



(51) International Patent Classification:
H05K 7/20 (2006.01) **H01L 23/36** (2006.01)

(21) International Application Number:
PCT/US2011/042915

(22) International Filing Date:
5 July 2011 (05.07.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
12/835,375 13 July 2010 (13.07.2010) US

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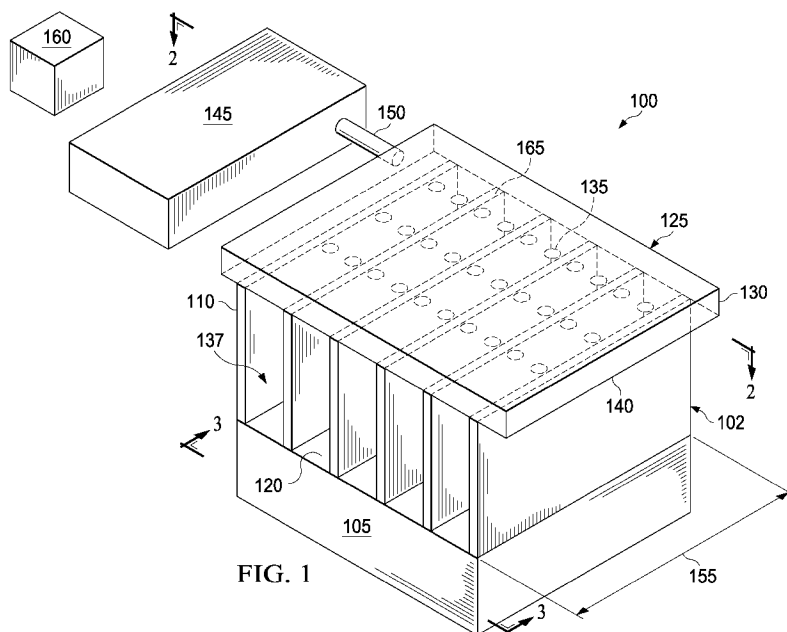
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, 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, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) Title: AIR JET ACTIVE HEAT SINK APPARATUS



(57) Abstract: An apparatus comprising a heat sink and a plenum. The heat sink includes a base and a plurality of heat exchange elements, connected to and raised above, a surface of the base. The plenum is located above the heat exchange elements. The plenum includes a housing configured to hold a positive air-pressure therein, and openings in a surface of the housing. The openings are positioned such that air exiting the plenum through the openings is directed to the heat sink.

AIR JET ACTIVE HEAT SINK APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

5 The present application is related to U.S. Patent Application No. 12/835,405 (docket no. 807929) to Salamon, entitled, "A HEAT SINK WITH STAGGERED HEAT EXCHANGE ELEMENTS" ("Salamon"), and which is commonly assigned with the present application and is incorporated herein by
10 reference in its entirety.

TECHNICAL FIELD OF THE INVENTION

 The present disclosure is directed, in general, to an active heat dissipation apparatus and methods of
15 manufacture thereof.

BACKGROUND OF THE INVENTION

 This section introduces aspects that may be helpful to facilitating a better understanding of the inventions.
20 Accordingly, the statements of this section are to be read in this light. The statements of this section are not to be understood as admissions about what is in the prior art or what is not in the prior art.

 Heat sinks are commonly used to increase the heat
25 transfer area of an electronic device to decrease the thermal resistance between the device and cooling medium, e.g., air. There is a growing trend, however, for

electronic devices to dissipate so much power that traditional heat sink designs are inadequate to sufficiently cool the device. Improved heat transfer efficiency from electronic devices would help extend the
5 lifetime of such devices.

SUMMARY OF THE INVENTION

One embodiment is an apparatus comprising a heat sink and a plenum. The heat sink includes a base and a
10 plurality of heat exchange elements, connected to and raised above, a surface of the base. The plenum is located above the heat exchange elements. The plenum includes a housing configured to hold a positive air-pressure therein, and openings in a surface of the
15 housing. The opening are positioned such that air exiting the plenum through the openings is directed to the heat sink.

Another embodiment is a system that comprises the above-described apparatus a structure configured to
20 produce heat, wherein the heat sink is thermally coupled to the structure.

Another embodiment is a method of manufacturing an apparatus. The method comprises providing the above-described heat sink and plenum. The method also
25 comprises positioning the plenum above the heat exchange elements, such that air exiting the plenum through the

openings is directed to the heat sink.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the disclosure are best
5 understood from the following detailed description, when
read with the accompanying FIGURES. Some features in the
figures may be described as "vertical" or "horizontal"
for convenience in referring to those features. Such
descriptions do not limit the orientation of such
10 features with respect to the natural horizon or gravity.
Various features may not be drawn to scale and may be
arbitrarily increased or reduced in size for clarity of
discussion. Reference is now made to the following
descriptions taken in conjunction with the accompanying
15 drawings, in which:

FIG. 1 presents a perspective view of an example
embodiment of the apparatus of the disclosure;

FIG. 2A presents a semitransparent plan view of the
apparatus along view line 2-2 shown in FIG. 1;

20 FIGS. 2B-2D present plan views of an alternative
embodiments of the apparatus of the disclosure, analogous
to the view presented in FIG. 2A;

FIG. 3A presents a sectional view of the apparatus
along view line 3-3 shown in FIG. 1; and

25 FIGS. 3B-3C present sectional views of an
alternative embodiments of the apparatus of the

disclosure, analogous to the view presented in FIG. 3A.

FIG. 4 presents a flow diagram of selected steps in an example method of manufacturing an apparatus of the disclosure, e.g., such as presented in FIGS. 1A-1B.

5 DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly
10 described or shown herein, embody the principles of the invention and are included within its scope. Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention
15 and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as
20 well as specific examples thereof, are intended to encompass equivalents thereof. Additionally, the term, "or," as used herein, refers to a non-exclusive or, unless otherwise indicated. Also, the various embodiments described herein are not necessarily mutually
25 exclusive, as some embodiments can be combined with one

or more other embodiments to form new embodiments.

Embodiments of the disclosure benefit from the recognition that boundary layers develop along the surfaces of a heat sink. Consequently, efficient heat
5 transfer from the heat sink to the surrounding air can be deterred because the primary means of heat transfer from the slow air flowing in the boundary layer at the surface and the faster moving cold air in the space farther away from the surface is thermal diffusion.

10 The embodiments described herein improve heat transfer efficiency by increasing the turbulence (or mixing) of air located in the channels between the heat exchange elements of a heat sink. For instance, increased air turbulence helps mix the hotter air next to
15 the heat exchange elements with the cooler air in the middle of channels, and thereby improve heat transfer. The increase in air turbulence (or mixing), achieved by forcing jets of air into the heat sink as described herein, are believed some cases to be capable of
20 improving the cooling factor of a heat sink by up to three times as compared to an analogous heat sink design but without the jets of air.

One embodiment of the disclosure is an apparatus. FIG. 1 presents a perspective view of an example
25 embodiment of the apparatus of the disclosure. FIG. 2A presents a semitransparent plan view of the apparatus

along view line 2-2 shown in FIG. 1. FIGs. 2B-2D present plan views of an alternative embodiments of the apparatus of the disclosure, analogous to the view presented in FIG. 2A. FIG. 3A presents a sectional view of the apparatus along view line 3-3 shown in FIG. 1. FIGs. 3B-3C present sectional views of an alternative embodiments of the apparatus of the disclosure, analogous to the view presented in FIG. 3A.

Turning to FIG. 1, the apparatus 100 comprises a heat sink 102. The heat sink 102 includes a base 105 and a plurality of heat exchange elements 110, connected to and raised above, a surface 120 of the base 105. The apparatus 100 comprises a plenum 125 located above the heat exchange elements 110. The plenum 125 includes a housing 130 configured to hold a positive air-pressure therein. Openings 135 are in a surface 140 of the housing 130. The openings 135 are positioned such that air exiting the plenum 125 through the openings 135 is directed to the heat sink 102. In various embodiments, for instance, the air flowing through the openings 135 can be directed to the elements 110 or to channels 137 located between the elements 110.

The term, plenum, as used herein refers to any gas delivery system capable of delivering air (e.g., any gas) to the openings. The plenum could include chambers, hoses and tubes that supply the air to the heat sink, or,

the there could be multiple plenums, e.g., configured as hoses and tubes.

The term, positive air-pressure, as used herein means that, when the apparatus 100 is in operation, the
5 atmospheric pressure inside the housing 130, at least for a period of time, is greater than the pressure outside of the housing 130. For instance, when air is provided to the plenum via a net-zero mass flux devices, such as
further described below, the plenum could have a
10 positive, negative or neutral pressure modes at different periods of time during the apparatus's operation.

In some embodiments, air flow, e.g., from a remote fan, or other means of circulating air, can transfer air into the plenum 125 and through the openings 135. In
15 some preferred embodiments, however, the apparatus 100 further includes one or more an air flow devices 145 coupled to the plenum (e.g., through one or more conduits 150) so as to provide the positive air-pressure to the housing 130.

20 Some embodiments of the air flow device 145 can be net-positive mass flux airflow devices. That is, there is a net positive mass flux of air out of the plenum's housing 130 when the air flow device 145 is operating.

Non-limiting example embodiments of such net-
25 positive mass flux devices 145 can include air-driver mechanisms such as pressurized gas cylinders, mechanical

compressors, diaphragm air pumps, (e.g., eccentric, vibrating, linear, rotating), piston air pumps or vane air pumps. For instance, in some cases the airflow device 145 can include one or more air compressor flow
5 pumps or compressed gas cylinders.

For instance, as illustrated in FIG, 2A the air flow device 145 can include a piston 210 that actuates a membrane 215 in a cylinder 220. The piston 210 can be actuated electro-magnetically or mechanically, e.g., by
10 an air-driver mechanism of the device (not shown) when the device 145 is operated.

Other embodiments of the air flow devices 145 can be net-zero mass flux airflow devices. That is, there is a net zero mass flux of air out of the plenum's housing 130
15 when the air flow device 145 is operating.

Non-limiting example embodiments of such net-zero mass flux devices 145 can include a piezo-electric element coupled to a driver and a membrane coupled to the driver, such that when the membrane is oscillated, air is
20 transferred into the housing 150. In other embodiments, however, piezo-electric elements can be used in positive-mass flux air-flow devices 145.

Some embodiments of the air flow device 145 can be configured to deliver an oscillating flow of air to the
25 plenum 125.

For instance, in some cases, the airflow device 145,

such as depicted in FIG. 2A, can be repeatedly turned off and on to deliver the oscillating flow of air to the housing 130 of the plenum 125.

For instance, in some cases, the airflow device 145
5 such as depicted in FIG. 2B, the plenum 125 further includes one or more flow valves 225 situated over one or more of the openings 135. For instance, in some applications, such as when the heat sink 102 is used to cool a micro-electronic device, the flow valves 225 can
10 be a MEMS device. The embodiment depicted in FIG. 2B depicts an individual valve 225 for each one of the openings 135. In other embodiments, however, a valve could be configured and situated to cover and uncover openings 135 to modulate air flow from more than one
15 opening 135 (e.g., a row or column of openings 135).

The valves 225 can be configured to cover or uncover the openings 135, when actuated, so as to provide a selected flow of air out of the openings 135. In some cases, the selected flow of air can be an oscillatory
20 flow of air out of the openings 135. In other cases, the selected flow can be a sequential operation of the valves 220 to drive air flow in a selected direction through the heat sink 102 (e.g., a direction parallel to the long dimension 155 of elements 110 depicted in FIG. 1). In
25 such cases, the airflow device 145 may simply deliver a constant flow of air to said housing to maintain a

positive air-pressure in the housing 130 while the valves 225 are repeatedly actuated open and closed. In other cases, the selected flow can be a sequential operation of the valves 220 in a selected direction through the heat sink 102 (e.g., a direction parallel to the long dimension 155 of elements 110 depicted in FIG. 1) to ensure effective and thorough mixing of air that is traversing the heat sink with the aid of an external source, such as a fan or air blower. In still other cases, however, the airflow device 145 can also be turned on and off while the valves 225 are actuated, e.g., to produce more complex patterns of air flow through the openings 135.

In some embodiments, as illustrated in FIG. 2C, to facilitate the transfer of air through selected openings 135, the housing 130 can be divided into two or more chambers 230, 232, 234.

As further illustrated in FIG. 2C, the apparatus 100 can include air-flow devices 145 that are individually coupled to each one of the chambers (e.g., one of chambers 230, 232 or 234) so as to selectively provide the positive air-pressure to the chambers 230, 232, 234. Additionally there can be conduits 150 that direct air-flow from one of the air-flow devices 145 to one of the chambers 230, 232, 234 of the housing 130, or, in some embodiments to separate chambers (e.g., hoses or tubes)

that are considered as being individually housed.

When one of the chambers 230 is provided with the positive air-pressure, air is selectively directed through one or more of the openings 135 that are within the one chamber 230. In some instances, by providing the positive air-pressure to the chambers in sequence (e.g., chamber 230, chamber 232 and then chamber 234) air flow through the openings 135 can be driven in a selected direction through the heat sink 102. In some instances, by providing the positive air-pressure to the chambers in sequence (e.g., chamber 230, chamber 232 and then chamber 234) air flow through the openings 135 can be driven so as to ensure effective and thorough mixing of air that is traversing the heat sink in corporation with an external air-circulating source (e.g., a fan or air blower). In some cases, the flow of air to the individual chambers 230, 232, 234 can be oscillated (e.g., by turning the air-flow devices 145 on and off) to provide an oscillatory air flow to one or more of the chambers 230, 232, 234 and through the openings 135.

In some embodiments, to facilitate the transfer of air through selected openings 135 of the housing 130, the air flow through a multi-chambered housing 130 can be controlled using flow valves coupled to a plurality of conduits 150. For instance, as illustrated in FIG. 2D, flow valves 240 (e.g., solenoid valves) can be coupled to

one or more of the conduits 150 (e.g., fed from a central conduit 245) that are each coupled to one of the chambers 230, 232 234. The valves 240 can be configured to open and close the conduits 150 so as to provide a selected
5 flow of air to one or more of the chambers 230, 232, 234. Analogous to that discussed in the context of FIGs. 2B and 2C, the valves 240 can be opened and closed repeatedly to produce an oscillatory airflow through the openings 135, or, sequentially to direct air through the
10 openings 135 in the chambers 230, 232, 234 in a particular order, to facilitate directing airflow through the heat sink 102 in a particular direction.

Embodiments of the apparatus 100 can further include a control unit 160 (FIG. 1) that is configured to control
15 the one or more air flow devices 145 coupled to the plenum 125, actuate valves 225 situated over the openings 135 (FIG. 2B), or actuate valves 240 coupled to the conduits 150 (FIG. 2D), to deliver a desired pattern of air through the openings 135.

20 In some cases, the plenum 125 can rest directly on tops 165 of the heat exchange elements 110. In other cases, however, such as illustrated in FIG. 3A, the plenum 125 can be separated from the tops 165 of the elements 110 by a gap 310. For instance, in some
25 embodiments, the gap 310 between the housing 130 and the tops 165 is up to about 3 mm. Minimizing the gap 310 is

desirable to place the openings 135 close to the regions of the heat sink 102 where air turbulence is desired. For instance, if the openings 135 are located too far away from the elements 110, then the momentum of the air will be dissipated or diffused before it reaches the heat sink 102. Additionally, a large gap 310 can undesirably increase the vertical profile of the apparatus 100. Also, too a large gap 310 may allow air to bypass the heat exchange elements 110, thereby reducing the efficiency of heat transfer.

As further illustrated in FIG. 3A, some embodiments of the apparatus 100 includes one or more air-flow diverters to increase air turbulence element's 110 surfaces so as to increase heat transfer. In some cases, the diverter 315 can be structures on sides 320 of one or more heat exchange elements 110. For instance, some embodiments of the diverters 315 can include vertical slots located directly below one of the openings 135, e.g., to provide the minimum impedance to air from the opening 135 to the element 110 and enhance air turbulence near the side 320. In some cases, the diverter 325 can be a structure on the surface 140 of the housing 130 in a vicinity of one or more of the openings 135. For instance, some embodiments of such diverters 325 can include a nozzle jet structure located around the opening 135 to, e.g., direct airflow from the opening 135 to a

side 320 of the element 110 and thereby increase air mixing. In still other embodiments, the diverters 315, 325 can be configured to direct air away from the sides 320 and into the center of the channels 137 between the elements 110, e.g., to increase air mixing via longer-range thermal mixing mechanisms. The diverters could also be used to drive air laterally through the heat sink 102. Additional examples of suitable air-flow diverter designs are presented in the above-incorporated Patent Application No. 12/165,193.

The position and size of the openings 135 can be cooperatively adjusted to facilitate increased air turbulence. In some embodiments, for example, the size 330 (e.g., a diameter for circular openings) of the openings 135 can range from one-tenth of a thickness 335 of the heat exchange elements 110 to one-half of a width 340 of the channel 137 between the elements 110.

The position of the openings 135 relative to the elements 110 can depend on the element's thickness 335, the opening's size 330 and the force of air flow through the openings 135.

For instance, as illustrated in FIG. 3A, when thickness 335 of the elements 110 is relatively large compared to the size 330 openings 135, it can be advantageous for the openings 135 to be substantially aligned with one side 320 of one of the heat exchange

elements 110. In some cases, the openings 135 can direct air to or along the sides 320 of the heat exchange elements 110. E.g., the openings 135 can be placed directly over one side 320 of one of the heat exchange
5 elements 110, or, the opening 135 can be offset from the heat exchange element 110, but have a shape that is substantially oriented, e.g., angled, so as to direct air to the side of the heat exchange elements 110. Such an aligned opening 135 can help increase the air turbulence
10 near one of the element's sides 320.

For instance, as illustrated in FIG. 3B, such as when the thickness 335 of the elements 110 is relatively small compared to the size 330 opening 135, it can be advantageous for the openings 135 to be centered directly
15 over one of the heat exchange elements 110. Such a centered opening 135 can maximum air turbulence near both of the element's sides 320.

For instance, as illustrated in FIG. 3C, when there is a strong force of air-flow through the openings 135,
20 it can be advantageous to locate the openings 135 substantially over the center of the channels 137. For instance, air from the openings 135 can spread out laterally once the air hits the surface 120 of the base 105, and then impinges on the sides 320 of the elements
25 110 thereby increasing air turbulence next to the sides 320.

For many of the example embodiments presented herein, such as in FIGs. 1-3C, the heat exchange elements 110 are depicted as being rectangular-shaped planar fins. In some embodiments such a heat exchange elements 110 design can be desirable, e.g., because such structures can be relatively simple and inexpensive to manufacture. In other embodiment, however, it may be advantageous for the heat exchange elements 110 to have other shapes. Examples of other heat exchange element designs are presented in Patent Application Nos. 12/165,063; 12/165,193; and 12/165,225, all of which are incorporated by reference herein in their entirety. Non-limiting example designs include: bent or curved fins, fins that include flow diverters, monolithic structurally complex designs, or active heat sink designs.

One skilled in the art would be familiar with the appropriate sizes of the base 105 and the elements 110 and width 340 of spacing between the elements 110 (FIG. 3A), to use for particular cooling applications. Example of such sizes and spacings are presented in the above-incorporated Salamon application.

Some embodiments of the plenum 125 include a low profile housing 130 so as not to increase the vertical profile of the apparatus 100. For instance in some embodiments the housing 130 has a height 350 that is less than 10 percent of a height 355 of the heat sink 102

(FIG. 3A). For some microelectronic applications for example, the thickness 350 is up to about 5 mm. In some embodiments, the lateral dimensions of the housing 130 are substantially the same as the lateral dimensions as
5 the heat sink 102.

As further illustrated in FIG. 3A, another embodiment of the disclosure is a system 360. The system 360 comprises an apparatus 100, such as any of the embodiments of the apparatus 100 discussed in the context
10 of FIGs. 1-3C. For instance, the apparatus 100 comprises the heat sink 102, the plenum 120 and in some cases, the air-flow device 145 coupled to the plenum 120 so as to provide the positive air-pressure to the housing 130. The system 360 also comprises a structure 370 configured
15 to produce heat. The heat sink 102 of the apparatus 100 is coupled to the structure 370. One skilled in the art would be familiar with means to couple a heat sink to a structure so as to achieve efficient heat transfer.

For instance, in some embodiments the apparatus is
20 an electrical device, and the heat generating structure 370 includes an integrated circuit, or, in other cases, a power supply of the electrical device. In some embodiments the system 360 is a heat exchanger and the heat generating structure 370 is a pipe that carries a
25 heated fluid therein (e.g., water, air, refrigerant). For instance, a plurality of heat sinks 102 can be

thermally coupled to a heat pipe structure 370 that is configured to circulate fluid from another device that generates heat, e.g., a motor or electrical power supply (not shown). In other embodiments, however, heat pipes
5 could be incorporated within the base 105. Although the base 105 and structure 370 are depicted as having a planar interface 375, in other cases, the interface 375 could be non-planar (e.g., such as when the structure 370 is the wall of a cylindrical pipe).

10 Another embodiment of the disclosure is a method of manufacturing an apparatus. FIG. 4 presents a flow diagram of selected steps in an example method 400 of manufacturing an apparatus 100 of the disclosure, such as any of the embodiments discussed in the context of FIGS.
15 1-3C.

With continuing reference to FIGS. 1-3C throughout, the method 400 comprises a step 410 of providing a heat sink 102. The heat sink includes a base 105 and a plurality of heat exchange elements 110, connected to and
20 raised above, a surface 120 of base 105. The heat sink could be a commercially available sink or any of the heat sink designs disclosed in any of above-incorporated patent applications.

The method 400 also comprises a step 420 of
25 providing a plenum 125, the plenum 125 including a housing 130 configured to hold a positive air-pressure

therein and, openings 135 in a surface 140 of the housing 130. Providing the plenum 125 in step 420, in some cases, can include a step 430 of forming the openings 135 in a first metal sheet (e.g., via stamping or drilling) and a step 435 of forming the housing 130 by coupling walls to the sheet and then coupling a second sheet to the walls to form an enclosed cavity in the housing 130.

The method also comprises a step 440 of positioning the plenum 125 above the heat exchange elements 110, such that air exiting the plenum 125 through the openings 110 is directed to the heat sink 102.

Some embodiments of the method further include a step 450 of coupling an air-flow device 145 to the plenum 125 so as to provide the positive air-pressure to the housing 130. For instance conduits 150 can be attached from the output of the air-flow device 145 to the housing 130.

Although the embodiments have been described in detail, those of ordinary skill in the art should understand that they could make various changes, substitutions and alterations herein without departing from the scope of the disclosure.

WHAT IS CLAIMED IS:

1. An apparatus, comprising:
a heat sink including:
5 a base, and
a plurality of heat exchange elements,
connected to and raised above, a surface of said base;
and
a plenum located above said heat exchange elements,
10 wherein said plenum includes:
a housing configured to hold a positive air-
pressure therein, and
openings in a surface of said housing, said
opening positioned such that air exiting said plenum
15 through said openings is directed to said heat sink.
2. The apparatus of Claim 1, further including one
or more air flow devices coupled to said plenum so as
to provide said positive air-pressure to said housing.
3. The apparatus of Claim 2, wherein said airflow
20 device is a net-positive mass flux airflow device.
4. The apparatus of Claim 2, wherein said airflow
device is a net-zero mass flux airflow device.
5. The apparatus of Claim 4, wherein said net-zero
mass flux airflow device includes a piezo-electric
25 element and a membrane coupled to a driver, such that
when said membrane is oscillated, air is transferred into

said housing.

6. The apparatus of Claim 1, wherein said housing is divided into two or more chambers such that, when one of said chambers is provided with said positive air-
5 pressure, air is selectively directed through one or more of said openings that are within said one chamber.

7. The apparatus of Claim 6, further including air-flow devices that are individually coupled to each one of said chambers so as to selectively provide said
10 positive air-pressure to said chambers.

8. A system, comprising:

an apparatus, including:

a heat sink including:

a base, and

15 a plurality of heat exchange elements,
connected to and raised above, a surface of said base;
and

a plenum located above said heat exchange
elements, wherein said plenum includes:

20 a housing configured to hold a positive
air-pressure therein, and

openings in a surface of said housing,
said opening positioned such that air exiting said plenum
through said openings is directed to said heat sink; and

25 a structure configured to produce heat, wherein said
heat sink is thermally coupled to said structure.

9. The system of Claim 8, further including an air flow device coupled to said plenum so as to provide said positive air-pressure to said housing.

10. A method of manufacturing an apparatus,
5 comprising:

providing a heat sink, said heat sink including:

a base, and

a plurality of heat exchange elements,
connected to and raised above, a surface of said base;

10 and

providing a plenum, said plenum including:

a housing configured to hold a positive air-
pressure therein, and

openings in a surface of said housing; and

15 positioning said plenum above said heat exchange
elements, such that air exiting said plenum through said
openings is directed to said heat sink.

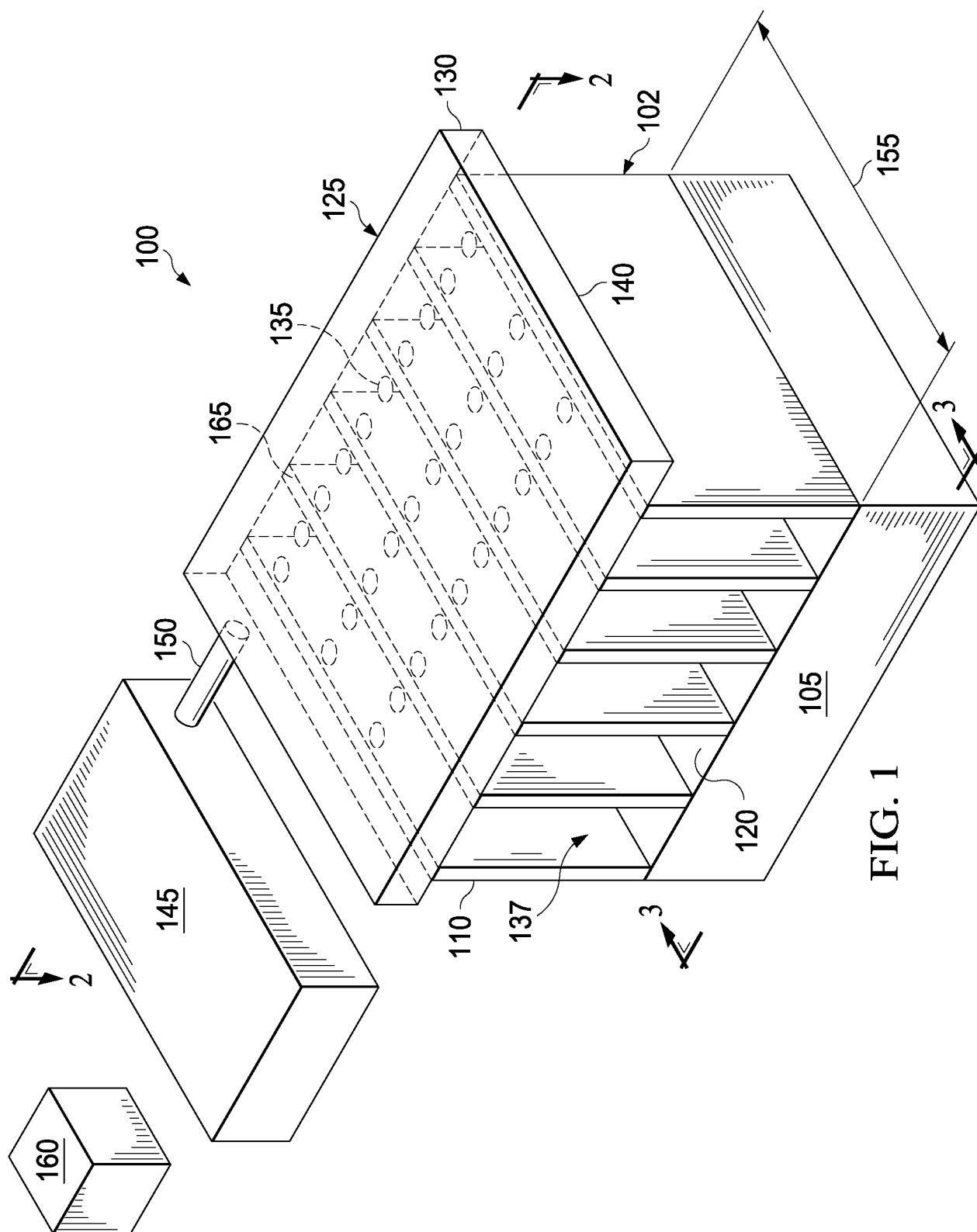


FIG. 1

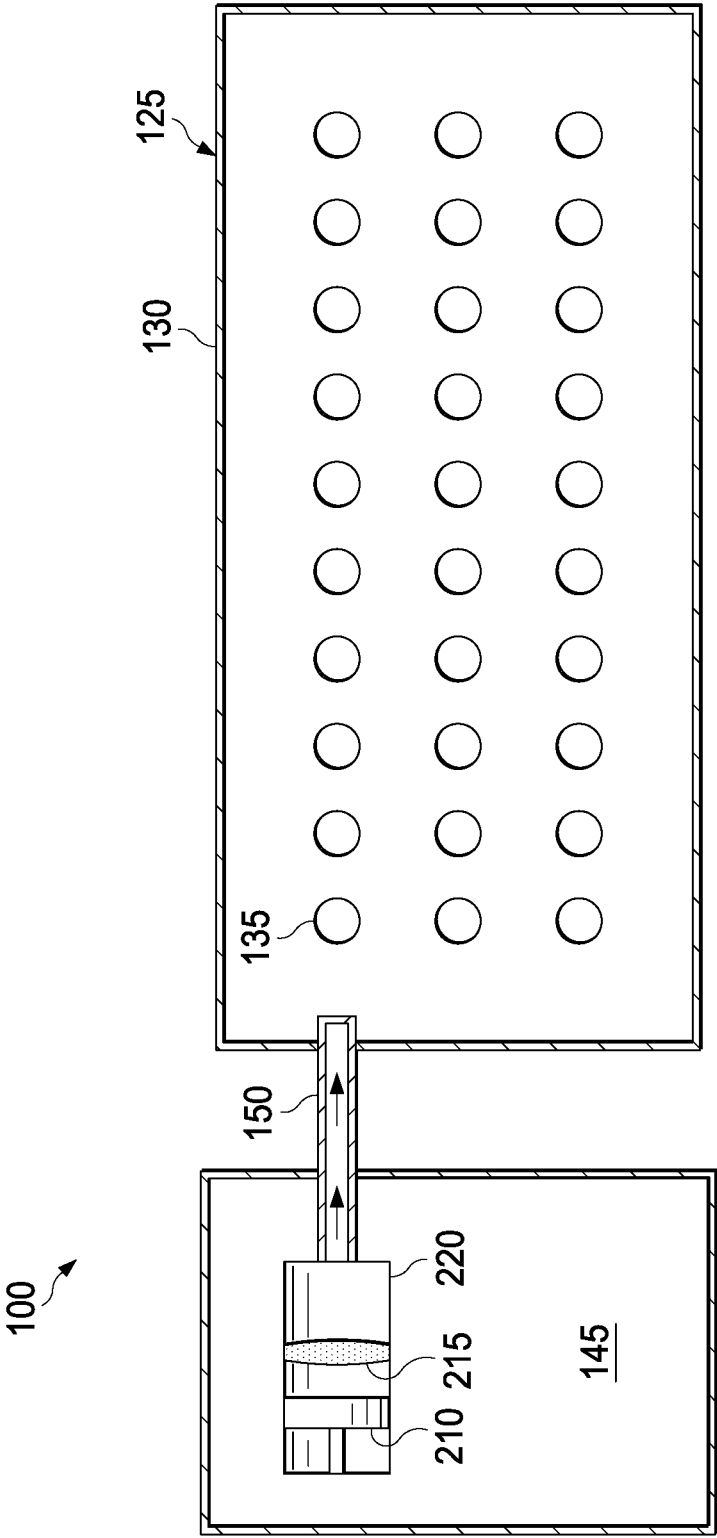


FIG. 2A

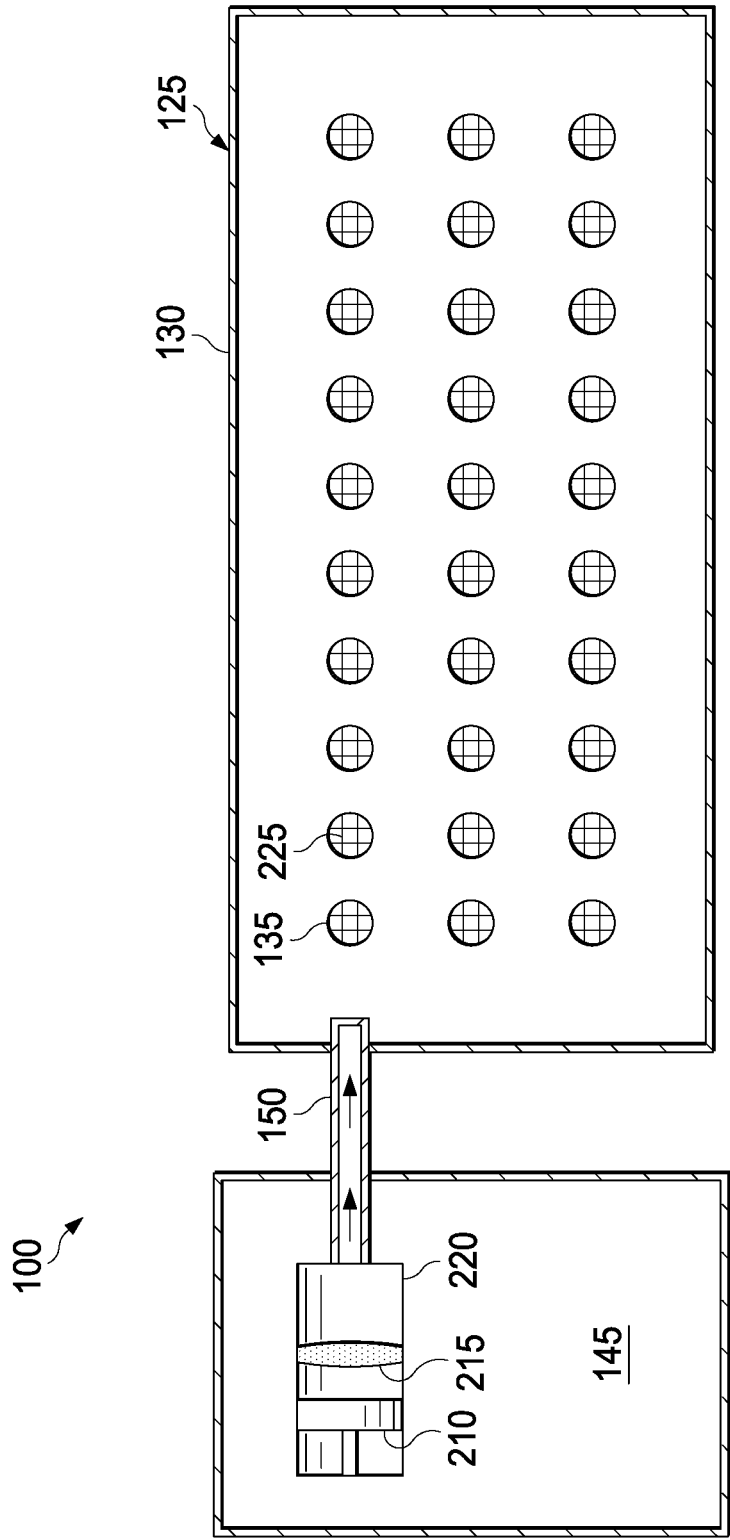


FIG. 2B

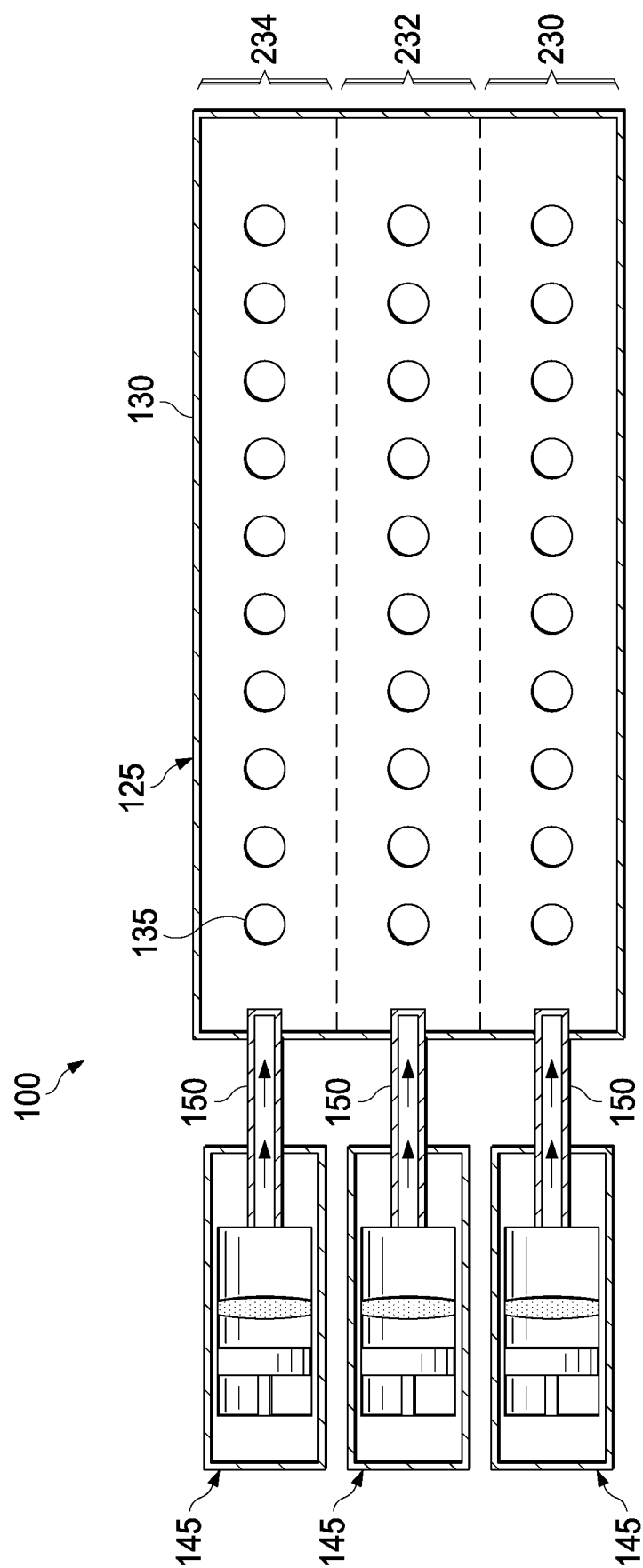


FIG. 2C

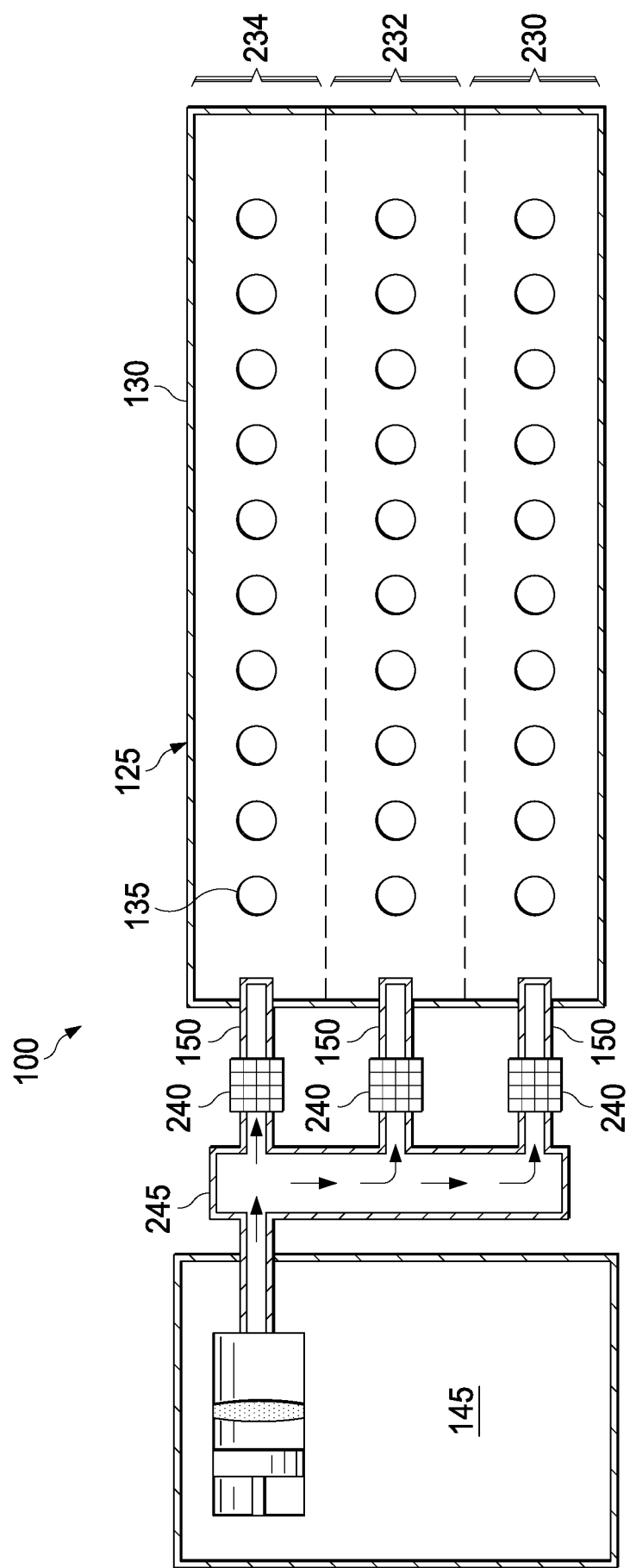


FIG. 2D

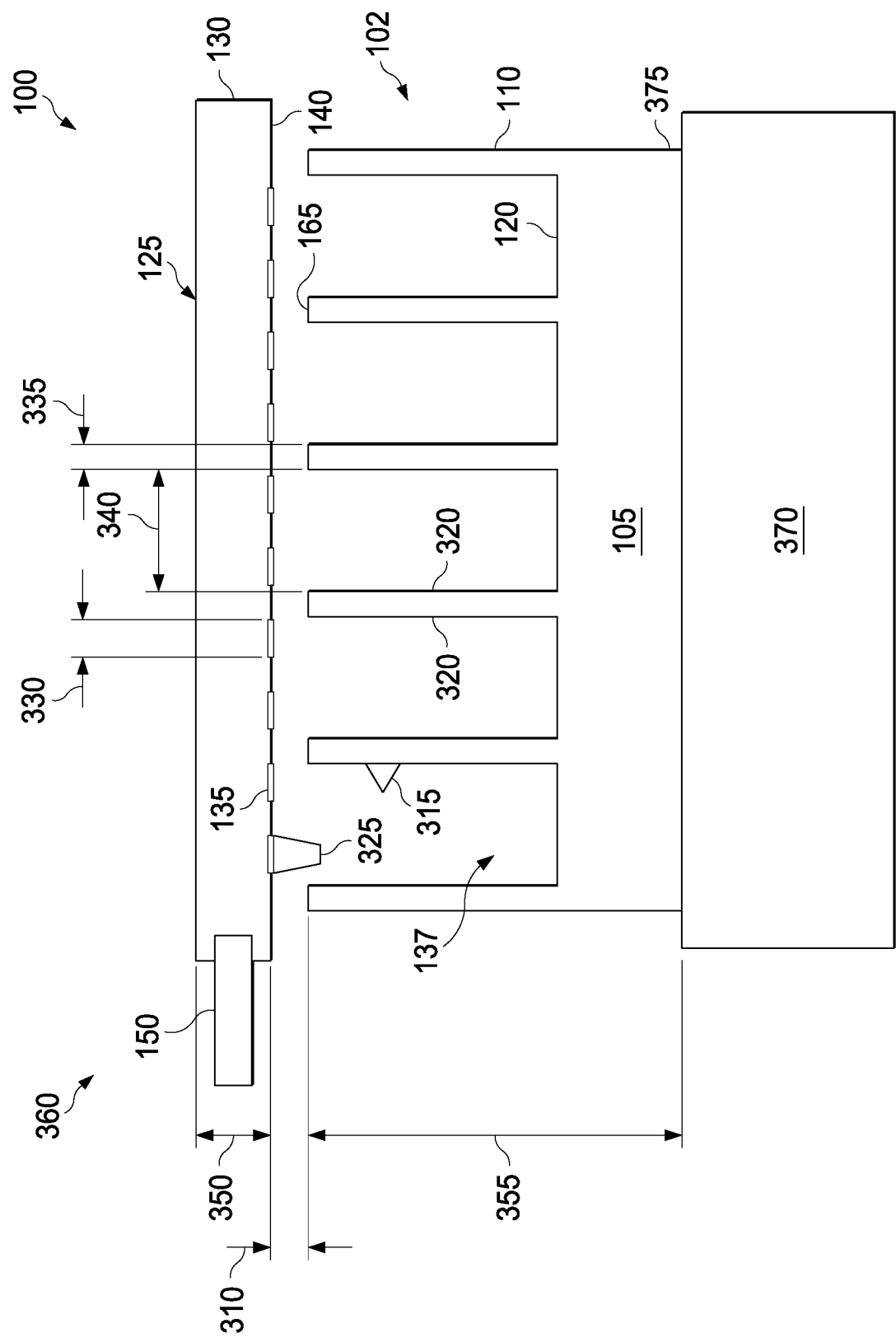


FIG. 3A

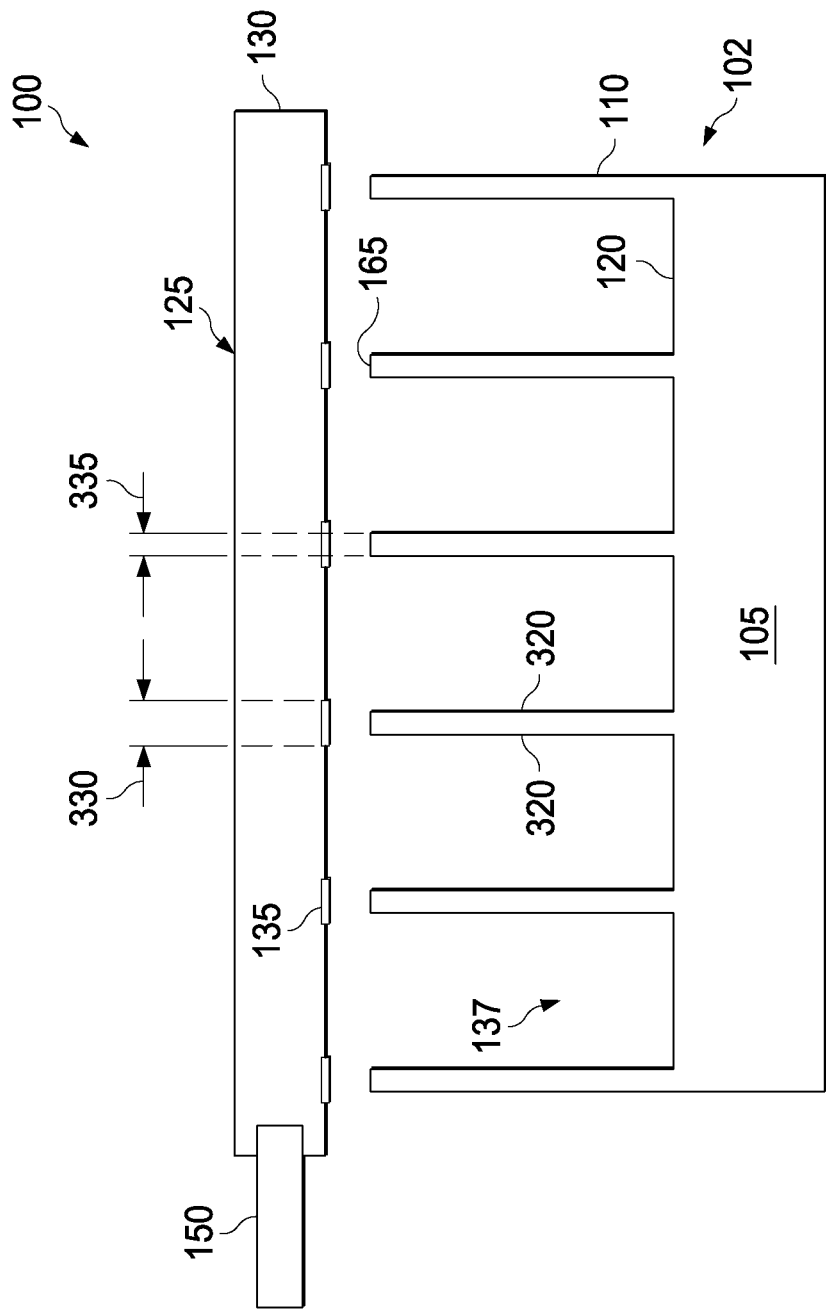


FIG. 3B

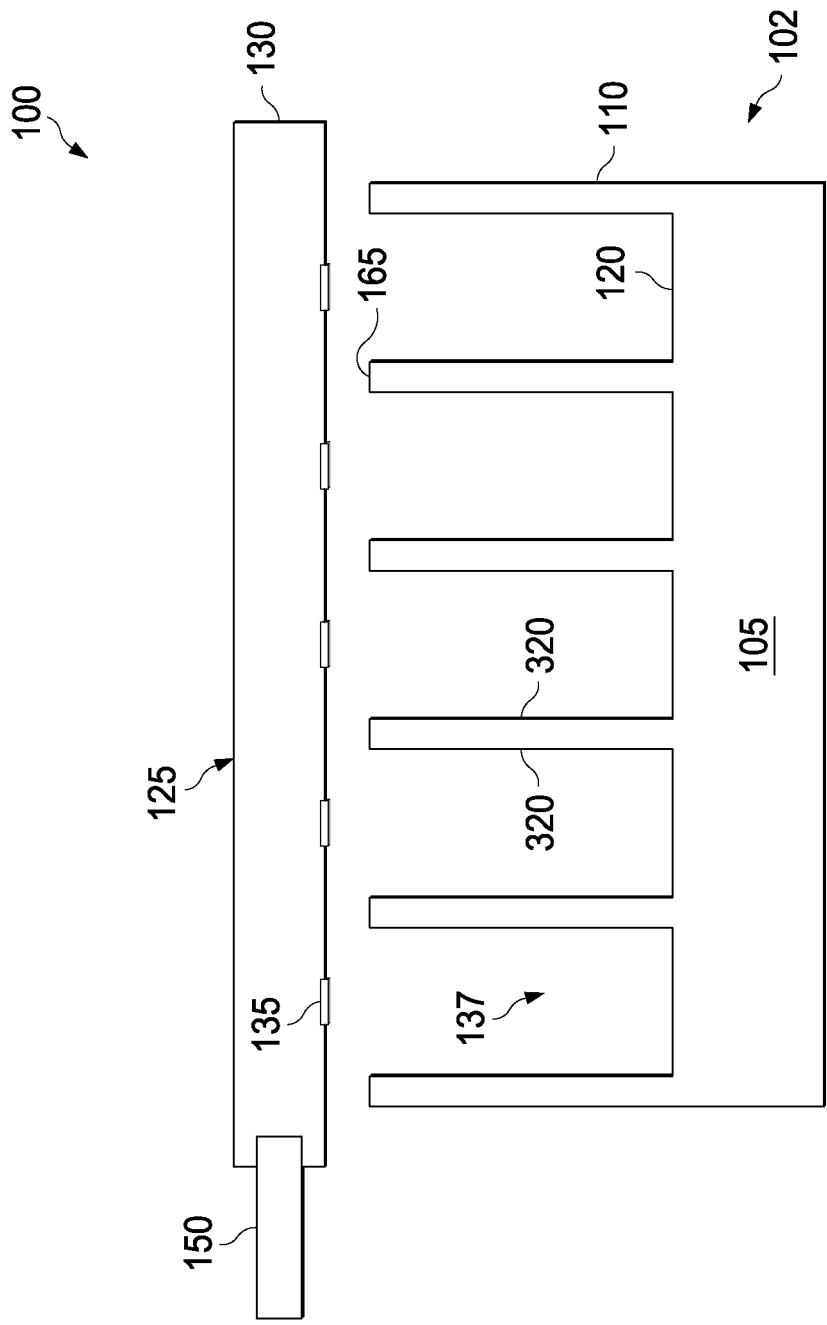


FIG. 3C

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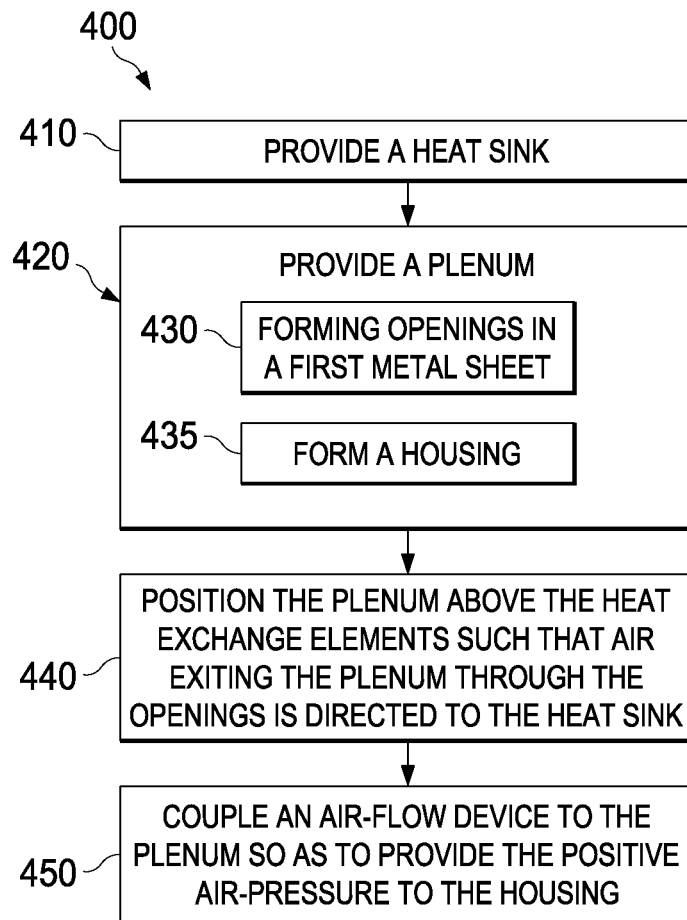


FIG. 4