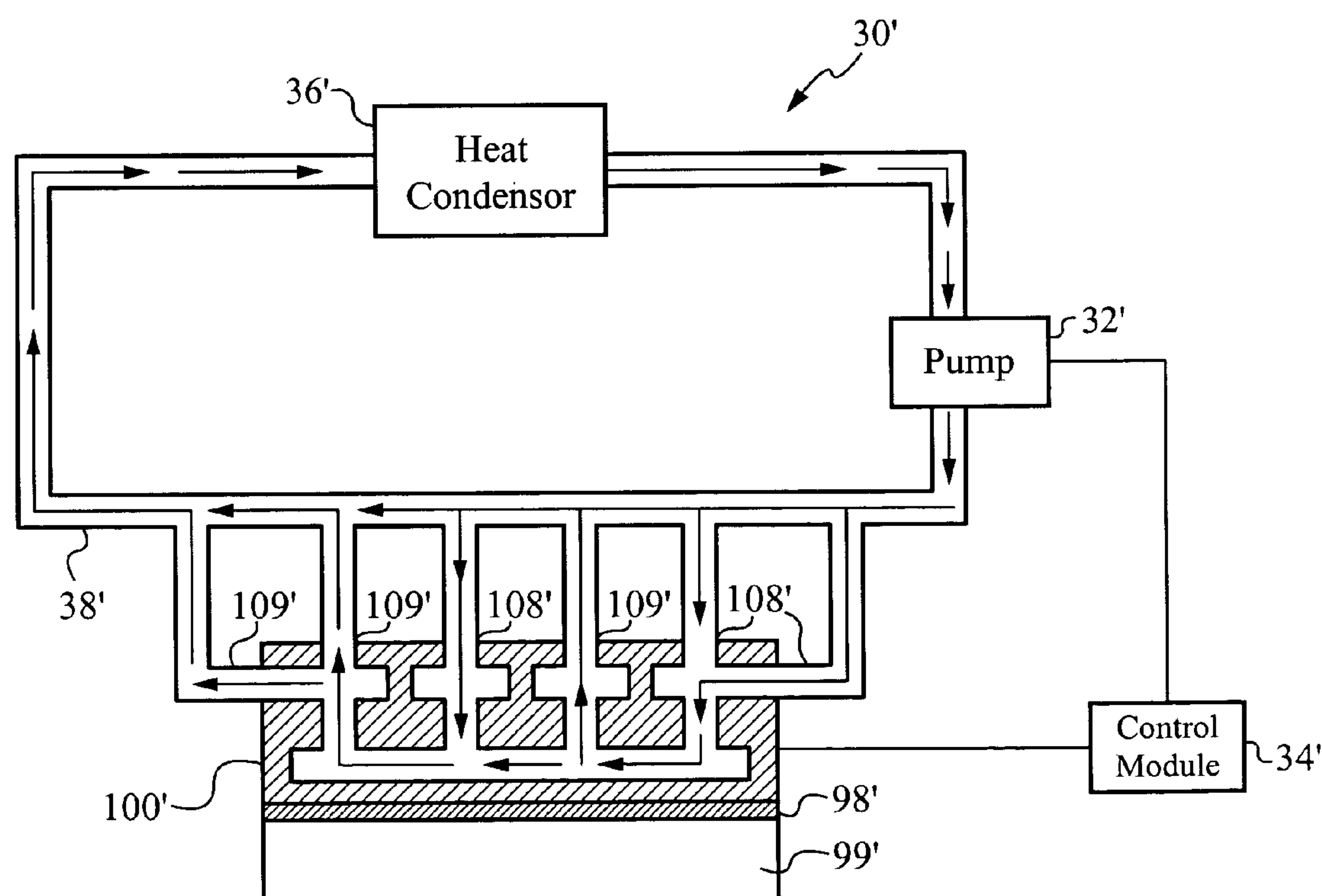
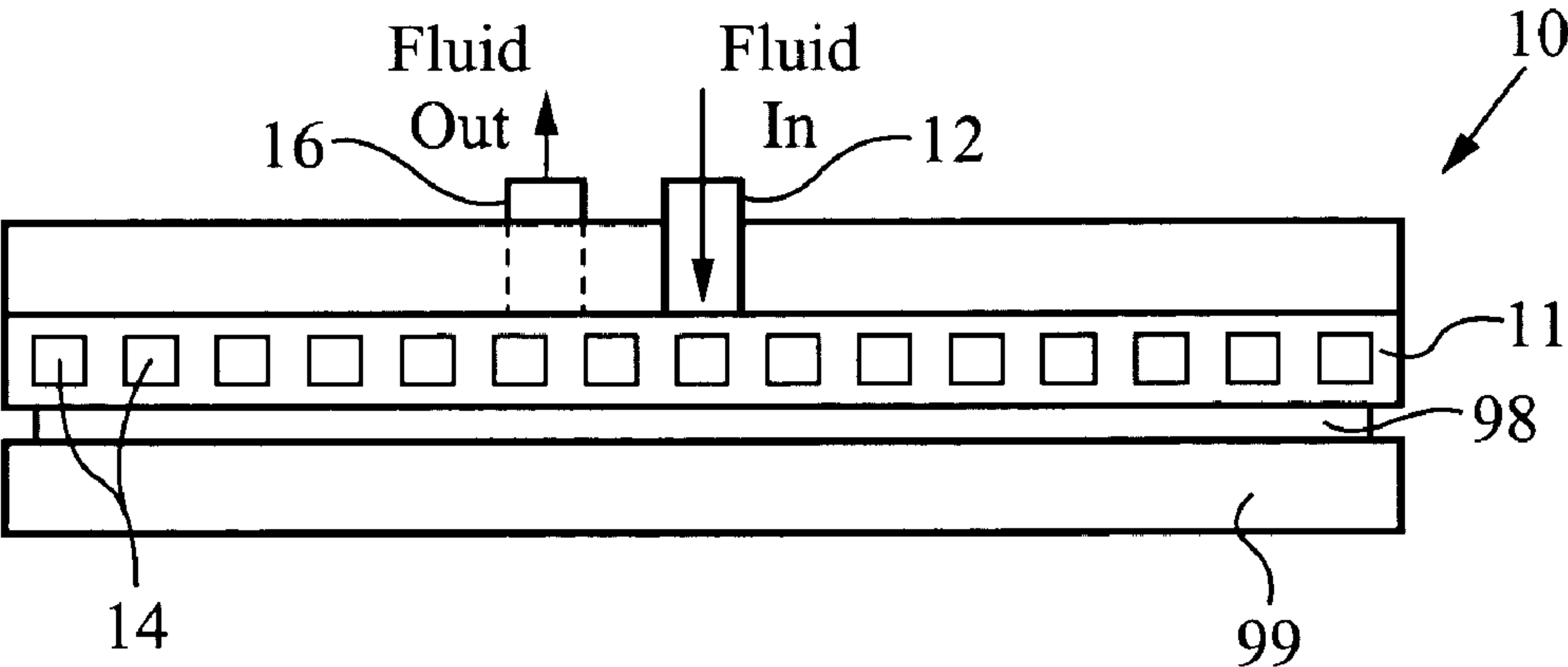


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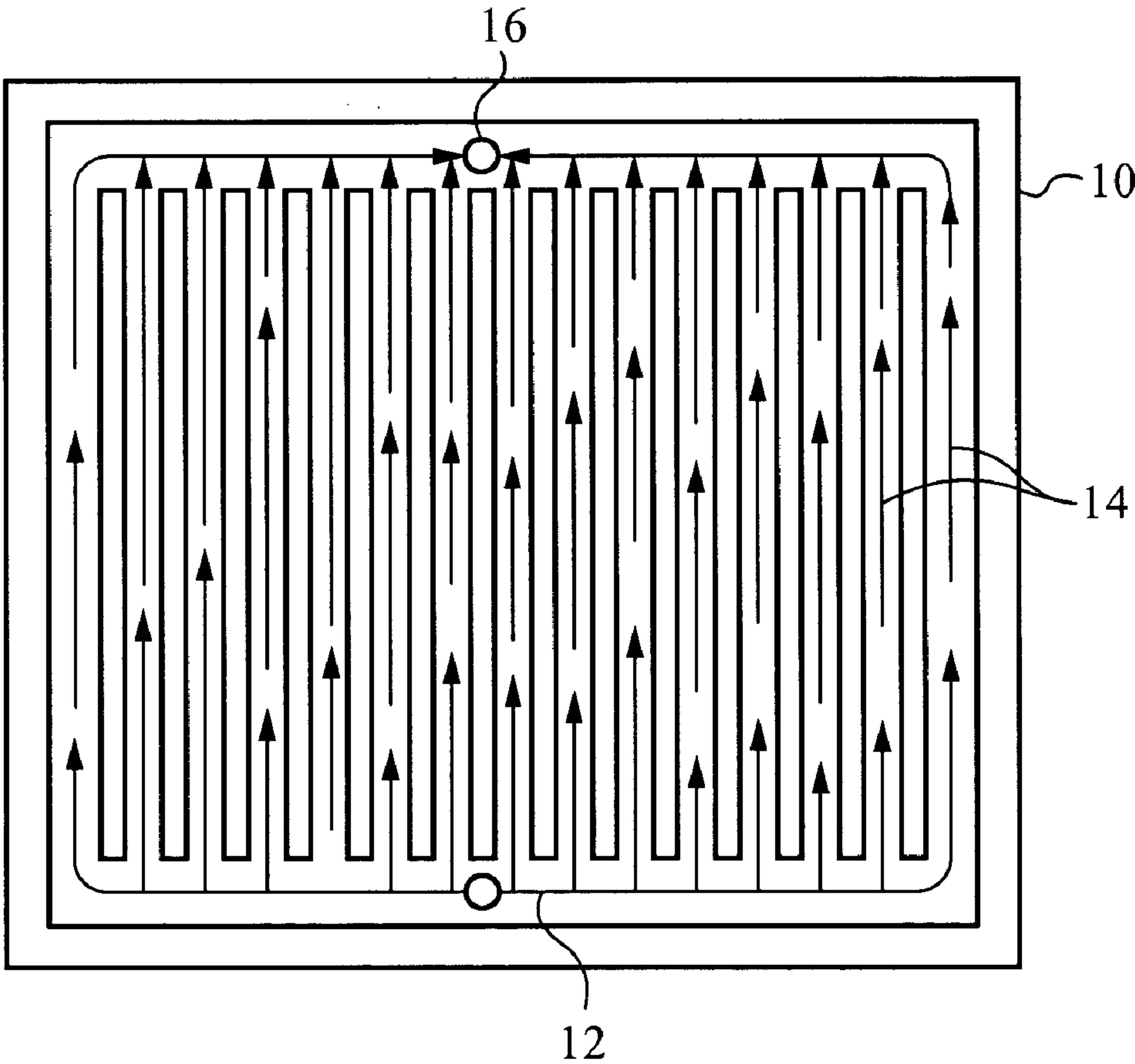
(19) **United States**(12) **Patent Application Publication**  
Upadhy et al.(10) **Pub. No.: US 2005/0211417 A1**(43) **Pub. Date: Sep. 29, 2005**(54) **INTERWOVEN MANIFOLDS FOR  
PRESSURE DROP REDUCTION IN  
MICROCHANNEL HEAT EXCHANGERS**(75) Inventors: **Girish Upadhy**, Mountain View, CA  
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**SUNNYVALE, CA 94086 (US)**(73) Assignee: **Cooligy, Inc.**(21) Appl. No.: **10/881,980**(22) Filed: **Jun. 29, 2004****Related U.S. Application Data**(63) Continuation-in-part of application No. 10/439,912,  
filed on May 16, 2003.(60) Provisional application No. 60/423,009, filed on Nov.  
1, 2002. Provisional application No. 60/442,383, filed  
on Jan. 24, 2003. Provisional application No. 60/455,  
729, filed on Mar. 17, 2003.**Publication Classification**(51) **Int. Cl.<sup>7</sup>** ..... **F28F 7/00**(52) **U.S. Cl.** ..... **165/80.4**(57) **ABSTRACT**

A microchannel heat exchanger coupled to a heat source and configured for cooling the heat source comprising a first set of fingers for providing fluid at a first temperature to a heat exchange region, wherein fluid in the heat exchange region flows toward a second set of fingers and exits the heat exchanger at a second temperature, wherein each finger is spaced apart from an adjacent finger by an appropriate dimension to minimize pressure drop in the heat exchanger and arranged in parallel. The microchannel heat exchanger includes an interface layer having the heat exchange region. Preferably, a manifold layer includes the first set of fingers and the second set of fingers configured within to cool hot spots in the heat source. Alternatively, the interface layer includes the first set and second set of fingers configured along the heat exchange region.

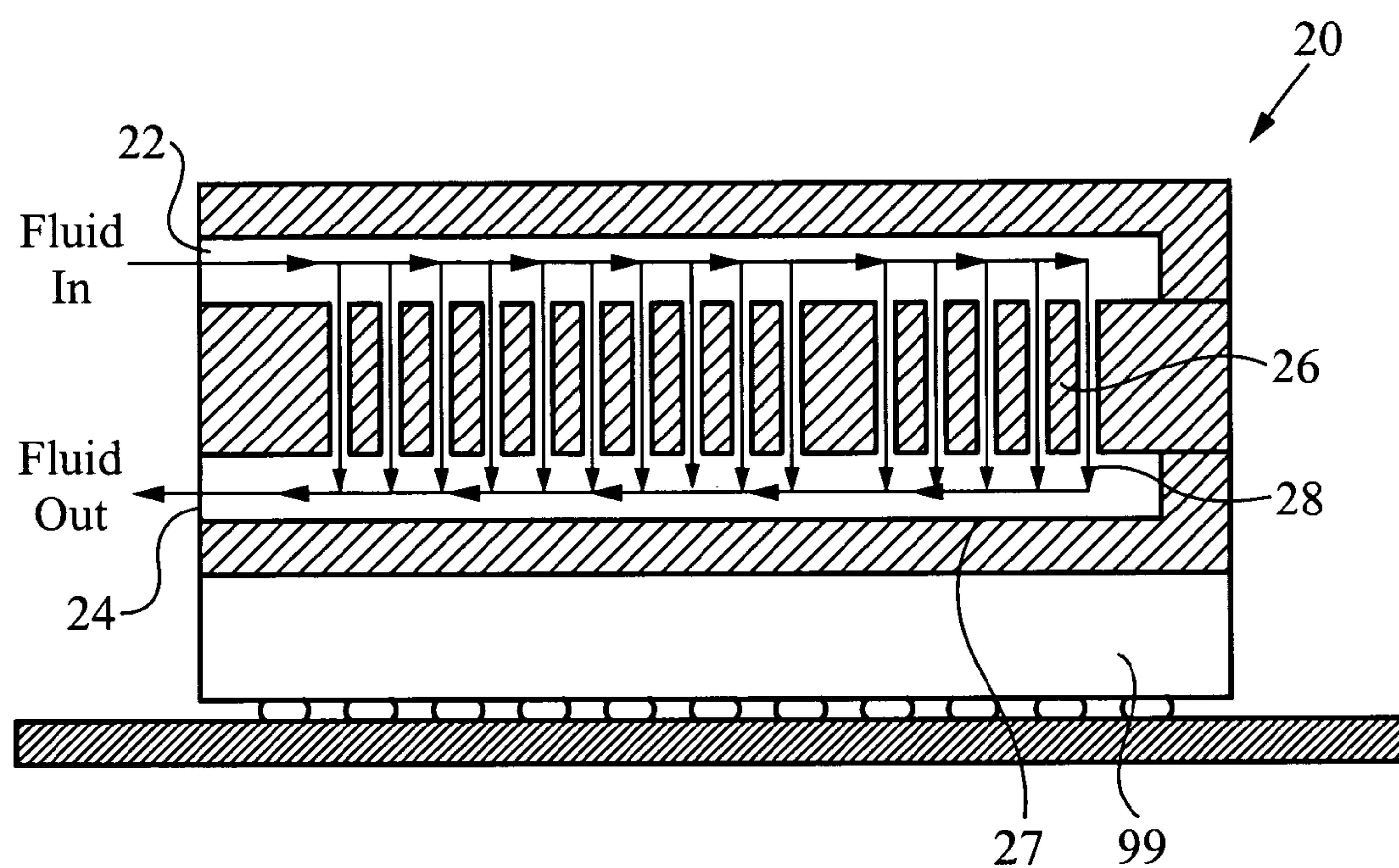




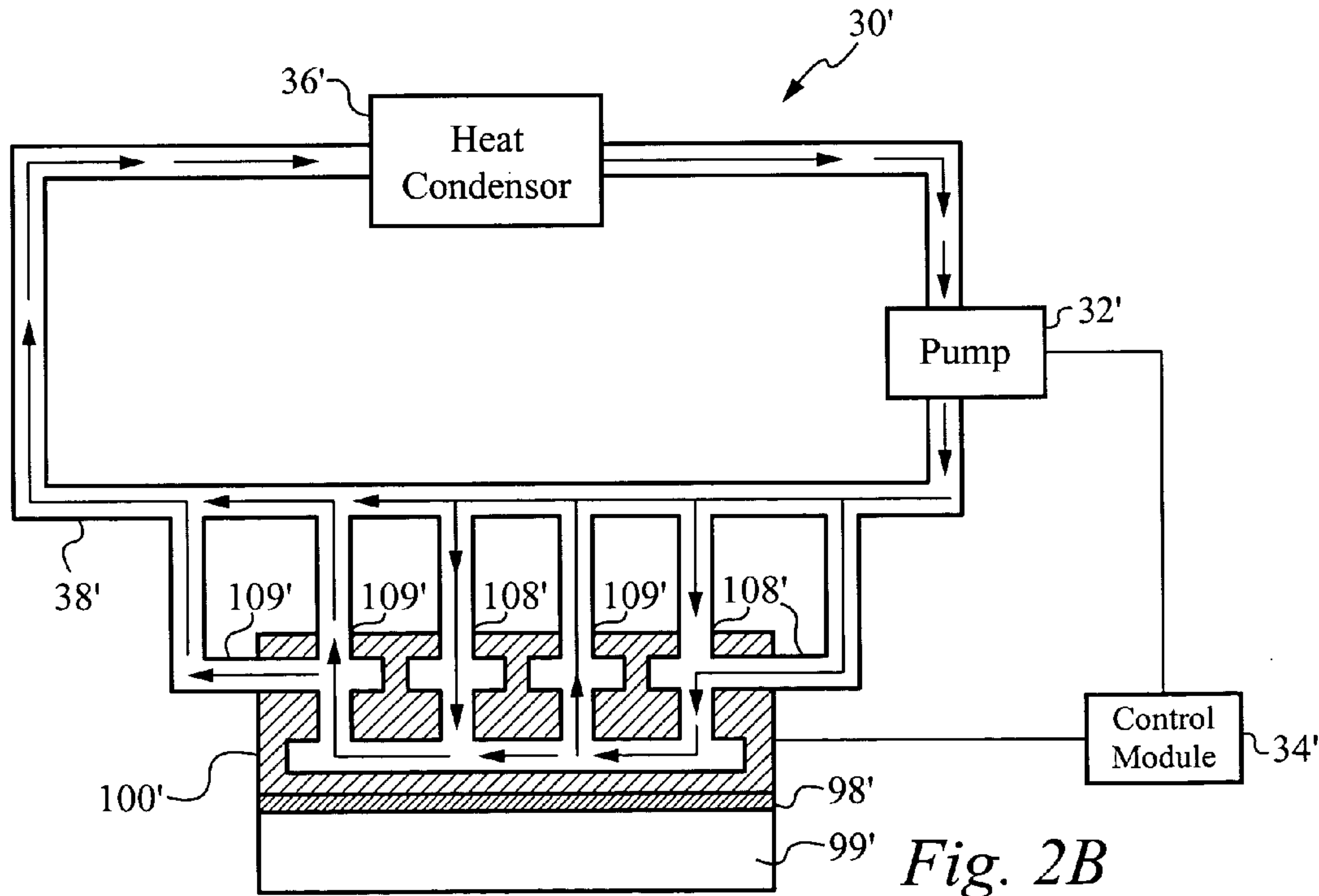
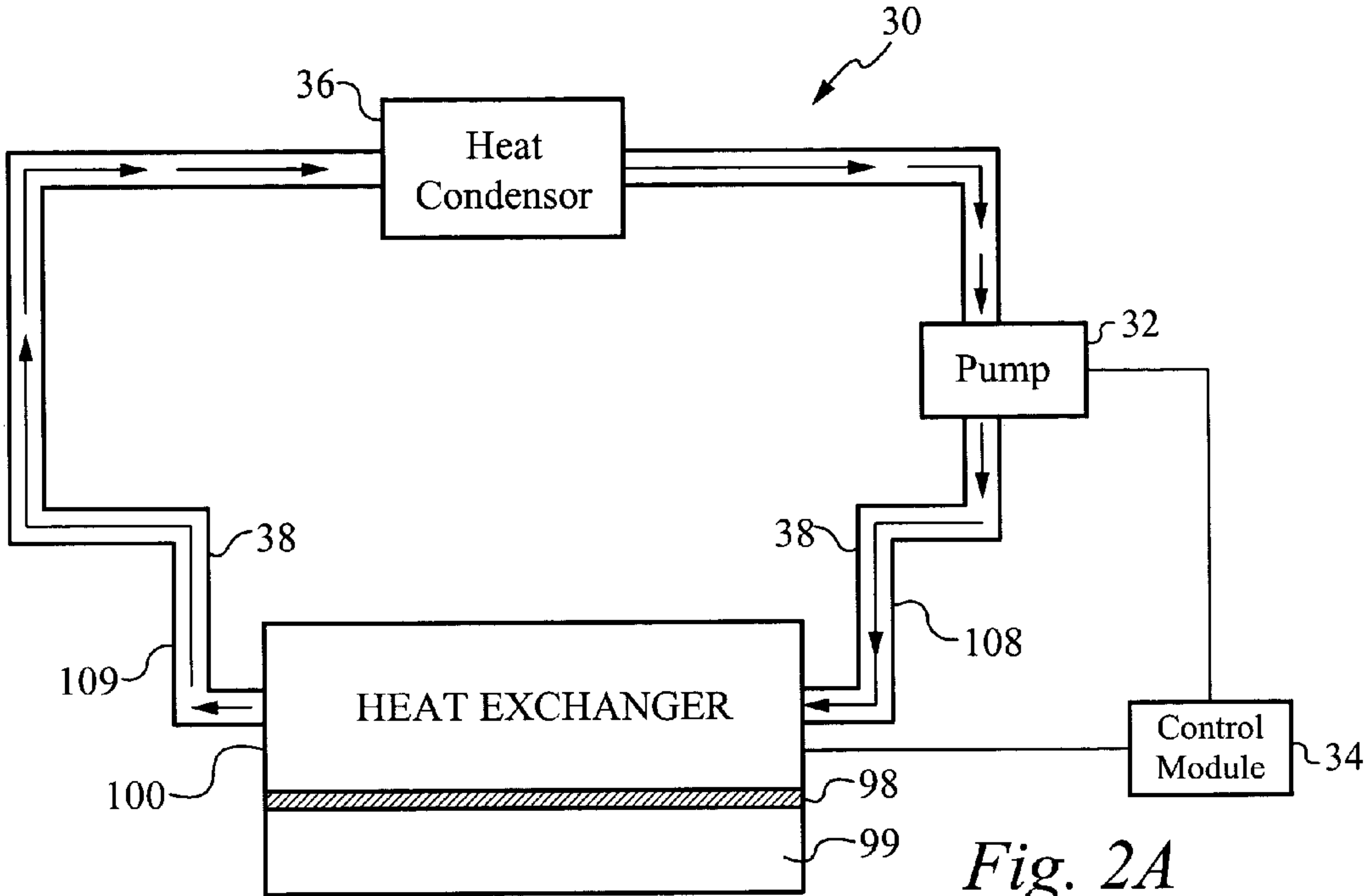
*Fig. 1A* (PRIOR ART)

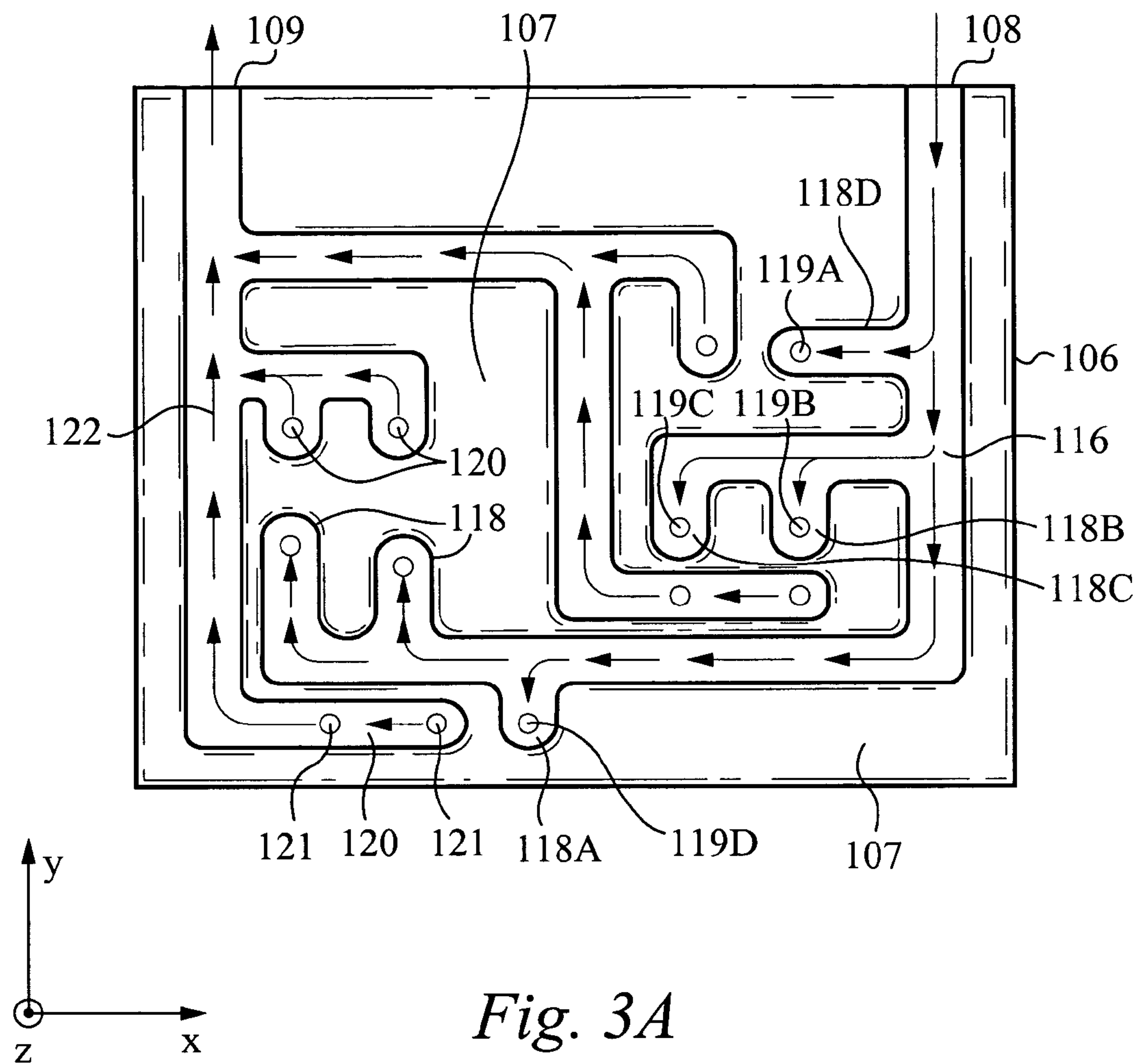


*Fig. 1B* (PRIOR ART)



*Fig. 1C* (PRIOR ART)







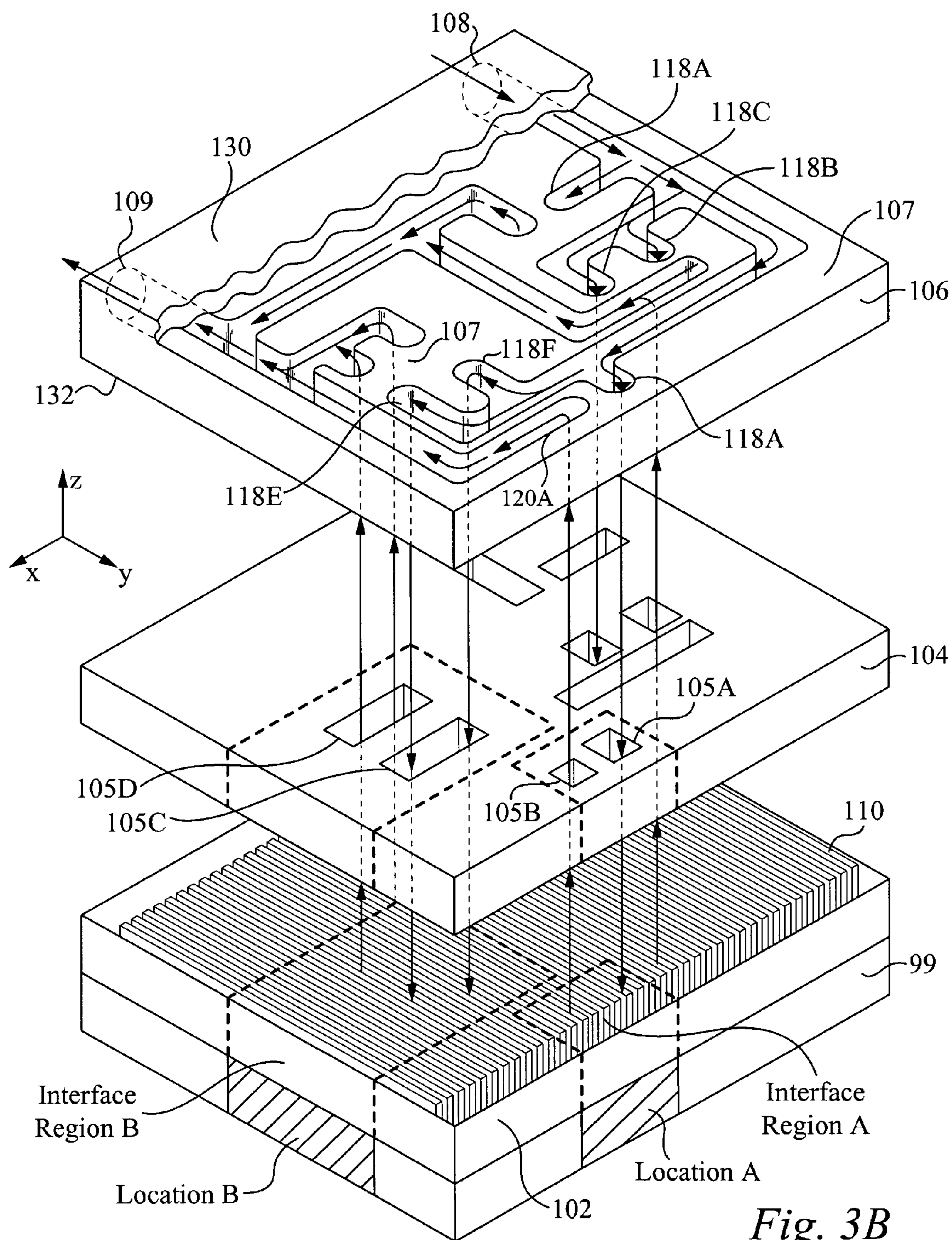


Fig. 3B

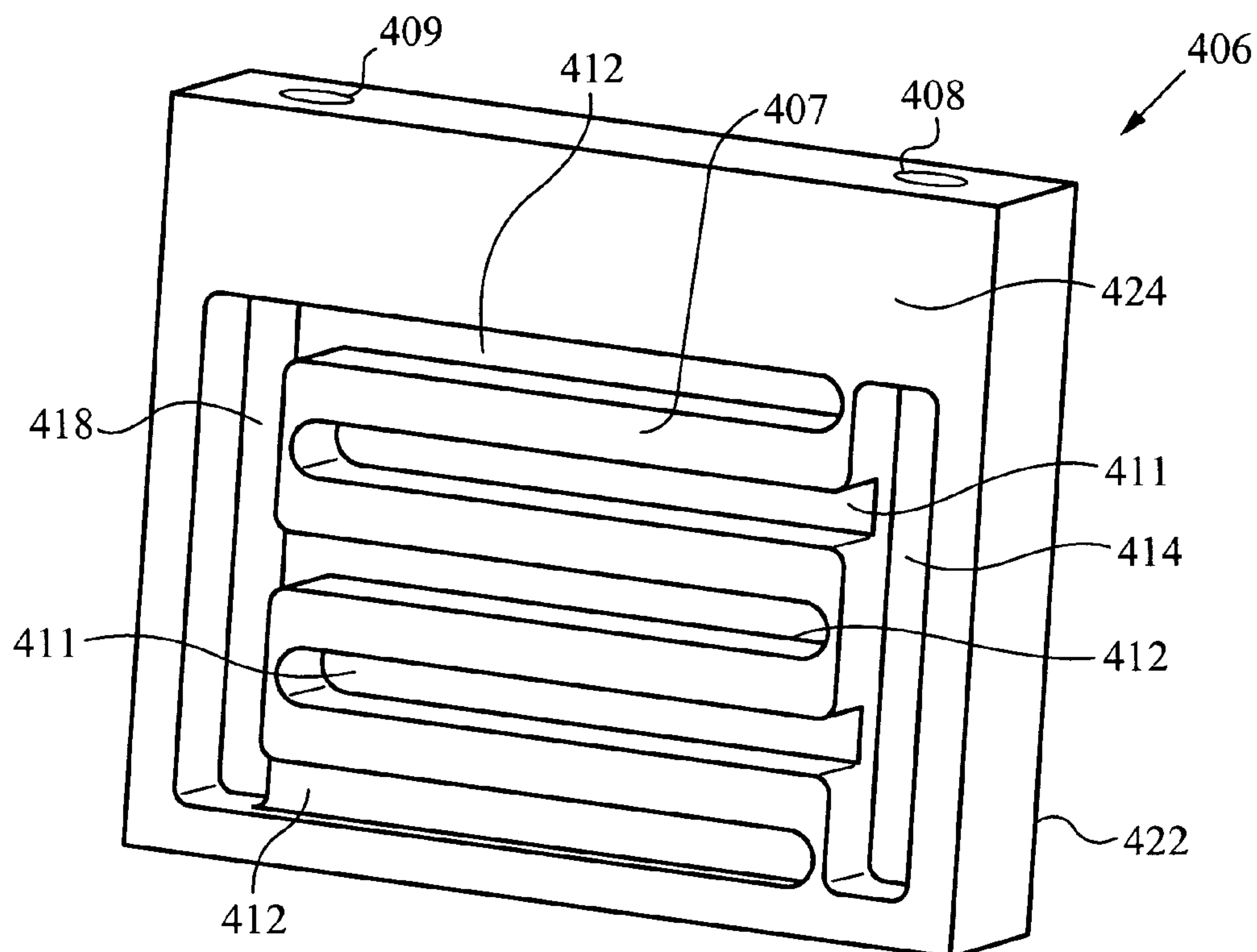


Fig. 4

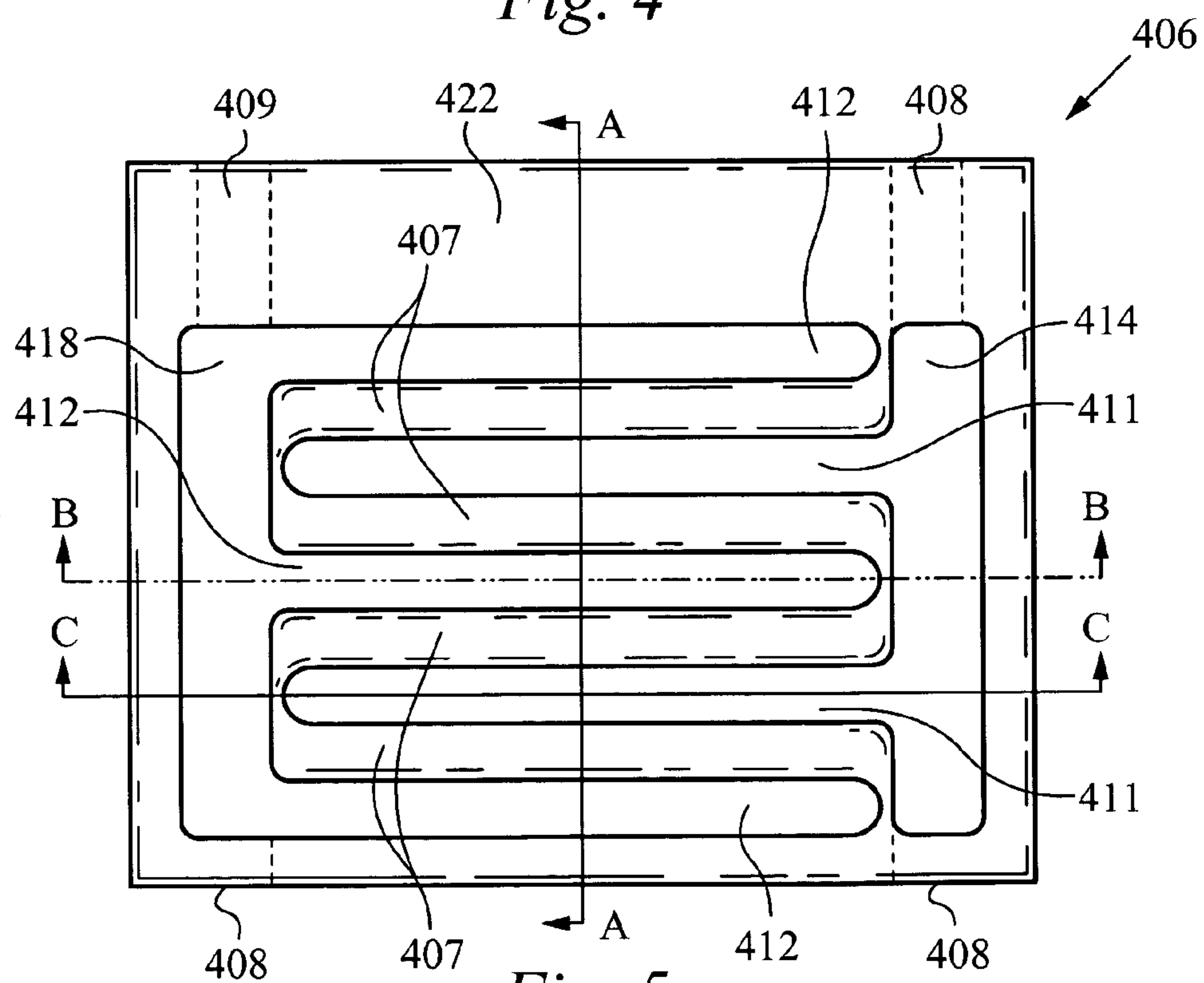


Fig. 5

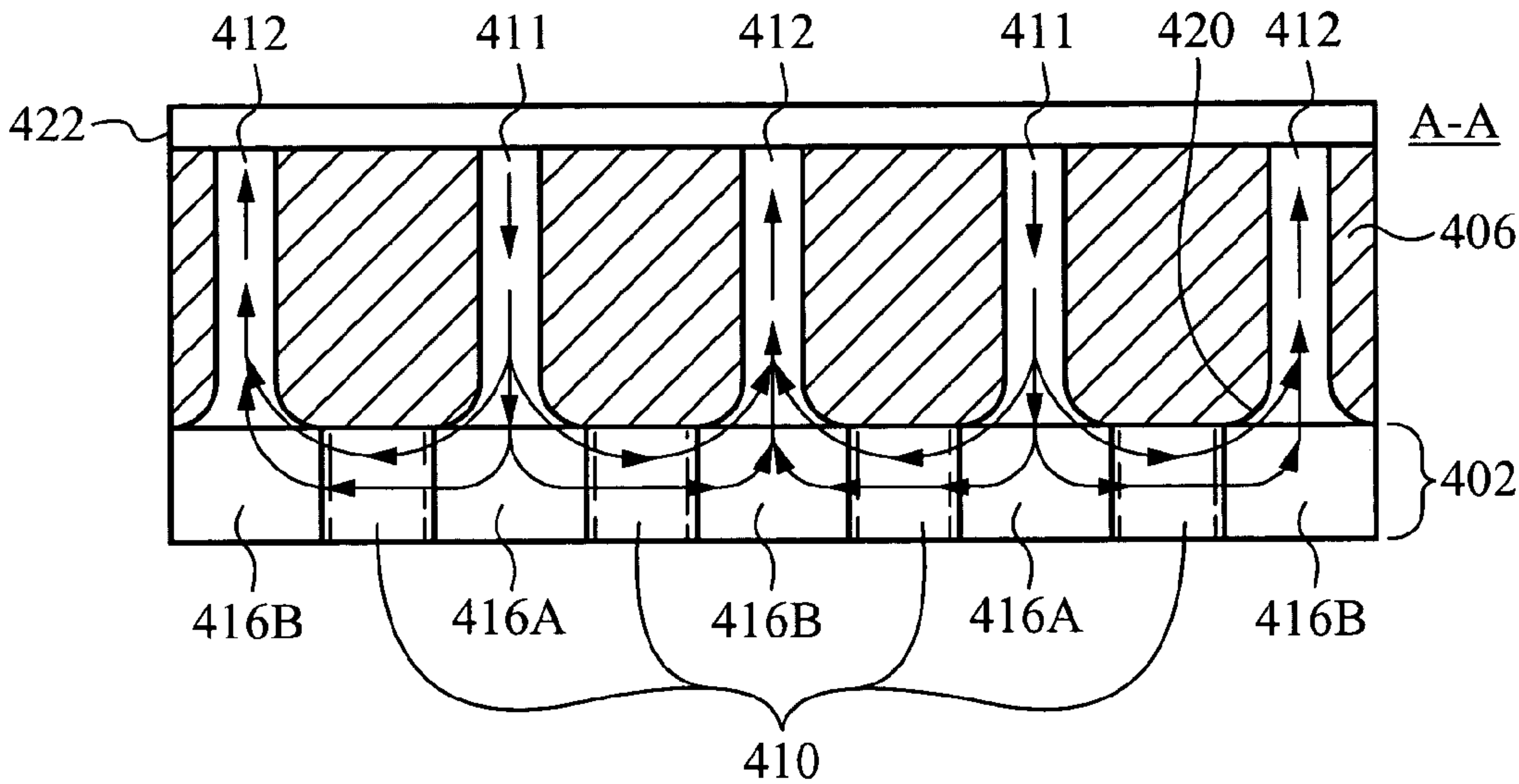


Fig. 6A

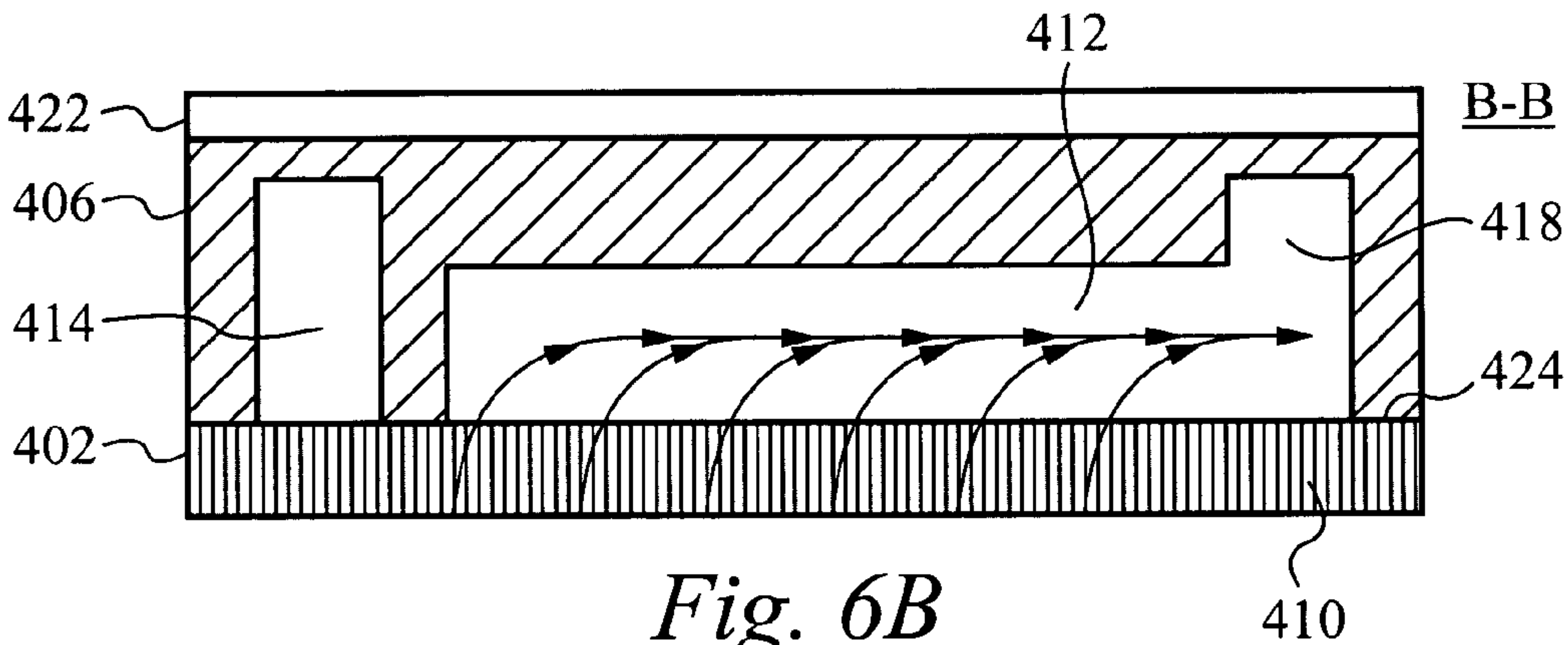


Fig. 6B

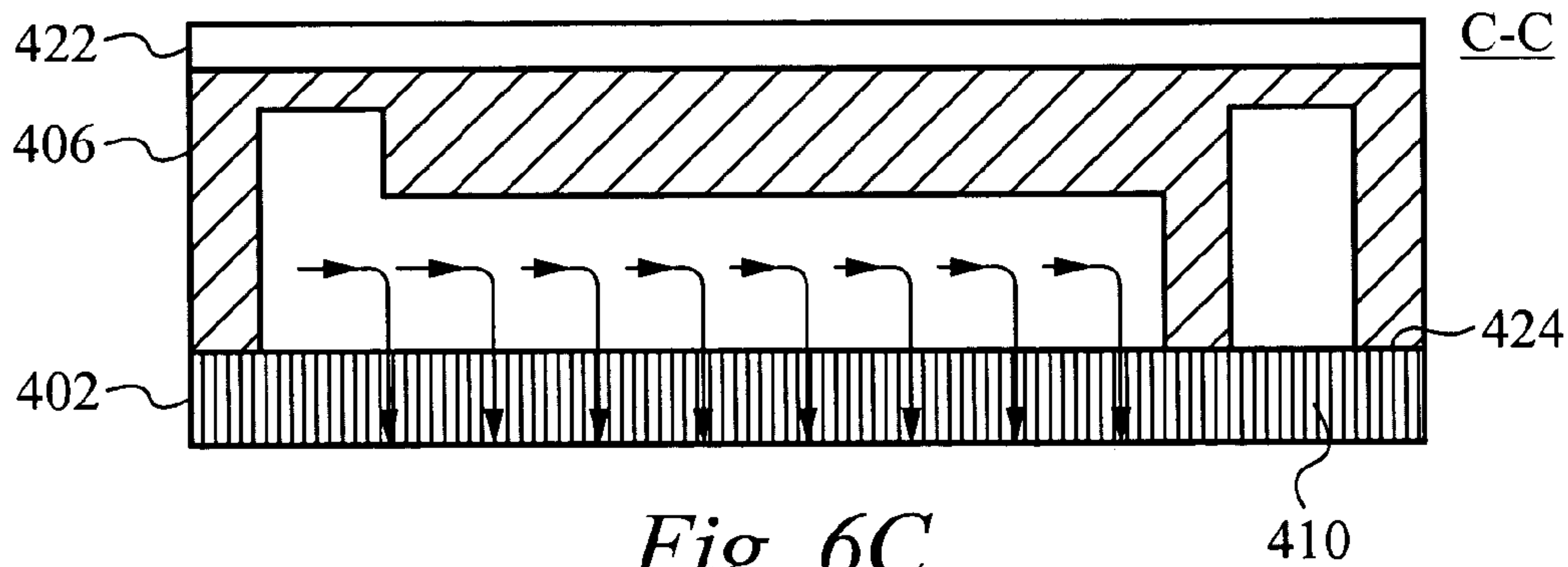
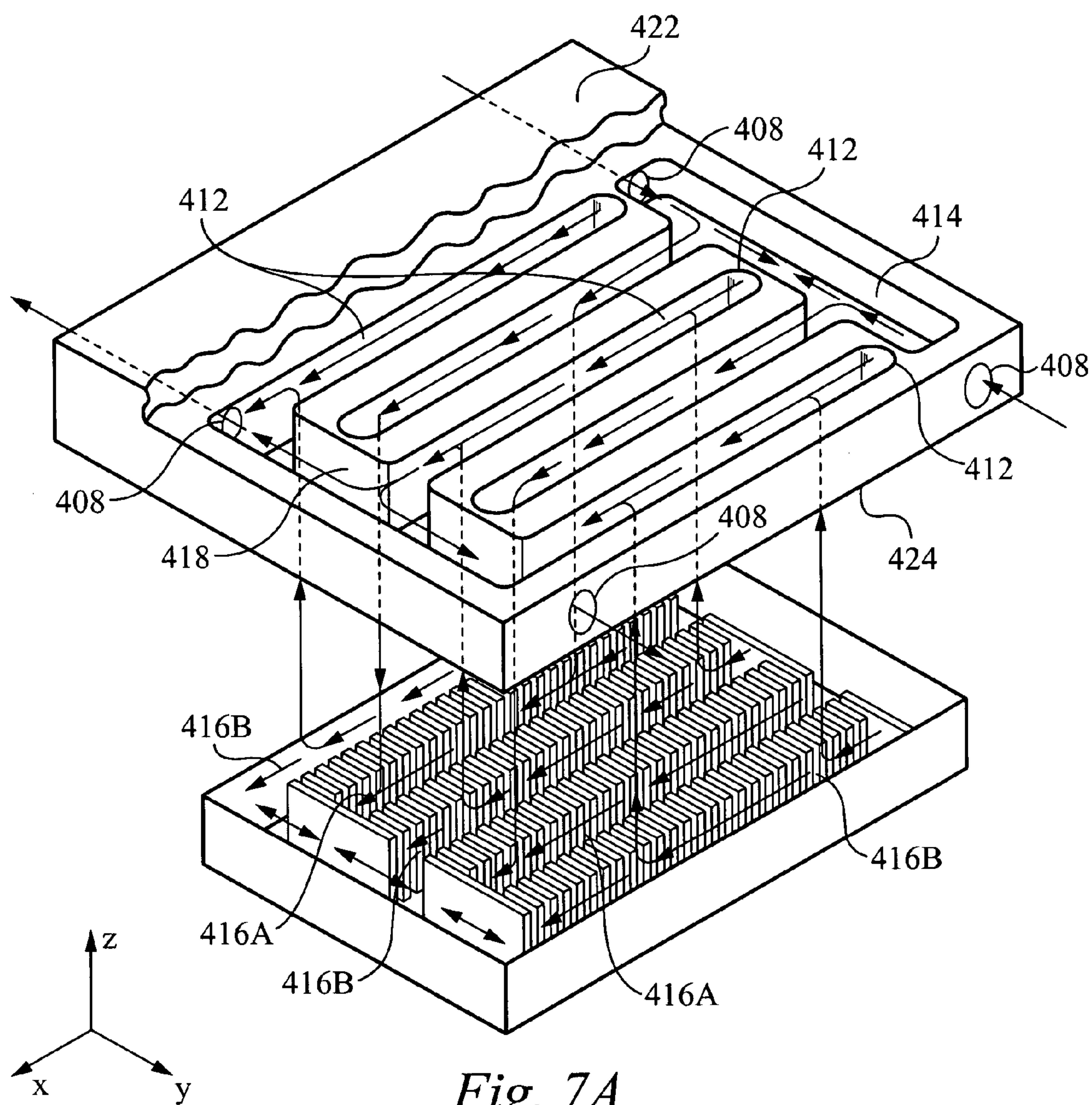
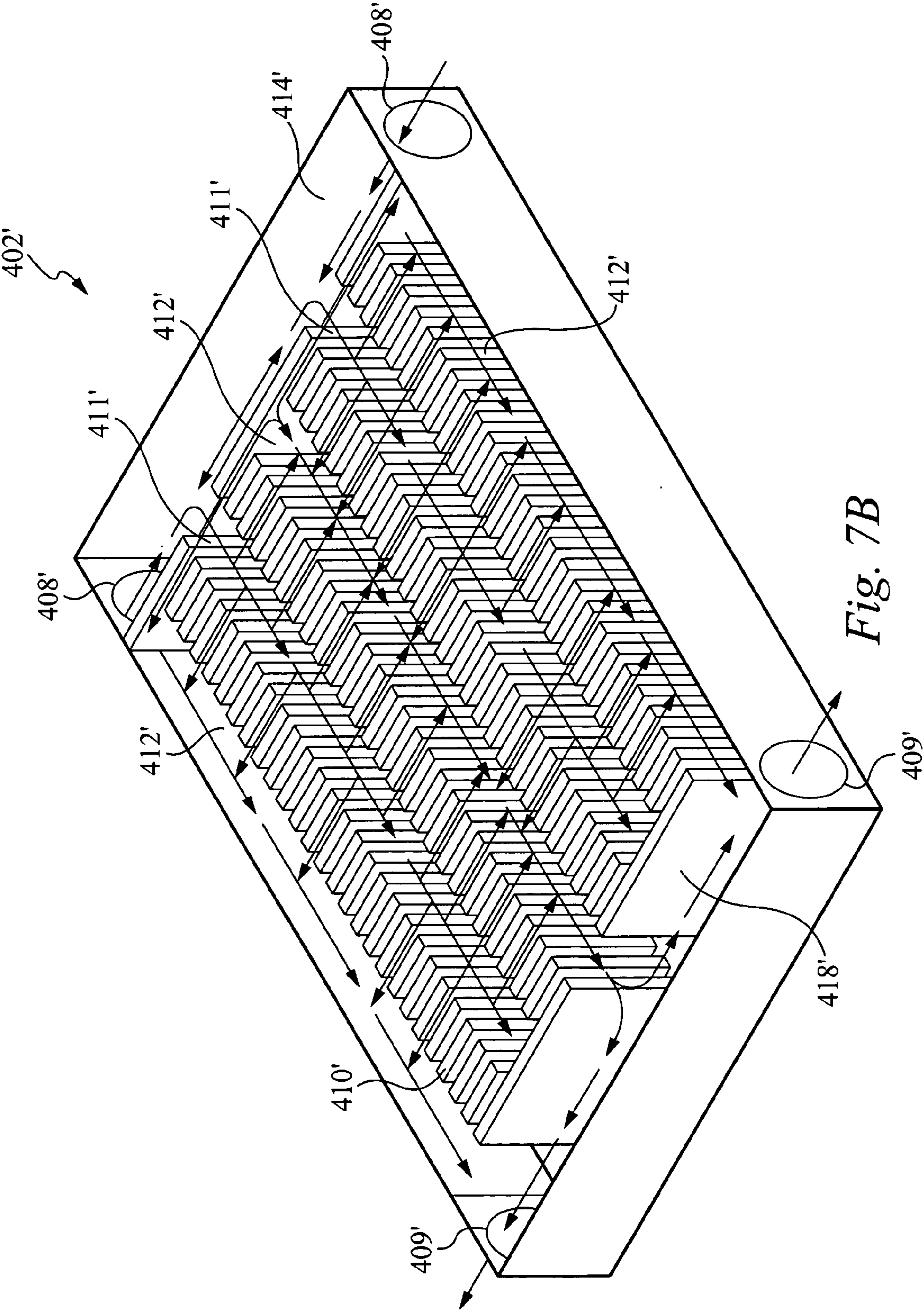


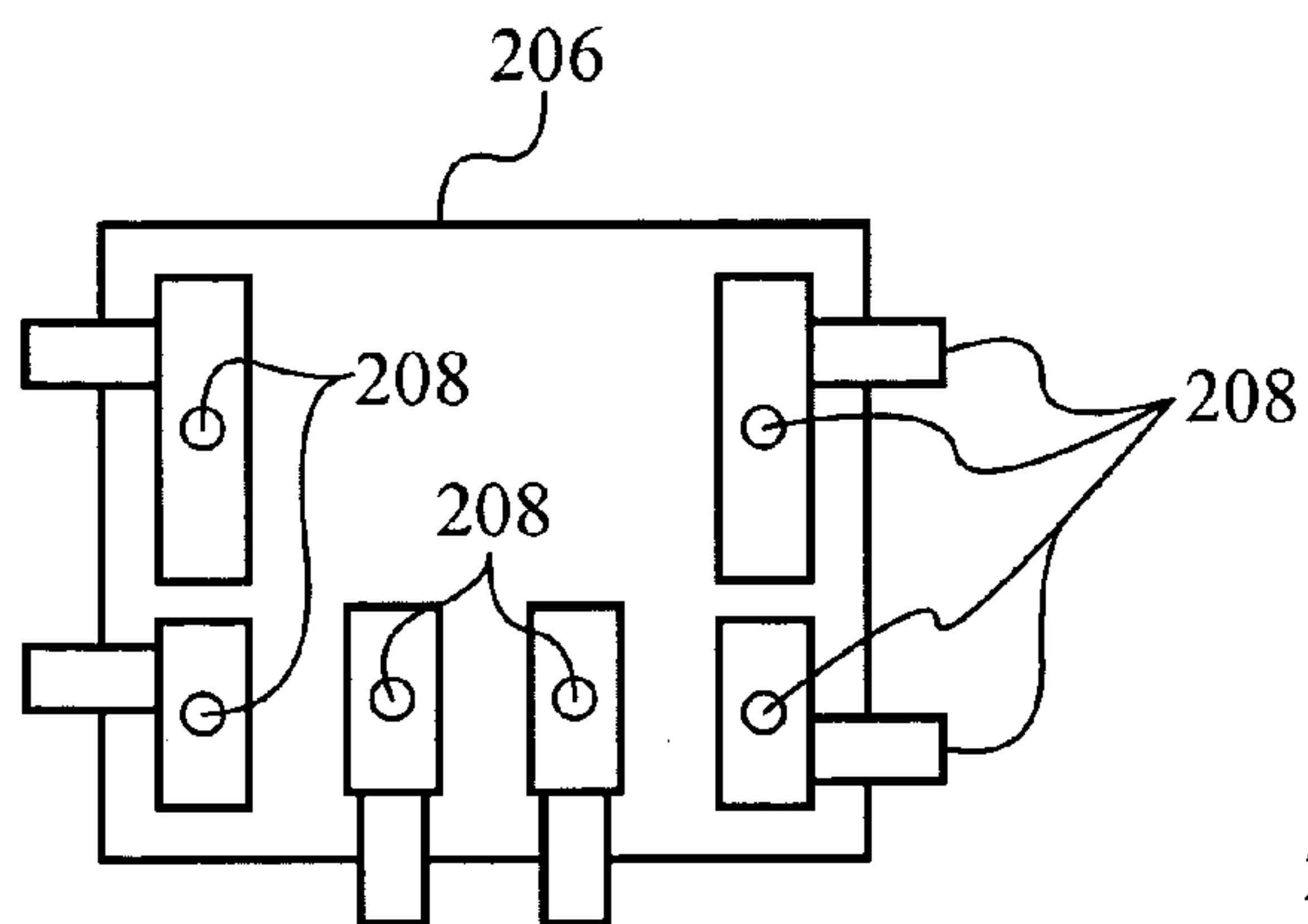
Fig. 6C



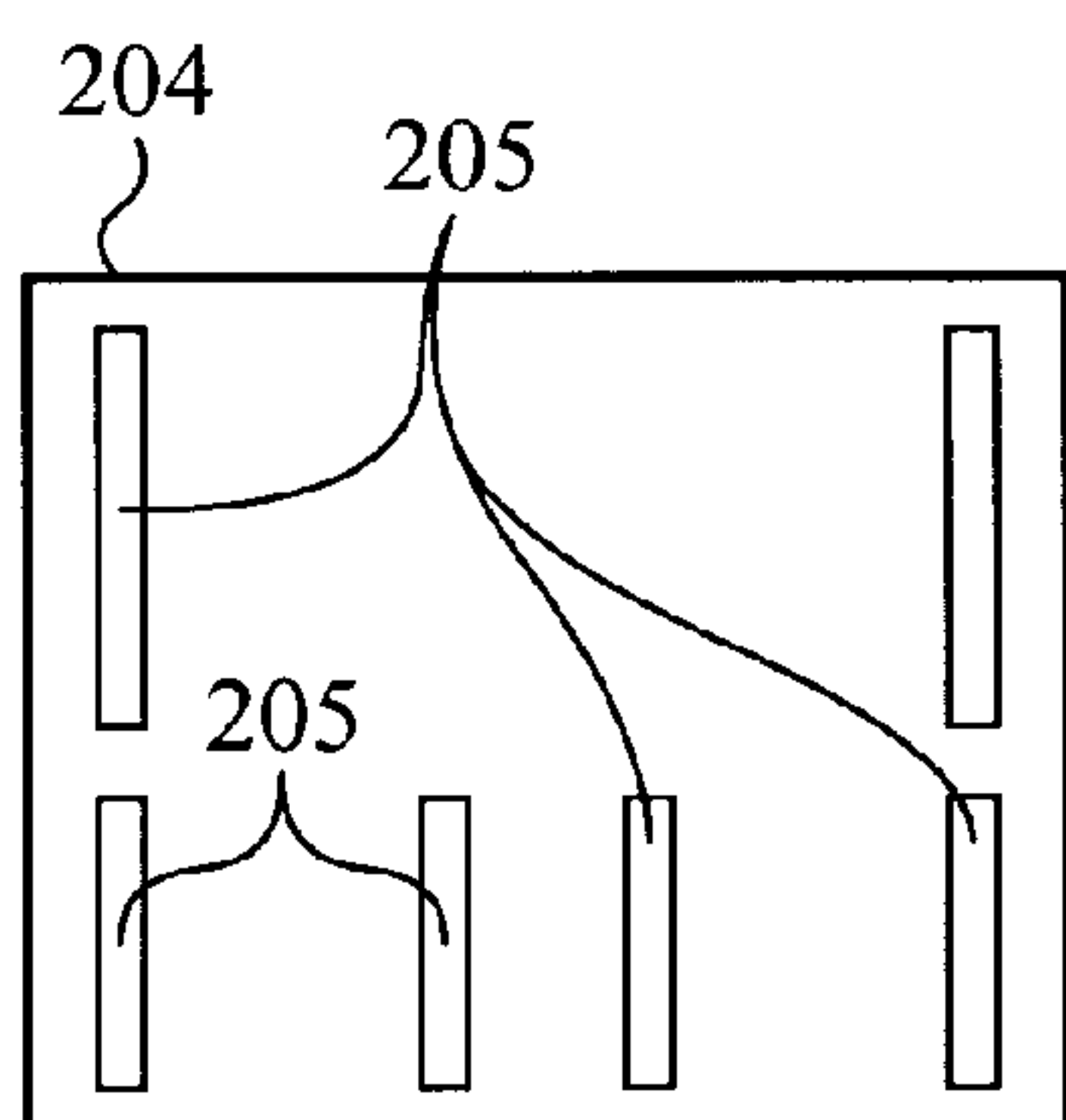


*Fig. 7A*

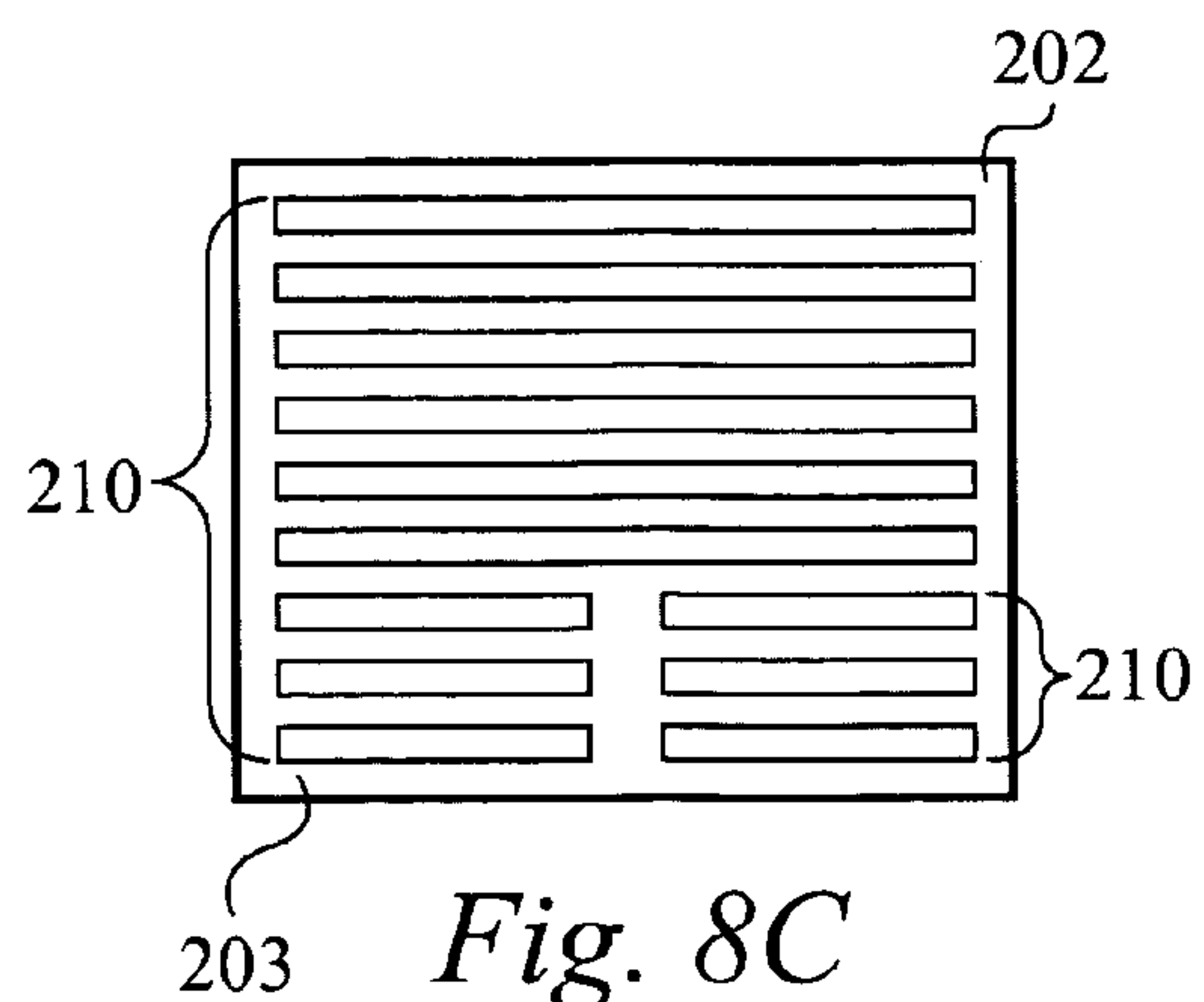




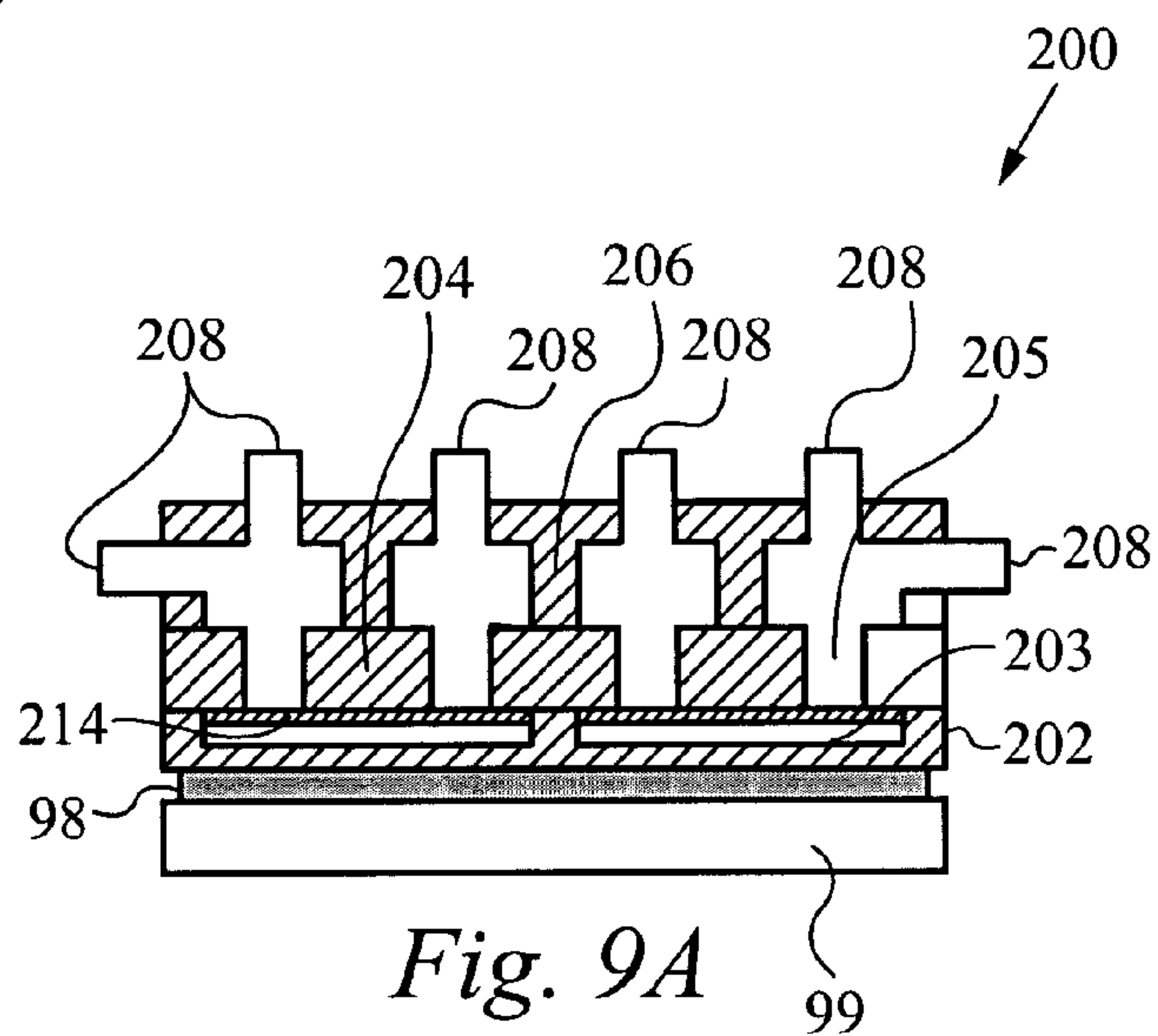
*Fig. 8A*



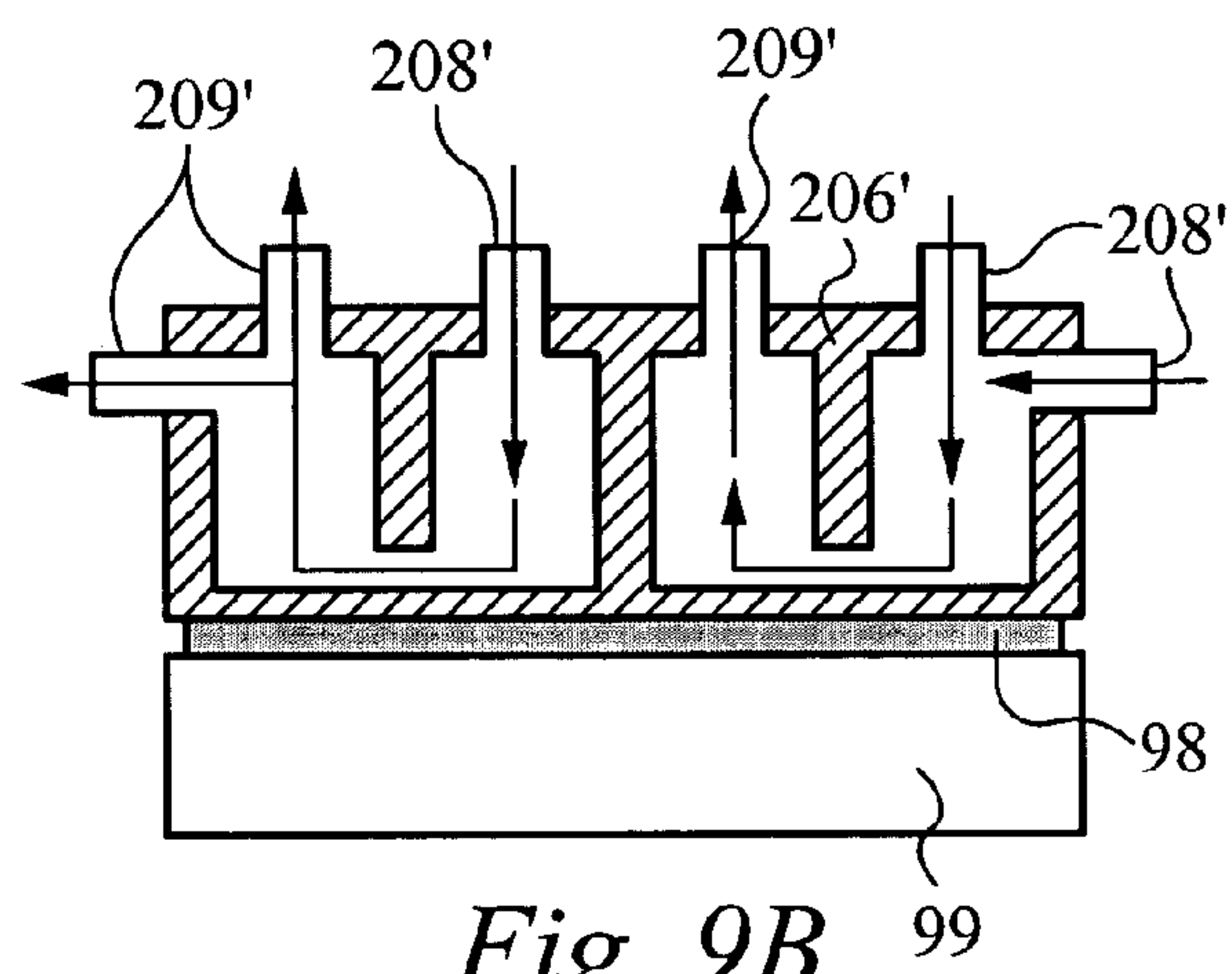
*Fig. 8B*



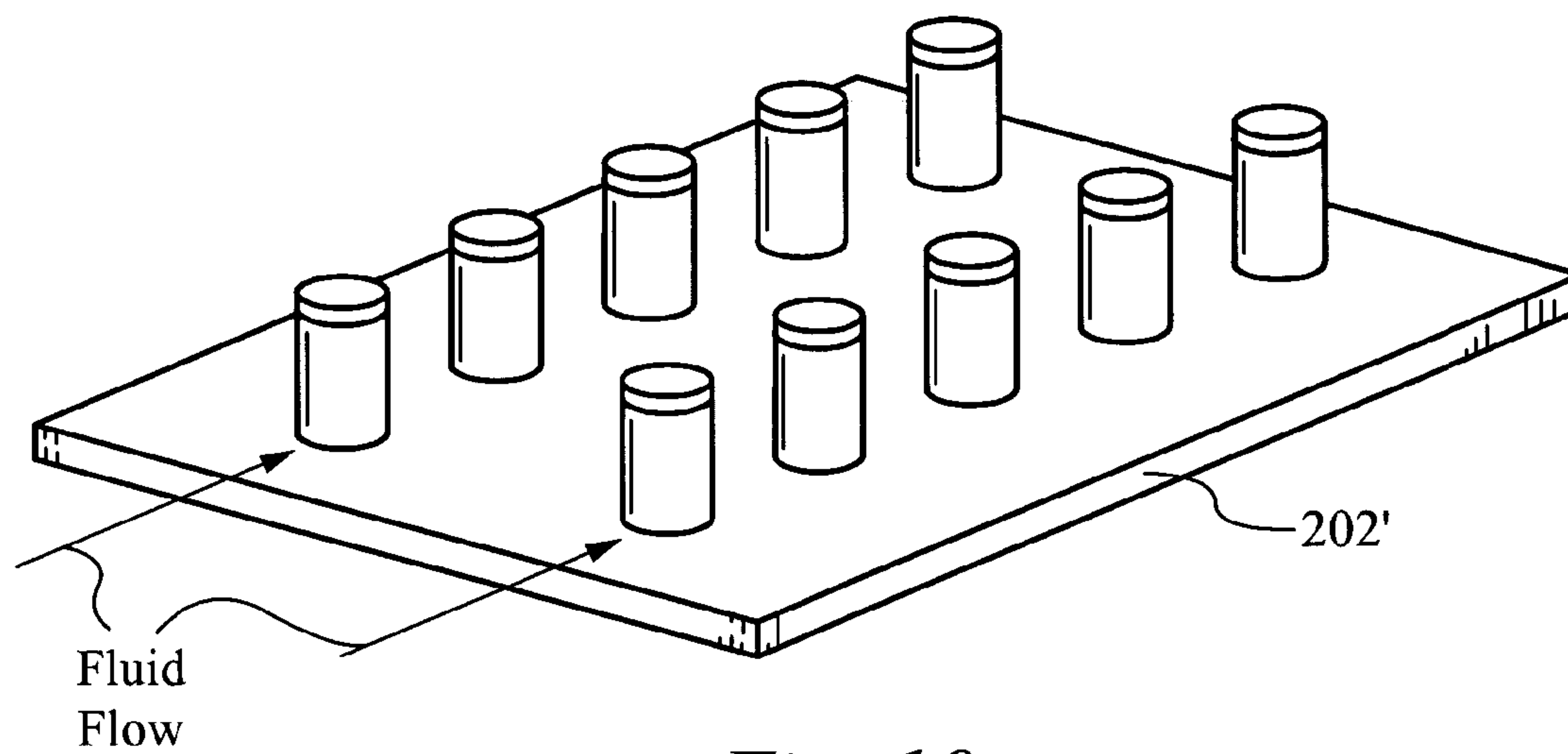
*Fig. 8C*



*Fig. 9A*



*Fig. 9B*



*Fig. 10*



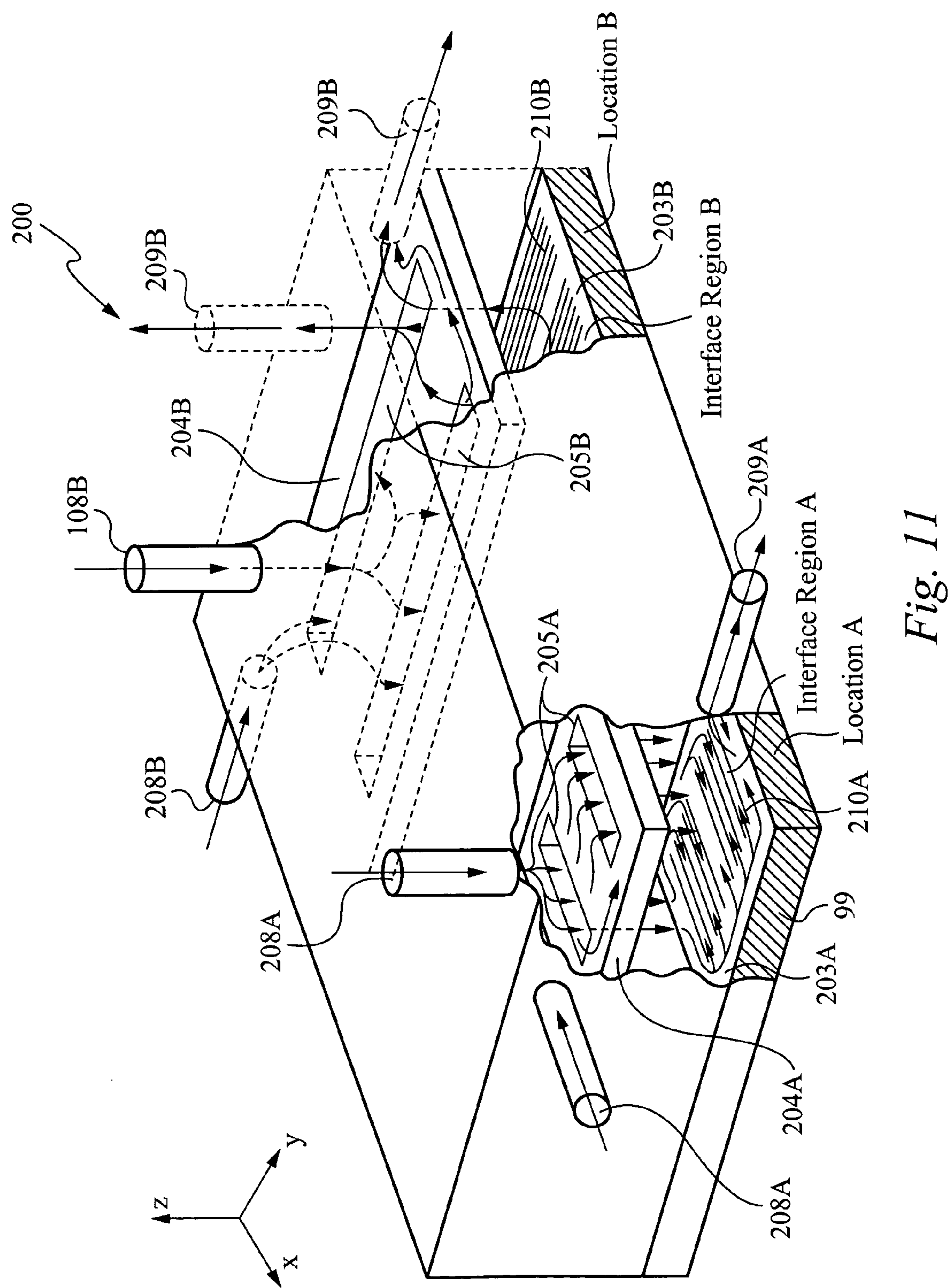
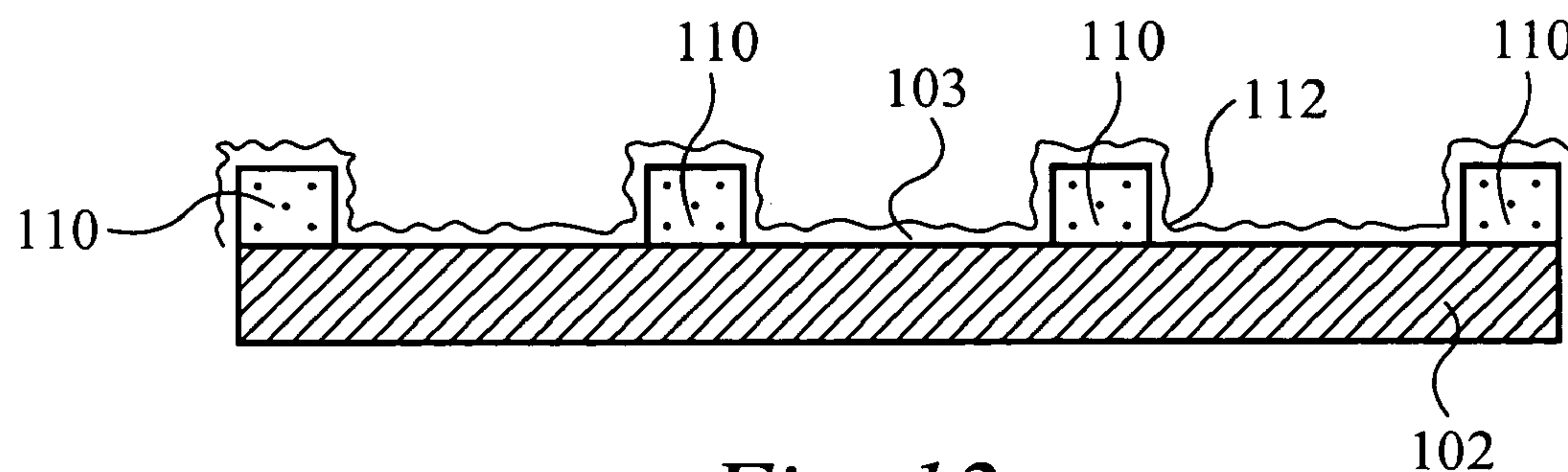
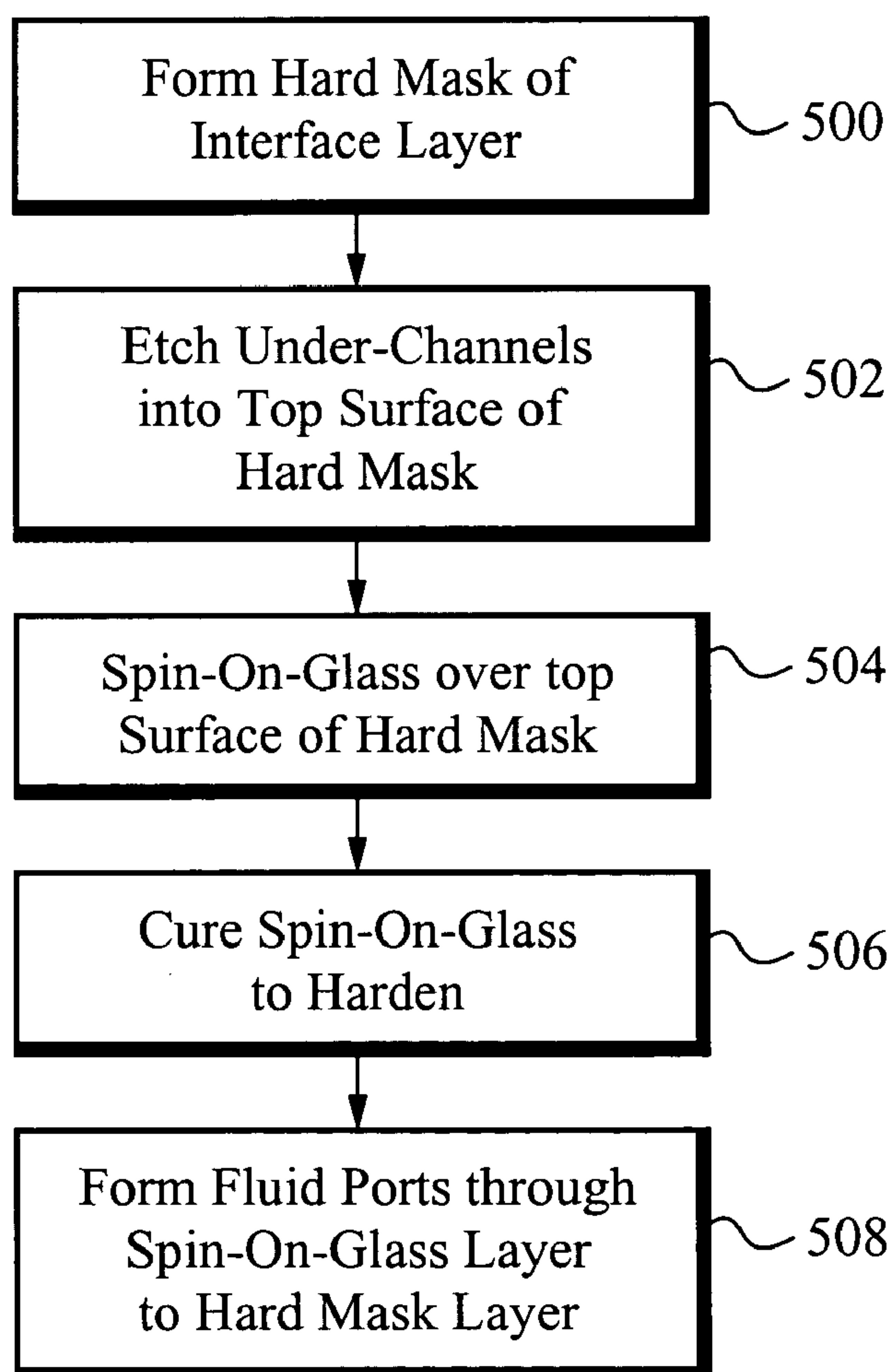


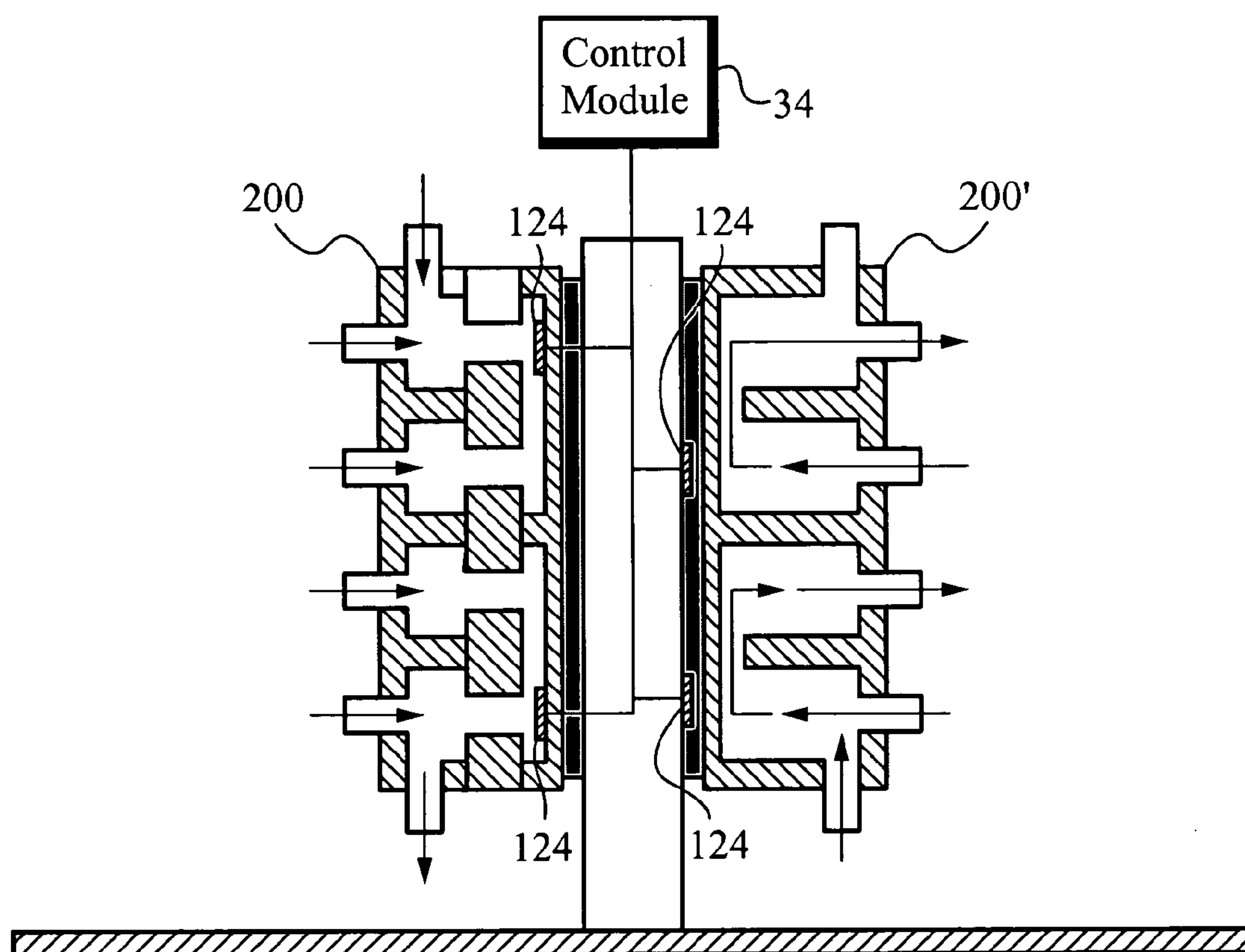
Fig. 11



*Fig. 12*



*Fig. 13*



*Fig. 14*



## INTERWOVEN MANIFOLDS FOR PRESSURE DROP REDUCTION IN MICROCHANNEL HEAT EXCHANGERS

### RELATED APPLICATIONS

[0001] This Patent application is a continuation in part of U.S. patent application Ser. No. 10/439,912, filed May 16, 2003, and entitled "INTERWOVEN MANIFOLDS FOR PRESSURE DROP REDUCTION IN MICROCHANNEL HEAT EXCHANGERS", hereby incorporated by reference, which claims priority under 35 U.S.C. 119 (e) of the co-pending U.S. Provisional Patent Application Ser. No. 60/423,009, filed Nov. 1, 2002 and entitled "METHODS FOR FLEXIBLE FLUID DELIVERY AND HOTSPOT COOLING BY MICROCHANNEL HEAT SINKS" which is hereby incorporated by reference, as well as co-pending U.S. Provisional Patent Application Ser. No. 60/442,383, filed Jan. 24, 2003 and entitled "OPTIMIZED PLATE FIN HEAT EXCHANGER FOR CPU COOLING" which is also hereby incorporated by reference, and co-pending U.S. Provisional Patent Application Ser. No. 60/455,729, filed Mar. 17, 2003 and entitled "MICROCHANNEL HEAT EXCHANGER APPARATUS WITH POROUS CONFIGURATION AND METHOD OF MANUFACTURING THEREOF", which is hereby incorporated by reference.

### FIELD OF THE INVENTION

[0002] The invention relates to a method and apparatus for cooling a heat producing device in general, and specifically, to an interwoven manifold for pressure drop reduction in a microchannel heat exchanger.

### BACKGROUND OF THE INVENTION

[0003] Since their introduction in the early 1980s, microchannel heat sinks have shown much potential for high heat-flux cooling applications and have been used in the industry. However, existing microchannels include conventional parallel channel arrangements which are used are not well suited for cooling heat producing devices which have spatially-varying heat loads. Such heat producing devices have areas which produce more heat than others. These hotter areas are hereby designated as "hot spots" whereas the areas of the heat source which do not produce as much heat are hereby termed, "warm spots".

[0004] FIG. 1A illustrates a prior art heat exchanger 10 which is coupled to an electronic device 99, such as a microprocessor via a thermal interface material 98. As shown in FIG. 1A, fluid generally flows from a single inlet port 12 and flows along the bottom surface 11 in between the parallel microchannels 14, as shown by the arrows, and exits through the outlet port 16. Although the heat exchanger 10 cools the electronic device 99, the fluid flows from the inlet port 12 to the outlet port 16 in a uniform manner. In other words, the fluid flows substantially uniformly along the entire bottom surface 11 of the heat exchanger 10 and does not supply more fluid to areas in the bottom surface 11 which correspond with hot spots in the device 99. In addition, the temperature of liquid flowing from the inlet generally increases as it flows along the bottom surface 11 of the heat exchanger. Therefore, regions of the heat source 99 which are downstream or near the outlet port 16 are not supplied with cool fluid, but actually fluid which has already been

heated upstream. In effect, the heated fluid actually propagates the heat across the entire bottom surface 11 of the heat exchanger and region of the heat source 99, whereby fluid near the outlet port 16 is so hot that it becomes ineffective in cooling heat source. In addition, the heat exchanger 10 having only one inlet 12 and one outlet 16 forces fluid to travel along the long parallel microchannels 14 in the bottom surface 11 for the entire length of the heat exchanger 10, thereby creating a large pressure drop.

[0005] FIG. 1B illustrates a side view diagram of a prior art multi-level heat exchanger 20. Fluid enters the multi-level heat exchanger 20 through the port 22 and travels downward through multiple jets 28 in the middle layer 26 to the bottom surface 27 and out port 24. In addition, the fluid traveling along the jets 28 may or may not uniformly flow down to the bottom surface 27. Nonetheless, although the fluid entering the heat exchanger 20 is spread over the length of the heat exchanger 20, the design does not provide more fluid to the hotter areas of the heat exchanger 20 and heat source that are in need of more fluid flow circulation.

[0006] In addition, conventional heat exchangers are made of materials which have high thermal resistance in the bottom surface, such that the heat exchanger has a coefficient of thermal expansion which matches that of the heat source 99. The high thermal resistance of the heat exchanger thereby does not allow sufficient heat exchange with the heat source 99. To account for the high thermal resistance, larger channel cross-sectional areas are chosen such that more thermal exchange occurs between the heat exchanger 10 and the heat source 99. In addition, the dimensions of the channels in the heat exchanger are scaled down and the distance between the channel walls and the hydraulic diameter is made smaller, the thermal resistance of the heat exchanger is reduced. However, a problem with using narrow microchannels is the increase in pressure drop along the channels. The increase in pressure drop places extreme demands on a pump driving the fluid through the heat exchanger. In addition, larger microchannel dimensions also cause a larger pressure drop between the inlet and outlet ports, due to the long distance that one or two phase fluid must travel. Further, boiling of the fluid in a microchannel heat exchanger causes a larger pressure drop for a given flowrate due to the mixing of fluid and vapor as well as the acceleration of the fluid into the vapor phase. Both of these factors increase the pressure drop per unit length. The large pressure drop created within the current microchannel heat exchangers require larger pumps which can handle higher pressures and thereby are not feasible in a microchannel setting.

[0007] What is needed is a microchannel heat exchanger which is configured to achieve proper temperature uniformity in the heat source. What is also needed is a heat exchanger which is configured to achieve proper uniformity in light of hot spots in the heat source. What is also needed is a heat exchanger having a relatively high thermal conductivity to adequately perform thermal exchange with the heat source. What is further needed is a heat exchanger which is configured to achieve a small pressure drop between the inlet and outlet fluid ports.

### SUMMARY OF THE INVENTION

[0008] In one aspect of the invention, a heat exchanger comprises an interface layer for cooling a heat source,



wherein the interface layer is configured to pass fluid therethrough and the interface layer includes a thickness within a range of about 0.3 millimeters to about 1.0 millimeters, and a manifold layer for circulating fluid to and from the interface layer, the manifold layer having a first set of fingers and a second set of fingers, wherein the first set of fingers are disposed in parallel with the second set of fingers and arranged to reduce pressure drop within the heat exchanger. The fluid can be in single phase flow condition. The fluid can be in two phase flow fluid conditions. At least a portion of the fluid can undergo a transition between single and two phase flow conditions in the interface layer. A particular finger in the first set can be spaced apart by an appropriate dimension from a particular finger in the second set to minimize the pressure drop in the heat exchanger. Each of the fingers can have the same length and width dimensions. At least one of the fingers can have a different dimension than the remaining fingers. The fingers can be arranged non-periodically in at least one dimension in the manifold layer. At least one of the fingers can have at least one varying dimension along a length of the manifold layer. The manifold layer can include more than three and less than 10 parallel fingers. The fingers in the first set and second set can be alternately disposed along a dimension of the manifold layer. The manifold layer can be configured to cool at least one interface hot spot region. The heat exchanger can also include at least one first port in communication with the first set of fingers, wherein fluid enters the heat exchanger through the at least one first port. The heat exchanger can also include at least one second port in communication with the second set of fingers, wherein fluid exits the heat exchanger through the at least one second port. The manifold layer can be positioned above the interface layer, wherein fluid flows downward through the first set of fingers and upward through the second set of fingers. The heat exchanger can also include a first port passage in communication with the first port and the first set of fingers, the first port passage configured to channel fluid from the first port to the first set of fingers. The heat exchanger can also include a second port passage in communication with the second port and the second set of fingers, the second port passage configured to channel fluid from the second set of fingers to the second port. The interface layer can be integrally formed with the heat source. The interface layer can be coupled to the heat source. The heat exchanger can also include an intermediate layer for channeling fluid to and from one or more predetermined positions in the interface layer via at least one conduit, the intermediate layer positioned between the interface layer and the manifold layer. The intermediate layer can be coupled to the interface layer and the manifold layer. The intermediate layer can be integrally formed with the interface layer and the manifold layer. The at least one conduit can have at least one varying dimension along the intermediate layer. The interface layer can include a coating thereupon, wherein the coating provides an appropriate thermal conductivity of at least 10 W/m-K. The interface layer can have a thermal conductivity of at least 100 W/m-K. The heat exchanger can also include a plurality of pillars configured in a predetermined pattern along the interface layer. At least one of the plurality of pillars can have an area dimension within the range of and including  $(10 \text{ micron})^2$  and  $(100 \text{ micron})^2$ . At least one of the plurality of pillars can have a height dimension within the range of and including 50 microns and 2 millimeters. At least two of the plurality

of pillars can be separate from each other by a spacing dimension within the range of and including 10 to 150 microns. The plurality of pillars can include a coating thereupon, wherein the coating has an appropriate thermal conductivity of at least 10 W/m-K. The interface layer can have a roughened surface. The interface layer can include a micro-porous structure disposed thereon. The porous microstructure can have a porosity within the range of and including 50 to 80 percent. The porous microstructure can have an average pore size within the range of and including 10 to 200 microns. The porous microstructure can have a height dimension within the range of and including 0.25 to 2.00 millimeters. The heat exchanger can also include a plurality of microchannels configured in a predetermined pattern along the interface layer. At least one of the plurality of microchannels can have an area dimension within the range of and including  $(10 \text{ micron})^2$  and  $(100 \text{ micron})^2$ . At least one of the plurality of microchannels can have a height dimension within the range of and including 50 microns and 2 millimeters. At least two of the plurality of microchannels can be separate from each other by a spacing dimension within the range of and including 10 to 150 microns. At least one of the plurality of microchannels can have a width dimension within the range of and including 10 to 100 microns. The plurality of microchannels can be coupled to the interface layer. The plurality of microchannels can be integrally formed with the interface layer. The plurality of microchannels can be divided into segmented arrays with at least one groove disposed therebetween, wherein the at least one groove is aligned with a corresponding finger. The plurality of microchannels can include a coating thereupon, wherein the coating has an appropriate thermal conductivity of at least 10 W/m-K. An overhang dimension can be within the range of and including 0 to 15 millimeters.

[0009] In another aspect of the present invention, a heat exchanger for cooling a heat source comprises a manifold layer including a first set of fingers in a first configuration, wherein each finger in the first set channels fluid at a first temperature, the manifold layer further including a second set of fingers in a second configuration, wherein each finger in the second set channels fluid at a second temperature, the first set and second set of fingers arranged parallel to each other, and an interface layer including a thickness within a range of about 0.3 to 1.0 millimeters, and configured to receive fluid at the first temperature at a plurality of first locations, wherein each first location is associated with a corresponding finger in the first set, the interface layer passing fluid along a plurality of predetermined paths to a plurality of second locations, wherein each second location is associated with a corresponding finger in the second set. The fluid can be in single phase flow conditions. The fluid can be in two phase flow conditions. At least a portion of the fluid can undergo a transition between single and two phase flow conditions in the interface layer. A particular finger in the first set can be spaced apart by an appropriate dimension from a particular finger in the second set, wherein the appropriate dimension reduces the pressure drop in the heat exchanger. The heat exchanger can also include at least one first port in communication with the first set of fingers, wherein fluid enters the heat exchanger through the at least one first port. The heat exchanger can also include at least one second port in communication with the second set of fingers, wherein fluid exits the heat exchanger through the at least one second port. The manifold layer can be positioned



above the interface layer, wherein fluid flows downward through the first set of fingers and upward through the second set of fingers. The interface layer can be integrally formed with the heat source. The interface layer can be coupled to the heat source. The fingers in the first set can be positioned in an alternating configuration with the fingers in the second set. Each of the fingers can have the same length and width dimensions. At least one of the fingers can have a different dimension than the remaining fingers. The fingers can be arranged non-periodically in at least one dimension in the manifold layer. At least one of the fingers can have at least one varying dimension along a length of the manifold layer. The manifold layer can include more than three and less than 10 parallel fingers. The heat exchanger can also include a first port passage in communication with the first port and the first set of fingers, the first port passage configured to channel fluid from the first port to the first set of fingers. The heat exchanger can also include a second port passage in communication with the second port and the second set of fingers, the second port passage configured to channel fluid from the second set of fingers to the second port. The heat exchanger can also include an intermediate layer for channeling fluid to and from one or more predetermined positions in the interface layer via at least one conduit, the intermediate layer positioned between the interface layer and the manifold layer. The conduit can be arranged in a predetermined configuration to channel fluid to one or more interface hot spot regions in the interface layer. The conduit can be arranged in a predetermined configuration to channel fluid from one or more interface hot spot regions in the interface layer. The intermediate layer can be coupled to the interface layer and the manifold layer. The intermediate layer can be integrally formed with the interface layer and the manifold layer. The conduit can have at least one varying dimension in the intermediate layer. The interface layer can include a coating thereupon, wherein the coating provides an appropriate thermal conductivity of at least 10 W/m-K. The interface layer can have a thermal conductivity is at least 10 W/m-K. The heat exchanger can also include a plurality of pillars configured in a predetermined pattern along the interface layer. At least one of the plurality of pillars can have an area dimension within the range of and including  $(10 \text{ micron})^2$  and  $(100 \text{ micron})^2$ . At least one of the plurality of pillars can have a height dimension within the range of and including 50 microns and 2 millimeters. At least two of the plurality of pillars can be separate from each other by a spacing dimension within the range of and including 10 to 150 microns. The plurality of pillars can include a coating thereupon, wherein the coating has an appropriate thermal conductivity of at least 10 W/m-K. The interface layer can have a roughened surface. The interface layer can include a micro-porous structure disposed thereon. The porous microstructure can have a porosity within the range of and including 50 to 80 percent. The porous microstructure can have an average pore size within the range of and including 10 to 200 microns. The porous microstructure can have a height dimension within the range of and including 0.25 to 2.00 millimeters. The heat exchanger can also include a plurality of microchannels configured in a predetermined pattern along the interface layer. At least one of the plurality of microchannels can have an area dimension within the range of and including  $(10 \text{ micron})^2$  and  $(100 \text{ micron})^2$ . At least one of the plurality of microchannels can have a height dimension within the range

of and including 50 microns and 2 millimeters. At least two of the plurality of microchannels can be separate from each other by a spacing dimension within the range of and including 10 to 150 microns. At least one of the plurality of microchannels can have a width dimension within the range of and including 10 to 100 microns. The microchannels can be coupled to the interface layer. The microchannels can be integrally formed with the interface layer. The microchannels can be divided into segments along a dimension of the interface layer, at least one groove disposed in between the divided microchannel segments. The microchannels can be continuous along a dimension of the interface layer. The at least one groove can be aligned with a corresponding finger. The plurality of microchannels can include a coating thereupon, wherein the coating has an appropriate thermal conductivity of at least 20 W/m-K. An overhang dimension can be within the range of and including 0 to 15 millimeters.

[0010] Other features and advantages of the present invention will become apparent after reviewing the detailed description of the preferred embodiments set forth below.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1A illustrates a side view of a conventional heat exchanger.

[0012] FIG. 1B illustrates a top view of the conventional heat exchanger.

[0013] FIG. 1C illustrates a side view diagram of a prior art multi-level heat exchanger.

[0014] FIG. 2A illustrates a schematic diagram of a closed loop cooling system incorporating a preferred embodiment of the flexible fluid delivery microchannel heat exchanger of the present invention.

[0015] FIG. 2B illustrates a schematic diagram of a closed loop cooling system incorporating an alternative embodiment of the flexible fluid delivery microchannel heat exchanger of the present invention.

[0016] FIG. 3A illustrates a top view of an alternative manifold layer of the heat exchanger in accordance with the present invention.

[0017] FIG. 3B illustrates an exploded view of an alternative heat exchanger with the alternative manifold layer in accordance with the present invention.

[0018] FIG. 4 illustrates a perspective view of the preferred interwoven manifold layer in accordance with the present invention.

[0019] FIG. 5 illustrates a top view of the preferred interwoven manifold layer with interface layer in accordance with the present invention.

[0020] FIG. 6A illustrates a cross-sectional view of the preferred interwoven manifold layer with interface layer of the present invention along lines A-A.

[0021] FIG. 6B illustrates a cross-sectional view of the preferred interwoven manifold layer with interface layer of the present invention along lines B-B.

[0022] FIG. 6C illustrates a cross-sectional view of the preferred interwoven manifold layer with interface layer of the present invention along lines C-C.



[0023] FIG. 7A illustrates an exploded view of the preferred interwoven manifold layer with interface layer of the present invention.

[0024] FIG. 7B illustrates a perspective view of an alternative embodiment of the interface layer of the present invention.

[0025] FIG. 8A illustrates a top view diagram of an alternate manifold layer in accordance with the present invention.

[0026] FIG. 8B illustrates a top view diagram of the interface layer in accordance with the present invention.

[0027] FIG. 8C illustrates a top view diagram of the interface layer in accordance with the present invention.

[0028] FIG. 9A illustrates a side view diagram of the alternative embodiment of the three tier heat exchanger in accordance with the present invention.

[0029] FIG. 9B illustrates a side view diagram of the alternative embodiment of the two tier heat exchanger in accordance with the present invention.

[0030] FIG. 10 illustrates a perspective view of the interface layer having a micro-pin array in accordance with the present invention.

[0031] FIG. 11 illustrates a cut-away perspective view diagram of the alternate heat exchanger in accordance with the present invention.

[0032] FIG. 12 illustrates a side view diagram of the interface layer of the heat exchanger having a coating material applied thereon in accordance with the present invention.

[0033] FIG. 13 illustrates a flow chart of an alternative method of manufacturing the heat exchanger in accordance with the present invention.

[0034] FIG. 14 illustrates a schematic of an alternate embodiment of the present invention having two heat exchangers coupled to a heat source.

#### DETAILED DESCRIPTION OF THE PRESENT INVENTION

[0035] Generally, the heat exchanger captures thermal energy generated from a heat source by passing fluid through selective areas of the interface layer which is preferably coupled to the heat source. In particular, the fluid is directed to specific areas in the interface layer to cool the hot spots and areas around the hot spots to generally create temperature uniformity across the heat source while maintaining a small pressure drop within the heat exchanger. As discussed in the different embodiments below, the heat exchanger utilizes a plurality of apertures, channels and/or fingers in the manifold layer as well as conduits in the intermediate layer to direct and circulate fluid to and from selected hot spot areas in the interface layer. Alternatively, the heat exchanger includes several ports which are specifically disposed in predetermined locations to directly deliver fluid to and remove fluid from the hot spots to effectively cool the heat source.

[0036] It is apparent to one skilled in the art that although the microchannel heat exchanger of the present invention is described and discussed in relation to flexible fluid delivery

for cooling hot spot locations in a device, the heat exchanger is alternatively used for flexible fluid delivery for heating a cold spot location in a device. It should also be noted that although the present invention is preferably described as a microchannel heat exchanger, the present invention can be used in other applications and is not limited to the discussion herein.

[0037] FIG. 2A illustrates a schematic diagram of a closed loop cooling system 30 which includes a preferred flexible fluid delivery microchannel heat exchanger 400 in accordance with the present invention. In addition, FIG. 2B illustrates a schematic diagram of a closed loop cooling system 30 which includes an alternative flexible fluid delivery microchannel heat exchanger 200 with multiple ports 108, 109 in accordance with the present invention.

[0038] As shown in FIG. 2A, the fluid ports 108, 109 are coupled to fluid lines 38 which are coupled to a pump 32 and heat condenser 30. The pump 32 pumps and circulates fluid within the closed loop 30. It is preferred that one fluid port 108 is used to supply fluid to the heat exchanger 100. In addition, it is preferred that one fluid port 109 is used to remove fluid from the heat exchanger 100. Preferably a uniform, constant amount of fluid flow enters and exits the heat exchanger 100 via the respective fluid ports 108, 109. Alternatively, different amounts of fluid flow enter and exit through the inlet and outlet port(s) 108, 109 at a given time. Alternatively, as shown in FIG. 2B, one pump provides fluid to several designated inlet ports 108. Alternatively, multiple pumps (not shown), provide fluid to their respective inlet and outlet ports 108, 109. In addition, the dynamic sensing and control module 34 is alternatively employed in the system to variate and dynamically control the amount and flow rate of fluid entering and exiting the preferred or alternative heat exchanger in response to varying hot spots or changes in the amount of heat in a hot spot location as well as the locations of the hot spots.

[0039] The preferred embodiment is a three level heat exchanger 400 which includes an interface layer 402, at least one intermediate layer 404 and at least one manifold layer 406. The preferred manifold layer 402 and the preferred interface layer 402 are shown in FIG. 7 and the intermediate layer 104 is shown in FIG. 3B. Alternatively, as discussed below, the heat exchanger 400 is a two level apparatus which includes the interface layer 402 and the manifold layer 406, as shown in FIG. 7. As shown in FIGS. 2A and 2B, the heat exchanger 400 is coupled to a heat source 99, such as an electronic device, including, but not limited to a microchip and integrated circuit, whereby a thermal interface material 98 is preferably disposed between the heat source 99 and the heat exchanger 100. Alternatively, the heat exchanger 400 is directly coupled to the surface of the heat source 99. It is also apparent to one skilled in the art that the heat exchanger 400 is alternatively integrally formed into the heat source 99, whereby the heat exchanger 400 and the heat source 99 are formed as one piece. Thus, the interface layer 102 is integrally disposed with the heat source 99 and is formed as one piece with the heat source.

[0040] It is preferred that the heat exchanger 400 of the present invention is configured to be directly or indirectly in contact with the heat source 99 which is rectangular in shape, as shown in the figures. However, it is apparent to one skilled in the art that the heat exchanger 400 can have any



other shape conforming with the shape of the heat source **99**. For example, the heat exchanger of the present invention can be configured to have an outer semicircular shape which allows the heat exchanger (not shown) to be in direct or indirect contact with a corresponding semicircular shaped heat source (not shown). In addition, it is preferred that the heat exchanger **400** is slightly larger in dimension than the heat source within the range of and including 0.5-5.0 millimeters.

[0041] **FIG. 3A** illustrates a top view of the alternate manifold layer **106** of the present invention. In particular, as shown in **FIG. 3B**, the manifold layer **106** includes four sides as well as a top surface **130** and a bottom surface **132**. However, the top surface **130** is removed in **FIG. 3A** to adequately illustrate and describe the workings of the manifold layer **106**. As shown in **FIG. 3A**, the manifold layer **106** has a series of channels or passages **116, 118, 120, 122** as well as ports **108, 109** formed therein. The fingers **118, 120** extend completely through the body of the manifold layer **106** in the Z-direction as shown in **FIG. 3B**. Alternatively, the fingers **118** and **120** extend partially through the manifold layer **106** in the Z-direction and have apertures as shown in **FIG. 3A**. In addition, passages **116** and **122** extend partially through the manifold layer **106**. The remaining areas between the inlet and outlet passages **116, 120**, designated as **107**, extend from the top surface **130** to the bottom surface **132** and form the body of the manifold layer **106**.

[0042] As shown in **FIG. 3A**, the fluid enters manifold layer **106** via the inlet port **108** and flows along the inlet channel **116** to several fingers **118** which branch out from the channel **116** in several directions in the X and/or Y directions to apply fluid to selected regions in the interface layer **102**. The fingers **118** are arranged in different predetermined directions to deliver fluid to the locations in the interface layer **102** corresponding to the areas at or near the hot spots in the heat source. These locations in the interface layer **102** are hereinafter referred to as interface hot spot regions. The fingers are configured to cool stationary as well as temporally varying interface hot spot regions. As shown in **FIG. 3A**, the channels **116, 122** and fingers **118, 120** are disposed in the X and/or Y directions in the manifold layer **106**. Thus, the various directions of the channels **116, 122** and fingers **118, 120** allow delivery of fluid to cool hot spots in the heat source **99** and/or minimize pressure drop within the heat exchanger **100**. Alternatively, channels **116, 122** and fingers **118, 120** are periodically disposed in the manifold layer **106** and exhibit a pattern, as in the preferred embodiment.

[0043] The arrangement as well as the dimensions of the fingers **118, 120** are determined in light of the hot spots in the heat source **99** that are desired to be cooled. The locations of the hot spots as well as the amount of heat produced near or at each hot spot are used to configure the manifold layer **106** such that the fingers **118, 120** are placed above or proximal to the interface hot spot regions in the interface layer **102**. The manifold layer **106** preferably allows one phase and/or two-phase fluid to circulate to the interface layer **102** without allowing a substantial pressure drop from occurring within the heat exchanger **100** and the system **30** (**FIG. 2A**). The fluid delivery to the interface hot spot regions creates a uniform temperature at the interface hot spot region as well as areas in the heat source adjacent to the interface hot spot regions.

[0044] The dimensions as well as the number of channels **116** and fingers **118** depend on a number of factors. In one embodiment, the inlet and outlet fingers **118, 120** have the same width dimensions. Alternatively, the inlet and outlet fingers **118, 120** have different width dimensions. The width dimensions of the fingers **118, 120** are preferably within the range of and including 0.25-0.50 millimeters. In one embodiment, the inlet and outlet fingers **118, 120** have the same length and depth dimensions. Alternatively, the inlet and outlet fingers **118, 120** have different length and depth dimensions. In another embodiment, the inlet and outlet fingers **118, 120** have varying width dimensions along the length of the fingers. The length dimensions of the inlet and outlet fingers **118, 120** are within the range of and including 0.5 millimeters to three times the size of the heat source length. In addition, the fingers **118, 120** have a height or depth dimension within the range and including 0.25-0.50 millimeters. In addition, less than 10 or more than 30 fingers per centimeter are disposed in the manifold layer **106**. However, it is apparent to one skilled in the art that between 10 and 30 fingers per centimeter in the manifold layer is alternatively contemplated.

[0045] It is contemplated within the present invention to tailor the geometries of the fingers **118, 120** and channels **116, 122** to be in non-periodic arrangement to aid in optimizing hot spot cooling of the heat source. In order to achieve a uniform temperature across the heat source **99**, the spatial distribution of the heat transfer to the fluid is matched with the spatial distribution of the heat generation. As the fluid flows along the interface layer through the microchannels **110**, its temperature increases and as it begins to transform to vapor under two-phase conditions. Thus, the fluid undergoes a significant expansion which results in a large increase in velocity. Generally, the efficiency of the heat transfer from the interface layer to the fluid is improved for high velocity flow. Therefore, it is possible to tailor the efficiency of the heat transfer to the fluid by adjusting the cross-sectional dimensions of the fluid delivery and removal fingers **118, 120** and channels **116, 122** in the heat exchanger **100**.

[0046] For example, a particular finger can be designed for a heat source where there is higher heat generation near the inlet. In addition, it may be advantageous to design a larger cross section for the regions of the fingers **118, 120** and channels **116, 122** where a mixture of fluid and vapor is expected. Although not shown, a finger can be designed to start out with a small cross sectional area at the inlet to cause high velocity flow of fluid. The particular finger or channel can also be configured to expand to a larger cross-section at a downstream outlet to cause a lower velocity flow. This design of the finger or channel allows the heat exchanger to minimize pressure drop and optimize hot spot cooling in areas where the fluid increases in volume, acceleration and velocity due to transformation from liquid to vapor in two-phase flow.

[0047] In addition, the fingers **118, 120** and channels **116, 122** can be designed to widen and then narrow again along their length to increase the velocity of the fluid at different places in the microchannel heat exchanger **100**. Alternatively, it may be appropriate to vary the finger and channel dimensions from large to small and back again many times over in order to tailor the heat transfer efficiency to the expected heat dissipation distribution across the heat source



99. It should be noted that the above discussion of the varying dimensions of the fingers and channels also apply to the other embodiments discussed and is not limited to this embodiment.

[0048] Alternatively, as shown in FIG. 3A, the manifold layer 106 includes one or more apertures 119 in the inlet fingers 118. In the three tier heat exchanger 100, the fluid flowing along the fingers 118 flows down the apertures 119 to the intermediate layer 104. Alternatively, in the two-tier heat exchanger 100, the fluid flowing along the fingers 118 flows down the apertures 119 directly to the interface layer 102. In addition, as shown in FIG. 3A, the manifold layer 106 includes apertures 121 in the outlet fingers 120. In the three tier heat exchanger 100, the fluid flowing from the intermediate layer 104 flows up the apertures 121 into the outlet fingers 120. Alternatively, in the two-tier heat exchanger 100, the fluid flowing from the interface layer 102 flows directly up the apertures 121 into the outlet fingers 120.

[0049] In the embodiment shown in FIG. 3A, the inlet and outlet fingers 118, 120 are open channels which do not have apertures. The bottom surface 103 of the manifold layer 106 abuts against the top surface of the intermediate layer 104 in the three tier exchanger 100 or abuts against the interface layer 102 in the two tier exchanger. Thus, in the three-tier heat exchanger 100, fluid flows freely to and from the intermediate layer 104 and the manifold layer 106. The fluid is directed to and from the appropriate interface hot spot region by conduits 105 in the intermediate layer 104. It is apparent to one skilled in the art that the conduits 105 are directly aligned with the fingers, as described below or positioned elsewhere in the three tier system.

[0050] FIG. 3B illustrates an exploded view of the three tier heat exchanger 100 with the alternate manifold layer in accordance with the present invention. Alternatively, the heat exchanger 100 is a two layer structure which includes the manifold layer 106 and the interface layer 102, whereby fluid passes directly between the manifold layer 106 and interface layer 102 without passing through the intermediate layer 104. It is apparent to one skilled in the art that the configuration of the manifold, intermediate and interface layers are shown for exemplary purposes and is thereby not limited to the configuration shown.

[0051] As shown in FIG. 3B, the intermediate layer 104 includes a plurality of conduits 105 which extend there-through. The inflow conduits 105 direct fluid entering from the manifold layer 106 to the designated interface hot spot regions in the interface layer 102. Similarly, the apertures 105 also channel fluid flow from the interface layer 102 to the exit fluid port(s) 109. Thus, the intermediate layer 104 also provides fluid delivery from the interface layer 102 to the exit fluid port 109 where the exit fluid port 108 is in communication with the manifold layer 106.

[0052] The conduits 105 are positioned in the interface layer 104 in a predetermined pattern based on a number of factors including, but not limited to, the locations of the interface hot spot regions, the amount of fluid flow needed in the interface hot spot region to adequately cool the heat source 99 and the temperature of the fluid. The conduits have a width dimension of 100 microns, although other width dimensions are contemplated up to several millimeters. In addition, the conduits 105 have other dimensions dependent

on at least the above mentioned factors. It is apparent to one skilled in the art that each conduit 105 in the intermediate layer 104 has a same shape and/or dimension, although it is not necessary. For instance, like the fingers described above, the conduits alternatively have a varying length and/or width dimension. Additionally, the conduits 105 may have a constant depth or height dimension through the intermediate layer 104. Alternatively, the conduits 105 have a varying depth dimension, such as a trapezoidal or a nozzle-shape, through the intermediate layer 104. Although the horizontal shape of the conduits 105 are shown to be rectangular in FIG. 2C, the conduits 105 alternatively have any other shape including, but not limited to, circular (FIG. 3A), curved and elliptical. Alternatively, one or more of the conduits 105 are shaped and contour with a portion of or all of the finger or fingers above.

[0053] The intermediate layer 104 is horizontally positioned within the heat exchanger 100 with the conduits 105 positioned vertically. Alternatively, the intermediate layer 104 is positioned in any other direction within the heat exchanger 100 including, but not limited to, diagonal and curved forms. Alternatively, the conduits 105 are positioned within the intermediate layer 104 in a horizontally, diagonally, curved or any other direction. In addition, the intermediate layer 104 extends horizontally along the entire length of the heat exchanger 100, whereby the intermediate layer 104 completely separates the interface layer 102 from the manifold layer 106 to force the fluid to be channeled through the conduits 105. Alternatively, a portion of the heat exchanger 100 does not include the intermediate layer 104 between the manifold layer 106 and the interface layer 102, whereby fluid is free to flow therebetween. Further, the intermediate layer 104 alternatively extends vertically between the manifold layer 106 and the interface layer 102 to form separate, distinct intermediate layer regions. Alternatively, the intermediate layer 104 does not fully extend from the manifold layer 106 to interface layer 102.

[0054] It is preferred that the heat exchanger 100 of the present invention is larger in width than the heat source 99. In the case where the heat exchanger 100 is larger than the heat source 99, an overhang dimension exists. The overhang dimension is the farthest distance between one outer wall of the heat source 99 and the interior fluid channel wall of the heat exchanger 100, such as the inner wall of the inlet port 408 (FIG. 4). In the preferred embodiment, the overhang dimension is within the range of and including 0 to 5 millimeters for single phase and 0 to 15 millimeters for two phase fluid.

[0055] FIG. 10 illustrates a perspective view of one embodiment of an interface layer 202' in accordance with the present invention. As shown in FIG. 10, the interface layer 202' includes a series of pillars 203 which extend upwards from a top surface of the interface layer 202'. In addition, FIG. 10 illustrates a microporous structure 213 disposed on the top surface of the interface layer 202'. It is apparent that the interface layer 202' can include only the microporous structure 213 as well as a combination of the microporous structure with any other interface layer feature (e.g. microchannels, pillars, etc.). In addition, the interface layer 202' of the present invention preferably has a thickness dimension within the range of and including 0.3 to 0.7 millimeters for single phase fluid and 0.3 to 1.0 millimeters for two phase fluid.



[0056] In the embodiment of the heat exchanger which utilizes a microporous structure **213** disposed upon the interface layer **202'**, the microporous structure **213** has an average pore size within the range of and including 10 to 200 microns for single phase as well as two phase fluid. In addition, the microporous structure **213** has a porosity within the range and including 50 to 80 percent for single phase as well as two phase fluid. The height of the microporous structure **213** is within the range of and including 0.25 to 2.00 millimeters for single phase as well as two phase fluid.

[0057] In the embodiment which utilizes pillars and/or microchannels along the interface layer **202'**, the interface layer **202'** of the present invention has a thickness dimension in the range of and including 0.3 to 0.7 millimeters for single phase fluid and 0.3 to 1.0 millimeters for two phase fluid. In addition, the area of at least one pillar, or microchannel, is in the range of and including  $(10 \text{ micron})^2$  and  $(100 \text{ micron})^2$  for single phase as well as two phase fluid. In addition, the area of the separation distance between at least two of the pillars and/or microchannels is in the range of and including 10 microns to 150 microns for single phase as well as two phase fluid. The width dimension of the microchannels are in the range of and including 10 to 100 microns for single phase as well as two phase fluid. The height dimension of the microchannels and/or pillars is within the range of and including 50 to 800 microns for single phase fluid and 50 microns to 2 millimeters for two phase fluid. It is contemplated by one skilled in the art that other dimension are alternatively contemplated.

[0058] **FIG. 3B** illustrates a perspective view of the interface layer **102** in accordance with the present invention. As shown in **FIG. 3B**, the interface layer **102** includes a bottom surface **103** and a plurality of microchannel walls **110**, whereby the area in between the microchannel walls **110** channels or directs fluid along a fluid flow path. The bottom surface **103** is flat and has a high thermal conductivity to allow sufficient heat transfer from the heat source **99**. Alternatively, the bottom surface **103** includes troughs and/or crests designed to collect or repel fluid from a particular location. The microchannel walls **110** are configured in a parallel configuration, as shown in **FIG. 3B**, whereby fluid preferably flows between the microchannel walls **110** along a fluid path. Alternatively, the microchannel walls **110** have non-parallel configurations.

[0059] It is apparent to one skilled in the art that the microchannel walls **110** are alternatively configured in any other appropriate configuration depending on the factors discussed above. For instance, the interface layer **102** alternatively has grooves in between sections of microchannel walls **110**, as shown in **FIG. 8C**. In addition, the microchannel walls **110** have dimensions which minimize the pressure drop or differential within the interface layer **102**. It is also apparent that any other features, besides microchannel walls **110** are also contemplated, including, but not limited to, pillars (**FIG. 10**), roughed surfaces, and a microporous structure, such as sintered metal and silicon foam (**FIG. 10**). However, for exemplary purposes, the parallel microchannel walls **110** shown in **FIG. 3B** is used to describe the interface layer **102** in the present invention.

[0060] The microchannel walls **110** allow the fluid to undergo thermal exchange along the selected hot spot loca-

tions of the interface hot spot region to cool the heat source **99** in that location. The microchannel walls **110** have a width dimension within the range of 10-100 microns and a height dimension within the range of 50 microns to two millimeters, depending on the power of the heat source **99**. The microchannel walls **110** have a length dimension which ranges between 100 microns and several centimeters, depending on the dimensions of the heat source, as well as the size of the hot spots and the heat flux density from the heat source. Alternatively, any other microchannel wall dimensions are contemplated. The microchannel walls **110** are spaced apart by a separation dimension range of 50-500 microns, depending on the power of the heat source **99**, although any other separation dimension range is contemplated.

[0061] Referring back to the assembly in **FIG. 3B**, the top surface of the manifold layer **106** is cut away to illustrate the channels **116**, **122** and fingers **118**, **120** within the body of the manifold layer **106**. The locations in the heat source **99** that produce more heat are hereby designated as hot spots, whereby the locations in the heat source **99** which produce less heat are hereby designated as warm spots. As shown in **FIG. 3B**, the heat source **99** is shown to have a hot spot region, namely at location A, and a warm spot region, namely at location B. The areas of the interface layer **102** which abut the hot and warm spots are accordingly designated interface hot spot regions. As shown in **FIG. 3B**, the interface layer **102** includes interface hot spot region A, which is positioned above location A and interface hot spot region B, which is positioned above location B.

[0062] As shown in **FIGS. 3A and 3B**, fluid initially enters the heat exchanger **100** through one inlet port **108**. The fluid then preferably flows to one inlet channel **116**. Alternatively, the heat exchanger **100** includes more than one inlet channel **116**. As shown in **FIGS. 3A and 3B**, fluid flowing along the inlet channel **116** from the inlet port **108** initially branches out to finger **118D**. In addition, the fluid which continues along the rest of the inlet channel **116** flows to individual fingers **1181B** and **118C** and so on.

[0063] In **FIG. 3B**, fluid is supplied to interface hot spot region A by flowing to the finger **118A**, whereby fluid flows down through finger **118A** to the intermediate layer **104**. The fluid then flows through the inlet conduit **105A** positioned below the finger **118A** to the interface layer **102**, whereby the fluid undergoes thermal exchange with the heat source **99**. The fluid travels along the microchannels **110** as shown in **FIG. 3B**, although the fluid may travel in any other direction along the interface layer **102**. The heated liquid then travels upward through the conduit **105B** to the outlet finger **120A**. Similarly, fluid flows down in the Z-direction through fingers **118E** and **118F** to the intermediate layer **104**. The fluid then flows through the inlet conduit **105C** down in the Z-direction to the interface layer **102**. The heated fluid then travels upward in the Z-direction from the interface layer **102** through the outlet conduit **105D** to the outlet fingers **120E** and **120F**. The heat exchanger **100** removes the heated fluid in the manifold layer **106** via the outlet fingers **120**, whereby the outlet fingers **120** are in communication with the outlet channel **122**. The outlet channel **122** allows fluid to flow out of the heat exchanger through one outlet port **109**.

[0064] In one embodiment, the inflow and outflow conduits **105** are positioned directly or nearly directly above the



appropriate interface hot spot regions to directly apply fluid to hot spots in the heat source 99. In addition, each outlet finger 120 is configured to be positioned closest to a respective inlet finger 119 for a particular interface hot spot region to minimize pressure drop therebetween. Thus, fluid enters the interface layer 102 via the inlet finger 118A and travels the least amount of distance along the bottom surface 103 of the interface layer 102 before it exits the interface layer 102 to the outlet finger 120A. It is apparent that the amount of distance which the fluid travels along the bottom surface 103 adequately removes heat generated from the heat source 99 without generating an unnecessary amount of pressure drop. In addition, as shown in FIGS. 3A and 3B, the corners in the fingers 118, 120 are curved to reduce pressure drop of the fluid flowing along the fingers 118.

[0065] It is apparent to one skilled in the art that the configuration of the manifold layer 106 shown in FIGS. 3A and 3B is only for exemplary purposes. The configuration of the channels 116 and fingers 118 in the manifold layer 106 depend on a number of factors, including but not limited to, the locations of the interface hot spot regions, amount of flow to and from the interface hot spot regions as well as the amount of heat produced by the heat source in the interface hot spot regions. For instance, the preferred configuration of the manifold layer 106 includes an interdigitated pattern of parallel inlet and outlet fingers that are arranged along the width of the manifold layer, as shown in FIGS. 4-7A and discussed below. Nonetheless, any other configuration of channels 116 and fingers 118 is contemplated.

[0066] FIG. 4 illustrates a perspective view of the preferred manifold layer 406 in accordance with the heat exchanger of the present invention. The manifold layer 406 in FIG. 4 preferably includes a plurality of interwoven or inter-digitated parallel fluid fingers 411, 412 which allow one phase and/or two-phase fluid to circulate to the interface layer 402 without allowing a substantial pressure drop from occurring within the heat exchanger 400 and the system 30 (FIG. 2A). As shown in FIG. 8, the inlet fingers 411 are arranged alternately with the outlet fingers 412. However, it is contemplated by one skilled in the art that a certain number of inlet or outlet fingers can be arranged adjacent to one another and is thereby not limited to the alternating configuration shown in FIG. 4. In addition, the fingers are alternatively designed such that a parallel finger branches off from or is linked to another parallel finger. Thus, it is possible to have many more inlet fingers than outlet fingers and vice versa.

[0067] The inlet fingers or passages 411 supply the fluid entering the heat exchanger to the interface layer 402, and the outlet fingers or passages 412 remove the fluid from the interface layer 402 which then exits the heat exchanger 400. The preferred configuration of the manifold layer 406 allows the fluid to enter the interface layer 402 and travel a very short distance in the interface layer 402 before it enters the outlet passage 412. The substantial decrease in the length that the fluid travels along the interface layer 402 substantially decreases the pressure drop in the heat exchanger 400 and the system 30 (FIG. 2A).

[0068] As shown in FIGS. 4-5, the preferred manifold layer 406 includes a passage 414 which is in communication with two inlet passages 411 and provides fluid thereto. As shown in FIGS. 8-9 the manifold layer 406 includes three

outlet passages 412 which are in communication with passage 418. Preferably the passages 414 in the manifold layer 406 have a flat bottom surface which channels the fluid to the fingers 411, 412. Alternatively, the passage 414 has a slight slope which aids in channeling the fluid to selected fluid passages 411. Alternatively, the inlet passage 414 includes one or more apertures in its bottom surface which allows a portion of the fluid to flow down to the interface layer 402. Similarly, the passage 418 in the manifold layer has a flat bottom surface which contains the fluid and channels the fluid to the port 408. Alternatively, the passage 418 has a slight slope which aids in channeling the fluid to selected outlet ports 408. In addition, the passages 414, 418 have a dimension width of approximately 2 millimeters, although any other width dimensions are alternatively contemplated.

[0069] The passages 414, 418 are in communication with ports 408, 409 whereby the ports are coupled to the fluid lines 38 in the system 30 (FIG. 2A). The manifold layer 406 preferably includes horizontally configured fluid ports 408, 409. Alternatively, the manifold layer 406 includes vertically and/or diagonally configured fluid ports 408, 409, as discussed below, although not shown in FIG. 4-7. Alternatively, the manifold layer 406 does not include passage 414. Thus, fluid is directly supplied to the fingers 411 from the ports 408. Again, the manifold layer 411 alternatively does not include passage 418, whereby fluid in the fingers 412 directly flows out of the heat exchanger 400 through ports 408. It is apparent that although two ports 408 are shown in communication with the passages 414, 418, any other number of ports are alternatively utilized.

[0070] The inlet passages 411 preferably have dimensions which allow fluid to travel to the interface layer without generating a large pressure drop along the passages 411 and the system 30 (FIG. 2A). The inlet passages 411 preferably have a width dimension in the range of and including 0.25-5.00 millimeters, although any other width dimensions are alternatively contemplated. In addition, the inlet passages 411 preferably have a length dimension in the range of and including 0.5 millimeters to three times the length of the heat source. Alternatively, other length dimensions are contemplated. In addition, as stated above, the inlet passages 411 extend down to or slightly above the height of the microchannels 410 such that the fluid is channeled directly to the microchannels 410. The inlet passages 411 preferably have a height dimension in the range of and including 0.25-5.00 millimeters. It is apparent to one skilled in the art that the passages 411 do not extend down to the microchannels 410 and that any other height dimensions are alternatively contemplated. It is apparent to one skilled in the art that although the inlet passages 411 have the same dimensions, it is contemplated that the inlet passages 411 alternatively have different dimensions. In addition, the inlet passages 411 alternatively have varying widths, cross sectional dimensions and/or distances between adjacent fingers, varying dimensions. In particular, the passage 411 has areas with a larger width or depths as well as areas with narrower widths and depths along its length. The varied dimensions allow more fluid to be delivered to predetermined interface hot spot regions in the interface layer 402 through wider portions while restricting flow to warm spot interface hot spot regions through the narrow portions.



[0071] In addition, the outlet passages **412** preferably have dimensions which allow fluid to travel to the interface layer without generating a large pressure drop along the passages **412** as well as the system **30** (**FIG. 2A**). The outlet passages **412** preferably have a width dimension in the range of and including 0.25-5.00 millimeters, although any other width dimensions are alternatively contemplated. In addition, the outlet passages **412** preferably have a length dimension in the range of and including 0.5 millimeters to three times the length of the heat source. In addition, the outlet passages **412** extend down to the height of the microchannels **410** such that the fluid easily flows upward in the outlet passages **412** after horizontally flowing along the microchannels **410**. The inlet passages **411** preferably have a height dimension in the range of and including 0.25-5.00 millimeters, although any other height dimensions are alternatively contemplated. It is apparent to one skilled in the art that although outlet passages **412** have the same dimensions, it is contemplated that the outlet passages **412** alternatively have different dimensions. Again, the inlet passage **412** alternatively have varying widths, cross sectional dimensions and/or distances between adjacent fingers.

[0072] The inlet and outlet passages **411**, **412** are preferably segmented and distinct from one another, as shown in **FIGS. 4 and 5**, whereby fluid among the passages do not mix together. In particular, as shown in **FIG. 8**, two outlet passages are located along the outside edges of the manifold layer **406**, and one outlet passage **412** is located in the middle of the manifold layer **406**. In addition, two inlet passages **411** are configured on adjacent sides of the middle outlet passage **412**. This particular configuration causes fluid entering the interface layer **402** to travel the a short distance in the interface layer **402** before it flows out of the interface layer **402** through the outlet passage **412**. However, it is apparent to one skilled in the art that the inlet passages and outlet passages may be positioned in any other appropriate configuration and is thereby not limited to the configuration shown and described in the present disclosure. The number of inlet and outlet fingers **411**, **412** are more than three within the manifold layer **406** but less than 10 per centimeter across the manifold layer **406**. It is also apparent to one skilled in the art that any other number of inlet passages and outlet passages may be used and thereby is not limited to the number shown and described in the present disclosure.

[0073] Preferably, the manifold layer **406** is coupled to the intermediate layer (not shown), whereby the intermediate layer (not shown) is coupled to the interface layer **402** to form a three-tier heat exchanger **400**. The intermediate layer discussed herein is referred to above in the embodiment shown in **FIG. 3B**. The manifold layer **406** is alternatively coupled to the interface layer **402** and positioned above the interface layer **402** to form a two-tier heat exchanger **400**, as shown in **FIG. 7A**. **FIGS. 6A-6C** illustrate cross-sectional schematics of the preferred manifold layer **406** coupled to the interface layer **402** in the two tier heat exchanger. Specifically, **FIG. 6A** illustrates the cross section of the heat exchanger **400** along line A-A in **FIG. 5**. In addition, **FIG. 6B** illustrates the cross section of the heat exchanger **400** along line B-B and **FIG. 6C** illustrates the cross section of the heat exchanger **400** along line C-C in **FIG. 5**. As stated above, the inlet and outlet passages **411**, **412** extend from the top surface to the bottom surface of the manifold layer **406**. When the manifold layer **406** and the interface layer **402** are coupled to one another, the inlet and outlet passages **411**,

**412** are at or slightly above the height of the microchannels **410** in the interface layer **402**. This configuration causes the fluid from the inlet passages **411** to easily flow from the passages **411** through the microchannels **410**. In addition, this configuration causes fluid flowing through the microchannels to easily flow upward through the outlet passages **412** after flowing through the microchannels **410**.

[0074] In the preferred embodiment, the intermediate layer **104** (**FIG. 3B**) is positioned between the manifold layer **406** and the interface layer **402**, although not shown in the figures. The intermediate layer **104** (**FIG. 3B**) channels fluid flow to designated interface hot spot regions in the interface layer **402**. In addition, the intermediate layer **104** (**FIG. 3B**) is preferably utilized to provide a uniform flow of fluid entering the interface layer **402**. Also, the intermediate layer **104** is preferably utilized to provide fluid to interface hot spot regions in the interface layer **402** to adequately cool hot spots and create temperature uniformity in the heat source **99**. Although, the inlet and outlet passages **411**, **412** are preferably positioned near or above hot spots in the heat source **99** to adequately cool the hot spots, although it is not necessary.

[0075] **FIG. 7A** illustrates an exploded view of the alternate manifold layer **406** with the an alternative interface layer **102** of the present invention. Preferably, the interface layer **102** includes continuous arrangements of microchannel walls **110**, as shown in **FIG. 3B**. In general operation, similar to the preferred manifold layer **106** shown in **FIG. 3B**, fluid enters the manifold layer **406** at fluid port **408** and travels through the passage **414** and towards the fluid fingers or passages **411**. The fluid enters the opening of the inlet fingers **411** and preferably flows the length of the fingers **411** in the X-direction, as shown by the arrows. In addition, the fluid flows downward in the Z-direction to the interface layer **402** which is positioned below to the manifold layer **406**. As shown in **FIG. 7A**, the fluid in the interface layer **402** traverses along the bottom surface in the X and Y directions of the interface layer **402** and performs thermal exchange with the heat source **99**. The heated fluid exits the interface layer **402** by preferably flowing upward in the Z-direction via the outlet fingers **412**, whereby the outlet fingers **412** channel the heated fluid to the passage **418** in the manifold layer **406** in the X-direction. The fluid then flows along the passage **418** and exits the heat exchanger by flowing out through the port **409**.

[0076] The interface layer, as shown in **FIG. 7A**, includes a series of grooves **416** disposed in between sets of microchannels **410** which aid in channeling fluid to and from the passages **411**, **412**. In particular, the grooves **416A** are located directly beneath the inlet passages **411** of the alternate manifold layer **406**, whereby fluid entering the interface layer **402** via the inlet passages **411** is directly channeled to the microchannels adjacent to the groove **416A**. Thus, the grooves **416A** allow fluid to be directly channeled into specific designated flow paths from the inlet passages **411**, as shown in **FIG. 5**. Similarly, the interface layer **402** includes grooves **416B** which are located directly beneath the outlet passages **412** in the Z-direction. Thus, fluid flowing horizontally along the microchannels **410** toward the outlet passages are channeled horizontally to the grooves **416B** and vertically to the outlet passage **412** above the grooves **416B**.



[0077] FIG. 6A illustrates the cross section of the heat exchanger 400 with manifold layer 406 and interface layer 402. In particular, FIG. 6A shows the inlet passages 411 interwoven with the outlet passages 412, whereby fluid flows down the inlet passages 411 and up the outlet passages 412. In addition, as shown in FIG. 6A, the fluid flows horizontally through the microchannel walls 410 which are disposed between the inlet passages and outlet passages and separated by the microchannels 410. Alternatively, the microchannel walls are continuous (FIG. 3B) and are not separated by the grooves. As shown in FIG. 6A, either or both of the inlet and outlet passages 411, 412 preferably have a curved surface 420 at their ends at the location near the grooves 416. The curved surface 420 directs fluid flowing down the passage 411 towards the microchannels 410 which are located adjacent to the passage 411. Thus, fluid entering the interface layer 102 is more easily directed toward the microchannels 410 instead of flowing directly to the groove 416A. Similarly, the curved surface 420 in the outlet passages 412 assists in directing fluid from the microchannels 410 to the outer passage 412.

[0078] In an alternative embodiment, as shown in FIG. 7B, the interface layer 402' includes the inlet passages 411' and outlet passages 412' discussed above with respect to the manifold layer 406 (FIGS. 8-9). In the alternative embodiment, the fluid is supplied directly to the interface layer 402' from the port 408'. The fluid flows along the passage 414' towards the inlet passages 411'. The fluid then traverses laterally along the sets of microchannels 410' and undergoes heat exchange with the heat source (not shown) and flows to the outlet passages 412'. The fluid then flows along the outlet passages 412' to passage 418', whereby the fluid exits the interface layer 402' by via the port 409'. The ports 408', 409' are configured in the interface layer 402' and are alternatively configured in the manifold layer 406 (FIG. 7A).

[0079] It is apparent to one skilled in the art that although all of the heat exchangers in the present application are shown to operate horizontally, the heat exchanger alternatively operates in a vertical position. While operating in the vertical position, the heat exchangers are alternatively configured such that each inlet passage is located above an adjacent outlet passage. Therefore, fluid enters the interface layer through the inlet passages and is naturally channeled to an outlet passage. It is also apparent that any other configuration of the manifold layer and interface layer is alternatively used to allow the heat exchanger to operate in a vertical position.

[0080] FIGS. 8A-8C illustrate top view diagrams of another alternate embodiment of the heat exchanger in accordance with the present invention. In particular, FIG. 8A illustrates a top view diagram of an alternate manifold layer 206 in accordance with the present invention. FIGS. 8B and 8C illustrate a top view of an intermediate layer 204 and interface layer 202. In addition, FIG. 9A illustrates a three tier heat exchanger utilizing the alternate manifold layer 206, whereas FIG. 9B illustrates a two-tier heat exchanger utilizing the alternate manifold layer 206.

[0081] As shown in FIGS. 8A and 9A, the manifold layer 206 includes a plurality of fluid ports 208 configured horizontally and vertically. Alternatively, the fluid ports 208 are positioned diagonally or in any other direction with respect to the manifold layer 206. The fluid ports 208 are placed in

selected locations in the manifold layer 206 to effectively deliver fluid to the predetermined interface hot spot regions in the heat exchanger 200. The multiple fluid ports 208 provide a significant advantage, because fluid can be directly delivered from a fluid port to a particular interface hot spot region without significantly adding to the pressure drop to the heat exchanger 200. In addition, the fluid ports 208 are also positioned in the manifold layer 206 to allow fluid in the interface hot spot regions to travel the least amount of distance to the exit port 208 such that the fluid achieves temperature uniformity while maintaining a minimal pressure drop between the inlet and outlet ports 208. Additionally, the use of the manifold layer 206 aids in stabilizing two phase flow within the heat exchanger 200 while evenly distributing uniform flow across the interface layer 202. It should be noted that more than one manifold layer 206 is alternatively included in the heat exchanger 200, whereby one manifold layer 206 routes the fluid into and out-of the heat exchanger 200 and another manifold layer (not shown) controls the rate of fluid circulation to the heat exchanger 200. Alternatively, all of the plurality of manifold layers 206 circulate fluid to selected corresponding interface hot spot regions in the interface layer 202.

[0082] The alternate manifold layer 206 has lateral dimensions which closely match the dimensions of the interface layer 202. In addition, the manifold layer 206 has the same dimensions of the heat source 99. Alternatively, the manifold layer 206 is larger than the heat source 99. The vertical dimensions of the manifold layer 206 are within the range of 0.1 and 10 millimeters. In addition, the apertures in the manifold layer 206 which receive the fluid ports 208 are within the range between 1 millimeter and the entire width or length of the heat source 99.

[0083] FIG. 11 illustrates a broken-perspective view of a three tier heat exchanger 200 having the alternate manifold layer 200 in accordance with the present invention. As shown in FIG. 11, the heat exchanger 200 is divided into separate regions dependent on the amount of heat produced along the body of the heat source 99. The divided regions are separated by the vertical intermediate layer 204 and/or microchannel wall features 210 in the interface layer 202. However, it is apparent to one skilled in the art that the assembly shown in FIG. 11 is not limited to the configuration shown and is for exemplary purposes.

[0084] As shown in FIG. 3, the heat source 99 has a hot spot in location A and a warm spot, location B, whereby the hot spot in location A produces more heat than the warm spot in location B. It is apparent that the heat source 99 may have more than one hot spot and warm spot at any location at any given time. In the example, since location A is a hot spot and more heat in location A transfers to the interface layer 202 above location A (designated in FIG. 11 as interface hot spot region A), more fluid and/or a higher rate of liquid flow is provided to interface hot spot region A in the heat exchanger 200 to adequately cool location A. It is apparent that although interface hot spot region B is shown to be larger than interface hot spot region A, interface hot spot regions A and B, as well as any other interface hot spot regions in the heat exchanger 200, can be any size and/or configuration with respect to one another.

[0085] Alternatively, as shown in FIG. 11, the fluid enters the heat exchanger via fluid ports 208A is directed to



interface hot spot region A by flowing along the intermediate layer **204** to the inflow conduits **205A**. The fluid then flows down the inflow conduits **205A** in the Z-direction into interface hot spot region A of the interface layer **202**. The fluid flows in between the microchannels **210A** whereby heat from location A transfers to the fluid by conduction through the interface layer **202**. The heated fluid flows along the interface layer **202** in interface hot spot region A toward exit port **209A** where the fluid exits the heat exchanger **200**. It is apparent to one skilled in the art that any number of inlet ports **208** and exit ports **209** are utilized for a particular interface hot spot region or a set of interface hot spot regions. In addition, although the exit port **209A** is shown near the interface layer **202A**, the exit port **209A** is alternatively positioned in any other location vertically, including but not limited to the manifold layer **209B**.

[0086] Similarly, in the example shown in FIG. 11, the heat source **99** has a warm spot in location B which produces less heat than location A of the heat source **99**. Fluid entering through the port **208B** is directed to interface hot spot region B by flowing along the intermediate layer **204B** to the inflow conduits **205B**. The fluid then flows down the inflow conduits **205B** in the Z-direction into interface hot spot region B of the interface layer **202**. The fluid flows in between the microchannels **210** in the X and Y directions, whereby heat generated by the heat source in location B is transferred into the fluid. The heated fluid flows along the entire interface layer **202B** in interface hot spot region B upward to exit ports **209B** in the Z-direction via the outflow conduits **205B** in the intermediate layer **204** whereby the fluid exits the heat exchanger **200**.

[0087] Alternatively, as shown in FIG. 9A, the heat exchanger **200** alternatively includes a vapor permeable membrane **214** positioned above the interface layer **202**. The vapor permeable membrane **214** is in sealable contact with the inner side walls of the heat exchanger **200**. The membrane is configured to have several small apertures which allow vapor produced along the interface layer **202** to pass therethrough to the outlet port **209**. The membrane **214** is also configured to be hydrophobic to prevent liquid fluid flowing along the interface layer **202** from passing through the apertures of the membrane **214**. More details of the vapor permeable membrane **114** is discussed in co-pending U.S. application Ser. No. 10/366,128, filed Feb. 12, 2003 and entitled, "VAPOR ESCAPE MICROCHANNEL HEAT EXCHANGER" which is hereby incorporated by reference.

[0088] The microchannel heat exchanger of the present invention alternatively has other configurations not described above. For instance, the heat exchanger alternatively includes a manifold layer which minimizes the pressure drop within the heat exchanger in having separately sealed inlet and outlet apertures which lead to the interface layer. Thus, fluid flows directly to the interface layer through inlet apertures and undergoes thermal exchange in the interface layer. The fluid then exits the interface layer by flowing directly through outlet apertures arranged adjacent to the inlet apertures. This porous configuration of the manifold layer minimizes the amount of distance that the fluid must flow between the inlet and outlet ports as well as maximizes the division of fluid flow among the several apertures leading to the interface layer.

[0089] The details of how the heat exchanger **100** as well as the individual layers in the heat exchanger **100** are

fabricated and manufactured are discussed below. The following discussion applies to the preferred and alternative heat exchangers of the present invention, although the heat exchanger **100** in FIG. 3B and individual layers therein are expressly referred to for simplicity. It is also apparent to one skilled in the art that although the fabrication/manufacturing details are described in relation to the present invention, the fabrication and manufacturing details also alternatively apply to conventional heat exchangers as well as two and three-tier heat exchangers utilizing one fluid inlet port and one fluid outlet port as shown in FIGS. 1A-1C.

[0090] Preferably, the interface layer **102** has a coefficient of thermal expansion (CTE) which is approximate or equal to that of the heat source **99**. Thus, the interface layer **102** preferably expands and contracts accordingly with the heat source **99**. Alternatively, the material of the interface layer **102** has a CTE which is different than the CTE of the heat source material. An interface layer **102** made from a material such as Silicon has a CTE that matches that of the heat source **99** and has sufficient thermal conductivity to adequately transfer heat from the heat source **99** to the fluid. However, other materials are alternatively used in the interface layer **102** which have CTEs that match the heat source **99**.

[0091] The interface layer **102** in the heat exchanger **100** preferably has a high thermal conductivity for allowing sufficient conduction to pass between the heat source **99** and fluid flowing along the interface layer **102** such that the heat source **99** does not overheat. The interface layer **102** is preferably made from a material having a high thermal conductivity of 100 W/m-K. However, it is apparent to one skilled in the art that the interface layer **102** has a thermal conductivity of more or less than 100 W/m-K and is not limited thereto.

[0092] To achieve the preferred high thermal conductivity, the interface layer is preferably made from a semiconductor substrate, such as Silicon. Alternatively, the interface layer is made from any other material including, but not limited to single-crystalline dielectric materials, metals, aluminum, nickel and copper, Kovar, graphite, diamond, composites and any appropriate alloys. An alternative material of the interface layer **102** is a patterned or molded organic mesh.

[0093] As shown in FIG. 12, it is preferred that the interface layer **102** is coated with a coating layer **112** to protect the material of the interface layer **102** as well as enhance the thermal exchange properties of the interface layer **102**. In particular, the coating **112** provides chemical protection that eliminates certain chemical interactions between the fluid and the interface layer **102**. For example, an interface layer **102** made from aluminum may be etched by the fluid coming into contact with it, whereby the interface layer **102** would deteriorate over time. The coating **112** of a thin layer of Nickel, approximately 25 microns, is thus preferably electroplated over the surface of the interface layer **102** to chemically pacify any potential reactions without significantly altering the thermal properties of the interface layer **102**. It is apparent that any other coating material with appropriate layer thickness is contemplated depending on the material(s) in the interface layer **102**.

[0094] In addition, the coating material **112** is applied to the interface layer **102** to enhance the thermal conductivity of the interface layer **102** to perform sufficient heat exchange



with the heat source **99**, as shown in **FIG. 12**. For example, an interface layer **102** having a metallic base covered with plastic can be thermally enhanced with a layer of Nickel coating material **112** on top of the plastic. The layer of Nickel has a thickness of at least 25 microns, depending on the dimensions of the interface layer **102** and the heat source **99**. It is apparent that any other coating material with appropriate layer thickness is contemplated depending on the material(s) in the interface layer **102**. The coating material **112** is alternatively used on material already having high thermal conductivity characteristics, such that the coating material enhances the thermal conductivity of the material. The coating material **112** is preferably applied to the bottom surface **103** as well as the microchannel walls **110** of the interface layer **102**, as shown in **FIG. 12**. Alternatively, the coating material **112** is applied to either of the bottom surface **103** or microchannel walls **110**. The coating material **112** is preferably made from a metal including, but not limited to, Nickel and Aluminum. However, the coating material **112** is alternatively made of any other thermally conductive material.

[0095] The interface layer **102** is preferably formed by an etching process using a Copper material coated with a thin layer of Nickel to protect the interface layer **102**. Alternatively, the interface layer **102** is made from Aluminum, Silicon substrate, plastic or any other appropriate material. The interface layer **102** being made of materials having poor thermal conductivity are also coated with the appropriate coating material to enhance the thermal conductivity of the interface layer **102**. One method of electroforming the interface layer is by applying a seed layer of chromium or other appropriate material along the bottom surface **103** of the interface layer **102** and applying electrical connection of appropriate voltage to the seed layer. The electrical connection thereby forms a layer of the thermally conductive coating material **112** on top of the interface layer **102**. The electroforming process also forms feature dimensions in a range of 10-100 microns. The interface layer **102** is formed by an electroforming process, such as patterned electroplating. In addition, the interface layer is alternatively processed by photochemical etching or chemical milling, alone or in combination, with the electroforming process. Standard lithography sets for chemical milling are used to process features in the interface layer **102**. Additionally, the aspect ratios and tolerances are enhanceable using laser assisted chemical milling processes.

[0096] The microchannel walls **110** are preferably made of Silicon. The microchannel walls **110** are alternatively made of any other materials including, but not limited to, patterned glass, polymer, and a molded polymer mesh. Although it is preferred that the microchannel walls **110** are made from the same material as that of the bottom surface **103** of the interface layer **102**, the microchannel walls **110** are alternatively made from a different material than that of the rest of the interface layer **102**.

[0097] It is preferred that the microchannel walls **110** have thermal conductivity characteristics of at least 10 W/m-K. Alternatively, the microchannel walls **110** have thermal conductivity characteristics of more than 10 W/m-K. It is apparent to one skilled in the art that the microchannel walls **110** alternatively have thermal conductivity characteristics of less than 10 W/m-K, whereby coating material **112** is applied to the microchannel walls **110**, as shown in **FIG. 12**,

to increase the thermal conductivity of the wall features **110**. For microchannel walls **110** made from materials already having a good thermal conductivity, the coating **112** applied has a thickness of at least 25 microns which also protects the surface of the microchannel walls **110**. For microchannel walls **110** made from material having poor thermal conductivity characteristics, the coating **112** has a thermal conductivity of at least 50 W/m-K and is more than 25 microns thick. It is apparent to one skilled in the art that other types of coating materials as well as thickness dimensions are contemplated.

[0098] To configure the microchannel walls **110** to have an adequate thermal-conductivity of at least 10 W/m-K, the walls **110** are electroformed with the coating material **112** (**FIG. 12**), such as Nickel or other metal, as discussed above. To configure the microchannel walls **110** to have an adequate thermal conductivity of at least 50 W/m-K, the walls **110** are electroplated with Copper on a thin metal film seed layer. Alternatively, the microchannel walls **110** are not coated with the coating material. It is understood that the thermal conductivity characteristics of the microchannel walls **110** and the coating **112**, when appropriate, also apply to the pillars **203** (**FIG. 10**) and any appropriate coating applied thereon.

[0099] The microchannel walls **110** are preferably formed by a hot embossing technique to achieve a high aspect ratio of channel walls **110** along the bottom surface **103** of the interface layer **102**. The microchannel wall features **110** are alternatively fabricated as Silicon structures deposited on a glass surface, whereby the features are etched on the glass in the desired configuration. The microchannel walls **110** are alternatively formed by a standard lithography techniques, stamping or forging processes, or any other appropriate method. The microchannel walls **110** are alternatively made separately from the interface layer **102** and coupled to the interface layer **102** by anodic or epoxy bonding. Alternatively, the microchannel features **110** are coupled to the interface layer **102** by conventional electroforming techniques, such as electroplating.

[0100] There are a variety of methods that can be used to fabricate the intermediate layer **104**. The intermediate layer is preferably made from Silicon. It is apparent to one skilled in the art that any other appropriate material is contemplated including, but not limited to glass, laser-patterned glass, polymers, metals, glass, plastic, molded organic material or any composites thereof. Preferably, the intermediate layer **104** is formed using plasma etching techniques. Alternatively, the intermediate layer **104** is formed using a chemical etching technique. Other alternative methods include machining, etching, extruding and/or forging a metal into the desired configuration. The intermediate layer **104** is alternatively formed by injection molding of a plastic mesh into the desired configuration. Alternatively, the intermediate layer **104** is formed by laser-drilling a glass plate into the desired configuration.

[0101] The manifold layer **106** is manufactured by a variety of methods. It is preferred that the manifold layer **106** is fabricated by an injection molding process utilizing plastic, metal, polymer composite or any other appropriate material, whereby each layer is made from the same material. Alternatively, as discussed above, each layer is made from a different material. The manifold layer **106** is alter-



natively generated using a machined or etched metal technique. It is apparent to one skilled in the art that the manifold layer **106** is manufactured utilizing any other appropriate method.

[0102] The intermediate layer **104** is coupled to the interface layer **102** and manifold layer **106** to form the heat exchanger **100** using a variety of methods. The interface layer **102**, intermediate layer **104** and manifold layer **106** are preferably coupled to one another by an anodic, adhesive or eutectic bonding process. The intermediate layer **104** is alternatively integrated within features of the manifold layer **106** and interface layer **102**. The intermediate layer **104** is coupled to the interface layer **102** by a chemical bonding process. The intermediate layer **104** is alternatively manufactured by a hot embossing or soft lithography technique, whereby a wire EDM or Silicon master is utilized to stamp the intermediate layer **104**. The intermediate layer **104** is then alternatively electroplated with metal or another appropriate material to enhance the thermal conductivity of the intermediate layer **104**, if needed.

[0103] Alternatively, the intermediate layer **104** is formed along with the fabrication of the microchannel walls **110** in the interface layer **102** by an injection molding process. Alternatively, the intermediate layer **104** is formed with the fabrication of the microchannel walls **110** by any other appropriate method. Other methods of forming the heat exchanger include, but are not limited to soldering, fusion bonding, eutectic Bonding, intermetallic bonding, and any other appropriate technique, depending on the types of materials used in each layer.

[0104] Another alternative method of manufacturing the heat exchanger of the present invention is described in FIG. 13. As discussed in relation to FIG. 13, an alternative method of manufacturing the heat exchanger includes building a hard mask formed from a silicon substrate as the interface layer (step 500). The hard mask is made from silicon dioxide or alternatively spin-on-glass. Once the hard mask is formed, a plurality of under-channels are formed in the hard mask, wherein the under-channels form the fluid paths between the microchannel walls **110** (step 502). The under-channels are formed by any appropriate method, including but not limited to HF etching techniques, chemical milling, soft lithography and xenon difluoride etch. In addition, enough space between each under-channel must be ensured such that under-channels next to one another do not bridge together. Thereafter, spin-on-glass is then applied by any conventional method over the top surface of the hard mask to form the intermediate and manifold layers (step 504). Following, the intermediate and manifold layers are hardened by a curing method (step 506). Once the intermediate and manifold layers are fully formed and hardened, one or more fluid ports are formed into the hardened layer (step 508). The fluid ports are etched or alternatively drilled into the manifold layer. Although specific methods of fabricating the interface layer **102**, the intermediate layer **104** and manifold layer **106** are discussed herein, other known methods known in art to manufacture the heat exchanger **100** are alternatively contemplated.

[0105] FIG. 14 illustrates an alternative embodiment of the heat exchanger of the present invention. As shown in FIG. 6, two heat exchangers **200**, **200'** are coupled to one heat source **99**. In particular, the heat source **99**, such as an

electronic device, is coupled to a circuit board **96** and is positioned upright, whereby each side of the heat source **99** is potentially exposed. A heat exchanger of the present invention is coupled to one exposed side of the heat source **99**, whereby both heat exchangers **200**, **200'** provide maximum cooling of the heat source **99**. Alternatively, the heat source is coupled to the circuit board horizontally, whereby more than one heat exchanger is stacked on top of the heat source **99** (not shown), whereby each heat exchanger is electrically coupled to the heat source **99**; More details regarding this embodiment are shown and described in co-pending U.S. patent application Ser. No. 10/072,137, filed Feb. 7, 2002, entitled "POWER CONDITIONING MODULE" which is hereby incorporated by reference.

[0106] As shown in FIG. 14, the heat exchanger **200** having two layers is coupled to the left side of the heat source **99** and the heat exchanger **200'** having three layers is coupled to the right side of the heat source **99**. It is apparent to one skilled in the art that the preferred or alternative heat exchangers are coupled to the sides of the heat source **99**. It is also apparent to one skilled in the art that the alternative embodiments of the heat exchanger **200'** are alternatively coupled to the sides of the heat source **99**. The alternative embodiment shown in FIG. 14 allows more precise hot spot cooling of the heat source **99** by applying fluid to cool hot spots which exist along the thickness of the heat source **99**. Thus, the embodiment in FIG. 14 applies adequate cooling to hot spots in the center of the heat source **99** by exchanging heat from both sides of the heat source **99**. It is apparent to one skilled in the art that the embodiment shown in FIG. 14 is used with the cooling system **30** in FIGS. 2A-2B, although other closed loop systems are contemplated.

[0107] As stated above, the heat source **99** may have characteristics in which the locations of one or more of the hot spots change due to different tasks required to be performed by the heat source **99**. To adequately cool the heat source **99**, the system **30** alternatively includes a sensing and control module **34** (FIGS. 2A-2B) which dynamically changes the amount of flow and/or flow rate of fluid entering the heat exchanger **100** in response to a change in location of the hot spots.

[0108] In particular, as shown in FIG. 14, one or more sensors **124** are placed in each interface hot spot region in the heat exchanger **200** and/or alternatively the heat source **99** at each potential hot spot location. Alternatively, a plurality of heat sources are uniformly placed in between the heat source and heat exchanger and/or in the heat exchanger itself. The control module **38** (FIG. 2A-2B) is also coupled to one or more valves in the loop **30** which control the flow of fluid to the heat exchanger **100**. The one or more valves are positioned within the fluid lines, but are alternatively positioned elsewhere. The plurality of sensors **124** are coupled to the control module **34**, whereby the control module **34** is preferably placed upstream from heat exchanger **100**, as shown in FIG. 2. Alternatively, the control module **34** is placed at any other location in the closed loop system **30**.

[0109] The sensors **124** provide information to the control module **34** including, but not limited to, the flow rate of fluid flowing in the interface hot spot region, temperature of the interface layer **102** in the interface hot spot region and/or heat source **99** and temperature of the fluid. For example,



referring to the schematic in **FIG. 14**, sensors positioned on the interface **124** provide information to the control module **34** that the temperature in a particular interface hot spot region in heat exchanger **200** is increasing whereas the temperature in a particular interface hot spot region in heat exchanger **200'** is decreasing. In response, the control module **34** increases the amount of flow to heat exchanger **200** and decreases the amount of flow provided to heat exchanger **200'**. Alternatively, the control module **34** alternatively changes the amount of flow to one or more interface hot spot regions in one or more heat exchangers in response to the information received from the sensors **118**. Although the sensors **118** are shown with the two heat exchangers **200**, **200'** in **FIG. 14**, it is apparent that the sensors **118** are alternatively coupled with only one heat exchanger.

[0110] The present invention has been described in terms of specific embodiments incorporating details to facilitate the understanding of the principles of construction and operation of the invention. Such reference herein to specific embodiments and details thereof is not intended to limit the scope of the claims appended hereto. It will be apparent to those skilled in the art that modifications may be made in the embodiment chosen for illustration without departing from the spirit and scope of the invention.

What is claimed is:

1. A heat exchanger comprising:
  - a. an interface layer for cooling a heat source, wherein the interface layer is configured to pass fluid therethrough and the interface layer includes a thickness within a range of about 0.3 millimeters to about 1.0 millimeters; and
  - b. a manifold layer for circulating fluid to and from the interface layer, the manifold layer having a first set of fingers and a second set of fingers, wherein the first set of fingers are disposed in parallel with the second set of fingers and arranged to reduce pressure drop within the heat exchanger.
2. The heat exchanger according to claim 1 wherein the fluid is in single phase flow condition.
3. The heat exchanger according to claim 1 wherein the fluid is in two phase flow fluid conditions.
4. The heat exchanger according to claim 1 wherein at least a portion of the fluid undergoes a transition between single and two phase flow conditions in the interface layer.
5. The heat exchanger according to claim 1 wherein a particular finger in the first set is spaced apart by an appropriate dimension from a particular finger in the second set to minimize the pressure drop in the heat exchanger.
6. The heat exchanger according to claim 1 wherein each of the fingers have the same length and width dimensions.
7. The heat exchanger according to claim 1 wherein at least one of the fingers has a different dimension than the remaining fingers.
8. The heat exchanger according to claim 1 wherein the fingers are arranged non-periodically in at least one dimension in the manifold layer.
9. The heat exchanger according to claim 1 wherein at least one of the fingers has at least one varying dimension along a length of the manifold layer.
10. The heat exchanger according to claim 1 wherein the manifold layer includes more than three and less than 10 parallel fingers.
11. The heat exchanger according to claim 1 wherein the fingers in the first set and second set are alternately disposed along a dimension of the manifold layer.
12. The heat exchanger according to claim 1 wherein the manifold layer is configured to cool at least one interface hot spot region.
13. The heat exchanger according to claim 1 further comprising at least one first port in communication with the first set of fingers, wherein fluid enters the heat exchanger through the at least one first port.
14. The heat exchanger according to claim 13 further comprising at least one second port in communication with the second set of fingers, wherein fluid exits the heat exchanger through the at least one second port.
15. The heat exchanger according to claim 1 wherein the manifold layer is positioned above the interface layer, wherein fluid flows downward through the first set of fingers and upward through the second set of fingers.
16. The heat exchanger according to claim 13 further comprising a first port passage in communication with the first port and the first set of fingers, the first port passage configured to channel fluid from the first port to the first set of fingers.
17. The heat exchanger according to claim 16 further comprising a second port passage in communication with the second port and the second set of fingers, the second port passage configured to channel fluid from the second set of fingers to the second port.
18. The heat exchanger according to claim 1 wherein the interface layer is integrally formed with the heat source.
19. The heat exchanger according to claim 1 wherein the interface layer is coupled to the heat source.
20. The heat exchanger according to claim 1 further comprising an intermediate layer for channeling fluid to and from one or more predetermined positions in the interface layer via at least one conduit, the intermediate layer positioned between the interface layer and the manifold layer.
21. The heat exchanger according to claim 20 wherein the intermediate layer is coupled to the interface layer and the manifold layer.
22. The heat exchanger according to claim 20 wherein the intermediate layer is integrally formed with the interface layer and the manifold layer.
23. The heat exchanger according to claim 20 wherein the at least one conduit has at least one varying dimension along the intermediate layer.
24. The heat exchanger according to claim 1 wherein the interface layer includes a coating thereupon, wherein the coating provides an appropriate thermal conductivity of at least 10 W/m-K.
25. The heat exchanger according to claim 1 wherein the interface layer has a thermal conductivity of at least 100 W/m-K.
26. The heat exchanger according to claim 1 further comprising a plurality of pillars configured in a predetermined pattern along the interface layer.
27. The heat exchanger according to claim 26 wherein at least one of the plurality of pillars has an area dimension within the range of and including (10 micron)<sup>2</sup> and (100 micron)<sup>2</sup>.
28. The heat exchanger according to claim 26 wherein at least one of the plurality of pillars has a height dimension within the range of and including 50 microns and 2 millimeters.



**29.** The heat exchanger according to claim 26 wherein at least two of the plurality of pillars are separate from each other by a spacing dimension within the range of and including 10 to 150 microns.

**30.** The heat exchanger according to claim 26 wherein the plurality of pillars include a coating thereupon, wherein the coating has an appropriate thermal conductivity of at least 10 W/m-K.

**31.** The heat exchanger according to claim 1 wherein the interface layer has a roughened surface.

**32.** The heat exchanger according to claim 1 wherein the interface layer includes a micro-porous structure disposed thereon.

**33.** The heat exchanger according to claim 32 wherein the porous microstructure has a porosity within the range of and including 50 to 80 percent.

**34.** The heat exchanger according to claim 32 wherein the porous microstructure has an average pore size within the range of and including 10 to 200 microns.

**35.** The heat exchanger according to claim 32 wherein the porous microstructure has a height dimension within the range of and including 0.25 to 2.00 millimeters.

**36.** The heat exchanger according to claim 1 further comprises a plurality of microchannels configured in a predetermined pattern along the interface layer.

**37.** The heat exchanger according to claim 36 wherein at least one of the plurality of microchannels has an area dimension within the range of and including  $(10 \text{ micron})^2$  and  $(100 \text{ micron})^2$ .

**38.** The heat exchanger according to claim 36 wherein at least one of the plurality of microchannels has a height dimension within the range of and including 50 microns and 2 millimeters.

**39.** The heat exchanger according to claim 36 wherein at least two of the plurality of microchannels are separate from each other by a spacing dimension within the range of and including 10 to 150 microns.

**40.** The heat exchanger according to claim 36 wherein at least one of the plurality of microchannels has a width dimension within the range of and including 10 to 100 microns.

**41.** The heat exchanger according to claim 36 wherein the plurality of microchannels are coupled to the interface layer.

**42.** The heat exchanger according to claim 36 wherein the plurality of microchannels are integrally formed with the interface layer.

**43.** The heat exchanger according to claim 36 wherein the plurality of microchannels are divided into segmented arrays with at least one groove disposed therebetween, wherein the at least one groove is aligned with a corresponding finger.

**44.** The heat exchanger according to claim 36 wherein the plurality of microchannels include a coating thereupon, wherein the coating has an appropriate thermal conductivity of at least 10 W/m-K.

**45.** The heat exchanger according to claim 1 wherein an overhang dimension is within the range of and including 0 to 15 millimeters.

**46.** A heat exchanger for cooling a heat source comprising:

- a. a manifold layer including a first set of fingers in a first configuration, wherein each finger in the first set channels fluid at a first temperature, the manifold layer further including a second set of fingers in a second configuration, wherein each finger in the second set

channels fluid at a second temperature, the first set and second set of fingers arranged parallel to each other; and

- b. an interface layer including a thickness within a range of about 0.3 to 1.0 millimeters, and configured to receive fluid at the first temperature at a plurality of first locations, wherein each first location is associated with a corresponding finger in the first set, the interface layer passing fluid along a plurality of predetermined paths to a plurality of second locations, wherein each second location is associated with a corresponding finger in the second set.

**47.** The heat exchanger according to claim 46 wherein the fluid is in single phase flow conditions.

**48.** The heat exchanger according to claim 46 wherein the fluid is in two phase flow conditions.

**49.** The heat exchanger according to claim 46 wherein at least a portion of the fluid undergoes a transition between single and two phase flow conditions in the interface layer.

**50.** The heat exchanger according to claim 46 wherein a particular finger in the first set is spaced apart by an appropriate dimension from a particular finger in the second set, wherein the appropriate dimension reduces the pressure drop in the heat exchanger.

**51.** The heat exchanger according to claim 46 further comprising at least one first port in communication with the first set of fingers, wherein fluid enters the heat exchanger through the at least one first port.

**52.** The heat exchanger according to claim 51 further comprising at least one second port in communication with the second set of fingers, wherein fluid exits the heat exchanger through the at least one second port.

**53.** The heat exchanger according to claim 46 wherein the manifold layer is positioned above the interface layer, wherein fluid flows downward through the first set of fingers and upward through the second set of fingers.

**54.** The heat exchanger according to claim 46 wherein the interface layer is integrally formed with the heat source.

**55.** The heat exchanger according to claim 46 wherein the interface layer is coupled to the heat source.

**56.** The heat exchanger according to claim 46 wherein the fingers in the first set are positioned in an alternating configuration with the fingers in the second set.

**57.** The heat exchanger according to claim 46 wherein each of the fingers have the same length and width dimensions.

**58.** The heat exchanger according to claim 46 wherein at least one of the fingers has a different dimension than the remaining fingers.

**59.** The heat exchanger according to claim 46 wherein the fingers are arranged non-periodically in at least one dimension in the manifold layer.

**60.** The heat exchanger according to claim 46 wherein at least one of the fingers has at least one varying dimension along a length of the manifold layer.

**61.** The heat exchanger according to claim 46 wherein the manifold layer includes more than three and less than 10 parallel fingers.

**62.** The heat exchanger according to claim 52 further comprising a first port passage in communication with the first port and the first set of fingers, the first port passage configured to channel fluid from the first port to the first set of fingers.



**63.** The heat exchanger according to claim 62 further comprising a second port passage in communication with the second port and the second set of fingers, the second port passage configured to channel fluid from the second set of fingers to the second port.

**64.** The heat exchanger according to claim 46 further comprising an intermediate layer for channeling fluid to and from one or more predetermined positions in the interface layer via at least one conduit, the intermediate layer positioned between the interface layer and the manifold layer.

**65.** The heat exchanger according to claim 64 wherein the conduit is arranged in a predetermined configuration to channel fluid to one or more interface hot spot regions in the interface layer.

**66.** The heat exchanger according to claim 64 wherein the conduit is arranged in a predetermined configuration to channel fluid from one or more interface hot spot regions in the interface layer.

**67.** The heat exchanger according to claim 64 wherein the intermediate layer is coupled to the interface layer and the manifold layer.

**68.** The heat exchanger according to claim 64 wherein the intermediate layer is integrally formed with the interface layer and the manifold layer.

**69.** The heat exchanger according to claim 64 wherein the conduit has at least one varying dimension in the intermediate layer.

**70.** The heat exchanger according to claim 46 wherein the interface layer includes a coating thereupon, wherein the coating provides an appropriate thermal conductivity of at least 10 W/m-K.

**71.** The heat exchanger according to claim 46 wherein the interface layer has a thermal conductivity is at least 100 W/m-K.

**72.** The heat exchanger according to claim 46 further comprising a plurality of pillars configured in a predetermined pattern along the interface layer.

**73.** The heat exchanger according to claim 72 wherein at least one of the plurality of pillars has an area dimension within the range of and including  $(10 \text{ micron})^2$  and  $(100 \text{ micron})^2$ .

**74.** The heat exchanger according to claim 72 wherein at least one of the plurality of pillars has a height dimension within the range of and including 50 microns and 2 millimeters.

**75.** The heat exchanger according to claim 72 wherein at least two of the plurality of pillars are separate from each other by a spacing dimension within the range of and including 10 to 150 microns.

**76.** The heat exchanger according to claim 72 wherein the plurality of pillars include a coating thereupon, wherein the coating has an appropriate thermal conductivity of at least 10 W/m-K.

**77.** The heat exchanger according to claim 46 wherein the interface layer has a roughened surface.

**78.** The heat exchanger according to claim 46 wherein the interface layer includes a microporous structure disposed thereon.

**79.** The heat exchanger according to claim 78 wherein the porous microstructure has a porosity within the range of and including 50 to 80 percent.

**80.** The heat exchanger according to claim 78 wherein the porous microstructure has an average pore size within the range of and including 10 to 200 microns.

**81.** The heat exchanger according to claim 78 wherein the porous microstructure has a height dimension within the range of and including 0.25 to 2.00 millimeters.

**82.** The heat exchanger according to claim 46 further comprises a plurality of microchannels configured in a predetermined pattern along the interface layer.

**83.** The heat exchanger according to claim 82 wherein at least one of the plurality of microchannels has an area dimension within the range of and including  $(10 \text{ micron})^2$  and  $(100 \text{ micron})^2$ .

**84.** The heat exchanger according to claim 82 wherein at least one of the plurality of microchannels has a height dimension within the range of and including 50 microns and 2 millimeters.

**85.** The heat exchanger according to claim 82 wherein at least two of the plurality of microchannels are separate from each other by a spacing dimension within the range of and including 10 to 150 microns.

**86.** The heat exchanger according to claim 82 wherein at least one of the plurality of microchannels has a width dimension within the range of and including 10 to 100 microns.

**87.** The heat exchanger according to claim 82 wherein the microchannels are coupled to the interface layer.

**88.** The heat exchanger according to claim 82 wherein the microchannels are integrally formed with the interface layer.

**89.** The heat exchanger according to claim 82 wherein the microchannels are divided into segments along a dimension of the interface layer, at least one groove disposed in between the divided microchannel segments.

**90.** The heat exchanger according to claim 82 wherein the microchannels are continuous along a dimension of the interface layer.

**91.** The heat exchanger according to claim 89 wherein the at least one groove is aligned with a corresponding finger.

**92.** The heat exchanger according to claim 82 wherein the plurality of microchannels include a coating thereupon, wherein the coating has an appropriate thermal conductivity of at least 10 W/m-K.

**93.** The heat exchanger according to claim 46 wherein an overhang dimension is within the range of and including 0 to 15 millimeters.

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