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(54) MULTIPLE THERMAL CIRCUIT HEAT SPREADER

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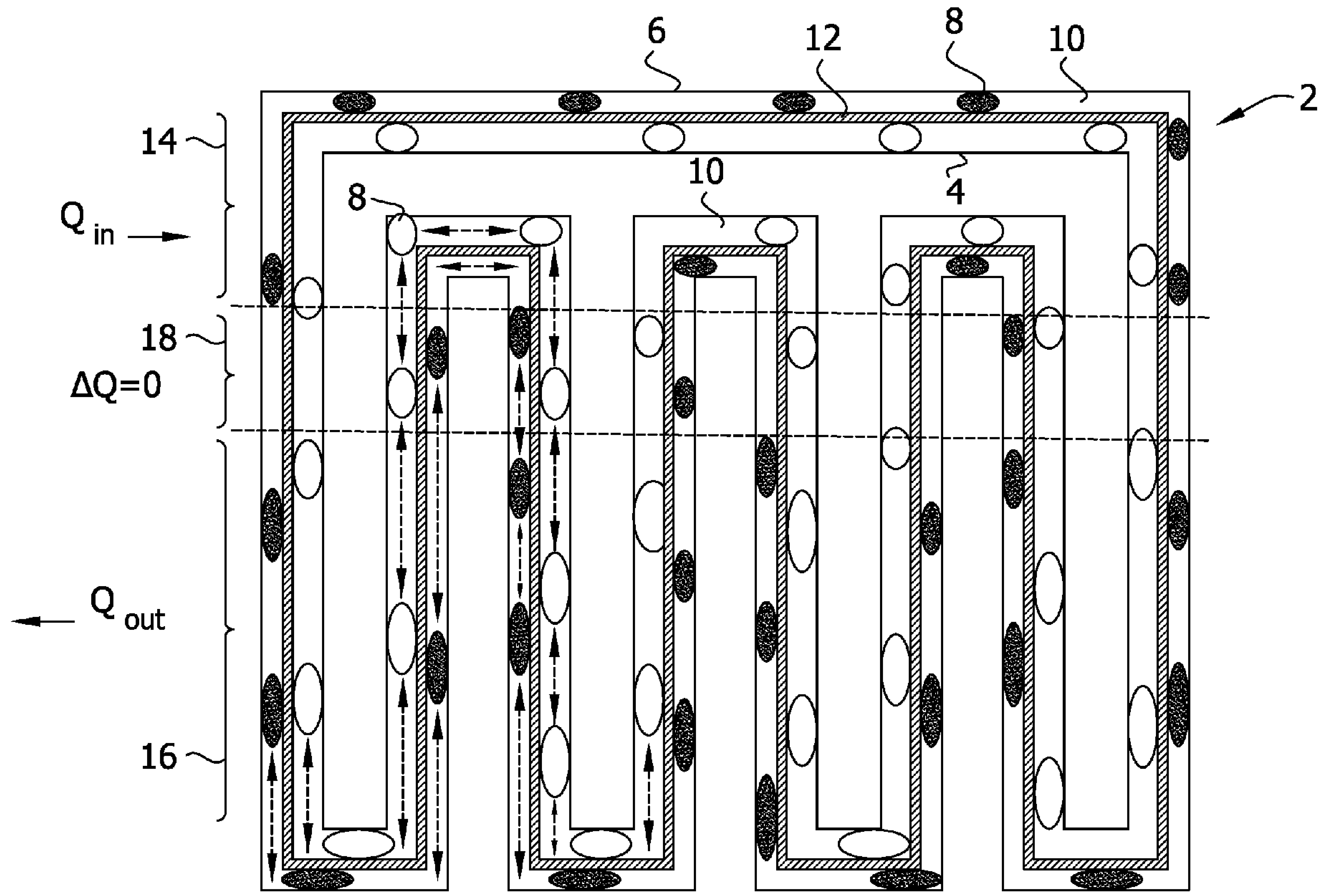
(57) **ABSTRACT**

A heat spreader has more than one thermal circuit to give better performance over a wider range of heat input regimes. Different working fluids may be used in the different thermal circuits. The thermal circuits may extend in three dimensions to improve the density of the channels in limited space.



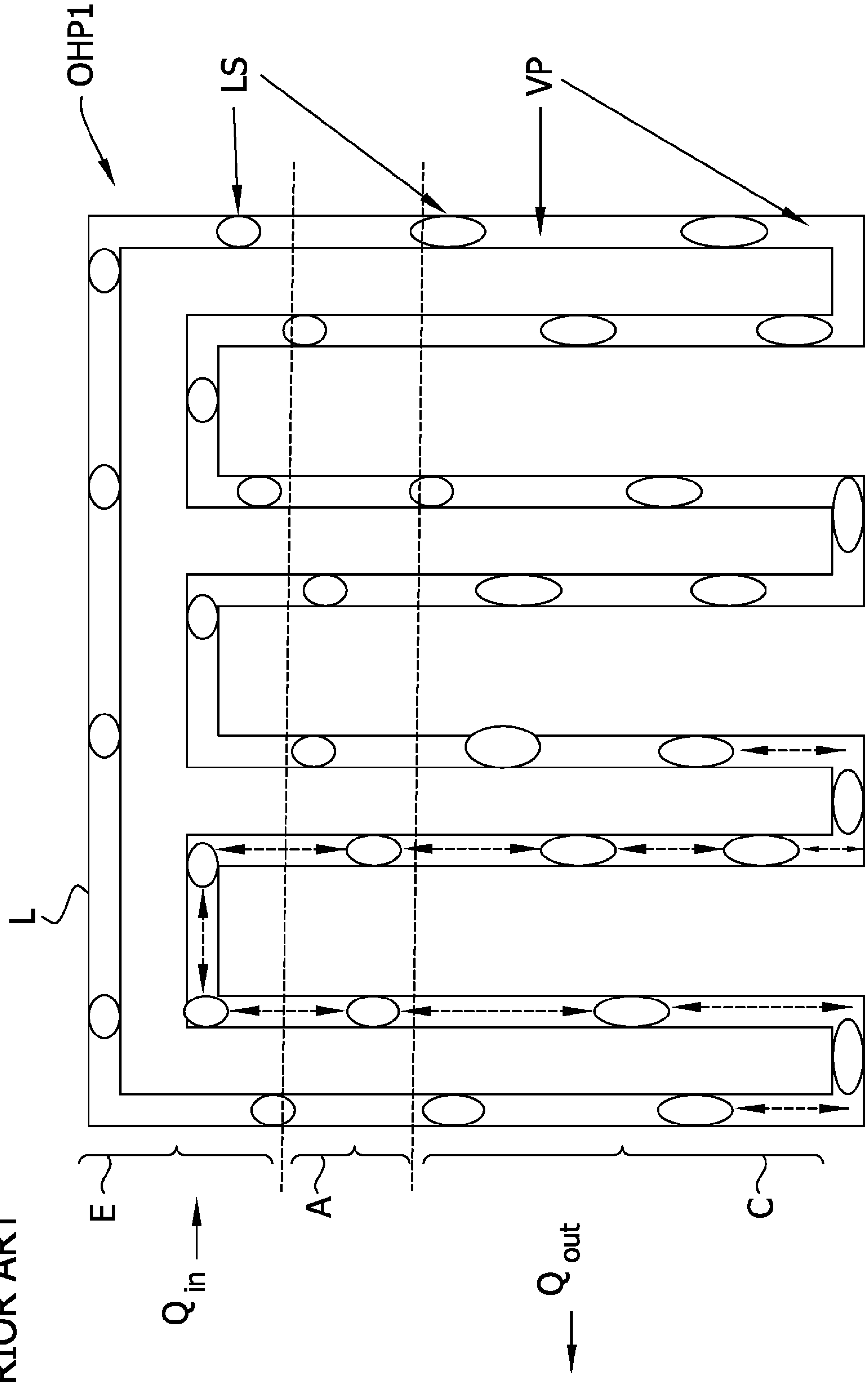


FIG. 1
PRIOR ART

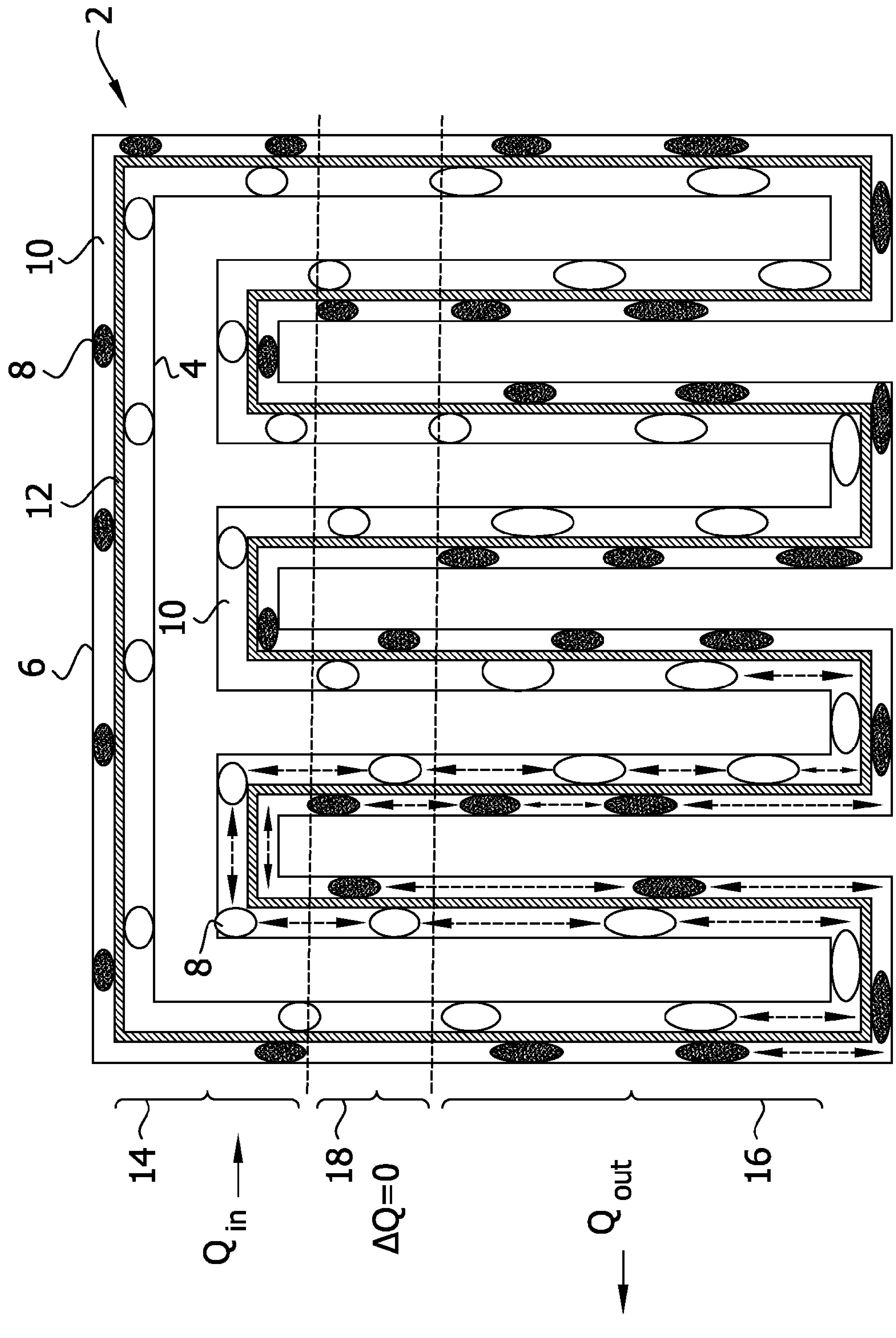


FIG. 2

FIG. 3

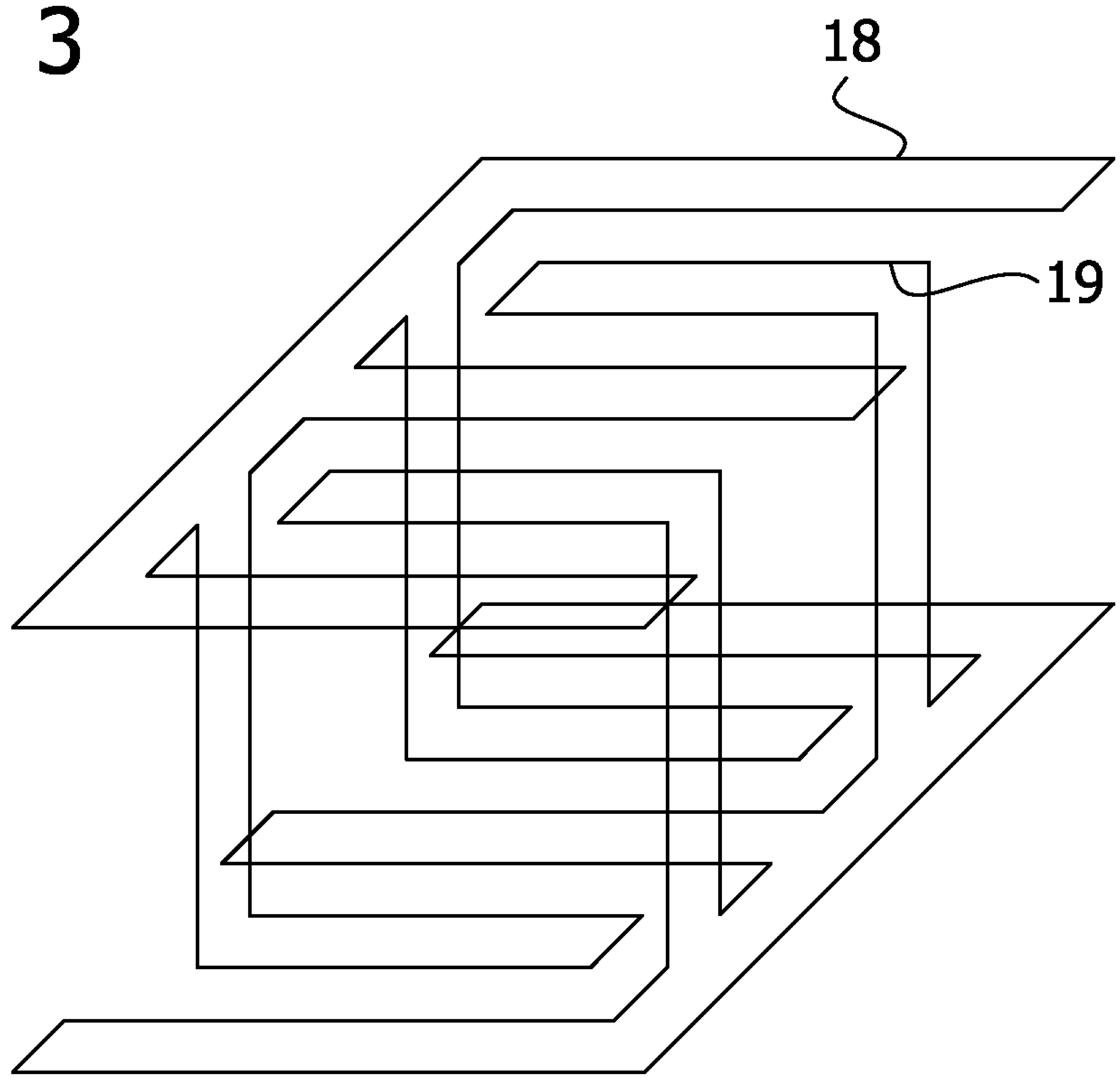
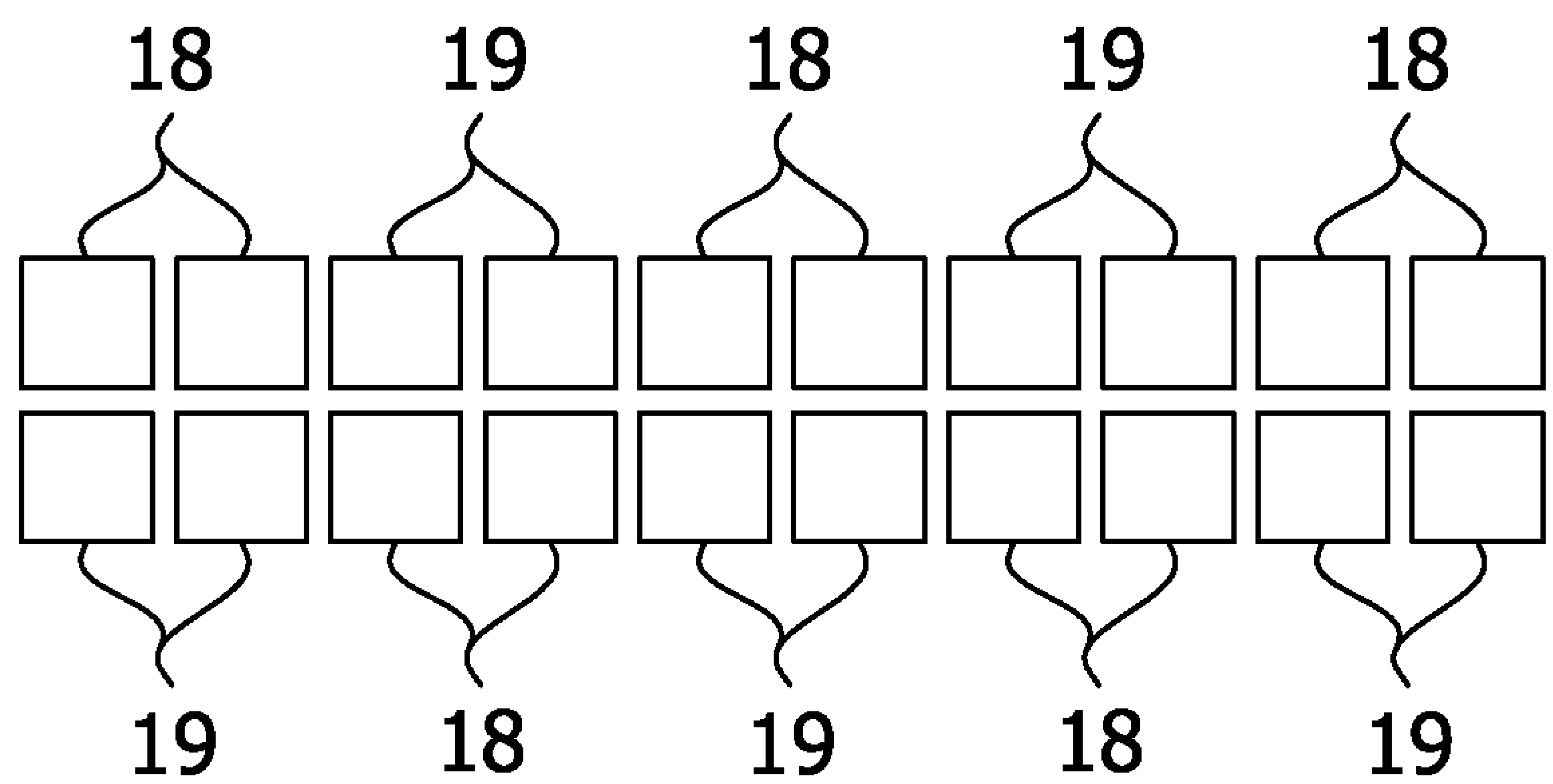


FIG. 3A



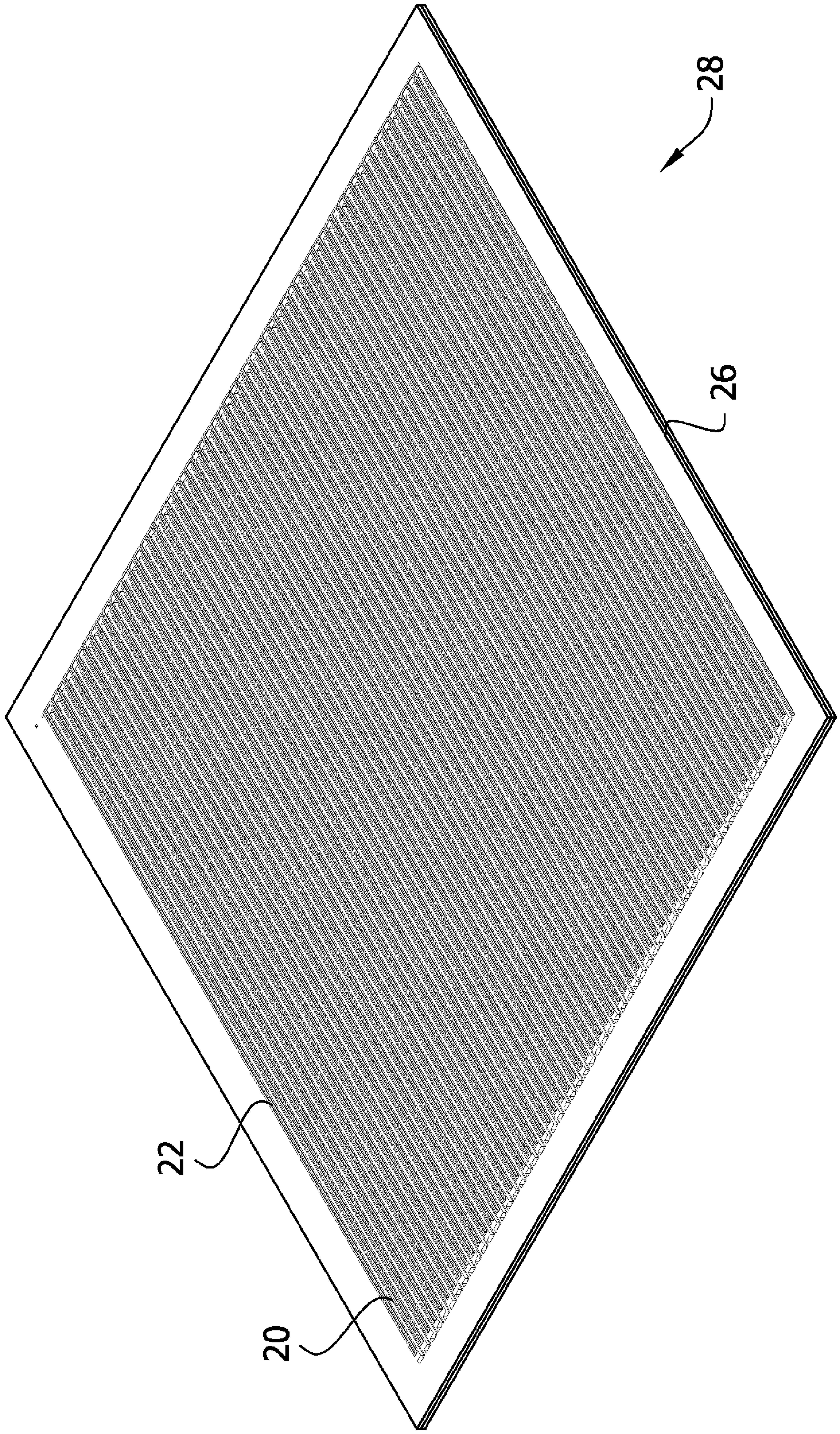


FIG. 4

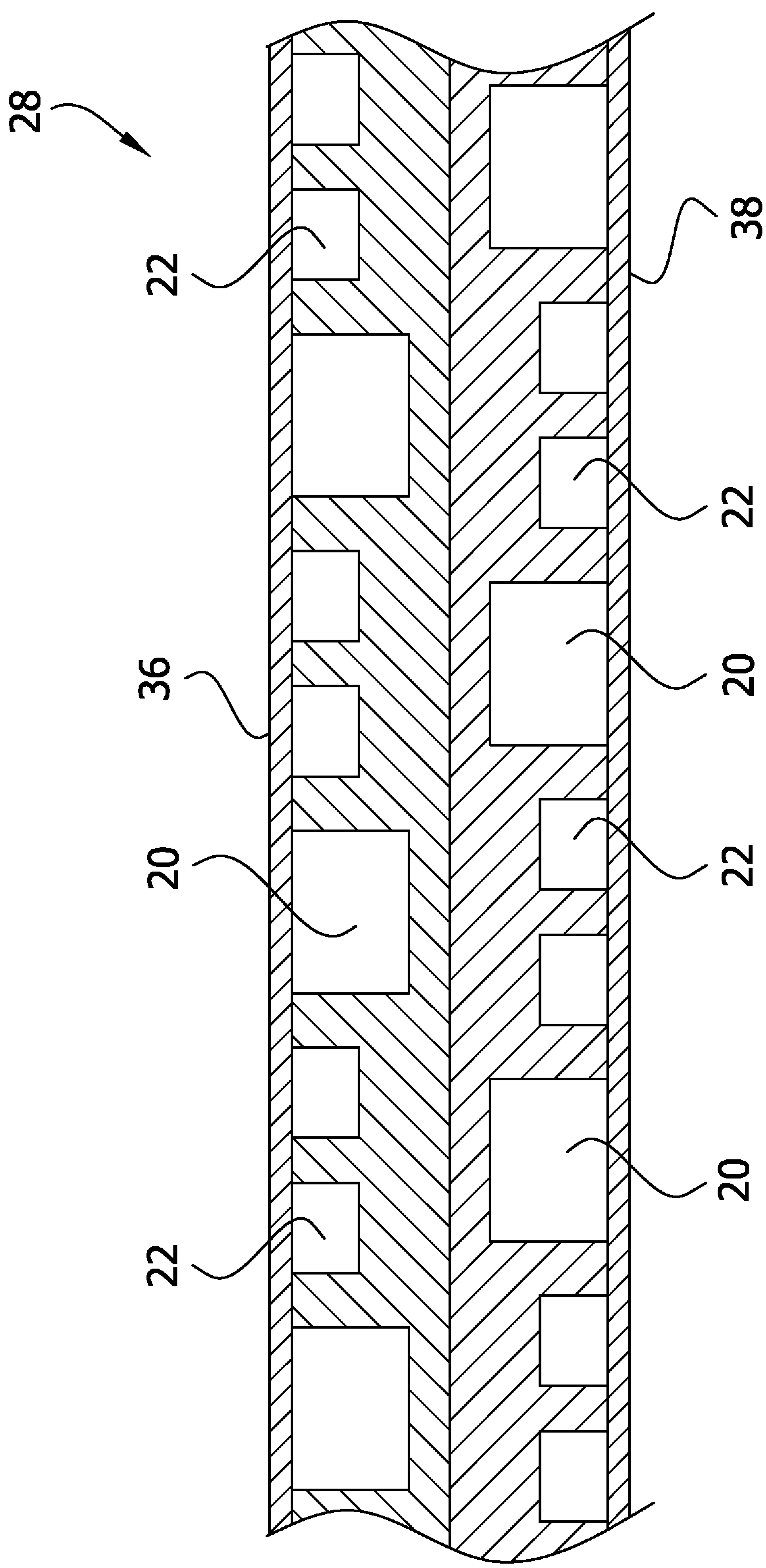


FIG. 5

FIG. 6

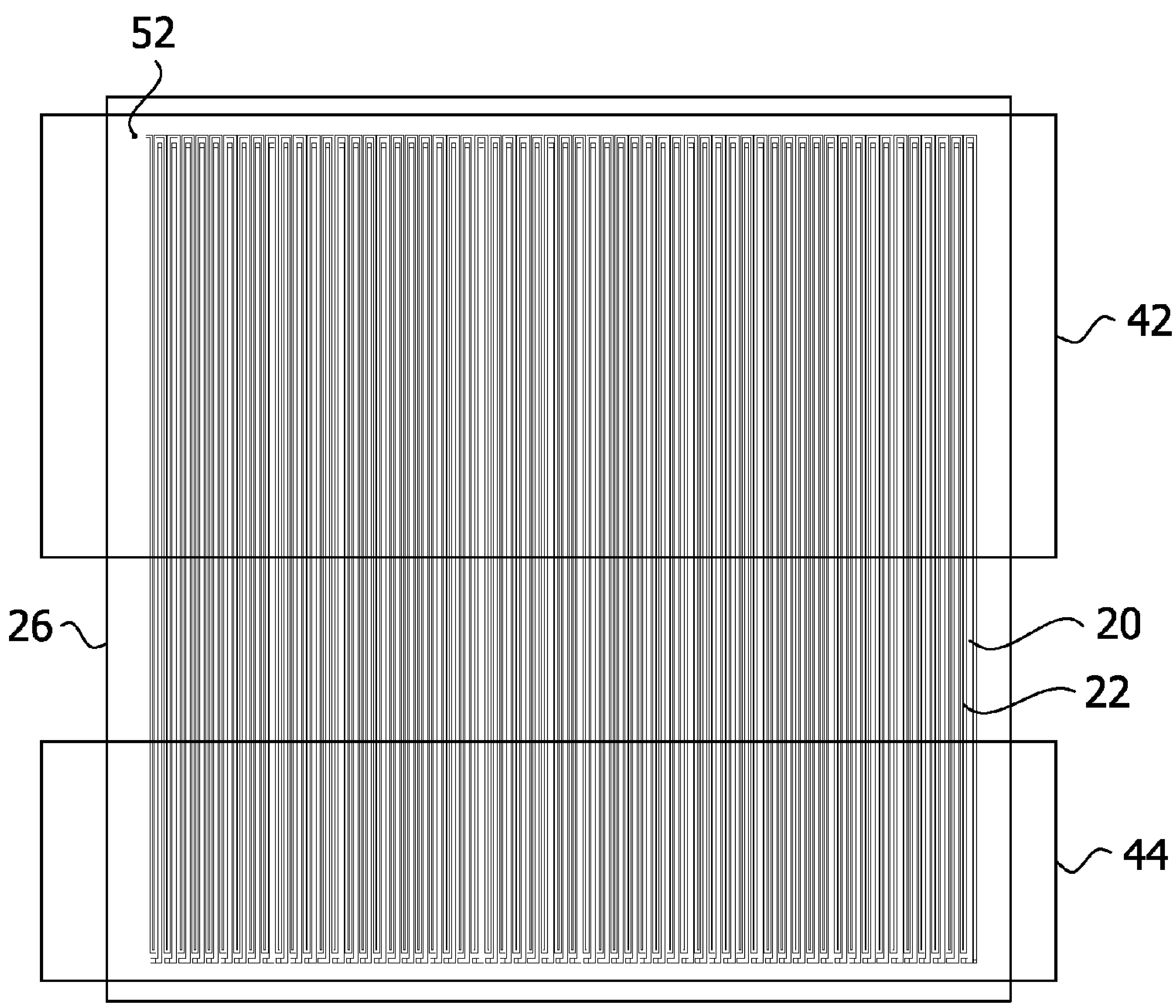


FIG. 6A

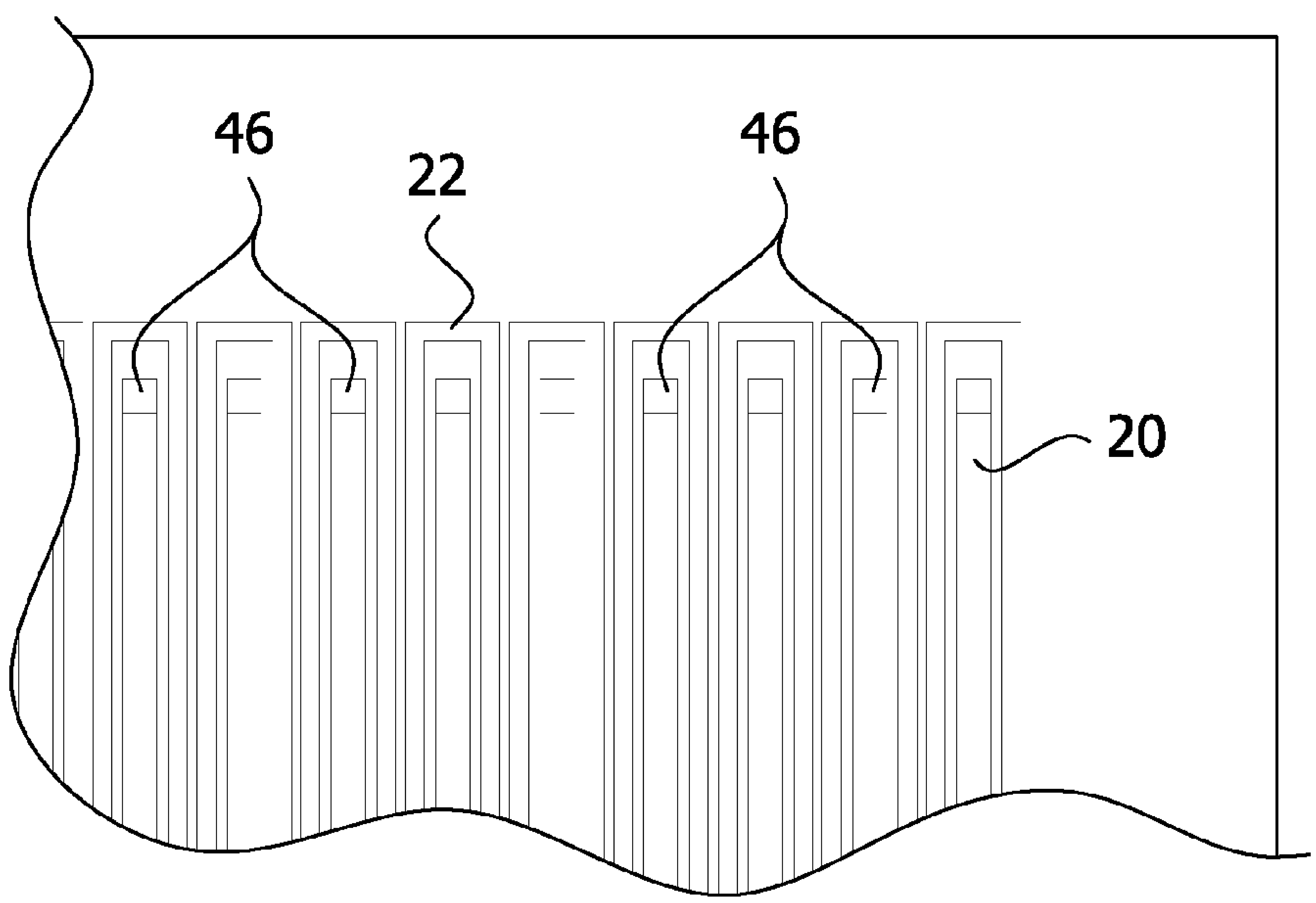


FIG. 6B

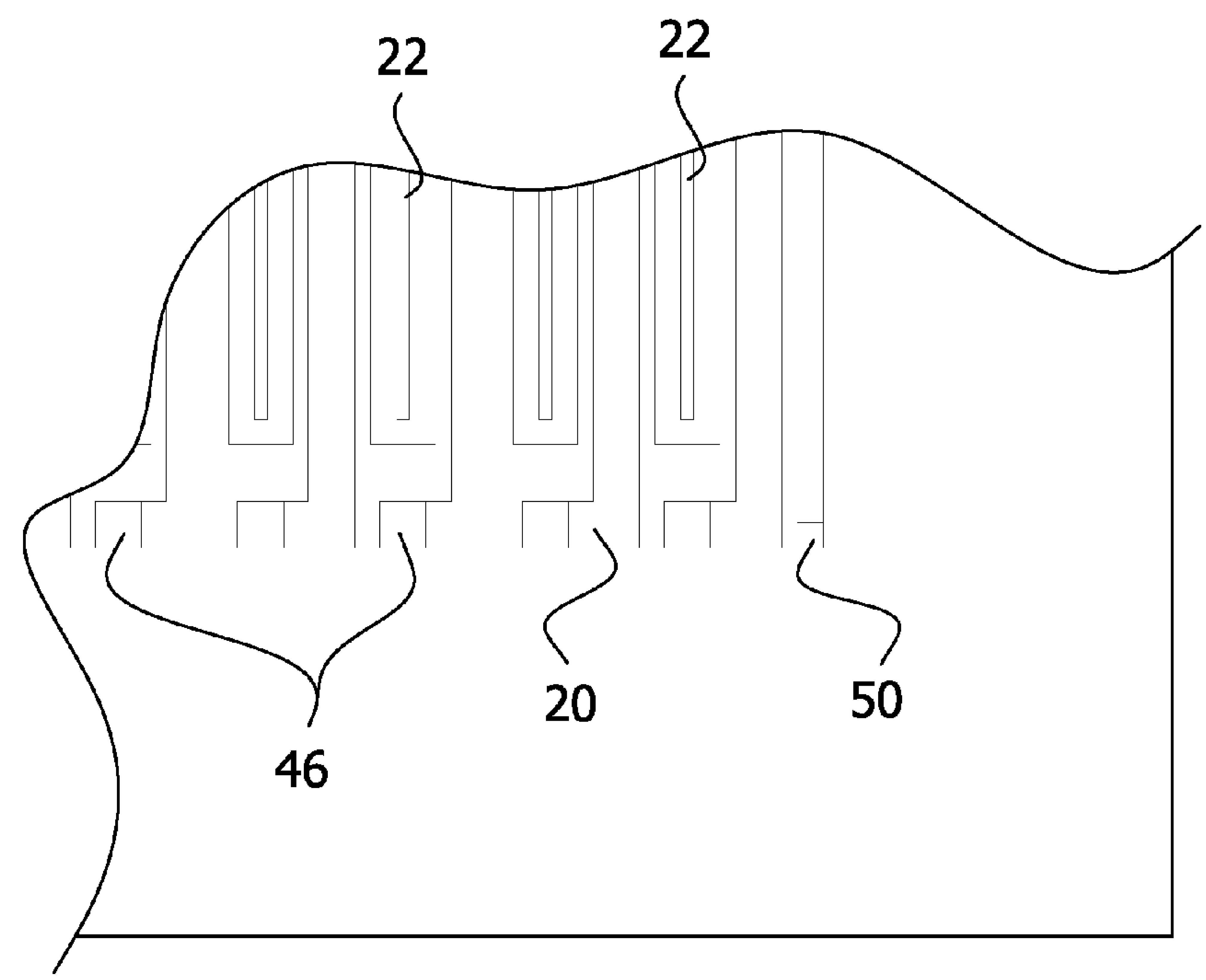


FIG. 7

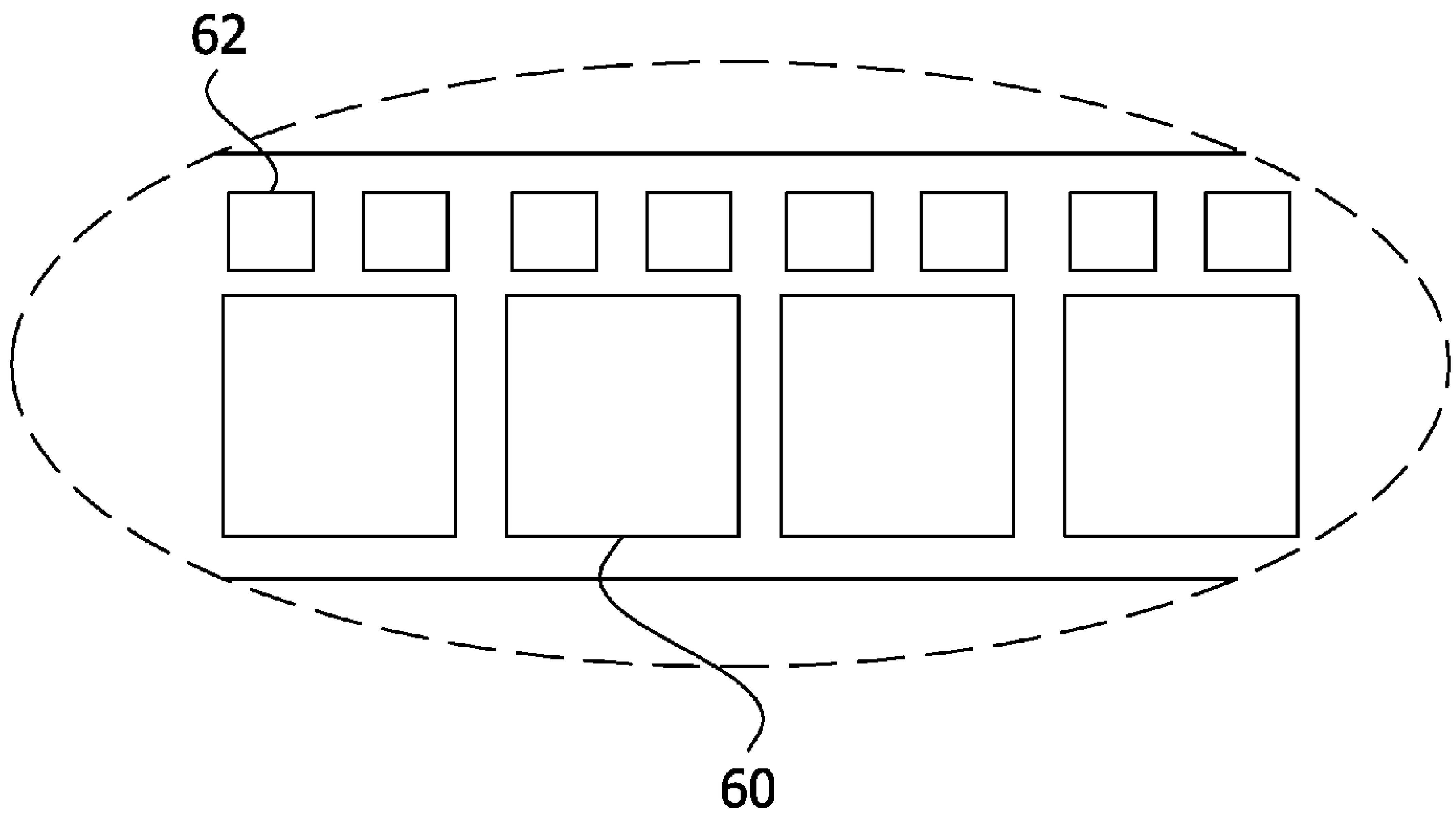


FIG. 7A

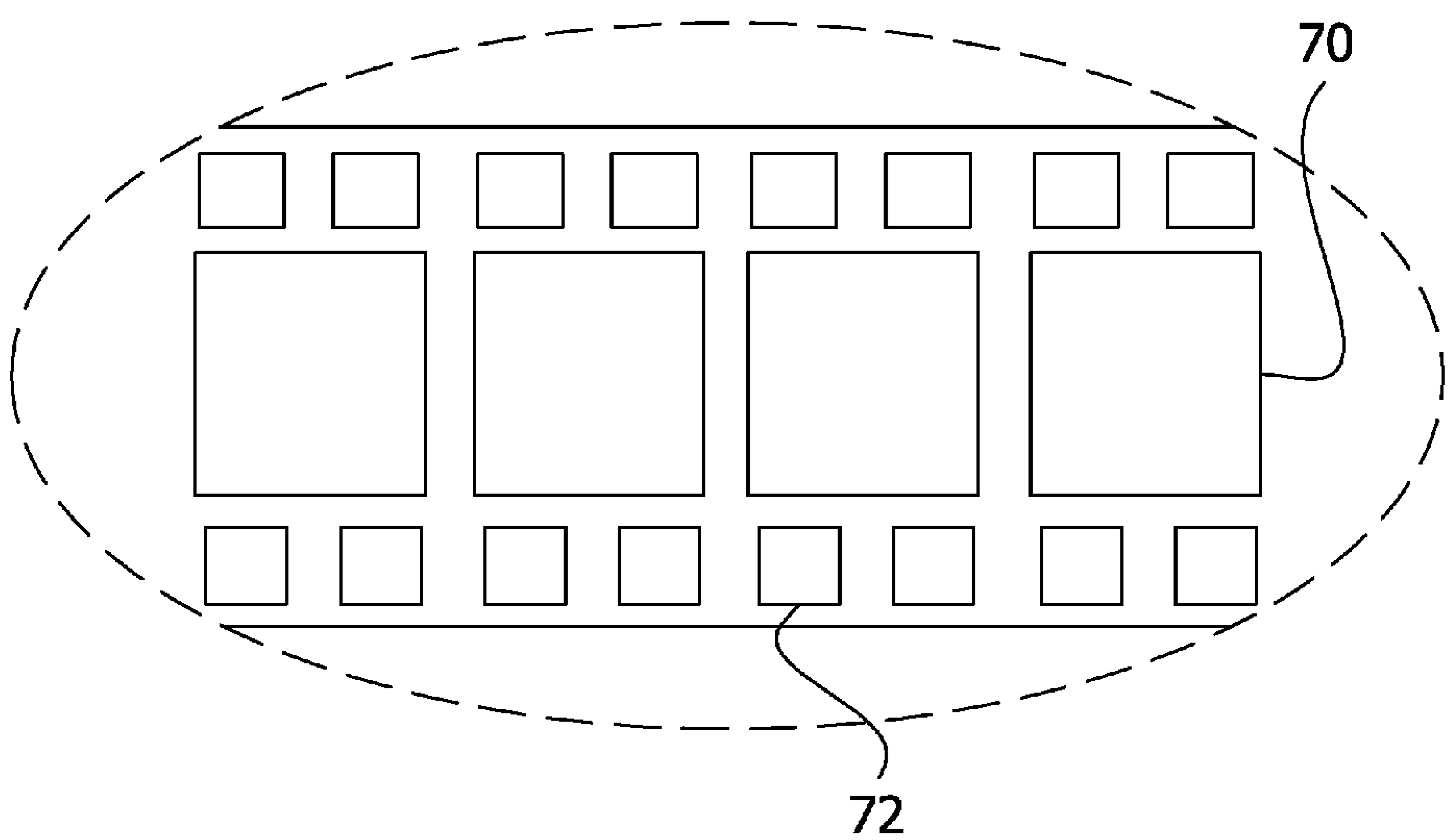


FIG. 8

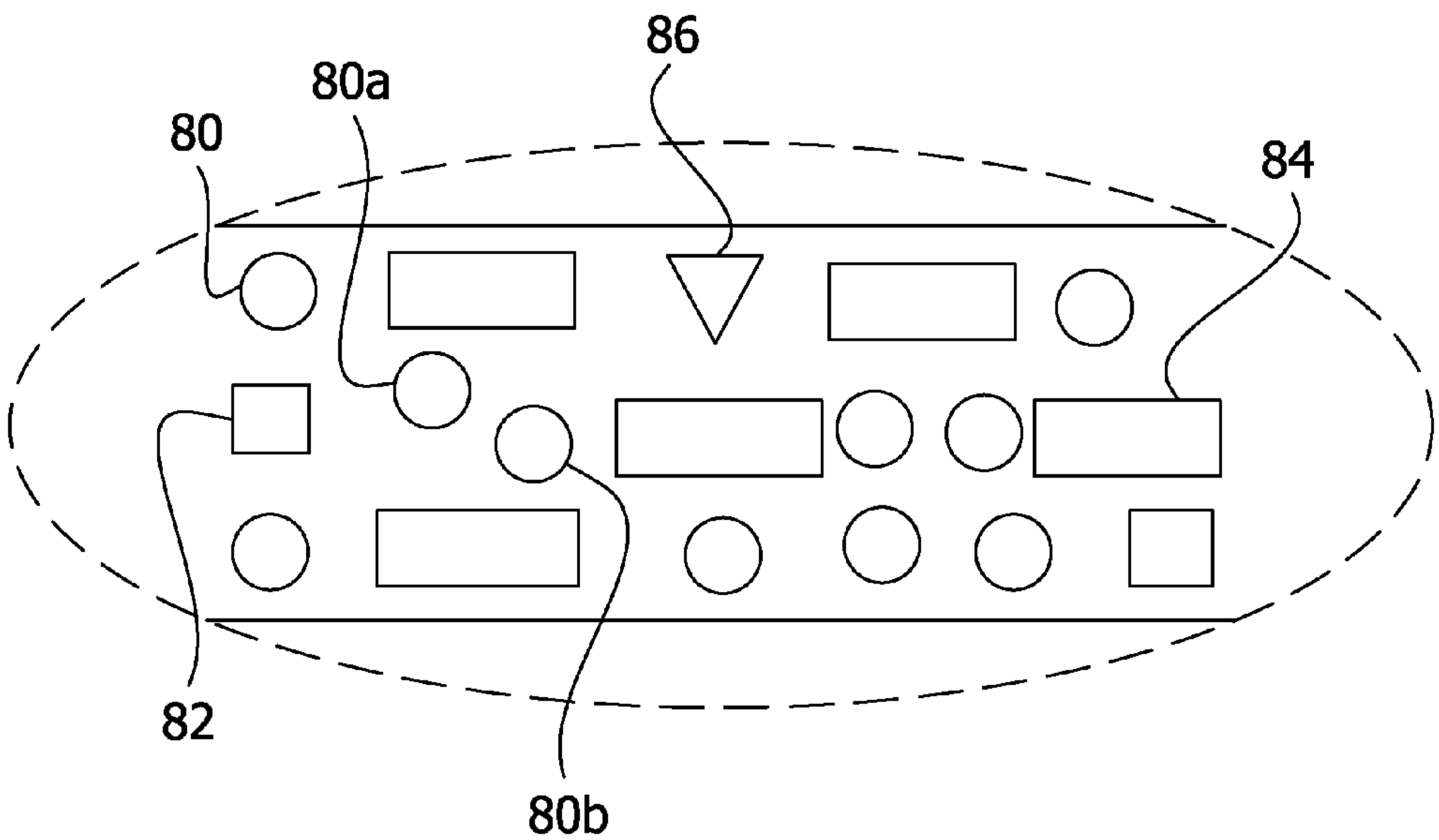


FIG. 9

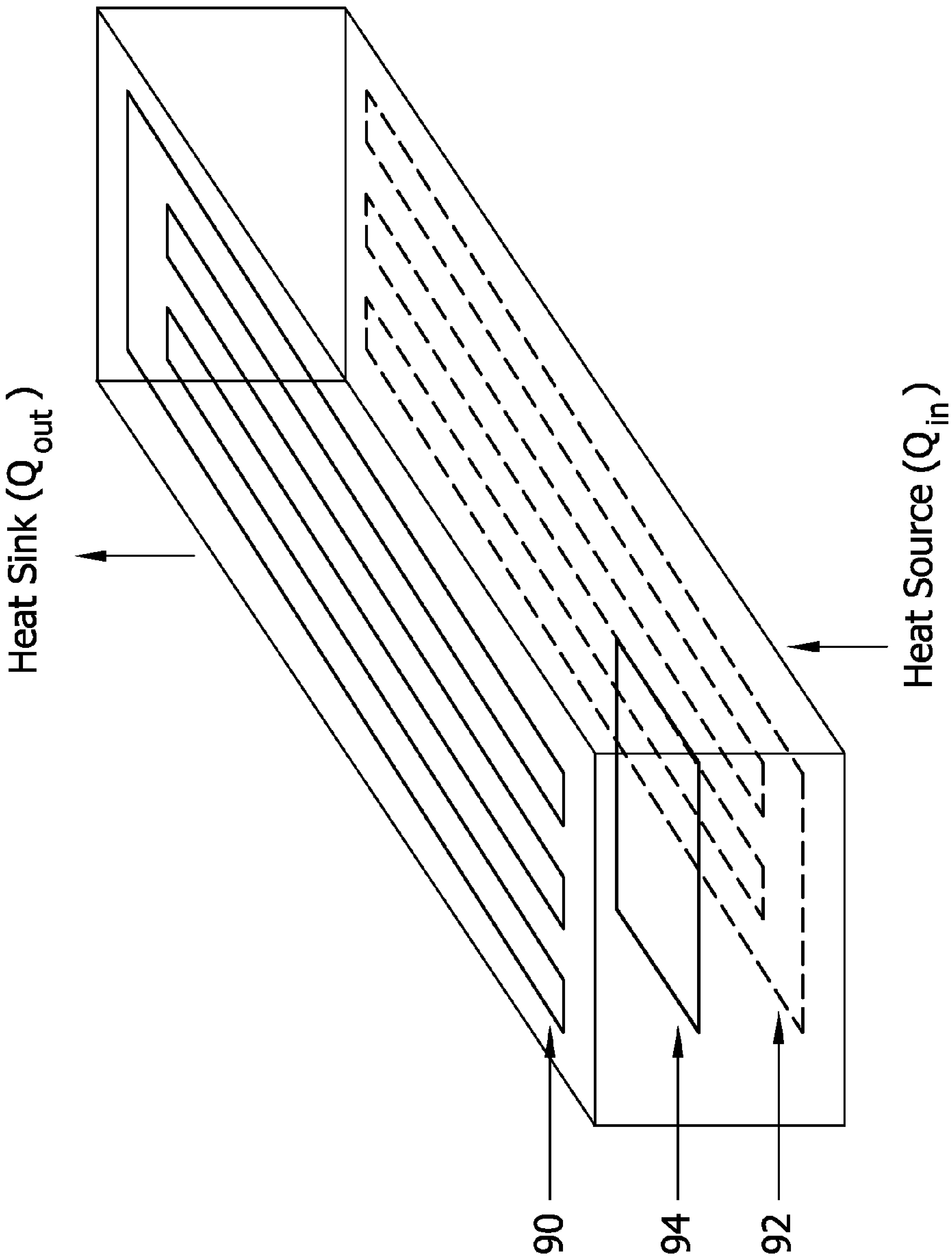
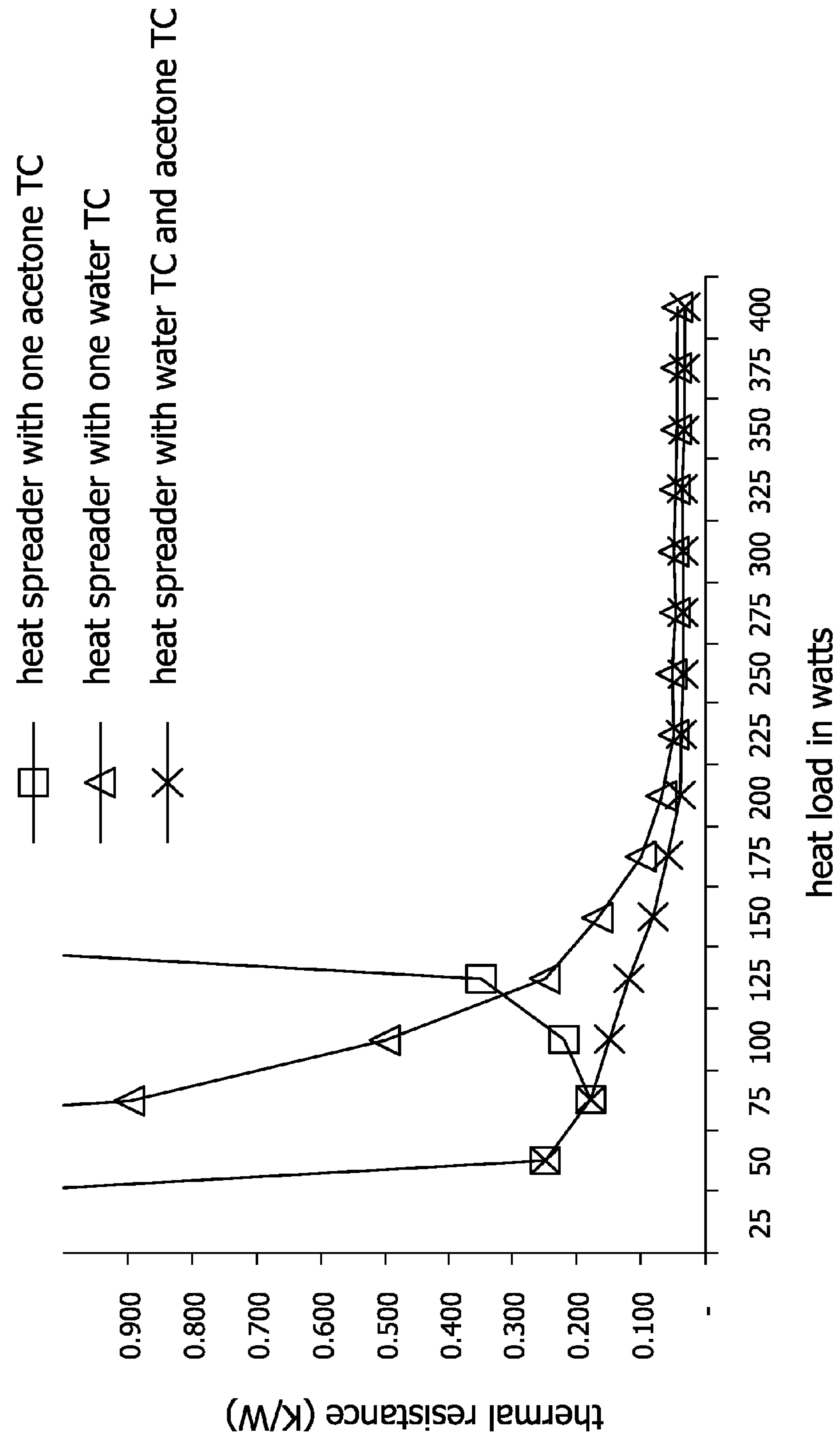


FIG. 10


heat spreader with one acetone TC
heat spreader with one water TC
heat spreader with water TC and acetone TC
thermal resistance (K/W)
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
-
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
heat load in watts

MULTIPLE THERMAL CIRCUIT HEAT SPREADER

FIELD OF THE INVENTION

[0001] The present invention relates generally to a heat spreader using a plurality of thermal circuits (each thermal circuit sometimes referred to elsewhere as an oscillating heat pipe, loop-type heat pipe, or pulsating heat pipes) which can have many shapes and sizes and be made of a variety of materials and working fluids in order to handle a wide range of heat flux and total heat load and be able to operate in different orientations all while maintaining a minimal temperature difference between the area(s) of the spreader that receive heat and the areas of the spreader that reject heat.

BACKGROUND OF THE INVENTION

[0002] First proposed by Akachi (see, e.g., U.S. Pat. No. 4,921,041), an oscillating heat pipe (OHP) utilizes the oscillating motion of liquid slugs and vapor plugs enclosed in a series of meandering tubes to efficiently transfer heat from the heat source at the oscillating heat pipe's evaporator section to the heat sink at the oscillating heat pipe's condenser section. If the tubing has a small enough diameter, the surface tension forces of the working fluid overcome gravitational forces and distinct liquid plugs and vapor slugs form throughout the tubing volume. When heat is added to the evaporator section, the liquid plugs and vapor slugs inside the tubing at the evaporator section receive the heat, causing them to increase in temperature and pressure and expand. Portions of the liquid slugs in the evaporator section evaporate and expand even further. The pressure difference between the evaporator section and condenser section drives the liquid slugs and vapor plugs toward the condenser section where heat is transferred to the heat sink. When the working fluid travels to the condenser section, the liquid slugs and vapor plugs lose temperature and pressure and portions of the vapor plugs condense. Thus, both sensible and latent heat is transferred out of the thermal circuit to the heat sink at the condenser section. This causes contraction of the liquid plugs and vapor slugs inside the tubing at the condenser section. In addition, the liquid slugs and vapor plugs previously occupying the space in the condenser section are forced by the incoming flow to travel toward the evaporator section, where they receive heat from the heat source and restart the cycle. In this way, heat is transferred from the evaporator section to the condenser section using both convective heat transfer (liquid and vapor flows) and phase change heat transfer (evaporation and condensation). Lastly, because the oscillating heat pipe has no internal wick structure, the fabrication cost can be very low and when the oscillating motion starts, no capillary limitation exists in an oscillating heat pipe. Experimental results show that it is not susceptible to dry out at high thermal power densities as opposed to vapor chambers and traditional heat pipes.

[0003] There are generally two types of oscillating heat pipes by its tubing characteristics: tubular oscillating heat pipe and flat plate oscillating heat pipe (FP-OHP). The latter has advantages in the cooling of electric devices as shown by Akachi (see, e.g., U.S. Pat. No. 5,737,840). The flat plate oscillating heat pipe has channels engraved on a metallic plate, which design is more suitable to its applications on electronic devices than the tubular oscillating heat pipes. Previous research revealed that many factors would affect the performance of flat plate oscillating heat pipe, such as meandering turn number, working fluid, charging ratio, and filling ratio. For example, Borgmeyer and Ma in their article *Experimental Investigations of Oscillating Motions in a Flat Plate Pulsating Heat Pipe* (*J. Thermophysics and Heat Transfer*, pp. 405-409, vol. 21, no. 2 April-June 2007) describe successfully sealing a copper flat plate oscillating heat pipe with square internal channels of 1.59 mm hydraulic diameter. The Borgmeyer and Ma article is incorporated herein by reference. The oscillating motion of liquid plugs in an oscillating heat pipe has been observed to be dependent on the working orientation. Khandekar et al. (*Thermofluid Dynamic Study of Flat-Plate Closed-Loop Pulsating Heat Pipes, Microscale Thermophysical Eng'g* 3:303-317, 2002) conducted the experiments on aluminum **6** turn flat plate oscillating heat pipes, all sealed with transparent glass and charged with ethanol and water, and found that flat plate oscillating heat pipe with larger rectangular cross section and filling ratio below 0.3 is less dependent on gravity. The lowest thermal resistance of 1 K/W was achieved with $2.2\times2.0\ mm^2$ rectangular channel. The Khandekar et al. article is incorporated herein by reference. In the research of Thompson el al. reported in *Experimental Investigation of Miniature Three-Dimensional Flat-Plate Oscillating Heat Pipe* (*J. Heat Transfer*, vol. 131, issue 4 043210, 9 pgs., April 2009), a three dimensional flat plate oscillating heat pipe design was proposed, in which the channel density over unit heating area is dramatically increased. The hydraulic diameter of the channel was 0.762 mm, and charged with acetone at 0.8 volume fraction (i.e. 80% of channel's volume filled with acetone fluid). A much lower thermal resistance of 0.07° C./W was achieved and the heat flux was up to $20\ W/cm^2$. The Thompson et al. article is incorporated herein by reference. Other pertinent work was reported by Cheng et al. in *An Investigation of Flat-Plate Oscillating Heat Pipes* (*J. Electron. Packaging*, vol. 132, issue 4, 041009, 6 pgs., December 2010). The Cheng et al. article is incorporated herein by reference.

[0004] Using this heat transfer mechanism, a thermal circuit utilizes both convective as well as phase change heat transfer to move thermal energy from the heat source at the heat spreader's evaporator section(s) to the heat sink at condenser section(s). Importantly, such a heat transfer mechanism requires some minimum amount of heat load (start up power) at the evaporator section of the heat spreader to activate the flow of liquid slugs and vapor plugs within a thermal circuit due to inertia, gravity and frictional forces between the working fluid and the thermal circuit walls. At the other extreme, at some higher heat load (critical power), the heat flux between the heat spreader's walls at the evaporator section and the working fluid within a thermal circuit is so great that a vapor phase remains constant in the area of the thermal circuit nearest the evaporator section of the heat spreader, and as a result the mass and heat transfer mechanism described above ceases to function at such critical power. It has been shown that thermal circuits charged with some working fluids (e.g., acetone) have relatively low "start up power" but also have relatively low "critical power" which makes such thermal circuit useful in low heat load applications but not useful in higher heat load applications. By contrast, thermal circuits charged with other working fluids (e.g., water) have relatively high required "start-up power" and relatively high "critical power" which make them useful for applications requiring high heat flux heat transfer but less useful if lesser amounts of heat need to be dissipated.

[0005] Oscillating heat pipes have generally higher critical powers than alternative heat spreading technologies such as heat pipes and vapor chambers. Also, oscillating heat pipes are less affected by gravity than traditional heat pipes and to have the ability to transport heat greater distances with less heat transfer rate degradation. Unfortunately, traditional single-loop oscillating heat pipes suffer from the following undesirable attributes that have prevented more widespread application: A) unpredictable temperature spikes in their evaporator section(s)s; B) limited operating power ranges (i.e. an oscillating heat pipe heat spreader designed for minimal thermal resistance at a relatively low thermal input power has an undesirably high thermal resistance when relatively high thermal input power is applied; and conversely an oscillating heat pipe heat spreader designed for minimal thermal resistance at a relatively high thermal input power has an undesirably high thermal resistance when relatively low thermal input power is applied to it); and C) generally lower overall heat transport capability (e.g. higher thermal resistance at given thermal input powers) than is desired by end users of heat spreading technologies. These undesirable attributes are considered at present to be inherent to the traditional oscillating heat pipe design and their applicability to heat spreaders.

SUMMARY

[0006] A heat spreading device for transferring heat from a heat source to a heat sink constructed according to the principles of the present invention generally comprises a first conduit extending in a loop and having a length between the heat source and the heat sink. A second conduit proximate the first conduit and in thermal communication with the first conduit over at least some of the length of the first conduit.

[0007] Other objects and features of the present invention will be in part apparent and in part pointed out hereinafter.

BRIEF DESCRIPTION OF DRAWINGS

[0008] FIG. **1** is a schematic plan view of a traditional oscillating heat pipe heat spreader;

[0009] FIG. **2** is a schematic plan view of one configuration of a multiple thermal circuit heat spreader with two fluidly independent thermal circuits that are thermally in communication by way of a thermally conductive wall;

[0010] FIG. **3** is a schematic perspective of one configuration of a three-dimensional multiple thermal circuit heat spreader;

[0011] FIG. **3**A is a cross section of the schematic of FIG. **3**;

[0012] FIG. **4** is a perspective of another configuration of a three dimensional thermal circuit emplaced within a flat plate heat spreader with its top lid removed and the thermal circuit's channels exposed and with staggered large channels;

[0013] FIG. **5** is a fragmentary cross section of the three dimensional heat spreader shown in FIG. **4**, but showing both the top and bottom lids attached to the flat plate;

[0014] FIG. **6** is a top plan view of thermal circuit heat spreader shown in FIGS. **4** and **5** with the top lid removed;

[0015] FIG. **6**A is an enlarged fragmentary view of an upper portion of the heat spreader of FIG. **6**, but showing a bottom side of the flat plate with the bottom lid removed;

[0016] FIG. **6**B is an enlarged fragmentary view of a lower right side portion of the heat spreader of FIG. **6**;

[0017] FIG. **7** is a schematic, fragmentary cross section of another flat plate multiple thermal circuit heat spreader showing a stacked arrangement of thermal circuits in the plate;

[0018] FIG. **7**A is a schematic, fragmentary cross section of still another flat plate multiple thermal circuit heat spreader showing a stacked arrangement of thermal circuits in the plate;

[0019] FIG. **8** is a schematic, fragmentary cross section of yet another flat plate multiple thermal circuit heat spreader showing a stacked arrangement of thermal circuits in the plate;

[0020] FIG. **9** is a schematic perspective of another configuration of multiple thermal circuit heat spreader; and

[0021] FIG. **10** is a graph showing thermal resistance across a range of heat loads using multiple thermal circuits compared to a heat spreader with only one thermal circuit and one working fluid.

[0022] Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION OF THE DRAWINGS

[0023] A conventional oscillating heat pipe OHP**1** having a single loop L or channel forming a single thermal circuit is schematically illustrated in FIG. **1**. The loop L has been evacuated, partially charged with a working fluid and then sealed in order to develop liquid slugs LS and vapor plugs VP within the loop. As drawn, the vapor plugs VP are the spaces between the liquid slugs. When heat (Q_{in}) is applied to an evaporator section E of the oscillating heat pipe OHP**1** the liquid slugs LS expand and partially evaporate, and exert a pressure on the adjacent slugs LS and plugs VP. The pressure difference leads to a mass transfer of the vapor and liquid in the evaporator section E to the lower pressure regions in a condenser section C where the vapor condenses and the liquid slugs LS contract. An adiabatic section A of the oscillating heat pipe OHP**1** is present between the evaporator section E and the condenser section C. The heat transfer in the adiabatic section A is essentially zero (i.e., $\Delta Q=0$). Because the thermal circuit loop L meanders to-and-from the evaporator section E and condenser section S, the expanding and contracting forces continuously send slugs and plugs between the evaporator section E and condenser section C which produces an oscillating motion of slugs and plugs. The oscillating motion is illustrated in one of the three turnbacks of the loop L in FIG. **1** by dashed double arrows between adjacent liquid slugs LS. This mechanism transfers heat with both convective heat transfer (flow of liquid slugs LS and vapor plugs VP between sections of different temperatures) as well as phase change heat transfer (evaporation and condensation of the working fluid within thermal circuit).

[0024] Referring now to FIG. **2**, a multiple thermal circuit spreader constructed according to the principles of the present invention is generally indicated at **2**. The multiple thermal circuit spreader includes in the illustrated embodiment has an inner thermal circuit **4** and an outer thermal circuit **6**. Each of the thermal circuits **4**, **6** forms liquid slugs **8** and vapor plugs **10** substantially as described above for the oscillating heat pipe OHP**1** of FIG. **1**. Oscillation of the liquid slugs **8** and vapor plugs **10** is shown in one of the three turnbacks of the thermal circuits **4**, **6**. For clarity of illustration, the liquid slugs **8** of the inner thermal circuit **4** are depicted with filled-in ovals, while the liquid slugs **8** of the outer thermal circuit **6** are depicted by unfilled ovals. The inner and outer thermal circuits **4**, **6** are each closed loops and have no fluid communication between them. However, the inner and outer thermal circuits are in thermal communication with each other by way of a thermally conductive wall **12**. The conductive wall is cross hatched in FIG. **2** to facilitate understanding of the various parts of the heat spreader **2**. In this way each thermal circuit **4**, **6** not only transfers heat between an evaporator section **14** and a condenser section **16** (like the thermal circuit loop L of FIG. **1**) but also to the adjacent thermal circuit should a temperature difference between the inner and outer thermal circuits exist. The heat spreader **2** further includes an adiabatic section **18** between the evaporator section **14** and the condenser section **16** where essentially no heat transfer occurs (i.e., $\Delta Q=0$).

[0025] It will be understood that although two thermal circuits **4**, **6** are illustrated in the heat spreader of FIG. **2**, a heat spreader according to the present invention may have more thermal circuits. The thermal circuits may not necessary be closed loops. Still further, the thermal circuits may be in thermal communication with each other over less than their entire lengths. For example and without limitation, the thermal circuits may be in thermal communication with each other on the evaporation section of the spreader, or only in the condenser section of the spreader. There may be more than one evaporator section and/or more than one condenser section of the heat spreader, and they may have different sizes and shapes. For example, perhaps on one quadrant of the plate is an evaporator section, while the remaining area of the plate is a condenser. In another example, there may be two or more distinct evaporator sections and/or two or more distinct condenser sections. Therefore a description of a spreader including one evaporator section and one condenser section in this description will be understood to apply to spreaders having more than one evaporator section and/or more than one condenser section. Although the thermal circuits **4**, **6** are shown going back and forth several times between the evaporator section **14** and the condenser section **16**, they may be constructed so as not to go back and forth.

[0026] Referring now to FIGS. **3** and **3**A, a multiple thermal circuit is diagrammatically illustrated where multiple interconnected thermal circuits (in this case two, first thermal circuit **18** and second thermal circuit **19**) are fluidly independent but thermally in communication but where the thermal circuits meander not only in two dimensions (as shown in FIGS. **1** and **2**) but in three dimensions (e.g. in the z-plane) thus increasing turn number of each thermal circuit for a given x-y surface area. The z-direction is exaggerated somewhat in FIG. **3** to illustrate the point.

[0027] Two three-dimensional thermal circuits **20** and **22** engraved on the both sides of two piece base **26** of a heat spreader **28** are shown in FIGS. **4**-**6**B. It will be understood that the base **26** may be made of one piece of material, or more than two pieces of material within the scope of the present invention. As illustrated, the base **26** is formed by two sheets connected together. Thermal circuits **20** and **22** may have different channel profiles. In the illustrated embodiment, the channels of thermal circuit **20** are larger in cross sectional area than the channels of thermal circuit **22**. The cross sectional shapes of the thermal circuit channels may be different than shown and/or different from each other within the scope of the present invention. The thermal circuits **20**, **22** may be charged with different working fluids, and each thermal circuit may have different internal surface treatments. Although less preferred, the same working fluid could be charged to both circuits. The thermal circuits **20**, **22** are arranged side-by-side on each of the opposite faces of the solid base **26**. FIG. **5** shows the heat spreader of FIG. **4**, but with the top and bottom cover plates **36**, **38** attached to the top and bottom faces of the base **26**. The cover plates **36**, **38** are placed on both sides of base **26** to enclose and seal thermal circuits **20** and **22**, and may be attached in a suitable manner to the base such as by brazing, soldering, welding or other methods. The channels of the thermal circuits **20**, **22** are arranged to have the greatest channel density in a limited space, one thermal circuit **20** has a large hydraulic diameter, and extends back and forth between the top and bottom faces of solid base **26**. Thermal circuit **22** has a channel of much smaller hydraulic diameter, and is engraved in the base on the face of the base opposite of thermal circuit **20**. The channels of thermal circuit **22** also extend back and forth between the top and bottom faces of the base **26**

[0028] In FIG. **6**, the heat spreader in FIGS. **4** and **5** is shown in a top plan view (x-y plane) without the cover plate **36** (FIG. **5**) so that the thermal circuits **20** and **22** in the top face of the base **26** are exposed. An upper section of the heat spreader (as oriented in FIG. **6**) represents a condenser section **42** and a lower section of the heat spreader **28** represents an evaporator section **44**. FIG. **6**A shows an enlarged, fragmentary view of the back side of the base **26** in the condenser section **42**, and FIG. **6**B is a further enlarged, fragmentary view of the front side of the base **26** in the evaporator section **44**. The thermal circuits **20**, **22** meander to and from condenser section **42** and evaporator section **44**. Thermal circuit **20** meanders to-and-from the condenser section **42** and the evaporator section **44** on the front side in a series of L-shaped conduits that at each end have a port such as **46** that transports the working fluid in thermal circuit **20** from the front side to the back side (see, FIG. **6**B). On the back side of the base **26** the pattern is slightly different for thermal circuit **20**. For thermal circuit **22** there are only 2 ports connecting front and back side of the heat spreader base **26**—port **50** and port **52**. Viewing the front side of the heat spreader **28**, thermal circuit **22** meanders to-and-from condenser section **42** and evaporator section **44** in a lengthy pattern that weaves in-and-around thermal circuit **20** and then connects to the backside at one of two distant ports **50** and **52**. Using these ports, thermal circuits **20** and **22** turn in the z-plane, meaning they travel to from the front side of the heat spreader base **26** shown in FIG. **6** to the back side shown in FIG. **6**A. A completed heat spreader **28** (FIG. **5**) would have the thermal circuits **20**, **22** sealed on front and back sides (by application of the cover plates **36**, **38**), evacuated, partially charged with working fluid(s), and would transfer heat from a heat source in thermal communication with evaporator section **44** to a heat sink in thermal communication with condenser section **42**. The completed heat spreader **28** might be outfitted with external heat transfer enhancements (not shown) such as fins, grooves or other heat transfer efficiency improvements known to those practiced in heat spreading applications.

[0029] The multi-loop or multiple thermal circuit design may use thermal circuits with different working fluids and/or different geometries and/or channel patterns through the heat spreader. Referring again to FIG. **5**, each channel of the thermal circuit **20** having the larger cross sectional area has two small channels of the thermal circuit **22** above or below it, alternating with each row of channels. If the larger cross sectional area channel of the thermal circuit **20** and corresponding two channels of thermal circuit **22** having smaller cross section areas are considered a "group of channels", these "group of channels" are staggered so that the big channel is on top of the small channels in one row and the big channel is below the small channels in adjacent rows. The advantage of this staggered arrangement is its good thermal coupling between the front side and back side of the heat spreader **28** as well as good thermal coupling between the two thermal circuits **20**, **22**. Because the staggering is achieved by a turn in the z-plane, turn number is increased and heat transport capability is also raised. However, the invention's channel arrangements are not limited to the staggered arrangement and may vary in design and manufacturing method.

[0030] FIGS. **7**, **7**A and **8** are fragmentary cross sections of plates of other heat spreaders having different arrangements of multiple thermal circuits. FIG. **7** shows a heat spreader including thermal circuit **60** having larger cross sectional area channels, and thermal circuit **62** having smaller cross sectional area channels. The thermal circuits **60**, **62** are arranged one above the other and are each confined to a single plane. FIG. **7**A shows a heat spreader having a thermal circuit **70** having larger cross sectional area channels that are confined to a single, central plane. The heat spreader further includes a thermal circuit **72** having smaller cross sectional area channels that meander from one side of the heat spreader to the other and on opposite sides of the thermal circuit **70**. Finally, FIG. **8** illustrates a head spreader that includes four different thermal circuits, each having a different cross sectional shape. A first thermal circuit **80** has a circular cross section and moves in the not only in the x-y direction, but also in the z-direction through three separate levels, as may be seen in FIG. **8**. By way of general illustration, in one of the middle levels, the channels **80***a*, **80***b* are slightly vertically offset. A second of the thermal circuits **82** has a square cross section and makes only one pass between a middle and lower level of the heat spreader. A larger third thermal circuit **84** has a rectangular cross section and passes through all three levels of the heat spreader. Finally, thermal circuit **86** has a triangular cross section and is an open, rather than closed loop circuit. The purpose of FIG. **8** is to show that any number of different shapes and arrangements of thermal circuits may be used within the scope of the present invention.

[0031] The thermal circuit's shape is not limited to being square in cross section. Circular, triangular, rectangular, T-type, and any other cross sectional geometry may be used such as is suitable for a given set of design parameters and issues (e.g., channel density, heat transfer performance, heat spreader size, manufacturability, etc.). When a thermal circuit heat spreader includes multiple thermal circuits (or multiple loops), the channel shape for each loop can be different from others as shown in FIG. **8**. Even for one thermal circuit meandering throughout the heat spreader's volume, the channel shape may vary from one shape such as rectangular channel to another such as triangular one at different regions of the heat spreader. A variety of fluids may be used in the larger and smaller cross section area channels of the multiple thermal circuit heat spreader of the present invention. For example, the working fluid in a thermal circuit can be a single fluid, a plurality of miscible fluids, a plurality of immiscible fluids, or a combination of miscible and immiscible fluids Furthermore, by applying low-concentration nanofluids (e.g., fluids comprised of a base fluid that has been mixed chemically, sonically, physically, or otherwise with nanoparticles of a separate substance) as the working fluids in the thermal circuits one can reduce the temperature variation at the thermal circuits evaporator section(s) and also extend its working limits (e.g. the lowest and highest functioning input powers). By way of general example, the working fluids may contain suspended particles of ultra-high conductivity material such as nanoscale particles of diamond, gold, silver, etc. that have been suspended in the base solution. In one more particular example, the larger cross sectional area channel thermal circuit may be charged with a diamond-water nanofluid to improve the effective thermal conductivity of the big channel thermal circuit.

[0032] The internal surfaces of the thermal circuit may be smooth, rough, treated to be hydrophobic with the working fluid, and/or treated to be hydrophilic with the working fluid. For example, copper surface pre-treated by oxidization has shown to enhance heat transfer performance of certain thermal circuits charged with water as working fluid. Further, hydrophilic surface treatments on metals (e.g. microgrooves or chemical coatings) have proven to increase the contact angle of working fluid and in doing so increase the evaporative heat transfer rate between such surface and the working fluid. Also, the inner channel surfaces may be manipulated to be hydrophobic, hydrophilic, or hydrophobic in one area (e.g. condenser) and hydrophilic in another area (e.g. evaporator) using a variety of techniques including surface coatings, laser formed micro/nano structures, and controlled chemical reactions, etc.

[0033] The shape of the multiple thermal circuit heat spreader may be flat plate, cylindrical, or any other geometry. The evaporator section(s) may be at the center of the heat spreader, on one or more edges, in one or more corners, or any other location. The orientation of the heat spreader (i.e. the location of the heat source(s) relative to the heat sink(s) in a gravitational field) may be with heat source(s) on top of, to the side of, below, or in any relative position to the heat sink(s).

[0034] The multiple thermal circuit heat spreader may be made from any shell material, including non-metals with relatively low thermal conductivities because material conductivity is a relatively small contributor to the heat spreader's overall heat transport capability if the wall thickness of the material is relatively small. For example and without limitation, at 100 microns of wall thickness the impact of the wall's thermal conductivity will contribute little to overall thermal resistance of the heat spreader. The multiple thermal circuit heat spreader shell and internal tubing may be manufactured in a variety of processes, including but not limited to: brazing, stamping, photo-chemical etching, hot forging, cold forging, mechanical engraving, welding, water-jet cutting, laser etching, or any other positive or negative fabricating process of embedding and sealing thermal circuits in shell material.

[0035] The multiple thermal circuit design may also use a combination of loops where the combination of thermal circuits is such that they increase or decrease the heat transfer between the thermal circuits. For example, in FIG. **9** there are three loops or thermal circuits comprising a top thermal circuit **90** (which is in closest thermal communication with the heat source); a bottom thermal circuit **92** (which is in closest thermal communication with the heat sink); and a middle thermal circuit **94** located between top thermal circuit **90** and bottom thermal circuit **92**. Middle thermal circuit **94** may be designed to improve or reduce the heat transfer occurring directly through the cross-sectional area between top and bottom thermal circuits **90**, **92**. It is believed that in some instances, orthogonal heat transfer (i.e. thermal energy transfer directly through the cross section of the heat spreader from the heat source to the heat sink) in a single loop oscillating heat pipe or even a multiple thermal circuit heat spreader may prevent the lateral heat transfer needed to dissipate thermal energy in more than one dimension. To increase that lateral heat transfer a thermal circuit such as middle thermal circuit **94** shown in FIG. **9** may actually serve to insulate the top thermal circuit **90** from the bottom thermal circuit **92** at one or more cross-sections of the heat spreader. As shown in FIG. **9**, the middle thermal circuit **94** is located only at the near end. In other instances it may behoove the heat spreader designer to use middle thermal circuit **94**—as shown in FIG. **9**—to increase the orthogonal heat transfer between top thermal circuit **90** and bottom thermal circuit **92** at one or more cross-sections within the heat spreader. In the illustrated embodiment of FIG. **9**, the middle thermal circuit **94** has a working fluid, but the middle thermal circuit could be embodied by, for example, a void, a insulating material, or a high thermal conductivity material.

[0036] The heat spreaders are comprised of more than one thermal circuit, and each thermal circuit may meander back and forth between the heat spreader's evaporator section(s) and condenser section(s), or it may only traverse one Section (e.g., the middle thermal circuit **94** of FIG. **9**), or a select number of sections. A 180-degree change in direction of a thermal circuit is referred to as a "turn", and a 90-degree turn is considered a half turn. Because turn number is proven to be positively related to thermal circuit heat spreader heat transfer capability, the turns in the invented heat spreader's thermal circuits may be in two- or three-dimensions (i.e., not only in the x-y plane but also in the x-z or y-z plane). Three dimensional turns are beneficial when there is a limited surface area in the x-y plane which limits thermal circuit turn number and therefore thermal circuit heat transfer capability; however, additional thermal circuit turns can be achieved in the x-z or y-z planes and thus increase thermal circuit turn number and thermal circuit heat transfer capability by utilizing the z-plane without exceeding the x-y surface area limitations.

[0037] Conventional oscillating heat pipes have the advantage of being able to transport heat greater distances between their evaporator and condenser sections than traditional heat pipes or vapor chambers. They also have the advantage of being less affected by gravity. However, comparing with other types of heat pipes, such as loop heat pipe and vapor chamber, prior oscillating heat pipes have suffered from high startup power, high thermal resistances, and sharp temperature spikes at the evaporator section(s) which have prevented them from finding much commercial acceptance. At least some embodiments of the invention disclosed herein resolve these issues by incorporating a plurality of fluidly independent but thermally communicating thermal circuits on a single heat spreading device. By using multiple thermal circuits on the same heat spreader (where thermal circuits may be of the same or different sizes, patterns, hydraulic diameters and/or working fluids) the invented heat spreader is able to transfer heat efficiently at both lower start-up powers and at higher critical powers. Further, it has been empirically observed that by having thermal circuits in thermal communication with at least one other fluidly independent thermal circuit the likelihood of either thermal circuit ceasing to function temporarily (which is a cause of unpredictable temperature spikes in the evaporator section(s) of single loop oscillating heat pipes) is exponentially reduced thus creating an overall lower thermal resistance at any single power input level. Finally, by utilizing three-dimensional turns the heat spreader can transfer greater amounts of thermal energy with lower overall thermal resistance at specified areas for receiving and rejecting heat. FIG. **10** is a graph of a heat spreader's thermal resistance at increasing heat loads (from 0-400 watts) with the following thermal circuit options: a) one thermal circuit charged with acetone; b) one thermal circuit charged with water; and c) two thermal circuits, one charged with water and the other charged with acetone. As can be seen the heat spreader with both a water thermal circuit and an acetone thermal circuit has better overall performance across a broader range of input powers. Finally, it may be optimal to have a thermal circuit situated vis-à-vis the heat source(s), heat sink(s), and the other thermal circuits in such a way that increases or decreases thermal communication between the sources, sinks and other thermal circuits in order to optimize the spreader's overall heat transfer capacity.

[0038] Having described the invention in detail, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims.

[0039] When introducing elements of the present invention or the preferred embodiments(s) thereof, the articles "a", "an", "the" and "said" are intended to mean that there are one or more of the elements. The terms "comprising", "including" and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0040] In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

[0041] As various changes could be made in the above products and methods without departing from the scope of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A heat spreading device for transferring heat from a heat source to a heat sink, the heat spreader device comprising:

a first conduit extending in a loop and having a length between the heat source and the heat sink;

a second conduit proximate the first conduit and in thermal communication with the first conduit over at least some of the length of the first conduit.

2. A heat spreading device as set forth in claim **1** wherein the second conduit is in thermal communication with the first conduit over substantially the entire length of the first conduit.

3. A heat spreading device as set forth in claim **1** wherein the second conduit conforms to the first conduit over the entire length of the first conduit.

4. A heat spreading device as set forth in claim **1** wherein the second conduit is in thermal communication with the first conduit over a portion of the first conduit near only one of either the heat source or the heat sink.

5. A heat spreading device as set forth in claim **1** further comprising a working fluid in the first and second conduit.

6. A heat spreading device as set forth in claim **5** wherein at least one of the working fluid in the first conduit and the working fluid in the second conduit includes nanoparticles.

7. A heat spreading device as set forth in claim **5** wherein the working fluid in the first conduit is different from the working fluid in the second conduit.

8. A heat spreading device as set forth in claim **1** wherein the first and second conduits are each formed at least in part out of a single piece of material.

9. A heat spreading device as set forth in claim **1** comprising a first plate and a second plate, portions of the first and second conduits being defined in the material of the first plate, and portions of the first and second conduits being defined in the material of the second plate.

10. A heat spreading device as set forth in claim **1** wherein the first and second conduits follow tortuous paths.

11. A heat spreading device as set forth in claim **9** wherein the first and second conduits each include segments extending in three different dimensions.

12. A heat spreading device as set forth in claim **1** wherein an internal surface of at least a portion of one of the first or second conduits is treated to optimize heat transfer.

13. A heat spreading device as set forth in claim **1** wherein the device is adapted to receive heat from at least two spaced apart heat sources.

14. A heat spreading device as set forth in claim **13** wherein the device is adapted to reject heat to at least two spaced apart heat sinks.

15. A heat spreading device as set forth in claim **1** wherein the device is adapted to reject heat to at least two spaced apart heat sinks.

16. A heat spreading device as set forth in claim **1** wherein the first and second conduits are free of fluid communication with each other.

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