sheet **522** and rear sheet **520** in applications where a pad **510** is operated at lower temperatures.

[0215] Fluid flowing along path **514** encounters a pattern of alternating constrictions **532** and enlarged areas corresponding to cups **530**. Although the inventors do not wish to be bound by any particular theory of operation, this alternating pattern of areas of greater and lesser cross-sectional area is thought to help to prevent chamber **518** from becoming overly inflated and overly rigid as heat exchange fluid **513** flows through pad **510**. This pattern may also assist heat transfer between thermally-conductive members **524** and heat exchange fluid **513**.

[0216] In some embodiments of the invention the cross-sectional area of path **514** in constricted areas **532** is about 50% or less, (in some embodiments 25% or less, or even 10% or less) of the cross-sectional area of path **514** in the vicinity of a thermally-conductive member **524**. In all such embodiments, the cross-sectional area in constricted areas **532** can be said to be "substantially less" than the cross sectional areas adjacent thermally-conductive members **524**.

[0217] The configuration of path **514** can be adjusted by altering the manner in which rear sheet **520** is formed. For example, making cups **530** deeper increases the cross-sectional areas of path **514** in its parts adjacent to thermally-conductive members **524**. The configuration of path **514** can also be adjusted by altering the paths of connecting lines **523**. For example, the cross-sectional area of constricted portions **532** can be made smaller by making the opposing connecting lines **523** closer to one another. Similarly, the cross-sectional area of constricted portions **532** can be made larger by making the opposing connecting lines **523** farther apart from one another.

[0218] **FIG. 37F** shows an alternative embodiment of the invention wherein connecting lines **523** are straight and constricted portions **532** are defined, in part, between opposing spot connections **523**A and **523**B. **FIG. 37G** shows a pad **510**A which is similar to pad **510**. In pad **510**A the pattern of cupped areas **530** and back sheet **520** and connecting lines **523** and spot connections **523**A and **523**B is such that path **514** follows a zig-zag course.

[0219] **FIGS. 38A** to **38**C illustrate the fact that a pad according to the invention can be very flexible and can be made to conform with a surface of a body such as the cylindrical body **540**. Body **540** can be anything that it is desired to heat or cool with a pad **510** according to the invention. Body **540** may be a portion of a body of a living being, such as a human or animal, or may be a part of a device, machine or the like.

[0220] **FIGS. 39A through 39C** show thermal reservoirs **550**A, **550**B and **550**C (collectively thermal reservoirs **550**) as provided by another aspect of the invention. Each thermal reservoir **550** comprises a bladder **552** containing a heat storage material, which is preferably a liquid, such as water, that has a phase transition (e.g. freezing/melting) at a temperature in a range of interest. The heat storage material can either take in or give out heat.

[0221] A number of thermally-conductive members **524** penetrate the material of bladder **552** on at least one face thereof. Thermally-conductive members **524** provide paths of very high thermal conductivity between their outer faces **524**A and the heat storage material contained within bladder **552**. Thermal reservoirs **550** may be used as ice packs, or may be used to warm or cool a heat exchange fluid, or the like.

[0222] Each bladder **552** is made of a suitable material (which may be a material of the same type as used for the pads **510** described above). While bladders **552** are preferably flexible, in some embodiments of the invention, bladders **552** are of a stiffer material, such as a plastic, that holds its shape.

[0223] Thermally-conductive members **524** may be arranged in any suitable patterns on thermal reservoirs **550**.

Thermally-conductive members **524** may be disposed on one or more sides of a thermal reservoir **550**.

[0224] **FIGS. 39D, 39E** and **39**F show a thermal reservoir **555** that combines structural features of a pad **556** that is like pad **510** of **FIGS. 36A and 36B**, and a bladder **557** filled with a heat storage material **558**. Bladder **557** may, for example, be filled with water. The water may be frozen. A heat exchange fluid may subsequently be cooled by circulating it through pad **556**.

[0225] As shown in **FIGS. 39E and 39F** the front sheet **522** of pad **556** forms a portion of one wall of bladder **557**. Faces **524**A of thermally- conductive members **524** are in contact with heat storage material **558**. Faces **524**B of thermally-conductive members **524** are in contact with heat exchange fluid **513** in pad **556**. As heat exchange fluid **513** is circulated through pad **556** it is either warmed or cooled. Whether heat exchange fluid is warmed or cooled depends upon the relative temperatures of the heat storage material **558** and the incoming heat exchange fluid **513**.

[0226] In the embodiment illustrated in **FIGS. 39D** to **39**F, bladder **557** is formed by affixing a sheet **559** to pad **556** in any suitable way. For example, sheet **559** may be welded to pad **556** to provide fluid-tight bladder **557**. In the illustrated embodiment, sheet **559** has been formed (for example by vacuum forming) to allow a relatively large volume of heat storage material **558** to be contained in bladder **557** without distortion of front sheet **522** of pad **556**.

[0227] One or more drain ports (not shown) may optionally be provided to allow heat storage material **558** to be added or changed. In some embodiments, a hole is punched through the walls of bladder **557**. Heat storage fluid **558** is introduced through the punched hole. The hole is then sealed by a rivet and washer as described in the appended PCT application.

[0228] **FIGS. 39G and 39H** show a thermal reservoir according to a further embodiment of the invention in which bladder **557** is roughly lenticular in cross section when filled with thermal storage material **558**.

[0229] **FIGS. 40A** to **40**E show systems for heating or cooling a living being (a "subject") or an object which incorporate one or more heat exchange pads, as described above and/or one or more thermal reservoirs as described above. **FIG. 40A** shows a system **560** that has a pad **510** connected in a fluid circuit **562** through which a heat exchange fluid **513** is circulated by a pump **564**. Outer faces **524**A of the thermally-conductive members **524** of pad **510** are in thermal contact with an ice pack **565**. System **560** includes a heat exchanger **566**, which could comprise another pad **510**, a pad as described in PCT patent application No. PCT/CA2004/001660, or some other heat exchanger. Heat exchanger **566** is in contact with a body to be cooled. For example, heat exchanger **566** may be in contact with a portion of a human or animal body to be cooled.

[0230] Fluid **513** passes out of pad **510** at outlet **516**, along tube **567**A to heat exchanger **566**. Fluid **513** returns to pad **510** by way of tube **567**B, pump **564** and tube **567**C. A controller **568** (which may comprise any suitable programmable controller or control circuitry, for example) senses a temperature of heat exchange fluid **513** circulating past a temperature sensor **569** and controls pump **564** to adjust a rate of flow of the heat exchange fluid **513** to maintain a desired temperature. Additional temperature sensors (not shown) may be provided in other parts of fluid circuit **562** (for example at heat exchanger **566**) to provide additional inputs to controller **568**.

[0231] The provision of a pad **510** equipped with thermally- conductive members **524** helps to facilitate transfer of heat from circulating heat exchange fluid **513** into ice pack **565**. Apparatus **560** could use a pad of one of the types described in PCT patent application No. PCT/CA2004/001660 in place of pad **510**.

[0232] **FIG. 40B** shows a system **570** for heating or cooling that is similar to system **560** of **FIG. 40A** but differs in two respects. In system **570** temperature sensor **569** senses the temperature of heat exchange fluid **513** returning to pad **510** from heat exchanger **566** instead of the temperature of heat exchange fluid being carried from pad **510** to heat exchanger **566**. Also, system **570** has a thermal reservoir **555** which may be like that shown in **FIGS. 39D, 39E** and **39**F, for example. Thermally-conductive members **524** of pad **10** are in contact with thermally-conductive members **524** of thermal reservoir **555**.

[0233] In some embodiments of the invention, thermally-conductive members **524** are arranged in complementary patterns on pad **510** and thermal reservoir **555**. In some embodiments of the invention, the faces of thermally-conductive members **524** of pad **510** have shapes that are complementary to the shapes of the faces that they contact of thermally-conductive members **524** of thermal reservoir **555**. For example, the faces of both sets of thermally-conductive members may be flat so that a large area of contact is made between the thermally-conductive members **524** of pad **510** and the thermally-conductive members **524** of thermal reservoir **555**. In some embodiments, magnets or other means may be provided to urge the thermally-conductive members **524** of pad **510** into contact with the thermally-conductive members **524** of thermal reservoir **555** to ensure maximum surface area contact between the thermally-conductive members **524** of pad **510** and the thermally-conductive members of thermal reservoir **555**. For example, a small rare-earth magnet may be embedded in a thermally-conductive member **524** of pad **510** and another small magnet of opposite orientation or a piece of ferromagnetic material may be embedded in the corresponding thermally-conductive member of heat reservoir **555**.

[0234] **FIG. 40C** shows a cooling system **572** which is similar to system **560** except for the locations in circuit **562** of pump **564** and temperature sensor **569** and the arrangement of pad **510**. System **572** uses a larger pad **510** than is shown in system **560**. In system **572**, pad **510** is wrapped around ice pack **565**. Another feature of system **572** is that heat exchanger **566** is expressly indicated as being equipped with thermally- conductive members **524**.

[0235] **FIG. 40D** shows a heating or cooling system **574** in which heat exchange fluid circulating in pad **510** is in contact with a thermal reservoir **575** having thermally-conductive members **524** on multiple faces. Thermal reservoir **575** has a first group **577** of thermally-conductive members **524** on its top surface and a second group **578** of thermally-conductive members **524** on its bottom surface. Thermally-conductive members of pad **510** are in contact with both sets of thermally-conductive members of thermal reservoir **575** to enable a relatively high rate of heat transfer between heat exchange fluid **513** circulating in pad **510** and the heat exchange material **558** in thermal reservoir **575**.

[0236] **FIG. 40E** shows a system **580** for warming or cooling a person, animal or object having an integrated thermal reservoir **555** like that shown in **FIGS. 39D through 39F**. A heat exchange fluid **513** is heated or cooled as it circulates through integrated thermal reservoir **555**. The fluid passes through a heat exchanger **566** which is in thermal contact with a person, animal or object to be heated or cooled.

[0237] In alternative systems like those of **FIGS. 40A** to **40**E, a pad **510** containing a heat exchange fluid **513** could be immersed in or in contact with a liquid that acts as a thermal reservoir. The liquid of the thermal reservoir may be at a temperature suitable to take up or give heat to the heat exchange fluid **513** circulating in the pad **510**. for example, in some embodiments, the liquid of the thermal reservoir may comprise a volume of cold water or ice water.

[0238] Another embodiment of the invention is illustrated by **FIG. 41** which shows a system **590** for cooling a person or object. System **590** comprises a source **592** of compressed heat exchange fluid **593**, which may comprise compressed air, for example. An air compressor (not shown) may be provided to fill source **592** with compressed air. Heat exchange fluid is allowed to pass through a control valve **594** into an expansion chamber **596**. Expansion of heat exchange fluid **593** causes heat exchange fluid **593** to become cooler. The cooled heat exchange fluid **593** passes from expansion chamber **596** into a heat exchanger **598**. Heat exchanger **598** is in contact with a person or animal or object to be cooled. After passing through heat exchanger **598**, the heat exchange fluid may be vented as indicated at **599**.

[0239] Heat exchanger **598** may comprise a pad (for example a pad **510**) as described herein or a heat exchanger as described in PCT patent application No. PCT/CA2004/001660. The heat exchanger **598** of **FIG. 41** has thermally-conductive members **524** that are in contact with heat exchange fluid **593** inside heat exchanger **598** and extend through a wall of heat exchange **598** to contact a body to be cooled.

[0240] A controller **600**, which may comprise a programmable controller or another suitable control circuit or mechanism operates control valve **594** in response to a temperature sensed at temperature sensor **602**.

[0241] System **590** could be used in any of many ways including to cool a subject's body in a case where cooling is required for some medical purpose or to provide comfort for a person in a hot environment, for example.

[0242] In lieu of, or in addition to an expansion chamber, system **590** could include a suitable "metering" device to decrease the pressure of the heat exchange fluid without the use of an expansion chamber. For example, system **590** may comprise an expansion valve, capillary line, etc. Such devices are known to those skilled in the fields of air conditioning and refrigeration.

[0243] **FIGS. 42A, 42B** and **42**C are views of a pad **610** according to an alternative embodiment of the invention. Pad **610** is substantially similar to pad **510** shown in **FIG. 37A** except that, in addition to thermally-conductive members **524** passing through front sheet **522**, pad **610** includes additional thermally-conductive members **624** that pass through rear sheet **520**. Pad **610** can exchange heat with thermal reservoirs or other heat sources or sinks on both of its sides. For example, when used in a system like system **560** or **570** (see **FIGS. 40A and 40B**) a pad **610** could be in thermal contact with ice packs, or thermal reservoirs **555** on both sides of the pad **610**. In the alternative, pad **610** may be immersed in a bath of liquid, in which case, the addition of thermally-conductive members **624** provides for a higher rate of heat transfer between the liquid and a heat exchange fluid **513** circulating in the pad **610**.

[0244] Where a component (e.g. a member, pump, valve, sensor, controller, assembly, element, device, circuit, etc.) is referred to above, unless otherwise indicated, reference to that component (including a reference to a "means") should be interpreted as including as equivalents of that component any component which performs the function of the described component (i.e., that is functionally equivalent), including components which are not structurally equivalent to the disclosed structure which performs the function in the illustrated exemplary embodiments of the invention.

[0245] As will be apparent to those skilled in the art in the light of the foregoing disclosure, many alterations and modifications are possible in the practice of this invention without departing from the spirit or scope thereof. For example:

[0246] Thermally-conductive members **14** or **114** may have any suitable shapes and arrangements. Those illustrated herein are but examples.

[0247] Flexible material **30** may have different compositions in different parts of a heat exchanger according to the invention. Different suitable flexible materials **30** may be used for material **30** in different parts of a heat exchanger.

[0248] A heat exchanger according to the invention is not necessarily rectangular or parallel-sided. A heat exchanger according to the invention could have other shapes. Heat exchangers according to some embodiments of the invention are elongated and have fluid inlets and fluid outlets located in areas at opposed ends of a long axis.

[0249] The arrangements of heat exchangers shown in the Figures could be applied to warm a subject instead of to cool a subject.

What is claimed is:

1. A flexible heat exchanger comprising:

a volume having at least one inlet for receiving a heat exchange fluid and at least one outlet; and,

a flexible front sheet essentially impermeable to the heat exchange fluid, the front sheet carrying a plurality of substantially-rigid members, each of the members comprising an exposed thermally-conductive surface on a thermally-conductive first body on an outside of the front sheet and having a thermally-conductive portion extending from the thermally-conductive first body, through the front sheet, and into the volume, each of the plurality of members comprising opposed gripping surfaces held firmly against opposed sides of the front sheet.

2. A flexible heat exchanger according to claim 1 wherein the volume is defined between the front sheet and a flexible rear sheet.

3. A flexible heat exchanger according to claim 2 wherein the rear sheet is shaped to provide indentations at locations that are adjacent to the substantially-rigid members and the thermally-conductive portions of the substantially-rigid members project into the indentations.

4. A flexible heat exchanger according to claim 3 wherein wherein the members are arranged in rows to provide a plurality of substantially unbroken lines of the front sheet extending between the rows of the members.

5. A flexible heat exchanger according to claim 1 wherein wherein the members are arranged in rows to provide a plurality of substantially unbroken lines of the front sheet extending between the rows of the members.

6. A flexible heat exchanger according to claim 4 wherein the members are arranged in an array such that the plurality of substantially unbroken lines of the front sheet includes first and second sets each comprising a plurality of the unbroken lines wherein the unbroken lines of the first set intersect with the unbroken lines of the second set.

7. A flexible heat exchanger according to claim 1 having drape.

8. A flexible heat exchanger according to claim 1 wherein the volume comprises a channel extending from the inlet to the outlet wherein a cross-section of the channel varies periodically along a length of the channel.

9. A flexible heat exchanger according to claim 8 wherein the thermally-conductive members are spaced apart along the channel and the channel includes constricted areas located between the thermally-conductive members.

10. A flexible heat exchanger according to claim 8 wherein the channel is a sinuous channel.

11. A flexible heat exchanger according to claim 1 wherein the thermally-conductive surface of the first body is spaced outwardly from the outside of the front sheet.

12. A flexible heat exchanger according to claim 1 wherein an area of the thermally-conductive surface of the first bodies exceeds a total cross sectional area of the thermally-conductive portions measured where the thermally-conductive portions pass through the front sheet.

13. A flexible heat exchanger according to claim 1 wherein the thermally-conductive portions project into the volume past an inside face of the front sheet by distances of at least 3 mm.

14. A flexible heat exchanger according to claim 1 wherein the thermally-conductive portions each have a thermal conductivity of at least 50 $Wm^{-1}K^{-1}$.

15. A flexible heat exchanger according to claim 1 wherein the thermally-conductive portions each have a thermal conductivity of at least 100 $Wm^{-1}K^{-1}$.

16. A flexible heat exchanger according to claim 1 wherein the thermally-conductive portions are made of metal.

17. A flexible heat exchanger according to claim 16 wherein the thermally-conductive portions are made of metals selected from the group consisting of: aluminum, copper, gold, silver, alloys of two or more of aluminum, copper, gold, or silver with one another and alloys of one or more of aluminum, copper, gold, or silver with one or more other metals.

18. A flexible heat exchanger according to claim 1 wherein the outside of the front sheet is faced with an absorbent fabric and the thermally-conductive portions of the members project through the absorbent fabric.

19. A flexible heat exchanger according to claim 1 wherein the plurality of the members covers at least 30% of an area of the outside of the front sheet.

20. A flexible heat exchanger according to claim 2 wherein the front and rear sheets are attached to one another in a pattern of attached areas to provide a sinuous channel in the volume, the sinuous channel and extending between the inlet and outlet.

21. A flexible heat exchanger according to claim 20 wherein the members are spaced apart along the channel, each of the members is located in a wider portion of the channel and the channel has a plurality of narrower portions spaced apart along the channel, the narrower portions each located between an upstream one of the members and a downstream one of the members.

22. A flexible heat exchanger according to claim 1 wherein, for each of the plurality of members, the sheet is received in a groove extending circumferentially around the member.

23. A flexible heat exchanger according to claim 1 wherein each of the plurality of members comprises a rivet having a head on the outside of the front sheet and a washer on an inside of the front sheet, the thermally-conductive body comprises a head of the rivet and the front sheet is gripped between the head of the rivet and the washer.

24. A flexible heat exchanger according to claim 1 wherein the thermally-conducting surface is either flush with or projects outwardly from an outside surface of the wall.

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