



(51) International Patent Classification:

H01M 4/04 (2006.01) H01M 2/20 (2006.01)
H01M 10/653 (2014.01)

(21) International Application Number:

PCT/US2022/078445

(22) International Filing Date:

20 October 2022 (20.10.2022)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

63/257,935 20 October 2021 (20.10.2021) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, 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,

(54) Title: BATTERY SYSTEM

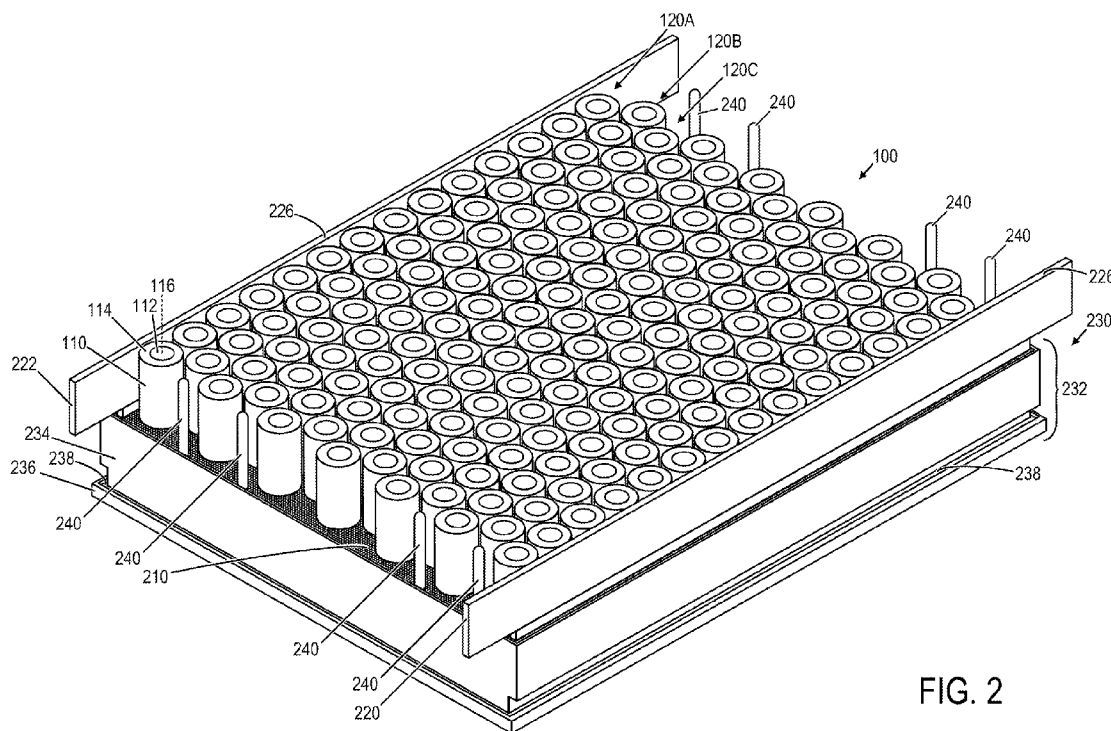


FIG. 2

(57) Abstract: A battery system and a method of manufacturing a battery system are disclosed. The battery system includes one or more battery modules. Each battery module includes a module body forming a tub having an interior volume; a set of cylindrical battery cells arranged in an array within the interior volume of the tub of the module body; a circuit board that covers the open face of the tub and includes electrical contacts that electrically interface with a pair of battery terminals of each cylindrical battery cell of the set to define: a plurality of series electrical pathways among respective subsets of the set of cylindrical battery cells, and a plurality of parallel electrical pathways among the plurality of series electrical pathways; and cured potting resin encapsulating at least a portion of the set of cylindrical battery cells within the tub of the module body.

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, CV, 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, ME, 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))*

BATTERY SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. provisional patent application number 63/257,935, filed October 20, 2021, the entirety of which is hereby incorporated herein by reference for all purposes.

BACKGROUND

[0002] Electric batteries can be used in a variety of electronic devices to store and provide electrical energy to electronic components. As an example, electric vehicles and hybrid-electric vehicles include an on-board battery system having one or more batteries for storing and providing electrical energy to an electric motor and other electrical loads on-board the vehicle.

SUMMARY

[0003] According to an example of the present disclosure, a battery system comprises one or more battery modules. Each battery module includes a module body forming a tub having an interior volume and a set of cylindrical battery cells arranged in an array within the interior volume of the tub of the module body. A central axis of each cylindrical battery cell of the set is aligned parallel with a central axis of each other cylindrical battery cell of the set. Each cylindrical battery cell of the set includes a pair of battery terminals on a first end of the cylindrical battery cell that faces outward from an open face of the tub of the module body. Each battery module further includes a circuit board that covers the open face of the tub and includes electrical contacts that electrically interface with the pair of battery terminals of each cylindrical battery cell of the set to define a plurality of series electrical pathways among respective subsets

of the set of cylindrical battery cells, and a plurality of parallel electrical pathways among the plurality of series electrical pathways. Each battery module further includes cured potting resin encapsulating at least a portion of the set of cylindrical battery cells within the tub of the module body.

[0004] According to another example of the present disclosure, a method of manufacturing a battery system that includes one or more battery modules comprises: obtaining a module body, the module body forming a tub having an interior volume; obtaining a set of cylindrical battery cells, each cylindrical battery cell of the set including a pair of battery terminals on a first end of the cylindrical battery cell; obtaining a fixture having a set of openings arranged in an array that each accommodates a portion of a respective cylindrical battery cell of the set of cylindrical battery cells; loading the fixture with the portion that includes the first end of each cylindrical battery cell of the set into a respective opening of the set of openings to arrange the set of cylindrical battery cells in the array; placing an exposed portion of each cylindrical battery cell of the set loaded in the fixture into the interior volume of the tub; potting the exposed portion of each cylindrical battery cell of the set within the interior volume of the tub with a potting resin to obtain a cured potting resin that encapsulates the exposed portion of each cylindrical battery cell of the set within the interior volume of the tub; removing the fixture from the set of cylindrical battery cells; potting an additional portion of each cylindrical battery cell of the set within the interior volume of the tub with additional potting resin to obtain additional cured potting resin that encapsulates the additional portion of each cylindrical battery cell of the set within the interior volume of the tub; obtaining a circuit board having electrical contacts that, when electrically interfaced with the pair of battery terminals of each cylindrical battery cell of the set defines: a plurality of series electrical pathways among respective subsets

of the set of cylindrical battery cells, and a plurality of parallel electrical pathways among the plurality of series electrical pathways; aligning the electrical contacts of the circuit board with the pair of battery terminals of each cylindrical battery cell of the set with the circuit board covering an open face of the tub to enclose the interior volume; and electrically interfacing the electrical contacts of the circuit board with the pair of battery terminals of each cylindrical battery of the set via an intermediate wire-bonded electrical pathway to form the plurality of series electrical pathways among respective subsets of the set of cylindrical battery cells, and the plurality of parallel electrical pathways among the plurality of series electrical pathways.

[0005] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 depicts an example of a set of cylindrical battery cells 100 for a battery module arranged in an array.

[0007] FIG. 2 depicts the set of cylindrical battery cells of FIG. 1 partially encapsulated by cured potting resin with a pair of busbars within a portion of a module body of a battery module.

[0008] FIG. 3 depicts an example fixture that can assist in alignment of the set of cells, busbars, and module body of FIG. 2 during assembly of the battery module.

[0009] FIG. 4 depicts an example circuit board electrically interfaced with the set of cells, and busbars of the battery module of FIG. 2.

[0010] FIG. 5 depicts an example of perimeter enclosure walls added to the module body of FIG. 4.

[0011] FIG. 6 shows the configuration of the battery module of FIG. 5 with the addition of cured potting resin on the opposite side of circuit board from the set of cells.

[0012] FIG. 7 shows the configuration of the battery module of FIG. 6 as assembled battery module 700.

[0013] FIGS. 8A and 8B depict features of an example battery system that combines two instances of the set of cells of FIG. 1.

[0014] FIG. 9 depicts features of an example battery system that combines four instances of the set of cells of FIG. 1.

[0015] FIG. 10 depicts features of an example battery system that combines the battery modules of FIG. 9 using a different busbar configuration.

[0016] FIG. 11 depicts an example busbar having a cross section that tapers along its length dimension.

[0017] FIG. 12 depicts an example circuit diagram showing series and parallel electrical pathways that can be defined by the circuit board of FIG. 4 for the set of cells of FIG. 1.

[0018] FIG. 13 depicts an example circuit diagram showing series and parallel electrical pathways that can be defined by the circuit board of FIG. 8B for two instances of the set of cells of FIG. 1.

[0019] FIGS. 14A and 14B depict a flow diagram of an example method of manufacturing a battery system that includes one or more battery modules.

[0020] FIG. 15 depicts a detailed view of a portion of an example circuit board that can form part of the circuit boards described herein.

DETAILED DESCRIPTION

[0021] FIG. 1 depicts an example of a set of cylindrical battery cells 100 for a battery module arranged in an array. As described with reference to example cylindrical battery cell 110, each cylindrical battery cell of the set of cells 100 includes a pair of battery terminals 112 and 114 at a first end 102 (i.e., a terminal end) of the cell that opposes a second end 104 (i.e., a base end) of the cell. In this example, terminal 112 takes the form of an anode and terminal 114 takes the form of a cathode of cell 110. Alternatively, terminal 112 can take the form of a cathode and terminal 114 can take the form of an anode of cell 110. In the example of FIG. 1, a central axis 116 of each cylindrical battery cell of the set of cells 100 is aligned parallel with a central axis of each other cylindrical battery cell of the set of cells.

[0022] Additionally, in the example of FIG. 1, the set of cells 100 are arranged in a plurality of rows 120A, 120B, 120C, etc., with each row including a plurality of cells. For example, within FIG. 1, each of rows 120A, 120B, 120C, etc. of the array includes 14 cells, and the array includes 13 rows. The arrangement of the set of cells 100 of FIG. 1 features a gap or spacing between neighboring cells to provide clearance for the introduction of a potting resin, as described in further detail with reference to FIG. 2.

[0023] Furthermore, in this example, the array of the set of cells 100 has a staggered formation in which cells of neighboring rows (e.g., 110A and 110B, or 110B and 110C) are offset from each other in a length dimension of each of the neighboring rows. As an example, the offset can correspond to half the distance between two cells

of a neighboring row. This staggered formation can increase packing density of cells within a given volume while also maintaining suitable free space between cells for cell potting and isolation. It will be understood that the set of cells 100 can include any suitable quantity of cells forming a two-dimensional array of any suitable arrangement of two or more cells in each of the two dimensions of the array.

[0024] FIG. 2 depicts the set of cells 100 of FIG. 1 partially encapsulated by cured potting resin 210 with a pair of busbars 220 and 222 within a portion 232 of a module body 230 for an example battery module. In this example, cured potting resin 210 encapsulates a portion of each cylindrical battery cell of the set of cells 100 extending from the base end 104 of the cell that opposes the terminal end 102, while the remaining portion of the cell including the terminal end projects outward from the resin.

[0025] The set of cells 100 partially encapsulated by cured potting resin 210 retains the set of cells in the arrangement previously described with reference to FIG. 1. For example, the central axis 116 of each cylindrical battery cell of the set of cells 100 is aligned parallel with a central axis of each other cylindrical battery cell of the set of cells. Additionally, as in FIG. 1, the set of cells 100 of FIG. 2 are arranged in the plurality of rows 120A, 120B, 120C, etc., with each row including a plurality of cells. The array of the set of cells 100 in FIG. 2 also has the staggered formation of FIG. 1 in which cells of neighboring rows are offset from each other in the length dimension of each of the neighboring rows.

[0026] The arrangement of the set of cells 100 of FIG. 2 features a gap or spacing between neighboring cells that is occupied by cured potting resin 210. Additionally, a gap or spacing between the set of cells 100 and perimeter wall 234 is occupied by cured potting resin 210 in the example of FIG. 2. This configuration

enables each cell of the set of cells 100 to be separated from perimeter wall 234 and from neighboring cells by cured potting resin 210, thereby providing thermal and/or electrical insulation and structural support for the arrangement of the set of cells via the cured potting resin.

[0027] Portion 232 of module body 230 forms a lower portion of a tub having an interior volume that is occupied by cured potting resin 210 in FIG. 2. In this example, portion 232 of module body 230 includes a perimeter wall 234 and a base 236. In at least some examples, perimeter wall 234 and base 236 can be formed from separate components and/or from different materials. As an example, base 236 can take the form of a cooling plate formed from metal, ceramic, or other suitable material that provides a suitable level of thermal conductivity to assist in dissipating heat from the set of cells 100. Perimeter wall 234 can be formed from a different material from base 236, such as a non-metallic, polymer, as an example. Suitable materials for perimeter wall 234 can include materials that do not conduct electricity and have relatively lower thermal conductivity as compared to base 236.

[0028] In at least some examples, portion 232 of module body 230 further includes an intermediate layer 238 disposed between base 236 and the base end 104 of each cell of the set of cells 100. As an example, intermediate layer 238 can form a continuous layer that covers base 236 within at least a region of the base defined by perimeter wall 234. Intermediate layer 238 can take the form of an adhesive and/or electrical insulation layer, as an example.

[0029] As an adhesive layer, intermediate layer 238 can assist in retaining the arrangement of the set of cells 100 relative to module body 230 during potting and prior to curing of the potting resin. Additionally, intermediate layer 238 as an adhesive layer can improve and maintain contact between the base end 104 of the set of cells 100 and

base 236, thereby improving thermal conductivity between the set of cells and the base. As an electrical insulation layer, intermediate layer 238 can electrically insulate the set of cells 100 from base 236. An example material suitable for intermediate layer 238 is Temprion (TM), which is an adhesive thermal tape. However, other suitable adhesive can be used. Materials suitable for intermediate layer 238 (including Temprion (TM)) can provide a suitable level of thermal conductivity between the set of cells 100 and the base 236 to assist in dissipating heat from the set of cells 100 to the base.

[0030] Within the example of FIG. 2, intermediate layer 238 extends beyond perimeter wall 234 and is disposed between the perimeter wall 234 and base 236. In this example, intermediate layer 238, as an adhesive layer, can assist in retaining the arrangement of perimeter wall 234 relative to base 236. Additionally, intermediate layer 238 can serve as a seal between perimeter wall 234 and base 236 to reduce or eliminate leakage of potting resin during potting and prior to curing of the resin. In other examples, perimeter wall 234 and base 236 can be integrated into a single component, and intermediate layer 238 can cover base 236 within the region defined by perimeter wall 234. Furthermore, in other examples, intermediate layer 238 can be omitted.

[0031] Busbars 220 and 222 depicted in FIG. 2 are represented in simplified form. Depending on implementation, busbar 220 forms one of an anode or cathode busbar of the battery module, and busbar 222 forms the other of the anode or cathode busbar of the battery module. It will be understood that busbars 220 and 222 can take various forms and shapes depending on implementation. In the example of FIG. 2, each of busbars 220 and 222 extend beyond perimeter wall 234 on opposing sides of module body 230 to provide two anode terminals and two cathode terminals of the battery module. However, in at least some examples, each busbar extends beyond the perimeter

wall on one side of the module body, such as depicted in FIGS. 8A and 8B to provide one of an anode terminal or a cathode terminal of the battery module.

[0032] Furthermore, in at least some examples, busbars can have a shape that tapers along a linear dimension of the busbar. As an example, each busbar can have a largest cross section at a portion of the busbar that corresponds to an anode terminal or a cathode terminal of the battery module (e.g., the portion the projects beyond the module body), and the busbar can taper to a reduced cross section along a length dimension of the busbar along which subsets of battery cells of the battery module are electrically interfaced with the busbar.

[0033] A portion of each of busbars 220 and 222 is encapsulated with the set of cells 100 by cured potting resin 210. Busbars 220 and 222 also feature a gap or spacing between the busbars and neighboring cells, and between the busbars and portions of the perimeter wall 234 that is occupied by cured potting resin 210. This configuration provides thermal and/or electrical insulation and structural support for the arrangement of busbars 220 and 222 within the battery module.

[0034] Busbars 220 and 222 are electrically conductive, and can be formed from metal (e.g., aluminum) that provides suitable electrical conductivity. Within the example of FIG. 1, busbars 220 and 222 extend beyond perimeter wall 234 to interface with other electrical systems and components thereof. In at least some examples, a surface 226 (e.g., an upper surface in FIG. 2) of each of busbars 220 and 222 facing outward from the open face of the tub formed by portion 232 of module body 230 is coplanar with the terminal end 102 of the set of cells 100. This configuration enables a planar circuit board to be electrically interfaced with the terminals 112 and 114 of the set of cells 100 and with busbars 220 and 222, as described in further detail herein.

[0035] Portion 232 of module body 230 further includes a plurality of alignment structures 240 that can assist in alignment of a circuit board that is electrically interfaced with the set of cells 100 and the busbars 220 and 222. As an example, alignment structures 240 can form part of perimeter wall 234. Alignment structures 240 can take the form of posts that extend outward from the open face of the tub formed by module body 230. Alignment structures 240 can be formed from a material that does not conduct electricity, such as a polymer, as an example.

[0036] In at least some examples, alignment structures 240 project outward a distance along axis 116 that is greater than a height of the set of cells 100 and the busbars 220 and 222, enabling the alignment structures to pass through at least a portion of the circuit board as shown in FIG. 4. Furthermore, in at least some examples, alignment structures 240 are spatially distributed at various locations to improve alignment of the circuit board with module body 230, the set of cells 100, and busbars 220 and 222. In the example depicted in FIG. 2, alignment structures 240 are distributed at various locations along a perimeter defined by perimeter wall 234. For example, a set of four of alignment structures 240 are located along a first side of perimeter wall 234, and another set of four alignment structures 240 are located along a second side of the perimeter wall that opposes the first side. However, it will be understood that other suitable alignment structure configurations can be used.

[0037] FIG. 3 depicts an example fixture 300 that can assist in alignment of the set of cells 100, busbars 220 and 222, and portion 232 of module body 230 during assembly of the battery module. As an example, module body 230 can assist in alignment during an initial potting of a first portion of the set of cells 100 and busbars 220 and 222 within the tub formed by portion 232 of module body 230 to obtain the configuration of cured potting resin 210 shown in FIG. 2.

[0038] Fixture 300 defines a set of openings 310 arranged in an array that each accommodates a portion of a respective cylindrical battery cell of the set of cells 100. The terminal end 102 of each cell of the set of cells 100 can be loaded into a respective opening of the set of openings 310 of fixture 300 to obtain the arrangement of the set of cells of FIGS. 1 and 2. Within FIG. 3, the exposed portion extending from the base end 104 of each cell of the set of cells 100 that resides outside of fixture 300 projects into the interior volume of the tub formed by portion 232 of module body 230. This exposed portion of the cells is encapsuled by the cured potting resin 210, previously described with reference to FIG. 2.

[0039] Openings 310 can form a circular bore having a diameter that is equal to or slightly larger than a diameter of the cylindrical battery cells of set 100, at least on a side of fixture 300 that faces toward base 236 of module body 230. In at least some examples, the circular bore of openings 310 can pass through fixture 300. However, in at least some examples, openings 310 can have a narrower diameter at a side of fixture 300 that faces away from base 236. This reduction in diameter of openings 310 can be used to define a depth at which the set of cells 100 penetrate the fixture, thereby defining a length of each cell along axis 116 that is exposed outside of the fixture. In at least some examples, fixture 300 includes a set of standoff structures 340 that define a standoff distance between fixture 300 and perimeter wall 324. This standoff distance can also define a depth at which the set of cells 100 penetrate the fixture 300, thereby defining a length of each cell along axis 116 that is exposed outside of the fixture.

[0040] Fixture 300 further defines openings 320 and 322 that accommodate and align busbars 220 and 222 with the set of cells 100 and portion 232 of module body 230. Such alignment can be used to provide the configuration of FIG. 2 in which busbars 220 and 220 are spaced apart from the set of cells 100 and from perimeter wall

234, thereby permitting potting resin to occupy space between the busbars and the set of cells and perimeter wall.

[0041] Fixture 300 further includes openings 330 that accommodate alignment structures 240, previously described with reference to FIG. 2, thereby ensuring alignment of fixture 300 with portion 232 of module body 230 during potting.

[0042] In at least some examples, fixture 300 can be loaded with the set of cells 100 and busbars 220 and 222, and placed in alignment with portion 232 of module body 230 before intermediate layer 238 and base 236 are added to perimeter wall 234. Following alignment of fixture 300, potting can be performed by adding potting to the tub defined by portion 232 of module body 230. As an example, fixture 300 can further define one or more openings 350 by which potting resin can be added to the tub.

[0043] Upon curing of the potting resin, fixture 300 can be removed from portion 232 of module body 230, from the set of cells 100, and from busbars 220 and 222 to provide the configuration of FIG. 2.

[0044] FIG. 4 depicts an example circuit board 400 (e.g., a PCB) electrically interfaced with the set of cells 100, and busbars 220 and 220 of the battery module. Circuit board 400 is depicted in simplified form in FIG. 4. Further details of circuit board 400 are described with reference to FIGS. 12 and 13.

[0045] Circuit board 400 can define a plurality of series electrical pathways among respective subsets of the set of cells 100, and a plurality of parallel electrical pathways among the plurality of series electrical pathways. Given the flexibility in circuit design made available by circuit boards, example circuit board 400 can define a variety of series and parallel configurations for the set of cells 100. As an example, circuit board 400 can define 13 parallel electrical pathways for the set of cells 100 in which each parallel electrical pathway includes 14 cells arranged in series to form a

series electrical pathway. However, by changing the layout of circuit board 400, a different quantity of series and parallel configurations can be achieved for the set of cells 100.

[0046] FIG. 4 further shows alignment structures 240 projecting through corresponding openings 410 formed in circuit board 400, thereby aligning the circuit board with the set of cells 100, busbars 220 and 222, and portion 232 of module body 230.

[0047] FIG. 5 depicts an example of perimeter enclosure walls 500 of module body 230 added to the battery module of FIG. 4. Perimeter enclosure walls 500 form an extension of the tub formed by portion 232 of module body 230. This extension of the tub defines the remaining interior volume of the tub between the cured resin potting 210 shown in FIG. 2 and the interior facing side of circuit board 400 for potting.

[0048] Within FIG. 5, an example cutaway 502 of perimeter enclosure wall 500 and perimeter wall 234 is provided to reveal the interior volume of module body 230 between base 236 and circuit board 400 following additional potting. As shown by cutaway 502, cured potting resin potting 210 of FIG. 2 and supplemental cured potting resin 510 form an integrated cured potting resin core 512 that encapsulates the set of cells 100 and busbars 220 and 222 within the interior region of the tub between base 236 up to circuit board 400. In this example, cured potting resin 510 is formed from the same material as cured potting resin 210.

[0049] Also in the example of FIG. 5, busbars 220 and 222 project through openings 520 and 522 formed in a perimeter enclosure walls 500 on opposing sides of module body 230 to enable the busbars to interface with other electrical systems and components thereof. Furthermore, in at least some examples, a portion of circuit board 400 and associated electrical pathways thereof can project outward through an opening

formed in a perimeter of enclosure walls 500 to interface with external electrical components, including a battery system controller (e.g., a battery management system), as an example. As described with reference to FIGS. 12 and 13, for example, a circuit board can include one or more connectors or connector regions, which can be exposed on an exterior of the enclosure of the battery system for interfacing with a controller. Portions of circuit board 400 that project through the enclosure walls can be lined with a seal to reduce leakage of potting resin and reduce or eliminating cell venting along the circuit board. However, in at least some examples, potting resin is provided during the potting process at a level that does not reach or interface with the circuit board. This configuration can be used to avoid or reduce contact of potting resin at the terminal end of the cells.

[0050] In at least some examples, seals 530 and 532 can be provided between perimeter enclosure walls 500 and busbars 220 and 222 along a perimeter of openings 520 and 522. Seals 530 and 532 can reduce leakage of potting resin prior to curing of cured potting resin 512 and isolate the interior region of module body 230 from an exterior of the module body. For example, cell venting can be reduced or eliminated along the busbars by uses of seals 530 and 532.

[0051] In at least some examples, a seal 540 can be provided between a perimeter of circuit board 400 and perimeter enclosure walls 500. Seal 540 can reduce leakage of potting resin prior to curing of cured potting resin 512 and isolate the interior region of module body 230 from an opposing side of circuit board 400 from the interior region. Furthermore, in at least some examples, seals can be provided along a perimeter of openings 410 of circuit board 400 to reduce leakage and provide isolation at locations where alignment structures 240 protrude through the circuit board. Furthermore, in at least some examples, circuit board 400 can define one or more openings (schematically

depicted at 560 through which potting resin can be introduced into the tub formed by the module body as part of the potting process.

[0052] Within FIG. 5, perimeter enclosure walls 500 form a lip 550 along the perimeter of module body 230 on an opposite side of circuit board 400 from the set of cells 100. FIG. 6 shows the configuration of the battery module of FIG. 5 with the addition of cured potting resin 600 on the opposite side of circuit board 400 from the set of cells 100 to at least partially occupy the region defined by lip 550 of FIG. 5 and an outward face of the circuit board. In at least some examples, a depth of cured potting resin 600 can be defined such that an air gap is maintained between an upper surface of resin 600 and an upper wall (e.g., upper wall 710 of FIG. 7) of the battery module to promote venting of cell gases and/or heat from the battery module.

[0053] In at least some examples, cured potting resin 610 is formed of a material that differs from cured potting resin 210 and 510 of cured potting resin core 512. As an example, cured potting resin 610 covering the outward face of circuit board 400 has a lower density than cured potting resin 210 and 510 of cured potting resin core 512. The material of cured potting resin 610 can provide greater thermal conductivity and gas permeation per unit volume as compared to cured potting resin 210 and 510 of cured potting resin core 512. Furthermore, this configuration can be used to direct cell venting or rupture through the top of the battery system rather than a side or bottom, and can provide soft venting of the battery system.

[0054] While FIG. 6 depicts perimeter enclosure walls 500 being provided with base 236 exposed, in at least some examples, perimeter enclosure walls 500 can feature an enclosure floor that in combination with the perimeter enclosure walls depicted in FIG. 6 surrounds or otherwise encapsulates the module body including base 236.

[0055] FIG. 7 shows the configuration of the battery module of FIG. 6 as assembled battery module 700. In this example, module body 230 further includes an upper wall 710 that forms a cover for perimeter enclosure wall 500. In at least some examples, upper wall 710 can include one or more vents, an example of which is represented schematically in simplified form in FIG. 7 as vent 720. Additionally or alternatively, perimeter enclosure walls 500 can include one or more vents, for example, within a region formed by lip 550. In at least some examples, the perimeter enclosure wall 500 or upper wall 710 can define a channel that is not potted to direct cell gases to the one or more vents. The location of these various vents can be defined for a particular use or implementation of battery module 700. For example, ventilation pathways for a given installation of battery module 700 can be directed in any suitable direction relative to module body 230 by selective placement of such vents.

[0056] A battery module, such as example battery module 700 can be referred to as a battery system or can form part of a battery system in combination with one or more other battery modules or components thereof. As an example, multiple instances of battery module 700 can be combined to form a battery system that achieves a desired level of battery performance and capacity. As yet another example, two or more instances of a battery module, such as example battery module 700, can share components to form a battery system that achieves a desired level of battery performance and capacity. Examples of components that can be shared between or among two or more battery modules include a circuit board, busbars, cured resin potting, module body components, etc. In each of these examples, multiple instances of a set of cylindrical battery cells, such as the set of cells 100, can be combined to form the battery system.

[0057] FIGS. 8A and 8B depict features of an example battery system 800 that combines two instances of the set of cells 100 of FIG. 1, represented in FIGS. 8A and 8B by a first set of cells 100-1 and a second set of cells 100-2. In FIG. 8A, a first busbar 220-1 is shared by the first set of cells 100-1 and the second set of cells 100-2 to provide an anode or cathode terminal 810 for battery system 800, and a second busbar 222-1 is shared by the first set of cells 100-1 and the second set of cells 100-2 to provide the other of the anode or cathode terminal 812 for the battery system.

[0058] In FIG. 8B, a circuit board 400-1 is electrically interfaced with the first set of cells 100-1, the second set of cells 100-2, busbar 220-1 and busbar 222-2 to define a plurality of series electrical pathways among respective subsets of the two sets of cells 100-1 and 100-2, and a plurality of parallel electrical pathways among the plurality of series electrical pathways. As an example, circuit board 400-1 can define 26 parallel electrical pathways among the two sets of cells 100-1 and 100-2 in which each parallel electrical pathway includes 14 cells arranged in series. Within FIG. 8B, the cells and portions of the busbars residing beneath circuit board 400-1 are represented by broken lines.

[0059] The components of battery system 800 of FIGS. 8A and 8B can be combined using a shared module body and can be potted together using the various stages of potting previously described with reference to FIGS. 2-6. Cells of each set of cells 100-1, 100-2, etc. can be positioned within a module body for potting by separate fixtures (e.g., separate instances of fixture 300 of FIG. 3) or by a shared fixture that accommodates each of the cells. In this example, battery system 800 can be characterized as including a single battery module 802 having twice the quantity of cells as battery module 700 of FIG. 7.

[0060] FIG. 9 depicts features of an example battery system 900 that combines four instances of the set of cells 100 of FIG. 1, represented by a first set of cells 100-1 and a second set of cells 100-2 that form a first battery module 802-1, and a third set of cells 100-3 and a fourth set of cells 100-4 that form a second battery module 802-2. Accordingly, in this example, battery system 900 includes two instances of battery module 802 previously described with reference to FIG. 8B, as represented by modules 802-1 and 802-2 in FIG. 9.

[0061] In FIG. 9, first busbar 220-1 is shared by the first set of cells 100-1 and the second set of cells 100-2 of battery module 802-1, and a third busbar 220-2 is shared by the third set of cells 100-3 and the fourth set of cells 100-4 of battery module 802-2. Busbars 220-1 and 220-2 are electrically interfaced with each other via a first busbar interconnect 920-1 to collectively provide one of an anode or cathode busbar having a corresponding anode or cathode terminal 910. In the example of FIG. 9, second busbar 222-1 is shared by the first set of cells 100-1 and the second set of cells 100-2 of battery module 802-1, and a fourth busbar 222-2 is shared by the third set of cells 100-3 and the fourth set of cells 100-4 of battery module 802-2. Busbars 222-1 and 222-2 are electrically interfaced with each other via a second busbar interconnect 920-2 to collectively provide the other of the anode or cathode busbar having a corresponding anode or cathode terminal 912. While busbar interconnects 920-1 and 920-2 are depicted in this example, in other examples a single busbar can be used in place of two or more busbars and associated interconnects.

[0062] In FIG. 9, circuit board 400-1 is electrically interfaced with the first set of cells 100-1, the second set of cells 100-2, busbar 220-1 and busbar 222-1 to define a first plurality of series electrical pathways among respective subsets of the two sets of cells 100-1 and 100-2, and a first plurality of parallel electrical pathways among the

first plurality of series electrical pathways. As previously described with reference to FIG. 8B, circuit board 400-1 can define 26 parallel electrical pathways among the two sets of cells 100-1 and 100-2 in which each parallel electrical pathway includes 14 cells arranged in series.

[0063] Also in FIG. 9, a second circuit board 400-2 is electrically interfaced with the third set of cells 100-3, the fourth set of cells 100-4, busbar 220-2 and busbar 222-2 to define a second plurality of series electrical pathways among respective subsets of the two sets of cells 100-3 and 100-4, and a second plurality of parallel electrical pathways among the second plurality of series electrical pathways. As previously described with reference to circuit board 400-1, circuit board 400-2 can similarly define 26 parallel electrical pathways among the two sets of cells 100-3 and 100-4 in which each parallel electrical pathway includes 14 cells arranged in series.

[0064] In this example, the first plurality of series electrical pathways defined by circuit board 400-1 and the second plurality of series electrical pathways defined by circuit board 400-2 are electrically interfaced in parallel to provide a greater quantity of parallel electrical pathways each formed from 14 cells arranged in series for battery system 900. For example, the quantity of parallel electrical pathways is combined to obtain a total of 52 parallel electrical pathways. Within FIG. 9, the cells and portions of the busbars residing beneath the circuit boards are represented by broken lines.

[0065] In this example, the first plurality of series electrical pathways defined by circuit board 400-1 and the second plurality of series electrical pathways defined by circuit board 400-2 are electrically interfaced with each other by a circuit board interconnect 930. However, in other examples, two circuit boards can be electrically interfaced with each other via an electrical connector located on each circuit board. The use of interconnects to connect two or more circuit boards can be used for scenarios

where circuit board size is limited. However, in still further examples, circuit boards 400-1 and 400-2 of battery system 900 can be replaced by a single circuit board.

[0066] Battery modules 802-1 and 802-2 can be potted separately or together, and can share a common module body or utilize separate module bodies. Cells of each battery module can be positioned within a module body for potting by separate fixtures or by a shared fixture that accommodates each of the cells. Two or more module bodies can be combined into a shared battery system enclosure. Any suitable quantity of battery modules and associated cells can be combined as described with reference to FIG. 9. Additionally, any suitable quantity of respective instances of battery system 900 can be combined by interconnecting anode and cathode terminals of the busbars to form a superset of battery systems to provide a suitable battery performance and capacity for a given implementation.

[0067] FIG. 10 depicts features of an example battery system 1000 that combines previously described battery modules 800-1 and 800-2 using a different busbar configuration from the example of FIG. 9. In the example of FIG. 10, a busbar interconnect 1020 for busbars 220-1 and 220-2 forms one of an anode terminal and a cathode terminal 1010. While busbar interconnect 1020 is depicted in this example, in other examples a single busbar can be used in place of two or more busbars and associated interconnects. Furthermore, in the example of FIG. 10, busbars 222-1 and 222-2 each provide instances of the other of the anode terminal and cathode terminal from terminal 1010, as depicted at 1012-1 and 1012-2, respectively. Collectively, the configuration of battery system 1000 of FIG. 10 provides 26 parallel electrical pathways among the four sets of cells 100-1, 100-2, 100-3, and 100-4 in which each parallel electrical pathway includes 28 cells arranged in series. Any suitable quantity of battery modules and associated cells can be combined as described with reference to FIG. 10.

Additionally, any suitable quantity of respective instances of battery system 1000 can be combined by interconnecting anode and cathode terminals of the busbars to form a superset of battery systems to provide a suitable battery performance and capacity for a given implementation.

[0068] FIG. 11 depicts an example busbar 1100 having a cross section 1110 that tapers along its length dimension 1112 from a larger cross section at an anode or cathode terminal 1114 of the busbar to a narrower cross section. By tapering the cross section of the busbar, a uniform current density can be achieved. Any of the busbar examples described herein can utilize a tapered busbar, such as example busbar 1100.

[0069] FIG. 12 depicts an example circuit diagram 1200 showing series and parallel electrical pathways that can be defined by circuit board 400 of FIG. 4 for the set of cells 100 of FIG. 1. In this example, a circuit board 400-12 (as an example of circuit board 400 of FIG. 4) is depicted overlaid upon the series of cells 100 of FIG. 1, a first busbar 220-12 and a second busbar 222-12, which are depicted by broken lines where residing beneath the circuit board.

[0070] Circuit board 400-12, in this example, provides 13 parallel electrical pathways in which each parallel electrical pathway is formed by a series electrical pathway of 14 cells of the set of cells 100. Furthermore, in this example, each respective subset of cells that forms a series electrical pathway includes cylindrical battery cells located in different rows of the plurality of rows, and at least two cells located in the same row. This example illustrates the flexibility of the circuit board in decoupling a spatial relationship of the cells from the functional location of the cells within the circuit, thereby enabling a given set of cells configured in a given spatial arrangement to form any suitable combination of series and parallel electrical pathways to provide a suitable level of battery performance and capacity.

[0071] Within FIG. 12, an example cell 110 of the set of cells 100 includes a first terminal 112 (e.g., an interior anode terminal) and a second terminal 114 (e.g., an exterior cathode terminal), as previously described with reference to FIG. 1. Solid lines residing within a boundary of circuit board 400-12 in FIG. 12 represent electrical pathways (e.g., traces) defined by the circuit board. Solid circles (e.g., as shown at 1210) within the boundary of circuit board 400-12 represent locations where the electrical pathways of the circuit board interface with a terminal of a cell of the set of cells 100, busbar 220-12, or busbar 222-12. These solid circles can take the form of wire bonds, as an example.

[0072] Within FIG. 12, pairs of cells of the set of cells 100 are electrically interfaced with each other via an inter-cell electrical pathway (an example of which is shown at 1212) of circuit board 400-12 that electrically couples first terminal 112 (e.g., an anode) of a first cell to second terminal 114 (e.g., a cathode) of a second cell to form part of a series electrical pathway. Subsets of cells of the set of cells 100 can form series electrical pathways by interconnecting the subset of cells via corresponding inter-cell electrical pathways. Each series electrical pathway formed among a subset of cells electrically interfaces with busbar 220-12 on a first end of the series and with busbar 222-12 on a second end of the series electrical pathway. As an example, a series electrical pathway that includes example cell 110 and 13 other cells forming a subset of cells electrically interfaces with busbar 220-12 via a first cell-busbar electrical pathway 1230 and with busbar 222-12 via a second cell-busbar electrical pathway 1232. FIG. 12 depicts example locations of a first busbar terminal 1250 of busbar 220-12 and a second busbar terminal 1252 of busbar 222-12.

[0073] Circuit board 400-12 further defines interconnecting electrical pathways that electrically interface with and span the inter-cell electrical pathways of each series

of cells, an example of which is depicted at 1214. These interconnecting electrical pathways may be referred to as inter-cell rivers. In this example, circuit board 400-12 defines 13 interconnecting electrical pathways or inter-cell rivers that correspond to the 13 parallel electrical pathways that each feature 14 cells arranged in series. Furthermore, in this example, the interconnecting electrical pathways or inter-cell rivers can terminate at one or more connectors of circuit board 400-12, which include connectors 1220 and 1222 in this example.

[0074] Circuit board 400-12 further defines interconnecting electrical pathways that electrically interface with and span the cell-busbar electrical pathways for each busbar. These interconnecting electrical pathways may be referred to as cell-busbar rivers. For example, a first interconnecting electrical pathway 1216 or cell-busbar river electrically interfaces with and spans cell-busbar electrical pathways associated with busbar 220-12, which includes example cell-busbar electrical pathway 1230. A second interconnecting electrical pathway 1218 or cell-busbar river electrically interfaces with and spans cell-busbar electrical pathways associated with busbar 222-12, which includes example cell-busbar electrical pathway 1232. Furthermore, in this example, the interconnecting electrical pathways or cell-busbar rivers can terminate at one or more connectors of circuit board 400-12, which include connectors 1220 and 1222 in this example.

[0075] Connectors 1220 and 1222 carrying electrical pathways of the inter-cell rivers and the cell-busbar rivers can be electrically interfaced with a controller 1224 of the battery module or battery system, which is represented schematically in FIG. 12. As an example, controller 1224 can include and/or implement a battery management system (BMS), including a variety of BMS functions. Examples of BMS functions include sensing voltage or other electrical parameters of the set of cells via the inter-

cell rivers and cell-busbar rivers. As previously described, portions of the circuit board may extend beyond walls of the enclosure, and controller 1224 may be located outside of the enclosure wall.

[0076] FIG. 13 depicts an example circuit diagram 1300 showing series and parallel electrical pathways that can be defined by a circuit board 400-13 (as an example of circuit board 400-1 of FIG. 8B). Circuit board 400-13 is depicted overlaid upon the sets of cells 100-1 and 100-2, first busbar 220-1 and second busbar 222-2 of FIG. 8B, which are depicted by broken lines at locations residing beneath the circuit board.

[0077] In the example of FIG. 13, the circuit board provides 26 parallel electrical pathways for the series electrical pathways in which each series electrical pathway includes 14 cells. Circuit board 400-13 in this example includes electrical pathways having a similar configuration as circuit board 400-12 of FIG. 12, but accommodates twice as many cells. Furthermore, in this example, each respective subset that forms a series electrical pathway includes cylindrical battery cells located in different rows of the plurality of rows, and at least two cells located in the same row. This example again illustrates the flexibility of the use of circuit boards in decoupling a spatial relationship of the cells from the functional location of the cells within the circuit, thereby enabling a given set of cells configured in a given spatial arrangement to form any suitable combination of series and parallel electrical pathways to provide a suitable level of battery performance and capacity.

[0078] FIGS. 14A and 14B depict a flow diagram of an example method 1400 of manufacturing a battery system that includes one or more battery modules.

[0079] At 1410, the method includes obtaining a module body. The module body forms a tub having an interior volume, as previously described with reference to the example of FIGS. 2 – 7.

[0080] At 1412, the method includes obtaining a set of cylindrical battery cells. As an example, the set of cylindrical battery cells obtained at 1412 can include the set of cells 100 of FIG. 1. Each cylindrical battery cell of the set including a pair of battery terminals on a first end of the cylindrical battery cell, as previously described with reference to example battery cell 110 of FIG. 1.

[0081] At 1414, the method includes obtaining a fixture having a set of openings arranged in an array that each accommodates a portion of a respective cylindrical battery cell of the set of cylindrical battery cells. As an example, the fixture obtained at 1414 can include example fixture 300 previously described with reference to FIG. 3.

[0082] At 1416, the method includes obtaining intermediate layer material that includes an adhesive. Examples of intermediate layer materials are described with reference to intermediate layer 238 of FIG. 2. At 1418, the method includes applying the intermediate layer material to a base of the tub to obtain an intermediate layer. The intermediate layer obtained at 1418 is described with reference to example intermediate layer 238 of FIG. 2. In at least some examples, applying the intermediate layer material at 1418 is performed after the following described steps associated with placement of the set of cells and busbars. As an example, the intermediate layer material can be applied to the base of the tub prior to assembling the base with other components of the tub, such as the perimeter walls.

[0083] At 1420, the method includes loading the fixture with the portion that includes the first end of each cylindrical battery cell of the set into a respective opening of the set of openings to arrange the set of cylindrical battery cells in the array.

[0084] At 1422, the method includes obtaining a first busbar and a second busbar. At 1424, the method includes loading the fixture with the first and second

busbars. However, in other examples, the fixture may be used for cell positioning and not for positioning the busbars. In these examples, the busbars could be loaded into the tub without use of the fixture for busbar positioning during potting.

[0085] At 1426, the method includes placing an exposed portion of each cylindrical battery cell of the set and the first and second busbars loaded in the fixture into the interior volume of the tub. As previously described with reference to FIG. 3, alignment structures of the module body can be used to align the fixture with the module body.

[0086] At 1428, the method includes potting the exposed portion of each cylindrical battery cell of the set and the first and second busbars within the interior volume of the tub with a potting resin to obtain a cured potting resin that encapsulates the exposed portion of each cylindrical battery cell of the set and the first and second busbars within the interior volume of the tub.

[0087] At 1430, the method includes removing the fixture from the set of cylindrical battery cells and the first and second busbars following curing of the potting resin.

[0088] Referring to FIG. 14B, at 1432, the method includes obtaining a circuit board, such as previously described example circuit board 400 of FIG. 4. The circuit board obtained at 1432, when electrically interfaced with the pair of battery terminals of each cylindrical battery cell of the set defines: a plurality of series electrical pathways among respective subsets of the set of cylindrical battery cells, and a plurality of parallel electrical pathways among the plurality of series electrical pathways.

[0089] At 1434, the method includes aligning the electrical contacts of the circuit board with the pair of battery terminals of each cylindrical battery of the set and the busbars with the circuit board covering an open face of the tub to enclose the interior

volume. As previously described with reference to FIG. 4, alignment structures 240 can be used to align the circuit board with various components, including the cells and the busbars.

[0090] At 1436, the method includes electrically interfacing the electrical contacts of the circuit board with the pair of battery terminals of each cylindrical battery cell of the set. As an example, the electrical contacts of the circuit board can be electrically interfaced with the pair of battery terminals of each cylindrical battery cell via an intermediate wire-bonded electrical pathway to form the plurality of series electrical pathways among respective subsets of the set of cylindrical battery cells, and the plurality of parallel electrical pathways among the plurality of series electrical pathways. For the busbars, the method at 1436 includes electrically interfacing a first end of the plurality of parallel electrical pathways on a first side of the array with the first busbar via the circuit board, and electrically interfacing a second end of the plurality of parallel electrical pathways on a second side of the array with the second busbar with the circuit board.

[0091] At 1438, the method includes potting an additional portion of each cylindrical battery cell of the set and the first and second busbars within the interior volume of the tub with additional potting resin to obtain additional cured potting resin that encapsulates the additional portion of each cylindrical battery cell of the set and the busbars within the interior volume of the tub.

[0092] At 1440, the method includes potting an outward face of the circuit board on an opposite side of the circuit board from the set of cylindrical battery cells with a second potting resin to obtain cured potting resin covering the outward face of the circuit board.

[0093] At 1442, the method includes enclosing the battery module with an upper wall, such as previously described with reference to upper wall 710 of FIG. 7.

[0094] In examples in which multiple battery modules are being combined to obtain the battery system, the method can further include, at 1444, combining the battery module with one or more other battery modules. Example techniques for combining two or more battery modules are described in further detail with reference to FIGS. 8A, 8B, 9, and 10.

[0095] At 1446, the method includes obtaining a device housing. In at least some examples, the module body formed by the tub and upper wall takes the form of the device housing or a portion thereof. In other examples, the battery module and module body thereof can be mounted in a device housing or can be combined with one or more housing components to form the device housing. At 1448, the method includes mounting the one or more battery modules within the device housing.

[0096] In the preceding examples described with reference to FIGS. 1-7 and method 1400 of FIGS. 14A and 14B, initial potting of the cells and busbar is performed within a tub formed by the module body. In another example, initial potting of the cells and/or busbar can be performed within a mold (e.g., a polymer mold or other suitable material) using a fixture, such as example fixture 300. Upon curing of the potting resin during this initial potting stage, the potted components (e.g., the cells and busbar) can be removed from the mold along with the cured potting resin, and installed in an enclosure, which can include base 236 and intermediate layer 238. A subsequent potting stage can be performed with respect to the remaining portions of the cells and busbars as previously described to obtain the potted resin core. Thus, in this example, perimeter wall 234 can be omitted from the assembled battery module and battery system.

[0097] The example circuit boards described herein can take various forms and configurations, and can be electrically interfaced in various ways with components, including cylindrical battery cells, busbars, interconnects, and other electrical and/or electronic components.

[0098] As an example, a circuit board can take the form of a PCB having electrical pathways (e.g., traces) and associated openings in the board at respective locations for receiving wire bonds that electrically connect the electrical pathways of the circuit board to the various components, including the cylindrical battery cells, busbars, interconnects, and other electrical and/or electronic components. These wire bonds can be formed of aluminum and can serve as fuses of a desired rating, in at least some examples. The electrical pathways (e.g., traces) of the circuit board can be located on a side of the circuit board that faces away from the base of the module body and from the set of cells, as an example. Alternatively or additionally, the electrical pathways of the circuit board can be located on a side of the circuit board that faces toward the base of the module body and the set of cells.

[0099] As an alternative or in addition to the above example, a circuit board can take the form of a PCB having electrical pathways (e.g., traces) and associated connectors mounted on the board at respective locations for receiving corresponding connectors that are electrically connected to the various components, the cylindrical battery cells, busbars, interconnects, and other electrical and/or electronic components. In this example, the connectors for electrically interfacing the circuit board with the cells and busbars can be located on a side of the circuit board that faces toward the base of the module body.

[00100] PCBs offer the ability to incorporate additional components such as thermistors for temperature sensing and heaters for temperature control onto the circuit

board. For example, thermistors can be distributed on the circuit board at various locations to sense temperature at various locations of the battery module, which corresponds to particular cells in the vicinity of the thermistors. Heaters (e.g., electrically powered heaters) can be distributed on the circuit board at various locations to selectively provide temperature control at corresponding locations of the battery module. The circuit board can define electrical pathways for the thermistors, heaters, and other on-board components that terminate at one or more connectors, such as example connectors 1220 and 1222 of FIGS. 12 and 13. Temperature sensing and temperature control of the battery system or individual battery modules thereof can be performed by a controller, such as example controller 1224 of FIGS. 12 and 13 via these electrical pathways. In at least some examples, thermistors, heaters, and other components on-board the circuit board can be located on a cell-facing side of the circuit board, and electrical pathways for these components can be located on the cell-facing side and/or on the opposing side of the circuit board. Within FIGS. 12 and 13, an example component 1260 is depicted, which schematically represents a thermistor, heater, or other component that can be mounted on the circuit board.

[00101] FIG. 15 depicts a detailed view of a portion of an example circuit board 400-15 that can form part of any of the circuit boards described herein. Within FIG. 15, an upper face of circuit board 400-15 is shown that faces away from the set of cells. Circuit board 400-15 defines openings, such as example openings 1520-1 and 1520-2 through which wire bonds can be electrically connected to battery terminals. This configuration can be used to avoid or reduce obstructing the venting mechanism of the cells. As an example, wire bond 1510 electrically interfaces first terminal 112 (e.g., an anode terminal) of a first cell with second terminal 114 (e.g., a cathode terminal) of a second cell. Additionally, in this example, wire bond 1510 is electrical contact with an

electrical pathway 1530 of circuit board 400-15 (a portion of which is schematically depicted in FIG. 15).

[00102] According to an example of the present disclosure, a battery system comprises: one or more battery modules, each battery module including: a module body forming a tub having an interior volume; a set of cylindrical battery cells arranged in an array within the interior volume of the tub of the module body, wherein: a central axis of each cylindrical battery cell of the set is aligned parallel with a central axis of each other cylindrical battery cell of the set, and each cylindrical battery cell of the set includes a pair of battery terminals on a first end of the cylindrical battery cell that faces outward from an open face of the tub of the module body; and a circuit board that covers the open face of the tub and includes electrical contacts that electrically interface with the pair of battery terminals of each cylindrical battery cell of the set to define: a plurality of series electrical pathways among respective subsets of the set of cylindrical battery cells, and a plurality of parallel electrical pathways among the plurality of series electrical pathways; and cured potting resin encapsulating at least a portion of the set of cylindrical battery cells within the tub of the module body. In this example or other examples disclosed herein, the battery system can further comprise a first busbar that electrically interfaces with a first end of the plurality of parallel electrical pathways on a first side of the array; and a second busbar that electrically interfaces with a second end of the plurality of parallel electrical pathways on a second side of the array that opposes the first side. In this example or other examples disclosed herein, the battery system comprises two or more battery modules; wherein the first busbar spans the two or more battery modules by electrically interfacing with the first end of the plurality of parallel electrical pathways on the first side of the array of each of the two or more battery modules; and wherein the second busbar spans the two or more battery modules

by electrically interfacing with the second end of the plurality of parallel electrical pathways on the first side of the array of each of the two or more battery modules. In this example or other examples disclosed herein, the battery system comprises two or more battery modules and a third busbar; wherein the first busbar spans the two or more battery modules by electrically interfacing with the first end of the plurality of parallel electrical pathways on the first side of the array of each of the two or more battery modules; wherein the second busbar electrically interfaces with the second end of the plurality of parallel electrical pathways on the second side of the array of a first of the two or more battery modules that opposes the first side; and wherein the third busbar electrically interfaces with the second end of the plurality of parallel electrical pathways on the second side of the array of a second of the two or more battery modules that opposes the first side. In this example or other examples disclosed herein, the first busbar and the second busbar are each at least partially encapsulated by the cured potting resin within the interior volume of the tub. In this example or other examples disclosed herein, the array has a staggered formation in which the set of cylindrical battery cells are arranged in a plurality of rows; and wherein cylindrical battery cells of neighboring rows among the plurality of rows are offset from each other in a length dimension of each of the neighboring rows. In this example or other examples disclosed herein, each respective subset that forms a series electrical pathway includes cylindrical battery cells located in different rows of the plurality of rows, and at least two cells located in the same row. In this example or other examples disclosed herein, the electrical contacts of the circuit board electrically interface with the pair of battery terminals of each cylindrical battery cell via an intermediate wire-bonded electrical pathway. In this example or other examples disclosed herein, the cured potting resin fully encapsulates the set of cylindrical battery cells within the interior volume of the

tub of the module body along the cylindrical walls of the set of cylindrical battery cells. In this example or other examples disclosed herein, the module body includes a plurality of alignment posts that are each accommodated by a respective opening defined in the circuit board. In this example or other examples disclosed herein, the battery system further comprises additional cured potting resin covering an outward face of the circuit board on an opposite side of the circuit board from the set of cylindrical battery cells. In this example or other examples disclosed herein, the additional cured potting resin covering the outward face of the circuit board has a lower density than the cured potting resin encapsulating at least the portion of the set of cylindrical battery cells within the interior volume of the tub of the module body. In this example or other examples disclosed herein, the battery system further comprises an adhesive and electrical insulation layer disposed between a base of the tub of the module body and a second end of each cylindrical battery cell of the set. In this example or other examples disclosed herein, the base of the tub of the module body forms a cooling plate formed from metal. In this example or other examples disclosed herein, the battery system comprises two or more battery modules; and wherein the circuit board of each battery module of the two or more battery modules forms a portion of a shared circuit board that spans each of the two or more battery modules.

[00103] According to another example of the present disclosure, a method of manufacturing a battery system that includes one or more battery modules comprises: obtaining a module body, the module body forming a tub having an interior volume; obtaining a set of cylindrical battery cells, each cylindrical battery cell of the set including a pair of battery terminals on a first end of the cylindrical battery cell; obtaining a fixture having a set of openings arranged in an array that each accommodates a portion of a respective cylindrical battery cell of the set of cylindrical

battery cells; loading the fixture with the portion that includes the first end of each cylindrical battery cell of the set into a respective opening of the set of openings to arrange the set of cylindrical battery cells in the array; placing an exposed portion of each cylindrical battery cell of the set loaded in the fixture into the interior volume of the tub; potting the exposed portion of each cylindrical battery cell of the set within the interior volume of the tub with a potting resin to obtain a cured potting resin that encapsulates the exposed portion of each cylindrical battery cell of the set within the interior volume of the tub; removing the fixture from the set of cylindrical battery cells; potting an additional portion of each cylindrical battery cell of the set within the interior volume of the tub with additional potting resin to obtain additional cured potting resin that encapsulates the additional portion of each cylindrical battery cell of the set within the interior volume of the tub; obtaining a circuit board having electrical contacts that, when electrically interfaced with the pair of battery terminals of each cylindrical battery cell of the set defines: a plurality of series electrical pathways among respective subsets of the set of cylindrical battery cells, and a plurality of parallel electrical pathways among the plurality of series electrical pathways; aligning the electrical contacts of the circuit board with the pair of battery terminals of each cylindrical battery cell of the set with the circuit board covering an open face of the tub to enclose the interior volume; and electrically interfacing the electrical contacts of the circuit board with the pair of battery terminals of each cylindrical battery of the set via an intermediate wire-bonded electrical pathway to form the plurality of series electrical pathways among respective subsets of the set of cylindrical battery cells, and the plurality of parallel electrical pathways among the plurality of series electrical pathways. In this example or other examples disclosed herein, the method further comprises: obtaining a first busbar and a second busbar; prior to potting the additional portion of each cylindrical battery cell

of the set with the additional potting resin: electrically interfacing a first end of the plurality of parallel electrical pathways on a first side of the array with the first busbar, and electrically interfacing a second end of the plurality of parallel electrical pathways on a second side of the array with the second busbar; and wherein at least a portion of the first busbar and the second busbar are encapsulated within the interior volume of the tub by the additional potting resin. In this example or other examples disclosed herein, the method further comprises: potting an outward face of the circuit board on an opposite side of the circuit board from the set of cylindrical battery cells with a second potting resin to obtain a second cured potting resin covering the outward face of the circuit board. In this example or other examples disclosed herein, the method further comprises: obtaining a device housing; and mounting the battery module within the device housing (e.g., an enclosure of the battery system). In this example or other examples disclosed herein, the method further comprises: obtaining an adhesive and electrical insulation layer; and applying the adhesive and electrical insulation layer to a base of the tub prior to placing the exposed portion of each cylindrical battery cell of the set into the interior volume of the tub.

[00104] It will be understood that the configurations and/or approaches described herein are exemplary in nature, and that these specific embodiments or examples are not to be considered in a limiting sense, because numerous variations are possible. The specific routines or methods described herein may represent one or more of any number of processing techniques. As such, various acts illustrated and/or described may be performed in the sequence illustrated and/or described, in other sequences, in parallel, or omitted. Likewise, the order of the above-described processes may be changed.

[00105] The subject matter of the present disclosure includes all novel and non-obvious combinations and sub-combinations of the various processes, systems and configurations, and other features, functions, acts, and/or properties disclosed herein, as well as any and all equivalents thereof.

CLAIMS:

1. A battery system, comprising:

one or more battery modules, each battery module including:

a module body forming a tub having an interior volume;

a set of cylindrical battery cells arranged in an array within the interior volume of the tub of the module body, wherein:

a central axis of each cylindrical battery cell of the set is aligned parallel with a central axis of each other cylindrical battery cell of the set, and

each cylindrical battery cell of the set includes a pair of battery terminals on a first end of the cylindrical battery cell that faces outward from an open face of the tub of the module body; and

a circuit board that covers the open face of the tub and includes electrical contacts that electrically interface with the pair of battery terminals of each cylindrical battery cell of the set to define:

a plurality of series electrical pathways among respective subsets of the set of cylindrical battery cells, and

a plurality of parallel electrical pathways among the plurality of series electrical pathways; and

cured potting resin encapsulating at least a portion of the set of cylindrical battery cells within the tub of the module body.

2. The battery system of claim 1, further comprising:

a first busbar that electrically interfaces with a first end of the plurality of parallel electrical pathways on a first side of the array; and

a second busbar that electrically interfaces with a second end of the plurality of parallel electrical pathways on a second side of the array that opposes the first side.

3. The battery system of claim 2, wherein the battery system comprises two or more battery modules;

wherein the first busbar spans the two or more battery modules by electrically interfacing with the first end of the plurality of parallel electrical pathways on the first side of the array of each of the two or more battery modules; and

wherein the second busbar spans the two or more battery modules by electrically interfacing with the second end of the plurality of parallel electrical pathways on the first side of the array of each of the two or more battery modules.

4. The battery system of claim 2, wherein the battery system comprises two or more battery modules and a third busbar;

wherein the first busbar spans the two or more battery modules by electrically interfacing with the first end of the plurality of parallel electrical pathways on the first side of the array of each of the two or more battery modules;

wherein the second busbar electrically interfaces with the second end of the plurality of parallel electrical pathways on the second side of the array of a first of the two or more battery modules that opposes the first side; and

wherein the third busbar electrically interfaces with the second end of the plurality of parallel electrical pathways on the second side of the array of a second of the two or more battery modules that opposes the first side.

5. The battery system of claim 2, wherein the first busbar and the second busbar are each at least partially encapsulated by the cured potting resin within the interior volume of the tub.

6. The battery system of claim 1, wherein the array has a staggered formation in which the set of cylindrical battery cells are arranged in a plurality of rows; and
wherein cylindrical battery cells of neighboring rows among the plurality of rows are offset from each other in a length dimension of each of the neighboring rows.

7. The battery system of claim 6, wherein each respective subset that forms a series electrical pathway includes cylindrical battery cells located in different rows of the plurality of rows, and at least two cells located in the same row.

8. The battery system of claim 1, wherein the electrical contacts of the circuit board electrically interface with the pair of battery terminals of each cylindrical battery cell via an intermediate wire-bonded electrical pathway.

9. The battery system of claim 8, wherein the cured potting resin fully encapsulates the set of cylindrical battery cells within the interior volume of the tub of the module body along the cylindrical walls of the set of cylindrical battery cells.

10. The battery system of claim 1, wherein the module body includes a plurality of alignment posts that are each accommodated by a respective opening defined in the circuit board.

11. The battery system of claim 1, further comprising:
additional cured potting resin covering an outward face of the circuit board on an opposite side of the circuit board from the set of cylindrical battery cells.
12. The battery system of claim 11, wherein the additional cured potting resin covering the outward face of the circuit board has a lower density than the cured potting resin encapsulating at least the portion of the set of cylindrical battery cells within the interior volume of the tub of the module body.
13. The battery system of claim 1, further comprising:
an adhesive and electrical insulation layer disposed between a base of the tub of the module body and a second end of each cylindrical battery cell of the set.
14. The battery system of claim 13, wherein the base of the tub of the module body forms a cooling plate formed from metal.
15. The battery system of claim 1, wherein the battery system comprises two or more battery modules; and
wherein the circuit board of each battery module of the two or more battery modules forms a portion of a shared circuit board that spans each of the two or more battery modules.
16. A method of manufacturing a battery system that includes one or more battery modules, the method comprising:

obtaining a module body, the module body forming a tub having an interior volume;

obtaining a set of cylindrical battery cells, each cylindrical battery cell of the set including a pair of battery terminals on a first end of the cylindrical battery cell;

obtaining a fixture having a set of openings arranged in an array that each accommodates a portion of a respective cylindrical battery cell of the set of cylindrical battery cells;

loading the fixture with the portion that includes the first end of each cylindrical battery cell of the set into a respective opening of the set of openings to arrange the set of cylindrical battery cells in the array;

placing an exposed portion of each cylindrical battery cell of the set loaded in the fixture into the interior volume of the tub;

potting the exposed portion of each cylindrical battery cell of the set within the interior volume of the tub with a potting resin to obtain a cured potting resin that encapsulates the exposed portion of each cylindrical battery cell of the set within the interior volume of the tub;

removing the fixture from the set of cylindrical battery cells;

potting an additional portion of each cylindrical battery cell of the set within the interior volume of the tub with additional potting resin to obtain additional cured potting resin that encapsulates the additional portion of each cylindrical battery cell of the set within the interior volume of the tub;

obtaining a circuit board having electrical contacts that, when electrically interfaced with the pair of battery terminals of each cylindrical battery cell of the set defines:

a plurality of series electrical pathways among respective subsets of the set of cylindrical battery cells, and

a plurality of parallel electrical pathways among the plurality of series electrical pathways;

aligning the electrical contacts of the circuit board with the pair of battery terminals of each cylindrical battery cell of the set with the circuit board covering an open face of the tub to enclose the interior volume; and

electrically interfacing the electrical contacts of the circuit board with the pair of battery terminals of each cylindrical battery of the set via an intermediate wire-bonded electrical pathway to form the plurality of series electrical pathways among respective subsets of the set of cylindrical battery cells, and the plurality of parallel electrical pathways among the plurality of series electrical pathways.

17. The method of claim 16, further comprising:

obtaining a first busbar and a second busbar;

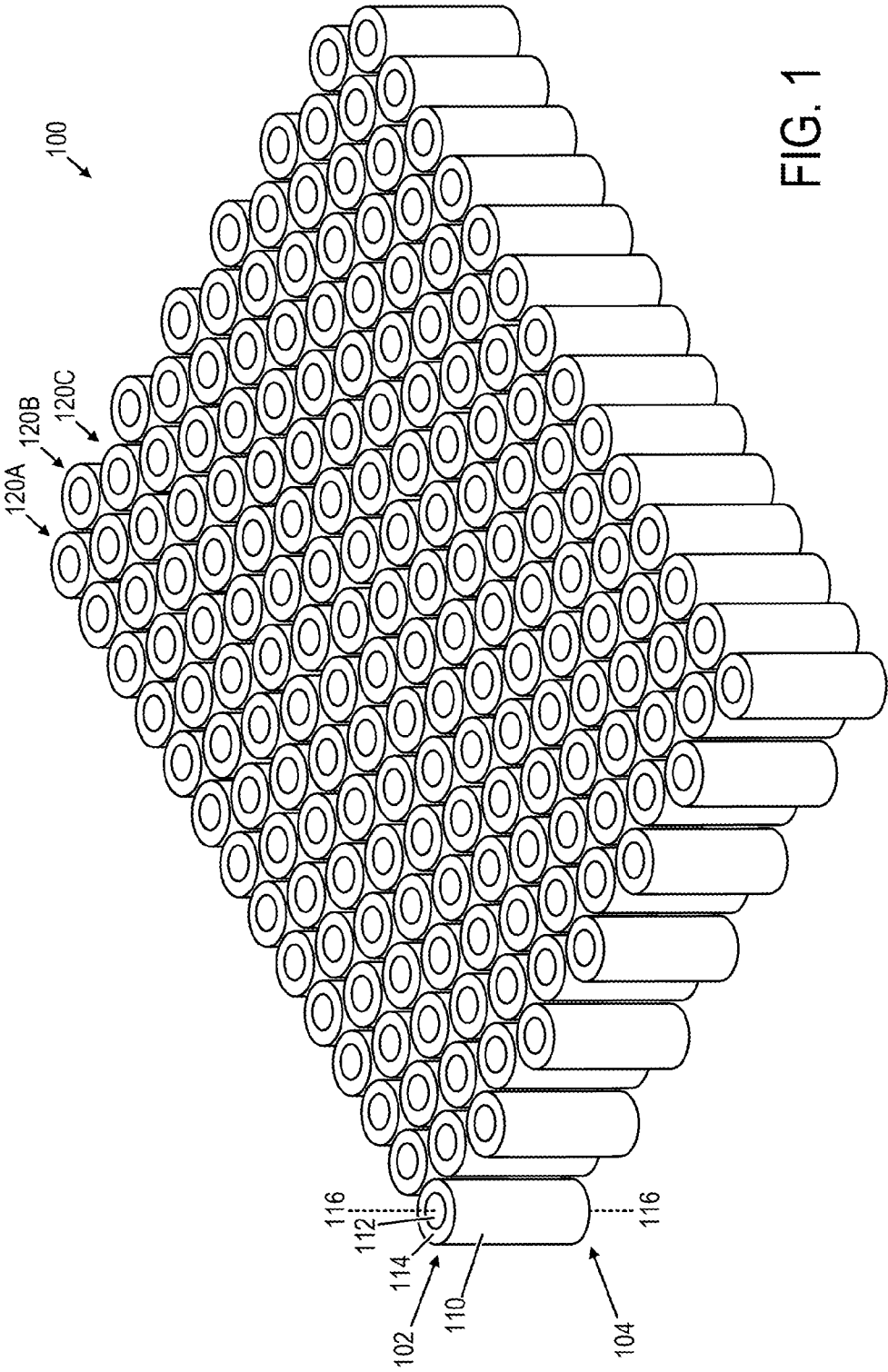
prior to potting the additional portion of each cylindrical battery cell of the set with the additional potting resin:

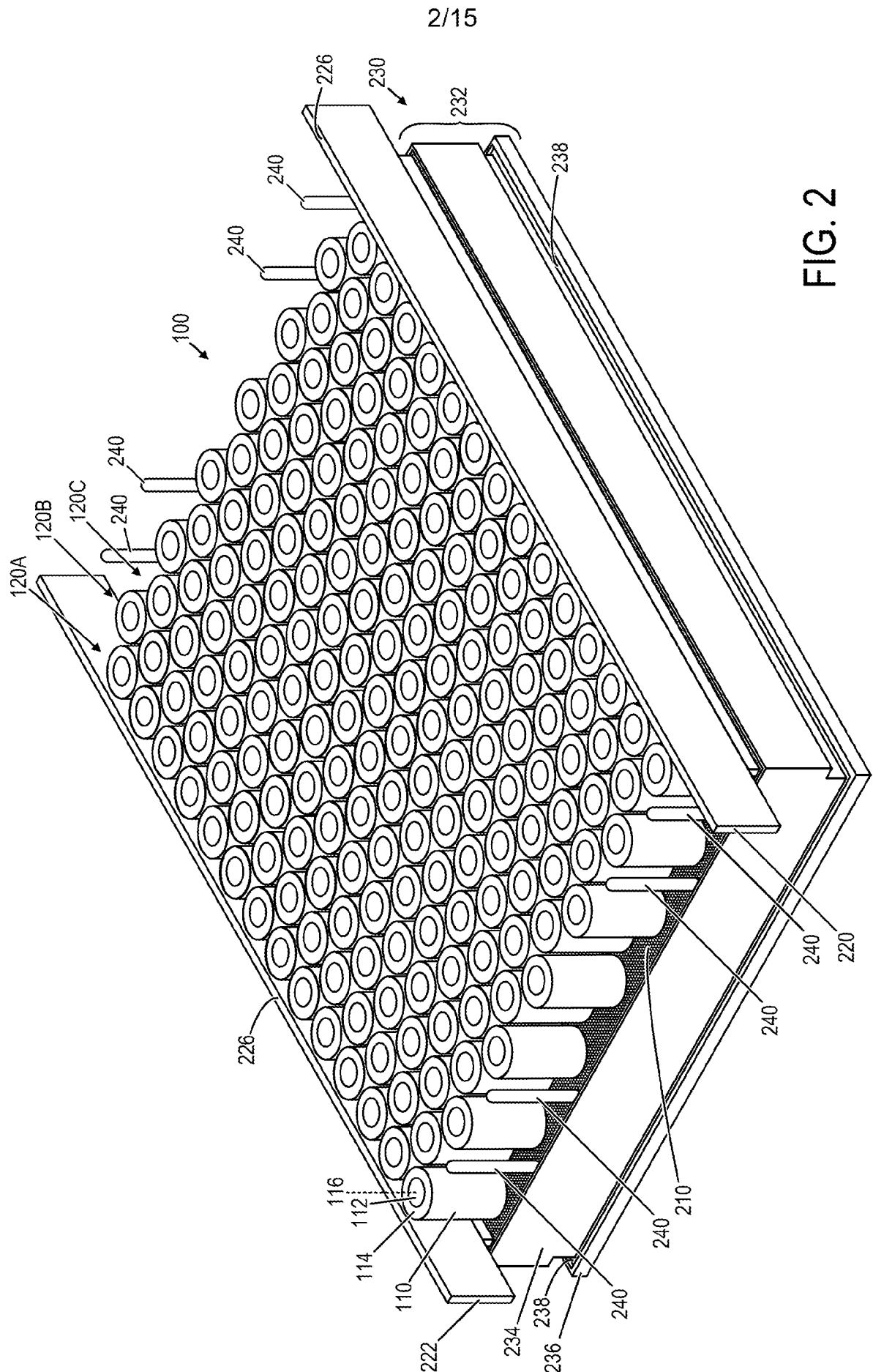
electrically interfacing a first end of the plurality of parallel electrical pathways on a first side of the array with the first busbar, and

electrically interfacing a second end of the plurality of parallel electrical pathways on a second side of the array with the second busbar; and

wherein at least a portion of the first busbar and the second busbar are encapsulated within the interior volume of the tub by the additional potting resin.

18. The method of claim 17, further comprising:
potting an outward face of the circuit board on an opposite side of the circuit board from the set of cylindrical battery cells with a second potting resin to obtain a second cured potting resin covering the outward face of the circuit board.
19. The method of claim 16, further comprising:
obtaining a device housing; and
mounting the battery module within the device housing.
20. The method of claim 16, further comprising:
obtaining an adhesive and electrical insulation layer; and
applying the adhesive and electrical insulation layer to a base of the tub prior to placing the exposed portion of each cylindrical battery cell of the set into the interior volume of the tub.





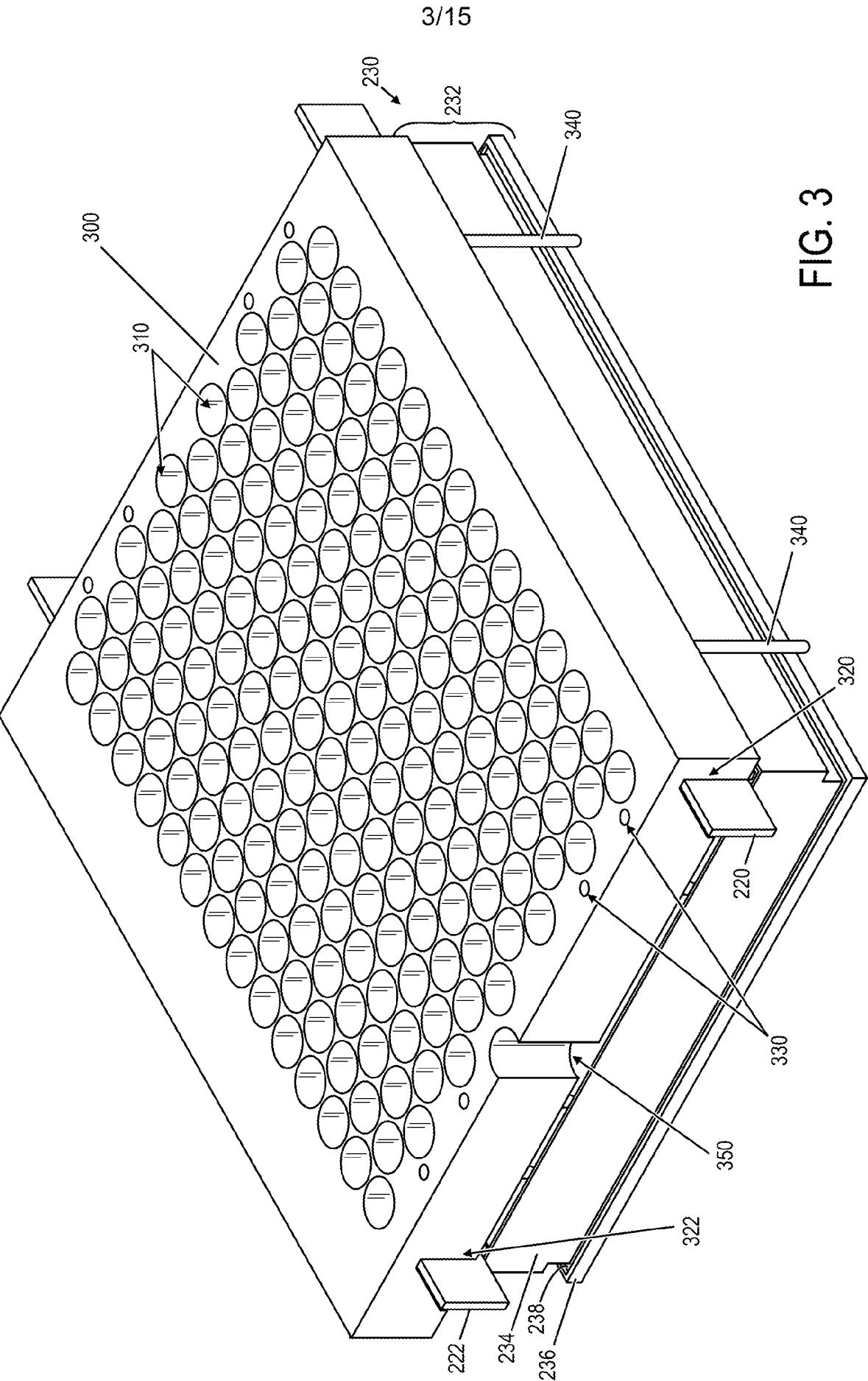
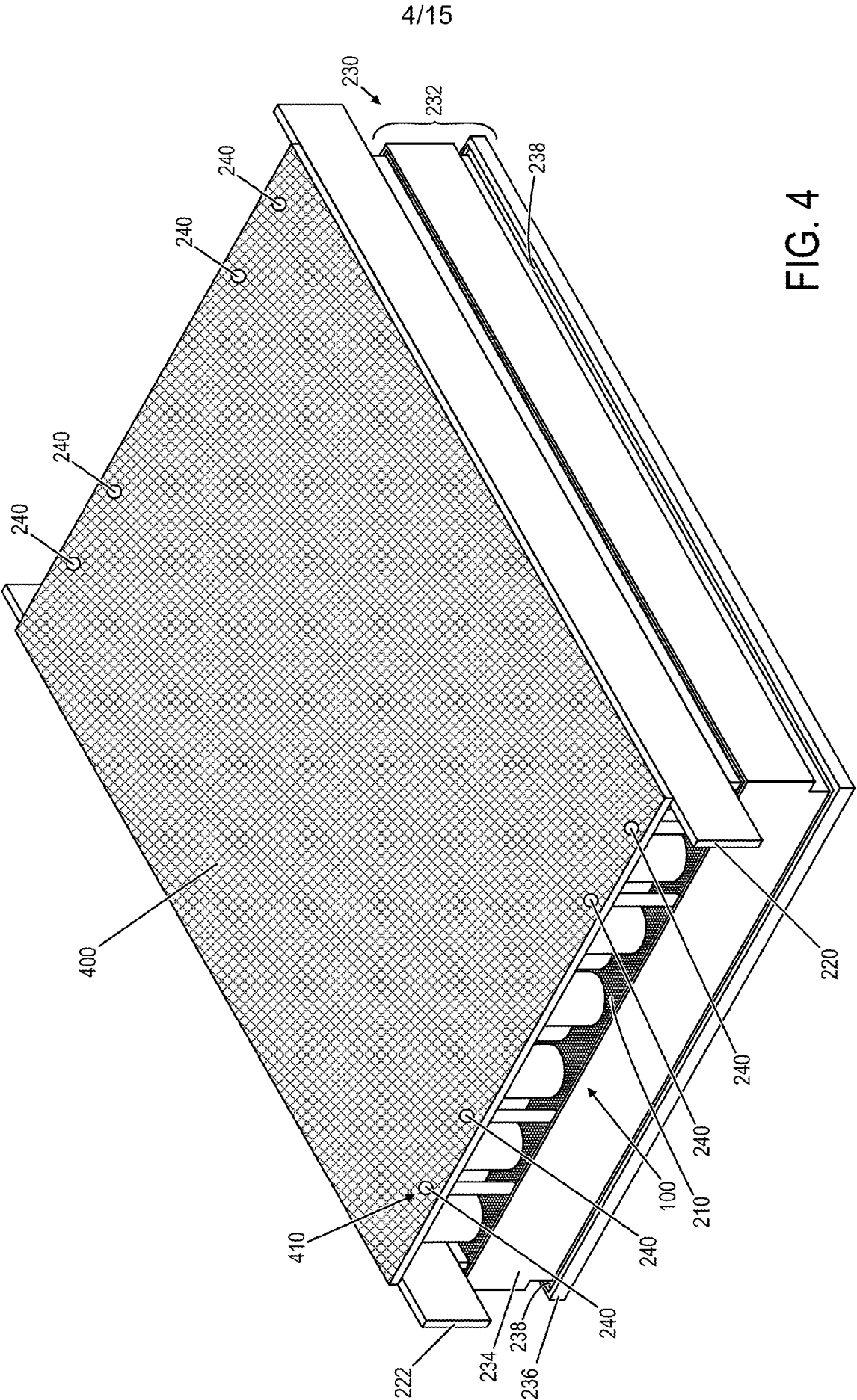


FIG. 3



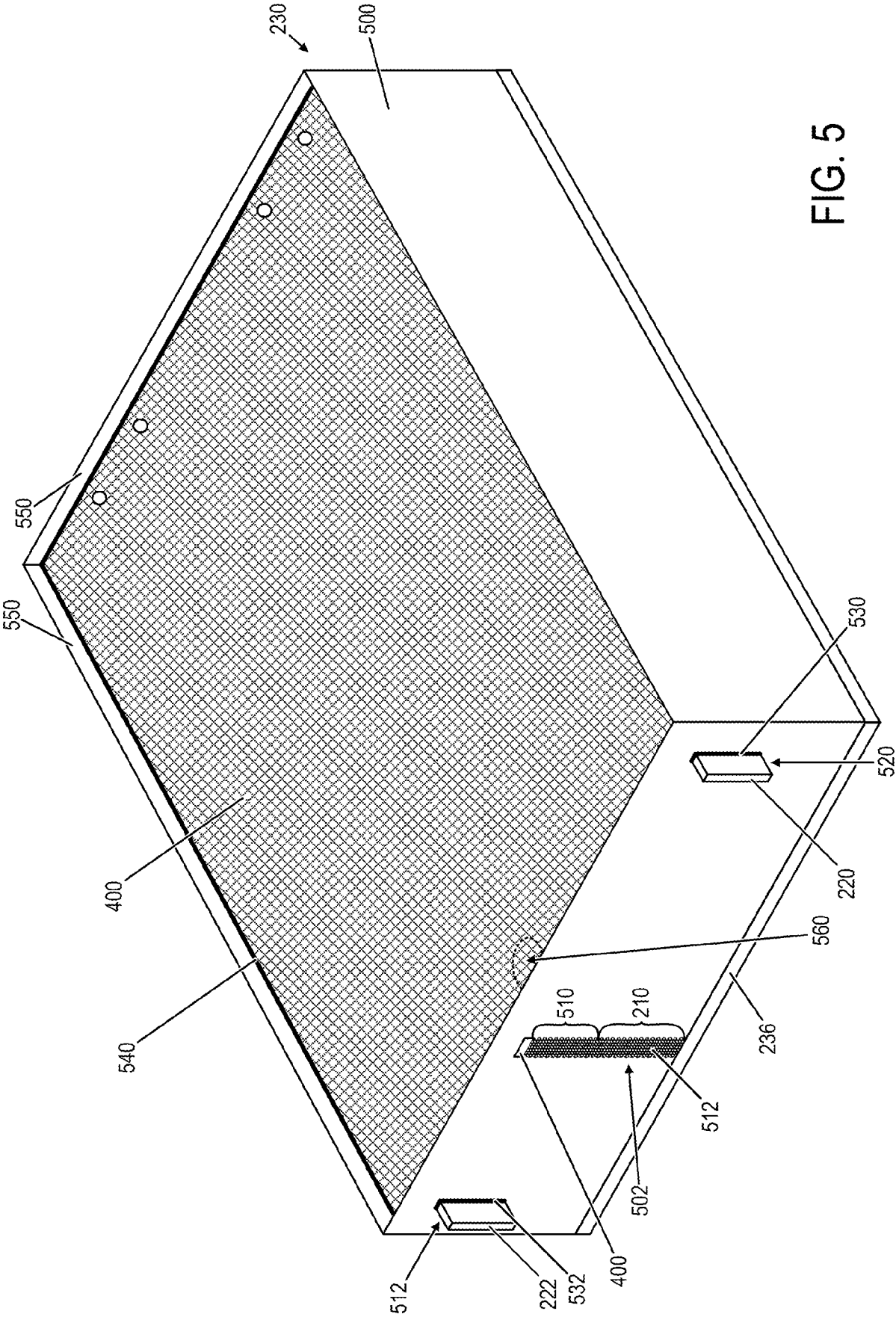


FIG. 5

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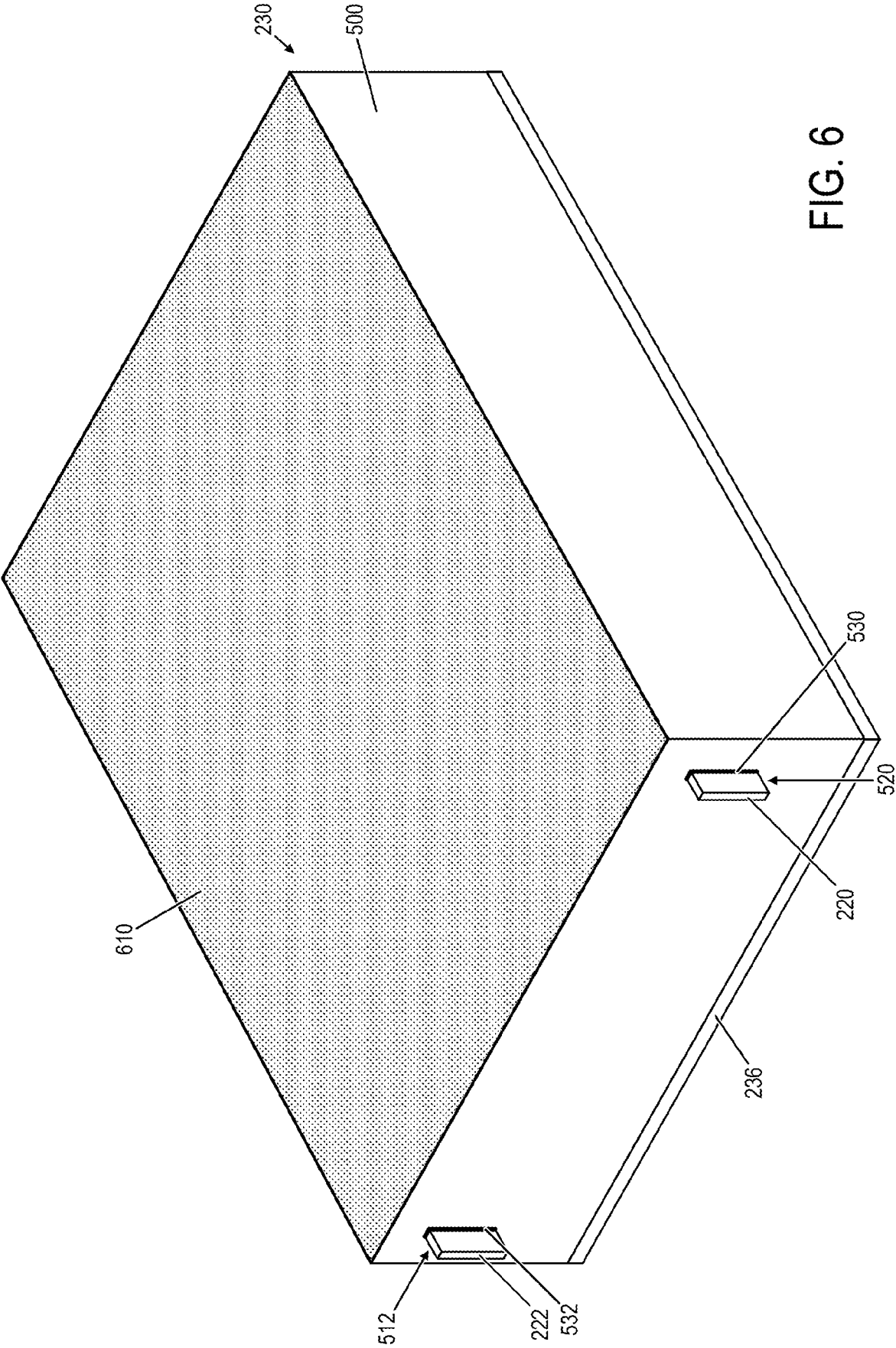
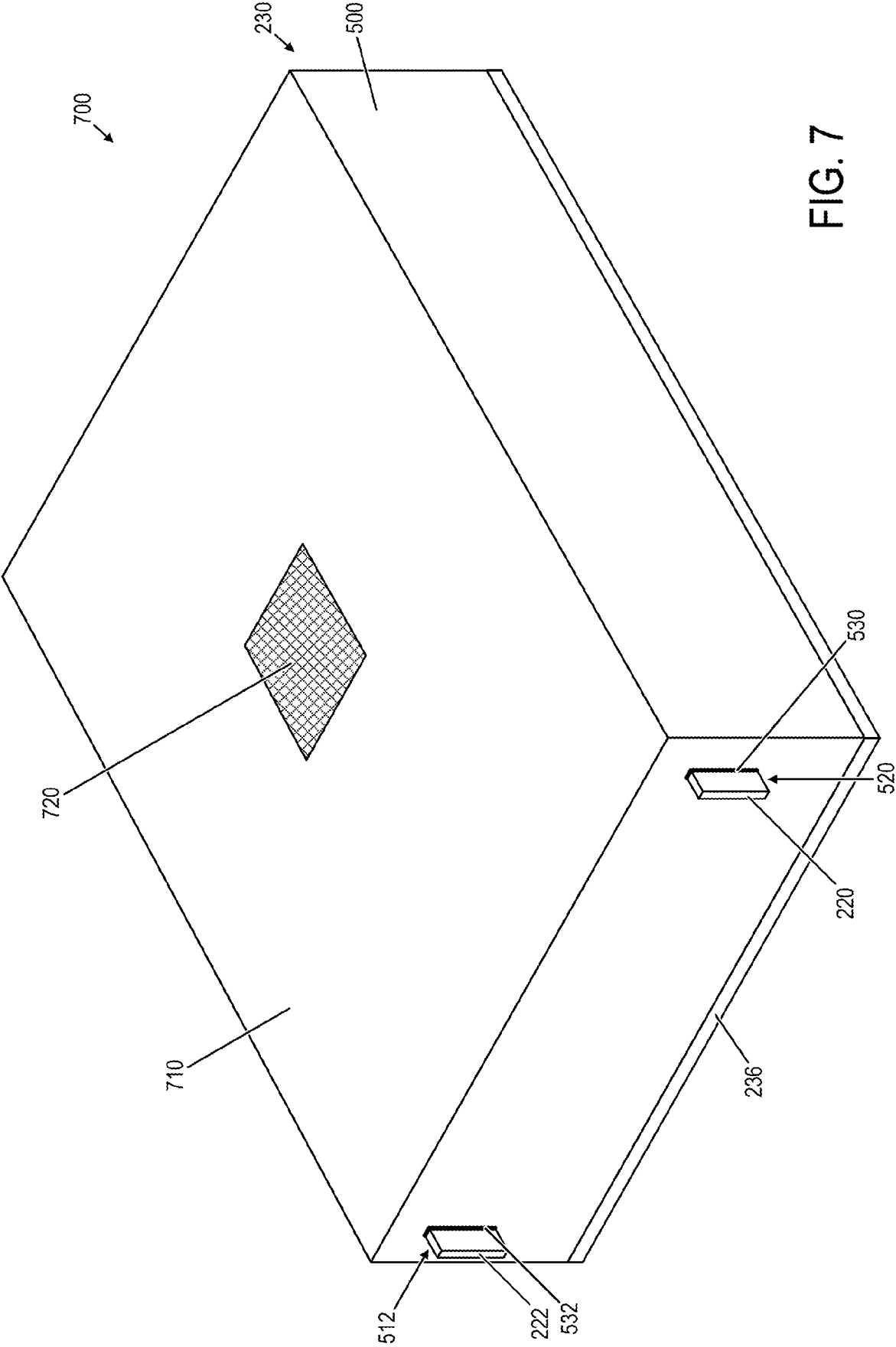


FIG. 6

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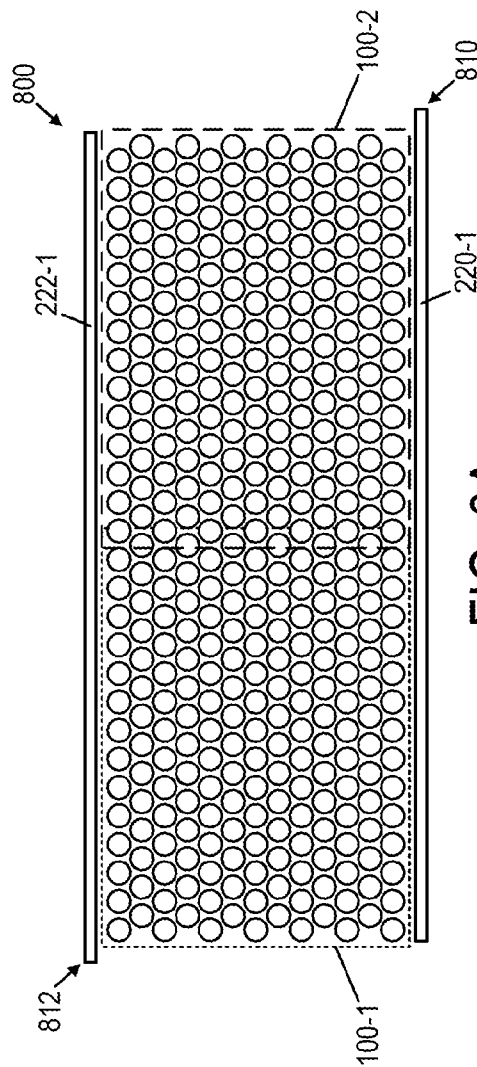


FIG. 8A

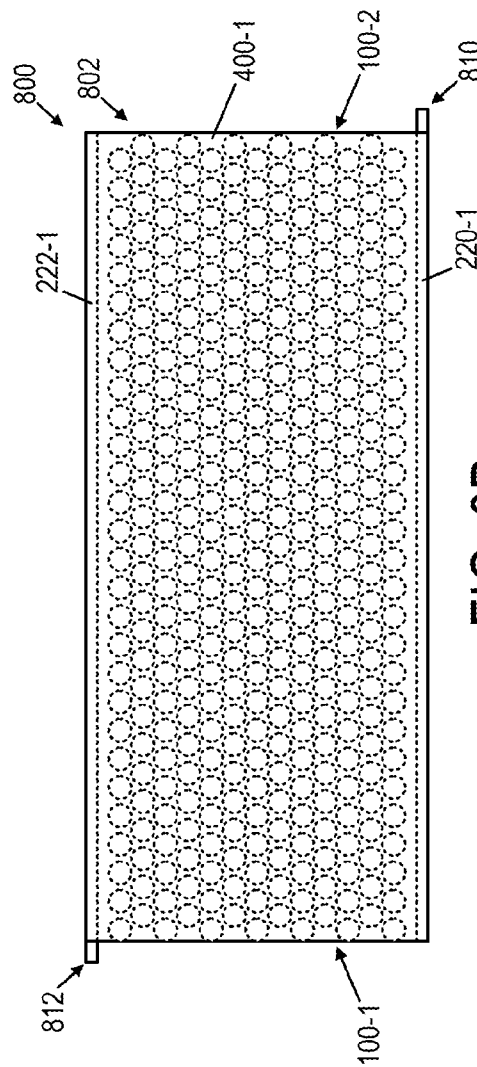


FIG. 8B

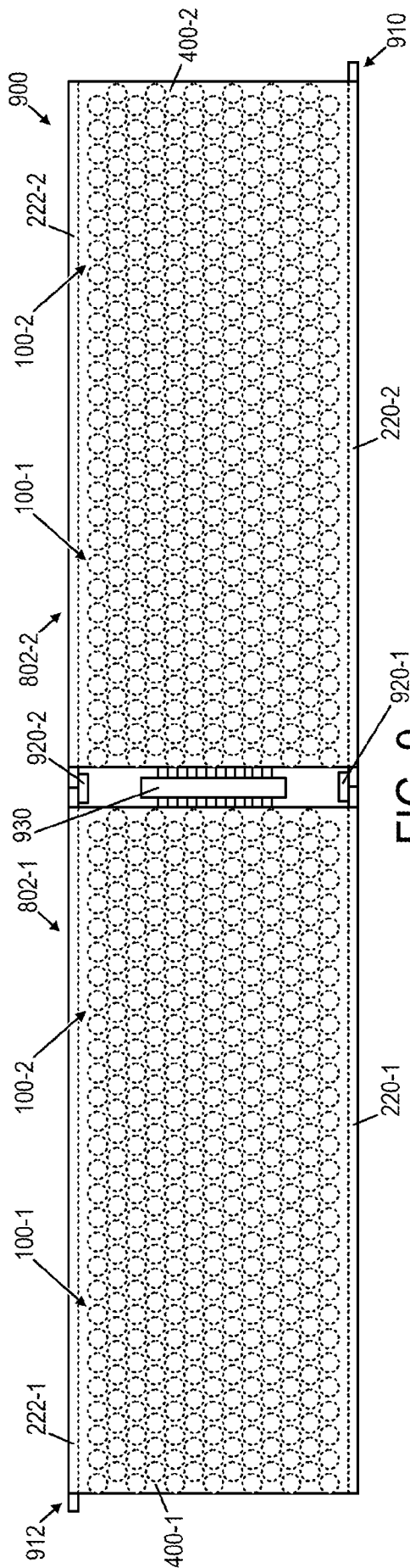


FIG. 9

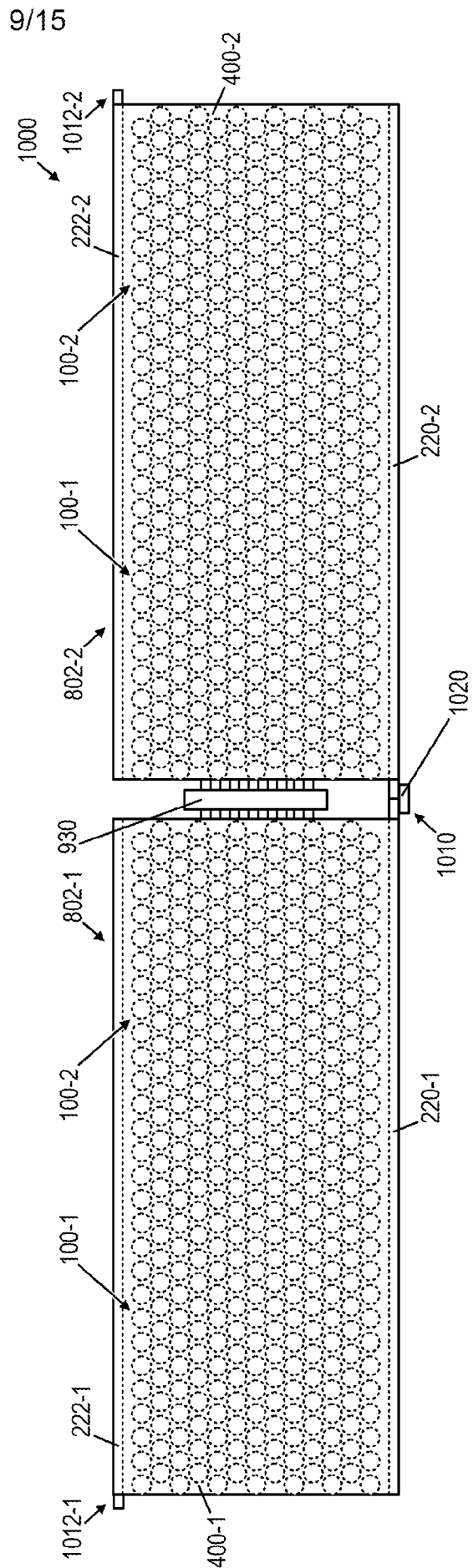


FIG. 10

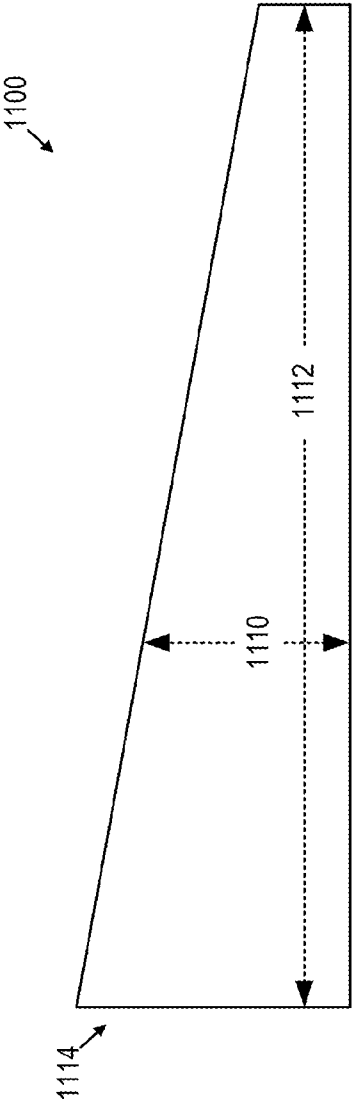


FIG. 11

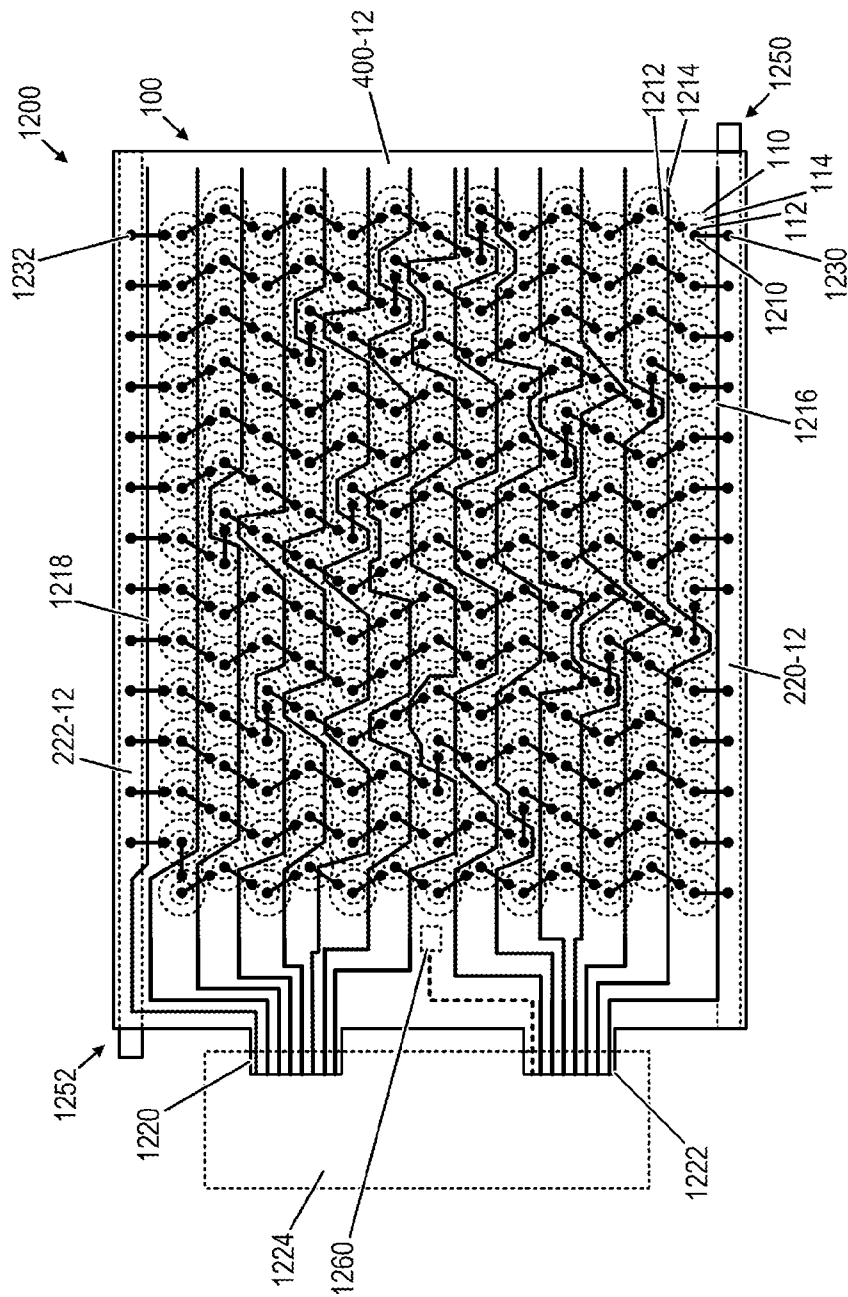


FIG. 12

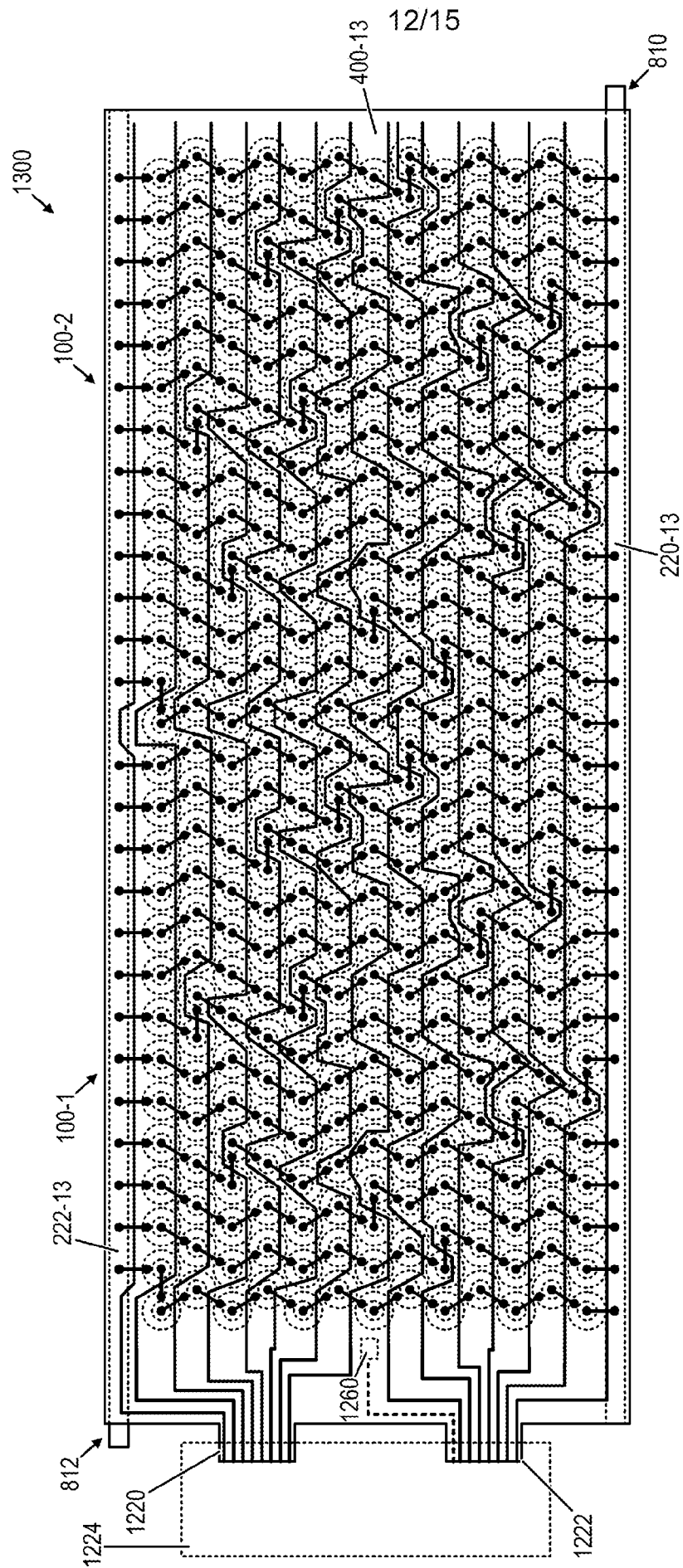


FIG. 13

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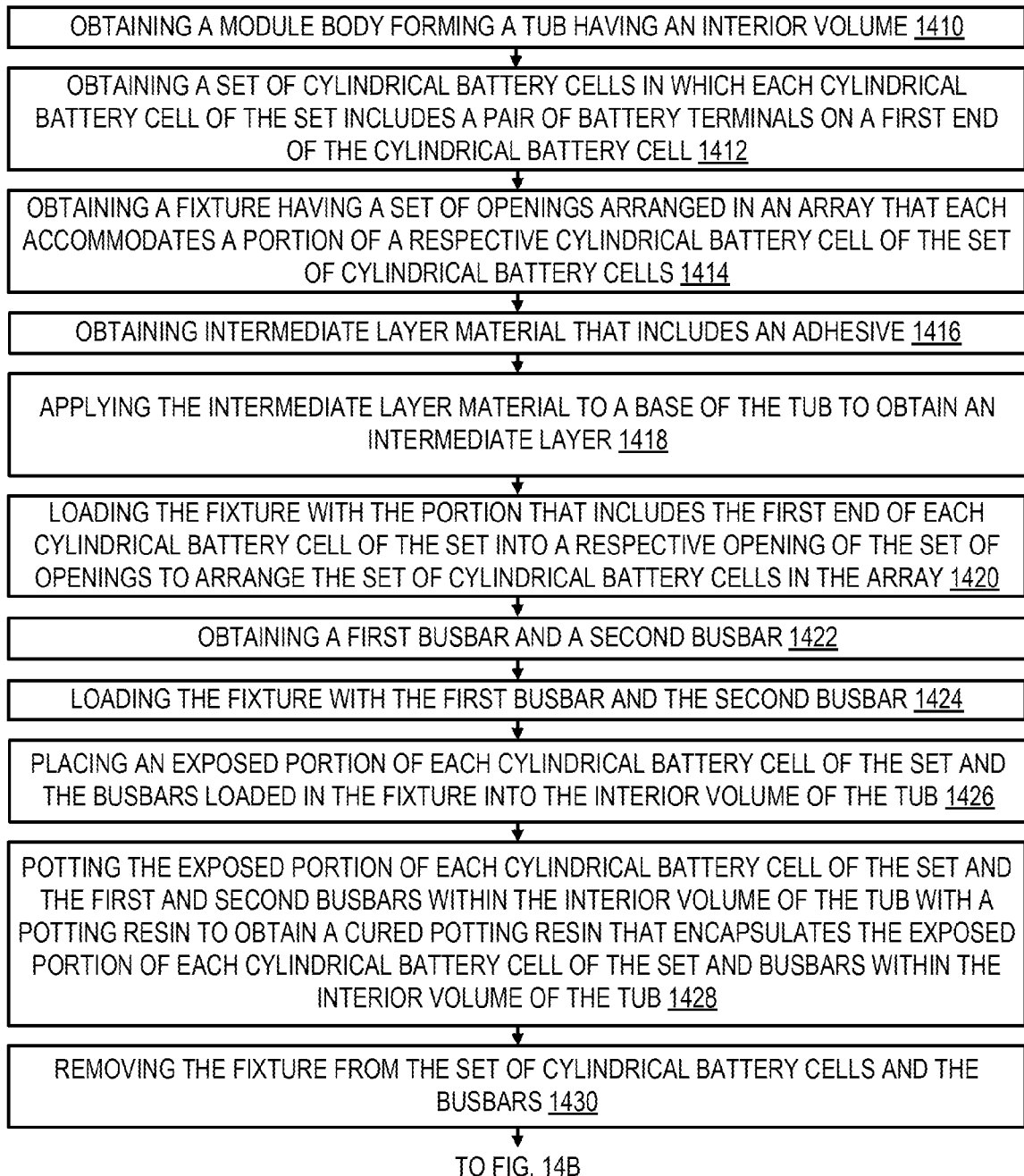


FIG. 14A

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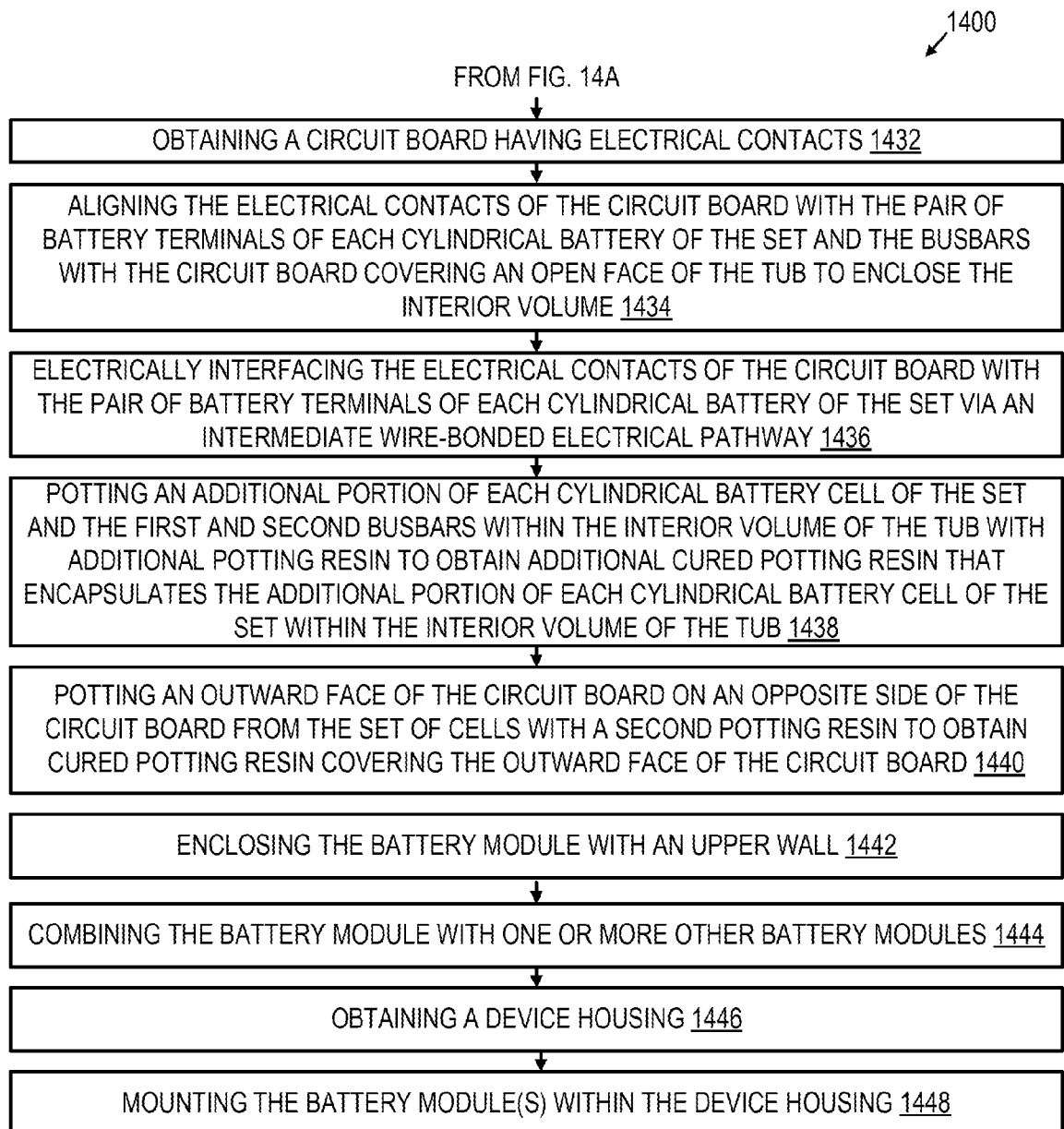


FIG. 14B

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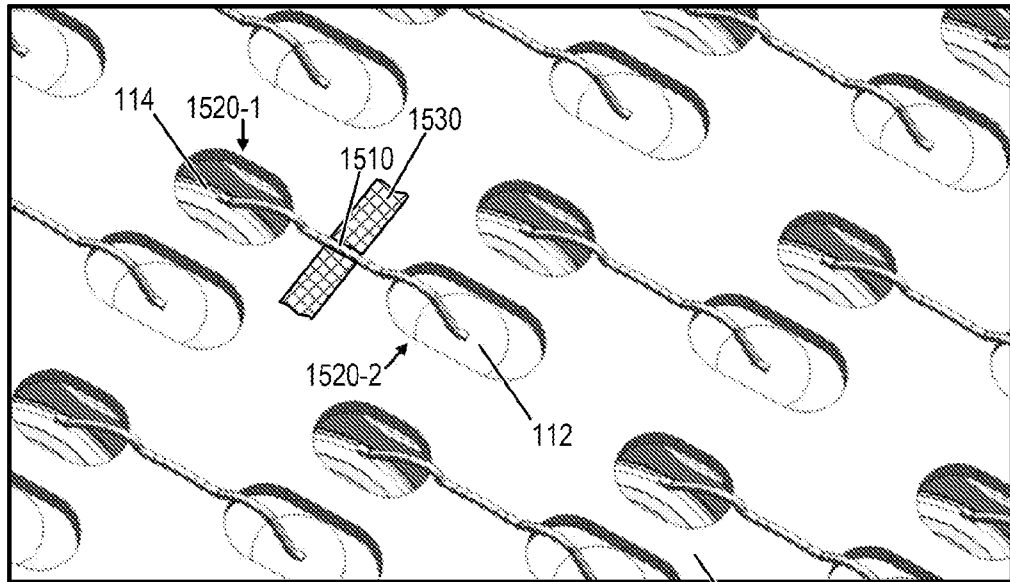


FIG. 15

400-15

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2022/078445

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - INV. - H01M 4/04; H01M 10/653 (2022.01)

ADD. - H01M 2/20 (2022.01)

CPC - INV. - H01M 4/04; H01M 10/653 (2022.08)

ADD. - H01M 50/284 (2022.08)

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)

See Search History document

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

See Search History document

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y --- A	US 2014/0234668 A1 (FASTER FASTER INC.) 21 August 2014 (21.08.2014) entire document	1, 6-8, 10, 15 --- 2, 9, 11, 13, 14, 16, 19, 20 --- 3-5, 12, 17, 18
Y --- A	US 2015/0104689 A1 (BOSTON-POWER INC.) 16 April 2015 (16.04.2015) entire document	2 --- 3-5
Y --- A	US 3,784,411 A (CILIBERTI) 08 January 1974 (08.01.1974) entire document	9
Y --- A	US 2017/0155104 A1 (SANYO ELECTRIC CO. LTD.) 01 June 2017 (01.06.2017) entire document	11 --- 12
Y --- A	US 2019/0386269 A1 (CPS TECHNOLOGY HOLDINGS LLC) 19 December 2019 (19.12.2019) entire document	13, 14, 16, 19, 20 --- 17, 18

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“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

“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

“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

“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

“&” document member of the same patent family

Date of the actual completion of the international search

06 December 2022

Date of mailing of the international search report

JAN 06 2023

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