(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
25 October 2007 (25.10.2007)

PCT

(10) International Publication Number
WO 2007/120530 A2

(51) International Patent Classification:
H05K 7/20 (2006.01)

(21) International Application Number:
PCT/US2007/008190

(22) International Filing Date: 30 March 2007 (30.03.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/788,545 30 March 2006 (30.03.2006) US

(71) Applicant (*for all designated States except US*): **COOLIGY, INC.** [US/US]; 800 Maude Ave, Mountain View, CA 94043 (US).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **HOM, James** [US/US]; 4028 Farm Hill Blvd., #4, Redwood City, CA 94061 (US). **UPADHYA, Girish** [US/US]; 9509 Tobrina Lane, Austin, TX 78759 (US). **WERNER, Douglas, E.** [US/US]; 4199 Tobin Circle, Santa Clara, CA 95054 (US). **MUNCH, Mark** [US/US]; 12758 Leander Drive, Los Altos Hills, CA 94022 (US). **TSAO, Paul** [US/US]; 1816 Alford Avenue, Los Altos, CA 94024 (US). **CONWAY, Bruce** [US/US]; 15 Ventura Avenue, La Honda, CA 94020 (US). **ZHOU, Peng** [CN/US]; 535 Pierce Street, #1104, Albany, CA 94706 (US). **BREWER, Richard** [US/US]; 573 Cutwater Lane, Foster City, CA 94404 (US).

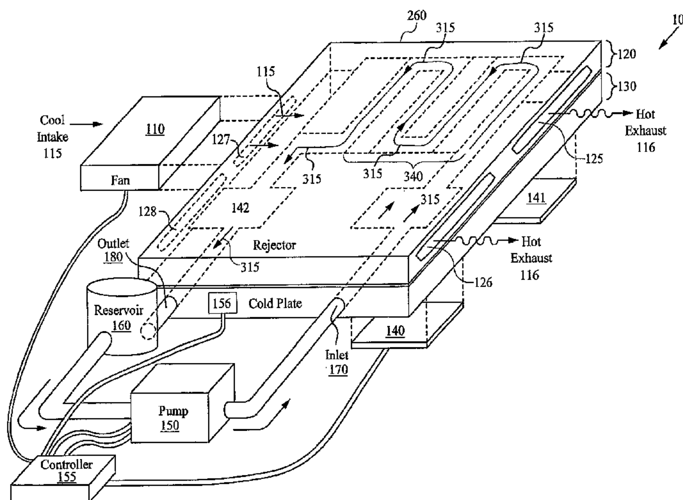
(74) Agents: **HAVERSTOCK, Thomas, B.** et al.; Haverstock & Owens LLP, 162 North Wolfe Road, Sunnyvale, CA 94086 (US).

(81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: INTEGRATED LIQUID TO AIR CONDUCTION MODULE



(57) **Abstract:** An integrated cooling system for cooling systems such as laptops or subsystems such as a graphics card is disclosed. An integrated cooling system includes a first layer having a contact area configured for coupling to a heat source, wherein the first layer has a fluid path passes adjacent to the contact area where the heat source is in thermal contact with first layer. Coupled to the first layer is a second layer to which a number of air fins are attached. The invention includes a pump that is connected to the fluid path forming a closed path for circulating a fluid through the first layer. Within the first layer, the fluid path will contain a plurality of fluid fins which control the flow of a fluid within the fluid path. Within the fluid path, a structure providing a double-counter flow adjacent to one or more electronic devices. Additionally the fluid path can include a microchannel plate structure. The system can include a includes a programmable controller connect the an air-mover, pump and temperature sensing device. A reservoir can be connected to the fluid path.

WO 2007/120530 A2

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTEGRATED LIQUID TO AIR CONDUCTION MODULE

Related Applications

This Patent Application claims priority under 35 U.S.C. 119 (e) of the co-pending U.S. Provisional Patent Application, Serial No. 60/788,545 filed March 30, 2006, and entitled "MULTI CHIP COOLING ". The Provisional Patent Application, Serial 60/788,545 filed March 30, 2006, and entitled "MULTI CHIP COOLING" is also hereby incorporated by reference.

Field of the Invention

This invention relates generally to heat exchangers. More specifically, the present invention relates to methods of and systems for cooling multi-chip using a combination of liquid and air cooling structures.

Background of the Invention

Cooling current semiconductor structures presents significant challenges for traditional cooling structures, such as fan-mounted heat sinks and heat pipes. For instance, modern high performance processors have very high heat dissipation requirements, but traditional cooling structures cannot satisfy these requirements. Fan-mounted heat sinks often do not move sufficient air quickly enough to cool a modern processor. Similarly, heat pipes are limited in both the amount of heat they can dissipate and the distance they can move the heat from the heat source. Hence, conventional cooling techniques that use heat pipes or fan-mounted heat sinks are not adequate for cooling modern electronics.

These limitations are even more apparent with systems that incorporate multiple electronic components, each generating heat. For example, high performance laptops are increasingly used as replacements for desktop systems. These laptops integrate on a small footprint many electronics components such as CPUs, graphics processors, and memory hub controllers. System-level and component-level cooling solutions each has its drawbacks.

System-level solutions are sub-optimal because any solution optimized for one system is necessarily sub-optimal for another system. Cooling solutions addressing cooling on an individual component basis decreases the system reliability by requiring additional

critical components, joints, and connections, failure of any one of which could cause a system failure.

Summary of the Invention

Embodiments of the present invention provide more efficient cooling of systems that contain multiple heat-generating electronic devices. In a first aspect of the present invention, an integrated cooling system includes a first cooling structure stacked on top of a second cooling structure. The first cooling structure is for circulating a first cooling medium, and the second cooling structure is for circulating a second cooling medium different from the first medium. In one embodiment, the system includes a fluid path in the first cooling structure. The fluid path contains a microchannel structure. Preferably, the first cooling medium is water and the second cooling medium is air.

Preferably, the fluid path includes a double-counter structure. The double-counter structure is a multi-pass flow structure with the predominant flow path counter to that of the flow in the second medium. The purpose of the multi-pass flow structure is spread the heat over a larger area and to maximize the time during which the fluid is flowing under the air fins and transferring heat. In one embodiment, the system also includes a pump coupled to the fluid path.

In a second aspect of the invention, an integrated cooling system includes a first layer, a second layer, and a pump. The first layer is coupled to the second layer. The first layer has a contact area configured for coupling to a heat source and has a fluid path adjacent to the contact area. The second layer has a plurality of air fins. The pump is coupled to the fluid path and forms a closed path for circulating a fluid through the first layer.

Preferably, the second layer seals to the first layer to provide an inner surface of the fluid path. In one embodiment, the fluid path has a fluid contact area with the second layer that is greater than two times the contact area of the first layer with the heat source. Preferably, the first layer and the second layer both have a thermal conductivity of at least 15 W/(mK) or greater.

In one embodiment, the fluid path contains a plurality of fluid fins that are substantially equally spaced over the contact area. Preferably, the fluid fins have a thermal conductivity of 15 W/(mK) or greater and are evenly spaced.

Preferably, the system includes a heat source coupled to the contact area. The heat

source can include one or more electronic devices. The fluid path includes a double-counter structure. In some embodiments, the system includes a programmable controller coupled to a temperature-sensing element within the fluid path. The programmable controller is programmed to increase a fluid flow rate within the fluid path when the temperature-sensing element detects an increase in temperature. Alternatively, or additionally, the programmable controller is programmed to increase the air-mover speed when the detected temperature increases and decrease the air-mover speed when the temperature decreases.

In one embodiment, the direction of fluid pumping from the inlet to the outlet where the fluid has cooled the more before reaching the pump. Typically, this fluid flow direction is where the flow-path distance is the longest from a port and the highest dissipation heat source.

In another embodiment, the system also includes a fluid reservoir coupled to or within the fluid path, preferably coupled to the pump.

Preferably, the first layer includes an enclosure that forms at least one airflow channel and at least one air-mover coupled to at least one airflow channel. The air fins within the channel have a shape that can be, but not limited to, folded, pin, hexagonal, airfoil, ruffled, herringbone, lanced, louvered, or any combination of these.

In a third aspect of the invention, an integrated cooling system includes a first layer, a plurality of fluid fins, a second layer coupled to the first layer, a plurality of pin and folded air fins, an air-mover, a heat source, a pump, and a programmable controller. The first layer has a first side containing a contact area for coupling a heat source adjacent to it. The first layer contains a fluid path adjacent to the contact area and a heat-transfer area adjacent to the second layer having an area greater than two times the contact area. The fluid path contains a double-counter flow path structure adjacent to at least a portion of the heat source. The first layer has a thermal conductivity of at least 15 W/mK.

The plurality of fluid fins are placed in the flow path over the heat source which includes the double-counter flow path. The fins are evenly spaced and thermally conductive with the first layer contact area, with the fluid in the fluid path, and with the second layer. The fluid fins have a thermal conductivity of at least 15 W/mK.

The air fins coupled to the second layer are covered with an enclosure to create one or more air channels. A channel divider, the air fins shape, and the placement of the air fins control the rate and direction of a cooling airflow.

Preferably, the second layer seals to the first layer to provide an inner surface of the fluid path. In one embodiment, the flow path is optimized to maximize cooling of each electronic device. In another embodiment, the flow path is optimized to minimize the temperature of each electronic device. In yet another embodiment, the flow path is optimized to maximize the cooling of a selected electronic device.

The programmable controller is connected to the air-mover and the pump in a manner where it controls the speed of the pump and air-mover. In one embodiment, the programmable controller controls the pump flow rate and air-mover rate. The programmable controller includes the ability to take temperature measurements from a location on the first layer or second layer assembly. The controller can be integrated with the mother board and use information provided by the chips to control the air movers and pumps. The controller uses the temperature information to control the pump flow rate and the air-mover rate including the state of the pump and air-mover.

In a fourth aspect of the invention, a method of manufacturing an integrated cooling system is disclosed. In the manufacturing method, a first layer is provided with a first side configured with coupling areas for one or more electronic devices and a second side configured to seal with a second layer. The first structure has a fluid path configured to channel fluid from an inlet to an outlet where the fluid path passes over the coupling area for the heat source. Preferably, the flow path contains fluid fins over the coupling areas for the electronic devices. In another embodiment, the flow path has a double-counter flow structure over a coupling area. In another embodiment, the flow path has a mirochannel plate assembly.

As another step in the manufacture of the current invention, second layer for circulating a cooling medium is provided and sealed to the first layer. Attached to the second layer is a plurality of air fins. Additionally, all or part of the air fins can be mounted to or formed as an integral part of the second layer.

In another of the manufacturing steps, a pump is coupled to the fluid path forming a closed flow path. In another of the manufacturing steps, a programmable controller is attached to the pump.

Preferably, the seal between second layer and the first layer defines an inner surface of the closed fluid path. In one embodiment, the fluid path contact area between the first and second layer is greater than the contact areas with the electronic devices. Preferably the

materials from which the first and second layer are formed have a thermal conductivity of 15 W/(mK) or greater. In some embodiments the programmable controller has a means for measuring a temperature, controlling a fluid flow rate of the pump. Preferably the programmable controller will increase fluid flow rate when the temperature increases and decrease the rate when the temperature drops. In another embodiment, the pump is turned on when the temperature exceeds a specific temperature and turned off when the temperature falls below a specific temperature.

In other embodiments the pump inlet is coupled to the port that has the longest flow-path distance between the port and the highest dissipation heat source.

In another embodiment, a reservoir is coupled to the flow path.

Brief Description of the Drawings

Figure 1 shows an integrated cooling system, including a heat rejector assembly, according to a first embodiment of the invention.

Figure 2 is an exploded phantom view of the heat rejector assembly of Figure 1.

Figure 3 is a top cross-sectional view of the cold-plate assembly of Figure 1, showing fluid channels over multiple heat sources.

Figure 4 is a perspective view of an integrated cooling system for a computer card according to a second embodiment of the invention.

Figure 5 is a top cross-sectional view of the cold-plate assembly of Figure 4 showing macro channels and the microchannels for the cooling of a processor and memory chips.

Figure 6 is a side cross-sectional view of the cold-plate assembly and heat-rejector assembly of Figure 4 showing a microchannel subassembly joined to macro channel base through a hole in the cold plate.

Figure 7 is a flow chart for fabricating an integrated cooling system in accordance with the present system.

Detailed Description of the Present Invention

Embodiments of the present invention are directed to integrated cooling systems in which a liquid-based cold-plate assembly and an air-based heat exchanger (a heat rejector assembly) are configured as an integrated unit. Integrated cooling systems in accordance

with the present invention advantageously improve system reliability, improve the ability to cool multiple electronic components with one system, and reduce cost.

In one embodiment of the invention, fluid-cooled and air-cooled heat exchangers are stacked on top of each other, above a heat-generating device, thereby more efficiently cooling the heat-generating device.

In another embodiment, a cooling fluid path includes a double-counter flow structure. In a this structure, the fluid path includes a first segment that "doubles back,"or changes direction by 180 degrees along a second segment adjacent to the first. The fluid path then repeats this pattern of doubling back any number of times. In this way, the time in which the fluid flow is adjacent to the heat source is maximized, thus increasing the transfer of heat. Further, the predominant flow direction of the first fluid is counter to that of the flow direction of the second fluid.

In still another embodiment, the system includes a first contact for coupling to a heat source and a second contact area for dissipating heat. Preferably, the second contact area is greater than the first contact area.

Figure 1 is a perspective view of a preferred embodiment of an integrated cooling system 100 for cooling a laptop computer according to a first embodiment of the present invention. The cooling system 100 includes a cold-plate assembly 130 coupled to a heat-rejector assembly 120, thereby forming an integrated cold-plate heat-rejector assembly. One surface of the heat-rejector assembly 120 is adjacent to the cold-plate assembly 130 and forms a top plate and seals to the cold-plate assembly 130. The integrated cold-plate heat-rejector assembly overlies and thus cools first, second, and third electronic devices 140-142, respectively.

The heat-rejector assembly 120 includes air vents 125-127, all fluidly coupled to a cooling fan 110. The cold-plate assembly 130 includes an inlet 170 and outlet 180 fluidly coupled to the flow path 315. Coupled to the inlet 170 and outlet 180 is a pump 150. The pump 150, integrated cold-plate 130 heat-rejector 120 assembly , and reservoir 160 thus form a closed loop fluid path.

The cooling fan 110 generates an airflow 115 entering the vent 127 and passing through the heat-rejector assembly 120. Additional fans (not shown) can be attached to the heat-rejector assembly 120 and generated additional an air flow through vent 128. The airflow 115 exits the heat-rejector assembly 120 out the vents 125 and 126 as heated exhaust

116. The vents 125, 126 and 127 are preferably formed in the heat-rejector cover 260 and define one or more air channels through the heat-rejector assembly 120.

The fluid path 315 starts with the pump 150 outlet and enters the inlet 170 to the cold-plate assembly 130. The fluid path 315 passes adjacent to a first electronic component 140 where the path 315 has an area over the electronic device 140 that preferably is substantially equal to the coupling area of the device. The fluid path then enters into a double-counter flow structure 340. The double-count flow structure 340 overlies the electronic device 141 and has an area that is preferably substantially larger than the coupling area of the underlying electronic device 141. The path then passes adjacent to a third electronic device 141 where the flow path 315 is sized to have an area greater than the coupling area for the electronic device 141. The flow path 315 exits the cold-plate assembly 130 at the outlet 180. The outlet 180 couples to the reservoir 160 where the reservoir is coupled to the pump 150 inlet. Although Figure 1 depicts the inlet 170 and outlet 160 originating from the cold-plate assembly, it will be appreciated that the location of the inlet 170 and outlet 160 can be through the heat-reject assembly 120 or any combination of the two.

A controller 155 is coupled to the fan 110, to the pump 150, and to a temperature-sensing element 156. The temperature-sensing element 156 is coupled to and thus monitors a temperature of the cold plate 130. In operation, the controller 155 is programmed to sense the temperature of the cold plate 130 sensed by the temperature-sensing element 156 and, in response, control the pump 150, the fan 110, or both. As one example, when the temperature of the cold plate 130 is above a predetermined threshold value, the controller 155 turns on the pump 150 to thereby cool the cold plate 130, turns on the fan 110 to thereby cool remove heat through the vents 125 and 126, or to turn on both the pump 150 and the fan 110. When the temperature of the cold plate 130 falls below a threshold value, the pump 150, fan 110, or both are turned off. While Figure 1 depicts the temperature-sensing element 156 coupled to the cold-plate assembly 130, alternatively it can be coupled to the heat-rejector assembly 120 or integrally formed as part of one or more of the electronic chips 140-142.

In operation, the heat sources 140-142 each generate heat that radiates into the cold plate 130. The pump 150 pumps fluid from the reservoir 160, to the inlet 170, along the flow path 315 that includes the double-counter flow structure 340, and to the outlet 180. While above the heat sources 140-142, the fluid absorbs heat conducted from the heat sources 140-142 into the cold plate 130. The heated fluid moves the heat around the cold plate 130 where

it is transported to the heat-rejector assembly 120. The heat-rejector assembly 120 then conducts the heat into the air flowing from vents 127 and 128 to the exit vents 125 and 126. The temperature within the cold plate 130 is monitored by the temperature sensing element 156 and used by the controller 155 to control the pump 150, the fan 110, or both.

As described in detail below, heat is removed efficiently by (a) positioning the heat sources 140-142 adjacent to the flow path 315, (b) thermally coupling the electronic devices 140-142 to their respective contact areas, (c) selecting a size of the flow path to correspond to the contact area of a heat source, or (c) selecting a combination of these.

Figure 2 illustrates an exploded phantom view of the heat-rejector assembly 120 (Figure 1). The base of the heat-rejector assembly 200 consists of a rejector plate 201, folded air fins 230 and pin air fins 231 coupled to the rejector plate 201, an air channel divider 250, and a cover 260 with air intake vents 127 and 128 and exit vents 125 and 126.

The rejector plate 201 forms a fluid tight seal with the cold-plate assembly 130 (Figure 1). Folded air fins 230 and pin air fins 231 are mounted to the rejector plate 201 or formed as an integral part of the rejector plate 201.

In operation, the cover 260 preferably forms two air channels through the air fins., Air is forced, from the vents 127 and 128 by the fan 110 (Figure 1) and exits the vents 125 and 126. The folded air fins 230 and pin air fins 231 conduct heat from the rejector plate 201 and into the ambient environment, in this case the air within the air channels. However, air fins cause a back pressure impeding the air flow 115 (Figure 1). Because more back pressure is caused by the folded air fins 230, they are not used over the entire rejector plate 201. Part of the rejector plate 201 surface has pin air fins 231 attached to the heat-rejector plate 201. These pin air fins 231 function to accomplish the same goal as the folded air fins 230, though less efficiently but causing less back pressure. The pin fins 231 conduct heat from the rejector plate into the ambient environment and control the air flow 115 (Figure 1) within the air channel.

Figure 3 illustrates a top view of the preferred embodiment of the cold-plate assembly 130. The cold-plate assembly 130 couples to the heat sources shown in phantom under the cold-plate assembly 130. The heat sources shown represent a CPU 140, a memory hub controller 141, and GPU 142, typical of a laptop design.

The cold-plate assembly contains a fluid path 315 from the inlet 170 through the three flow path structures 330, 340, and 350 and to the outlet 180. The inlet 170 and outlet 180 are

coupled to a pump 150 (Figure 1) and reservoir 160 (Figure 1) and the flow of fluid through the fluid path 315 is as described above for Figure 1. More details of the structures 330, 340, and 350 are provided.

The flow path contains three fin structure, 330, 340, and 350. Each of these structures 330, 340 and 350 contains of a set of fluid fins 370 forming flow channels. Within the structures 330, 340, and 350 the fins are substantially parallel and substantially evenly spaced. It will be apparent that other orientations and other spacing are also contemplated. The fluid fins 370 conduct heat from the heat source, into the fluid, and directly to the heat rejector 120 (Figure 1). The fluid fins 370 provide several functions. First, the fluid fins 370 provide an even flow of fluid across the area adjacent to the heat source. Secondly, the fluid fins 370 provide conduction of heat from the heat source 140, 141, and 142 into the fluid within the fluid path 315. Thirdly, the fluid fins 370 are in thermal contact with the heat-rejector assembly 120 (Figure 1), then the fluid fins 370 directly conduct heat to the heat rejector assembly, 130 (Figure 1).

While figure 3 shows only one double-counter flow path over the electronic device 141, alternative embodiments of this invention can incorporate additional double-counter flow paths over other heat sources. Further, the scope of this invention covers the use of sequential double-counter flow paths or multiple double-counter flow paths that have parallel flows or multiple double-counter flow paths that are placed in differing orientations. In an alternative embodiment, the fluid fin structure 330 can be a MCP (microchannel plate) assembly.

Additionally, alternative embodiments can have fluid paths that pass adjacent to more or fewer heat sources.

Figure 4 is a perspective view of an integrated cooling system 400 in accordance with a second embodiment of the present invention. The integrated cooling system 400 includes a cold-plate assembly 410, coupled to the heat-rejector assembly 420, a pump 430, and a fan 440. Air-fins 421 are coupled to the heat-rejector assembly 420.

The cold-plate assembly 410 contains a fluid path and fluid which is pumped though the assembly 420 to distribute the heat generated by the heat source 460. The heat-rejector 420 is sealed to the cold-plate and defines an inner surface of the of the fluid path. A pump 430 is coupled to the fluid path though an inlet 431 and an outlet 432. The heat is conducted to the heat-rejector assembly 420, to the air fins 421, and into the ambient air flow generated

by the fan 440. Preferably an enclosure 450 covers the heat-rejector assembly 420 forming an air channel. Attached to one end of the air channel is a fan 440 that either pulls or pushes air through the air fins 421.

The pump 430 is any conventional pump, including but not limited to, an electro-osmotic pump and a mechanical pump. The air fins 421 are illustrated as straight air fin but the invention encompasses other air fin designs including but not limited to folded air fins.

Figure 5 illustrates a top view of the cold-plate assembly 410 of the second embodiment of the present invention as shown in Figure 4. The cold-palate assembly 410 contains macro channels 540 and a MPC assembly. Fluid enters the inlet 431 flow and enters the MCP assembly 530. The MCP assembly 530 is situated adjacent to a graphics processor 510 which is thermally coupled with the opposing side of cold-plate assembly 410. The fluid is distributed to flow evenly through the microchannels 520 and then into a macro channel 540. The macro channel 540 follows a path that either is adjacent or partially adjacent to the graphics memory 550 electronics. The graphics memory 550 is either in physical contact with the cold-plate assembly 410 or thermally coupled to the cold-plate assembly 410.

In operation, the fluid, acts to dissipate the conducted heat over a larger area for conduction into the environment, here the area of the heat-rejector assembly 420 (Figure 4). The fluid exits the cold-plate assembly 420 through the port 570.

While a graphics processor is referenced in this illustration, this invention is applicable to other computer cards such as but not limited to network processor, co-processors and high heat dissipation electronic components.

Figure 6 illustrates a side view of the cold-plate assembly 410 and hea 600 in accordance with a second embodiment of the present invention. A heat-rejector assembly 420 is coupled to the cold-plate assembly 410 forming an integrated cold-plate 410 and heat-rejector 420 assembly 600. The cold-plate assembly 420 includes the MCP assembly 630. This MCP assembly 630 is shown coupled to the cold-plate assemble 420 and as part of the fluid path from the pump 430 (Figure 4) where fluid flows into inlet 431, through the microchannel 630, and exits at the outlet 432, returning to the pump 430 (Figure 4).

Figure 7 is a flow chart for the fabrication 700 of the an integrated cooling system. In step 710 a first layer is provide. The first layer has a first side where one or more heat sources are thermally coupled with the first layer forming a contact area.

Preferably, the provided first layer has a thermal conductivity of 15 W/(mK) or greater. The first layer will be formed with a flow path. The flow path can be formed by any method including but not limited to stamping, casting, milling, or chemical etching. Preferably the flow path passes adjacent to the heat sources and is of sufficient size to substantially cover the heat source contact area. Further, as part of the flow path, a double-counter flow path is followed. In another embodiment the flow path does not have a double-counter flow pattern in the flow path.

As part of step 710, the fluid fins are provided in the flow path 315 (Figure 1). The fluid fins 370 (Figure 2) provide an even flow of fluid in the areas adjacent to the heat source. Preferably, the fluid fins 370 (Figure 2) are provided over the areas adjacent to the heat sources contact areas and within the double-counter flow area. Preferably, the fins are in parallel to each other, evenly spaced, and formed out of a thermally conductive material to conduct heat from the heat source contact areas to the fluid. Preferably, the fluid fins are thermally coupled with second layer when the second layer is sealed to the first layer. The fluid fins can be fabricated by machining processes including but not limited to casting, stamping, milling, chemical etching, or any combination thereof. In one embodiment, the fluid path can include a MCP assembly. The MCP structure is preferably formed on a separate structure that is inserted into the flow path through an opening in cold-plate assemble 410 (Figure 5). The MPC is sealed the first layer by a means not limited to brazing, welding, gluing, or a gasket and a attachment means.

The step 720 provides a second layer that his coupled to the first layer. Preferably, the second layer has a plate that seals to the first layer forming a closed fluid path. As part of the second layer are air fins 230 and 231 (Figure 2). The air fins can be attached or be formed into the plate 201 (Figure 2) that seals with the first layer . The air fins 230 and 231 (Figure 2) can include the types but are not limited to a hexagonal shaped, airfoil shaped, ruffled, herringbone, lanced, louvered, or any combination thereof. Perferably, the thermal conductivity of the air fins 230 and 231 (Figure 2), the plate 201 (Figure 2), is 15 W/(mK) or greater. The seal between the cold-plate 120 (Figure 1) and the heat-rejector 130 (Figure 1) can be formed by the means not limited to brazing, welding, gluing, or with a gasket. The air fins 230 and 231 (Figure 2) are coupled by the method not limited to soldering, welding, gluing, or any combination thereof.

In the step 730, a pump 150 (Figure 1) is provided and coupled to the fluid path 315 (Figure 1) in the first layer 130 (Figure 1), 410 (Figure 4). The pump 150 (Figure 1) is attached directly to the first layer 130 (Figure 1), 410 (Figure 4) or through tubing. In some embodiments, the coupling of the pump 150 (Figure 1) is through the second layer plate 201 (Figure 2) that seals to the first layer. The provided pump 150 (Figure 1) can be but is not limited to an electro-osmotic pump and a mechanical pump.

In step 740, one embodiment includes a programmable controller. The controller includes means for measuring a temperature on either the first layer and the second layer. The programable controller is electrically connected to the fan 110 (Figure 1) and the pump 150 (Figure 1).

For all embodiments of the present invention, the type of fluid used in the integrated liquid-based cooling system is preferably water-based. Alternatively, the fluid within the liquid-based cooling system is based on combinations of organic solutions including, but not limited to, propylene glycol, ethanol, ethylene glycol, and isopropanol (IPA). The fluid used in the liquid-based cooling system also preferably exhibits a low freezing temperature and has anti-corrosive characteristics.

While the invention has been described with reference to numerous specific details, one of ordinary skill in the art will recognize that the invention can be embodied in other specific forms without departing from the spirit of the invention. For instance, the figures and description refer to one embodiment without microchannels, replaced with fluid fins. Another embodiment with only fluid fins. However, additional embodiments include different numbers and types of semiconductor devices in various permutations. Hence, in some embodiments only one or two semiconductor devices are present and/or require a heat exchanger for cooling, while in other embodiments more than three semiconductor devices are housed in a single chassis that requires cooling. Thus, one of ordinary skill in the art will understand that the invention is not to be limited by the foregoing illustrative details, but rather is to be defined by the appended claims.

CLAIMS

What is claimed is:

1. An integrated cooling system comprising:
   a. a first cooling structure for circulating a first cooling medium; and
   b. a second cooling structure stacked on the first structure for circulating a second cooling medium different from the first cooling medium.

2. The system of claim 1 further comprising a fluid path and a high surface area to volume ratio structure in the fluid path wherein the first medium is a fluid and the fluid path is in the first cooling structure.

3. The system of claim 2 further comprising a double-counter flow structure in the fluid path.

4. The system of claim 3 further comprising a pump connected to the fluid path thereby forming a close fluid path.

5. The system of claim 4 wherein the first cooling medium is a liquid and the second cooling medium is air.

6. An integrated cooling system comprising:
   a. a first layer having a contact area configured for coupling to a heat source, wherein the first layer has a fluid path adjacent to the contact area;
   b. a second layer coupled to the first layer and having a plurality of air fins for passing air therethrough; and
   c. a pump connected to the fluid path.

7. The system of claim 6, wherein the second layer seals to the first layer to define an inner surface of the fluid path.

8. The system of claim 7, wherein the fluid path has a contact area with the second layer which is greater than the contact area of the first layer with the heat source.

9. The system of claim 6, wherein the first layer and the second layer both have a thermal conductivity of 15 W/(mK) or greater.

10. The system of claim 6, wherein the first layer has a plurality of fluid fins for controlling the flow of a fluid within the fluid path and wherein the fluid fins are substantially evenly spaced over the area adjacent to the heat source.

11. The system of claim 6, wherein the fluid fins have a thermal conductivity of 15 W/(mK) or greater.

12. The system of claim 6, further comprising a heat source coupled to the first layer.

13. The system of claim 12, wherein the heat source comprises one or more electronic devices.

14. The system of claim 13, wherein the fluid path comprises a double-counter flow structure adjacent to at least one or more electronic devices.

15. The system of claim 6, further comprising a programmable controller.

16. The system of claim 15, further comprising a means for detecting a temperature and communicating the temperature to the programmable controller.

17. The system of claim 16, wherein the programmable controller is programmed to adjust a flow rate of the fluid in response to the temperature.

18. The system of claim 15, wherein the programmable controller is programmed to adjust an air-mover speed in response to the temperature.

19. The system of claim 13, wherein the flow path is optimized to maximize cooling of each electronic device.

20. The system of claim 13, wherein the flow path is optimized to minimize the temperature of each electronic device.

21. The system of claim 13, wherein the flow path is optimized to maximize the cooling of a selected one of the electronic devices.

22. The system of claim 6, further comprising a fluid reservoir connected to the pump.

23. The system of claim 6, wherein the second layer is configured with at least one airflow channel.

24. The system of claim 23, further comprising at least one air-mover coupled to the at least one airflow channel.

25. The system of claim 6, wherein the air fins are configured to control the airflow path and a rate of the airflow within the airflow channel.

26. The system of claim 6, wherein the air fins have a shape that is folded, pin, hexagonal shaped, airfoil shaped, ruffled, herringbone, lanced, and louvered, or any combination thereof.

27. An integrated cooling system comprising:

a. a first layer having a first side for coupling to a heat source adjacent to a contact area,
wherein the first layer has a first port and a second port coupled to a fluid path adjacent to the contact area,
the fluid path has a heat-transfer area adjacent to the second layer which is greater than the contact area,

the fluid path is configured to provide a double-counter flow structure adjacent to at least one electronic device, and
the first layer has a conductivity constant of fifteen W/(mK) or greater;

b. a plurality of fluid fins in the first layer flow path substantially evenly spaced over the contact area, and wherein the fins have a thermal conductivity constant of fifteen W/(mK) or greater;

c. a second layer sealed to the first layer, thereby defining a fluid path with an inlet and an outlet suitable for pumping the fluid, wherein the second layer is configured with at least one air channel;

d. a plurality of pin fins and folded fins coupled to a side opposing the first layer, wherein the air fins are within at least one of the air channels;

e. an air-mover coupled to at least one of the air channels;

f. a heat source comprising at least one electronic device;

g. a pump coupled to the fluid flow path, wherein the pump inputs from the flow-path port that is the greatest flow-path distance from the greatest heat source; and

h. a programmable controller,
wherein the programmable controller has a means for measuring the temperature, is programmed to increase the fluid flow as a function of an increased temperature, and is programmed to increase an airflow from the air-mover as a function of an increased temperature.

28. A method of manufacturing an integrated cooling system comprising the steps of:

a. providing a first layer having a fluid path adjacent to a contact area for coupling to a heat source;

b. providing a second layer with a plurality of air fins overlying at least a portion of the contact area; and

c. coupling a pump to the fluid path.

29. The method of claim 28, wherein an interface of the first layer and second layer has an area that is greater than the contact area.

30. The method of claim 29, wherein the first and second layer have a thermal conductivity of 15 W/(mK) or greater.

31. The method of claim 28, further comprising the step of providing a plurality of fluid fins positioned in the fluid path and adjacent to at least one heat source.

32. The method of claim 28, further comprising the step of coupling a high surface area to volume ratio structure to the flowpath.

33. The method of claim 28, further comprising coupling one or more electronic devices to the contact area.

34. The method of claim 33, wherein the fluid path further comprises a double-counter flow structure adjacent to at least one electronic device.

35. The method of claim 34, further comprising coupling a programmable pump controller to the pump and the air-mover wherein the programmable controller provides a means for measuring a temperature, controlling a pump flow rate, and controlling an air-mover airflow wherein the increase in the fluid flow rate as a function of the temperature and the air flow is increased as a function of the temperature.

36. The method of claim 35, wherein the flow path is optimized to maximize cooling of each electronic device.

37. The system of claim 35, wherein the flow path is optimized to minimize the temperature of each electronic device.

38. The system of claim 35, wherein the flow path is optimized to maximize the cooling of a selected one of the electronic devices.

39. The method of claim 35, further comprising coupling a reservoir to the pump.

1/6

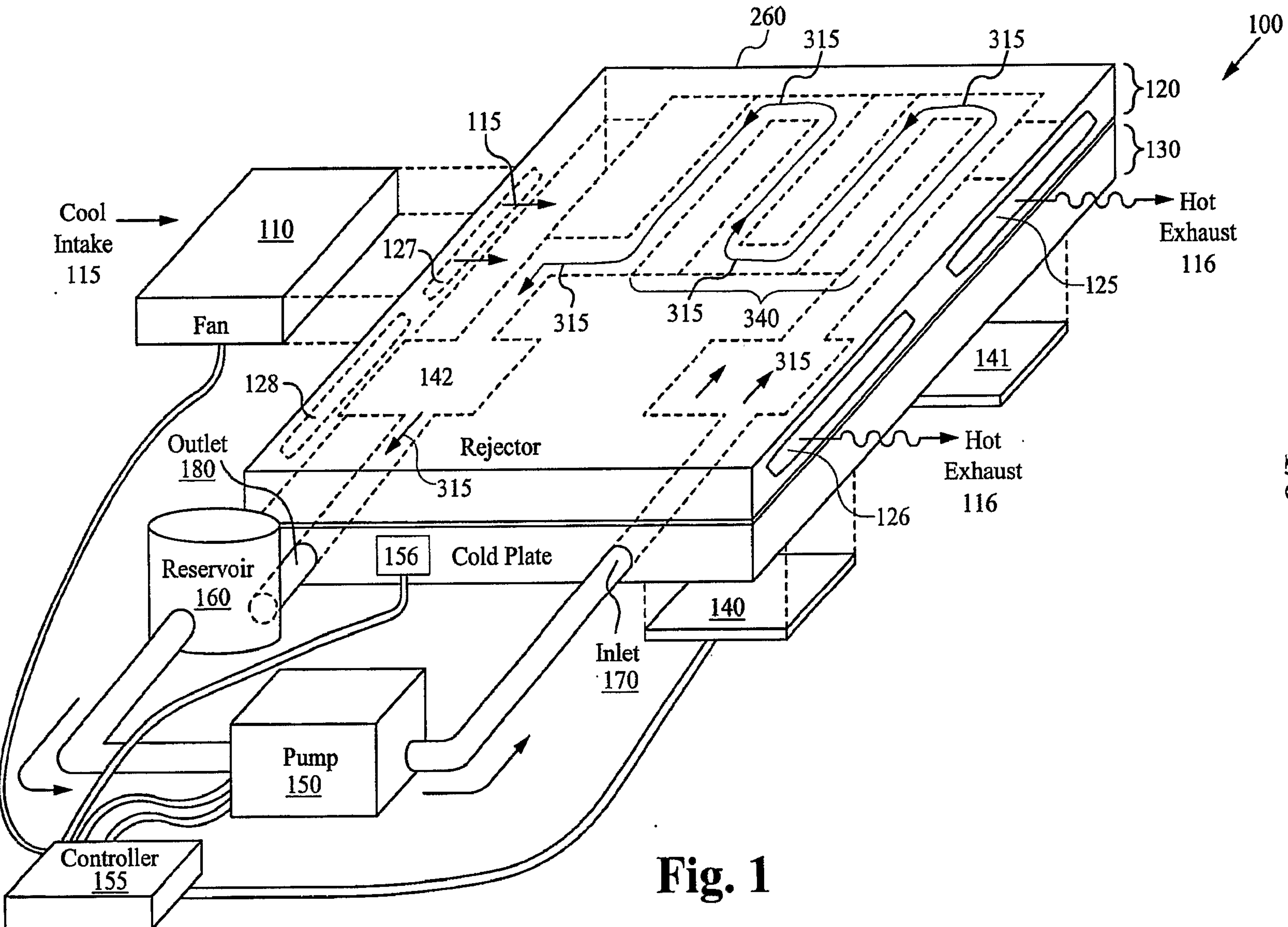


Fig. 1

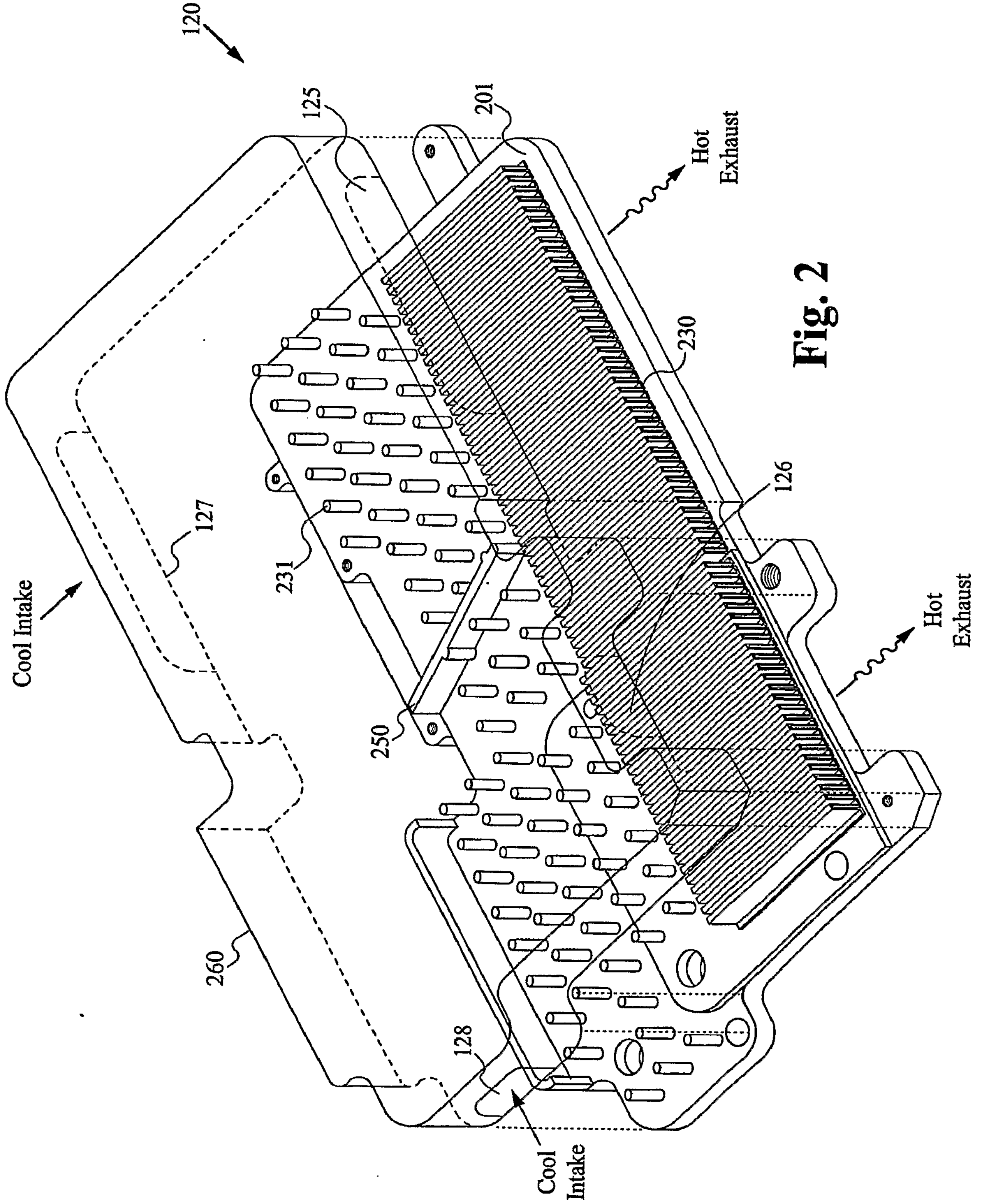


Fig. 2

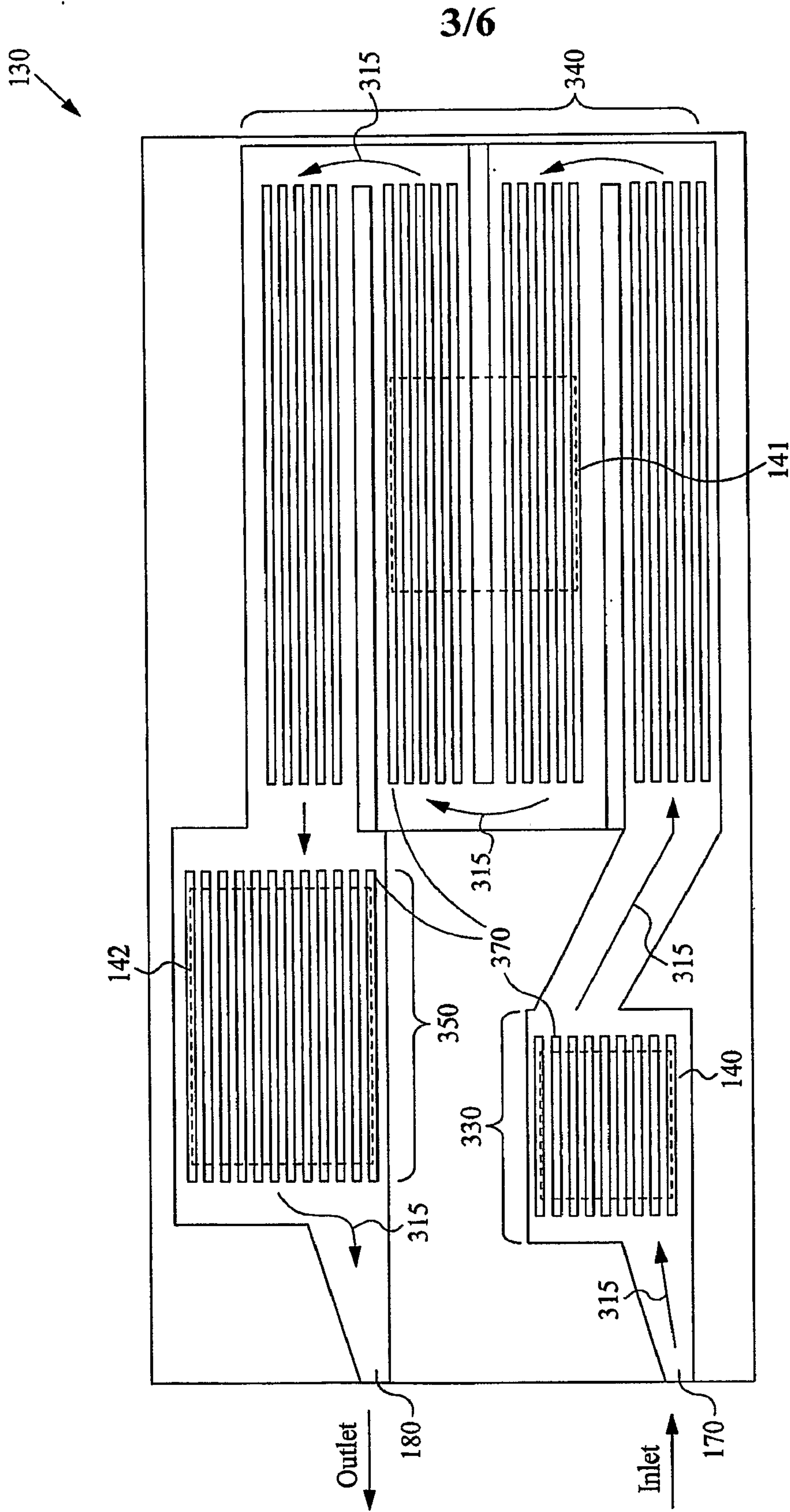


Fig. 3

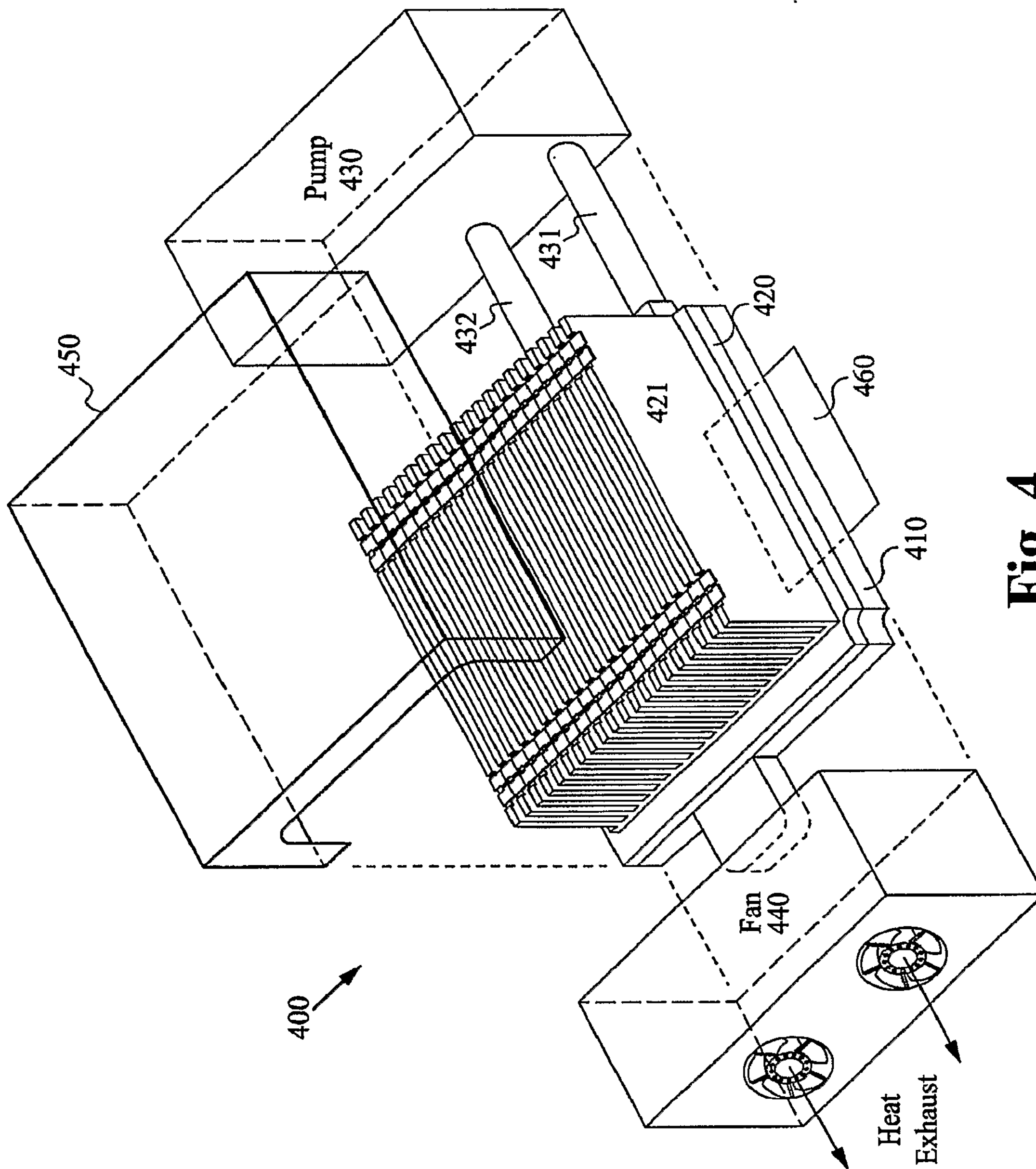


Fig. 4

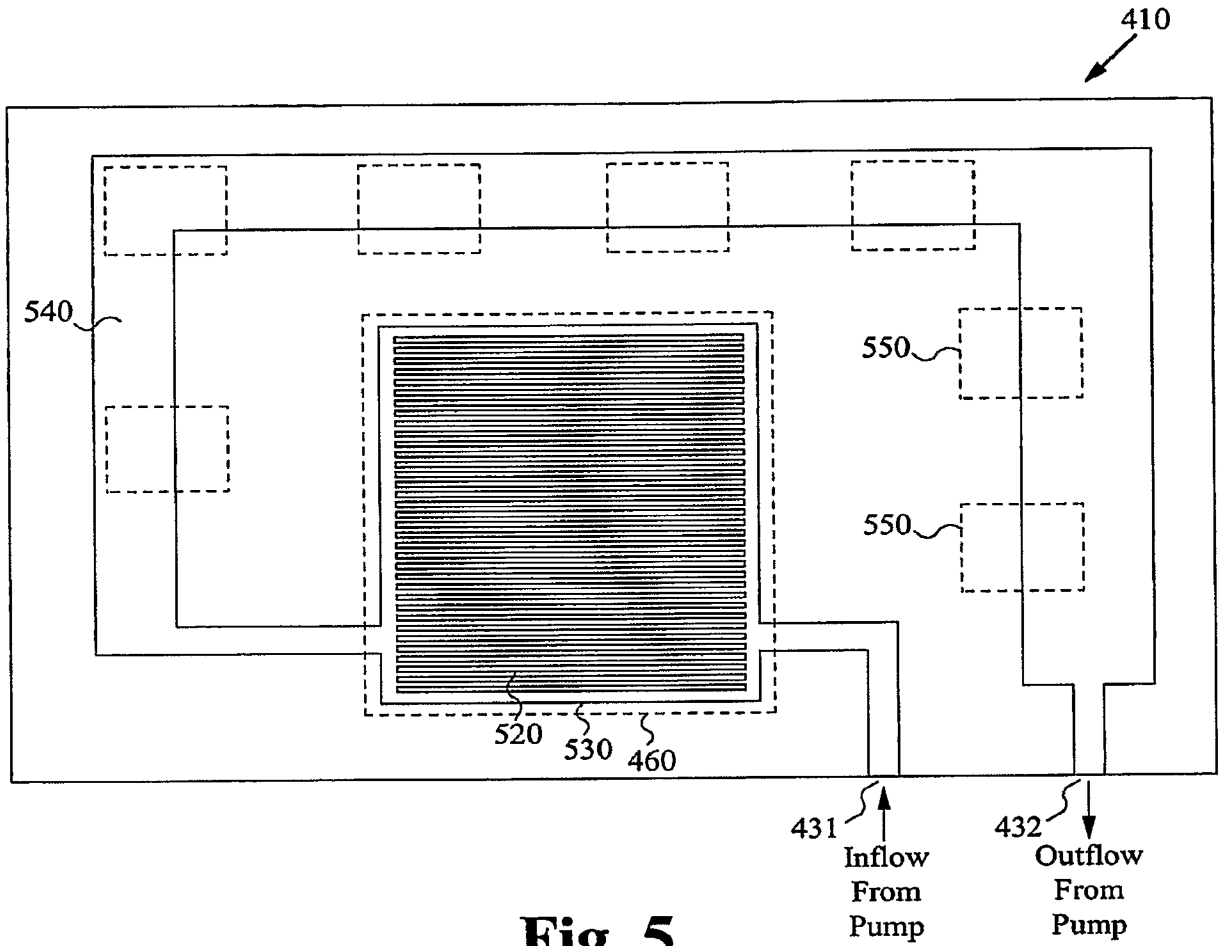


Fig. 5

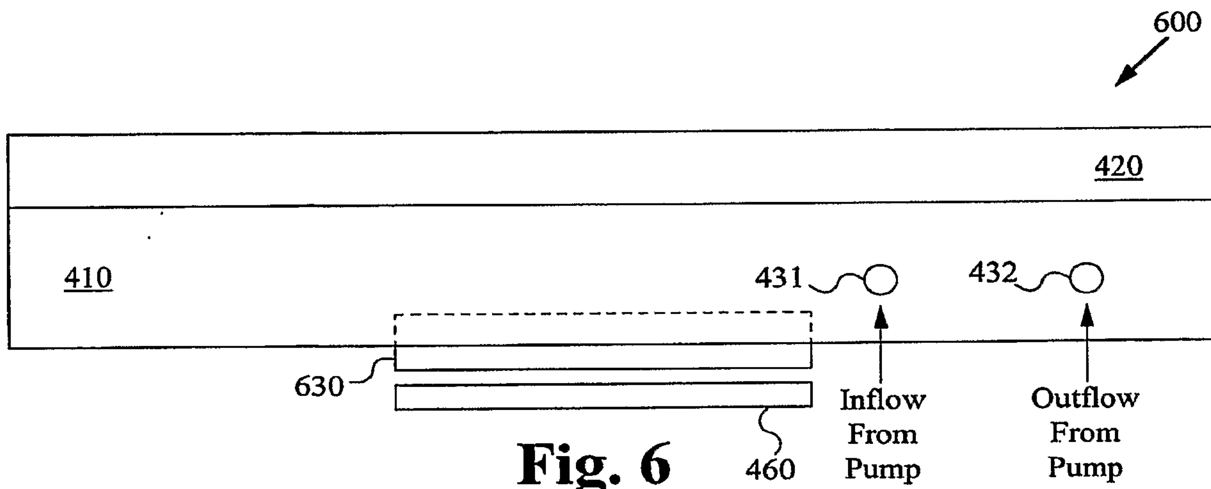


Fig. 6

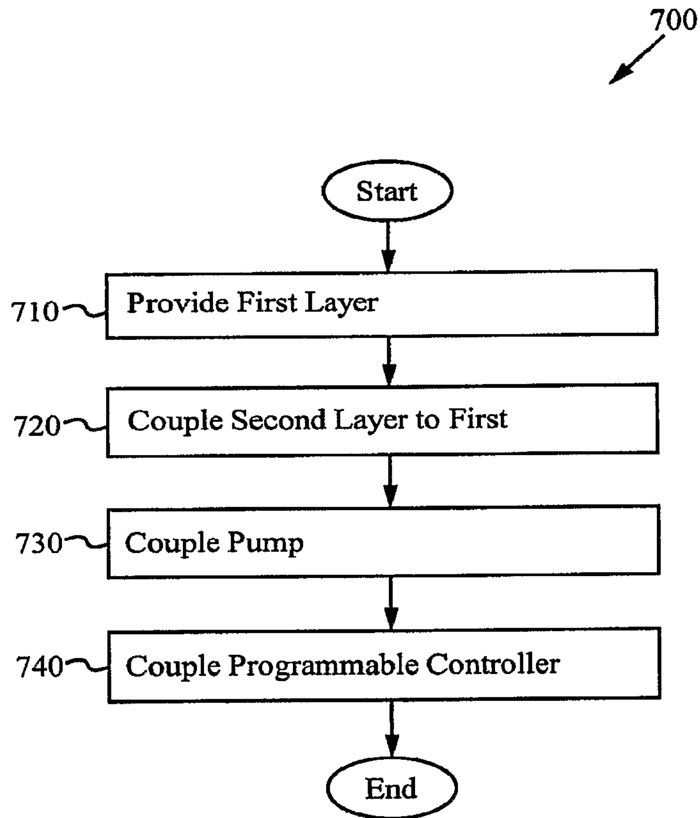


Fig. 7