



(51) International Patent Classification:

H01L 35/30 (2006.01) *H01L 27/16* (2006.01)
F25B 21/02 (2006.01) *H05K 1/18* (2006.01)

(21) International Application Number:

PCT/US2020/018801

(22) International Filing Date:

19 February 2020 (19.02.2020)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/808,205	20 February 2019 (20.02.2019)	US
16/417,149	20 May 2019 (20.05.2019)	US

(63) Related by continuation (CON) or continuation-in-part (CIP) to earlier application:

US

16/417,149 (CIP)

Filed on

20 May 2019 (20.05.2019)

(71) Applicant: **GENTHERM INCORPORATED** [US/US];
21680 Haggerty Road, Suite 101, Northville, Michigan
48167 (US).

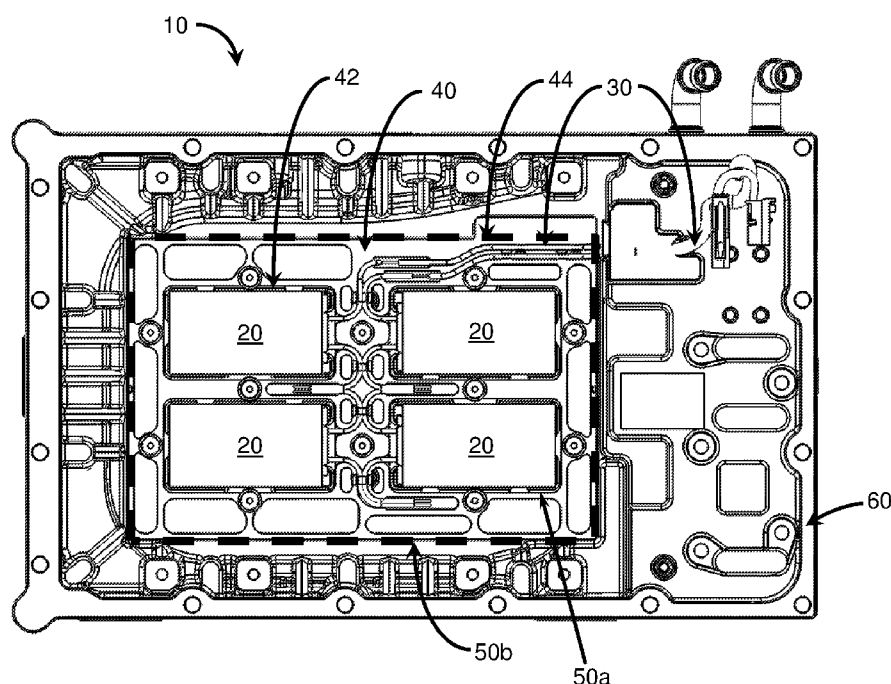
(72) Inventors: **JOVOVIC, Vladimir**; 21680 Haggerty Road,
Suite 101, Northville, Michigan 48167 (US). **POLIQIN,
Eric**; 21680 Haggerty Road, Suite 101, Northville, Michi-
gan 48167 (US). **HEIAN, Ellen, M.**; 21680 Haggerty Road,
Suite 101, Northville, Michigan 48167 (US).

(74) Agent: **ALTMAN, Daniel, E.**; Knobbe, Martens, Olson &
Bear, LLP, 2040 Main Street, 14th Floor, Irvine, California
92614 (US).

(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, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,

(54) Title: THERMOELECTRIC MODULE WITH INTEGRATED PRINTED CIRCUIT BOARD

FIG. 1A:



(57) Abstract: A thermoelectric module assembly for thermally conditioning a component includes first and second heat spreaders spaced apart from one another and at least one thermoelectric sub-assembly between and in thermal communication with the first and second heat spreaders. The at least one thermoelectric sub-assembly includes a plurality of thermoelectric devices and a printed circuit board having a plurality of electrical conduits. Each of the thermoelectric devices has a first end portion and a second end portion, the second end portion opposite from the first end portion, the first end portion mechanically coupled to the printed circuit board and in electrical communication with the plurality of electrical conduits, and the second end portion spaced from the printed circuit board.

DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, 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, 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:

— *with international search report (Art. 21(3))*

THERMOELECTRIC MODULE WITH INTEGRATED PRINTED CIRCUIT BOARD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of U.S. Non-Provisional Appl. No. 16/417,149, filed May 20, 2019, which claims priority to U.S. Provisional Application No. 62/808,205, filed February 20, 2019, each of which is hereby incorporated by reference in its entirety for all purposes and is to be considered a part of this specification.

BACKGROUND

Field

[0002] This application relates to thermoelectric devices and modules used for thermal management of components and/or systems, including but not limited to batteries.

Description of the Related Art

[0003] Power electronics and other electrical devices, such as batteries, can be sensitive to overheating, cold temperatures, extreme temperatures, and operating temperature limits. The performance of such devices may be diminished, sometimes severely, when the devices are operated outside of recommended temperature ranges. In semiconductor devices, integrated circuit dies can overheat and malfunction. In batteries, including, for example, batteries used for automotive applications in electrified or electrical vehicles, battery cells and their components can degrade when overheated or overcooled. Such degradation can manifest itself in reduced battery storage capacity and/or reduced ability for the battery to be recharged over multiple duty cycles. Furthermore, high performance batteries for use in large systems (including, for example, lithium based batteries used in electrical vehicles) have certain properties (e.g., charging characteristics) and/or safety-related events (e.g., potential fires due to over-temperature conditions) that make thermal management of the batteries and/or containment system desirable.

SUMMARY

[0004] In certain embodiments, a thermoelectric module assembly for thermally conditioning a component is provided. The assembly comprises first and second heat

spreaders spaced apart from one another. The assembly further comprises at least one thermoelectric sub-assembly between and in thermal communication with the first and second heat spreaders. The at least one thermoelectric sub-assembly comprises a printed circuit board comprising a plurality of electrical conduits. The at least one thermoelectric sub-assembly further comprises a plurality of thermoelectric devices. Each thermoelectric device of the plurality of thermoelectric devices has a first end portion and a second end portion, the second end portion opposite from the first end portion, the first end portion mechanically coupled to the printed circuit board and in electrical communication with the plurality of electrical conduits, and the second end portion spaced from the printed circuit board.

[0005] In certain embodiments, a thermoelectric system is provided. The system comprises a printed circuit board comprising a plurality of electrically conductive first tabs at a surface of the printed circuit board. The system further comprises at least one thermoelectric device mechanically coupled to the printed circuit board. The at least one thermoelectric device comprises a thermally conductive first plate, a thermally conductive second plate, and a plurality of thermoelectric elements in thermal communication with and in a region between the first plate and the second plate. The second plate comprises a first portion extending beyond a perimeter of the first plate and over an edge of the printed circuit board and over two first tabs of the plurality of first tabs. The first portion comprises two electrically conductive second tabs, each of the two second tabs in mechanical and electrical communication with a corresponding first tab of the two first tabs.

[0006] In certain embodiments, a thermoelectric system is provided. The system comprises a plurality of thermoelectric devices and a printed circuit board. Each thermoelectric device of the plurality of thermoelectric devices comprises a thermally conductive first plate, a thermally conductive second plate, and a plurality of thermoelectric elements in thermal communication with and in a region between the first plate and the second plate. The printed circuit board comprises a plurality of first electrical conduits and a plurality of second electrical conduits. The first electrical conduits are in electrical communication with the thermoelectric elements of the plurality of thermoelectric devices, and the second electrical conduits are in electrical communication with at least one thermal

sensor on at least one thermoelectric device of the plurality of thermoelectric devices and/or on the printed circuit board.

[0007] In certain embodiments, a method of fabricating at least one thermoelectric sub-assembly comprising a printed circuit board and a plurality of thermoelectric devices is provided. The method comprises providing the printed circuit board which comprises a plurality of electrical conduits and a plurality of electrically conductive first tabs in electrical communication with the plurality of electrical conduits. The method further comprises providing the plurality of thermoelectric devices, each thermoelectric device comprises a first end portion and a second end portion. The second end portion is opposite to the first end portion, and the first end portion comprises at least two electrically conductive second tabs. The method further comprises mechanically coupling the at least two second tabs of each thermoelectric device of the plurality of thermoelectric devices to corresponding first tabs of the printed circuit board such that the at least two second tabs are in electrical communication with the corresponding first tabs and the second end portion is spaced from the printed circuit board.

[0008] In certain embodiments, a method of fabricating a thermoelectric device comprising a first plate, a second plate, and a plurality of thermoelectric elements between and in electrical communication between the first plate and the second plate is provided. The method comprises providing the thermoelectric device. The second plate extends beyond a perimeter of the first plate along a portion of the thermoelectric device. The method further comprises applying a first sealant between the first plate and the second plate along the portion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIGs. 1A and 1B schematically illustrate a top view and an exploded view, respectively, of a portion of a thermoelectric module assembly.

[0010] FIGs. 2A and 2B schematically illustrate top views of portions of two example thermoelectric module assemblies in accordance for certain embodiments described herein.

[0011] FIGs. 3A and 3B schematically illustrate the example thermoelectric sub-assemblies of FIGs. 2A and 2B, respectively, in accordance with certain embodiments described herein.

[0012] FIGs. 4A-4C schematically illustrate electrical configurations of the PCB in accordance with certain embodiments described herein.

[0013] FIGs. 5A-5C schematically illustrate an exploded view of an example thermoelectric system in accordance with certain embodiments described herein.

[0014] FIG. 6 schematically illustrates an example soldering configuration in accordance with certain embodiments described herein.

[0015] FIG. 7A schematically illustrates a cross-sectional view of an example TED in accordance with certain embodiments described herein..

[0016] FIGs. 7B and 7C illustrate heat conduction during the soldering process from the first portion of the second plate along the second plate in accordance with certain embodiments described herein.

[0017] FIGs. 7D-7F schematically illustrate an example electrically and thermally conductive first layer of the second plate in accordance with certain embodiments described herein.

[0018] FIGs. 8A-8D schematically illustrate an example thermoelectric system in accordance with certain embodiments described herein.

[0019] FIGs. 9A-9D schematically illustrate another example thermoelectric system in accordance with certain embodiments described herein.

[0020] FIGs. 10A-10C schematically illustrate an example thermoelectric system comprising wire encapsulation in accordance with certain embodiments described herein.

[0021] FIGs. 11A-11C schematically illustrate an example TED in accordance with certain embodiments described herein.

[0022] FIGs. 12A and 12B schematically illustrate an example thermoelectric system comprising electrical conduits in accordance with certain embodiments described herein.

[0023] FIG. 13 is a flow diagram of an example method of fabricating at least one thermoelectric sub-assembly in accordance with certain embodiments described herein.

[0024] FIG. 14 is a flow diagram of an example method of fabricating a thermoelectric device in accordance with certain embodiments described herein.

DETAILED DESCRIPTION

[0025] FIGs. 1A and 1B schematically illustrate a top view and an exploded view, respectively, of a portion of a thermoelectric module assembly 10 comprising a plurality of thermoelectric devices 20 that are electrically interconnected with one another and to external circuitry by electrically conductive wires 30. The thermoelectric devices 20 are held in place (e.g., aligned and secured) by a molded plastic insert 40 with a plurality of holes 42 configured to receive and hold the thermoelectric devices 20 onto a first heat spreader 50a and below a second heat spreader 50b, the first heat spreader 50a in thermal communication with the cooling plate 60 (e.g., heat exchanger) of the thermoelectric module assembly 10. The plastic insert 40 also has a plurality of channels 44 configured to receive and hold the electrically conductive wires 30. Fabrication of the thermoelectric module assembly 10 of FIGs. 1A and 1B can be challenging and time-consuming since each of the thermoelectric devices 20 has to be separately inserted into the corresponding hole 42 of the plastic insert 40 and the various electrically conductive wires 30 have to be separately inserted into the corresponding channel 44 of the plastic insert 40, which can be cumbersome. In addition, due to the fragility of the connections between the electrical wires 30 and the thermoelectric devices 20, such fabrication has a significant probability of introducing failure conditions (e.g., broken electrical connections) which then must be corrected, further increasing the time and cost involved in the fabricating the thermoelectric module assembly 10.

[0026] FIGs. 2A and 2B schematically illustrate top views of portions of two example thermoelectric module assemblies 100 in accordance with certain embodiments described herein. The thermoelectric module assemblies 100 of FIGs. 2A and 2B can be configured for thermally conditioning a component (e.g., pumping heat from at least one electronic component, such as a battery, that can generate heat and/or has a performance that is sensitive to heat). The assembly 100 comprises first and second heat spreaders 110a,b (the second heat spreader 110b denoted by a dashed line in FIGs. 2A and 2B) spaced apart from one another. In certain embodiments, one or both of the first and second heat spreaders 110a,b can be in thermal communication with a heat exchanger 120 that is air-cooled, water-

cooled, and/or solid-cooled. The assembly 100 further comprises at least one thermoelectric sub-assembly 130 between and in thermal communication with (e.g., in contact with) the first and second heat spreaders 110a,b. For example, the first heat spreader 110a can be below the at least one thermoelectric sub-assembly 130 and the second heat spreader 110b can be above the at least one thermoelectric sub-assembly 130. While the portions of the example thermoelectric module assemblies 100 shown in FIGs. 2A and 2B each comprise one thermoelectric sub-assembly 130, in certain other embodiments, the assembly 100 can comprise other numbers (e.g., two or more) of thermoelectric sub-assemblies 130.

[0027] FIGs. 3A and 3B schematically illustrate the example thermoelectric sub-assemblies 130 of FIGs. 2A and 2B, respectively, in accordance with certain embodiments described herein. The at least one thermoelectric sub-assembly 130 comprises a printed circuit board (PCB) 200 comprising a plurality of electrical conduits 210 and a plurality of thermoelectric devices (TEDs) 300. Each TED 300 of the plurality of TEDs 300 has a first end portion 310 and a second end portion 320, the second end portion 320 opposite from the first end portion 310. The first end portion 310 is mechanically coupled to the PCB 200 and is in electrical communication with the plurality of electrical conduits 210, and the second end portion 320 is spaced from the PCB 200. While the thermoelectric sub-assemblies 130 shown in FIGs. 3A and 3B each comprise one PCB 200 and four TEDs 300, in certain other embodiments, the thermoelectric sub-assembly 130 can comprise other numbers (e.g., two or more) of PCBs 200 per thermoelectric sub-assembly 130 and/or other numbers (e.g., two, three, five or more) of TEDs 300 per thermoelectric sub-assembly 130.

[0028] In certain embodiments, the PCB 200 comprises a planar laminate structure having one or more electrically conductive layers (e.g., copper; aluminum; metal; metal alloy or composite) and one or more electrically insulating layers (e.g., fiberglass; resin; polymer; fibrous material preimpregnated with a resin material such as epoxy; solder mask). The one or more electrically conductive layers can be configured to provide the plurality of electrical conduits 210 which are in electrical communication with the plurality of TEDs 300. For example, portions of an electrically conductive layer can be electrically insulated from one another (e.g., with solder mask, plastic coating, conformal coating), and each of these portions can be in electrical communication with a corresponding TED 300, as

shown schematically in FIGs. 3A and 3B. At least some of the electrical conduits 210 are configured to provide electrical power to the TEDs 300. In certain embodiments, the PCB 200 comprises one or more alignment holes 220 configured to receive a corresponding one or more alignment protrusions (e.g., pins) extending from other portions of the assembly 100 (see, e.g., FIGs. 2A-2B and 3A-3B). For example, the one or more alignment holes 220 can be configured to mate with corresponding one or more alignment protrusions of a heat exchanger 120. The one or more alignment holes 220 and one or more alignment protrusions are configured to facilitate positioning of the thermoelectric sub-assembly 130 within the assembly 100. In certain embodiments, the PCB 200 is configured to hold in place (e.g., align and secure) the TEDs 300 and to eliminate cumbersome wire routing. In certain embodiments, the PCB 200 comprises a flexible, thin foil PCB.

[0029] In certain embodiments, at least some of the TEDs 300 are in series electrical communication with one another. For example, FIG. 4A schematically illustrates an example electrical configuration of the PCB 200 in which the electrical conduits 210 connect all of the TEDs 300 in series electrical communication with one another in accordance with certain embodiments described herein (e.g., as also shown in FIGs. 3A and 3B). In certain embodiments, at least some of the TEDs 300 are in parallel electrical communication with one another. For example, FIG. 4B schematically illustrates an example electrical configuration of the PCB 200 in which the electrical conduits 210 connect all of the TEDs 300 in parallel electrical communication with one another.

[0030] In certain embodiments, at least some of the TEDs 300 are in series electrical communication with one another and at least some of the TEDs 300 are in parallel electrical communication with one another. For example, FIG. 4C schematically illustrates an example electrical configuration of the PCB 200 in which the electrical conduits 210 include electrical switches and/or jumpers 211 on, for example, the PCB 200 to connect some of the TEDs 300 in series electrical communication with one another in accordance with certain embodiments described herein and connect the others TEDs 300 in parallel electrical communication with one another in accordance with certain embodiments described herein. A combination of series and parallel electrical connections of the TEDs 300 can be achieved by the PCB 200. The switches or jumpers 211 may be operated/controlled to connect all of

the TEDs 300 in series (for example, see FIG. 4A) or all of the TEDs 300 in parallel as discussed herein (for example, see FIG. 4B).

[0031] In certain embodiments, the PCB 200 and/or a controller (on the PCB 200 or separate from the PCB 200) can control a desired combination of series-parallel connections depending on, for example, input parameters as discussed herein, such as voltage, current, and/or temperatures, to improve operating efficiency of the TEDs 300. Operating longevity may also be improved when, for example, one or more of the TEDs 300 fail open (e.g., do not allow current to pass through after failure), the other TEDs 300 connected in parallel to the failed TED(s) 300 may continue operate as current continues to pass through the operating TEDs 300.

[0032] In certain embodiments, each TED 300 of the plurality of TEDs 300 comprises a thermally conductive first plate 330, a thermally conductive second plate 340, and a plurality of thermoelectric (TE) elements 350 in thermal communication with the first plate 330 and the second plate 340 and in a region between the first plate 330 and the second plate 340. In certain embodiments, each of the first plate 330 and the second plate 340 comprises a planar laminate structure (e.g., a printed circuit board) having one or more electrically conductive layers (e.g., copper; aluminum; metal; metal alloy or composite) and one or more electrically insulating layers (e.g., fiberglass; resin; polymer; fibrous material preimpregnated with a resin material such as epoxy). The one or more electrically conductive layers can be configured to provide electrical connections to the plurality of TE elements 350. For example, an outer electrically conductive layer of the one or more electrically conductive layers can comprise electrically conductive pads configured to be coupled (e.g., soldered) to the TE elements 350, and the pads can be in electrical communication with other pads (e.g., by electrically conductive lines formed by selective chemical etching of the electrically conductive layers and by electrically conductive vias formed through the electrically insulating layers). In certain embodiments, at least one TED 300 of the plurality of TEDs 300 has one or more heat radiative elements (e.g., fins) on at least one side of the TED 300.

[0033] In certain embodiments, each of the first plate 330 and the second plate 340 has an elongate shape, for example, a planar parallelogram shape (e.g., rhombus shape; rectangular shape; square shape) with four edges (e.g., a rectangular shape with two shorter

edges and two longer edges, as shown in FIGs. 2A-2B and 3A-3B). Each of the first plate 330 and the second plate 340 can have other planar shapes (e.g., polygonal) with other numbers of edges in accordance with certain embodiments described herein (e.g., triangular shapes with three edges; trapezoidal shapes with four edges; pentagonal shapes with five edges; hexagonal shapes with six edges; etc.). In certain embodiments, the first plate 330 has a first surface (e.g., a top surface of the first plate 330) configured to be in thermal communication with (e.g., in contact with) one of the first heat spreader 110a and the second heat spreader 110b and the second plate 340 has a second surface (e.g., a bottom surface of the second plate 340) configured to be in thermal communication with (e.g., in contact with) the other of the first heat spreader 110a and the second heat spreader 110b.

[0034] In certain embodiments, the plurality of TE elements 350 comprises p-type TE elements and n-type TE elements in electrical communication with one another through a plurality of shunts 352 (e.g., electrically conductive pads of the first plate 330 and the second plate 340). For example, the plurality of TE elements 350 can be arranged in a “stonehenge” configuration in which p-type and n-type TE elements 350 alternate with one another and are in series electrical communication with one another by shunts 352 which are alternately positioned on the first plate 330 and the second plate 340 such that electrical current can flow serially through the TE elements 350 and the shunts 352 in a serpentine fashion. In certain embodiments, the plurality of TE elements 350 are in thermal communication with the first plate 330 through the shunts 352 (e.g., electrically conductive pads) of the first plate 330 and in thermal communication with the second plate 340 through the shunts 352 (e.g., electrically conductive pads) of the second plate 340. In certain embodiments, some or all of a perimeter of the first plate 330 and the second plate 340 is sealed by at least one sealing material 360 (e.g., silicone; epoxy) which forms a seal (e.g., a water-tight seal; a hermetic seal) between a region containing the TE elements 350 between the first plate 330 and the second plate 340 and an environment surrounding the TED 300.

[0035] In certain embodiments, the PCB 200 is planar and each of the TEDs 300 of the thermoelectric sub-assembly 130 are planar. In certain such embodiments, the PCB 200 and the TEDs 300 are substantially planar with one another (e.g., as shown in FIGs. 2A-2B and 3A-3B), while in certain other embodiments, at least some of the TEDs 300 are not

planar with one another (e.g., are parallel with but offset from one another; are at a non-zero angle relative to one another) and/or the PCB 200 is not planar with one or more of the TEDs 300 (e.g., is parallel with but offset from one or more of the TEDs 300; is at a non-zero angle relative to one or more of the TEDs 300; is planar with one or more other TEDs 300).

[0036] In certain embodiments, at least a first TED 300 extends from the PCB 200 in a first direction and at least a second TED 300 extends from the PCB 200 in a second direction parallel to the first direction. In certain such embodiments, all of the TEDs 300 extend from the PCB 200 in directions that are parallel to one another. For example, as schematically illustrated by FIGs. 2A and 3A, two of the TEDs 300 extend from the PCB 200 in a first direction (e.g., towards the left) and two other TEDs 300 extend from the PCB 200 in a second direction (e.g., towards the right) which is opposite and parallel to the first direction. For another example, as schematically illustrated by FIGs. 2B and 3B, the four TEDs 300 all extend in the same direction (e.g., two of the TEDs 300 extending from the PCB 200 in FIG. 3B in a first downward direction and two other TEDs 300 extending from the PCB 200 in FIG. 3B in a second downward direction that is the same as the first downward direction). In certain other embodiments, each of the TEDs 300 extends from the PCB 200 in a corresponding direction that is not parallel to any of the directions in which the other TEDs 300 extend from the PCB 200.

[0037] The portions of the example thermoelectric module assemblies 100 shown in FIGs. 2A and 2B are coplanar with the thermoelectric sub-assembly 130 between and in thermal communication with the first and second heat spreaders 110a,b. As schematically illustrated in FIG. 2A, the first heat spreader 110a comprises a plurality of thermally conductive portions (e.g., generally rectangular islands), each of which is below and in thermal communication with a corresponding TED 300 of the assembly 100. As schematically illustrated in FIG. 2B, the first heat spreader 110a comprises a single continuous thermally conductive portion (e.g., a generally rectangular island) which is below and in thermal communication with the TEDs 300 of the assembly 100. In FIGs. 2A and 2B, the PCB 200 does not contact the first heat spreader 110a and comprises one or more alignment holes 220 which mate with one or more protrusions (e.g., alignment pins) which extend from one or more support surfaces beneath the PCB 200. The one or more support

surfaces and the one or more protrusions are configured to hold and support the PCB 200 such that the TEDs 300 extending from the PCB 200 are in mechanical and thermal communication with the first heat spreader 110a. FIGs. 2A and 2B do not show the second heat spreader 110b (e.g., which is above the PCB 200 and TEDs 300 of FIGs. 2A and 2B), but these figures use a dashed rectangular line to denote an area (e.g., footprint) of the second heat spreader 110b relative to the thermoelectric sub-assembly 130.

[0038] In certain embodiments, the first heat spreader 110a and the second heat spreader 110b are configured to transfer heat away from the component to be thermally conditioned. For example, the second heat spreader 110b can be configured to transfer heat to the TEDs 300 from the component to be thermally conditioned, and the first heat spreader 110a can be configured to transfer heat away from the TEDs 300. The second heat spreader 110b can comprise at least one first surface configured to be in thermal communication with the TEDs 300 and at least one second surface configured to be in thermal communication with the component to be thermally conditioned by the thermoelectric module assembly 100. The first heat spreader 110a can comprise at least one first surface configured to be in thermal communication with the TEDs 300. For example, at least one second surface of the first heat spreader 110a can comprise at least one heat dissipation structure (e.g., at least one fin) configured to transfer heat from the first heat spreader 110a to the ambient surroundings. For another example, the first heat spreader 110a can be configured to have a fluid coolant (e.g., liquid; air; refrigerant) flow therethrough. In certain embodiments, the second heat spreader 110b provides at least one cold side that receives heat from the component to be thermally conditioned and the first heat spreader 110a provides at least one hot side that serves as a heat sink which receives heat from the TEDs 300. In certain other embodiments, the first heat spreader 110a provides the at least one cold side and the second heat spreader 110b provides the at least one hot side.

[0039] In certain embodiments, the second heat spreader 110b (e.g., denoted by the dashed lines in FIGs. 2A and 2B) bounds a portion of a region between the first and second heat spreaders 110a,b, and the plurality of TEDs 300 is wholly within the region (e.g., as shown in FIGs. 2A and 2B). In certain embodiments, the assembly 100 further comprises at least one material (e.g., a sealing material; silicone; epoxy) extending along a perimeter of

the region between the first and second heat spreaders 110a,b and sealing (e.g., water-tight; hermetically) the region from ambient environment.

[0040] In certain embodiments, the PCB 200 extends from within the region to outside the region (e.g., as shown in FIG. 2A), while in certain other such embodiments, the PCB 200 is wholly within the region (e.g., as shown in FIG. 2B). Certain embodiments in which the PCB 200 extends across the perimeter of the region (see, e.g., FIG. 2A) such that the electrical connections between the PCB 200 (e.g., wire tabs 212) and the wires 140 are located outside the region (e.g., the sealed region) advantageously allow these electrical connections to be modified (e.g., repaired; replaced) without affecting the seal of the region and/or without further adversely impacting (e.g., disassembling) the thermoelectric module assembly 100. Certain embodiments in which the PCB 200 is wholly within the region (e.g., as shown in FIG. 2B) such that the electrical connections between the PCB 200 (e.g., wire tabs 212) and the wires 140 are located within the region (e.g., the sealed region) advantageously allow these electrical connections to be protected from the ambient environment.

[0041] In certain embodiments, the assembly 100 further comprises an insulator plate (not shown) comprising a thermally insulating material (e.g., polymer, plastic, rubber, and/or fiberglass) configured to be at least partially compressed by the first heat spreader 110a and the second heat spreader 110b during fabrication and during operation of the thermoelectric module assembly 100 while keeping the first heat spreader 110a and the second heat spreader 110b from contacting one another. In certain embodiments, the insulator plate generally surrounds the TEDs 300 and the PCB 200, and comprises at least one hole (e.g., cut-out) configured to accommodate the TEDs 300 and the at least one PCB 200. For example, the at least one hole can be configured to hold the at least one thermoelectric sub-assembly 130 such that the TEDs 300 are in thermal communication with the first and second heat spreaders 110a,b while the at least one PCB 200 is thermally insulated from the first and second heat spreaders 110a,b. In certain embodiments, the insulator plate is configured to allow the PCB 200 to extend from the TEDs 300 within the region between the first and second heat spreaders 110a,b to outside this region, while in certain other embodiments, the insulator plate is configured to allow the wires 140 to extend

from the PCB 200 within the region to outside the region (e.g., via a trench 160 as shown in FIG. 2B).

[0042] In certain embodiments, the assembly 100 further comprises a first thermally conductive material (e.g., copper layer, graphite foil, thermal grease, phase change material, gap filler) between and in thermal communication with the first heat spreader 110a and the first plates 330 of the TEDs 300 and/or a second thermally conductive material (e.g., copper layer, graphite foil, thermal grease, phase change material, gap filler; shown in FIG. 2B) between and in thermal communication with the second heat spreader 110b and the second plates 340 of the TEDs 300. In certain such embodiments, the holes of the insulator plate are configured to accommodate the first and second thermally conductive materials.

[0043] FIGs. 5A-5C schematically illustrate an exploded view of an example thermoelectric system in accordance with certain embodiments described herein. The thermoelectric system (e.g., a thermoelectric sub-assembly 130 as described herein with reference to FIGs. 2A-2B, 3A-3B, and 4A-4B) comprises a printed circuit board (PCB) 200 comprising a plurality of electrically conductive first tabs 230 at a surface of the PCB 200 and at least one thermoelectric device (TED) 300 mechanically coupled to the PCB 200. The at least one TED 300 comprises a thermally conductive first plate 330 and a thermally conductive second plate 340. The second plate 340 comprises a first portion 342 extending beyond a perimeter of the first plate 330 and over an edge 240 of the PCB 200 and over two first tabs 230 of the plurality of first tabs 230. The first portion 342 of the second plate 340 comprises two electrically conductive second tabs 344, each of the two second tabs 344 in mechanical and electrical communication with a corresponding first tab 230 of the two first tabs 230. The TED 300 further comprises a plurality of thermoelectric elements 350 in thermal communication with and in a region between the first plate 330 and the second plate 340.

[0044] In certain embodiments, the first tabs 230 comprise portions of the electrically conductive conduits 210 of the PCB 200, and the second tabs 344 comprise portions of the electrically conductive layers of the planar laminate structure (e.g., printed circuit board) of the second plate 340 of the TED 300. In certain embodiments, the first tabs 230 and the second tabs 344 are configured to be soldered together. For example, the first

tabs 230 and/or the second tabs 344 can comprise a solder material (e.g., solder with a hot air solder leveling (HASL) finish, solder preform, solder paste, solder flux, pre-flowed solder). FIG. 6 schematically illustrates an example soldering configuration in accordance with certain embodiments described herein. The top-left portion of FIG. 6 schematically illustrates an example mechanism (e.g., “solder robot”) for fabricating an example thermoelectric system (e.g., a thermoelectric sub-assembly 130 as shown in FIGs. 2A and 3A), in which the PCB 200 is positioned and held fixed (e.g., by two protrusions of a mounting fixture extending through the PCB 200). The four TEDs 300 are positioned such that the second tabs 344 (e.g., solder tabs) of the second plates 340 are over and contacting the first tabs 230 (e.g., solder tabs) of the PCB 200. A heat source (e.g., “hot bar”) of the mechanism is moved into position to press the corresponding first tabs 230 and second tabs 344 together while applying sufficient heat to allow flow of the solder of the first tabs 230 and the second tabs 344 and then removing the heat source, thereby affixing the second tabs 344 of the TED 300 to be in mechanical and electrical communication with the corresponding first tabs 230 of the PCB 200. In certain embodiments, the mechanism moves the heat source into position to repeat the soldering process for another TED 300. In certain embodiments, the mechanism can comprise multiple heat sources configured to solder multiple TEDs 300 to the PCB 200 simultaneously. In certain embodiments, a heated fixture is used to pre-warm the PCB 200 so that the solder reflow can be done with the heat source of the mechanism at a lower temperature, thereby facilitating soldering the second tabs 344 of the TEDs 300 to the first tabs 230 of the PCB 200.

[0045] The top-right portion of FIG. 6 schematically illustrates the first portion 342 of the second plate 340 of the TED 300 overlapping the edge 240 of the PCB 200 with the second tabs 344 of the TED 300 affixed to the first tabs 230 of the PCB 200. The PCB 200 comprises a plurality of electrical conduits 210 in electrical communication with the plurality of first tabs 230, with the plurality of electrical conduits 210 configured to provide electrical power to the at least one TED 300. For example, each of the two electrical conduits 210 shown in the top-right portion of FIG. 6 is in electrical communication with the TED 300 via the corresponding first tabs 230 and second tabs 344. The bottom portion of FIG. 6 schematically illustrates an example thermoelectric system (e.g., a thermoelectric sub-

assembly 130 as shown in FIGs. 2B and 3B) with the four TEDs 300 affixed to the surface of the PCB 200. In certain embodiments, the first plate 330 of the at least one TED 300 does not extend over the surface of the PCB 200.

[0046] FIG. 7A schematically illustrates a cross-sectional view of an example TED 300 in accordance with certain embodiments described herein. The first plate 330 of the TED 300 comprises first and second electrically and thermally conductive (e.g., copper) layers 336a,b laminated together with an electrically insulating (e.g., epoxy) layer 337 between the first and second layers 336a,b, and the second plate 340 of the TED 300 comprises first and second electrically conductive and thermally conductive (e.g., copper) layers 346a,b laminated together with an electrically insulating (e.g., epoxy) layer 347 between the first and second layers 346a,b. The second plate 340 further comprises second tabs 344 on the first portion 342 of the second plate 340. As shown in FIG. 7A, during the soldering process, the heat source (e.g., “hot bar”) can be positioned to apply heat to the first layer 346a on the first portion 342 of the second plate 340 while pressing the second tabs 344 to the corresponding first tabs 230 of the PCB 200 (not shown in FIG. 7A) such that the first tabs 230 and the second tabs 344 are soldered together. However, in certain embodiments, as the heat source is pressed against the first layer 346a on the first portion 342 of the second plate 340 to reflow the solder on the second tabs 344, which are on the opposite face of the first portion 342 (e.g., on the second layer 346b), heat is lost via heat conduction by the first layer 346a of the second plate 340. FIGs. 7B and 7C illustrate this heat conduction by arrows extending from the first portion 342 of the second plate 340 along the second plate 340.

[0047] FIGs. 7D-7F schematically illustrate an example electrically and thermally conductive first layer 346a of the second plate 340 in accordance with certain embodiments described herein. As schematically illustrated by FIG. 7D, the heat source of certain embodiments comprises a pair of protrusions configured to be pressed against corresponding portions of a first region of the first layer 346a above the second tabs 344 of the second plate 340. The first layer 346a comprises an etched region 348 (e.g., an etched line) extending at least partially across the first portion 342 of the second plate 340. The etched region 348 is configured to be positioned between the first region of the first layer 346a against which the heat source is pressed (e.g., a region above the second tabs 344) and a second region of the

first layer 346a extending away from the first region. The etched region 348 is configured to thermally insulate the second region of the first layer 346a from the first region of the first layer 346a (e.g., to reduce or prevent heat loss from the first region of the first layer 346a via heat conduction by the first layer 346a). For example, during the soldering process, the pair of protrusions of the heat source are pressed against the first region of the first layer 346a and heat up the solder material (e.g., solder with a hot air solder leveling (HASL) finish, solder preform, solder paste, solder flux, pre-flowed solder) of the second tabs 344 on the second layer 346b underneath the first region of the first layer 346a.

[0048] FIG. 7E schematically illustrates a top view of the first layer 346a and the etched region 348 in accordance with certain embodiments described herein and FIG. 7F schematically illustrates a perspective view of the first layer 346a and the etched region 348, with the first layer 346a and the electrically insulating layer 347 shown as being transparent so that the underlying second tabs 344 can be seen. As schematically illustrated by FIGs. 7E and 7F, the etched region 348 can at least partially bound two “tooth-shaped” areas of the first region of the first layer 346a, each above a corresponding second tab 344. Other shapes of the etched region 348 (e.g., linear; rectilinear; curved; serpentine) and the first region of the first layer 346a are also compatible with certain embodiments described herein. The width of the etched region 348 between the first and second regions of the first layer 346a is configured to provide sufficient thermal insulation to reduce (e.g., prevent) heat loss via heat conduction from the first region to the second region.

[0049] FIGs. 8A-8D schematically illustrate an example thermoelectric system in accordance with certain embodiments described herein. FIGs. 9A-9D schematically illustrate another example thermoelectric system in accordance with certain embodiments described herein. In certain embodiments (see, e.g., FIGs. 8A-8B and 9A-9B), the system comprises a gap 400 between the edge 240 of the PCB 200 and a first edge 370 of the at least one TED 300 and further comprises a compound 410 within the gap 400 and mechanically coupled to the edge 240 of the PCB 200 and the first edge 370 of the at least one TED 300. In certain embodiments, the gap 400 has a width (e.g., distance between the edge 240 of the PCB 200 and the first edge 370 of the TED 300) in a range of 0.3 mm to 2 mm or in a range of 0.3 mm to 1 mm (e.g., about 0.8 mm).

[0050] The compound 410 (e.g., sealing compound; epoxy) is configured to strengthen a mechanical coupling of the PCB 200 with the at least one TED 300 and to at least partially seal the two first tabs 230 and the two second tabs 344 that are in mechanical and electrical communication with the two first tabs 230. For example, the compound 410 can be inserted as a gel or liquid into the gap 400 after the TED 300 has been mounted to the PCB 200 (e.g., after the second tabs 344 of the TED 300 have been soldered to the corresponding first tabs 230 of the PCB 200), and the compound 410 can harden and affix to the first edge 370 of the TED 300 and to the edge 240 of the PCB 200 to form a rigid mechanical coupling between the TED 300 and the PCB 200. In certain embodiments (see, e.g., FIGs. 8B and 9B), the PCB 200 has a first thickness T_1 and the at least one TED 300 has a second thickness T_2 larger than the first thickness T_1 . In certain embodiments, the compound 410 has a third thickness T_3 within the gap 400 that is smaller than the second thickness T_2 of the TED 300, and in certain such embodiments, the third thickness T_3 is smaller than the first thickness T_1 of the PCB 200 (see, e.g., FIGs. 8B and 9B). By having the third thickness T_3 of the compound 410 less than the second thickness T_2 of the TED 300, certain embodiments advantageously avoid the compound 410 from contacting the top surface of the first plate 330 and potentially interfering with the thermal communication between the top surface of the first plate 330 and the heat spreader 110 that is in thermal communication with the top surface of the first plate 330 (e.g., either the first heat spreader 110a or the second heat spreader 110b).

[0051] In certain embodiments, as schematically illustrated by FIGs. 8B-8D, at least one of the PCB 200 and the first portion 342 of the second plate 340 comprises at least two trenches 420 configured to facilitate capillary flow of the compound 410 from the gap 400 to an area between the first portion 342 of the second plate 340 and the surface of the PCB 200. For example, as schematically illustrated by FIG. 8C, the first portion 342 of the second plate 340 can comprise a copper layer and the trenches 420 can comprise recesses which have been etched into the copper layer and which extend along a copper trace (e.g., having a width in a range of 2 mm to 3 mm) of the second tab 344. For example, the trenches 420 can be etched during the same etching process that is used to create the copper traces and the first tabs 230 of the PCB 200 and/or the copper traces and the second tabs 344

of the second plate 340. The trenches 420 can have a width (e.g., along a direction generally parallel to the first edge 370 of the TED 300) in a range of 0.5 mm to 1.5 mm (e.g., about 0.75 mm) with the second tabs 344 having a length (e.g., along a direction generally perpendicular to the first edge 370 of the TED 300) in a range of 2 mm to 5 mm (e.g., about 3 mm) and a width (e.g., along a direction generally parallel to the first edge 370 of the TED 300) in a range of 2 mm to 5 mm (e.g., about 3 mm). As schematically illustrated by FIG. 8D, the trenches 420 extend at least partially around the second tabs 344 and can be configured for capillary flow of the compound 410 through the trenches 420 (e.g., as shown by the dashed arrows of FIGs. 8B and 8D). In certain such embodiments, the compound 410 in the gap 400 and in the trenches 420 forms a seal (e.g., a hermetic seal) between the first and second tabs 230, 344 and the ambient environment.

[0052] Alternatively or in addition to the trenches 420 of the first portion 342 of the second plate 340 of the TED 300, the PCB 200 can comprise trenches at least partially around the first tabs 230 and configured to facilitate capillary flow of the compound 410 through the trenches. As schematically illustrated by FIGs. 8C and 8D, the trenches and the tabs (e.g., trenches 420 and second tabs 344) can have rounded corners (e.g., to facilitate the capillary flow of the compound 410 through the trenches). In certain embodiments, as schematically illustrated by FIG. 8D, the two trenches 420 can meet at an edge of the first portion 342 of the second plate 340, providing a port through which an excess portion of the compound 410 can flow out from between the PCB 200 and the first portion 342 of the second plate 340.

[0053] In certain embodiments, upon hardening, the compound 410 within the trenches 420 provides further strengthening of the mechanical coupling of the PCB 200 with the TED 300 and provide further sealing of the first and second tabs 230, 344. The trenches 420 can have a depth in a range of less than 200 microns or less than 100 microns (e.g., about 70 microns), which can correspond to the thickness of the copper layer which has been etched away to form the trenches 420. In certain embodiments, the remaining portions 422 of the copper layer on either side of the second tab 344, which remain after the etching of the trenches 420, advantageously provide further rigidity to the first portion 342 of the second plate 340.

[0054] In certain embodiments, as schematically illustrated by FIGs. 9B-9D, a coating 430 extends over the first surface of the PCB 200 and the first portion 342 of the second plate 340 of the at least one TED 300. The coating 430 is configured to strengthen a mechanical coupling of the PCB 200 with the at least one TED 300 and to at least partially seal the two first tabs 230 and the two second tabs 344 that are in mechanical and electrical communication with the two first tabs 230. The coating 430 (e.g., encapsulating coating; conformal coating; epoxy; silicone) can encapsulate and/or be conformal with the first portion 342 of the second plate 340 and the surface of the PCB 200, as schematically illustrated by FIGs. 9B-9D. In certain embodiments, the combination of the compound 410 in the gap 400 and the coating 430 over the first portion 342 of the second plate 340 and the surface of the PCB 200 form a seal (e.g., a hermetic seal) between the first and second tabs 230, 344 and the ambient environment. In certain such embodiments, the coating 430 is sufficiently thick to form the seal while being positioned and/or being sufficiently thin so as to not adversely interfere with the thermal communication between the bottom surface of the second plate 340 and the second heat spreader 110b. In certain embodiments, the coating 430 is configured to further strengthen the mechanical coupling of the PCB 200 with the TED 300.

[0055] FIGs. 10A-10C schematically illustrate an example thermoelectric system comprising wire encapsulation in accordance with certain embodiments described herein. As shown in FIGs. 10A-10C, the system comprises two electrically conductive wires 140, each wire 140 having an end in electrical communication with a corresponding first tab 230 of the plurality of first tabs 230 (e.g., wire tabs 212), and the wires 140 are configured to provide electrical power to the PCB 200. In certain embodiments, instead of wires 140, the PCB 200 can have a connector coupled (e.g., soldered; staked) to the PCB 200. The system shown in FIGs. 10A-10C further comprises a coating 440 (e.g., encapsulating coating; epoxy) covering the ends of the two wires 140. The coating 440 is configured to strengthen a mechanical coupling of the two wires 140 with the PCB 200 and to seal the ends of the two wires 140 (e.g., to hermetically seal the ends of the two wires 140 from the ambient environment). As shown in FIGs. 10B and 10C, the end of the wire 140 can comprise a portion of the electrically conductive wire 140 that is exposed (e.g., has the electrical insulation sheath 142

removed) and is in electrical communication with (e.g., soldered to) a corresponding electrical conduit 210 of the PCB 200 (e.g., wire tabs 212). In FIG. 10B, the exposed portion of the wire 140 is substantially straight, the wire 140 is positioned such that the sheath 142 is spaced from an edge of the PCB 200 by a gap 442, and the encapsulating coating 440 covers the exposed portion of the wire 140, a portion of the PCB 200 surrounding the exposed portion of the wire 140, and extends across the gap 442 to cover a portion of the sheath 142. In FIG. 10C, the exposed portion of the wire 140 is bent, the wire 140 is positioned such that the sheath 142 overlaps the edge of the PCB 200, and the encapsulating coating 440 covers the exposed portion of the wire 140, a portion of the sheath 142, and a portion of the PCB 200 surrounding the exposed portion of the wire 140 and the portion of the sheath 142.

[0056] FIGs. 11A-11C schematically illustrate an example TED 300 in accordance with certain embodiments described herein. The second plate 340 of the example TED 300 of FIGs. 11A-11C comprises a second portion 349 extending beyond the perimeter of the first plate 330, the second portion 349 (also shown as distance *D* in FIG. 11B) along a second edge 380 of the TED 300, the second edge 380 opposite to the first edge 370 of the TED 300. The TED 300 further comprises a sealant 360a (e.g., epoxy; silicone) between the first plate 330 and the second plate 340 along the first edge 370 of the TED 300 and a sealant 360b along the second edge 380 of the TED 300. In FIG. 11A, a dispensing system comprising a dispensing needle 500 (e.g., either positioned substantially perpendicular to the first edge 370 or at another non-zero angle relative to the first edge 370) is used to deposit the sealant 360a between the first plate 330 and the second plate 340 along the first edge 370 of the TED 300. One or both of the dispensing needle 500 and the TED 300 can be moved relative to the other to deposit the sealant 360a,b between the first plate 330 and the second plate 340 along other edges of the TED 300. In certain other embodiments, the dispensing system can use other dispensing methods, including but not limited to, jetting (e.g., analogous to ink jet printing). As schematically illustrated by FIGs. 11B and 11C, along the second edge 380 of the TED 300 opposite to the first edge 370 of the TED 300, the second plate 340 extends (e.g., overhangs) the perimeter of the first plate 330 (e.g., by a distance *D* in a range less than 1 mm or in a range of 0.2 mm to 1 mm; by about 0.5 mm), thereby providing a portion 349 of the second plate 340 that can advantageously facilitate dispensing of the

sealant 360b along the second edge 380 of the TED 300. In certain embodiments, the sealant 360a deposited along the first edge 370 of the TED 300 is the same as the sealant 360b deposited along the second edge 380 of the TED 300, while in certain other embodiments, the sealant 360a deposited along the first edge 370 is different from the sealant 360b deposited along the second edge 380. In certain embodiments, the sealant 360b is also applied along the other two sides of the TED 300 (e.g., the two longer sides of the TED 300).

[0057] FIGs. 12A and 12B schematically illustrate an example thermoelectric system comprising electrical conduits 210a,b in accordance with certain embodiments described herein. The example thermoelectric system (e.g., a thermoelectric sub-assembly 130 as described herein with reference to FIGs. 2A-2B, 3A-3B, and 4A-4B) comprises a plurality of TEDs 300, each TED 300 of the plurality of TEDs 300 comprising a thermally conductive first plate 330, a thermally conductive second plate 340, and a plurality of TE elements 350 in thermal communication with and in a region between the first plate 330 and the second plate 340. The example thermoelectric system further comprises a PCB 200 comprising a plurality of first electrical conduits 210a and a plurality of second electrical conduits 210b. The first electrical conduits 210a are in electrical communication with the TE elements 350 of the plurality of TEDs 300 (e.g., and are configured to provide electrical power to the TE elements 350 of the plurality of TEDs 300). The second electrical conduits 210b are in electrical communication with at least one thermal sensor 600 (e.g., thermocouple; thermistor; negative-temperature-coefficient thermistor) on at least one TED 300 of the plurality of TEDs 300 and/or on the PCB 200. By providing a PCB 200 which integrates the first electrical conduits 210a configured to transmit power to the TE elements 350 and the second electrical conduits 210b configured to transmit signals from the thermal sensors 600, certain such embodiments advantageously simplify the wiring for the thermoelectric module assembly 100.

[0058] In the example system shown in FIG. 12A, the second electrical conduits 210b comprise four pairs of electrical conduits 210b, each pair in electrical communication with a corresponding thermal sensor 600 on a corresponding one of the four TEDs 300. The dashed lines of one of the TEDs 300 in FIG. 12A show the second tabs 344 on the first portion 342 of the second plate 340 and the shunts 352 on the second plate 340 in the region

between the first plate 330 and the second plate 340. In certain embodiments, each of the second electrical conduits 210b comprises a solder tab (not shown in FIG. 12A) at an end located at the edge of the PCB 200 beneath the first portion 342 of the second plate 340 of the TED 300, the solder tabs configured to be soldered to corresponding solder tabs (not shown in FIG. 12A) of the second plate 340 of the TED 300. The other end of each second electrical conduit 210b can comprise an electrical connector (e.g., solder tab; not shown in FIG. 12A) that can be configured to be soldered to a corresponding wire or can be configured to mate with an electrical connector.

[0059] In the example system shown in FIG. 12B, the second electrical conduits 210b comprise two pairs of electrical conduits 210b, each pair in electrical communication with a corresponding thermal sensor 600 on the PCB 200. In certain embodiments, each of the second electrical conduits 210b comprises an electrical connection (e.g., solder tab; not shown in FIG. 12B) at an end located at the edge of the PCB 200. The electrical connection can be configured to be soldered to a corresponding wire or can be configured to mate with an electrical connector.

[0060] As schematically illustrated by FIGs. 12A and 12B, in certain embodiments, the second electrical conduits 210b extend between the first electrical conduits 210a. For example, a first set of the first electrical conduits 210a can extend along a first edge of the PCB 200 and a second set of the first electrical conduits 210a extend along a second edge of the PCB 200, the second edge opposite to the first edge, and at least some of the second electrical conduits 210b can extend between the first set of the first electrical conduits 210a and the second set of the first electrical conduits 210a (e.g., with portions of the second electrical conduits 210b parallel and adjacent to one another without the first electrical conduits 210a therebetween). In certain embodiments, the PCB 200 comprises at least one hole 220 extending through the PCB 200 (e.g., configured to mate with a corresponding protrusion of a mounting fixture and/or the thermoelectric module assembly 100), and the second electrical conduits 210b comprise curved portions that extend at least partially around the at least one hole 220.

[0061] FIG. 13 is a flow diagram of an example method 700 of fabricating at least one thermoelectric sub-assembly 130 comprising a printed circuit board 200 and a plurality

of thermoelectric devices 300 in accordance with certain embodiments described herein. In an operational block 710, the method 700 comprises providing the printed circuit board 200. The printed circuit board 200 comprises a plurality of electrical conduits 210 and a plurality of electrically conductive first tabs 230 in electrical communication with the plurality of electrical conduits 210. In an operational block 720, the method 700 further comprises providing the plurality of thermoelectric devices 300. Each thermoelectric device 300 comprises a first end portion 310 and a second end portion 320. The second end portion 320 is opposite to the first end portion 310, and the first end portion 310 comprises at least two electrically conductive second tabs 344. In an operational block 730, the method 700 further comprises mechanically coupling the at least two second tabs 344 of each thermoelectric device 300 of the plurality of thermoelectric devices 300 to corresponding first tabs 230 of the printed circuit board 200 such that the at least two second tabs 344 are in electrical communication with the corresponding first tabs 230 and the second end portion 320 is spaced from the printed circuit board 200.

[0062] FIG. 14 is a flow diagram of an example method 800 of fabricating a thermoelectric device 300 comprising a first plate 330, a second plate 340, and a plurality of thermoelectric elements 350 between and in electrical communication between the first plate 330 and the second plate 340 in accordance with certain embodiments described herein. In an operational block 810, the method 800 comprises providing the thermoelectric device 300. The second plate 340 extends beyond a perimeter of the first plate 330 along a portion 349 (e.g., a second edge 380) of the thermoelectric device 300. In an operational block 820, the method 800 further comprises applying a first sealant 360a between the first plate 330 and the second plate 340 along the portion 349.

[0063] Discussion of the various embodiments herein has generally followed the embodiments schematically illustrated in the figures. However, it is contemplated that the particular features, structures, or characteristics of any embodiments discussed herein may be combined in any suitable manner in one or more separate embodiments not expressly illustrated or described. In many cases, structures that are described or illustrated as unitary or contiguous can be separated while still performing the function(s) of the unitary structure. In many instances, structures that are described or illustrated as separate can be joined or

combined while still performing the function(s) of the separated structures. Various features and aspects of the disclosed embodiments can be combined with or substituted for one another. Any methods disclosed herein need not be performed in the order recited.

[0064] The ranges disclosed herein also encompass any and all overlap, sub-ranges, and combinations thereof. Language such as “up to,” “at least,” “greater than,” “less than,” “between,” and the like includes the number recited. With respect to the use of any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity. In general, terms used herein are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). If a specific number is intended, such an intent will be explicitly recited in the embodiment, and in the absence of such recitation, no such intent is present.

[0065] The following is a list of example numbered embodiments. The features recited in the below list of example embodiments can be combined with additional features disclosed herein. Furthermore, additional inventive combinations of features are disclosed herein, which are not specifically recited in the below list of example embodiments and which do not include the same features as the specific embodiments listed below. For sake of brevity, the below list of example embodiments does not identify every inventive aspect of this disclosure. The below list of example embodiments are not intended to identify key features or essential features of any subject matter described herein.

1. A thermoelectric module assembly for thermally conditioning a component, the assembly comprising:

first and second heat spreaders spaced apart from one another;

at least one thermoelectric sub-assembly between and in thermal communication with the first and second heat spreaders, the at least one thermoelectric sub-assembly comprising:

a printed circuit board comprising a plurality of electrical conduits; and

a plurality of thermoelectric devices, each thermoelectric device of the plurality of thermoelectric devices with a first end portion and a second end portion, the second end portion opposite from the first end portion, the first end portion mechanically coupled to the printed circuit board and in electrical communication with the plurality of electrical conduits, the second end portion spaced from the printed circuit board.

2. The assembly of embodiment 1, wherein each thermoelectric device of the plurality of thermoelectric devices comprises a thermally conductive first plate, a thermally conductive second plate, and a plurality of thermoelectric elements in thermal communication with the first plate and the second plate and in a region between the first plate and the second plate.

3. The assembly of embodiment 1 or 2, further comprising an insulator plate between the first and second heat spreaders, the insulator plate having at least one hole configured to hold the at least one thermoelectric sub-assembly.

4. The assembly of any one of embodiments 1 to 3, wherein the printed circuit board and the thermoelectric devices are substantially planar with one another.

5. The assembly of embodiment 4, wherein at least a first thermoelectric device of the plurality of thermoelectric devices extends from the printed circuit board in a first direction and at least a second thermoelectric device of the plurality of thermoelectric devices extends from the printed circuit board in a second direction parallel to the first direction.

6. The assembly of embodiment 5, wherein the second direction is opposite to the first direction.

7. The assembly of any one of embodiments 1 to 6, wherein the first and second heat spreaders bound a region between the first and second heat spreaders, the plurality of thermoelectric devices wholly within the region.

8. The assembly of embodiment 7, wherein the printed circuit board extends from within the region to outside the region.

9. The assembly of embodiment 7 or 8, wherein the printed circuit board is wholly within the region.

10. The assembly of any one of embodiments 7 to 9, further comprising at least one material in mechanical communication with the first heat spreader and the second heat spreader, the at least one material extending along a perimeter of the region and sealing the region.

11. The assembly of any one of embodiments 1 to 10, wherein at least some of the thermoelectric devices of the plurality of thermoelectric devices are in series electrical communication with one another.

12. The assembly of embodiment 11, wherein all of the thermoelectric devices of the plurality of thermoelectric devices are in series electrical communication with one another.

13. The assembly of any one of embodiments 1 to 12, wherein at least some of the thermoelectric devices of the plurality of thermoelectric devices are in parallel electrical communication with one another.

14. The assembly of embodiment 13, wherein all of the thermoelectric devices of the plurality of thermoelectric devices are in parallel electrical communication with one another.

15. The assembly of any one of embodiments 1 to 14, further comprising electrical switches in electrical communication with the plurality of thermoelectric devices, the electrical switches configured to place at least some of the plurality of thermoelectric in parallel electrical communication and the other of the plurality of thermoelectric in series electrical communication.

16. The assembly of embodiment 15, wherein the electrical switches are configured to place at least some of the plurality of thermoelectric in series electrical communication and the other of the plurality of thermoelectric in parallel electrical communication.

17. The assembly of any one of embodiments 1 to 16, further comprising a heat exchanger in thermal communication with the first heat spreader or the second heat spreader, wherein the printed circuit board comprises one or more holes configured to mate with corresponding one or more protrusions of the heat exchanger.

18. A thermoelectric system comprising:

a printed circuit board comprising a plurality of electrically conductive first tabs at a surface of the printed circuit board; and

at least one thermoelectric device mechanically coupled to the printed circuit board, the at least one thermoelectric device comprising:

a thermally conductive first plate;

a thermally conductive second plate comprising a first portion extending beyond a perimeter of the first plate and over an edge of the printed circuit board and over two first tabs of the plurality of first tabs, the first portion comprising two electrically conductive second tabs, each of the two second tabs in mechanical and electrical communication with a corresponding first tab of the two first tabs; and

a plurality of thermoelectric elements in thermal communication with and in a region between the first plate and the second plate.

19. The system of embodiment 18, wherein the first plate of the at least one thermoelectric device does not extend over the surface of the printed circuit board.

20. The system of embodiment 18 or 19, wherein the printed circuit board comprises a plurality of electrical conduits in electrical communication with the plurality of first tabs, the plurality of electrical conduits configured to provide electrical power to the at least one thermoelectric device.

21. The system of any one of embodiments 18 to 20, wherein the printed circuit board has a first thickness and the at least one thermoelectric device has a second thickness larger than the first thickness.

22. The system of any one of embodiments 18 to 21, further comprising a gap between the edge of the printed circuit board and a first edge of the at least one thermoelectric device, the system further comprising a compound within the gap and mechanically coupled to the edge of the printed circuit board and the first edge of the at least one thermoelectric device, the compound is configured to strengthen a mechanical coupling of the printed circuit board with the at least one thermoelectric device and to at least partially seal the two first tabs and the two second tabs that are in mechanical and electrical communication with two first tabs.

23. The system of embodiment 22, wherein at least one of the printed circuit board and the first portion of the second plate comprises at least two trenches configured to

facilitate capillary flow of the compound from the gap to an area between the first portion of the second plate and the surface of the printed circuit board.

24. The system of embodiment 23, wherein the at least two trenches are on the printed circuit board and extend at least partially around the two first tabs and/or the at least two trenches are on the first portion of the second plate and extend at least partially around the two second tabs.

25. The system of any one of embodiments 22 to 24, further comprising a coating extending over the surface of the printed circuit board and the first portion of the second plate of the at least one thermoelectric device, the coating configured to strengthen a mechanical coupling of the printed circuit board with the at least one thermoelectric device and to at least partially seal the two first tabs and the two second tabs that are in mechanical and electrical communication with the two first tabs.

26. The system of any one of embodiments 22 to 25, wherein the second plate comprising a second portion extending beyond the perimeter of the first plate, the second portion along a second edge of the at least one thermoelectric device, the second edge opposite to the first edge, the at least one thermoelectric device further comprises a sealant between the first plate and the second plate along the first edge of the at least one thermoelectric device and along the second edge of the at least one thermoelectric device.

27. The system of any one of embodiments 18 to 26, further comprising:

two electrically conductive wires, each wire having an end in electrical communication with a corresponding first tab of the plurality of first tabs, the wires configured to provide electrical power to the printed circuit board; and

a coating covering the ends of the two wires, the coating configured to strengthen a mechanical coupling of the two wires with the printed circuit board and to seal the ends of the two wires.

28. The system of any one of embodiments 18 to 27, wherein the second plate comprises an electrically and thermally conductive first layer and an electrically and thermally conductive second layer, the first and second layers laminated together with an electrically insulating layer therebetween, the first layer comprising an etched region

extending at least partially across the first portion of the second plate, the two electrically conductive second tabs on the second layer.

29. A thermoelectric system comprising:

a plurality of thermoelectric devices, each thermoelectric device of the plurality of thermoelectric devices comprising a thermally conductive first plate, a thermally conductive second plate, and a plurality of thermoelectric elements in thermal communication with and in a region between the first plate and the second plate; and

a printed circuit board comprising a plurality of first electrical conduits and a plurality of second electrical conduits, the first electrical conduits in electrical communication with the thermoelectric elements of the plurality of thermoelectric devices, the second electrical conduits in electrical communication with at least one thermal sensor on at least one thermoelectric device of the plurality of thermoelectric devices and/or on the printed circuit board.

30. The system of embodiment 29, wherein the first electrical conduits are configured to provide electrical power to the thermoelectric elements of the plurality of thermoelectric devices.

31. The system of embodiment 29 or 30, wherein the second electrical conduits extend between the first electrical conduits.

32. The system of embodiment 31, wherein a first set of the first electrical conduits extend along a first edge of the printed circuit board and a second set of the first electrical conduits extend along a second edge of the printed circuit board, the second edge opposite to the first edge, at least some of the second electrical conduits extending between the first set of the first electrical conduits and the second set of the first electrical conduits.

33. The system of any one of embodiments 29 to 32, wherein the printed circuit board further comprises at least one hole extending through the printed circuit board, the second electrical conduits comprising curved portions extending at least partially around the at least one hole.

34. The system of any one of embodiments 29 to 33, wherein portions of the second electrical conduits are parallel and adjacent to one another without the first electrical conduits therebetween.

35. A method of fabricating at least one thermoelectric sub-assembly comprising a printed circuit board and a plurality of thermoelectric devices, the method comprising:

providing the printed circuit board, the printed circuit board comprising a plurality of electrical conduits and a plurality of electrically conductive first tabs in electrical communication with the plurality of electrical conduits;

providing the plurality of thermoelectric devices, each thermoelectric device comprising a first end portion and a second end portion, the second end portion opposite to the first end portion, the first end portion comprising at least two electrically conductive second tabs; and

mechanically coupling the at least two second tabs of each thermoelectric device of the plurality of thermoelectric devices to corresponding first tabs of the printed circuit board such that the at least two second tabs are in electrical communication with the corresponding first tabs and the second end portion spaced from the printed circuit board.

36. The method of embodiment 35, wherein the at least two second tabs and/or the corresponding first tabs comprises a solder material and said mechanically coupling the at least two second tabs to the corresponding first tabs comprises soldering the at least two second tabs to the corresponding first tabs.

37. The method of embodiment 36, wherein said soldering comprises positioning the at least two second tabs to contact the corresponding first tabs and pressing the at least two second tabs and the corresponding first tabs together while using a heat source to apply sufficient heat to allow flow of the solder material, and then removing the heat source.

38. The method of embodiment 37, wherein the at least two second tabs are on a first side of a plate of the thermoelectric device, the plate comprising a second side opposite to the first side, the second side comprising an electrically and thermally conductive first layer comprising an etched region extending at least partially across the first layer between a first region of the first layer against which the heat source is pressed and a second region of the

first layer extending away from the first region, the etched region configured to thermally insulate the second region from the first region.

39. The method of any one of embodiments 36 to 38, further comprising, after soldering the at least two second tabs to the corresponding first tabs, placing a compound within a gap between an edge of the printed circuit board and an edge of the first end portion of the thermoelectric device, and flowing the compound to at least partially seal the at least two second tabs and the corresponding first tabs and hardening the compound to strengthen a mechanical coupling of the printed circuit board with the thermoelectric device.

40. A method of fabricating a thermoelectric device comprising a first plate, a second plate, and a plurality of thermoelectric elements between and in electrical communication between the first plate and the second plate, the method comprising:

providing the thermoelectric device, the second plate extending beyond a perimeter of the first plate along at least a portion of the thermoelectric device; and

applying a first sealant between the first plate and the second plate along the portion.

41. The method of embodiment 40, wherein the first sealant comprises epoxy and/or silicone.

42. The method of embodiment 40 or 41, wherein the thermoelectric device comprises a first edge and a second edge opposite to the first edge, the portion of the thermoelectric device comprising the second edge.

43. The method of embodiment 42, wherein the method further comprises applying a second sealant between the first plate and the second plate along the first edge.

44. The method of embodiment 43, wherein said applying the second sealant comprises using a dispensing needle to place the second sealant along the first edge.

[0066] Various embodiments have been described above. Although the inventions have been described with reference to these specific embodiments, the descriptions are intended to be illustrative and are not intended to be limiting. Various modifications and applications may occur to those skilled in the art without departing from the spirit and scope of the inventions as defined in the appended claims.

WHAT IS CLAIMED IS:

1. A thermoelectric module assembly for thermally conditioning a component, the assembly comprising:

first and second heat spreaders spaced apart from one another;

at least one thermoelectric sub-assembly between and in thermal communication with the first and second heat spreaders, the at least one thermoelectric sub-assembly comprising:

a printed circuit board comprising a plurality of electrical conduits; and

a plurality of thermoelectric devices, each thermoelectric device of the plurality of thermoelectric devices with a first end portion and a second end portion, the second end portion opposite from the first end portion, the first end portion mechanically coupled to the printed circuit board and in electrical communication with the plurality of electrical conduits, the second end portion spaced from the printed circuit board.

2. The assembly of claim 1, wherein each thermoelectric device of the plurality of thermoelectric devices comprises a thermally conductive first plate, a thermally conductive second plate, and a plurality of thermoelectric elements in thermal communication with the first plate and the second plate and in a region between the first plate and the second plate.

3. The assembly of claim 1 or 2, further comprising an insulator plate between the first and second heat spreaders, the insulator plate having at least one hole configured to hold the at least one thermoelectric sub-assembly.

4. The assembly of any one of claims 1 to 3, wherein the printed circuit board and the thermoelectric devices are substantially planar with one another.

5. The assembly of claim 4, wherein at least a first thermoelectric device of the plurality of thermoelectric devices extends from the printed circuit board in a first direction and at least a second thermoelectric device of the plurality of thermoelectric devices extends from the printed circuit board in a second direction parallel to the first direction.

6. The assembly of claim 5, wherein the second direction is opposite to the first direction.

7. The assembly of any one of claims 1 to 6, wherein the first and second heat spreaders bound a region between the first and second heat spreaders, the plurality of thermoelectric devices wholly within the region.

8. The assembly of claim 7, wherein the printed circuit board extends from within the region to outside the region.

9. The assembly of claim 7 or 8, wherein the printed circuit board is wholly within the region.

10. The assembly of any one of claims 7 to 9, further comprising at least one material in mechanical communication with the first heat spreader and the second heat spreader, the at least one material extending along a perimeter of the region and sealing the region.

11. The assembly of any one of claims 1 to 10, wherein at least some of the thermoelectric devices of the plurality of thermoelectric devices are in series electrical communication with one another.

12. The assembly of claim 11, wherein all of the thermoelectric devices of the plurality of thermoelectric devices are in series electrical communication with one another.

13. The assembly of any one of claims 1 to 12, wherein at least some of the thermoelectric devices of the plurality of thermoelectric devices are in parallel electrical communication with one another.

14. The assembly of claim 13, wherein all of the thermoelectric devices of the plurality of thermoelectric devices are in parallel electrical communication with one another.

15. The assembly of any one of claims 1 to 14, further comprising electrical switches in electrical communication with the plurality of thermoelectric devices, the electrical switches configured to place at least some of the plurality of thermoelectric in parallel electrical communication and the other of the plurality of thermoelectric in series electrical communication.

16. The assembly of claim 15, wherein the electrical switches are configured to place at least some of the plurality of thermoelectric in series electrical communication and the other of the plurality of thermoelectric in parallel electrical communication.

17. The assembly of any one of claims 1 to 16, further comprising a heat exchanger in thermal communication with the first heat spreader or the second heat spreader, wherein the

printed circuit board comprises one or more holes configured to mate with corresponding one or more protrusions of the heat exchanger.

18. A thermoelectric system comprising:

a printed circuit board comprising a plurality of electrically conductive first tabs at a surface of the printed circuit board; and

at least one thermoelectric device mechanically coupled to the printed circuit board, the at least one thermoelectric device comprising:

a thermally conductive first plate;

a thermally conductive second plate comprising a first portion extending beyond a perimeter of the first plate and over an edge of the printed circuit board and over two first tabs of the plurality of first tabs, the first portion comprising two electrically conductive second tabs, each of the two second tabs in mechanical and electrical communication with a corresponding first tab of the two first tabs; and

a plurality of thermoelectric elements in thermal communication with and in a region between the first plate and the second plate.

19. The system of claim 18, wherein the first plate of the at least one thermoelectric device does not extend over the surface of the printed circuit board.

20. The system of claim 18 or 19, wherein the printed circuit board comprises a plurality of electrical conduits in electrical communication with the plurality of first tabs, the plurality of electrical conduits configured to provide electrical power to the at least one thermoelectric device.

21. The system of any one of claims 18 to 20, wherein the printed circuit board has a first thickness and the at least one thermoelectric device has a second thickness larger than the first thickness.

22. The system of any one of claims 18 to 21, further comprising a gap between the edge of the printed circuit board and a first edge of the at least one thermoelectric device, the system further comprising a compound within the gap and mechanically coupled to the edge of the printed circuit board and the first edge of the at least one thermoelectric device, the compound is configured to strengthen a mechanical coupling of the printed circuit board with

the at least one thermoelectric device and to at least partially seal the two first tabs and the two second tabs that are in mechanical and electrical communication with two first tabs.

23. The system of claim 22, wherein at least one of the printed circuit board and the first portion of the second plate comprises at least two trenches configured to facilitate capillary flow of the compound from the gap to an area between the first portion of the second plate and the surface of the printed circuit board.

24. The system of claim 23, wherein the at least two trenches are on the printed circuit board and extend at least partially around the two first tabs and/or the at least two trenches are on the first portion of the second plate and extend at least partially around the two second tabs.

25. The system of any one of claims 22 to 24, further comprising a coating extending over the surface of the printed circuit board and the first portion of the second plate of the at least one thermoelectric device, the coating configured to strengthen a mechanical coupling of the printed circuit board with the at least one thermoelectric device and to at least partially seal the two first tabs and the two second tabs that are in mechanical and electrical communication with the two first tabs.

26. The system of any one of claims 22 to 25, wherein the second plate comprising a second portion extending beyond the perimeter of the first plate, the second portion along a second edge of the at least one thermoelectric device, the second edge opposite to the first edge, the at least one thermoelectric device further comprises a sealant between the first plate and the second plate along the first edge of the at least one thermoelectric device and along the second edge of the at least one thermoelectric device.

27. The system of any one of claims 18 to 26, further comprising:

two electrically conductive wires, each wire having an end in electrical communication with a corresponding first tab of the plurality of first tabs, the wires configured to provide electrical power to the printed circuit board; and

a coating covering the ends of the two wires, the coating configured to strengthen a mechanical coupling of the two wires with the printed circuit board and to seal the ends of the two wires.

28. The system of any one of claims 18 to 27, wherein the second plate comprises an electrically and thermally conductive first layer and an electrically and thermally conductive second layer, the first and second layers laminated together with an electrically insulating layer therebetween, the first layer comprising an etched region extending at least partially across the first portion of the second plate, the two electrically conductive second tabs on the second layer.

29. A thermoelectric system comprising:

a plurality of thermoelectric devices, each thermoelectric device of the plurality of thermoelectric devices comprising a thermally conductive first plate, a thermally conductive second plate, and a plurality of thermoelectric elements in thermal communication with and in a region between the first plate and the second plate; and

a printed circuit board comprising a plurality of first electrical conduits and a plurality of second electrical conduits, the first electrical conduits in electrical communication with the thermoelectric elements of the plurality of thermoelectric devices, the second electrical conduits in electrical communication with at least one thermal sensor on at least one thermoelectric device of the plurality of thermoelectric devices and/or on the printed circuit board.

30. The system of claim 29, wherein the first electrical conduits are configured to provide electrical power to the thermoelectric elements of the plurality of thermoelectric devices.

31. The system of claim 29 or 30, wherein the second electrical conduits extend between the first electrical conduits.

32. The system of claim 31, wherein a first set of the first electrical conduits extend along a first edge of the printed circuit board and a second set of the first electrical conduits extend along a second edge of the printed circuit board, the second edge opposite to the first edge, at least some of the second electrical conduits extending between the first set of the first electrical conduits and the second set of the first electrical conduits.

33. The system of any one of claims 29 to 32, wherein the printed circuit board further comprises at least one hole extending through the printed circuit board, the second electrical conduits comprising curved portions extending at least partially around the at least one hole.

34. The system of any one of claims 29 to 33, wherein portions of the second electrical conduits are parallel and adjacent to one another without the first electrical conduits therebetween.

35. A method of fabricating at least one thermoelectric sub-assembly comprising a printed circuit board and a plurality of thermoelectric devices, the method comprising:

providing the printed circuit board, the printed circuit board comprising a plurality of electrical conduits and a plurality of electrically conductive first tabs in electrical communication with the plurality of electrical conduits;

providing the plurality of thermoelectric devices, each thermoelectric device comprising a first end portion and a second end portion, the second end portion opposite to the first end portion, the first end portion comprising at least two electrically conductive second tabs; and

mechanically coupling the at least two second tabs of each thermoelectric device of the plurality of thermoelectric devices to corresponding first tabs of the printed circuit board such that the at least two second tabs are in electrical communication with the corresponding first tabs and the second end portion spaced from the printed circuit board.

36. The method of claim 35, wherein the at least two second tabs and/or the corresponding first tabs comprises a solder material and said mechanically coupling the at least two second tabs to the corresponding first tabs comprises soldering the at least two second tabs to the corresponding first tabs.

37. The method of claim 36, wherein said soldering comprises positioning the at least two second tabs to contact the corresponding first tabs and pressing the at least two second tabs and the corresponding first tabs together while using a heat source to apply sufficient heat to allow flow of the solder material, and then removing the heat source.

38. The method of claim 37, wherein the at least two second tabs are on a first side of a plate of the thermoelectric device, the plate comprising a second side opposite to the first

side, the second side comprising an electrically and thermally conductive first layer comprising an etched region extending at least partially across the first layer between a first region of the first layer against which the heat source is pressed and a second region of the first layer extending away from the first region, the etched region configured to thermally insulate the second region from the first region.

39. The method of any one of claims 36 to 38, further comprising, after soldering the at least two second tabs to the corresponding first tabs, placing a compound within a gap between an edge of the printed circuit board and an edge of the first end portion of the thermoelectric device, and flowing the compound to at least partially seal the at least two second tabs and the corresponding first tabs and hardening the compound to strengthen a mechanical coupling of the printed circuit board with the thermoelectric device.

40. A method of fabricating a thermoelectric device comprising a first plate, a second plate, and a plurality of thermoelectric elements between and in electrical communication between the first plate and the second plate, the method comprising:

providing the thermoelectric device, the second plate extending beyond a perimeter of the first plate along at least a portion of the thermoelectric device; and

applying a first sealant between the first plate and the second plate along the portion.

41. The method of claim 40, wherein the first sealant comprises epoxy and/or silicone.

42. The method of claim 40 or 41, wherein the thermoelectric device comprises a first edge and a second edge opposite to the first edge, the portion of the thermoelectric device comprising the second edge.

43. The method of claim 42, wherein the method further comprises applying a second sealant between the first plate and the second plate along the first edge.

44. The method of claim 43, wherein said applying the second sealant comprises using a dispensing needle to place the second sealant along the first edge.

FIG. 1A:

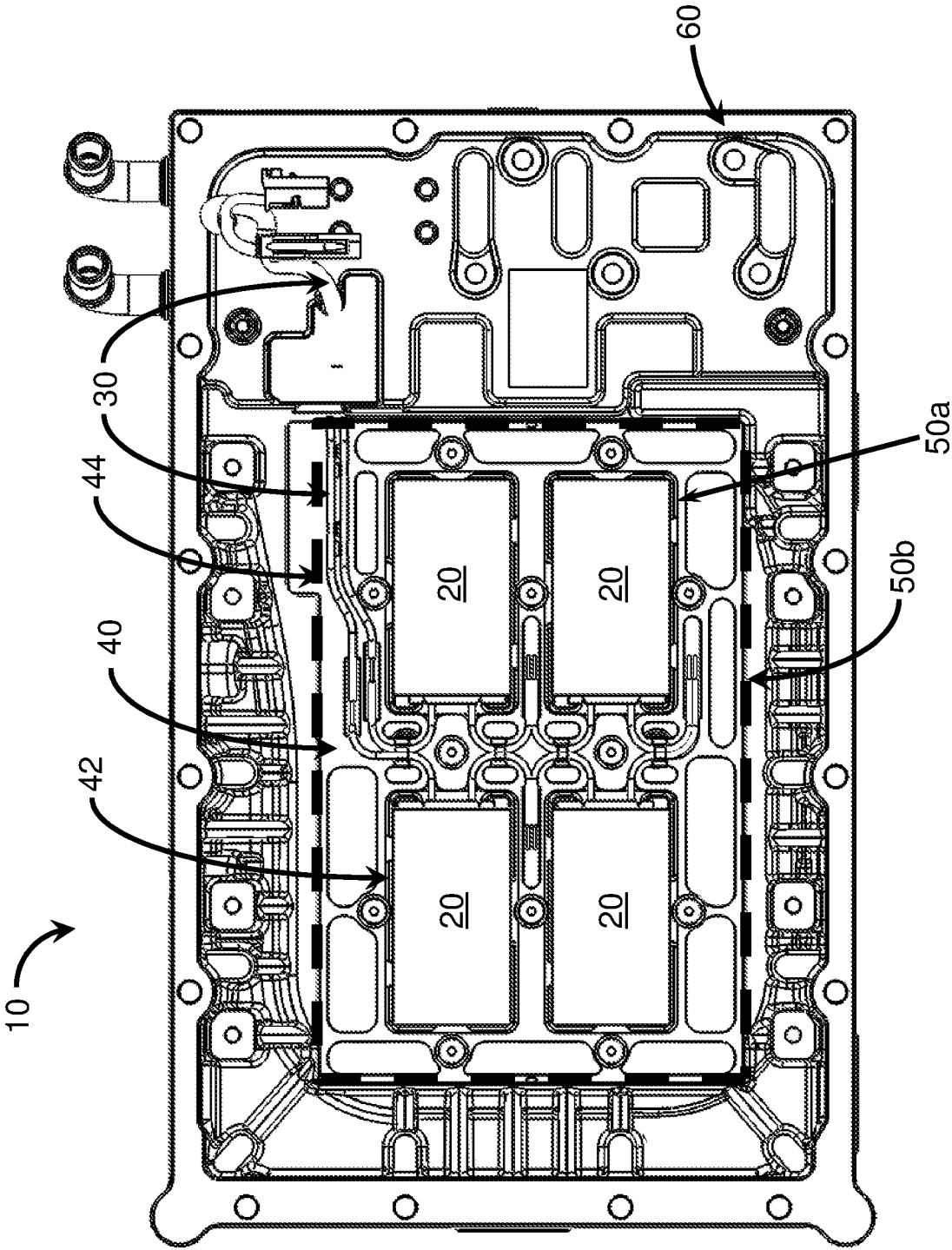


FIG. 1B:

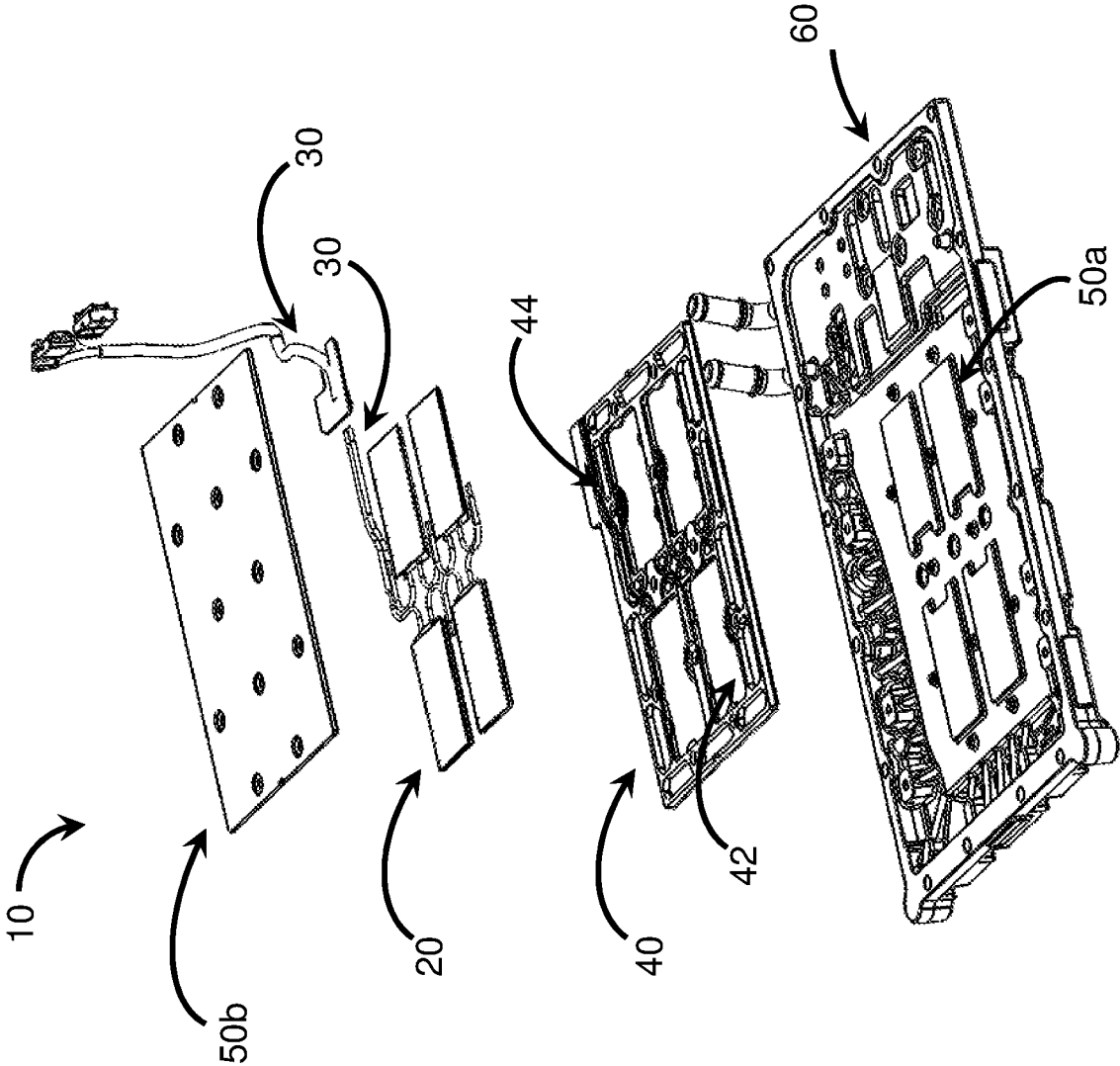


FIG. 2A:

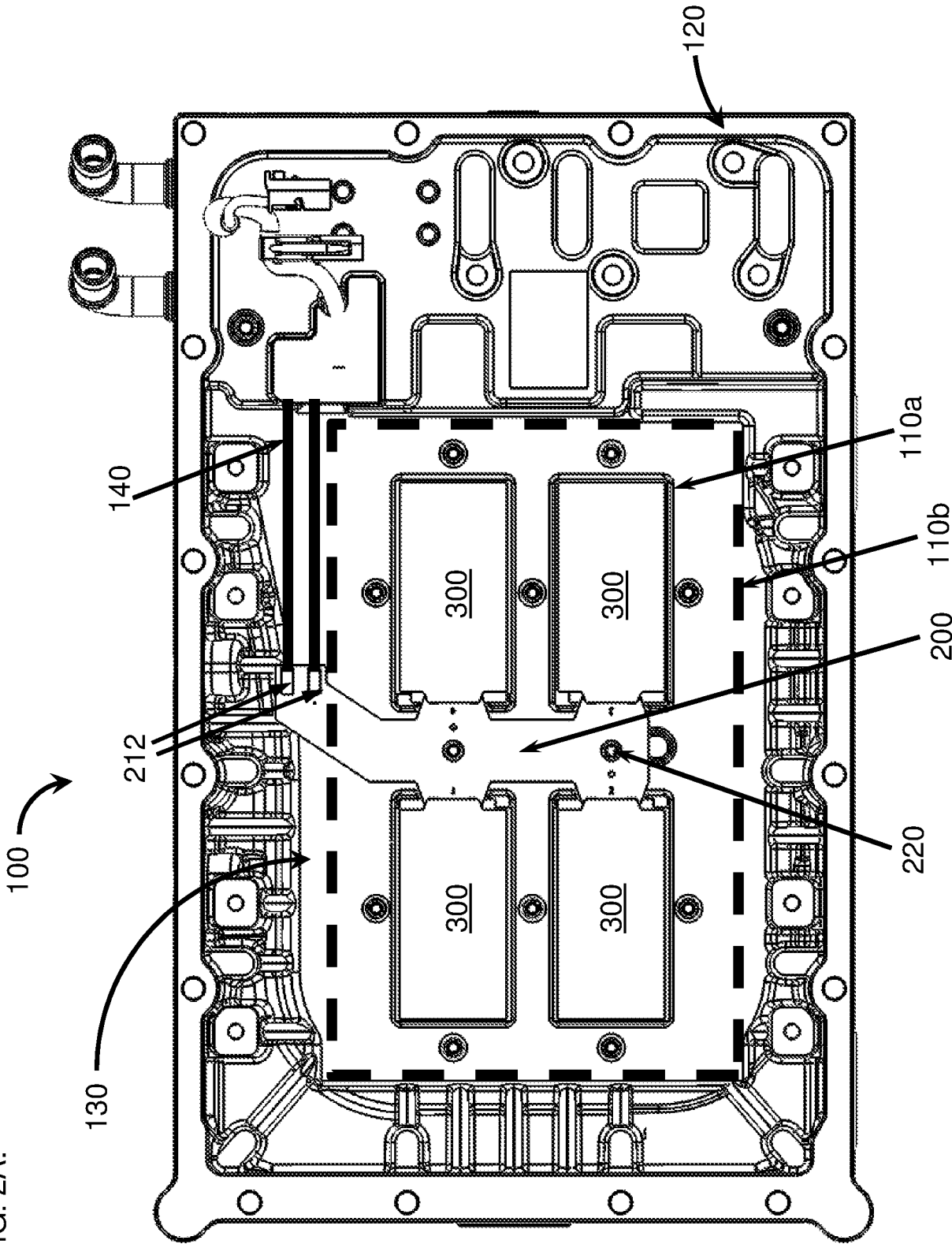


FIG. 2B:

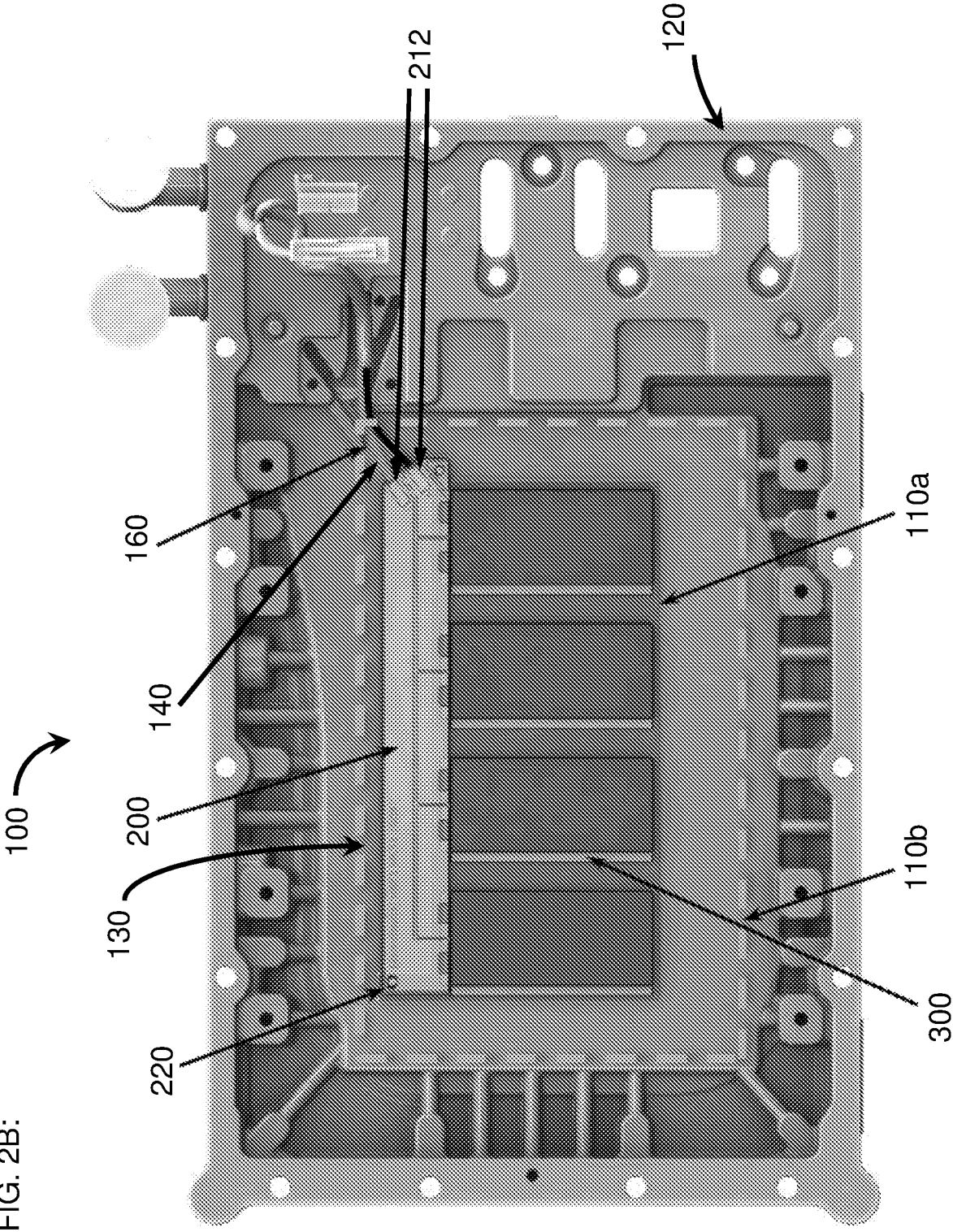


FIG. 3B:

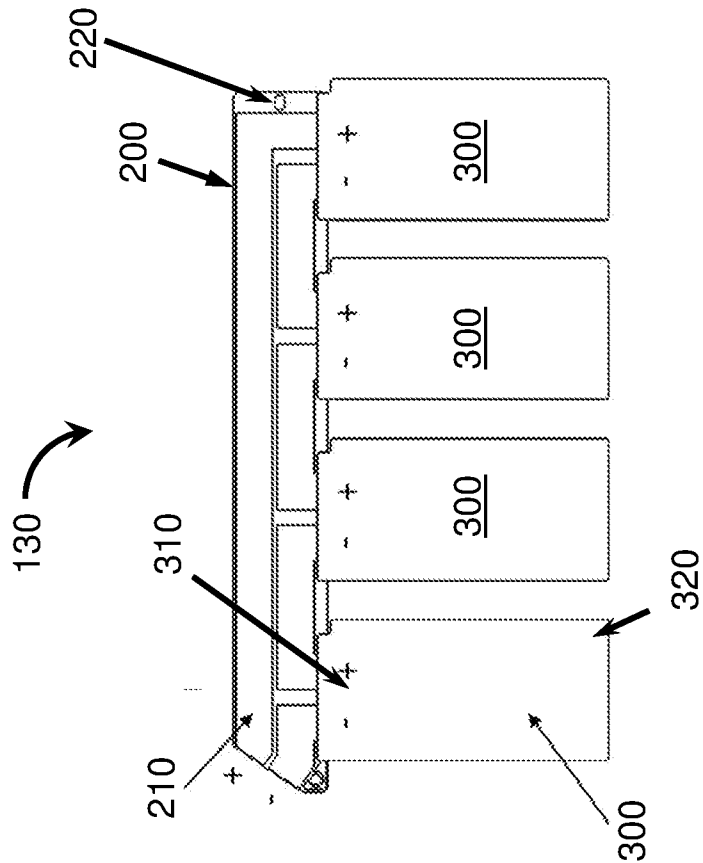


FIG. 3A:

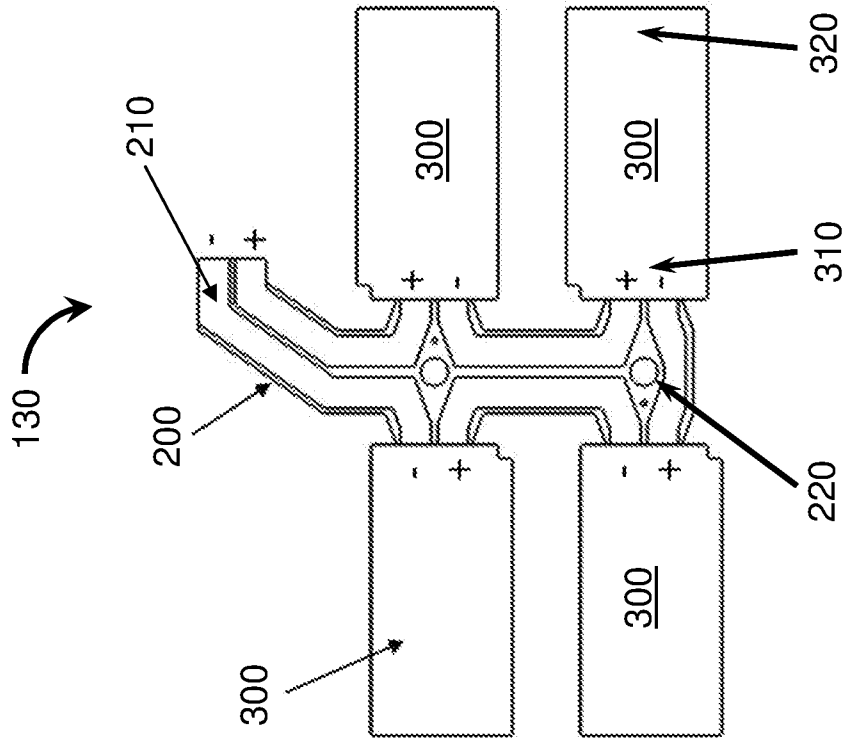


FIG. 4A:

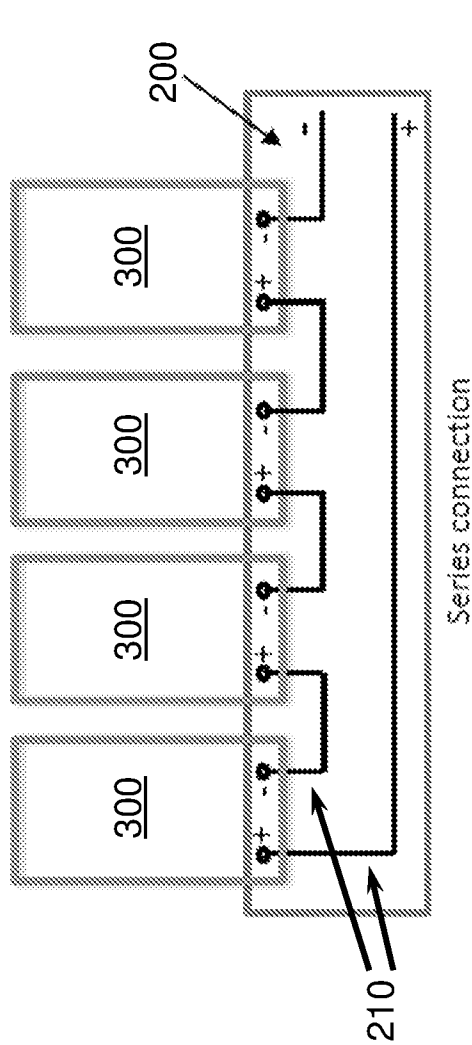


FIG. 4B:

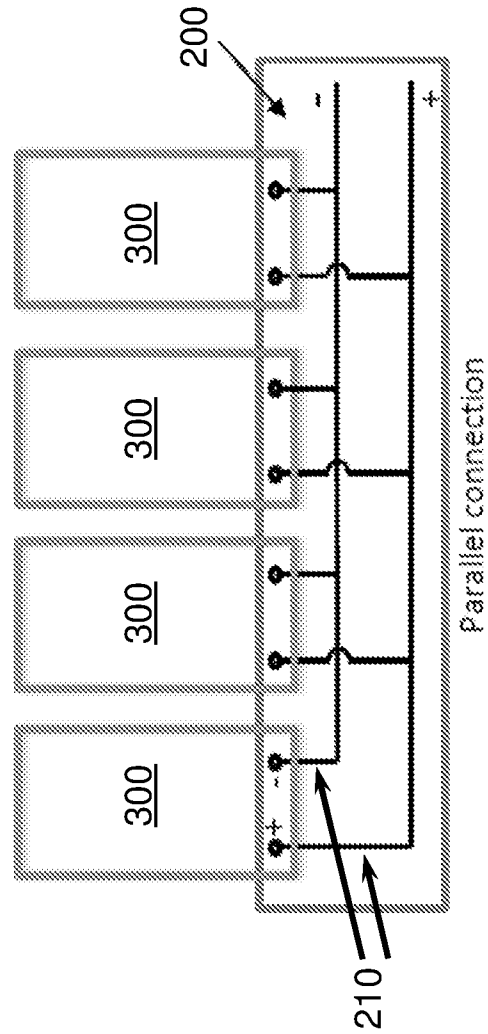


FIG. 4C:

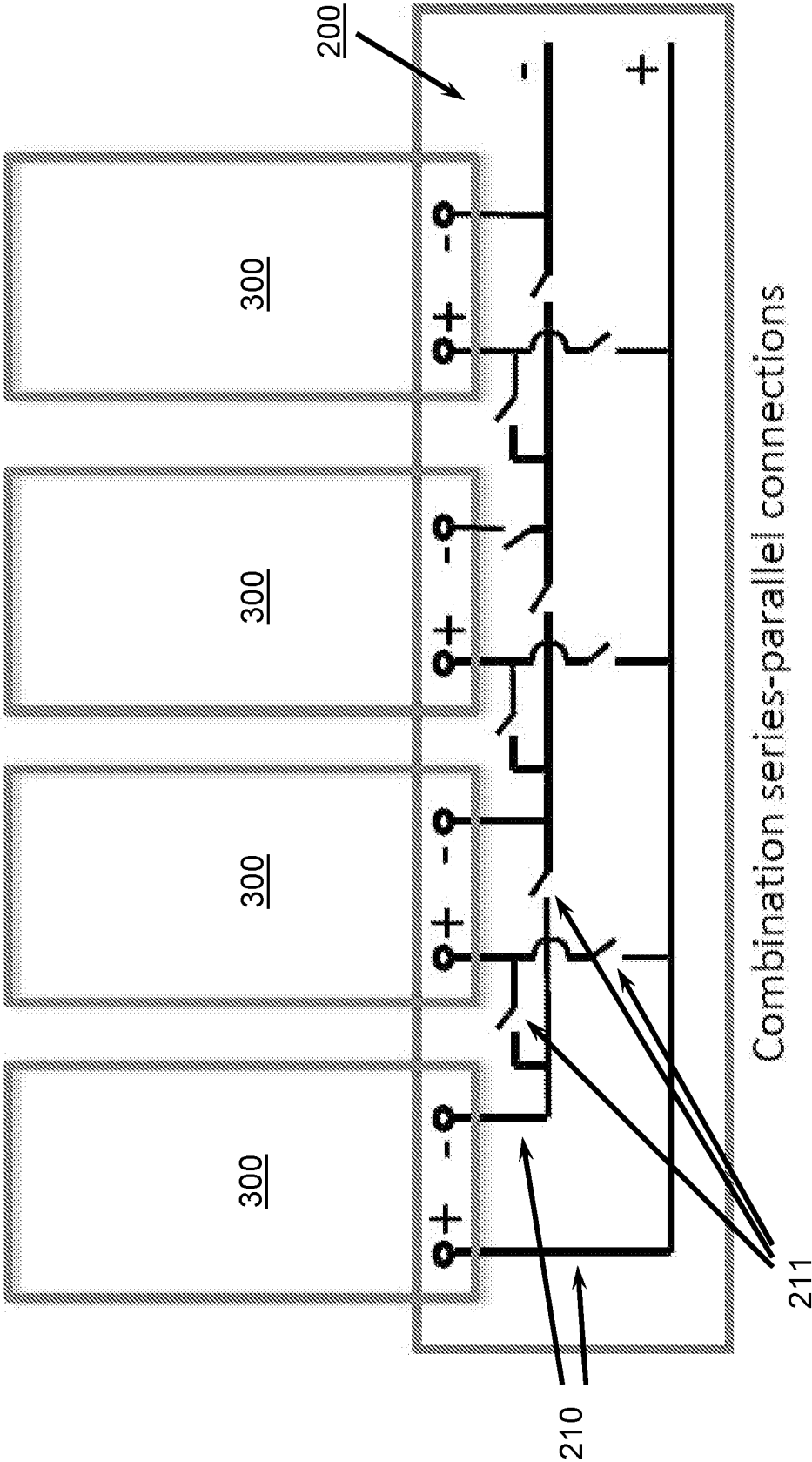


FIG. 5A:

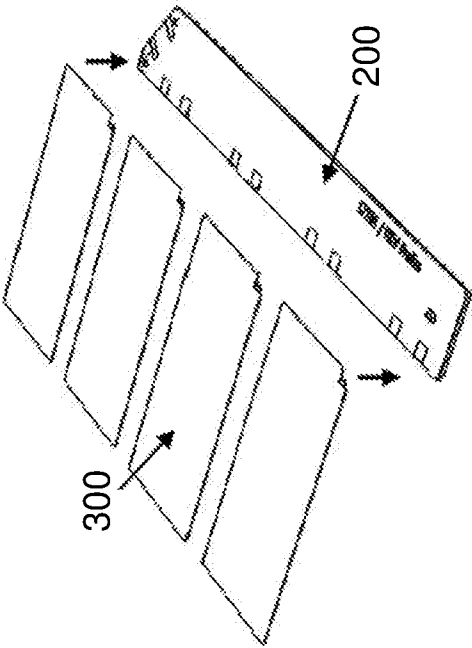


FIG. 5B:

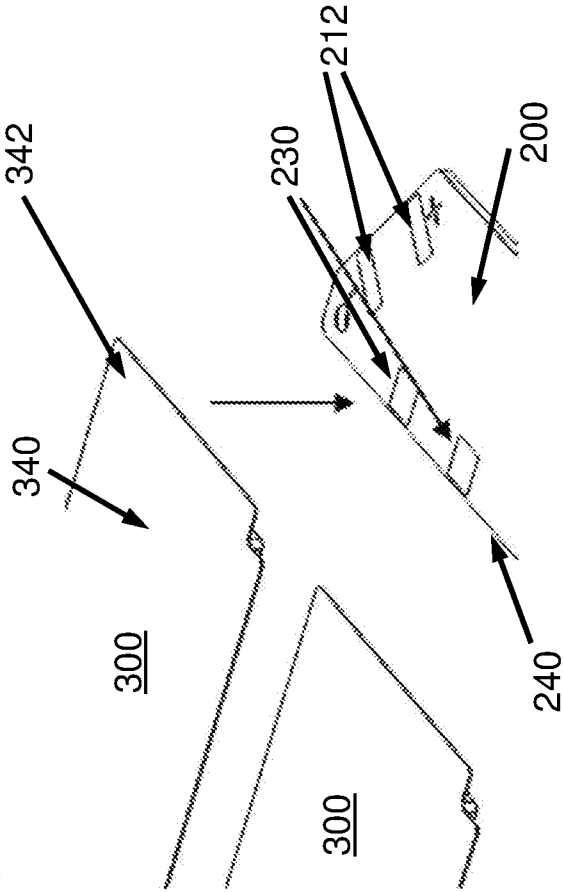


FIG. 5C:

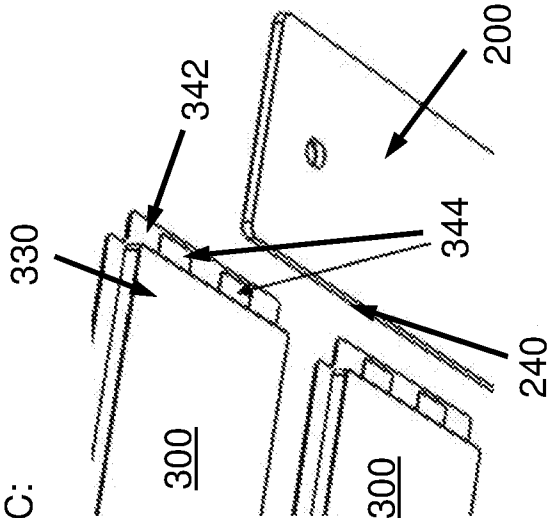


FIG. 6:

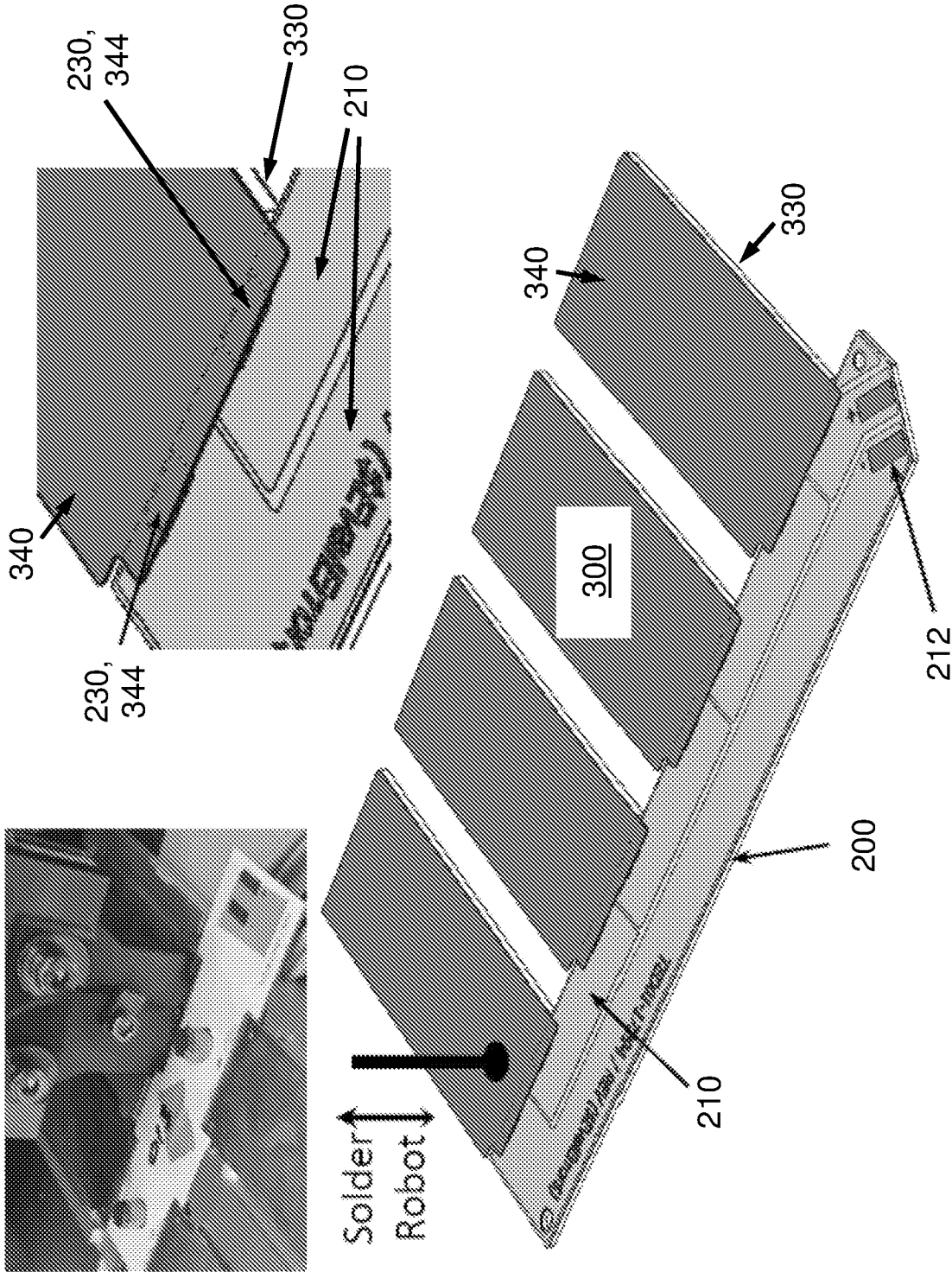


FIG. 7A:

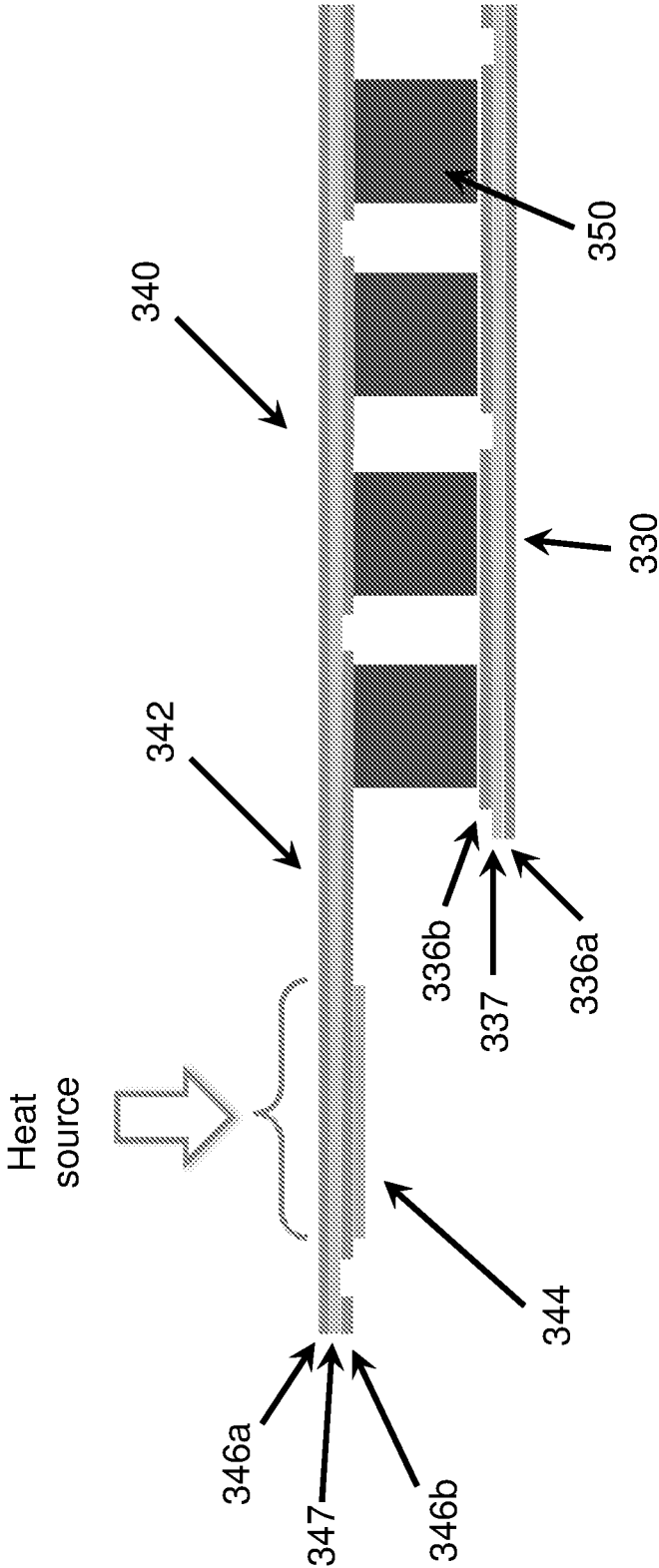


FIG. 7C:

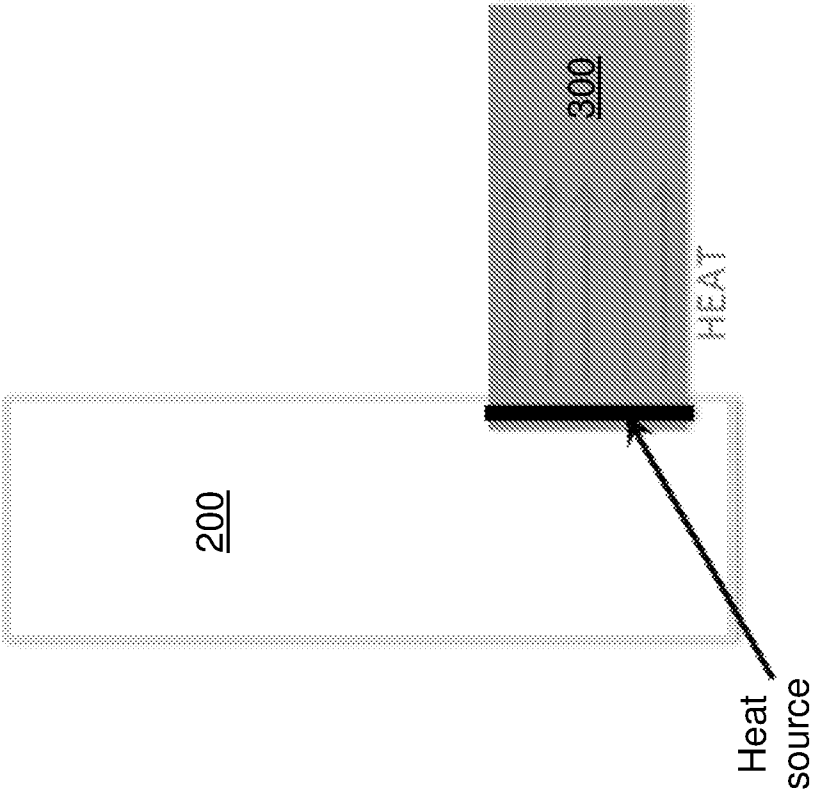


FIG. 7B:

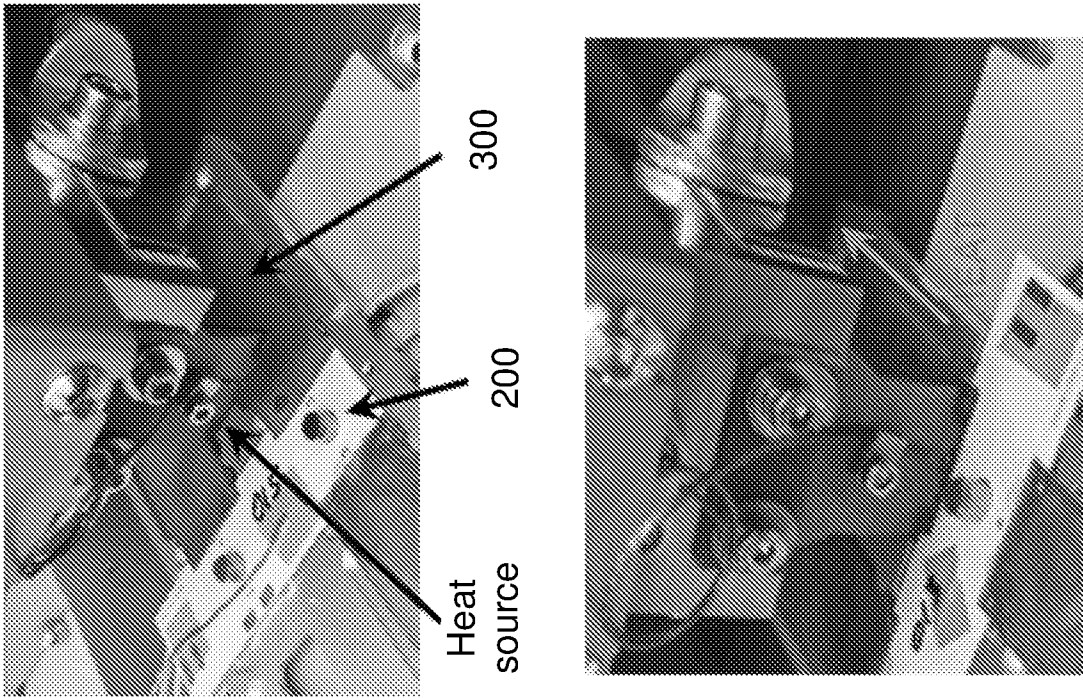


FIG. 7D:

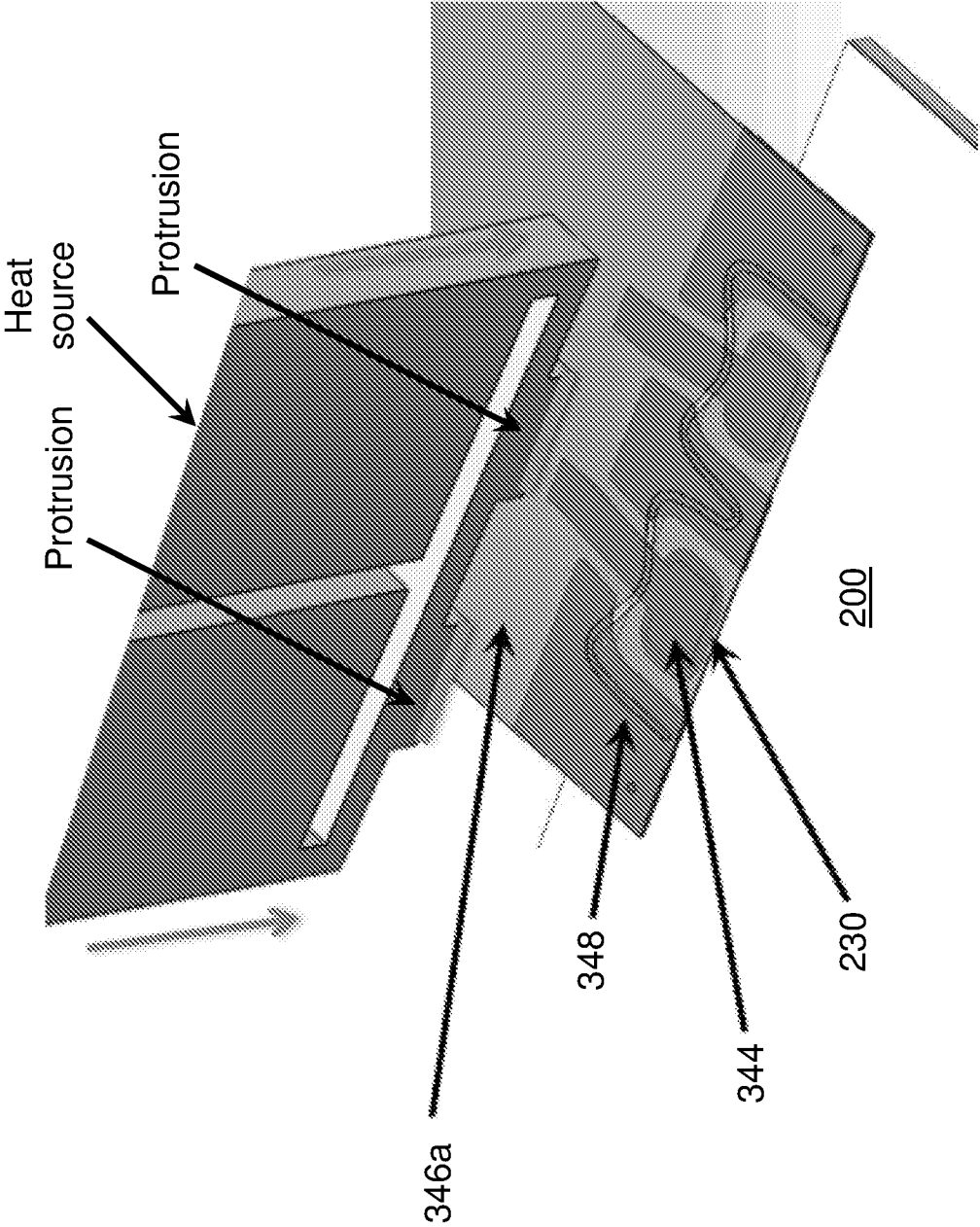


FIG. 7E:

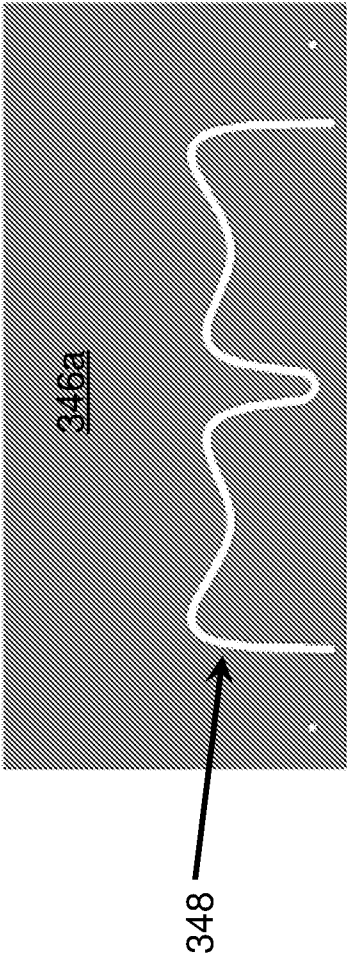


FIG. 7F:

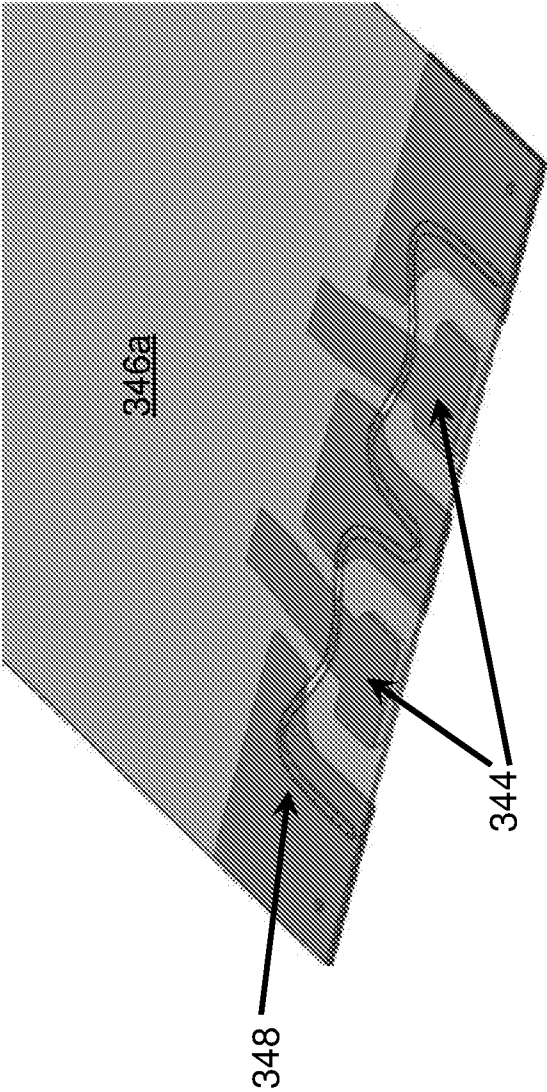


FIG. 8A:

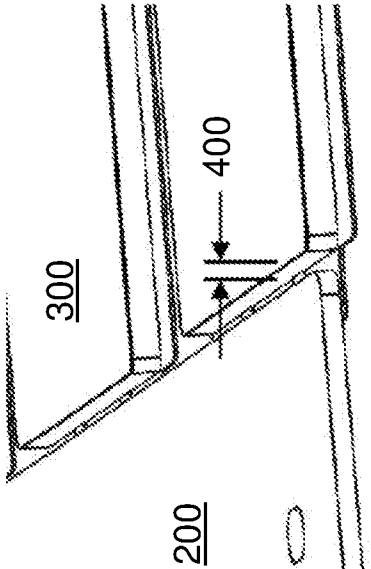


FIG. 8B:

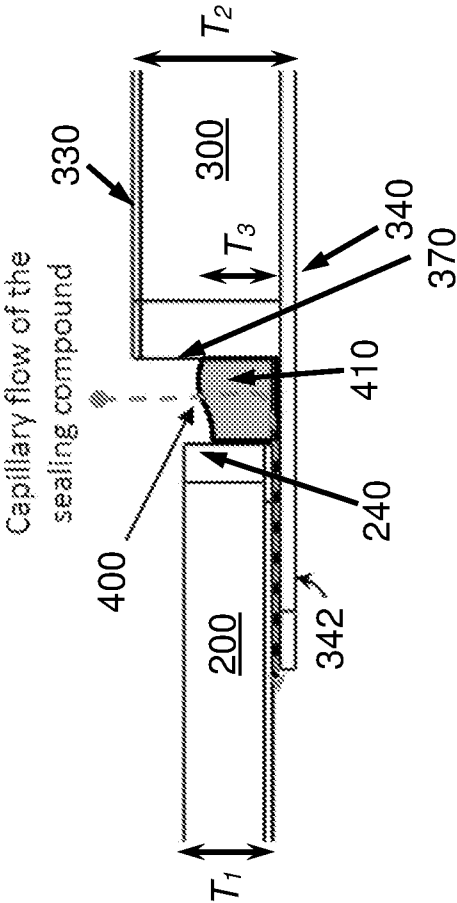


FIG. 8C:

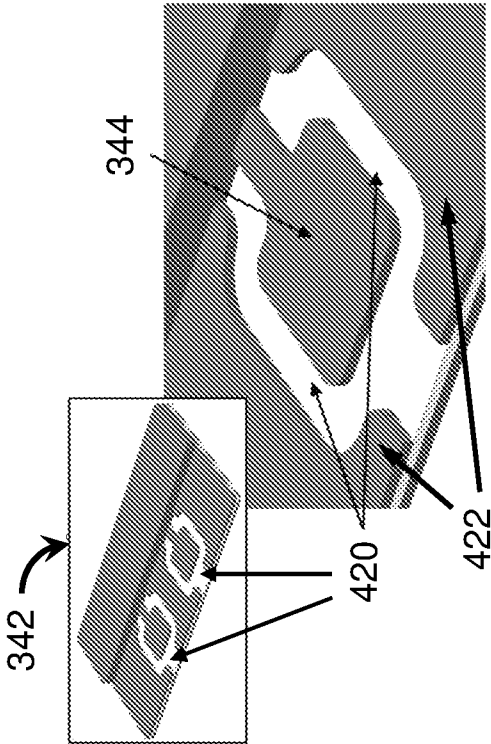


FIG. 8D:

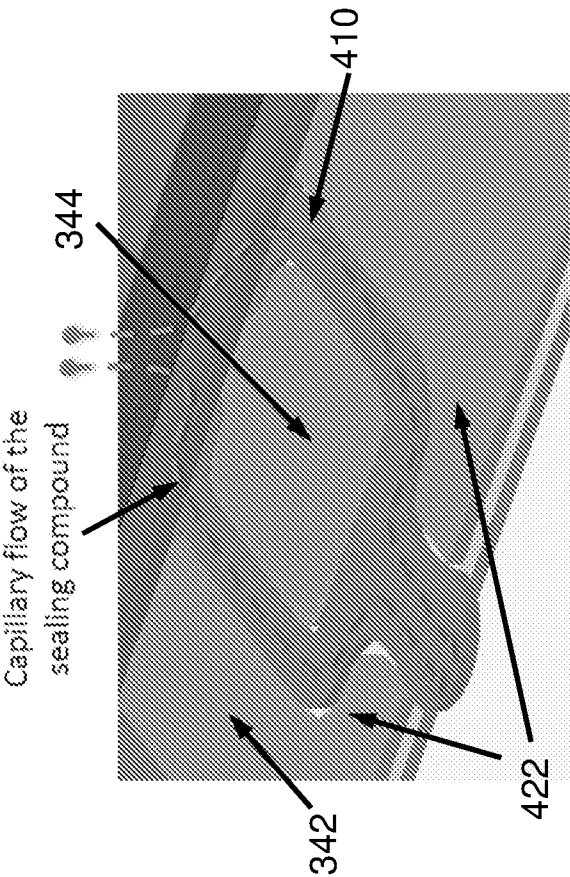


FIG. 9A:

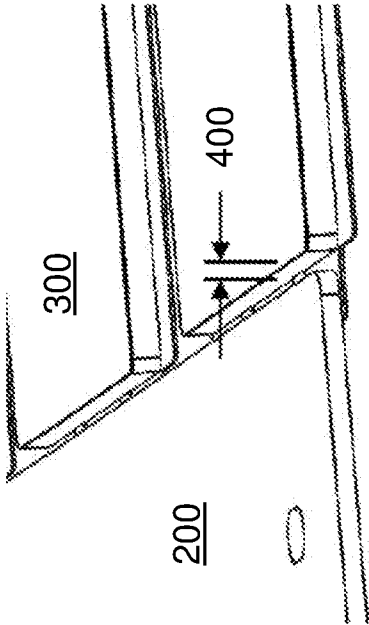


FIG. 9B:

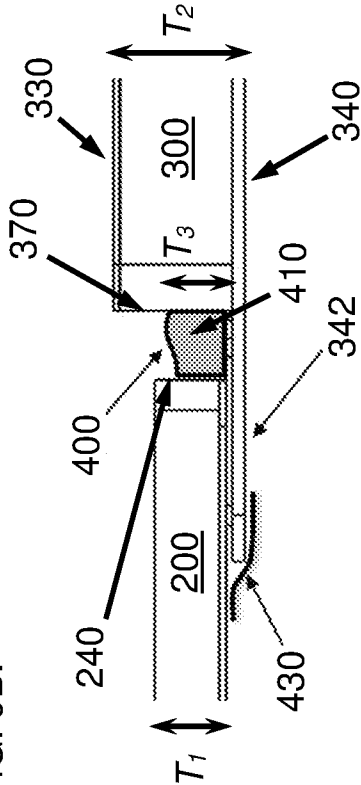


FIG. 9C:

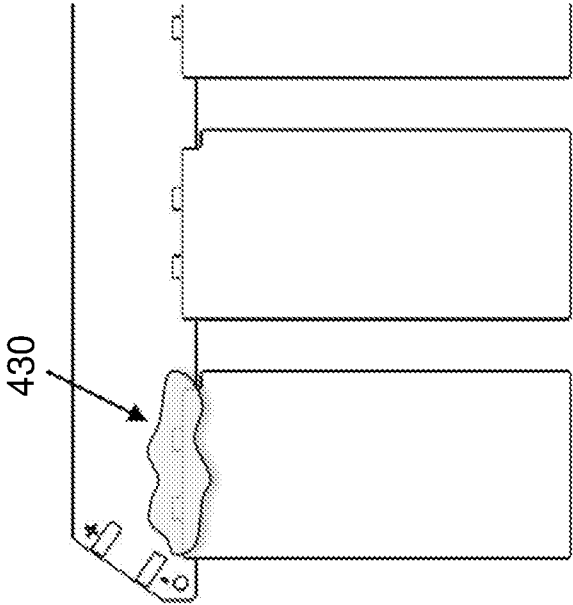


FIG. 9D:

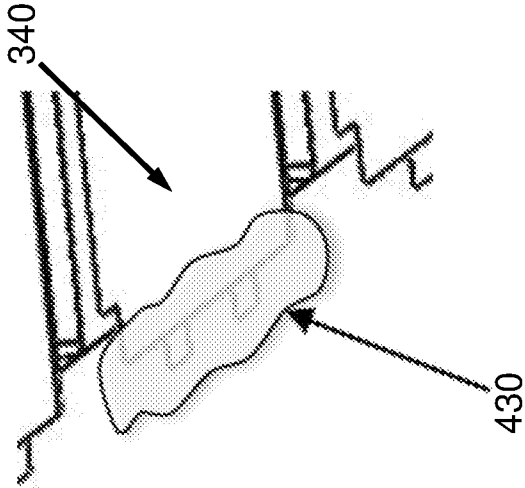


FIG. 10A:

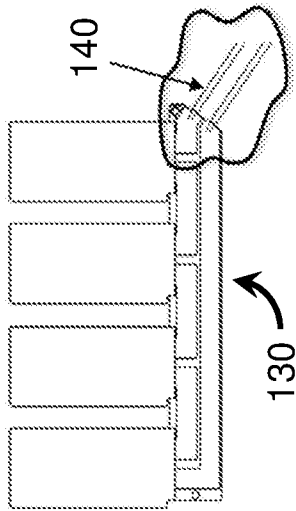


FIG. 10B:

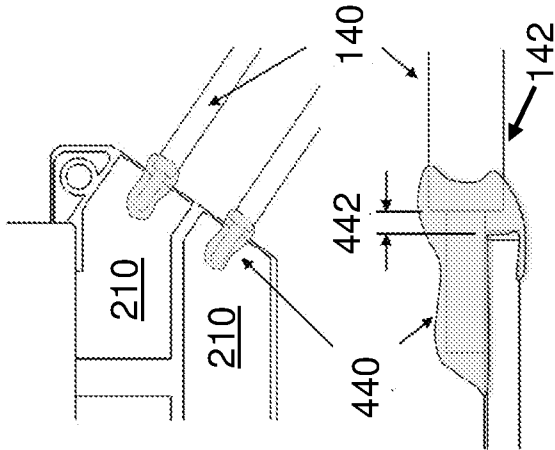


FIG. 10C:

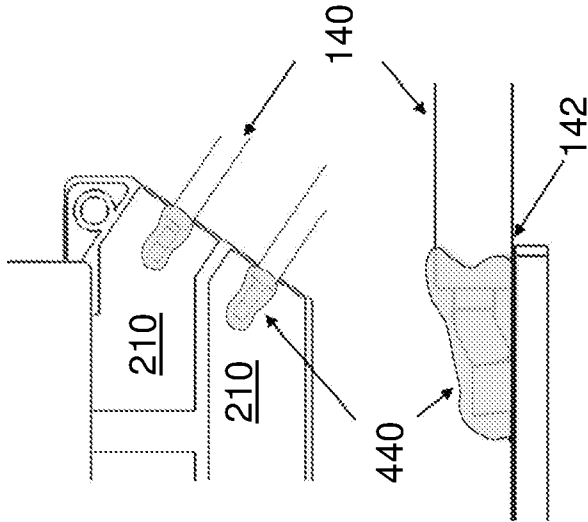


FIG. 11A:

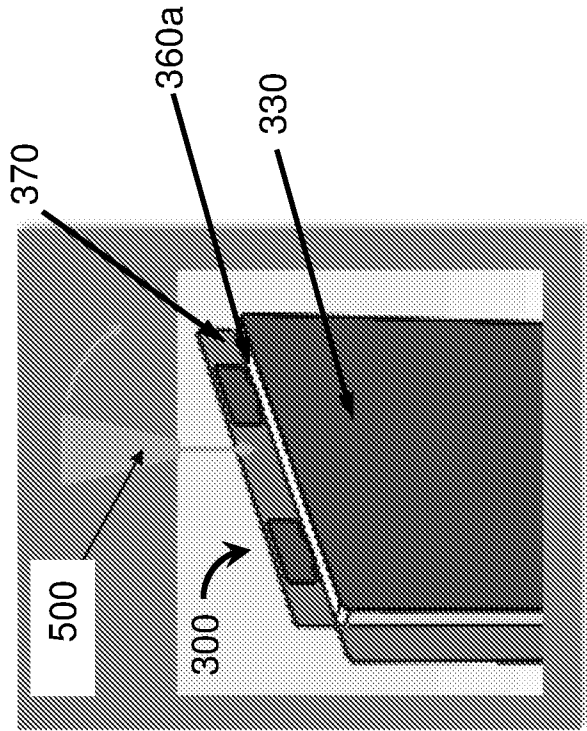


FIG. 11B:

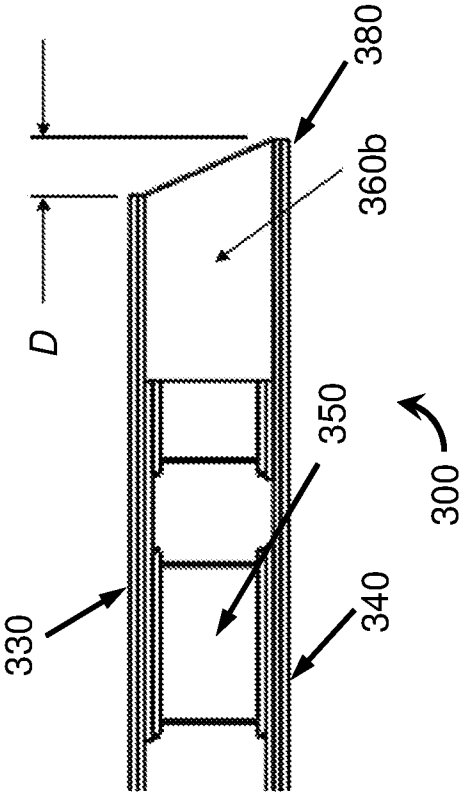


FIG. 11C:

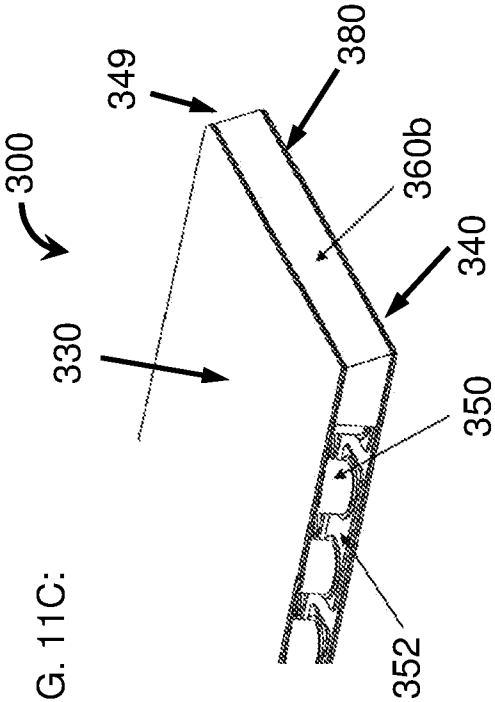


FIG. 12A:

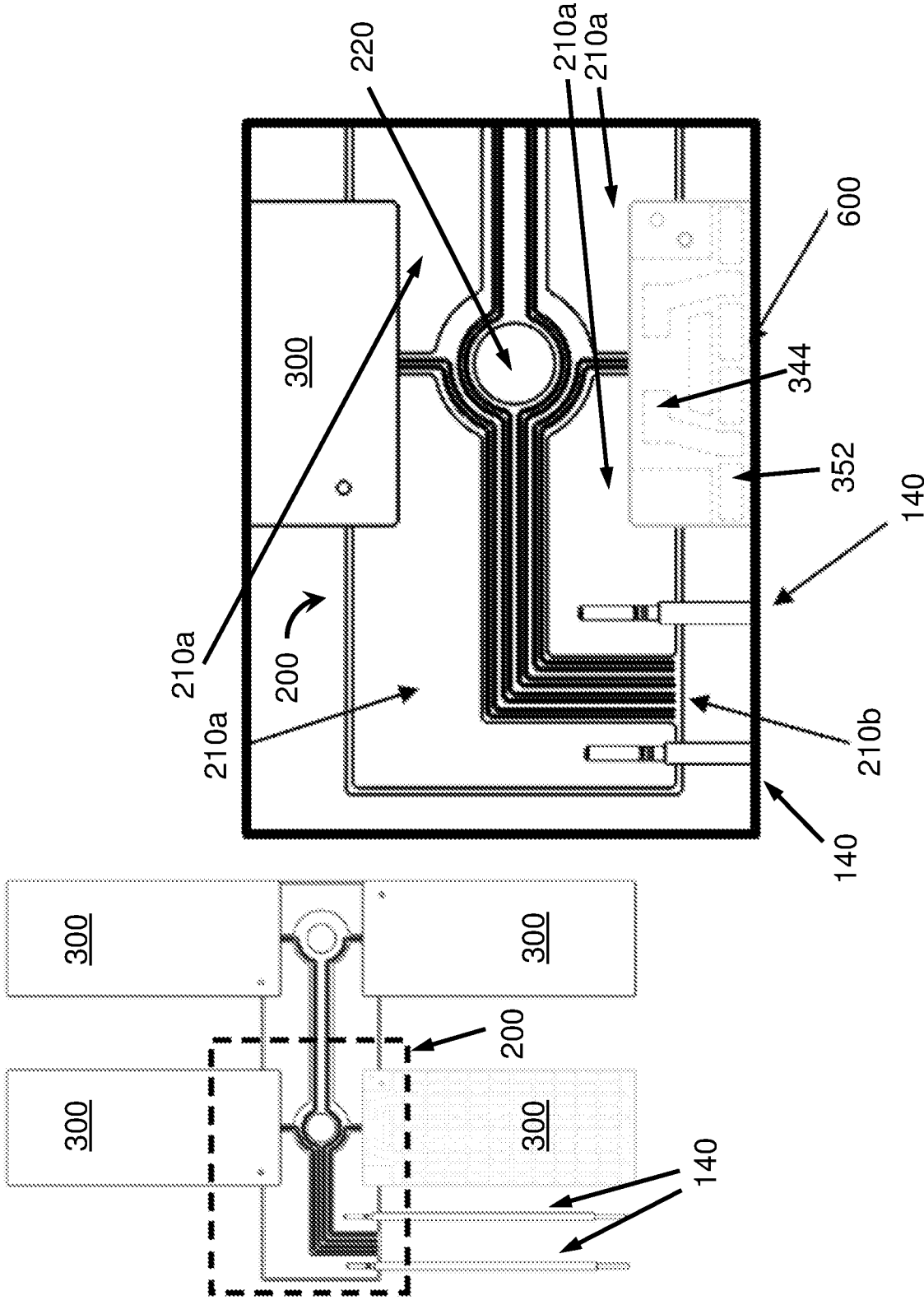


FIG. 12B:

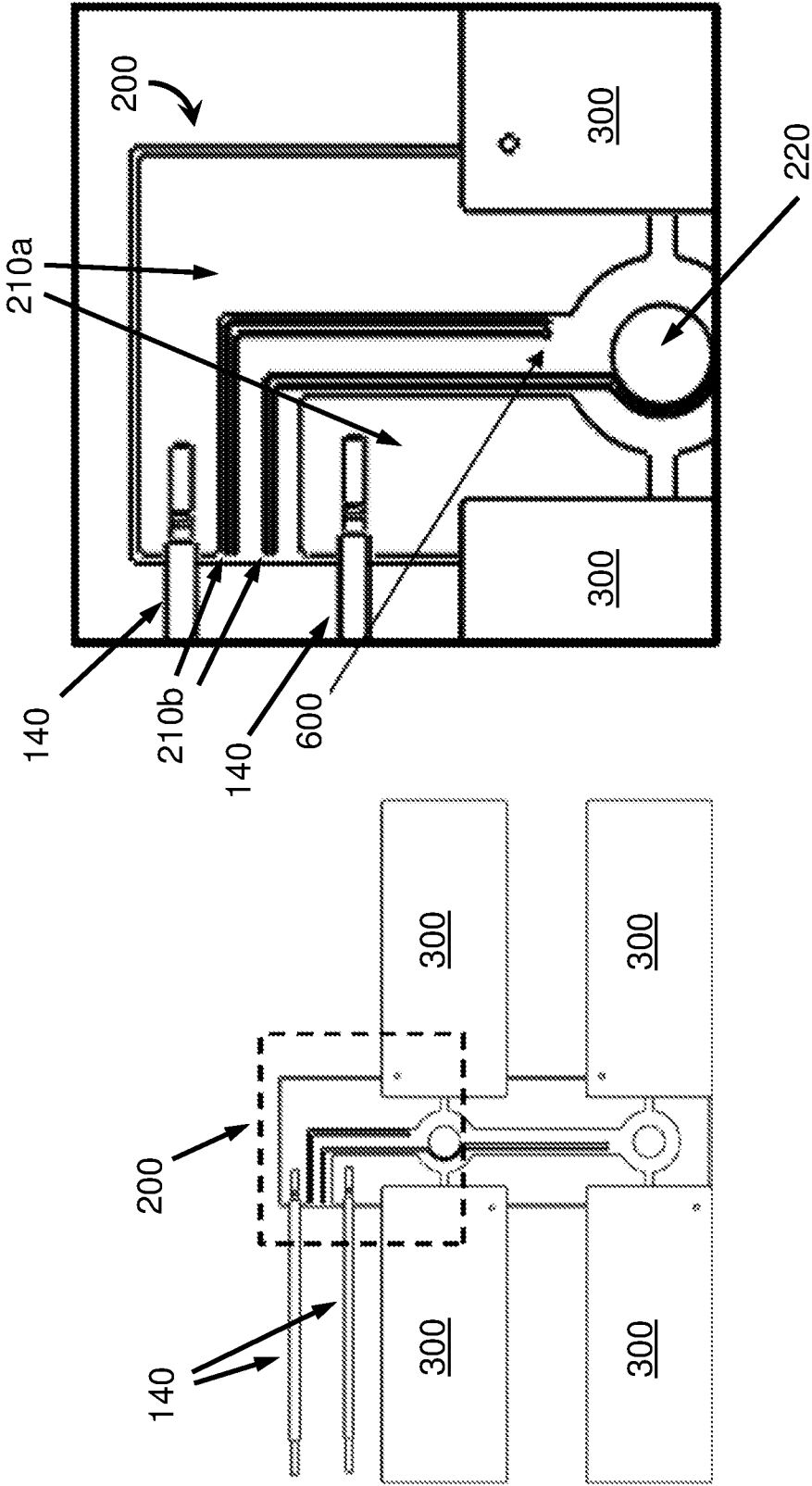


FIG. 13:

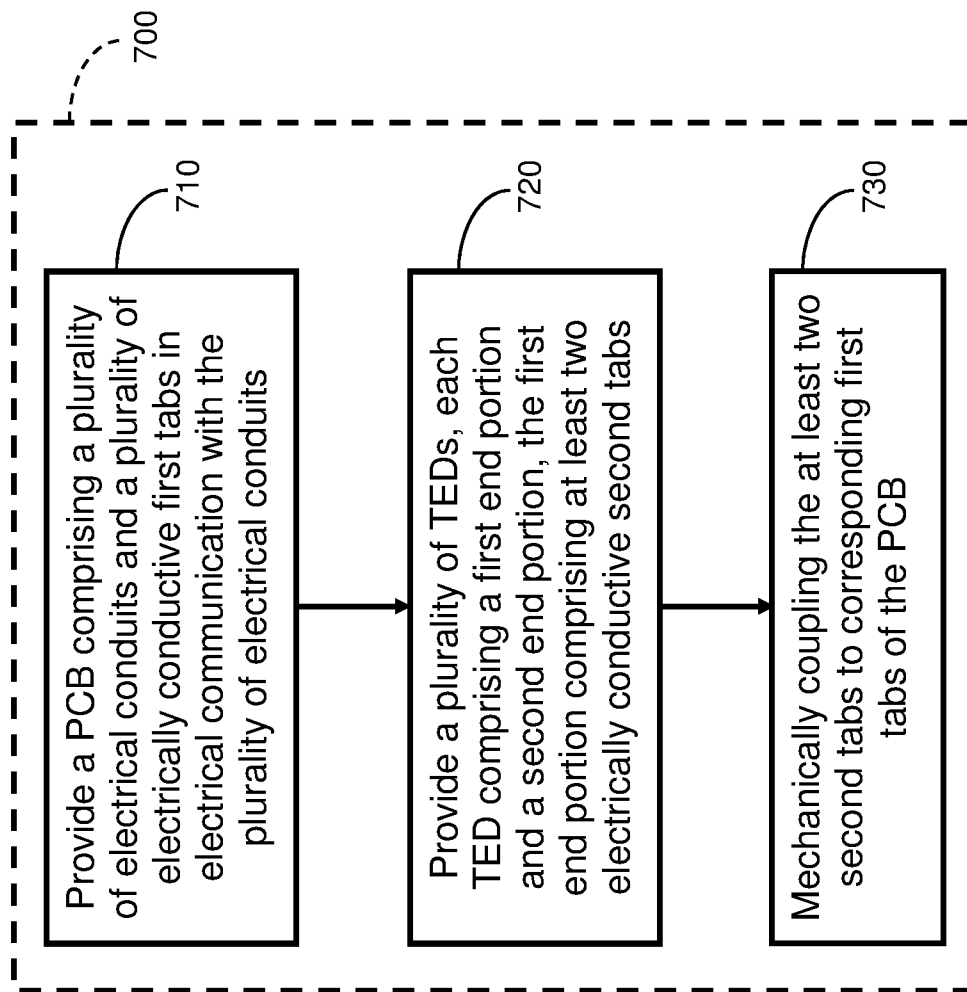
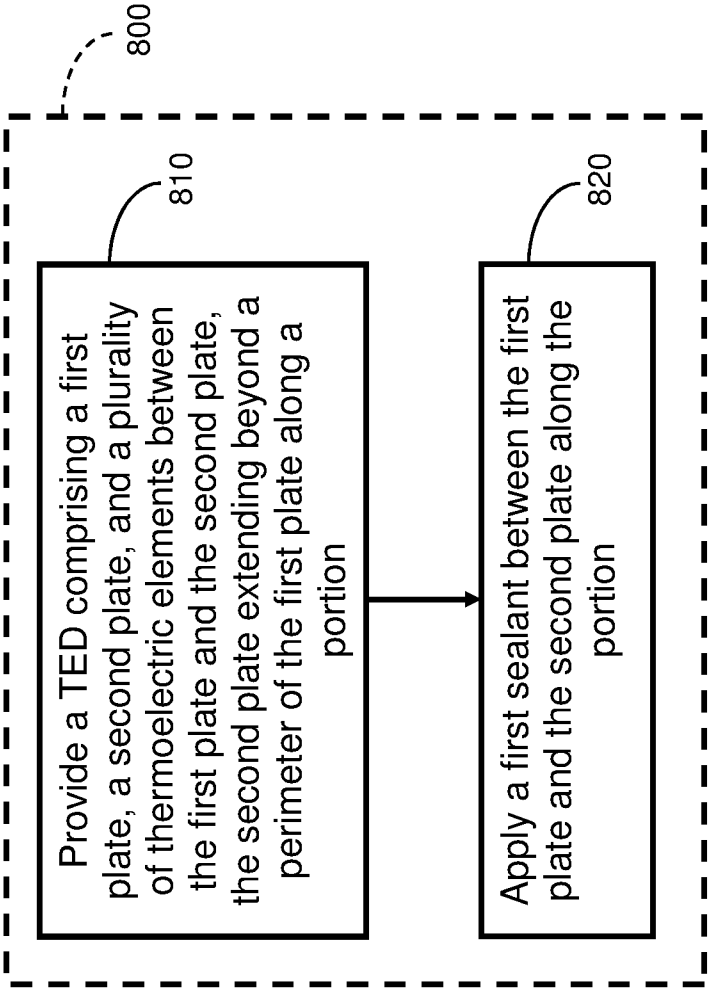


FIG. 14:



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2020/018801

A. CLASSIFICATION OF SUBJECT MATTER

H01L 35/30 (2006.01) F25B 21/02 (2006.01) H01L 27/16 (2006.01) H05K 1/18 (2006.01)

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)

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)

Database: PATENW (EPDOC, WPIAP and English full text databases). IPC and CPC (including sub-marks where they exist): H01L 35/00; H01L 37/00; H01L 27/16; H05K 1/00; H05K 3/00; F25B 21/00; H01L 23/34; F25B 21/02; H01L 23/38; H01M 10/6572. CPC (including sub-marks where they exist): H05K 2201/00; H05K 2203/00; F25B 2321/02; H05K 2201/10219; H05K 2201/066; H05K 2201/10416; F25B 2321/02; H01L 2023/4062. Keywords: thermoelectric, Seebeck, Peltier; heatsink, heat spreader, heat exchanger, cooling fin; printed circuit board; two, pair, second; plural, multiple; conduit, tube, route, path, wire, track; electrical; insulating; plate, sheet; series; parallel; switch; AND LIKE TERMS. Databases: Espacenet and Auspat. Search terms: Gentherm Incorporated (Applicant); Vladimir Jovovic (Inventor), Eric Poliquin (Inventor), Ellen Heian (Inventor); printed circuit board (Espacenet only); AND LIKE TERMS. Applicant and Inventor names searched in internal databases provided by IP Australia.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

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

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"D" document cited by the applicant in the international application	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
4 May 2020

Date of mailing of the international search report
04 May 2020

Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE
PO BOX 200, WODEN ACT 2606, AUSTRALIA
Email address: pct@ipaustalia.gov.au

Authorised officer

Richard Baker
AUSTRALIAN PATENT OFFICE
(ISO 9001 Quality Certified Service)
Telephone No. +61262832583

INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/US2020/018801
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2017/066261 A1 (ALPHABET ENERGY, INC.) 20 April 2017 Abstract, paragraphs 0022 to 0025, 0029 to 0031, 0036, 0038, 0068 to 0069, 0086 and 0087, figures 1, 2, 6A and 6B	1-17
X	CN 104282643 A (WUHAN FINE MEMS INC et al.) 14 January 2015 Abstract, paragraphs 0027 to 0028, figure 4(b)	1-17
X	US 2013/0291559 A1 (PHONONIC DEVICES, INC.) 07 November 2013 Abstract, paragraphs 0037 to 0048, figures 2 to 4	1-17
X	WO 2017/136793 A1 (ALPHABET ENERGY, INC.) 10 August 2017 Abstract, paragraphs 0018 to 0031, figures 1 and 2	1-17
X	WO 2017/100718 A1 (ALPHABET ENERGY, INC.) 15 June 2017 Abstract, paragraphs 0025 to 0038, figures 1 to 3	1-17
X	WO 2017/059256 A1 (ALPHABET ENERGY, INC.) 06 April 2017 Abstract, paragraphs 0017 to 0030 and 0036 to 0041, figures 1 to 6	1-17

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
the subject matter listed in Rule 39 on which, under Article 17(2)(a)(i), an international search is not required to be carried out, including
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Supplemental Box for Details

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-17

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

Supplemental Box**Continuation of: Box III**

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Claims 1 to 17 are directed to a thermoelectric module assembly for thermally conditioning a component, the assembly comprising: first and second heat spreaders spaced apart from one another; at least one thermoelectric sub-assembly between and in thermal communication with the first and second heat spreaders, the at least one thermoelectric sub-assembly comprising: a printed circuit board comprising a plurality of electrical conduits; and a plurality of thermoelectric devices, each thermoelectric device of the plurality of thermoelectric devices with a first end portion and a second end portion, the second end portion opposite from the first end portion, the first end portion mechanically coupled to the printed circuit board and in electrical communication with the plurality of electrical conduits, the second end portion spaced from the printed circuit board. The feature of a thermoelectric module assembly with the above mentioned features is specific to this group of claims.
- Claims 18 to 28 are directed to a thermoelectric system comprising: a printed circuit board comprising a plurality of electrically conductive first tabs at a surface of the printed circuit board; and at least one thermoelectric device mechanically coupled to the printed circuit board, the at least one thermoelectric device comprising: a thermally conductive first plate; a thermally conductive second plate comprising a first portion extending beyond a perimeter of the first plate and over an edge of the printed circuit board and over two first tabs of the plurality of first tabs, the first portion comprising two electrically conductive second tabs, each of the two second tabs in mechanical and electrical communication with a corresponding first tab of the two first tabs; and a plurality of thermoelectric elements in thermal communication with and in a region between the first plate and the second plate. The feature of a thermoelectric system with the above mentioned features is specific to this group of claims.
- Claims 29 to 34 are directed to a thermoelectric system comprising: a plurality of thermoelectric devices, each thermoelectric device of the plurality of thermoelectric devices comprising a thermally conductive first plate, a thermally conductive second plate, and a plurality of thermoelectric elements in thermal communication with and in a region between the first plate and the second plate; and a printed circuit board comprising a plurality of first electrical conduits and a plurality of second electrical conduits, the first electrical conduits in electrical communication with the thermoelectric elements of the plurality of thermoelectric devices, the second electrical conduits in electrical communication with at least one thermal sensor on at least one thermoelectric device of the plurality of thermoelectric devices and/or on the printed circuit board. The feature of a thermoelectric system with the above mentioned features is specific to this group of claims.
- Claims 35 to 39 are directed to a method of fabricating at least one thermoelectric sub-assembly comprising a printed circuit board and a plurality of thermoelectric devices, the method comprising: providing the printed circuit board, the printed circuit board comprising a plurality of electrical conduits and a plurality of electrically conductive first tabs in electrical communication with the plurality of electrical conduits; providing the plurality of thermoelectric devices, each thermoelectric device comprising a first end portion and a second end portion, the second end portion opposite to the first end portion, the first end portion comprising at least two electrically conductive second tabs; and mechanically coupling the at least two second tabs of each thermoelectric device of the plurality of thermoelectric devices to corresponding first tabs of the printed circuit board such that the at least two second tabs are in electrical communication with the corresponding first tabs and the second end portion spaced from the printed circuit board. The feature of a method of fabricating at least one thermoelectric sub-assembly with the above mentioned features is specific to this group of claims.
- Claims 40 to 44 are directed to a method of fabricating a thermoelectric device comprising a first plate, a second plate, and a plurality of thermoelectric elements between and in electrical communication between the first plate and the second plate, the method comprising: providing the thermoelectric device, the second plate extending beyond a perimeter of the first plate along at least a portion of the thermoelectric device; and applying a first sealant between the first plate and the second plate along the portion. The feature of a method of fabricating a thermoelectric device with the above mentioned features is specific to this group of claims.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

Supplemental Box

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. The only features common to all of the claimed inventions is a thermoelectric device comprising a plurality of thermoelectric elements. However it is considered that this combination of features is generic in this particular art.

Therefore in this light these common features cannot be a special technical feature. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a posteriori*.

INTERNATIONAL SEARCH REPORT		International application No.	
Information on patent family members		PCT/US2020/018801	
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.			
Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	Publication Date	Publication Number	Publication Date
WO 2017/066261 A1	20 April 2017	None	
CN 104282643 A	14 January 2015	CN 104282643 A	14 Jan 2015
		CN 104282643 B	11 Jan 2017
US 2013/0291559 A1	07 November 2013	US 2013291559 A1	07 Nov 2013
		US 8893513 B2	25 Nov 2014
		CN 104509220 A	08 Apr 2015
		CN 104509220 B	29 May 2018
		CN 104854414 A	19 Aug 2015
		CN 104854414 B	09 Jun 2017
		CN 107504713 A	22 Dec 2017
		CN 107504714 A	22 Dec 2017
		CN 107504715 A	22 Dec 2017
		CN 107504716 A	22 Dec 2017
		CN 107529608 A	02 Jan 2018
		EP 2847524 A1	18 Mar 2015
		EP 2847524 B1	02 Nov 2016
		EP 2848101 A2	18 Mar 2015
		EP 2848101 B1	10 Apr 2019
		JP 6378464 B1	22 Aug 2018
		JP 2018159540 A	11 Oct 2018
		JP 2015522943 A	06 Aug 2015
		JP 6403664 B2	10 Oct 2018
		JP 2018159539 A	11 Oct 2018
		JP 6431634 B2	28 Nov 2018
		JP 2015521272 A	27 Jul 2015
		KR 20150022808 A	04 Mar 2015
		KR 102023228 B1	19 Sep 2019
		KR 20150022811 A	04 Mar 2015
		RS 55575 B1	31 May 2017
		SM T201700089 B	08 Mar 2017
		US 2013291561 A1	07 Nov 2013
		US 8991194 B2	31 Mar 2015
		US 2013291562 A1	07 Nov 2013
		US 9103572 B2	11 Aug 2015
		US 2013291563 A1	07 Nov 2013

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

INTERNATIONAL SEARCH REPORT		International application No.	
Information on patent family members		PCT/US2020/018801	
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.			
Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	Publication Date	Publication Number	Publication Date
		US 9234682 B2	12 Jan 2016
		US 2013291556 A1	07 Nov 2013
		US 9310111 B2	12 Apr 2016
		US 2013291558 A1	07 Nov 2013
		US 9341394 B2	17 May 2016
		US 2013291557 A1	07 Nov 2013
		US 10012417 B2	03 Jul 2018
		US 2013291555 A1	07 Nov 2013
		US 2013291560 A1	07 Nov 2013
		WO 2013169772 A1	14 Nov 2013
		WO 2013169774 A2	14 Nov 2013
WO 2017/136793 A1	10 August 2017	WO 2017136793 A1	10 Aug 2017
WO 2017/100718 A1	15 June 2017	WO 2017100718 A1	15 Jun 2017
WO 2017/059256 A1	06 April 2017	WO 2017059256 A1	06 Apr 2017
End of Annex			