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(54) **Condenser assembly and thermal management system**

(57) A thermal management system (10) includes an evaporator (12) and a fluid circuit (14) that directs a cooling medium through a condenser (16). The example condenser provides improved heat transfer coefficients and stable operation by reducing condensate thickness and films that build up within fluid passages of the condenser (16) to provide improved thermal communication between the cooling medium and a cold plate (20). Each of the fluid passages (36) defined by the condenser is tapered such that an ever-decreasing flow area in a direction of flow from the inlet (26;60) toward the outlet (22; 48;62) is provided. The ever-decreasing area maintains a high shear velocity of the vapor such that the liquid film formed on the walls of the passages (36;58) remains thin.

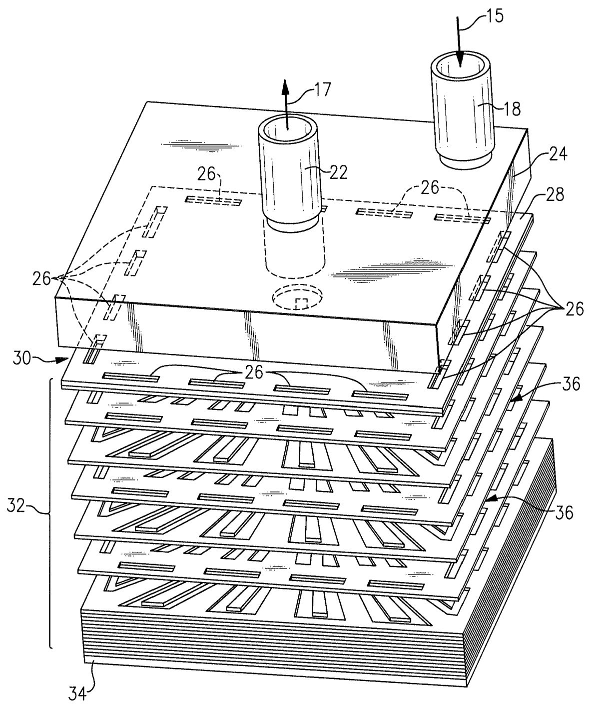

FIG.3

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Description

BACKGROUND

[0001] This disclosure generally relates to heat exchangers and particularly to condensers for maintaining high heat transfer during a phase change of a fluid under adverse inertial loading. A two phase system is often used to transfer heat from a heat source to a remotely located heat sink. If a compressor and expansion device is used in the loop, the heat sink can be at a higher temperature than the heat source, as with a vapor cycle system. The heat is dissipated to a heat sink in a condensing heat exchange assembly called a condenser. The heat sink may be in an environment of another flow loop. In the condenser, the coolant transitions between vapor and liquid phases. As an example, the heat from an electronics assembly may be removed by evaporative cold plates and dissipated by condensation to a heat sink. The heat exchange assembly therefore includes a condenser for removing heat from the cooling medium. The liquid/vapor cooling medium is routed through the condenser for transforming the vapor phase of the cooling medium back to mostly a liquid phase. Using the latent heat property of the coolant, heat is rejected from the condenser as heat is transferred from coolant through walls of the condenser to transform vapor into liquid. A primary resistance to heat transfer is the ever increasing thickness of liquid that accumulates on walls of fluid channels.

SUMMARY

[0002] A disclosed example thermal management system includes an evaporator and a fluid circuit that directs a cooling medium through a condenser. The example thermal management system utilizes a two-phase cooling medium that shifts between liquid and vapor phases as it rejects and accepts thermal energy. The example condenser has a shear driven flow and provides higher heat transfer coefficients by reducing condensate thickness and films that build up within fluid passages of the condenser to provide improved thermal communication between the cooling medium and a cold plate. Each of the fluid passages defined by the condenser is tapered such that an ever-decreasing flow area in a direction of flow from the inlet toward the outlet is provided. The ever-decreasing area maintains a high shear velocity of the vapor such that the liquid film formed on the walls of the passages remains thin. Additional benefits with the shear flow arrangement are that the liquid inventory in the condenser is minimized and stable. This is important for a vapor cycle system for stable operation and reduces the amount of refrigerant required. Tapered passages in the direction of flow thin the condensed liquid film, improve heat transfer.

[0003] These and other features disclosed herein can be best understood from the following specification and drawings, the following of which is a brief description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004]

Figure 1 is a schematic of an example thermal management system.

Figure 2 is a perspective view of an example condenser.

Figure 3 is an exploded view of the example condenser.

Figure 4 is a schematic view of a plurality of fluid passages defined by the example condenser.

Figure 5 is a plan view of one plate for the example condenser.

Figure 6 is a plan view of another plate for the example condenser.

Figure 7 is a schematic representation of a fluid passage defined within an example condenser.

Figure 8 is a schematic view of an example step for assembling an example condenser.

Figure 9 is a schematic representation of another step in assembling the example condenser.

Figure 10 is a schematic view of another step in assembling the example condenser.

Figure 11 is a schematic view of example flow passages defined in another example condenser.

Figure 12 is a plan view of an example odd layer for the example condenser.

Figure 13 is a plan view of an example even layer for the example condenser.

Figure 14 is a plan view of an end plate for the example condenser.

DETAILED DESCRIPTION

[0005] Referring to Figure 1, an example thermal management system 10 includes an evaporator 12 and a pump 19 that directs a cooling medium through a fluid circuit 14 including a condenser 16. The circuit 14 may also include a compressor and an expansion valve not shown here. The example thermal management system 10 utilizes a two phase cooling medium that transforms between liquid and vapor phases as it rejects and accepts thermal energy. In the evaporator 12, input heat 25 transforms all or a portion of the cooling medium into a vapor. The vapor is communicated to an inlet 18 of the condenser 16 where heat is transferred to cold plate 20 and condenses the vapor back into a substantially liquid form. As should be appreciated, the cooling medium will include both a vapor phase and a liquid phase throughout the thermal management system 10, with one of the phases making up a larger portion depending on the location within the system 10. From the condenser 16, the cooled and mostly liquid phase cooling medium exits through an outlet 22 for circulation back to the evaporator 12. Heat absorbed from the vapor within the condenser 16 is transmitted through cold plate 20, or other structure for transferring heat away from the condenser 16.

[0006] The example condenser 16 is a shear driven condenser 16 that provides higher heat transfer coefficients by reducing condensate thickness and films that build up within fluid passages of the condenser 16 to provide improved thermal communication between the cooling medium and the cold plate 20.

[0007] Referring to Figured 2 and 3, the example condenser 16 provides stable operation that is insensitive to orientation and external G forces. Vapor 15 enters the condenser 16 through an inlet 18 that is in fluid communication with an inlet manifold 24. The inlet manifold 24 provides for communication of the vapor to a plurality of inlets 26 defined within a top plate 28. The inlets 26 are defined about a periphery 30 of the top plate 28.

[0008] The inlets 26 in turn communicate the vapor 15 to a plurality of flow passages 36 (Figures 3 and 4) defined by a stacked plurality of plates 32. The vapor 15 is transmitted into the inlets 26 disposed about the periphery 30 of the condenser 16 to the flow passages 36 that direct the vapor radially inward towards the liquid phase outlet 22. Liquid 17 is then communicated back into the circuit 14.

[0009] Referring to Figure 4 with continued reference to Figures 2 and 3, each of the fluid passages 36 defined by the condenser 16 provides a tapered or ever decreasing flow area in a direction of flow from the inlets 26 toward the outlet 22. The ever decreasing area maintains a high shear velocity of the vapor such that the liquid film formed on the walls of the passages 36 remains thin. The primary resistance to condensation and conduction of heat out of the condensing vapor is the build up of liquid along the walls of the flow passages. The ever decreasing flow area provided by the example condenser 16 keeps the velocity of the vapor/liquid flow high, thereby decreasing the thickness of any condensate or liquid buildup along the walls of the fluid passages. The example condenser 16 uses a bonded stack of thin laminations wherein a matrix of flow passages contained by conductive material which is conductively coupled to the heat sink.

[0010] The overall heat transfer performance of a heat exchanger is (ηHA), the product of the fin efficiency (η), heat transfer coefficient (H) and the wetted area (A) for a cooler. This condenser 16 provides high values of all three factors. Excellent performance is achieved because the multi-layer construction of bonded interconnecting channels provides over ten times more wetted surface area than the heat flux footprint. Furthermore, the heat transfer coefficients are high because shear flow and disrupted flows create thin liquid film that in turn provide high convective condensation coefficients. Additionally, the fin efficiencies are high because the example condenser 16 provides nearly a 50% conduction area between the passages and the fin lengths relatively short.

[0011] The disclosed example heat exchanger 16 is constructed using a plurality of smaller passages rather than a few larger ones to provide a much higher wetted surface per footprint area. The higher surface area density minimizes conduction resistance because the conduction paths to the heat sink are short. With a high condensing heat transfer coefficient, the overall resistance to heat transfer is small because the conductive paths are generally very thermally efficient.

[0012] The fluid flow passages 36 are defined between the plurality of plates 32 that are stacked one on top the other. The fluid flow passages 36 originate from the inlets 26 that are disposed about the outer periphery 30, and extend generally radially inward and terminate at the central core than connects to the radially central outlet 22. The flow is generally radially inward, but must move periodically slightly laterally between layers within the lamination stack. The radial direction of fluid flow within the tapered passages 36 provides the desired shear driven or high velocity flow through the condenser 26.

[0013] Referring to Figures 5 and 6, with continued reference to Figure 4, the example condenser 16 is formed by the stacked plurality of plates 32. The plates 32 include the top plate 28 which includes the inlets 26 and an opening for the outlet 22. The manifold 24 is disposed on top of the top plate 28. A bottom plate 34 is also provided that does not include any openings or slot patterns that provide for fluid flow. Between the manifold 24 and the bottom plate 34 are the stacked plurality of alternating plates 32. In this example there are two patterns of plates that are utilized. A first plate 40 that includes a first slot pattern 42 and a second plate 44 that includes a second slot pattern 46. The first slot pattern 42 and the second slot pattern 46 provide for a continuous flow passage from the inlets 26 to a central opening 48 for the outlet 22. The first and second plates 40, 44 are stacked in an alternating arrangement such that the first and second slot patterns 42, 46 overlap. The overlapped portion of the passages that are formed are sized to maintain velocities similar the local radial velocities. Any number of stacked plurality of first and second plates 40 and 44 can be utilized as long as the number includes at least two of each of the first and second slot patterns 42 and 46 of plates to provide the desired configuration of fluid passage between the inlets 26 and the radially inward outlet 48. For illustrative purposes, the first and second plates 40, 44 which alternate in the stack are referred to as the odd and even layers. In assembly the stack 32, the top and bottom layers 28 and 34, and perhaps the manifold 24 are bonded together to form a hermetic unit.

[0014] Figure 4 is a schematic representation of the fluid flow passages 36 that include an every decreasing area toward the center outlet 48. The flow passages 36 are defined between fins 38 that absorb heat and communicate that heat through to the cold plate 20 shown in Figure 1. As is appreciated, each of the passages 36 includes an ever decreasing flow area from a radially outward most position towards a radially inward most position that defines the inlet. Each of the stacked plurality of plates 32 includes a portion of the flow passage 36 and is in communication with open slots within another of the stacked plurality of plates. The alternating stacked configuration provides for not only the ever decreasing or tapered flow passage area but also an alternating transverse movement that further eliminates the buildup of condensate films within the fluid passages. Also, higher velocity prevents the condensate from flowing back towards the inlet during inversion or other g-force transients. The higher pressure drop of a shear flow will also counteract the instable pressure recovery which occurs in straight channels. With pressure drops that are too low or negative, some legs of parallel channels can experience flow reversal, called liquid leg instability.

[0015] In this example, the decreasing area is provided by a reduction in the width of each slot in a direction toward the outlet opening 48. A first width 37 (Figure 4) is greater than a second width 35 that is disposed radially inward of the first width 37. The ever decreasing width of each of the flow passages 36 provides the decreasing flow area toward the outlet opening 48.

[0016] The shape each of the flow passages 36 is not required to be rectangular or trapezoidal, but may also include oblong shaped or any shape that provides a desired reduction in flow area in a direction toward the outlet opening 48.

[0017] Referring to Figures 5 and 6, each of the first and second plates 40, 44 define the corresponding one of the first and second slot patterns 42, 46. Each of the individual slots includes an area that decreases in a direction toward the outlet opening. In this example, the area decreases in a direction radially inward toward the outlet opening 48. The reduction in area maintains a desired velocity of cooling medium through the condenser that provides the desired high and stable heat transfer capability. In this example, each of the slot patterns 42, 46 includes a decreasing width in a direction towards the radially innermost portion of each of the plates 40, 44.

[0018] Referring to Figure 7, a cross section schematic representation of an example fluid flow path 36 is illustrated. Cooling medium in the mixed vapor and liquid phase alternates between slots 42 of the first plate 40 and slots 46 in the second plate 44. In this example one first plate 40 is shown sandwiched between two second plates 44. The alternating path of provided by defining alternating parts of the flow passage 36 through different plates directs flow transverse to the direction toward the outlet to further prevent built up of liquid. The transverse redirection of cooling medium interrupts the flow pattern to prevent condensation or liquid buildup along the inner walls of the fluid flow path. Accordingly, the example condenser 16 includes a flow passage configuration that provides an ever-decreasing flow area combined with frequently interrupted flow that eliminates effects from external G forces, orientation, or other external inertial forces. Also works in microgravity where other designs will be penalized.

[0019] Referring to Figures 8, 9 and 10, the example condenser 16 is assembled by placing a first plate 40 onto a bottom plate 34 or alternatively directly onto a cold plate 20 as is shown. In this example the cold plate 20 is supporting at least two if not more condensers 16. As appreciated, although one condenser 16 is illustrated in the previous figures, a gang or a plurality of condensers 16 could be mounted on a single cold plate to tailor heat transfer capabilities depending on application specific parameters. As is shown in Figure 8, 9 and 10 one of the first plates 40 is mounted to the cold plate 20. A second plate 44 is then stacked onto the first plate 40 to define a complete flow passage 36. Another first plate 40 is then stacked onto the second plate 44 and this process continues with alternate stacking of first and second plates 40,44 with corresponding although not identical first and second slot patterns 42,46 to define the plurality of fluid flow passages 36 through the condenser 16. Also, the parallel passage flow arrangement will be very tolerant should a blockage occur due particulate contamination. Flow will bypass blocked locations and use the remaining open flow area in that layer. The entire heat exchange can only be blocked when all the parallel flow paths on every layer and within each layer are blocked.

[0020] The example condenser 16 is constructed of a bonded stack of alternating first and second plates 40, 44. Each of the plates can be referred to as a lamination and is stacked upon each other to provide the desired flow passage configuration. In one example embodiment, each of the plates 40, 44 is formed as chemically photo etched copper laminations that are diffusion bonded to each other. Alternatively, each of the plates can be brazed or bonded stacks of aluminum or other types of material as is suitable for a specific application. As appreciated, the specific type of material and bonding process that is utilized to attach and provide the sealed flow passages are dependent on the application. As appreciated, certain materials are capable of withstanding temperatures of specific applications. The environmental conditions in which the condenser will need to operate are considered into developing and manufacturing and assembling each of the example condensers.

[0021] The previous example discloses a symmetrical condenser with radially outermost inlet such that flow was directed symmetrically and radially inward towards the central outlet 22. However, in some applications it is desired to have a more rectangular or non-symmetrical configuration where an inlet and outlet are disposed in a different orientation as may be desired for application specific parameters.

[0022] Referring to Figure 11, a schematic illustration is shown of another example condenser 52. In this example condenser 52, includes an even plate 54 and an odd plate 56 that are alternatively stacked to define a rectangular outer shape including a plurality of flow passages 58. An inlet 60 is disposed at one corner and an outlet 62 is disposed spaced part from the inlet 60. In this example the outlet 62 includes a round portion 64 open to an elongated slot 66. The outlet 62 thereby provides for communication of cooling medium in a vapor phase with the plurality non-symmetric fluid passages 58.

[0023] The fluid passages 58 are defined to include an ever-decreasing flow area in a direction toward the outlet

62 and away from the inlet 60. In other words, the flow passages 58 comprise a tapered or decreasing flow area in the direction of flow.

[0024] Referring to Figures 12, 13 and 14 with continued reference to Figure 11, the condenser 52 includes stacked plates that include the even plate 54 and an odd plate 56 that are alternatively stacked together define a plurality of flow passages 58. An end plate 68 (Figure 14) is provided at the top of the stacked plates and includes openings in fluid communication with the corresponding inlet 60 and outlet 62. The combined even and odd plates 54, 56 both define the inlet 62 that receives the cooling medium in a substantially vapor phase.

[0025] The even layer 54 includes a first slot configuration 70 and the odd layer includes a second slot configuration 72. The first and second slot configurations 70, 72 correspond with one another to provide a flow path between the inlet 60 and the outlet 62. Neither of the plates 54, 56 alone defines the entire flow path. Because the plates 54,56 are stacked one on top of each other, the flow passages 58 include significant of disruptions and discontinuities such that flow is alternately directed upward or downward between adjacent plates 54,56 to prevent the build of condensation or liquid films on each of the passages. Each of the slots in each of the first and second slot patterns 70, 72 includes a decreasing area in a direction of flow from the inlet 60 toward the outlet 62. The ever decreasing or tapered flow pattern provides the desired shear driven condenser that increases the velocity of the cooling medium as it is condensed to prevent the buildup of liquid film on the walls.

[0026] The flow passage configuration of the disclosed condensers provides high heat transfer in a compact and lightweight package. The stacked plates and radial flow path configuration provides short thermal conduction paths to improve heat transfer capability. The short conduction paths and the increased performance are provided because each of the condensers provides thin condensate layers that thin out any liquid buildup along the surfaces of the flow passages. Shear driven and tapered flow passages also provide a high degree of insensitivity to orientation and external inertial forces. Moreover, the fabrication of the example condenser is provided by alternately stacking different plates to define the desired flow passage patterns. The stacked plates are also designed to include and utilize common configurations of plates to reduce manufacturing cost.

[0027] Although an example embodiment has been disclosed, a worker of ordinary skill in this art would recognize that certain modifications would come within the scope of this disclosure. For that reason, the following claims should be studied to determine the scope and content of this invention.

Claims

1. A condenser assembly (16;52) comprising:

a stacked plurality of plates (32) that define a plurality of flow passages (36;58); and
an inlet (26;60) and outlet (22;48;62) in fluid communication with the flow passages, wherein the plurality of flow passages (36;58) defined by the stacked plurality of plates (32) includes a decreasing flow area in a direction of flow.

2. The assembly as recited in claim 1, wherein each of the plurality of flow passages (36;58) includes a width that decreases in a direction away from the inlet (26;60) and toward the outlet (22;48;62).

3. The assembly as recited in claim 1 or 2, wherein each of the stacked plurality of plates (32) include open slots in fluid communication with open slots (42,46;70,72) within another of the stacked plurality of plates such that each of the plurality of flow passages (36;58) is defined by open slots within at least two of the stacked plurality of plates.

4. The assembly as recited in claim 1, 2 or 3, wherein each of the stacked plurality of plates include a first plate (40;54) with a first pattern (42;70) of open slots and a second plate (44;58) with a second pattern (46;72) of open slots that are in fluid communication with the first pattern of open slots.

5. The assembly as recited in claim 3 or 4, wherein each of the slots (42,46;70,72) include a decreasing area in a direction toward the outlet and away from the inlet.

6. The assembly as recited in any preceding claim, wherein the plurality of flow passages (36;58) extend radially inward from an outer periphery (30) of the stacked plurality of plates (32) and the inlet (26;60) is in fluid communication with the outer periphery of the stacked plurality of plates and the outlet (22;48;62) is disposed radially inward of the inlet.

7. The assembly as recited in any preceding claim, wherein the stacked plurality of plates (32) are mounted to a cold plate (20).

8. A thermal management system comprising:

a flow path (14) for a cooling medium;
an evaporator (12) for transferring heat into the cooling medium; and
a condenser assembly as claimed in any preceding claim for transferring heat from the cooling medium.

9. A method of assembling a condenser comprising:

providing at least one first plate (40;54) having a first slot structure (42;70);

providing at least one second plate (44;58) having a second slot (46;72) structure that corresponds with the first slot structure; and

alternating stacking of the first plate (40;54) onto the second plate (44;58) to define a flow passage (36;58) from an inlet (26;60) toward an outlet (22;48;62), wherein the first slot structure and the second slot structure define flow areas that decrease in the direction of flow, such that the defined flow passage includes a decreasing flow area in the direction of flow.

10. The method of assembling a condenser as recited in claim 9, including bonding the first plate (40;54) to the second plate (44;58).

11. The method of assembling a condenser as recited in claim 9 or 10, including a bottom plate (34) on which the stacked first (40;54) and second plates (44;58) are mounted and a top plate (28) that is disposed on the stacked first and second plates.

12. The method of assembling a condenser as recited in claim 9, 10 or 11, including forming the first slot structure (42;70) and the second slot structure (46; 72) to define flow passages (36;58) that decrease in a direction radially inward of an outer periphery (30).

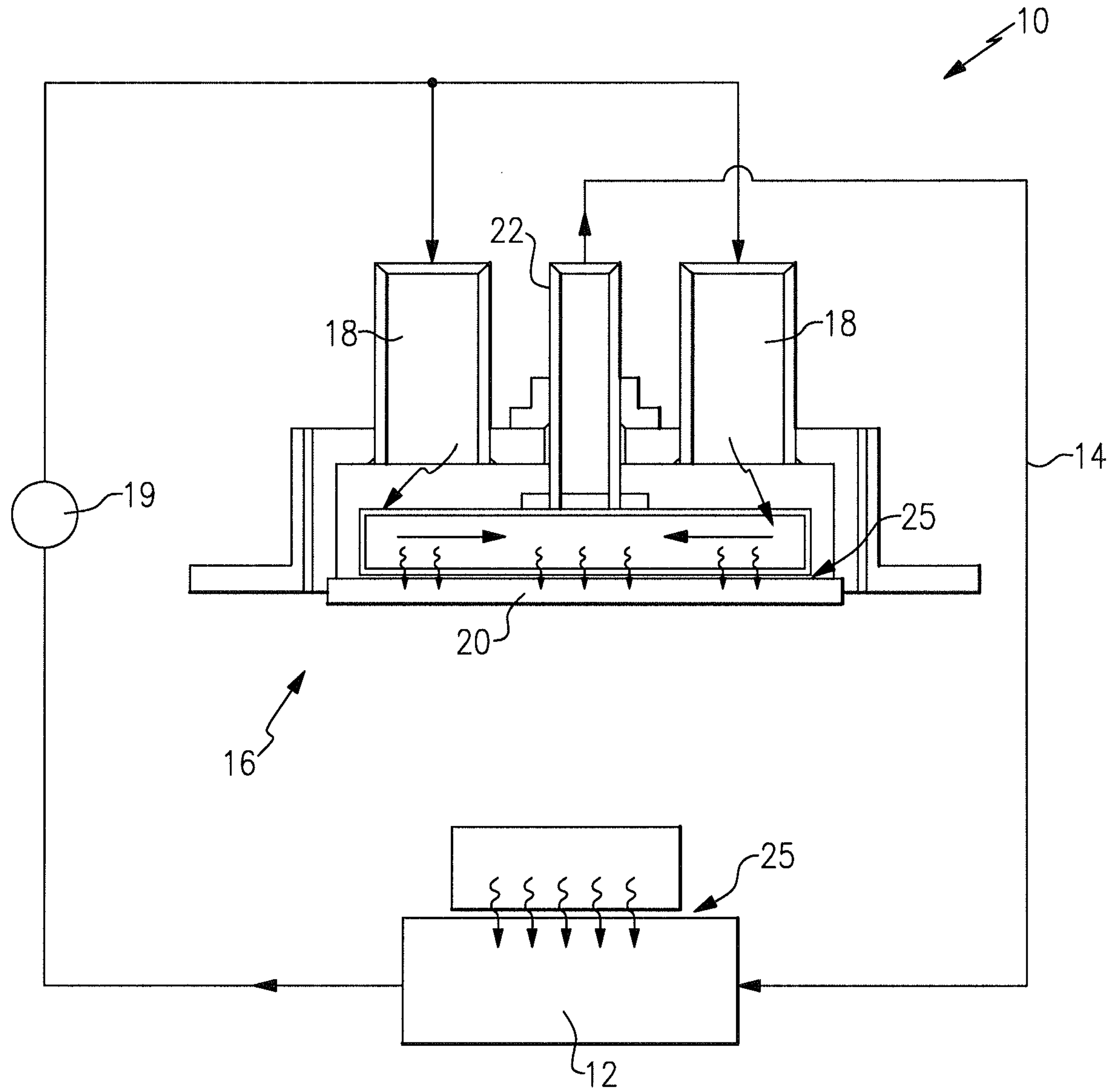

FIG.1

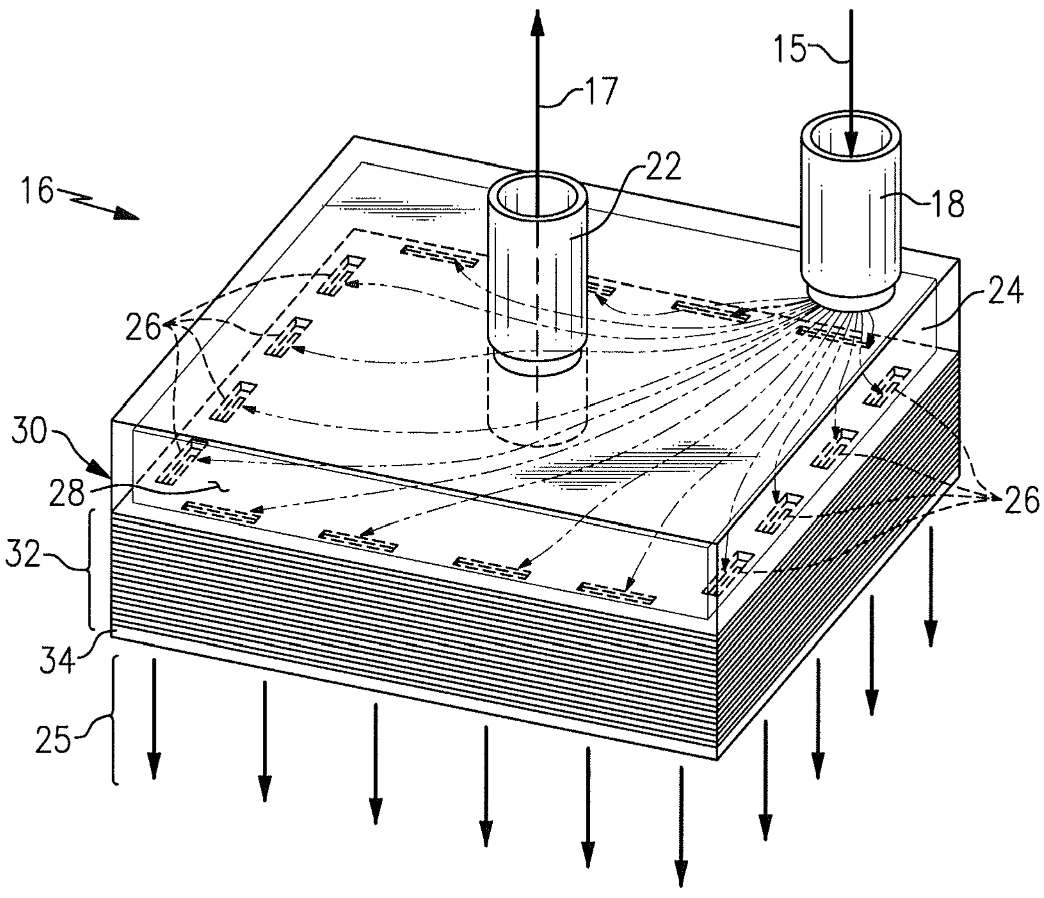

FIG.2

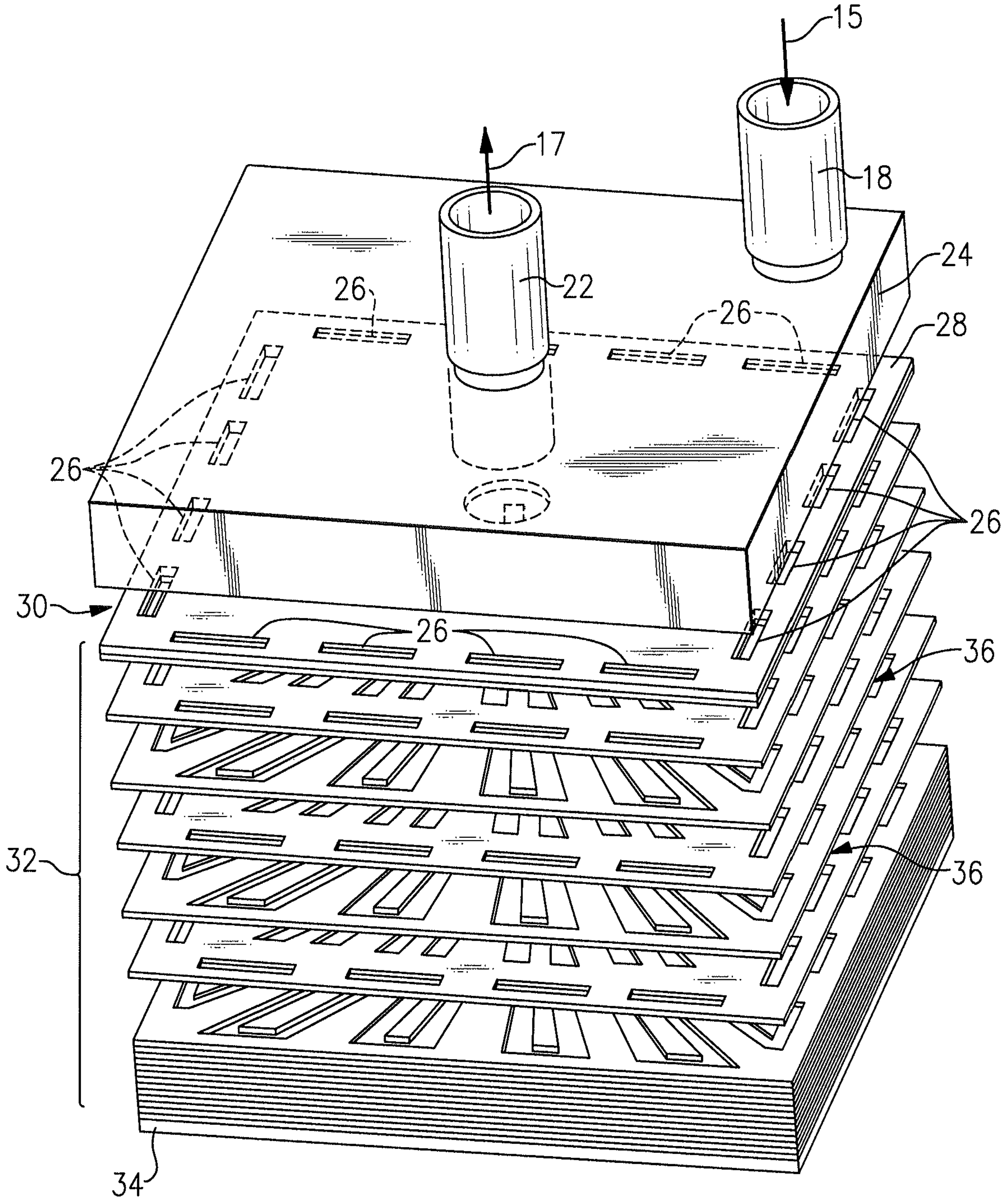

FIG.3

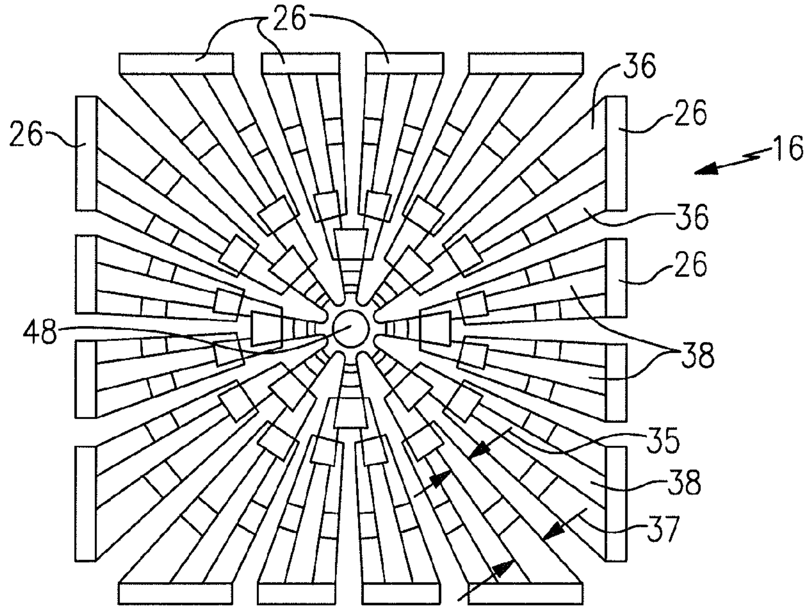

FIG.4

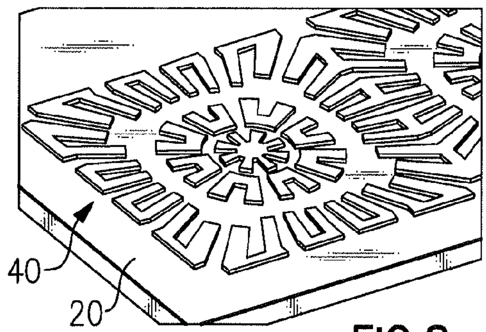

FIG.8

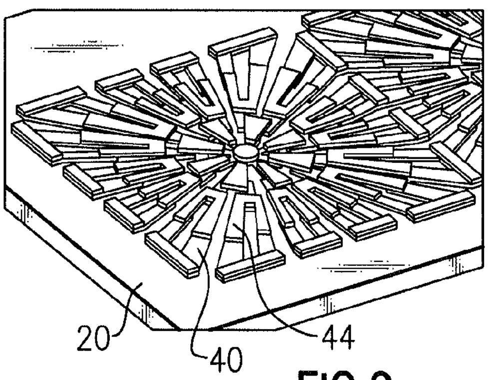

FIG.9

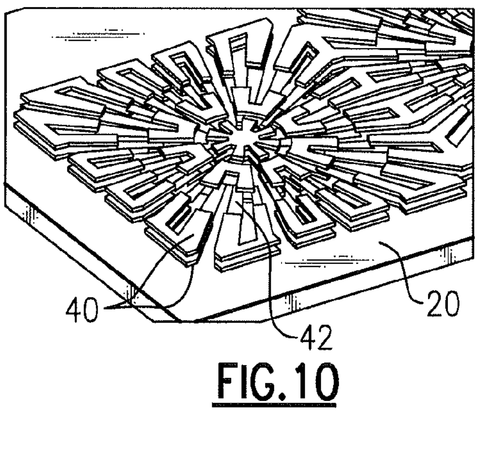

FIG.10

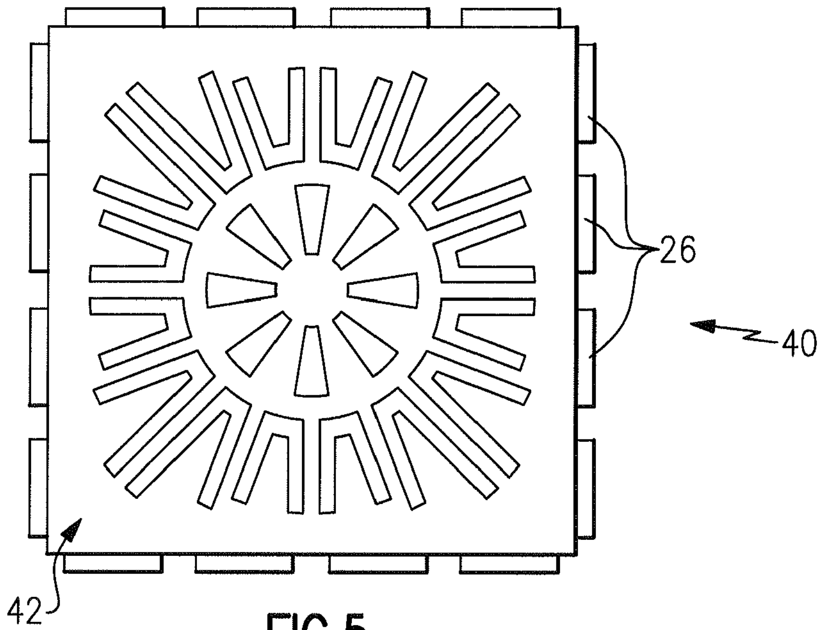

FIG.5

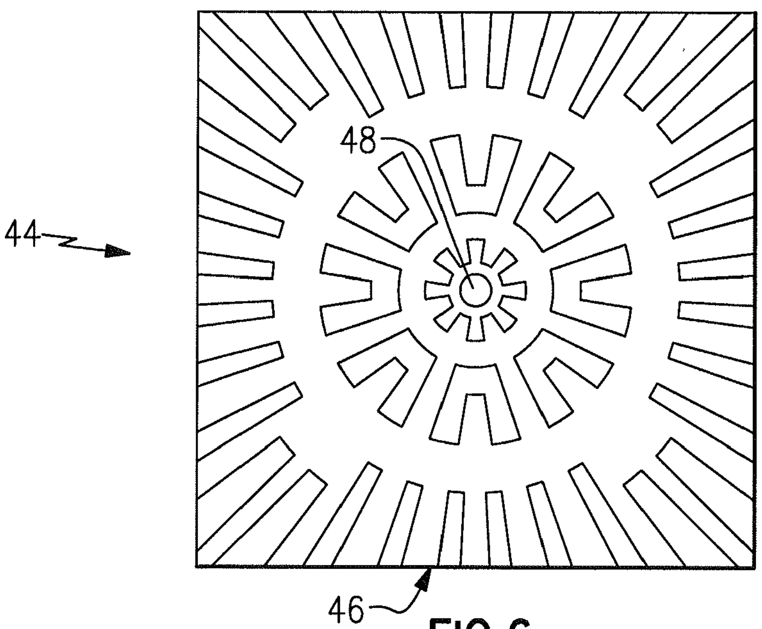

FIG.6

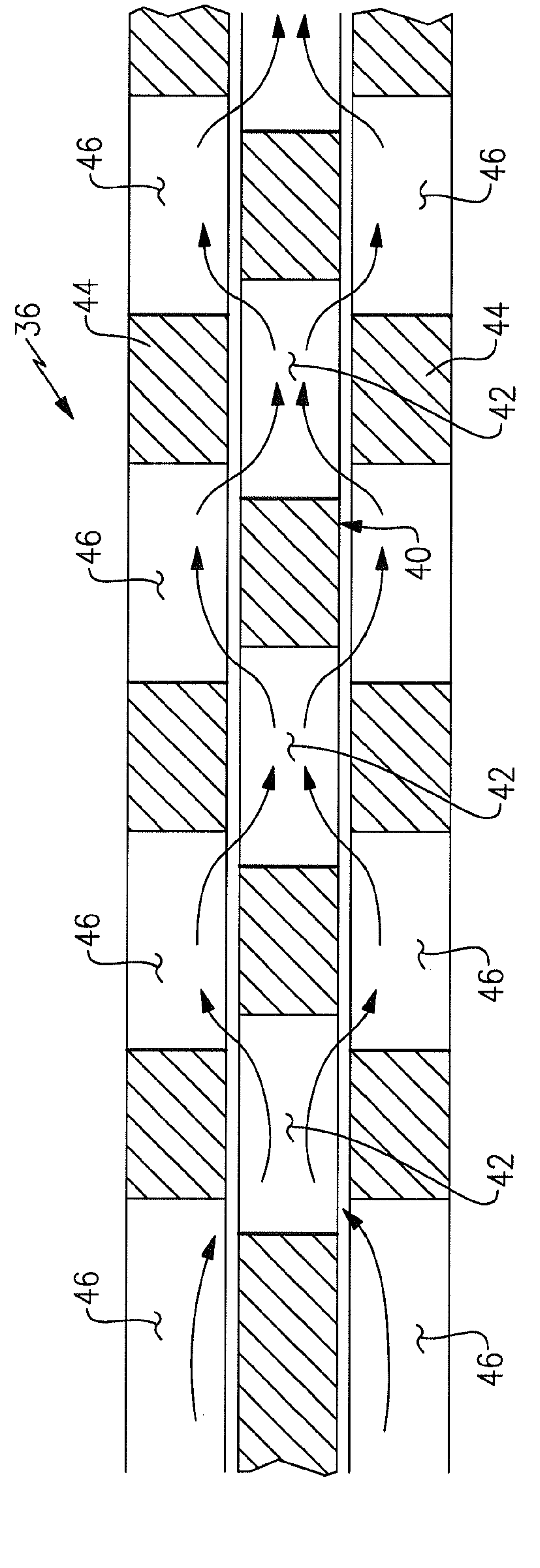

FIG.7

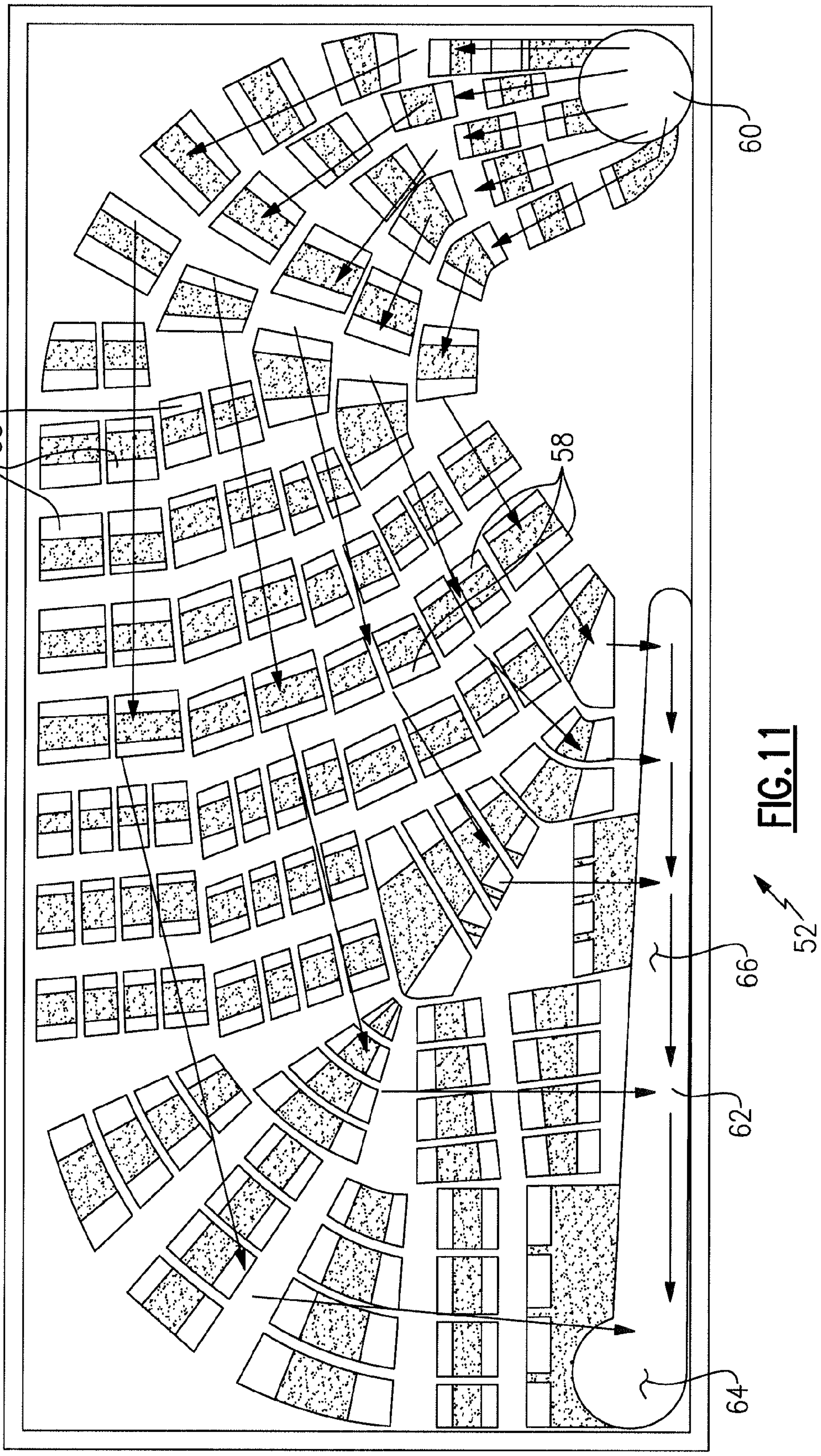

FIG.11

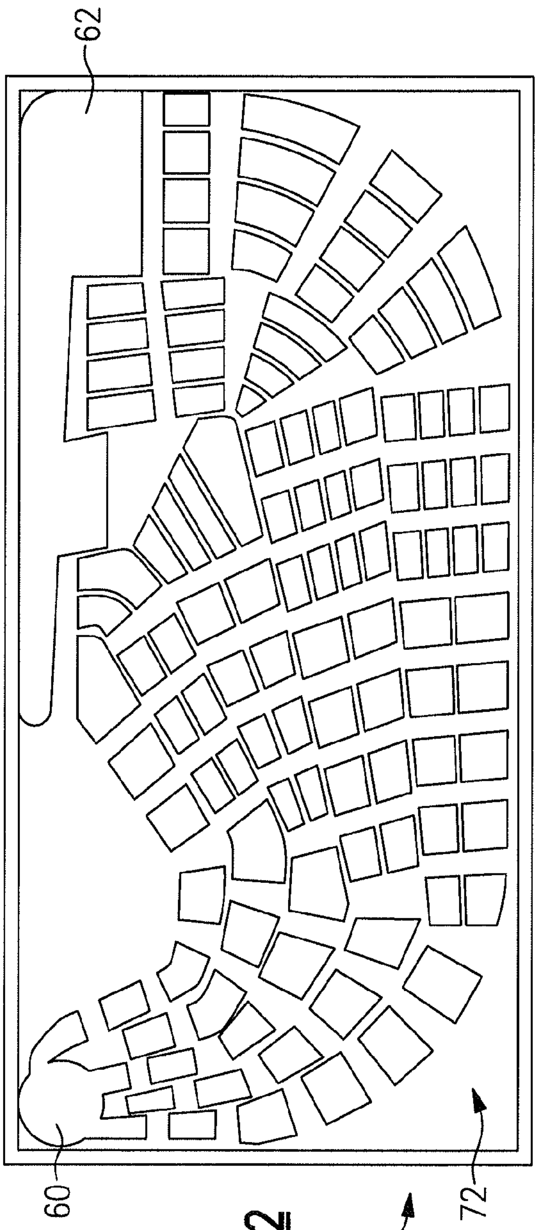

FIG.12

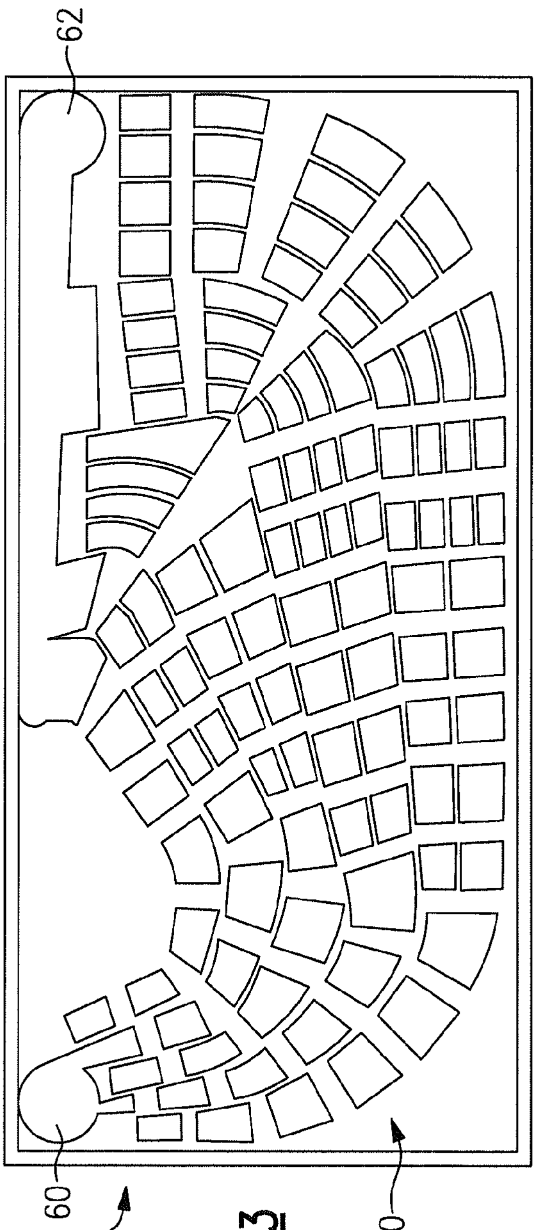

FIG.13

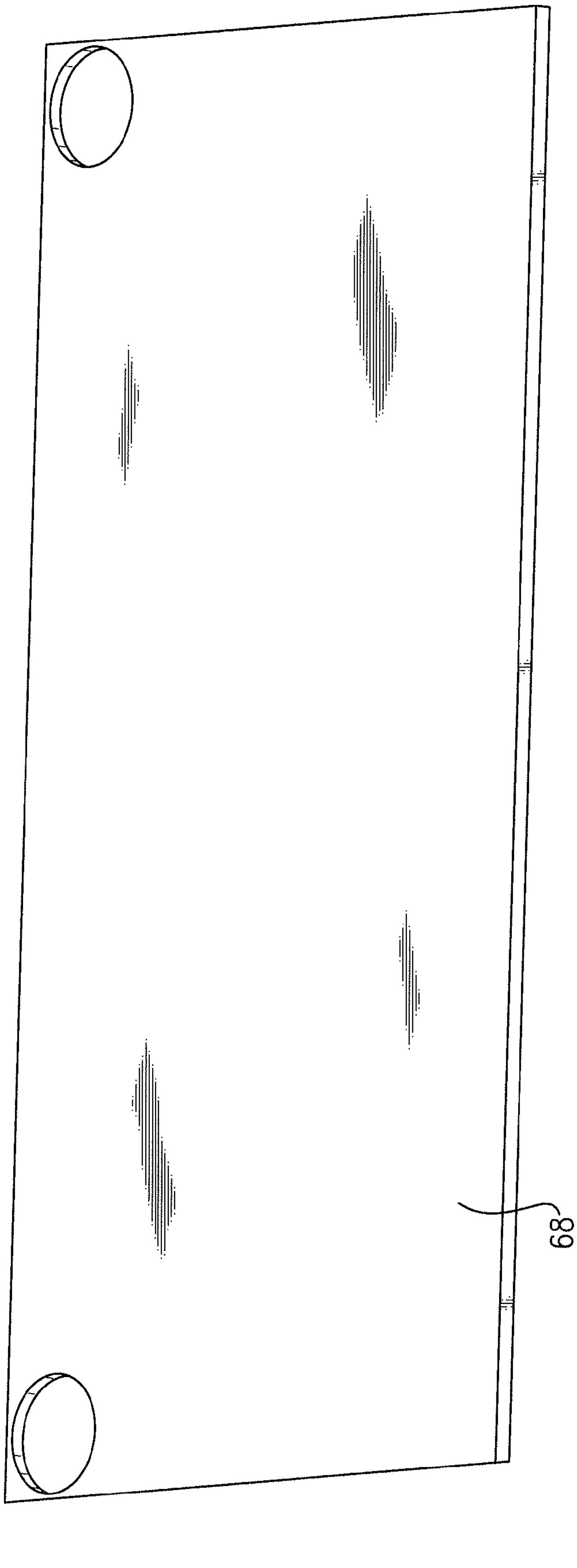

FIG.14