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(54) Title: BATTERY MODULE WITH ACTIVELY COOLED HIGH POWER ELECTRICAL INTERFACE

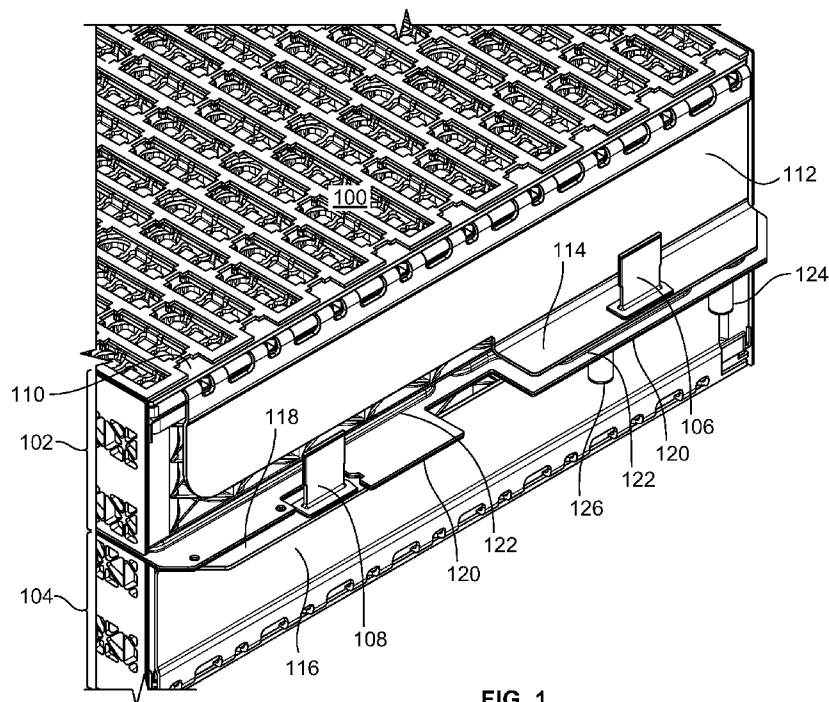


FIG. 1

(57) Abstract: Efficiency of a battery module is achieved using an actively cooled high power electrical interface. The battery module comprises a plurality of battery cells, at least one busbar coupled to the battery cells, a connector electrically coupled to the at least one busbar, and at least one cooling component that is thermally coupled to the first connector. The battery cells may be arranged in two layers, each layer containing a plurality of battery cells connected by a busbar. The connector comprises a contact through which the battery module may be coupled to an external circuit. The at least one cooling component provided cooling for the battery cells and the connectors and may be placed on the surface of the battery module or between layers of battery cells.



**(84) Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, 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, KM, ML, MR, NE, SN, TD, TG).

**Published:**

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## BATTERY MODULE WITH ACTIVELY COOLED HIGH POWER ELECTRICAL INTERFACE

### Cross Reference to Related Application

**[0001]** This disclosure claims the benefit of U.S. Provisional Application No. 62/760,435, filed November 13, 2018, which is hereby incorporated by reference in its entirety.

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### Summary

**[0002]** This disclosure is directed to high power batteries, and more specifically directed to actively cooling both the batteries and an electrical interface.

**[0003]** A vehicle such as an electric vehicle may include battery cells to provide and/or supplement the drive power for the vehicle. The vehicle may have limited space for battery cells. The battery cells may be part of modules that include other components such as control systems and cooling for the cells, and may be densely packed within a frame. Battery cells may be electrically connected to one another via contacts which may conduct high currents, *e.g.*, by connecting one or more batteries via wiring harnesses, busbars, etc. The selection of components within a battery module may be based on thermal considerations (*e.g.*, based on resistance/heat generation, cooling ability, thermal mass, etc.) and/or based on electrical considerations (*e.g.*, such as creepage and clearance).

**[0004]** High-power electrical connectors such as those that connect battery modules within a vehicle may typically be limited based primarily on thermal considerations. In such a system, resistance scales approximately linearly with the smallest component dimension (x, y, z, axial, or radial), while cooling ability scales with the two smallest dimensions and thermal mass scales with the three primary dimensions (x, y, and z). For a densely-packed battery system, the battery connector may reduce the overall volumetric energy density of the system (*e.g.*, on the order of 5-10 percent), for example, as a result of the smallest dimension of the connector being insufficiently small. Stated another way, because resistance scales approximately inverse-linearly with the smallest component dimension, the smallest dimension of connectors typically needs to be made sufficiently large to prevent overheating, which in turn reduces energy density of the system. Such connectors are passively cooled by ambient air, resulting in a heat transfer coefficient of 5-50 W/m<sup>2</sup>K. The connectors may also

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have a relatively low thermal mass for their volumes, and additional cooling may be achieved via heat sinking that occurs via connected busbars or cables.

**[0005]** The present disclosure overcomes the problems of conventional connectors by providing active cooling to connectors. In an exemplary embodiment of the present disclosure, the cooling capacity for electrical connectors between battery cells is increased providing an active heat sink adjacent to the connectors. A cooling component such as a cold plate having a flow of coolant may be thermally coupled to the connectors to substantially increase cooling capacity. The cooling component may be designed to interface with the connectors to increase or maximize heat exchange from the connectors to their associated cold elements, resulting in an effective heat transfer coefficient on the order of  $300\text{W/m}^2\text{K}$ . In an exemplary design, the improved electrical characteristics of the connectors due to active cooling may allow an increase in the connectors' ampacity on the order of 2.5X (*e.g.*, based on the square root of  $300\text{W/m}^2\text{K} / 50\text{W/m}^2\text{K}$ ). This increase in connector capacity may scale inversely with the dimension of the connector that is perpendicular to the area being cooled. In one test, it has been found that active cooling increased a connector's ampacity on the order of 2.0X. An increase in a connector's ampacity enables a smaller form factor connector to be used, thus increasing the energy density of battery systems.

**[0006]** In some embodiments, a battery module comprises a plurality of battery cells, at least one busbar electrically coupled to the battery cells, a first connector electrically coupled to the at least one busbar, and at least one cooling component thermally coupled to the first connector. The first connector comprises a contact configured for interfacing with a corresponding connector of an external circuit.

**[0007]** In some embodiments, the plurality of battery cells comprises a first battery cell layer and a second battery cell layer. The first connector is electrically coupled to the first battery cell layer via the at least one busbar and the battery module further comprises a second connector electrically coupled to the second battery cell layer. The battery cell layers may be located adjacent to each other within the battery module. In some embodiments, the at least one cooling component extends at least partially between the first battery cell layer and the second battery cell layer. The first connector may extend outward from the first battery cell layer, and the second connector may extend outward from the second battery cell layer. The at least one cooling component may similarly extend outward from the first battery cell layer and the second battery cell layer such that a surface of the at least one cooling component is

adjacent to the first connector and a surface of the at least one cooling component is adjacent to the second connector.

**[0008]** In some embodiments, the first connector and the second connector may extend from a shared side of the battery module. In other embodiments, the first connector and second connector may extend from different sides of the battery module. For example, the first connector may be on a first side of a substantially rectangular battery module, and the second connected may be on a second side of the battery module whose face is perpendicular to that of the first side. Alternatively, the second connector may be on a side of the batter module that is opposite the first side.

**[0009]** In some embodiments, the at least one cooling elements comprises a cooling manifold. The cooling manifold may comprise a coolant intake and a coolant outlet, and at least one fluid passage. The cooling manifold may have substantially the same shape as the battery module. For example, in embodiments where the battery module is substantially rectangular in shape, and wherein each battery cell layer is similarly substantially rectangular in shape, the cooling manifold may also be substantially rectangular in shape so that is can be placed on a surface of between battery cell layers of the battery module.

**[0010]** The at least one cooling component may be physically coupled to the first connector and the second connector. Such coupling may be achieved using an electrically insulating adhesive which substantially conducts thermal energy and substantially electrically insulates the at least one cooling component from the first connector and the second connector. The insulating adhesive may have an electrical resistivity of at least  $10^{10}$  Ohm-cm. The insulating adhesive may have a thermal conductivity of at least 0.5W/mK. The at least one cooling component may comprise a single cooling component. However, in some embodiments, the at least one cooling component may comprise a first cooling component associated with the first connector and a second cooling component associated with the second connector. The physical coupling of the cooling component to the first connector may comprise a first contact surface area and the physical coupling of the cooling component to the second connector may comprise a second contact surface area. The cooling component may also comprise a third surface area that is not in physical contact with either of the first connector or the second connector. The third surface area may be greater than the first contact surface area or the second contact surface area. The third surface area may even be greater than the combined surface area of the first contact surface and the second contact

surface. For example, the third surface area may be at least two times greater than the combined surface area of the first contact surface and the second contact surface.

**[0011]** In some embodiments, connectors of a battery module may be cooled by connecting, via a first connector of the battery module and at least one busbar, an external electrical circuit to a first battery cell layer of the battery module, and connecting, via a second connector of the battery module and the at least one busbar, the external electrical circuit to a second battery cell layer of the battery module, wherein the first battery cell layer and the second battery cell layer are electrically coupled within the battery module. At a coolant intake of the battery module, a flow of coolant to a cooling plate of the battery module is then provided, wherein the cooling plate extends substantially between the first battery cell layer and the second battery cell layer, and wherein the cooling plate includes a first cooling extension thermally and physically coupled to the first connector and a second cooling extension thermally and physically coupled to the second connector. The flow of coolant from the cooling plate is then received at a coolant outlet of the battery module.

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#### Brief Description of the Drawings

**[0012]** The above and other objects and advantages of the disclosure will be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which like reference characters refer to like parts throughout, and in which:

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**[0013]** FIG. 1 depicts an exemplary battery module in accordance with some embodiments of the present disclosure;

**[0014]** FIG. 2 depicts an exemplary partial side view of a battery module in accordance with some embodiments of the present disclosure;

**[0015]** FIG. 3 depicts a second exemplary battery module in accordance with some embodiments of the disclosure; and

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**[0016]** FIG. 4 depicts a second exemplary partial side view of a battery module in accordance with some embodiments of the disclosure.

#### Detailed Description

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**[0017]** FIG. 1 depicts an exemplary battery module 100 in accordance with an embodiment of the present disclosure. The battery module may include multiple battery cells

arranged, for example, in a rectangular shape and vertically stacked in two layers (*e.g.*, layers 102, 104), although other configurations may be utilized (*e.g.*, any suitable number of battery cells, battery cell shapes, relative locations of battery cells, layers, etc. may be utilized). High power contacts 106, 108 may allow the battery cells of battery module 100 to be connected to an external circuit. For example, the battery cells of battery module 100 may be electrically connected, via high power contacts 106, 108, to other battery modules or to a load (*e.g.*, to provide electrical power to an electrical motor and other components of an electrical vehicle). As depicted in FIG. 1, a first layer 102 of battery cells may be coupled internally (*e.g.*, in a parallel configuration or series configuration) via busbar 110. Busbar 110 is physically and/or electrically connected to terminal busbar 112 which extends along a side of layer 102. An electrical connector 114, which physically and/or electrically interfaces with terminal busbar 112, may extend from battery module 100 horizontally and may include vertically oriented high power contact 106 for electrical coupling to the external circuit, *e.g.*, by a cable and/or busbar. Similarly, a second layer 104 of battery cells may be coupled internally via another busbar (not shown) which is physically and/or electrically connected to terminal busbar 116, which extends along a side of layer 104. An electrical connector 118, which physically and/or electrically interfaces with terminal busbar 116, may extend from battery module 100 horizontally and may include vertically oriented high power contact 108 for electrical coupling to the external circuit.

**[0018]** The battery module may also include a cooling component to provide cooling to the battery cells and other components that experience heating during operation such as the connectors. Although a variety of cooling components may be utilized, in an exemplary embodiment the cooling component may be a cooling manifold 120 having a rectangular plate shape (*e.g.*, a cooling plate). A coolant may be circulated through channels 122 of the cooling manifold to increase the heat transfer, and in an exemplary embodiment may be provided via a coolant intake 124 and may exit the cooling manifold via a coolant outlet 126. The rectangular plate shape may generally match the rectangular shape of the battery cell arrangement and may be located in between two layers 102, 104 of battery cells, although cooling may be provided to additional surfaces of the battery cells in other embodiments. In some embodiments, the cooling manifold 120 may also extend outside of the battery module to cover a portion of the connector structure that is not used to make the electrical contact, thereby providing cooling of the connectors as well as the battery packs. For example,

cooling manifold 120 may cover at least a portion of the horizontally-extending portion of connectors 114, 118, leaving the vertically-extending contacts 106, 108 exposed for electrical contact with the external circuit. A bonding material such as an electrically insulating adhesive (e.g., a thermal interface material) may attach cooling manifold 120 to connectors 5 114, 118, such that thermal energy may be transferred from connectors 114, 118 to cooling manifold 120 while connectors 114, 118 remain electrically insulated from cooling manifold 120. For example, the electrically insulating adhesive may have an electrical resistivity of at least  $10^{10}$  Ohm-cm (e.g., approximately  $10^{10}$  Ohm-cm to approximately  $10^{12}$  Ohm-cm) and a thermal conductivity of at least 0.5W/mK (e.g., 0.5W/mK, 0.89W/mK, 3.4W/mK, or a 10 suitable range such as 0.89W/mK to 3.4W/mK).

**[0019]** As shown in FIG. 1, cooling plate 120 extends out from the side of battery module 100 and at least partially covers the top of the horizontally extending portion of connector 118 and the bottom of the horizontally extending portion of connector 114. Partially visible are cooling channels 122 of cooling plate 120. As illustrated, cooling 15 channels 122 do not extend along the portion of the cooling plate that covers the horizontally extending portion of connector 118, but they do at least partially extend along the portion of the cooling plate that covers the horizontally extending portion of connector 114. It will be understood that in some embodiments, cooling channels 122 may extend at least partially or fully over the portion of cooling plate 120 that covers connector 114, the portion of cooling 20 plate 120 that covers connector 118, or both.

**[0020]** It will be understood that in some embodiments, the cooling component of the present disclosure provides cooling to connector components and associated hardware external to the battery modules and is not limited to the cooling plate shown in FIG. 1. In some embodiments, the cooling component does not provide cooling to the inside of the 25 battery module. Additionally, while FIG. 1 shows connectors 114 and 118 located on the same side of battery module 100, it will be understood that connectors 114 and 118 may be located on different sides of battery module 100. For example, connector 114 may be located on a first side of battery module 100 and connector 118 may be located on a side of battery module 100 whose face is perpendicular to that of the side on which connector 114 is located. 30 Alternatively, connector 118 may be located on a side of battery module 100 that is opposite the side on which connector 114 is located.

**[0021]** FIG. 2 depicts an exemplary partial side view of battery module 100 described above in connection with FIG. 1. In an exemplary embodiment, upper terminal busbar 112 is associated with a first battery cell and lower terminal busbar 116 is associated with a second battery cell. Upper connector 114 is electrically coupled to upper terminal busbar 112, extends horizontally from upper terminal busbar 112, and includes vertically extending high power contact 106. Lower connector 118 is electrically coupled to lower terminal busbar 116, extends horizontally from lower terminal busbar 116, and includes a vertically extending high power contact 108. Cooling plate 120 is located between upper connector 114 and lower connector 118 and is thermally coupled to the horizontally extending portions of each of connectors 114, 118 via a respective layer of thermal interface material 200. In this manner, cooling plate 120 may provide heat transfer from upper connector 114 and lower connector 118, increasing the efficiency of the battery module.

**[0022]** FIG. 3 depicts a second exemplary battery module 300 in accordance with some embodiments on the disclosure. Battery cells of a first layer 302 of battery module 300 are electrically coupled, via a busbar (not shown) to terminal busbar 304. Similar to terminal busbar 112, terminal busbar 304 extends along a side of layer 302 and physically and/or electrically interfaces with electrical connector 306. Electrical connector 306 may extend horizontally from battery module 300 and may include vertically oriented bolts 308 to serve as contacts through which battery module 300 may be electrically coupled to an external circuit. Bolts 308 may be composed of any electrically conductive material, including copper, aluminum, silver, gold, steel, or any combination thereof, or any other suitable material. Battery cells of a second layer 310 may similarly be electrically coupled, via a busbar (not shown) to terminal busbar 312. Terminal busbar 312 extends along a side of layer 310 and physically and/or electrically interfaces with electrical connector 314. Electrical connector 314 may extend horizontally from battery module 300 and may include vertically oriented bolts 316 to serve as contacts through which battery module 300 may be electrically coupled to an external circuit. Bolts 316 may be composed of any of the materials listed above in connection with bolts 308. Bolts 316 may be composed of a different material than bolts 308.

**[0023]** Cooling plate 318 may be similar to cooling plate 120, and is located between the two layers 302, 310 of battery cells. A portion 320 of terminal busbar 304 may extend horizontally from battery module 300. Similarly, a portion 322 of terminal busbar 312 may

extend horizontally from battery module 300. A bonding material such as an electrically insulating adhesive (e.g., a thermal interface material) may attach cooling plate 318 to portions 320, 322, such that thermal energy may be transferred from portions 320, 322 to cooling plate 318 while portions 320, 322 remain electrically insulated from cooling plate 318. A coolant may be circulated through channels of cooling plate 318 (not shown) to increase the heat transfer, and in an exemplary embodiment may be provided via a coolant intake 324 and may exit the cooling plate via a coolant outlet 326.

**[0024]** FIG. 4 depicts a second exemplary partial side view of battery module 300 in accordance with some embodiments of the disclosure. In an exemplary embodiment, upper terminal busbar 304 is associated with a first battery cell and lower terminal busbar 312 is associated with a second battery cell. Upper connector 306 is electrically coupled to upper terminal busbar 304, extends horizontally from upper terminal busbar 304, and includes vertically extending bolts 308 to serve as high power electrical contacts. Lower connector 314 is electrically coupled to lower terminal busbar 312, extends horizontally from lower terminal busbar 312, and includes vertically extending bolts 316 to serve as high power electrical contacts. Cooling plate 318 is located between upper terminal busbar 304 and lower terminal busbar 312 and is thermally coupled to the horizontally extending portions of each of upper terminal busbar 304 and lower terminal busbar 312 via a respective layer of thermal interface material 400. In this manner, cooling plate 318 may provide heat transfer from upper terminal busbar 304 and lower terminal busbar 312, increasing the efficiency of the battery module.

**[0025]** The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the disclosure. However, it will be apparent to one skilled in the art that the specific details are not required to practice the methods and systems of the disclosure. Thus, the foregoing descriptions of specific embodiments of the present disclosure are presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. For example, the size, shape, and configuration of the cooling component may take many different forms in accordance with the present disclosure. It will be understood that while the cooling plate of FIG. 1 provides cooling to both the battery cells and the connectors, in some embodiments a separate cooling component can be used to provide

cooling to the connectors. In addition, in some embodiments an additional cooling component or channel can be provided to provide cooling to the other side of the connector (not shown in the FIG. 1). The embodiments described above were chosen and described in order to best explain the principles of the disclosure and its practical applications, to thereby  
5 enable others skilled in the art to best utilize the methods and systems of the disclosure and various embodiments with various modifications as are suited to the particular use contemplated. Additionally, different features of the various embodiments, disclosed or otherwise, can be mixed and matched or otherwise combined so as to create further embodiments contemplated by the disclosure.

What is Claimed is:

1. A battery module, comprising:
  - a plurality of battery cells;
  - at least one busbar electrically coupled to the battery cells;
  - 5 a first connector electrically coupled to the at least one busbar, wherein the first connector comprises a contact configured for interfacing with a corresponding connector of an external circuit; and
  - at least one cooling component thermally coupled to the first connector.
- 10 2. The battery module of claim 1, wherein the contact comprises a bolted electrical joint.
3. The battery module of claim 1, wherein the plurality of battery cells comprises a first battery cell layer and second battery cell layer, wherein the first connector comprises a first connector electrically coupled to the first battery cell layer via the at least one busbar, further  
15 comprising a second connector electrically coupled to the second battery cell layer via the at least one busbar.
4. The battery module of claim 3, wherein the first battery cell layer and the second battery cell layer are located adjacent to each other within the battery module.
- 20 5. The battery module of claim 4, wherein the at least one cooling component extends at least partially between the first battery cell layer and the second battery cell layer.
6. The battery module of claim 5, wherein the first connector extends outward from the  
25 first battery cell layer and the second connector extends outward from the second battery cell layer.
7. The battery module of claim 6, wherein the at least one cooling component extends outward from the first battery cell layer and the second battery cell layer adjacent to the first  
30 connector and adjacent to the second connector.

8. The battery module of claim 7, wherein the first connector and the second connector extend from a shared side of the battery module.
9. The battery module of claim 7, wherein the first connector and the second connector extend from different sides of the battery module.
10. The battery module of claim 9, wherein the first connector and the second connector extend from opposite sides of the battery module.
11. The battery module of claim 7, wherein the at least one cooling component comprises a cooling manifold.
12. The battery module of claim 11, wherein the cooling manifold comprises a coolant intake and a coolant outlet, and wherein the cooling manifold comprises at least one fluid passage.
13. The battery module of claim 11, wherein each of the battery cell layers and the cooling manifold have a rectangular shape.
14. The battery module of claim 7, wherein the at least one cooling component is physically coupled to the first connector and the second connector.
15. The battery module of claim 14, wherein the physical coupling comprises an electrically insulating adhesive, wherein the electrically insulating adhesive substantially conducts thermal energy and substantially electrically insulates the at least one cooling component from the first connector and the second connector.
16. The battery module of claim 15, wherein the electrically insulating adhesive has an electrical resistivity of at least  $10^{10}$  Ohm-cm.
17. The battery module of claim 15, wherein the electrically insulating adhesive of a thermal conductivity of at least 0.5W/mK.

18. The battery module of claim 14, wherein the at least one cooling component comprises a single cooling component.
- 5 19. The battery module of claim 14, wherein the at least one cooling component comprises a first cooling component associated with the first connector and a second cooling component associated with the second connector.
20. The battery module of claim 14, wherein the physical coupling of the cooling  
10 component to the first connector comprises a first contact surface area, wherein the physical coupling of the cooling component to the second connector comprises a second contact surface area, and wherein the cooling component comprises a third surface area that is not in physical contact with either of the first connector or the second connector.
- 15 21. The battery module of claim 20, wherein the third surface area is greater than either the first contact surface area or the second contact surface area.
22. The battery module of claim 20, wherein the third surface area is greater than the first  
20 contact surface area plus the second contact surface area.
23. The battery module of claim 20, wherein the third surface area is at least two times greater than the first contact surface area plus the second contact surface area.
24. A method comprising:  
25 connecting, via a first connector of a battery module and at least one busbar, an external electrical circuit to a first battery cell layer of the battery module;  
connecting, via a second connector of the battery module and the at least one busbar, the external electrical circuit to a second battery cell layer of the battery module, wherein the first battery cell layer and the second battery cell layer are electrically coupled within the  
30 battery module;  
providing, at a coolant intake of the battery module, a flow of coolant to a cooling plate of the battery module, wherein the cooling plate extends substantially between the first

battery cell layer and the second battery cell layer, and wherein the cooling plate includes a first cooling extension thermally and physically coupled to the first connector and a second cooling extension thermally and physically coupled to the second connector; and

5 receiving, at a coolant outlet of the battery module, the flow of coolant from the cooling plate.

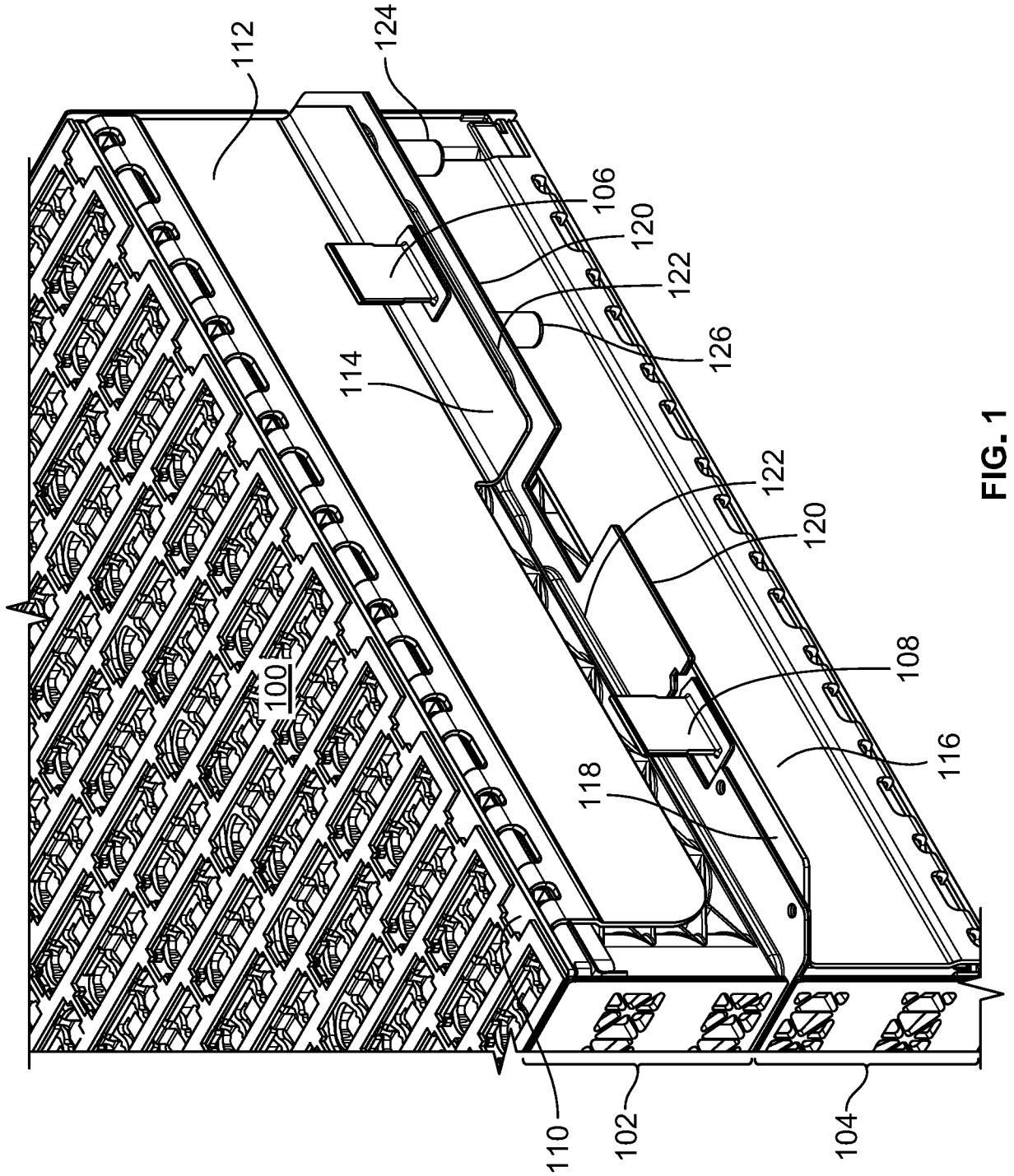


FIG. 1

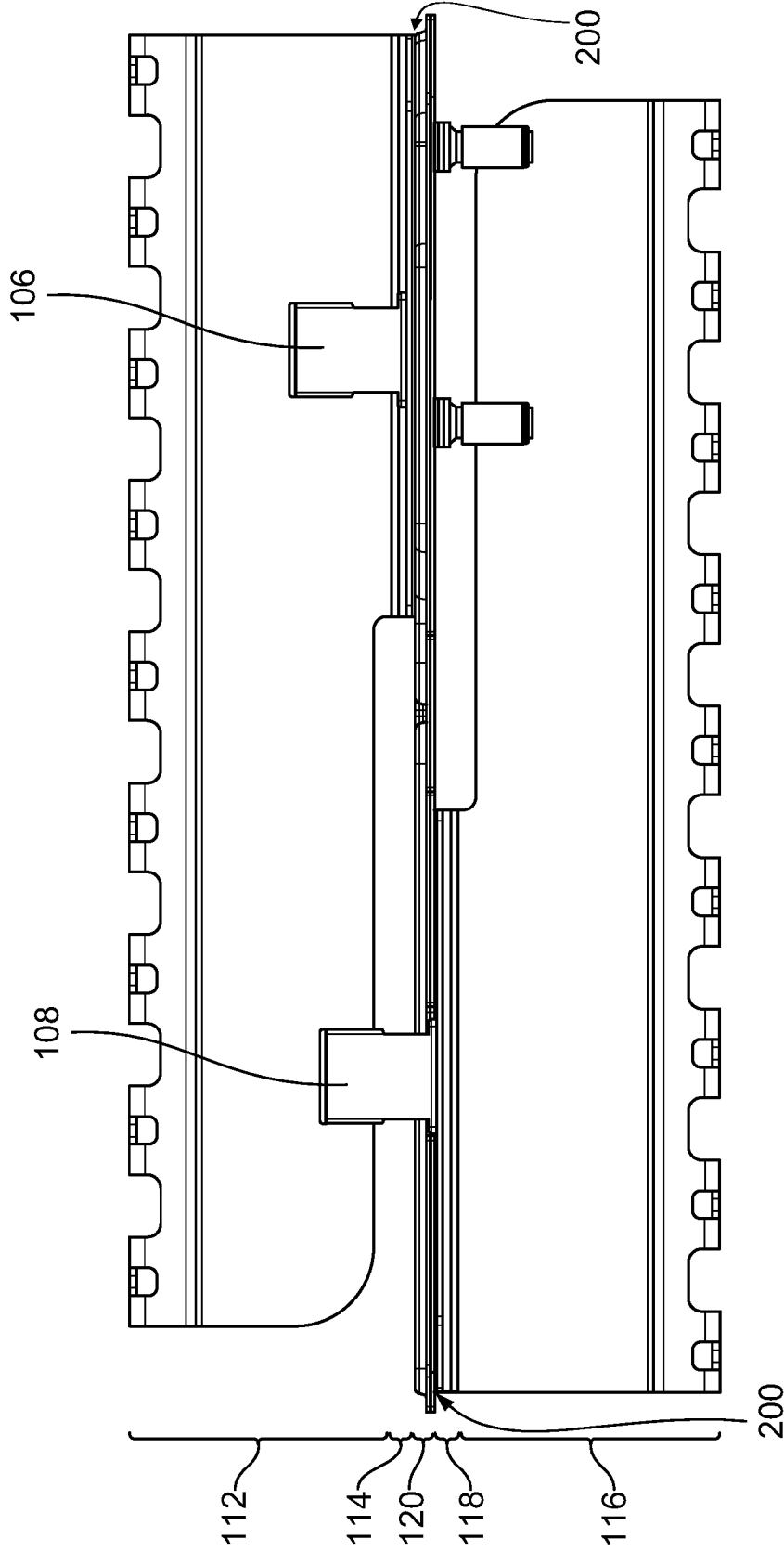


FIG. 2

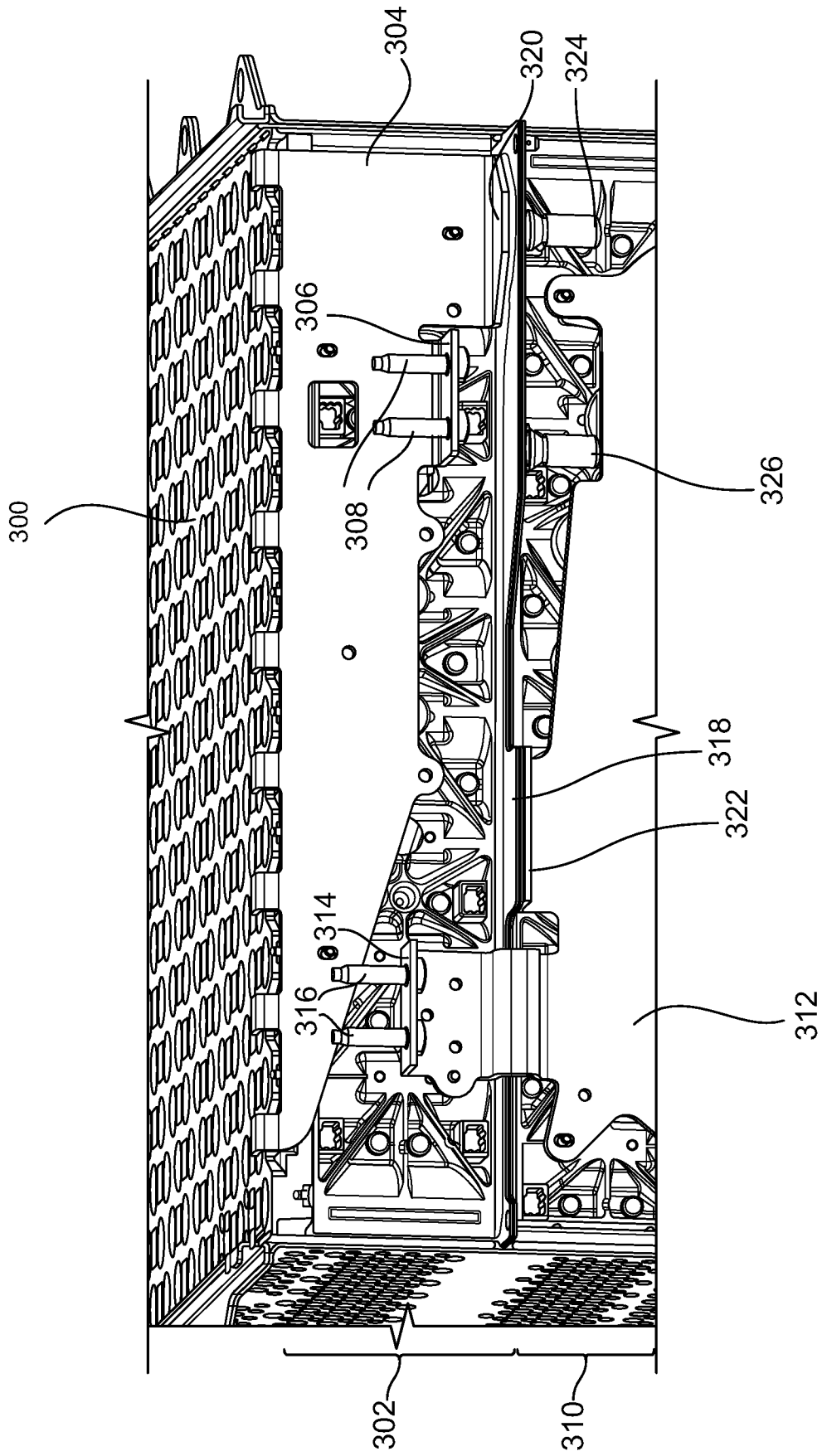


FIG. 3

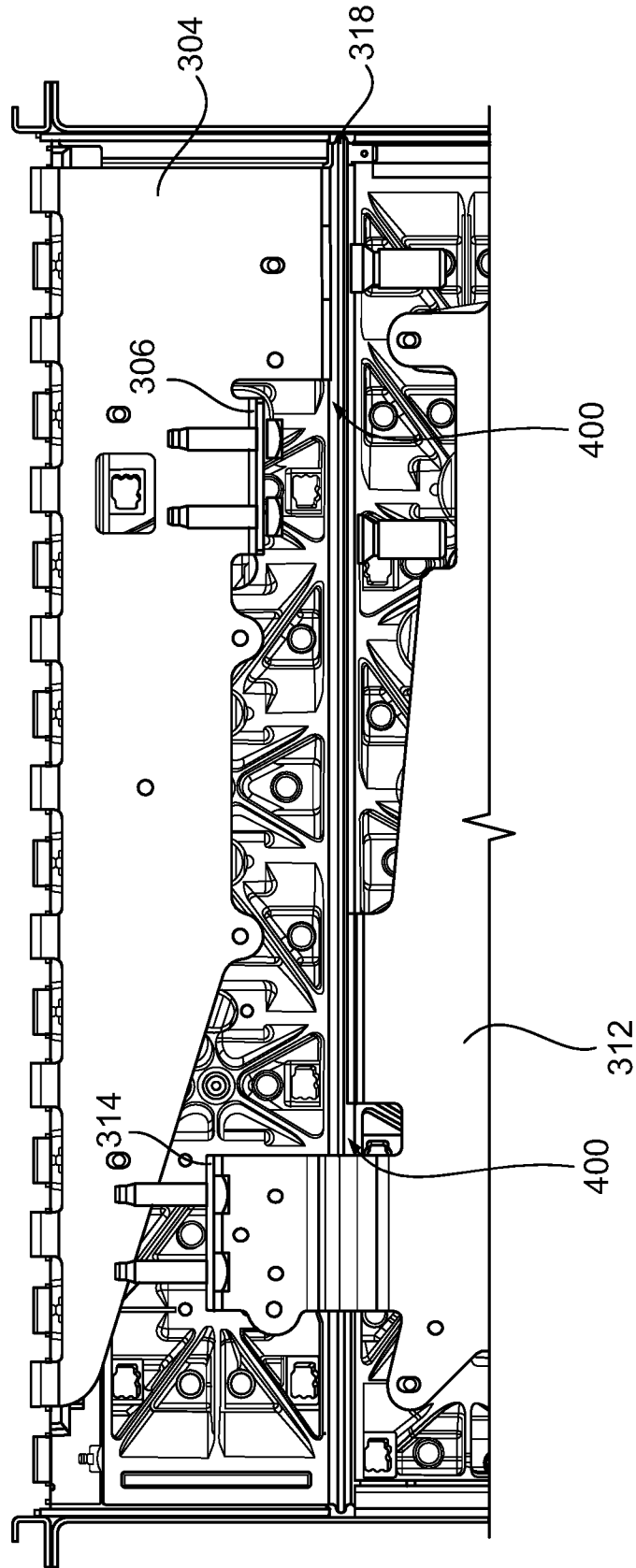


FIG. 4

**INTERNATIONAL SEARCH REPORT**

International application No  
PCT/US2019/060781

**A. CLASSIFICATION OF SUBJECT MATTER**  
 INV. H01M2/20 H01M2/30 H01M10/613 H01M10/6553 H01M10/6556  
 H01M10/6567  
 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)  
 H01M

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 A	EP 3 297 059 A1 (LG CHEMICAL LTD [KR]) 21 March 2018 (2018-03-21) paragraphs [0032], [0038], [0039], [0061] - [0065]; figures 1,3-5,9 -----	1-11,14, 18-23 12,13, 15-17,24
A	US 2012/177970 A1 (MARCHIO MICHAEL A [US] ET AL) 12 July 2012 (2012-07-12) paragraphs [0065] - [0071]; figures 13,14 -----	1-24
A	EP 2 879 228 A1 (VALEO SYSTEMES THERMIQUES [FR]) 3 June 2015 (2015-06-03) paragraphs [0015] - [0028]; figures 1-3 -----	1-24

Further documents are listed in the continuation of Box C.  See patent family annex.

\* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&amp;" document member of the same patent family</p>
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Date of the actual completion of the international search  <b>26 February 2020</b>	Date of mailing of the international search report  <b>05/03/2020</b>
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  <b>Möller, Claudia</b>
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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2019/060781

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 3297059	A1	21-03-2018	CN 107710450 A
			EP 3297059 A1
			JP 6496455 B2
			JP 2018530107 A
			KR 20170054878 A
			PL 3297059 T3
			US 2018159096 A1
			WO 2017082528 A1
-----			
US 2012177970	A1	12-07-2012	CN 103380511 A
			DE 112012000438 T5
			US 2012177970 A1
			WO 2012096844 A1
-----			
EP 2879228	A1	03-06-2015	CN 104779355 A
			EP 2879228 A1
			FR 3014249 A1
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