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[Continued on next page]

(54) Title: MODULAR HEAT EXCHANGER DESIGN

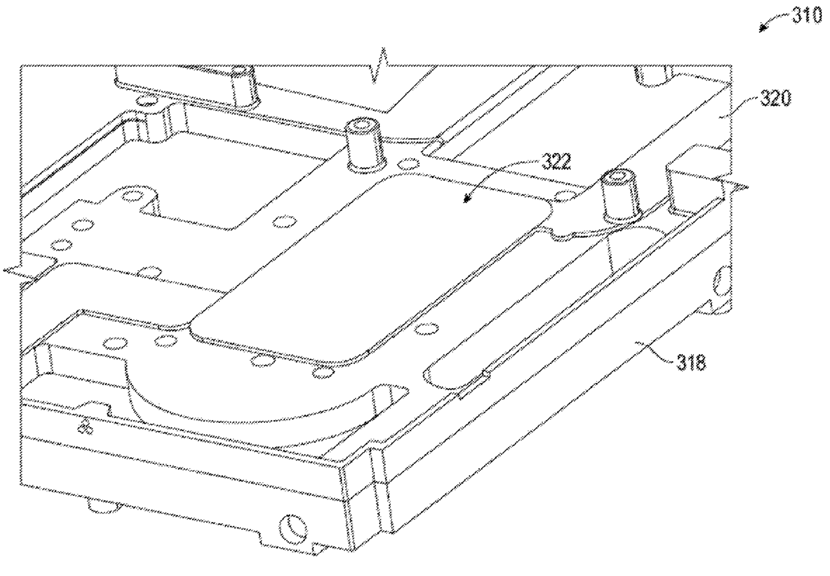

FIG. 3

(57) Abstract: A cold plate assembly is provided having a base defining a cooling channel and a heat exchanger friction-stir welded to the base, wherein the heat exchanger is located within a portion of the cooling channel, and the friction-stir welding between the heat exchanger and the base forms a fluid seal.

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Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

— *of inventorship (Rule 4.17(iv))*

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MODULAR HEAT EXCHANGER DESIGN

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Serial No. 62/173,119 entitled "Modular Heat Exchanger Design", filed June 9, 2016, under 35 U.S.C. § 119(e), and which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] The subject matter disclosed herein generally relates to heat exchangers and, more particularly, to heat exchangers and processes for forming the same.

[0003] Cold plate heat exchangers may be used to cool electronic components that are mounted thereto. In some electronics, the heat exchangers and thermal flow paths may be built into a structure that allows mounting of the electronics to be cooled. Current manufacturing processes for the cold plate style heat exchanger structures may involve multiple processes. The operations and processes of current manufacturing techniques may include machining, brazing, etc. along with multiple additional components, including fasteners, washers, etc.

SUMMARY

[0004] According to one embodiment a cold plate assembly is provided having a base defining a cooling channel and a heat exchanger friction-stir welded to the base, wherein the heat exchanger is located within a portion of the cooling channel, and the friction-stir welding between the heat exchanger and the base forms a fluid seal.

[0005] According to another embodiment, a cold plate assembly is provided as shown and described herein.

[0006] According to another embodiment, a method of manufacturing a cold plate assembly is provided as shown and described herein.

[0007] According to another embodiment, a cold plate assembly as formed as shown and described herein is provided.

[0008] According to another embodiment, a cold plate assembly is provided that includes a baseplate defining a cooling channel and a heat exchanger friction-stir welded to the baseplate, wherein the heat exchanger is located within a portion of the cooling channel, and the friction-stir welding between the heat exchanger and the baseplate forms a fluid seal.

[0009] In addition to one or more of the features described above, or as an alternative, further embodiments of the cold plate assembly may include a cover, the cover configured to attach to the baseplate.

[0010] In addition to one or more of the features described above, or as an alternative, further embodiments of the cold plate assembly may include that the cover forms a lid over the cooling channel where the heat exchanger is not located.

[0011] In addition to one or more of the features described above, or as an alternative, further embodiments of the cold plate assembly may include that the cover is friction-stir welded to a portion of the heat exchanger.

[0012] In addition to one or more of the features described above, or as an alternative, further embodiments of the cold plate assembly may include that the cover is friction-stir welded to the baseplate.

[0013] In addition to one or more of the features described above, or as an alternative, further embodiments of the cold plate assembly may include that the heat exchanger is integral with a component to be cooled by the heat exchanger.

[0014] In addition to one or more of the features described above, or as an alternative, further embodiments of the cold plate assembly may include that the heat exchanger comprises a plurality of fins defining a plurality of fluid channels between the plurality of fins.

[0015] In addition to one or more of the features described above, or as an alternative, further embodiments of the cold plate assembly may include that the cooling channel of the baseplate includes a plurality of cooling fins and the heat exchanger includes a plurality of cooling fins configured to interleave with the cooling fins of the baseplate.

[0016] In addition to one or more of the features described above, or as an alternative, further embodiments of the cold plate assembly may include that the baseplate includes a second cooling channel, the assembly further comprising a top cold plate friction stir welded on the baseplate over the second cooling channel.

[0017] According to another embodiment, a method of manufacturing a cold plate assembly is provided that includes friction stir welding a heat exchanger to a baseplate, the baseplate defining a cooling channel, the heat exchanger located within a portion of the cooling channel, and the friction-stir welding between the heat exchanger and the baseplate forms a fluid seal.

[0018] In addition to one or more of the features described above, or as an alternative, further embodiments of the method may include attaching a cover to the baseplate.

[0019] In addition to one or more of the features described above, or as an alternative, further embodiments of the method may include that the cover forms a lid over the cooling channel where the heat exchanger is not located.

[0020] In addition to one or more of the features described above, or as an alternative, further embodiments of the method may include friction-stir welding the cover to a portion of the heat exchanger.

[0021] In addition to one or more of the features described above, or as an alternative, further embodiments of the method may include friction-stir welding the cover to the baseplate.

[0022] In addition to one or more of the features described above, or as an alternative, further embodiments of the method may include that the heat exchanger is integral with a component to be cooled by the heat exchanger.

[0023] In addition to one or more of the features described above, or as an alternative, further embodiments of the method may include that the heat exchanger comprises a plurality of fins defining a plurality of fluid channels between the plurality of fins.

[0024] In addition to one or more of the features described above, or as an alternative, further embodiments of the method may include that the cooling channel of the baseplate includes a plurality of cooling fins and the heat exchanger includes a plurality of cooling fins, the method comprising interleaving the cooling fins of the baseplate with the cooling fins of the heat exchanger.

[0025] In addition to one or more of the features described above, or as an alternative, further embodiments of the method may include that the baseplate includes a second cooling channel, the method comprising friction stir welding a top cold plate on the baseplate over the second cooling channel.

[0026] Technical effects of embodiments of the present disclosure include a modular formed cold plate heat exchanger. Other technical effects include the elimination of brazing during heat exchanger manufacture along with the elimination of added parts that may have previously been required.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The subject matter is particularly pointed out and distinctly claimed at the conclusion of the specification. The foregoing and other features, and advantages of the present disclosure are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0028] FIG. 1A is an isometric view of a fin core used in cold plate assemblies;

[0029] FIG. 1B is a side view schematic of a prior configuration of a cold plate assembly;

[0030] FIG. 1C is a thermal flow progression of thermal energy through a cold plate assembly, indicating where a component may be installed;

[0031] FIG. 2 is an isometric view of a cold plate assembly as formed by prior techniques;

[0032] FIG. 3 is an isometric view of a cold plate assembly as formed by a technique described herein;

[0033] FIG. 4 is a schematic illustration of a friction-stir welding process as used by embodiments described herein;

[0034] FIG. 5 is a schematic illustration of a heat exchanger and installation in a cold plate assembly in accordance with an example embodiment;

[0035] FIG. 6 is an illustration of a heat exchanger attached to a structure in accordance with an example embodiment;

[0036] FIG. 7 is a schematic illustration of a cold plate assembly in accordance with an embodiment of the present disclosure; and

[0037] FIG. 8 is a schematic illustration of a cold plate assembly in accordance with another embodiment of the present disclosure.

DETAILED DESCRIPTION

[0038] As shown and described herein, various features of the disclosure will be presented. Various embodiments may have the same or similar features and thus the same or similar features may be labeled with the same reference numeral, but preceded by a different first number indicating the figure to which the feature is shown. Thus, for example, element “a” that is shown in FIG. 1 may be labeled “1a” and a similar feature in FIG. 2 may be labeled “2a.” Although similar reference numbers may be used in a generic sense, various embodiments will be described and various features may include changes, alterations, modifications, etc. as will be appreciated by those of skill in the art, whether explicitly described or otherwise would be appreciated by those of skill in the art.

[0039] FIG. 1A is an isometric view of fin core 102 of a heat exchanger 100. The fin core 102 includes a plurality of fins 104 that form channels therebetween. Fluid may be passed through the channels between the fins 104 to enable thermal cooling to a component or device. For example, as shown in FIG. 1B, the heat exchanger 100 is housed within a cold plate 104. Mounted on the cold plate 104 may be one or more components 106. The component 106 may be an electrical component that includes inductors, diodes, capacitors, etc., and in some embodiments the component 106 may be a power distribution system. As will be appreciated by those of skill in the art, the combination of the heat exchanger 100 and the cold plate 104 form a cold plate heat exchanger that may be used to cool electronics or other thermal energy generating devices.

[0040] Formed between the component 106 and the cold plate 104 may be a thermal interface 108. The thermal interface 108 is a joined surface between the component 106 and the cold plate 104 and enables the heat exchanger 100 to provide thermal cooling to the component 106. For example, working or operating fluid may pass through the heat exchanger 100 (and through the fin core 102 thereof) and heat or thermal energy may be passed from the component 106, through the thermal interface 108, and into the operating fluid that is passing through the channels formed by the fins 104 of the fin core 102. The heat exchanger 100 and cold plate 104 may be part of a cold plate assembly.

[0041] FIG. 1C shows a thermal gradient or flow path of a cooling fluid or operating fluid that may be used to work with the fin core 100 to cool a component, such as component 106, as the fluid flows through a cold plate assembly 110. For example, as shown, the component 106 may be mounted on the cold plate assembly 110 along a flow path 112. An operating fluid may enter the flow path 112 at an inlet 114, flow counter-clockwise in FIG. 1C, and exit the flow path 112 at outlet 116. As shown, the component 106 is located along the flow path 112 and thus may be cooled by the operating fluid passing below the component 106. The heat exchanger 100 (shown in FIGS. 1A and 1B) may be located within the cold plate assembly 110 and located directly below the component 106. Thus, the heat exchanger 100 may be part of the flow path 112, and an operating fluid may pass through the heat exchanger 100 to enable cooling of the component 106. The flow path 112 may be one or more cooling channels that are formed in or on the cold plate assembly 110.

[0042] Traditionally, the heat exchanger 100 is placed into and brazed as part of the flow path 112 and within a cooling channel in a cold plate assembly. The heat exchanger 100 may be vacuum brazed with an integrated lanced offset fin section that is then placed into the cooling channels of the cold plate assembly 110. After placement, the heat exchanger 100 may be brazed in place. The heat exchanger 100, in some configurations, may further be bolted into place and be surrounded by an O-ring or other type of seal that is configured to provide a fluid seal to keep the operating fluid within the fin core 100. That is, additional hardware may be required to provide a proper connection and fluid seal between the heat exchanger and the cold plate assembly.

[0043] Turning to FIG. 2, an isometric view of a cold plate assembly housing a heat exchanger is shown. Cold plate assembly 210 is formed from a base 218 and a cover or lid 220. The base 218 and the cover 220 may be machined into a proper configuration with a flow path or fluid channel formed between the base 218 and the cover 220. Also housed between the base 218 and the cover 220 at portion 222 may be a heat exchanger such as described above. The heat exchanger, housed at portion 222, may be provided with an operating fluid that passes through the cold plate assembly 210 along a flow path beneath the cover 220. The flow path may provide the operating fluid at an inlet side of the portion 222 at an inlet 224 and may exit the portion 222 at an outlet 226. FIG. 2 shows a prior configuration wherein machining is used to form both the base 218 and the cover 220 together, with the flow path or fluid channel formed in a surface of the base 218 between the base 218 and the cover 220. As such, the cover 220 is formed with substantially the same shape as the base 218, as shown in FIG. 2.

[0044] Complex cold plate assemblies for large power motor controllers have high density fin cores for enhanced thermal management. These cold plates are typically vacuum brazed. This manufacturing process is expensive. In addition, the high heat flux components such as insulated-gate bipolar transistor (IGBT) modules are mounted with thermal grease or other interface material between base plate and cold plate. In other configurations, a power module with fins is used with O-rings to eliminate thermal interface between the cold plate and an IGBT module. Embodiments provided herein are directed to an improved cold plate assembly and methods of manufacture. For example, a manufacturing method is provided herein where an IGBT module is integrally joined to a cold plate (e.g., by friction stir welding), thus eliminating the thermal interface. In addition, an interleaved machined fin structure is provided herein to replace lanced offset fin cores which provides adequate heat transfer co-efficient x-area to both sides of a cold plate.

[0045] Turning now to FIG. 3, a structure of a cold plate assembly 310 is shown in accordance with an embodiment of the present disclosure. As shown, a base 318 of the cold plate assembly 310 has a similar structure and configuration as the base 218 of FIG. 2. However, in accordance with embodiments disclosed herein, the cover 320 may not be machined at the same time as the base 218 or formed in the same shape or geometry thereof. In contrast, the cover 320 of embodiments disclosed herein may be modular and pre-fabricated, and in some embodiments may be formed from one or more parts or sections. In some embodiments, the cover 320 may sit or rest on a shoulder of the base 318 such that when the cover 320 is attached to the base 318, a fluid channel is formed and sealed between the base 318 and the cover 320.

[0046] As shown in FIG. 3, the portion 322 of the cover 320 is separate or distinct from the rest of the cover 320. That is, the portion 322, where a heat exchanger may be installed, may be separate from the cover 320 that is used to form parts of the fluid channel in the cold plate assembly 310. That is, in the embodiment shown in FIG. 3, the portion 322 may be a base or surface of a heat exchanger, and in some embodiments may be a base that supports a fin core that is attached directly to a surface of the base 318.

[0047] In some embodiments, a component may then be attached or connected to the heat exchanger at portion 322. In other embodiments, the portion 322 may represent the component itself. That is, in some embodiments, the fins of the heat exchanger may be formed integral with or attached directly to a component which may then be directly attached to the case 318.

[0048] In accordance with embodiments disclosed herein, the portions of the cover (cover 320, portion 322 (whether as a separate heat exchanger or as a component), etc.) may be friction-stir welded directly to the base 318. That is, cold plate machining may be used to create cooling channels within the base 318 into which pre-fabricated heat exchanger elements or sections (e.g., portion 322) may be placed. Once placed, the heat exchanger element may be friction-stir welded into or onto the base 318 of the cold plate assembly 310. The other portions of the cover 320, such as a lid or multiple lids, may be placed over channels formed in the base 318 of the cold plate assembly 310 and may also be friction-stir welded into place to create the internal cooling channels of the cold plate assembly 310.

[0049] Turning to FIG. 4, an example of friction-stir welding is shown. A tool 430 is provided that rotates as shown by tool rotation arrows 432. A contact force 434 is applied downward on the tool 430 such that a portion of the tool 430, such as a shoulder 440 and a probe 438, may contact a joint line 436. The joint line 436 may be a joint line between a surface of a cover or lid 420 and a surface of a base 418. As the tool 430 rotates, a probe 438 is used to contact the surface at the joint line 436 and a shoulder 440 of the tool 430 enables a smooth finish to be formed at a trailing edge 442. Thus, by means of the rotation 432 and the contact force 434, along with a traversing force 444, the two components of the joint line 436 may be friction-stir welded. As will be appreciated by those of skill in the art, friction-stir welding is a solid-state joining process wherein materials of two elements to be joined are not melted. Friction-stir welding uses a third body tool (e.g., tool 430) to join two facing surfaces (e.g., a cover 420 and a base 418 of a cold plate assembly). Heat is generated between the tool 430 and the materials of the base 418 and the cover 420, which leads to a very soft region near the tool 430. The tool 430 then mechanically intermixes the materials of the cover 420 and the base 418 at the place of the joint line 436. The softened material can then be joined, welded, or fused using mechanical pressure (which is applied by the tool 430, e.g., contact force 434).

[0050] Turning to FIG. 5, a schematic of a heat exchanger 550 and in indication of the heat exchanger 550 as friction-stir welded into a fluid channel of a cold plate assembly is shown. On the left side of FIG. 5 is a schematic of a modular heat exchanger 550. The modular heat exchanger 550 is formed from a base 552, a fin core 554, and a top 556. The modular heat exchanger 550 may be a pre-fabricated module that may be dropped into or installed within a manufactured or machined part. For example, with reference back to FIG. 3, the modular heat exchanger 550 may form or be installed into portion 322. The heat exchanger 550 may have a similar fin core to that shown and described above.

[0051] As will be appreciated by those of skill in the art, although the modular heat exchanger 550 is shown with a rectangular or square geometry with a top and a bottom, other configurations of modular heat exchangers may be used without departing from the scope of the present disclosure. That is, any geometry, shape, size, etc. may be used for the heat exchanger, and further, the top and/or bottom may be omitted based on the configuration and needs of a particular design. Thus, FIG. 5, and the other figures, are merely provided as examples and are not to be taken as limiting.

[0052] Shown on the right-hand side of FIG. 5, a schematic of the heat exchanger 550 as installed is shown. As shown, the heat exchanger 550 may be friction-stir welded into place as indicated by the edge or welding 558. Also shown on the right-hand side of FIG. 5 are two sections of a cover 520. The cover 520 may be substantially similar to the covers and lids described above and may also be friction-stir welded to a base. As shown, the friction-stir welding 558 may be continuous about the sections of the cover 520 and about the heat exchanger 550. Thus, a fluid seal may be provided to prevent leaking of the operating fluid. Due to the friction stir welding used to join the heat exchanger 550 and the sections of the cover 520 to a base, the heat exchanger 550 and the covers 520 may form a continuous surface. That is, the top 556 of the heat exchanger 550 may be mixed with the covers 520 during the friction-stir welding process, as described above.

[0053] FIG. 6 shows an image of a heat exchanger 650 as attached to a structure 660 in accordance with embodiments described herein.

[0054] FIG. 7 is a schematic illustration of a power module 701 as installed on a power module baseplate 703. The power module 701, through the power module baseplate 703, is mounted to a cold plate 705. In the non-limiting embodiment of FIG. 7, the power module baseplate 703 includes integral fins 707, which can, for example, be formed by machining or brazed fins. Similarly, as shown, there are cold plate fins 709 on the cold plate 705. The power module baseplate 703 is brazed by friction stir welding in a window cut out of the cold plate 705. The power module baseplate fins 707 are placed in the space between the cold plate fins 709 forming an interleaved fin structure, as shown. Such configuration allows for high heat dissipating components located on both sides of the cold plate 705 (e.g., above or below the cold plate 705 in FIG. 7).

[0055] Turning now to FIG. 8, a schematic illustration of a cold plate 821 having interleaved fins 823 and a cooling channel 825 is shown. A component configuration with such fin structure (e.g., fins 823) and cooling channel (e.g., cooling channel 825) is created by placing the power module baseplate 827 over the fins 823 of the cold plate 821 and friction stir welding the two components together. Further, as shown in FIG. 8, a top cold plate 829 and joining the top and bottom portions of the cold plate (e.g., cold plate 821 and top cold plate 829) by friction stir welding.

[0056] In some embodiments of the present disclosure, modified fin densities can be employed. For example, similar to the embodiments of FIGS. 7-8, high density fin arrangements can be manufactured such that individual plates have relatively low fin density but have the plates opposing each other with interleaved fins to obtain higher effective fin density.

[0057] Advantageously, embodiments described herein provide a cold plate assembly that is friction-stir welded. By having friction-stir welded components, embodiments disclosed herein may enabled modular components, including modular heat exchanger components, without added expense, costs, manufacturing times, or other impacts. For example, that may be significant lead-time reductions as compared to traditional cold plate assembly manufacturing processes. Further, there may be significant cost savings, by reducing the number of parts, components, operations, processes, etc. Moreover, the friction-stir welding process may enable joining of covers/heat exchangers with a base without the need for fillers, fasteners, etc.

[0058] Further, advantageously, in accordance with some embodiments, the heat exchanger may be formed integral or attached with the component to which it is designed to cool, and thus enable optimized thermal transfer. Further, the entire component (component with attached or integral heat exchanger) may be friction-stir welded into the cold plate to thus form an inseparable assembly.

[0059] Further, advantageously, a friction-stir welded cold plate assembly as described herein may enable a strong metallurgic bond to be formed between the friction-stir welded components, thus provided a fluid seal. Accordingly, advantageously, O-rings and other seals and/or bonding or fastening elements may be eliminated during the manufacturing process.

[0060] Moreover, advantageously, various embodiments provided herein can allow the elimination of thermal interface between power modules and cold plates. Removal of the thermal interface may enable temperature reductions of the power module. Accordingly, power modules as prepared in accordance with the present disclosure may have increased reliability. In addition, advantageously, embodiments provided herein can eliminate vacuum brazing and potentially reduce cold plate cost.

[0061] While the present disclosure has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the present disclosure is not limited to such disclosed embodiments. Rather, the present disclosure can be modified to incorporate any number of variations, alterations, substitutions, combinations, sub-combinations, or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the present disclosure. Additionally, while various embodiments of the present disclosure have been described, it is to be understood that aspects of the present disclosure may include only some of the described embodiments.

[0062] For example, although shown and described with respect to a particular shape and design for a heat exchanger, those of skill in the art will appreciate that any shape, design, configuration, or geometry may be used for the modular heat exchanger. Further, as described, the heat exchanger may be formed as attached to or integral with the component that is configured to be cooled. The unitary component-heat exchanger may then be installed into an appropriate portion of a fluid channel and then friction-stir welded into place to form a sealed, secure assembly.

[0063] Accordingly, the present disclosure is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

CLAIMS:

What is claimed is:

1. A cold plate assembly comprising:
a base defining a cooling channel; and
a heat exchanger friction-stir welded to the base, wherein the heat exchanger is located within a portion of the cooling channel, and the friction-stir welding between the heat exchanger and the base forms a fluid seal.

2. The cold plate assembly of claim 1, further comprising a cover, the cover configured to attach to the base.

3. The cold plate assembly of claim 2, wherein the cover forms a lid over the cooling channel where the heat exchanger is not located.

4. The cold plate assembly of any of claims 2-3, wherein the cover is friction-stir welded to a portion of the heat exchanger.

5. The cold plate assembly of any of claims 2-4, wherein the cover is friction-stir welded to the base.

6. The cold plate assembly of any of the preceding claims, wherein the heat exchanger is integral with a component to be cooled by the heat exchanger.

7. The cold plate assembly of any of the preceding claims, wherein the heat exchanger comprises a plurality of fins defining a plurality of fluid channels between the plurality of fins.

8. The cold plate assembly of any of the preceding claims, wherein the cooling channel of the baseplate includes a plurality of cooling fins and the heat exchanger includes a plurality of cooling fins configured to interleave with the cooling fins of the baseplate.

9. The cold plate assembly of any of the preceding claims, wherein the baseplate includes a second cooling channel, the assembly further comprising a top cold plate friction stir welded on the baseplate over the second cooling channel.

10. A method of manufacturing a cold plate assembly comprising:
friction-stir welding a heat exchanger to a base defining a cooling channel, wherein the heat exchanger is located within a portion of the cooling channel, and the friction-stir welding between the heat exchanger and the base forms a fluid seal.

11. The method of claim 10, further comprising attaching a cover to the base.

12. The method of claim 11, wherein the cover forms a lid over the cooling channel where the heat exchanger is not located.

13. The method of any of claims 11-12, comprising friction-stir welding the cover to a portion of the heat exchanger.

14. The method of any of claims 11-13, comprising friction-stir welding the cover to the base.

15. The method of any of claims 10-14, comprising forming the heat exchanger with a component to be cooled by the heat exchanger.

16. The method of any of claims 10-15, wherein the heat exchanger comprises a plurality of fins defining a plurality of fluid channels between the plurality of fins.

17. The method of any of claims 10-16, wherein the cooling channel of the baseplate includes a plurality of cooling fins and the heat exchanger includes a plurality of cooling fins, the method comprising interleaving the cooling fins of the baseplate with the cooling fins of the heat exchanger.

18. The method of any of claims 10-17, wherein the baseplate includes a second cooling channel, the method comprising friction stir welding a top cold plate on the baseplate over the second cooling channel.

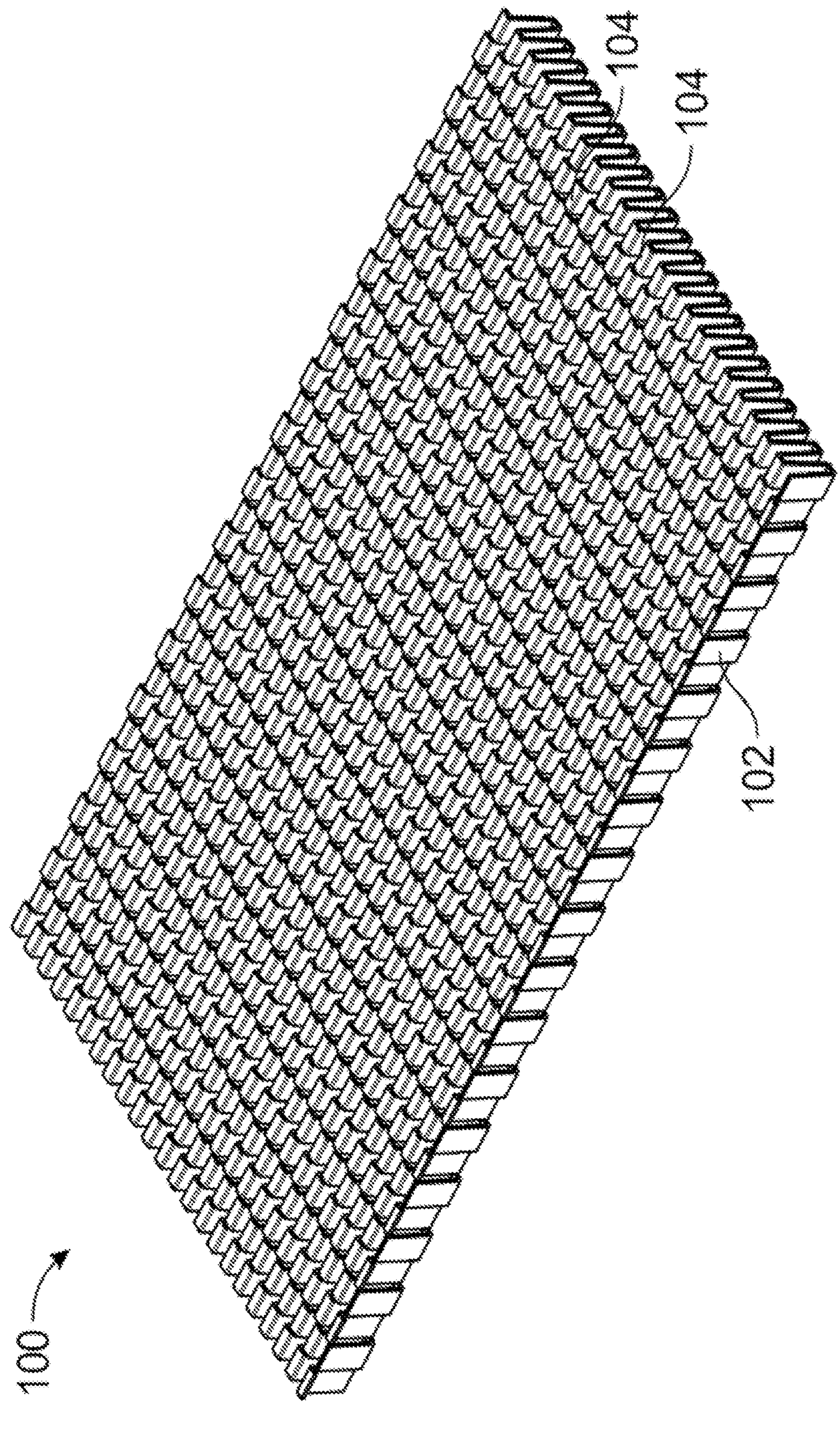

FIG. 1A

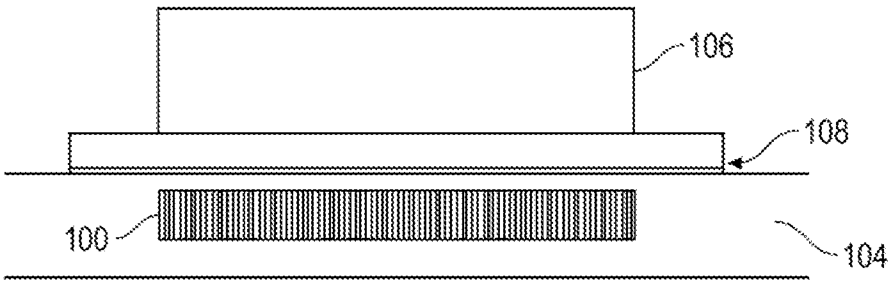

FIG. 1B
(Prior Art)

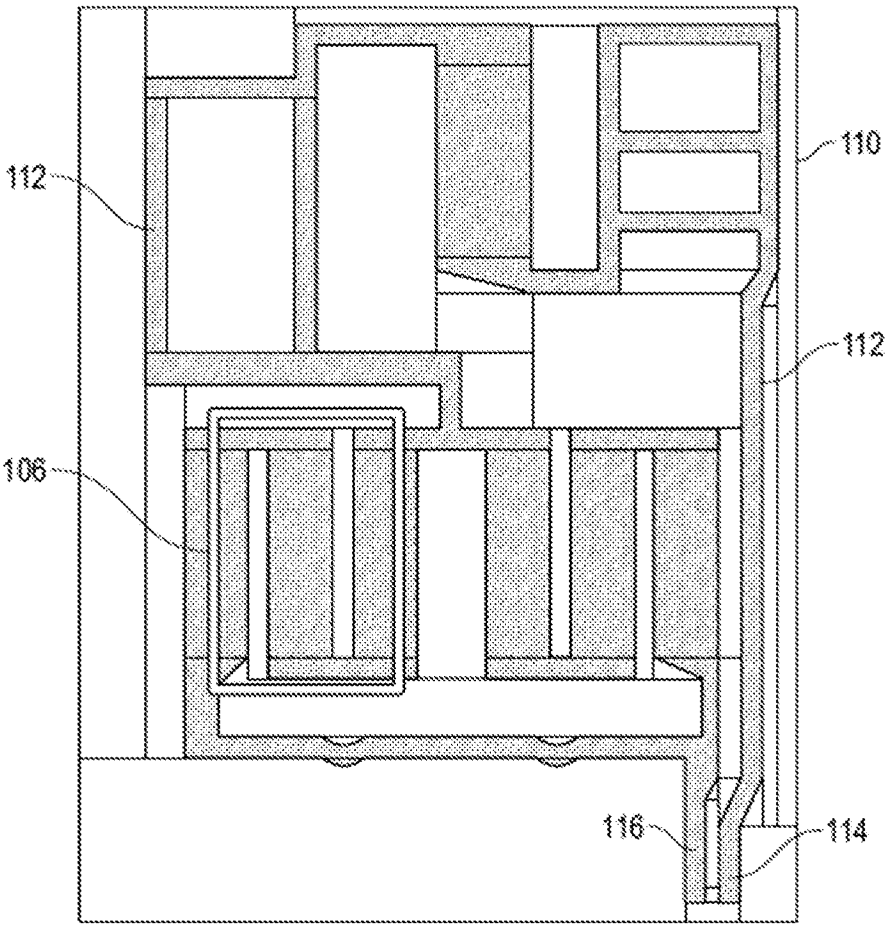

FIG. 1C

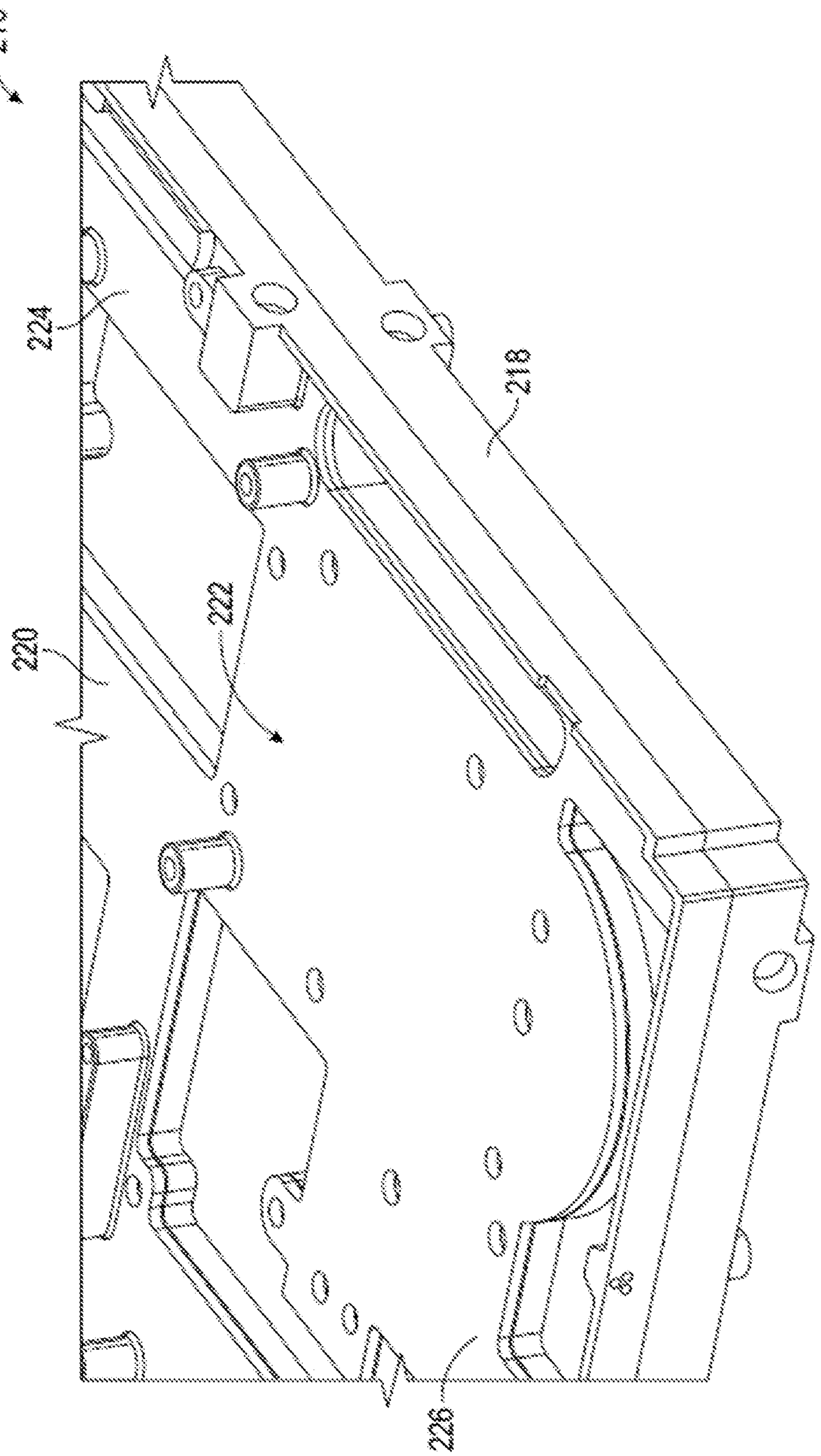

FIG. 2
(Prior Art)

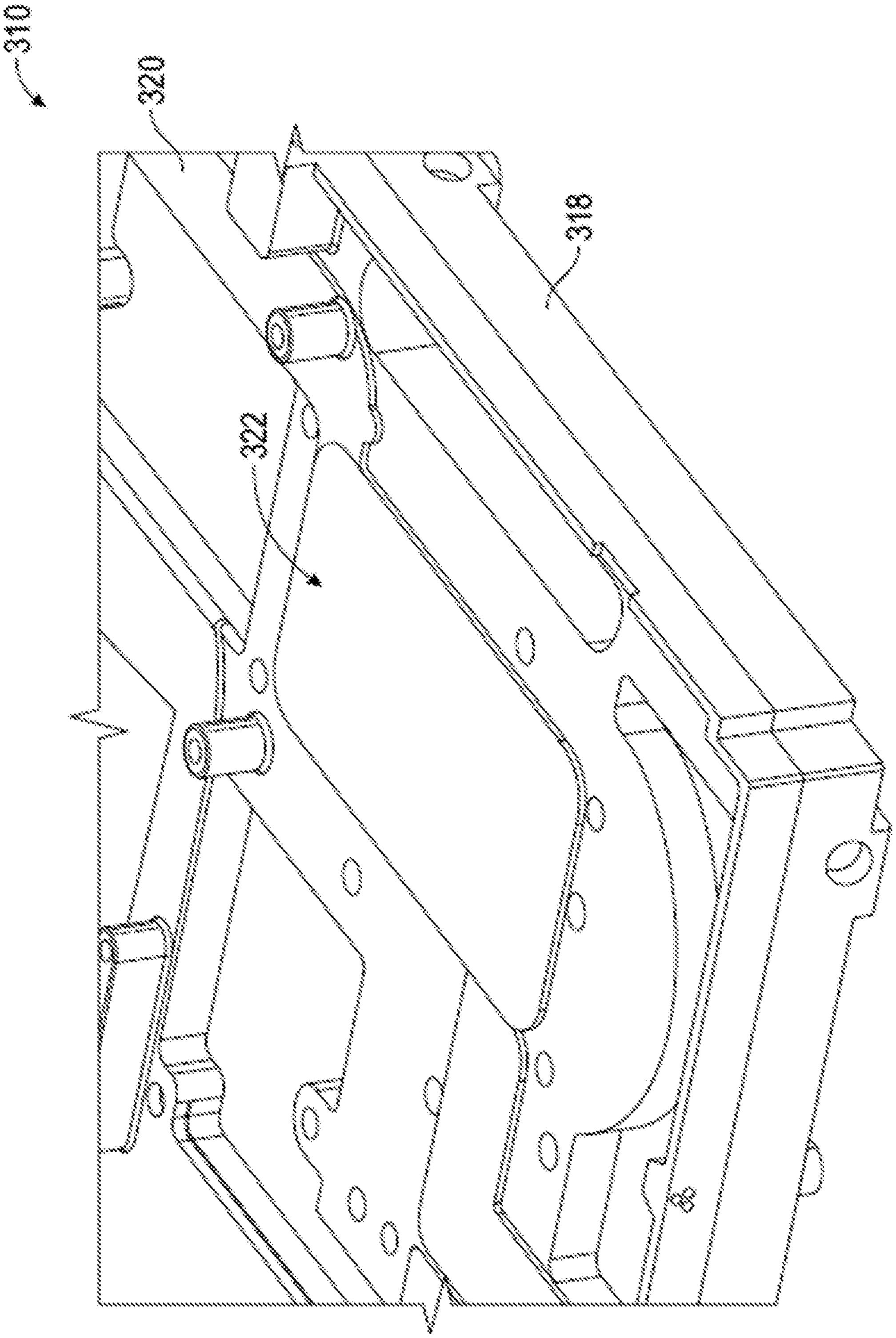

FIG. 3

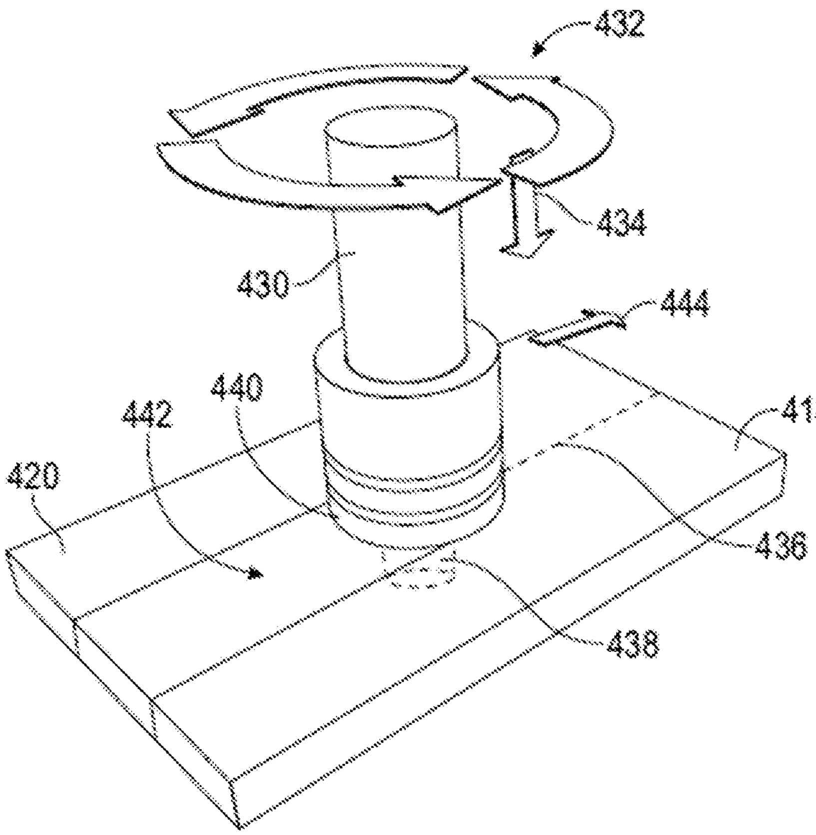
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FIG. 4

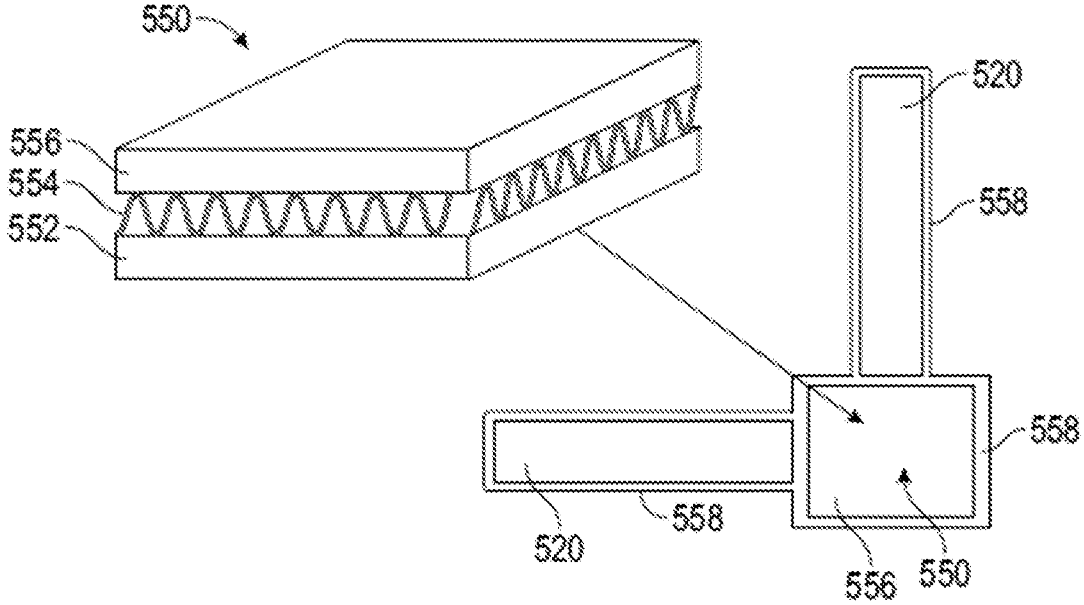
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FIG. 5

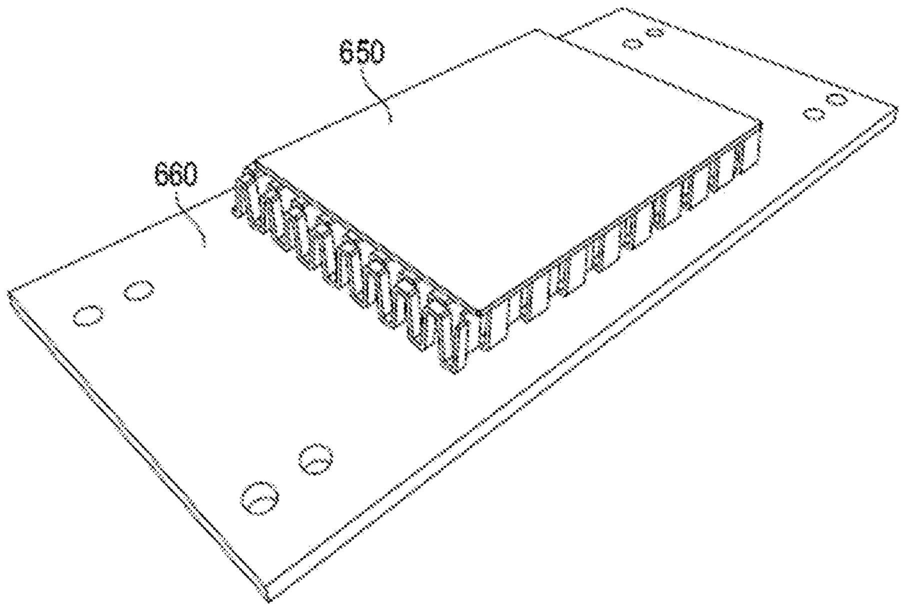

FIG. 6

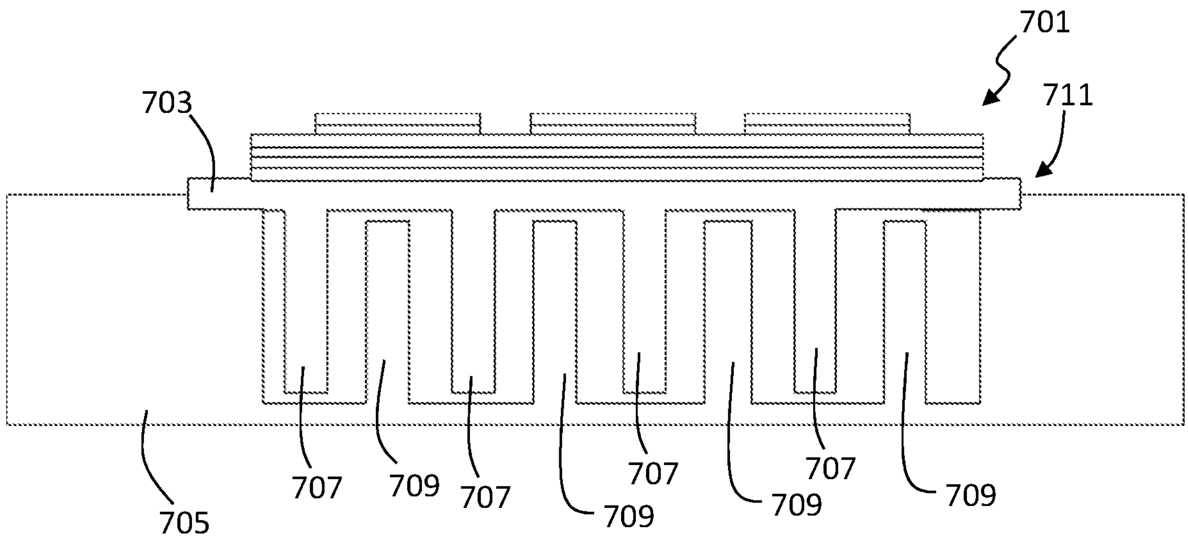

FIG. 7

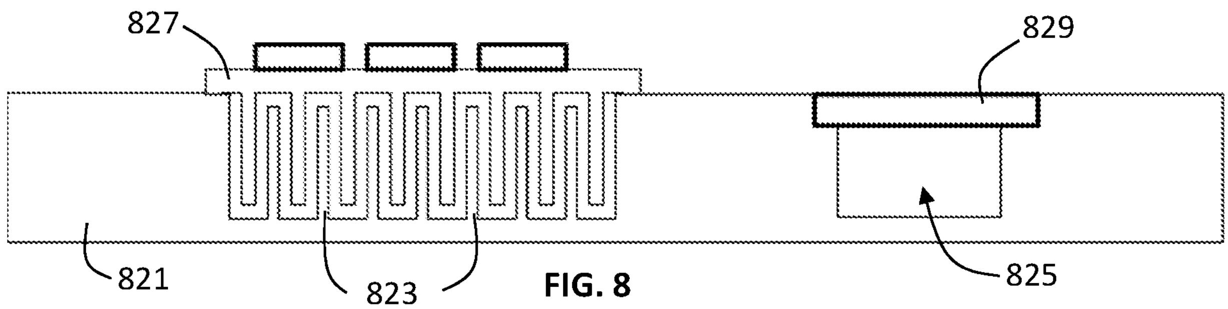

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/036654

A. CLASSIFICATION OF SUBJECT MATTER
INV. F28F3/02 B23K20/12 F28F3/12 H01L23/473 H01L21/48
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F28F B23K H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 8 966 759 B1 (ROMERO GUILLERMO L [US] ET AL) 3 March 2015 (2015-03-03) abstract; figures	1-8,10, 11,15-18 9,12-14
Y	DE 11 2012 003439 T5 (HITACHI AUTOMOTIVE SYSTEMS LTD [JP]) 8 May 2014 (2014-05-08) the whole document	9,12-14
X	US 2011/308059 A1 (SEO NOBUSHIRO [JP] ET AL) 22 December 2011 (2011-12-22) figures	1-8,10, 11,15-18

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 October 2016	20/10/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Mellado Ramirez, J

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2016/036654

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