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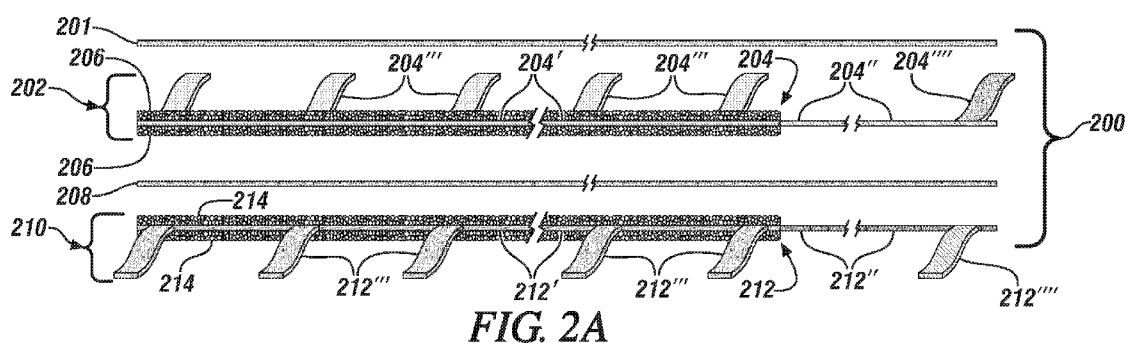


FIG. 2A

(57) Abstract: Lithium-based and sodium-based batteries and capacitors using metal foil current collectors, coated with porous layers of particles of active electrode materials for producing an electric current, may adapted to produce heat for enhancing output when the cells are required to periodically operate during low ambient temperatures. A self-heating cell may be placed in heat transfer contact with a working cell that is temporarily in a cold environment. Or one or both of the anode current collector and cathode current collectors of a heating cell may be formed with shaped extended portions, uncoated with electrode materials, through which cell current may be passed for resistance heating of the extended current collector areas. These extended current collector areas may be used to heat the working area of the cell in which they are incorporated, or to contact and heat an adjacent working cell.



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SELF-HEATING BATTERY

5 TECHNICAL FIELD

Some lithium-based and sodium-based batteries and capacitors are periodically exposed to a cold environment in which the energy and power outputs of their electrochemical cells could be improved if they could be heated effectively and inexpensively. This disclosure pertains to like or complementary
10 electrochemical cells, one of which has a self-heating capacity and may be used to periodically heat an adjacent working cell when it is exposed to a low temperature ambient environment. This disclosure also pertains to a cell having a working portion and a heating portion which is managed and controlled to be periodically activated to heat the working portion when it has been cooled in its operating
15 environment.

BACKGROUND

Relatively light weight lithium-based batteries and capacitors and sodium-based batteries and capacitors are energy efficient and are increasingly used in many
20 consumer applications. In some applications, such as in automotive vehicles, the battery or capacitor may be periodically exposed to low ambient temperatures that impair the performance of the cell. There remains a need to find effective methods of on-board heating of the cells of such batteries and capacitors during the occasions when they are required to work in a low temperature environment.

25

SUMMARY OF THE DISCLOSURE

Present lithium-based batteries often comprise an assembly of one or more electrochemical cells, each cell comprising an anode and cathode capable of intercalating and de-intercalating lithium from a non-aqueous electrolyte solution of a
30 suitable lithium electrolyte salt. The anode and cathode are physically separated from direct electrical contact by a porous separator. The anode is often formed of particles of an active anode material, such as graphite or lithium titanate, which are resin-bonded in uniformly-thick, porous layers on each side of a thin, metal (often copper) current collector foil having low electrical resistance. The current collector foil may,

for example, have a uniform thickness in the range of about five micrometers to fifteen micrometers and carry, on each opposing surface, a porous bonded coating layer of particulate electrode material that may range in thickness from about five micrometers to about one hundred micrometers, depending on the energy and power requirements of the cell.

The cathode is similarly formed of particles of an active cathode material, such as lithium iron phosphate (LiFePO_4), lithium manganese oxide (LMO, LiMn_2O_4), and lithium nickel manganese cobalt oxide (LiNiMnCoO_2). The selected active cathode material is likewise resin-bonded in porous uniformly thick layers on each side surface of a thin metal (often aluminum) current collector foil. The thicknesses of the porous cathode layers are usually comparable to the thickness of the corresponding anode material layers, depending on the electrical requirements of the electrochemical cell in which the cathode materials are used. Each of the anode and cathode material particles may be mixed with a quantity of electrically conductive carbon particles.

In many such batteries, each of the thin current collector foils is rectangular in shape, with side dimensions up to about 150 millimeters (in a stacked cell arrangement) and has an un-coated tab extending from one side for electrical connection with another electrode in an assembly of cells. In general present practice, the opposing major surfaces of the thin metallic current collectors are substantially fully covered with the porous layers of electrode material and the metallic current collectors provide a low-resistance path for the flow of electrons from and into their coatings of bonded electrode material during the operation (charge and discharge) of each lithium battery cell. All DC electrical current, flowing into and out of the cell, flows through the respective anode and cathode current collectors. The thin metal current collector compositions are selected to have relatively low electrical resistance so that resistance heating of the cell is not large. However, as will be described in detail below in this specification, present current collector shapes and compositions may be utilized with extended metal foil portions, not coated with electrode material, which may be shaped and modified to provide additional useful resistance heating during cell operation. This additional heating may be directed by the location or placement of the extended foil portion of the current collector and used to heat the instant working cell in which it is integrated, or an adjacent normal working cell.

In some cell assemblies, like-shaped anode and cathode layer structures are assembled in rectangular stacks with interposed thin, porous polymeric separators that physically separate the porous layers of opposing electrode materials but enable suitable infiltration with the electrolyte solution and the transport of lithium ions between the porous layers of electrode materials. In other cell structures, a long rectangular anode layer and a like-shaped long rectangular cathode layer, with interposed, like-shaped porous separator layers, may be formed as a wound or rolled lithium-based cell structure.

Lithium-based capacitors often have similar porous electrode and separator structures, but the respective anodes and cathodes are formed of particles of suitable presently known capacitor materials resin-bonded as porous layers to thin metallic current collector foils. The respective capacitor electrode materials are selected to efficiently absorb and de-absorb lithium ions from a suitable non-aqueous solution of a lithium electrolyte salt(s).

Sodium-based batteries and capacitors are similarly constructed, using particles of suitable known active anode and cathode compositions for the respective electrodes for the operation of the electrochemical cell of the battery or capacitor.

The electrode materials of each such lithium-based or sodium-based battery or capacitor are selected and formulated to function at a pre-determined temperature level or temperature range. Often such an operating temperature range may extend from about room temperature (e.g., 20°C-25°C) to about twenty to thirty Celsius degrees above room temperature. But in many applications for such batteries and capacitors, the device in which they are employed, such as automobiles, may be exposed to ambient temperatures that extend many degrees below the optimum operating temperature of the vehicle.

In accordance with practices of this invention, a unique battery or capacitor heating cell is prepared and adapted for self-heating when such heating is required. The battery or capacitor has a working portion and a self-heating portion as will be described. Alternatively, the heating cell may be adapted for use in combination with one or more separate regular working cells. In the latter application the heating cell will be placed in a stack or a roll in close proximity with a regular working cell, or group of working cells, of the battery or capacitor. The heating cell will often have a shape like that of the adjacent working cell or cells so that it can be

placed in heat-transfer contact with the chilled working cells to be heated. The electrode materials of the heating cell may have the same compositions or similar compositions as the electrode materials of the working cells of the battery or capacitor. The electrochemical reactions of the heating cell may be like the
5 electrochemical reactions of the working cell(s). The heating cell is activated by a suitable combination of temperature sensing and battery operation controllers when the heating cell or an adjacent working cell or group of cells requires heating in a cold environment.

In a first embodiment of the invention, a heating cell is prepared in which
10 the compositions of the electrode materials, the compositions and structures of the anode and cathode current collectors, and the composition of the electrolyte and its solvent(s) are determined to provide extra heat when the cell is activated. By producing such extra heat, in addition to a usable current, such a self-heating battery or capacitor cell may be periodically activated to generate and transfer heat to an
15 adjacent working cell which is presently required to function in a chilled ambient environment. The self-heating cell may be contained in the same pouch or container as the working cell. Or it may be separately contained in a material that enables the transfer of heat from the self-heating cell to an adjacent working cell whose function would be enhanced when it is warmed to a moderately higher temperature.

20 In accordance with a second embodiment of this invention, one or both of the current collector foils of the electrodes of the heating battery or capacitor cell are significantly modified so as to provide metallic electrically-resistive heating elements and surfaces for transferring heat to surfaces of its integral working cell or to surfaces of a closely positioned working cell or group of working cells.

25 As described above in this specification, the anode of a conventional lithium battery may, for example, be formed of a porous layer of lithium titanate particles and electrically-conductive carbon particles, resin-bonded to both sides of a suitably sized rectangular copper current collector foil. And the cathode may, for example, be formed of a porous layer of lithium iron phosphate particles and
30 conductive carbon particles resin-bonded to both sides of a like sized, rectangular aluminum current collector foil. Except for connector tabs at one side of each current collector foil, active electrode material is applied to most of the available surface area

in each side of each current collector in order to maximize the energy-providing performance of the battery cell.

However, in selected heating cells of this invention, a modified metal current collector foil is used in one or both of the anode and cathode of the cell. The shape of a portion of the current collector foil is retained to carry its porous layers of electrode material on each side. But it is recognized herein that in the function of the battery or capacitor, the current collector foil is heated by the flow of an electrical current in it. In normal cell operation the heating is accommodated by the thickness, surface area dimensions, and relatively low resistance of the current collector material. But, in the subject heating cell, the generation of heat in the current collector is increased by intentionally providing an extended portion of the current collector foil, which is uncoated with electrode material. At least one side (or edge) of the electrode material-carrying current collector foil shape or area is extended to provide a desired amount of additional foil material (not coated with electrode material) that will also be resistance heated when electrical current, produced or discharged in the function of the cell, is intentionally directed through the extended foil material. This extended uncoated portion of the current collector may be integral with the coated portion of the current collector or it may be a separate current collector foil material which is joined (e.g., welded or soldered) to a selected edge of the electrode-material-coated current collector. This enlarged and extended portion of the current collector is also strategically shaped for wrapping around a predetermined surface area of the cell in which it is located or around heat-accepting surfaces of one or more adjacent working cells. This wrapping with the current collector extension provides a predetermined amount of heating surface contact with the working cells (or with a working portion of its own self-heating cell). Connector tabs on the electrode material-coated area of the current collector of the heating cell, and on the extended uncoated portion of the current collector, are suitably utilized, by control means located in conjunction with the battery or capacitor-powered device, to control the operation of the heating cell to those times when ambient temperatures require self-heating or heating of adjacent working cells for powering a function of the automobile or other battery-powered or capacitor-powered device.

In some applications, the metal composition or the thickness of the extended portion of the current collector may be changed to provide increased

electrical resistance heating. And an outer side of the wrapped current collector (not in thermal contact with a surface to be heated) may be suitably coated with a thermally insulating material for directing more heat into the adjacent surface(s) to be heated. In applications in which current collector extensions from both electrodes of a heating cell are used, a non-conductive separator should be placed between the electrically conducting current collector extensions. And the size and shape of the extended portion of the current collector(s) may also be determined and used for enhancement of compaction or compression of the adjacent working cells.

In the above and following texts of this specification, describing practices of the subject invention, the descriptions are sometimes expressed in terms of a lithium battery. This is done with the intention and understanding that practices of the use of a heater cell may also be suitably adapted to lithium capacitors and to sodium-based batteries and capacitors using known electrode materials for the battery or capacitor.

Other advantages and embodiments of the invention will be apparent from the following illustrations of specific examples.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a schematic oblique view of a packaged core of a self-heating cell for a lithium battery that is placed side-by-side against a heat conducting surface of an enclosed packaged core of a working lithium battery. The heating cell is devised and managed to be activated when the working cell is temporarily operating in a chilled environment which has cooled the working cell to a temperature below its favored working temperature. Separate positive and negative electrode tabs are illustrated as extending from the top side of each of the heating cell core and of the core of the regular working cell.

Figure 1B is a schematic oblique view of an assembly of a packaged heating cell core and a packaged working cell core for a lithium battery, similar to the illustrated assembly in Figure 1A. However in the embodiment of Figure 1B an extended portion of the current collector foil (extending through the package container side) has been provided for one of the electrodes in the heating cell, and the extended portion of the current collector, serving as an electrically resistance heating element, has been wrapped around the sides and outer surface of the working cell core

package and around one side of the heater cell core package and partially around the outer side of the heater cell core package.

Figure 2A is a schematic enlarged side or edge view of the end portions of a first separator layer, a cathode electrode layer, a second separator layer, and an anode electrode layer for a self-heating cell (such as a lithium-ion battery cell) which is to be assembled by placing the layers in an overlying assembly and rolling them into a battery structure. Central portions of the strips of these cell elements have been cut away to reduce the size of the schematic illustration. In Figure 2A, the extended current collector foil heating members (not coated with electrode material) for both the cathode and anode are arranged with intervening separators. The extended current collector members are at the right side of the embodiment illustrated in Figure 2A. The assembly is rolled such that the heating current collector members are located on the outside of the rolled assembly.

Figure 2B is an end view of the rolled assembly of initially flat layers of the first separator, the cathode electrode, the second separator, and the anode electrode of Figure 2A. In Figure 2B the ends of the outer uncoated heating portions of the cathode current collector and the anode current collector are on opposite sides of the rolled assembly.

Figure 2C is a schematic oblique view of one end and a side of the rolled lithium battery assembly of Figure 2B. Positive and negative tabs for electrical connections to the current collectors of the working battery portion and the current collectors of the heating portion of the self-heating battery are illustrated. The positive connector tabs extend from the opposite side of the rolled battery structure from the negative connector tabs.

Figure 3A is schematic enlarged side or edge view of the end portions of a first separator, a cathode electrode, a second separator, and an anode electrode for a self-heating cell (such as a lithium battery cell) which is to be assembled by rolling the cell members. Again, central portions of the respective strips have been cut-away to reduce the size of the illustration. In Figure 3A extended, uncoated, current collector foil heating members for both the cathode and anode are arranged with intervening separators. The extended members are at the left side of the embodiment illustrated in Figure 3A. The assembly of overlying strips is to be rolled such that the heating current collector members are located on the inside of the rolled assembly.

Figure 3B is an end view of the rolled assembly of the first separator layer, the cathode electrode layer, the second separator layer, and the anode electrode layer of Figure 3A.

Figure 3C is a schematic oblique view of one end and a side of the rolled lithium battery assembly of Figure 3B. Positive and negative tabs for electrical connections to the current collectors of the working battery portion and the current collectors of the heating portion of the self-heating battery are illustrated. The positive connector tabs extend from the opposite side of the rolled battery structure from the negative connector tabs.

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DETAILED DESCRIPTION

In Figure 1A, a schematic illustration is provided of the rectangular outline of the packaged core member 10 of a self-heating lithium-ion battery cell placed in face-to-face heat transfer contact with a packaged working cell member 22.

5 In this example, the packaged self-heating cell 10 has a flat, rectangular shape. The self-heating cell 10 includes the anode, cathode, and separator members of a lithium-ion battery. These porous cell members, infused and infiltrated with a non-aqueous lithium electrolyte solution, are contained and sealed within a suitable thin-wall pouch or container 12. The cell-member-containing pouch 12 may, for
10 example, be formed of two facing polymer-coated aluminum sheets joined at their edges. The anode is formed of porous layers of particulate anode material resin-bonded to the opposing faces of an anode current collector foil. An uncoated anode current collector tab 14, indicating a negative charge, extends from the top side of the rectangular pouch-contained 12 assembly of core elements of the cell 10. The
15 cathode is formed of porous layers of particulate cathode material bonded to the opposing faces of a cathode current collector foil. An uncoated cathode current collector tab 16, indicating a positive (+) charge, also extends from the top side of the rectangular pouch 12. Except for the extending tab members 14, 16, the cell members and liquid electrolyte are sealed within the pouch 12 or other suitable
20 container.

 The compositions of the respective heating cell members may be selected from known compositions for lithium-ion battery anode materials, cathode materials, separator materials, and lithium-containing electrolyte salts and non-aqueous solvents. As an example, the heating cell 10 of Figure 1A (and 1B) may be formed of lithium
25 titanate and conductive carbon particles, resin bonded to a copper foil as an anode and particles of lithium manganese oxide and conductive carbon, resin-bonded to an aluminum current collector as a cathode. An exemplary electrolyte is a one molar solution of lithium hexafluorophosphate (LiPF_6) in equal portions by volume of ethylene carbonate, ethyl methyl carbonate, and diethyl carbonate. And the working
30 cell 22 may use graphite as an active anode material and lithium iron phosphate as the active cathode material. Working cell 22 may use the same electrolyte as the heating cell 10 or a different electrolyte.

In an illustrative example, a working cell 22 was formed with graphite particle anode, a particulate lithium iron phosphate cathode, and a 1M LiPF₆ electrolyte, weighing 0.3 kg, and having a current capacity of 10 Ah. A heating cell 10 was formed with a lithium manganese oxide cathode, a lithium titanate anode, and a 1M LiPF₆ electrolyte, weighing 0.04 kg, and having a current capacity of 1 Ah. The heating cell was operated at a discharge rate of 18C for 60 seconds during which time it displayed a heat generation of 2722 Joules using about thirty percent of the state of charge of the heating cell. The internal resistance and the external resistance of the heating cell were both 0.07 ohm at -30°C. The working cell and heating cell were placed side-by-side and the heating cell was capable of increasing the operating temperature of the working cell 10 degrees Celsius (from -30°C to -20°C).

Referring again to Figure 1A, the heating cell 10 is to function primarily as a self-heating cell when it is required to produce heat for the adjacent flat, rectangular-sided working lithium-ion battery cell core 22 enclosed within its pouch or like container 24. Anode current collector tab 26 and cathode current collector tab 28 extend from the top of the sealed container 24 in which working cell core 22 is sealed. And the function of working lithium-ion battery cell core 22 is to produce an electric current for powering, for example, an electric starting motor, an electric driving motor, and/or other electric power consuming devices in an automobile. When the ambient temperature is suitable for normal power-providing operation of the working lithium-ion battery core 22, operation of the heating cell core 10 may not be required. But the automobile or other device, powered by working battery core 22, will have a control system for the operation of working battery core 22. When the temperature of working battery core 22 falls below a specified level (or its performance related to temperature), the heating cell core 10 will be activated so that it produces its current in an external electrical circuit. It will thus function to provide heat which will be transferred from cell core 10 to working cell core 22.

As illustrated in Figure 1A, one flat rectangular side of heating cell core 10 is placed face-to face against a flat rectangular side of a lithium-ion battery cell core 22. During the operation of heating cell core 10, it generates heat within its whole cell and heat is transferred through its side which faces and is pressed against a rectangular side of working cell core 22. In an embodiment distinct from that

illustrated in Figure 1A, heating cell 10 and working cell 22 may be located within a common container, spaced apart by a separator, and infused with a common electrolyte solution. In this embodiment, the heating cell serves, when activated, to heat the common electrolyte in heating the working cell.

5

The embodiment of the heating cell 10' illustrated in Figure 1B provides an extended current collector foil 20 for markedly increasing the generation of heat using the current generation capacity of heating cell core 10', and for transferring the additional heat to and into working lithium-ion battery pouch 24 containing the cell members of working battery core 22. Heating cell 10' has been provided with a modified current collector 20 for one of its anode or cathode. In this embodiment, the modified current collector 20 is associated with its anode. An unseen portion of current collector 20 is coated on both sides with selected particles of active anode material which may be mixed with particles of conductive carbon and resin-bonded to the conventional portion of current collector 20 which is located in the heating cell core 10' retained within pouch 12'. But, as illustrated in Figure 1B, a larger, uncoated portion of current collector 20 extends through a slit in the left side of pouch 12' and is wrapped around three outer sides of pouch 24 of working cell 22 and a portion of the outer surfaces of pouch 12' of heating cell 10'. Connector tab 14' projects from the top side of the extended, uncoated portion of current collector 20.

In this embodiment of Figure 1B, when heating cell 10' is activated (by connection of its current collector tabs 14', 16' to an external circuit) for the purpose of heating working cell 22, the electrical current produced by cell 10' also flows in the uncoated, extended portion of current collector 20, heating it and surfaces that it contacts. Depending on the respective sizes of the sides of cell cores 10' and 22, the dimensions of the extended current collector foil may be up to 150 mm or so in width and several hundred millimeters in length.

In many examples of lithium-ion batteries, copper current collector foils are used for their low electrical resistance and their compatibility with particulate lithium-intercalating electrode materials that are bonded to them in porous electrode layers. But in a cell intended for heating itself or an adjacent working cell (like, e.g., cell 10'), the composition of the extended portion of the current collector foil, which is not coated with electrode material, may be selected for its electrical resistance

heating capability and its flexibility in being shaped for contact, like the wrap-around contact in Figure 1B, with cells of a working battery or capacitor. For example, at least the extended portion of the current collector 20 may be formed of copper, aluminum, stainless steel, nickel, metal alloys, or porous metal foam. The outer side of the extended portion of the current collector may be coated with an insulating material to better retain and direct its heat into the adjacent working cell.

Depending on the desired outside surface area of a working cell to be heated, the length of the extended portion (un-coated with active electrode material) of a current collector may be in the range of from one centimeter to about one-thousand centimeters. The extended portion of the current collector may be physically connected to the electrode material-coated portion of the current collector, and may be of a different composition, thickness, or structural character (e.g., it may be porous). The thickness of the extended portion of the current collector may be from about five micrometers to about 100 micrometers to protect the core of the working cell. The extended portion of the current collector may use several connector tabs to direct current flow to selected regions of the current collector and to avoid overheating of its tabs. The shape and size of the current collector foil may also be used to enhance compression or the assembly of the working cells and to protect them from outside damage.

20

Figures 2A, 2B, 2C, 3A, 3B, and 3C illustrate different embodiments of the invention that are applicable to rolled assemblies of the electrode and separator members of the lithium or sodium based batteries or capacitors. These embodiments and illustrations will be described in terms of a lithium-ion battery with the understanding that like practices can be readily adapted for lithium-based capacitors and sodium-based batteries and capacitors.

In Figure 2A, a side edge view is presented of an assembly of four rectangular strip members positioned horizontally (spaced apart for purposes of illustration) for subsequent folding or rolling into a self-heating lithium-ion battery structure 200 having two major parallel flat surfaces with generally semi-circular rounded edges. The assembled and rolled lithium-ion battery assembly 200 is illustrated in Figure 2C. The widths of the four rectangular strip members (for

example, about 100 to 200 millimeters) are the substantially the same. But their functions differ and their lengths may also differ as will be described.

In Figure 2A, the upper strip is a porous polymeric separator 201 which will be an outer member of the rolled battery assembly 200.

5 The next lower strip member of the assembly is a cathode electrode 202, comprising a central current collector foil 204. In a lithium-ion battery the cathode current collector foil may be formed of aluminum. Starting at its left end, as illustrated in Figure 2A, a portion 204' of the aluminum current collector foil 204 is coated with a porous layer of particles of active cathode material 206 (such as lithium
10 manganese oxide), resin-bonded to both major surfaces (top and bottom surfaces in Figure 2A) of the current collector foil 204. The length of the cathode-material-coated foil surfaces 204' depends on the properties of the cathode material and the energy and power requirements of the cathode member of the lithium-ion battery. The cathode material-coated length 204' of current collector foil 204 may, for
15 example, be several centimeters. A portion of the coated length 204' is broken out in Figure 2A. The remaining, uncoated portion 204'' of the current collector foil 204 has a length determined for providing heat to the assembled lithium-ion battery. The uncoated foil portion 204'' (also with a broken out section in Figure 2A) is the heating metal foil portion of the cathode of the assembled battery 200. As illustrated
20 in Figures 2A-2C, the length of the porous polymer separator 201 and the full length of the cathode current collector 204 are substantially the same.

 The next lower strip member of the lithium-ion battery assembly 200 is a second porous polymer separator member 208. Separator member 208 has a width and length for separating the coated and uncoated portions of the cathode electrode
25 202 and the coated and uncoated portions of the anode strip 210.

 The next lower strip member of the assembly is an anode electrode 210, formed of a central current collector foil 212. In a lithium-ion battery the anode current collector foil may be formed of copper. Starting at its left end, as illustrated in Figure 2A, a portion 212' of the copper current collector foil 212 is coated with a
30 porous layer of particles of active anode material 214 (such as graphite or lithium titanate), resin-bonded to both major surfaces of the current collector foil 204. The length of the anode-material-coated foil 212' depends on the properties of the anode material and the energy and power requirements of the anode member of the lithium-

ion battery. The anode material coated length 212' may be several centimeters. A portion of the coated length 212' is broken out in Figure 2A. The remaining, uncoated portion 212'' of the current collector foil 212 has a length determined for providing heat to the assembled lithium-ion battery. The uncoated foil portion 212'' is the heating metal foil portion of the anode of the assembled battery 200. A portion of the uncoated current collector foil portion 212'' is also broken out to fit the illustration in suitable drawing space. As illustrated in Figures 2A-2C, the length of the porous polymer separator 208 and the full length of the anode current collector 212 are substantially the same.

10 The cathode current collector foil 204 will have one or more electrical connector tabs 204''' extending from an end portion and other portions of its cathode material-coated portion 204' and will have at least one electrical connector tab 204'''' extending from its extended heating portion 204'' which is not coated with cathode material. These cathode connector tabs, 204''', 204'''' are illustrated in Figures 2A and 2C. The cathode tabs would have a positive (+) charge when battery 200 is operating. The anode current collector foil 208 will have one or more electrical connector tabs 208''' extending from an end portion and other portions of its anode material-coated portion 208' and will have at least one electrical connector tab 208'''' extending from its extended heating portion 208'' which is not coated with cathode material. These anode connector tabs are also illustrated in Figures 2A and 2C. The anode tabs would have a negative (-) charge when the battery 200 is operating.

Figure 2B illustrates an end view (or edge view) of the lithium-ion battery 200, formed as a rolled assembly of the four lithium-ion battery members illustrated as layered members in Figure 2A. As illustrated in Figures 2B and 2C, the rolled battery has generally flat upper and lower surfaces with generally semi-circular side edges. As seen in Figure 2B, one set of ends of the separator 201, the cathode 202, separator 208, and anode 210 are aligned in the interior of the rolled battery 200. In this illustration the electrode material coated portions of the separated anode and cathode layers extend through approximately three full rolled layers of the battery. The separator 201, the uncoated heater portion of cathode current collector 204'', separator 208, and the uncoated heater portion of anode current collector extend further in the rolled structure. As illustrated in Figure 2B, the lengths of the outer separator 201 and underlying cathode heater current collector foil 204'' permit them

to be extended about one and one-half turns, terminating at the bottom of the rolled structure of the self-heating battery 200. And the greater lengths of separator 208 and anode heater current collector foil 212'' permit them to extend in the wrapped structure to the upper surface of the rolled structure of the self-heating battery 200.

5 The rolled lithium-ion battery assembly 200 would be placed in a close-fitting container (not illustrated) in a dry, inert environment, the porous components suitably infiltrated with a suitable liquid solution of a lithium salt electrolyte, and the container sealed with only the electrical connector tabs extending outside of the container.

10 Thus, in the embodiment of the lithium-ion battery depicted in Figures 2A-2C, the cathode material-coated portion 204' of the wound cathode current collector foil 204 and the anode material coated portion 212' of the wound anode current collector foil 212 are located on the inner layers of the rolled battery assembly. And the heating portion 204'' of the wound cathode current collector foil 204 and the
15 heating portion 212'' of the anode current collector foil 212 are on the outer layers of the rolled battery assembly 200. The electrical energy producing function of the battery may be activated by connecting one or more of the working cathode tabs 204''' and one or more of the working anode tabs 212''' to an intended external working load, such as an electric motor on an automobile. However, when a
20 temperature sensor and a battery control system associated with the lithium-ion battery 200 senses that a low ambient temperature is affecting battery performance, the outer heating portions of the respective current collectors may be activated to heat the working portion of the battery. And heat from the outer heating portions of the current collectors 204'', 212'' may be transferred into an adjacent battery placed
25 against one of the outer surfaces of the lithium-ion battery cell 200.

 The heating function of one or both of the separated heated portions 204'', 212'' may be activated by connecting their respective connector tabs 204''', 212''' to an external load. Current flow through the heating portions of the uncoated current collector foils may be enhanced by using one electrode tab of the working portion of
30 the battery and an opposing tab of the heater portion of the battery cell to direct the current produced on the battery cell through the heating portion of the cathode current collector 204'' and/or the heating portion of the anode current collector 212''. And as described above in this specification, the heating capacities of the respective current

may be enhanced by forming the un-coated portion of the current collector(s) of a different metal composition or structure than the electrode material-coated portion of the current collector

5 In the embodiment of a self-heating lithium-ion battery structure as illustrated in Figures 3A-3C, the extended heating portions of the anode and cathode current collectors are positioned in the interior of the rolled battery structure 300.

In Figure 3A, a side edge view is presented of an assembly of four rectangular strip members positioned horizontally for rolling into a self-heating lithium-ion battery structure 300 having two major parallel flat surfaces with generally semi-circular rounded edges. The assembled and rolled lithium-ion battery assembly 300 is illustrated in Figures 3B and 3C. The widths of the four rectangular strip members (for example, about 100 to 200 millimeters) are the substantially the same. But their functions differ and their lengths may also differ as will be described.

15 In Figure 3A, the upper strip is a porous polymeric separator 301 which will be an outer member of the rolled battery assembly.

The next lower strip member of the illustrated assembly is a cathode electrode 302, comprising a central current collector foil 304. In a lithium-ion battery the cathode current collector foil may, for example, be formed of aluminum. Starting at its right end, as illustrated in Figure 3A, a portion 304' of the aluminum current collector foil 304 is coated with a porous layer of particles of active cathode material 306 (such as lithium manganese oxide), resin-bonded to both major surfaces 304' of the current collector foil 304. The length of the cathode material-coated foil 304' depends on the properties of the cathode material and the energy and power requirements of the cathode member of the lithium-ion battery. The cathode material-coated length 304' may be several centimeters. A portion of the coated length 304' is broken out in Figure 3A. The remaining, uncoated portion 304'' of the current collector foil 304 has a length determined for providing heat to the assembled lithium-ion battery. The uncoated foil portion 304'' is the heating metal foil portion of the cathode of the assembled battery 300. A portion of the illustrated uncoated foil portion is also broken out. But as illustrated in Figures 3A and 3B, the length of the porous polymer separator 301 and the full length of the cathode current collector 304 are substantially the same.

The next lower strip member of the illustrated lithium-ion battery assembly 300 is a second porous polymer separator member 308. Separator member 308 has a width and length for separating the coated and uncoated portions of the cathode electrode 302 and the coated and uncoated portions of the anode strip 310.

5 The next lower strip member of the illustrated assembly is an anode 310, comprising a central current collector foil 312. In a lithium-ion battery the anode current collector foil may, for example, be formed of copper. Starting at its right end, as illustrated in Figure 3A, a portion 312' of the copper current collector foil 312 is coated with a porous layer of particles of active anode material 314 (such as graphite or lithium titanate), resin-bonded to both major surfaces of the current collector foil
10 304. The length of the anode material-coated foil 312' depends on the properties of the anode material and the energy and power requirements of the anode member of the lithium-ion battery. The anode material-coated length 312' may be several centimeters. A portion of the coated length 312' is broken out in Figure 3A. The
15 remaining, uncoated portion 312'' of the current collector foil 312 has a length determined for providing heat to the assembled lithium-ion battery. The uncoated foil portion 312'' is the heating metal foil portion of the anode of the assembled battery 300. As illustrated in Figures 3A-3C, the length of the porous polymer separator 308 and the full length of the anode current collector 312 are substantially the same.

20 The cathode material-coated portion 304' of cathode current collector foil 304 will have one or more electrical connector tabs 304''' extending from an end portion and other portions of its cathode material-coated portion 304' and will have at least one electrical connector tab 304'''' extending from its extended heating portion 304'' which is not coated with cathode material. These cathode connector tabs are
25 illustrated in Figures 3A and 3C. The cathode tabs 304''' and 304'''' will typically have a positive (+) charge when the battery cell is discharging. The anode current collector foil 308 will have one or more electrical connector tabs 308''' extending from an end portion and other portions of its anode material-coated portion 308' and will have at least one electrical connector tab 308'''' extending from its extended
30 heating portion 308'' which is not coated with anode material. These anode electrical connector tabs are also illustrated in Figures 3A and 3C. The anode tabs will typically have a negative (-) charge when the battery cell is discharging.

Figure 3B illustrates an end view of a lithium-ion battery 300 formed as a rolled assembly of the four lithium-ion battery members illustrated as layered members in Figure 3A. As illustrated in Figure 3B, the rolled battery 300 has generally flat upper and lower surfaces with generally semi-circular sides. As seen in Figure 3B, the ends of the separator 301, the uncoated heater portion of cathode current collector 304'', separator 308, and the uncoated heater portion of anode current collector 312'' are placed at the left side of the interior of the rolled battery 300. In this illustration the lengths of the separators 301, 308, the uncoated heater portion 304'' of the cathode, and the unheated portion 312'' of the anode permit them to be wound about one and one-half turns in the interior of the rolled self-heating battery 300. Thereafter, the interposed separators 301, 308, the cathode material-coated portion 304' of cathode current collector 304, and the anode material-coated portion of 312' of anode current collector 312 are wound more than two and one-half turns in the rolled battery 300, ending with their matching edges on the upper outer surface of rolled battery as illustrated in Figures 3B and 3C.

The rolled lithium-ion battery assembly 300 would be placed in a close-fitting container (not illustrated) in a dry, inert environment, the porous components suitably infiltrated with a suitable liquid solution of a lithium salt electrolyte, and the container sealed with only the electrical connector tabs extending outside of the container.

Thus, in the embodiment of Figures 3A-3C, the separated, uncoated heating portions 304'' and 312'' of the cathode current collector 304 and the anode current collector 312 are located in the interior layers of the rolled lithium-ion battery 300. And the cathode material-coated portion 304' of the cathode current collector foil 304, the anode material-coated portion 312' of the anode current collector 312, with their interposed separators 301, 308 constitute the outer layers of the rolled battery 300. The electrical energy producing function of the battery may be activated by connecting one or more of the working cathode tabs 304''' and one or more of the working anode tabs 312''' to an intended external working load, such as an electric motor on an automobile. However, when a temperature sensor and a battery control system associated with the lithium-ion battery 300 senses that a low ambient temperature is affecting battery performance, the inner heating portions 304'', 312'' of

the respective current collectors may be activated to heat the working portion of the battery.

The heating function of one or both of the separated heated portions 304'', 312'' may be activated by connecting their respective connector tabs 304''', 312''' to an external load. Current flow through the heating portions of the uncoated current collector foils may be enhanced by using one electrode tab of the working portion of the battery and an opposing tab of the heater portion of the battery cell to direct the current produced on the battery cell through the heating portion of the cathode current collector 304'' and/or the heating portion of the anode current collector 312''. And as stated, the heating capacities of the respective current collector(s) may be enhanced by forming the un-coated portion of the current collector(s) of a different metal composition or different structure (e.g., porous metal foam) than the electrode material-coated portion of the current collector.

As described and illustrated in this specification, current collectors for the anodes and cathode of lithium and sodium based batteries and capacitors may be modified such that extended portions of the thin metal conductors, uncoated with electrode material, may be adapted for occasional, necessary heating of the cell in which they are located or in an adjacent cell or cells. Connector tabs on the extended portions of the current connectors may be utilized to enhance the flow of a heating current through the extended portions. The metal compositions and metal structures of the extended current collector sheet areas may be chosen for increased generation of heat. The sizes and shapes of the extended sheets may be adapted to bending or shaping for increased contact with an adjacent working cell to be heated. And the sizes and shapes of the extended current collector may be provided to closely compact and hold a working cell to the heating cell. Outer surfaces of the heating portions of the current collector sheets may be coated or covered with an insulating material to better direct the flow of the heat produced in them.

For management of the length of the subject disclosure, the above disclosures of the use of heating cells and working cells have been based on their usage in lithium-ion battery cells. However, it will be obvious to one skilled in the art of lithium-based capacitor cells and sodium-based battery and capacitor cells that self-heating cell/working cell combinations and extended current collectors may be

adapted for use in such related electrochemical cells. Electrode material compositions and electrolyte compositions are known and used in lithium capacitors and sodium-based batteries and capacitors and readily selected for use in their heating and working cells. And extended current collector foils, uncoated with active electrode
5 materials are readily adapted for use in lithium capacitors and sodium batteries and capacitors.

The above disclosures of illustrative embodiments are not intended to limit the proper scope of the following claims.

CLAIMS

1. A lithium-based battery or capacitor or a sodium-based battery or capacitor, the battery or capacitor comprising:

5 an anode composed of a metallic current collector foil having a porous layer of particles of an anode material bonded to each side of the anode current collector foil, a cathode composed of a metallic current collector foil having a like-sized and shaped porous layer of particles of a cathode material bonded to each side of the cathode current collector foil, the anode and
10 cathode being assembled with a layer of bonded anode material facing a layer of bonded cathode material which are held apart by at least one porous separator that is coextensive with the facing bonded anode and cathode material layers, the pores of the separator and of the layers of anode material and cathode material being infiltrated with a non-aqueous liquid electrolyte,
15 the current collector foils having connector tabs for electrical contact with an external electrical circuit for the flow of an electrical current to or from the battery or capacitor;

 the metal current collector foil of one or both of the anode and cathode including an additional foil portion that is un-coated with anode or
20 cathode material and that extends outside of its foil area of coated anode material or cathode material, the extended area of the metallic current collector foil having a connector tab for electrical contact with an external current consuming device such that an electrical current produced during operation of the battery or capacitor may be passed through the extended area of the
25 metallic current collector foil to heat the extended area of the current collector foil, the extended area of the metallic current collector foil being sized and shapeable for use, during operation of the battery or capacitor cell, to contact and heat the battery or capacitor or to contact and heat a separate functioning battery or capacitor.

30

2. A lithium-based battery or capacitor or a sodium-based battery or capacitor as stated in claim 1 in which the battery or capacitor has been assembled by rolling overlying rectangular strips, each having a length and a

common width, the respective rectangular strips comprising (i) a metallic current collector foil strip having a current producing portion of its length coated on both sides with a porous layer of cathode material and a heating portion of its length that is not coated with cathode material, (ii) a metallic
5 current collector foil strip having a portion of its length coated on both sides with a porous layer of anode material and a heating portion of its length that is not coated with anode material, and (iii) two porous separator layers which lie between and separate the anode and cathode metallic current collector foil strips

10

3. A lithium-based battery or capacitor or a sodium-based battery or capacitor as stated in claim 2 in which the heating portions of the metallic current collector strips are located as a rolled layer or layers at the inside of the rolled assembly.

15

4. A lithium-based battery or capacitor or a sodium-based battery or capacitor as stated in claim 2 in which the heating portions of the metallic current collector strips are located as a rolled layer or layers at the outside of the rolled assembly.

20

5. A lithium-based battery or capacitor or a sodium-based battery or capacitor as stated in claim 1 in which the battery or capacitor has been assembled with the anode material-coated portion of the anode current collector and the cathode material-coated portion of the cathode current
25 collector and the non-aqueous liquid electrolyte contained in a thin wall, air and water-free enclosure, the heating portion of one of the anode or cathode current collectors extending through the thin wall enclosure for heat transfer contact with another battery or capacitor.

30

6. A lithium-based battery or capacitor or a sodium-based battery or capacitor as stated in claim 1 in which the uncoated additional portion of the current collector foil of one of the anode or cathode is wrapped around its assembly of battery or capacitor members for the purpose of heating them

when its connector tab is connected with an external circuit, the wrapped portion of current collector foil having an side facing the battery or capacitor members and an external opposing side.

5 7. A lithium-based battery or capacitor or a sodium-based battery or capacitor as stated in claim 6 in which the external opposing side of the wrapped portion of the current collector foil is covered with a thermally insulating material to direct heat produced in the wrapped portion of the current collector foil into the adjacent assembly of members.

10

8. A lithium-based battery or capacitor or a sodium-based battery or capacitor as stated in claim 1 in which the uncoated additional portion of the metal current collector foil of one of the anode or cathode is wrapped around an adjacent assembly of a different assembly of battery or capacitor
15 members for the purpose of heating them when its connector tab is connected with an external circuit, the wrapped portion of current collector foil having an side facing the different assembly of battery or capacitor members and an external opposing side.

20 9. A lithium-based battery or capacitor or a sodium-based battery of capacitor as stated in claim 8 in which the external opposing side of the wrapped portion of the current collector foil is covered with a thermally insulating material to direct heat produced in the wrapped portion of the current collector foil into the adjacent assembly of members.

25

10. A lithium-based battery or capacitor or a sodium-based battery of capacitor as stated in claim 1 in which the uncoated additional portion of one of the anode or cathode is formed of a metal composition having a higher electrical resistance than the anode or cathode material-coated portion of the
30 current collector.

11. A combination of a first lithium-based battery cell or capacitor cell or a sodium-based battery cell or capacitor cell with a second lithium-based cell or sodium-based cell, the combination of cells comprising:

5 the combination in which the first battery or capacitor cell is a working cell that is constructed to produce a specified electrical current, when operating in a specified ambient temperature range, to an external electrically powered device, and the second battery or capacitor cell, which is placed in heat transfer contact with the working cell, is a self-heating cell that is constructed to produce a specified electrical current for heating itself and the
10 first cell when the first cell is operating while exposed to an ambient temperature below the specified ambient temperature range;

the working cell being formed of (i) an anode comprising an anode current collector foil coated on both sides with a porous layer of particulate anode material, (ii) a cathode comprising a cathode current collector foil
15 coated on both sides with a porous layer of particulate cathode material, (iii) one or more porous separators which physically separate anode and cathode material layers, and (iv) a non-aqueous electrolyte conductive of lithium ions or sodium ions between the anode and cathode materials; and

the self-heating cell being formed of (i) an anode comprising an anode current collector foil coated on both sides with a porous layer of
20 particulate anode material, (ii) a cathode comprising a cathode current collector foil coated on both sides with a porous layer of particulate cathode material, (iii) one or more porous separators which physically separate anode and cathode material layers, and (iv) a non-aqueous electrolyte conductive of
25 lithium ions or sodium ions between the anode and cathode materials.

12. A combination of a first cell and a second cell as stated in claim 11 in which the anode and cathode of each cell are flat layers of like peripheral shape, contained in separate cell containers, and the separate cell containers
30 are stacked in parallel alignment in heat transfer contact.

13. A combination of a first cell and a second cell as stated in claim 11 in which the anode and cathode of each cell are flat layers of like peripheral

shape, contained in the same cell container, immersed in the same electrolyte composition and the electrodes are stacked in parallel alignment.

14. A combination of a first cell and a second cell as stated in claim
5 11 in which the active anode material of the working cell is graphite and the active cathode material of the working cell is lithium iron phosphate, and the active anode material of the self-heating cell is lithium titanate and the active cathode material of the heating cell is lithium manganese oxide.

10 15. A lithium-based battery, the battery comprising:
an anode composed of a metallic current collector foil having a porous layer of particles of an anode material bonded to each side of the anode current collector foil, a cathode composed of a metallic current collector foil having a like-sized and shaped porous layer of particles of a cathode material
15 bonded to each side of the cathode current collector foil, the anode and cathode being assembled with a layer of bonded anode material facing a layer of bonded cathode material that are held apart by at least one porous separator that is coextensive with the facing bonded anode and cathode material layers, the pores of the separator and of the layers of anode material and cathode
20 material being infiltrated with a non-aqueous liquid electrolyte, the current collector foils having connector tabs for electrical contact with an external electrical circuit for the flow of an electrical current to or from the battery or capacitor;

the metal current collector foil of one or both of the anode and
25 cathode including an additional foil portion that is un-coated with anode or cathode material and that extends outside of its foil area of coated anode material or cathode material, the extended area of the metallic current collector foil having a connector tab for electrical contact with an external current consuming device such that an electrical current produced during operation of
30 the battery may be passed through the extended area of the metallic current collector foil to heat the extended area of the current collector foil, the extended area of the metallic current collector foil being sized and shapeable

for use, during operation of the lithium-based battery, to contact and heat the battery or to contact and heat a separate functioning lithium-based battery.

16. A lithium-based battery as stated in claim 15 in which the
5 battery has been assembled by rolling overlying rectangular strips, each having a length and a common width, the respective rectangular strips comprising (i) a metallic current collector foil strip having a current producing portion of its length coated on both sides with a porous layer of cathode material and a heating portion of its length that is not coated with cathode
10 material, (ii) a metallic current collector foil strip having a portion of its length coated on both sides with a porous layer of anode material and a heating portion of its length that is not coated with anode material, and (iii) two porous separator layers which lie between and separate the anode and cathode metallic current collector foil strips.

15

17. A lithium-based battery as stated in claim 16 in which the heating portions of the metallic current collector strips are located as a rolled layer or layers at the inside of the rolled assembly.

20 18. A lithium-based battery as stated in claim 16 in which the heating portions of the metallic current collector strips are located as a rolled layer or layers at the outside of the rolled assembly.

19. A lithium-based battery or capacitor or a sodium-based battery or capacitor as stated in claim 1 in which the coated portion and uncoated
25 portion of the metal current collector foil are different pieces of metal foil with are connected to each other to form a continuous metal current collector foil.

20. A lithium-based battery or capacitor or a sodium-based battery or capacitor as stated in claim 15 in which the coated portion and uncoated
30 portion of the metal current collector foil are different pieces of metal foil with are connected to each other to form a continuous metal current collector foil.

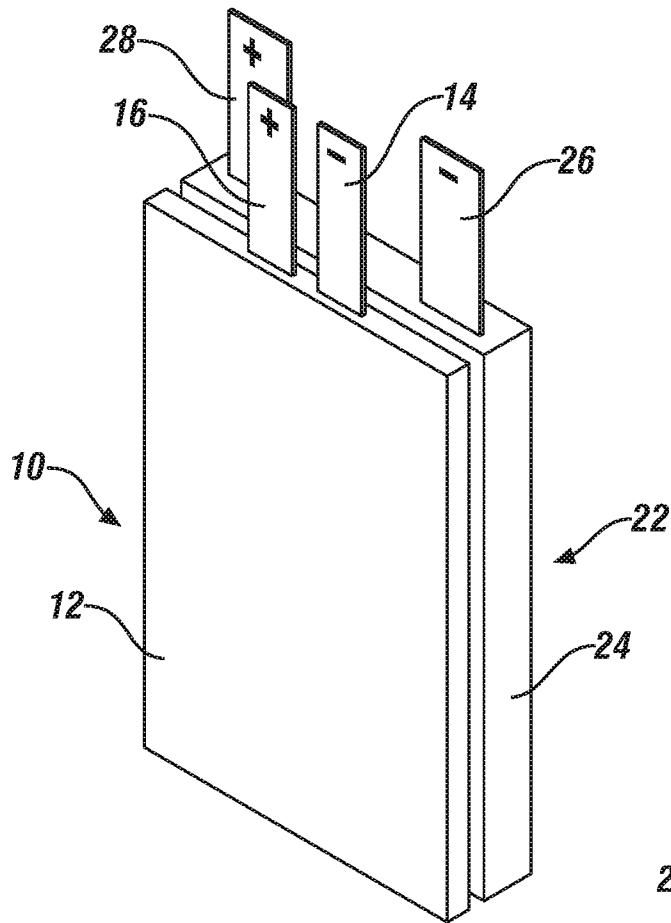


FIG. 1A

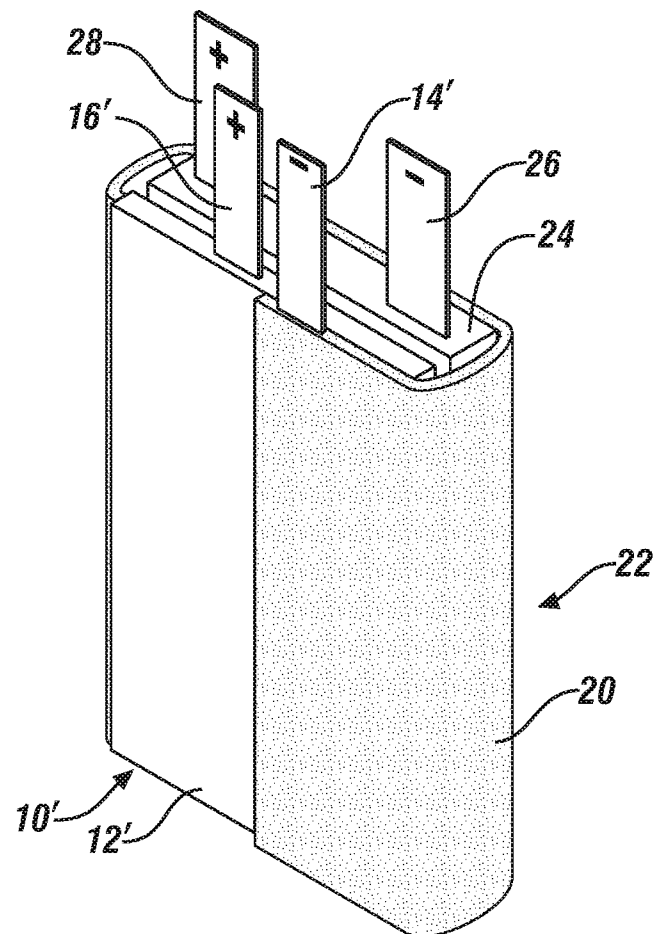


FIG. 1B

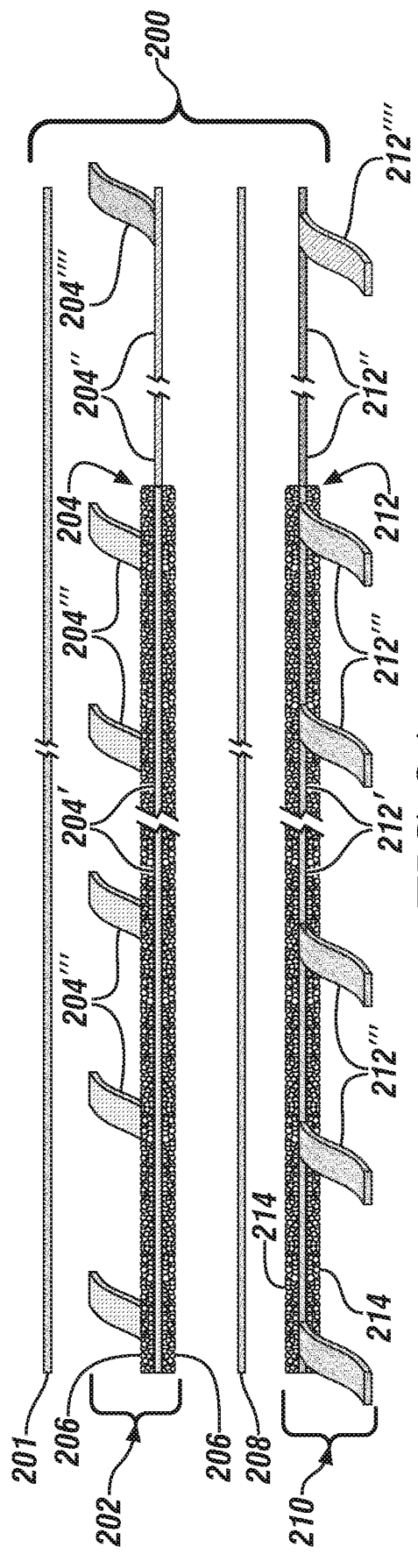


FIG. 2A

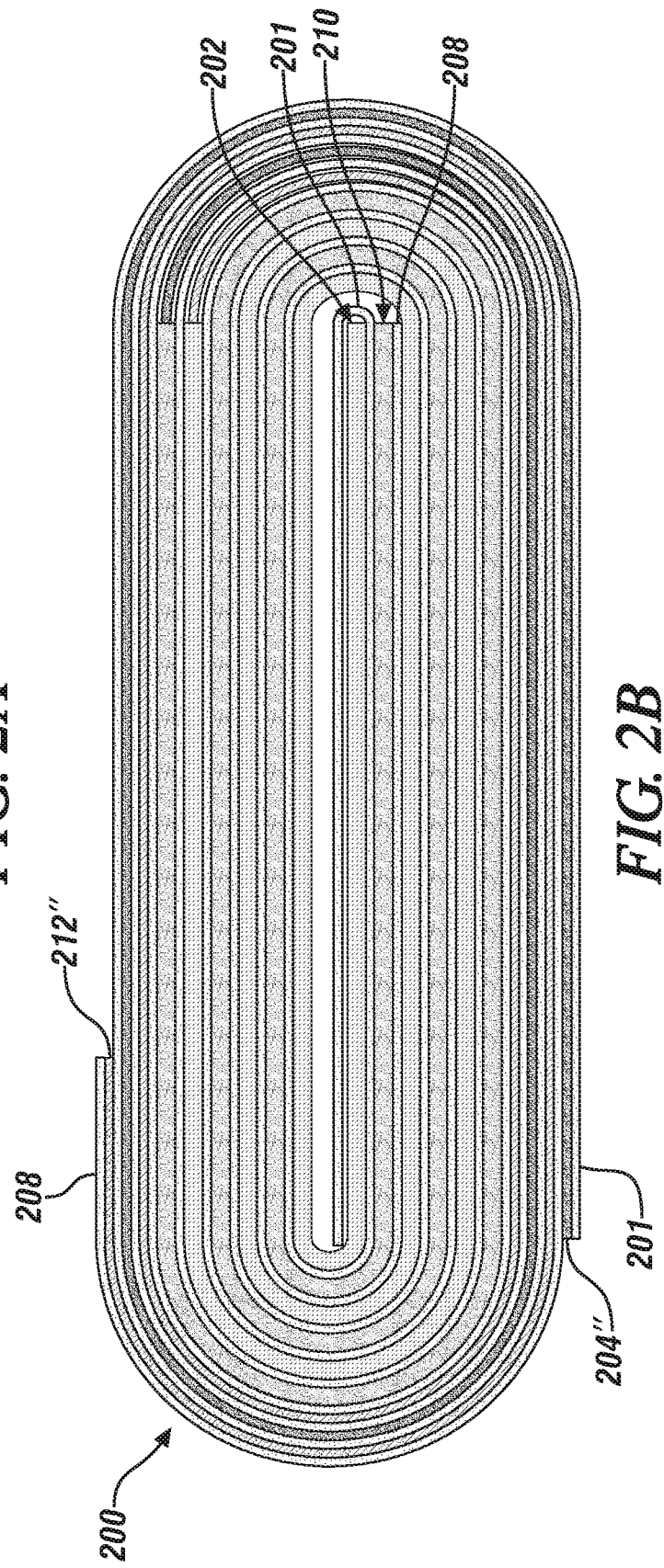


FIG. 2B

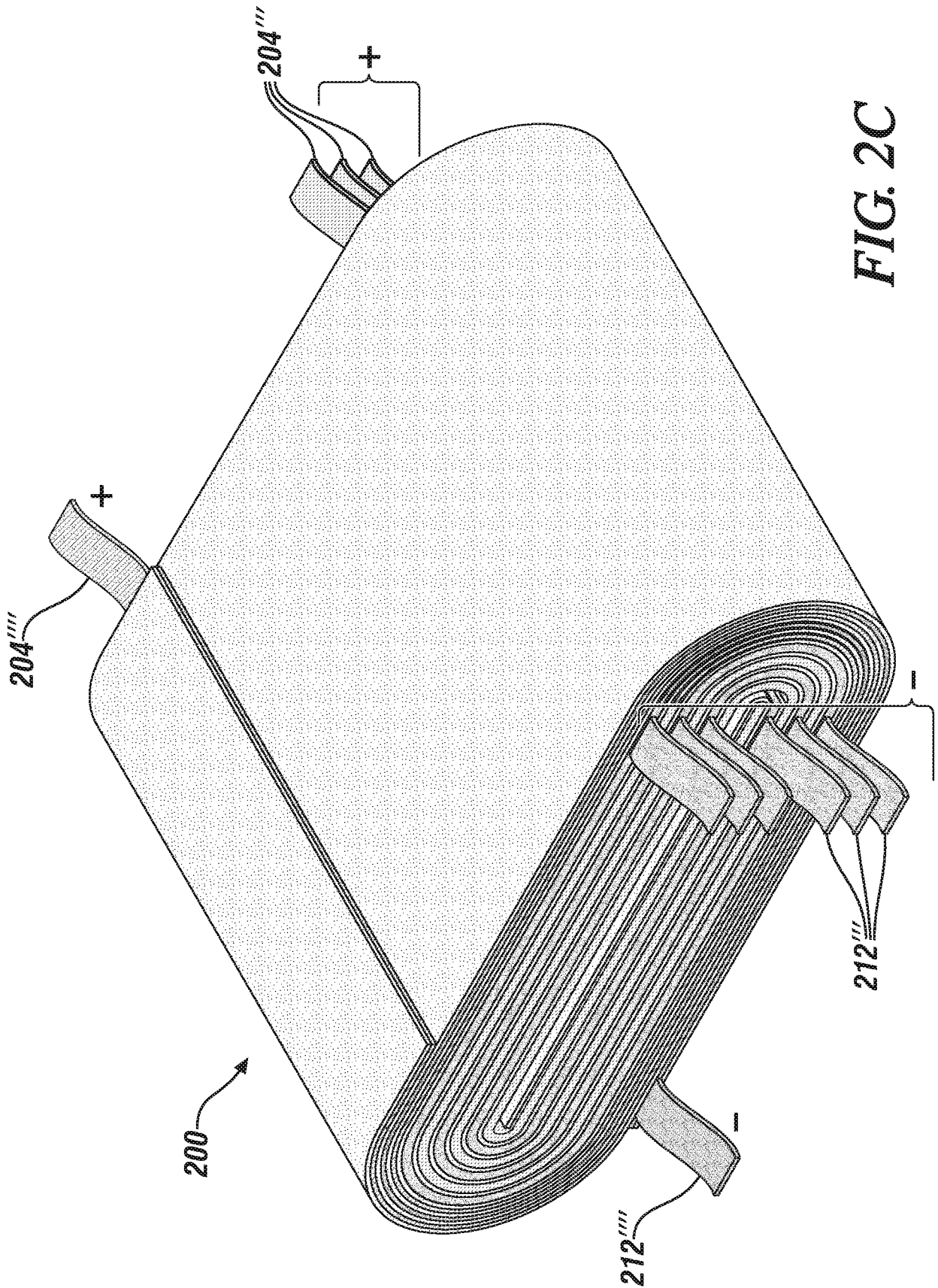


FIG. 2C

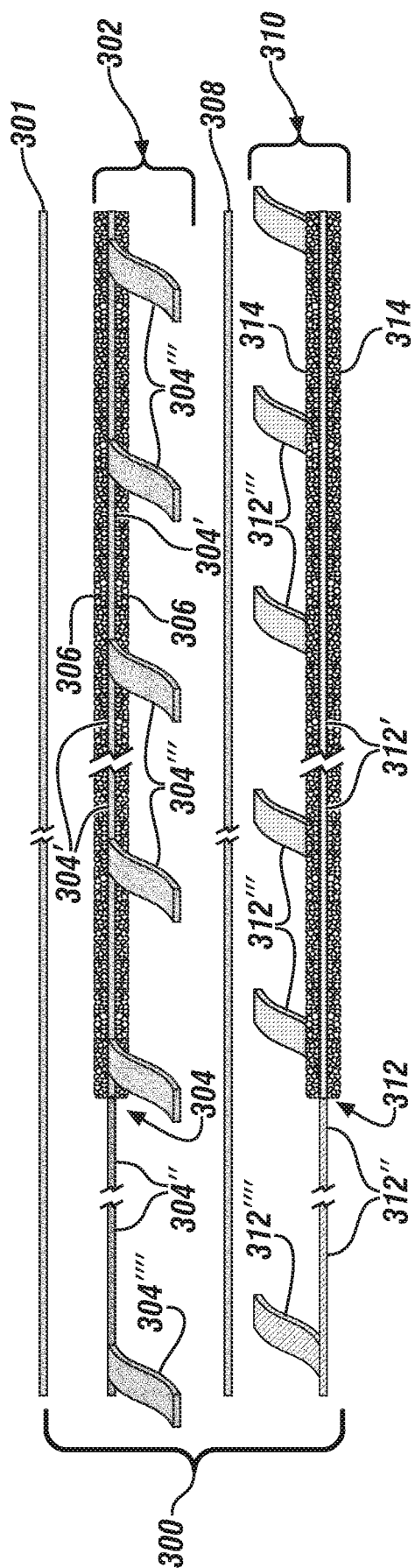


FIG. 3A

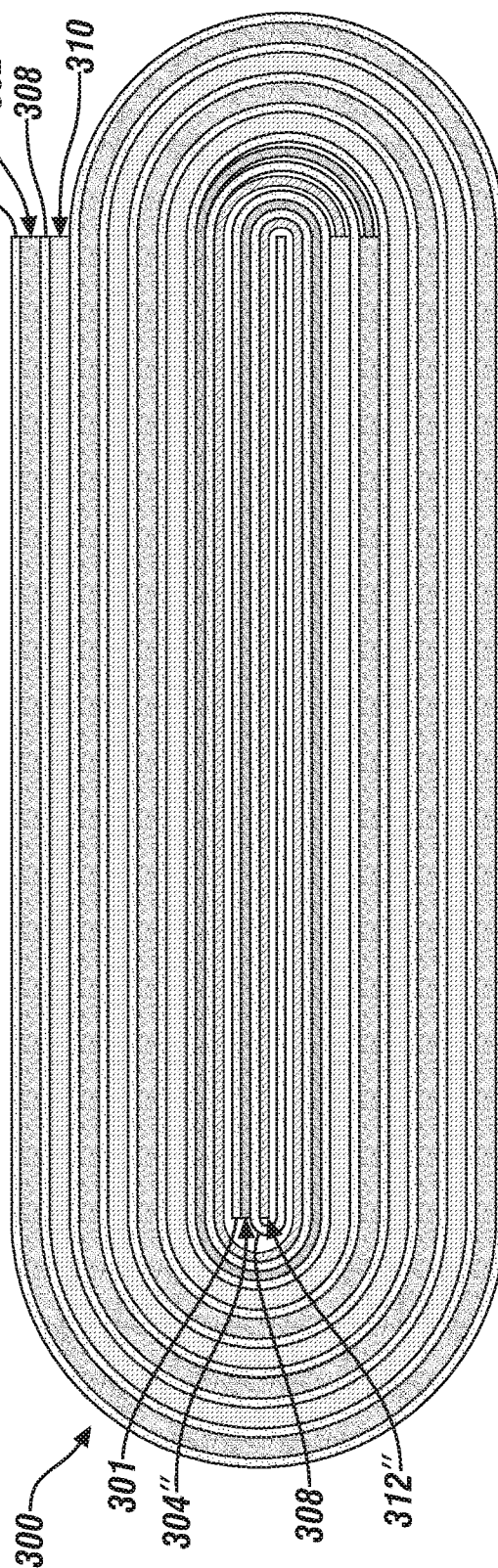
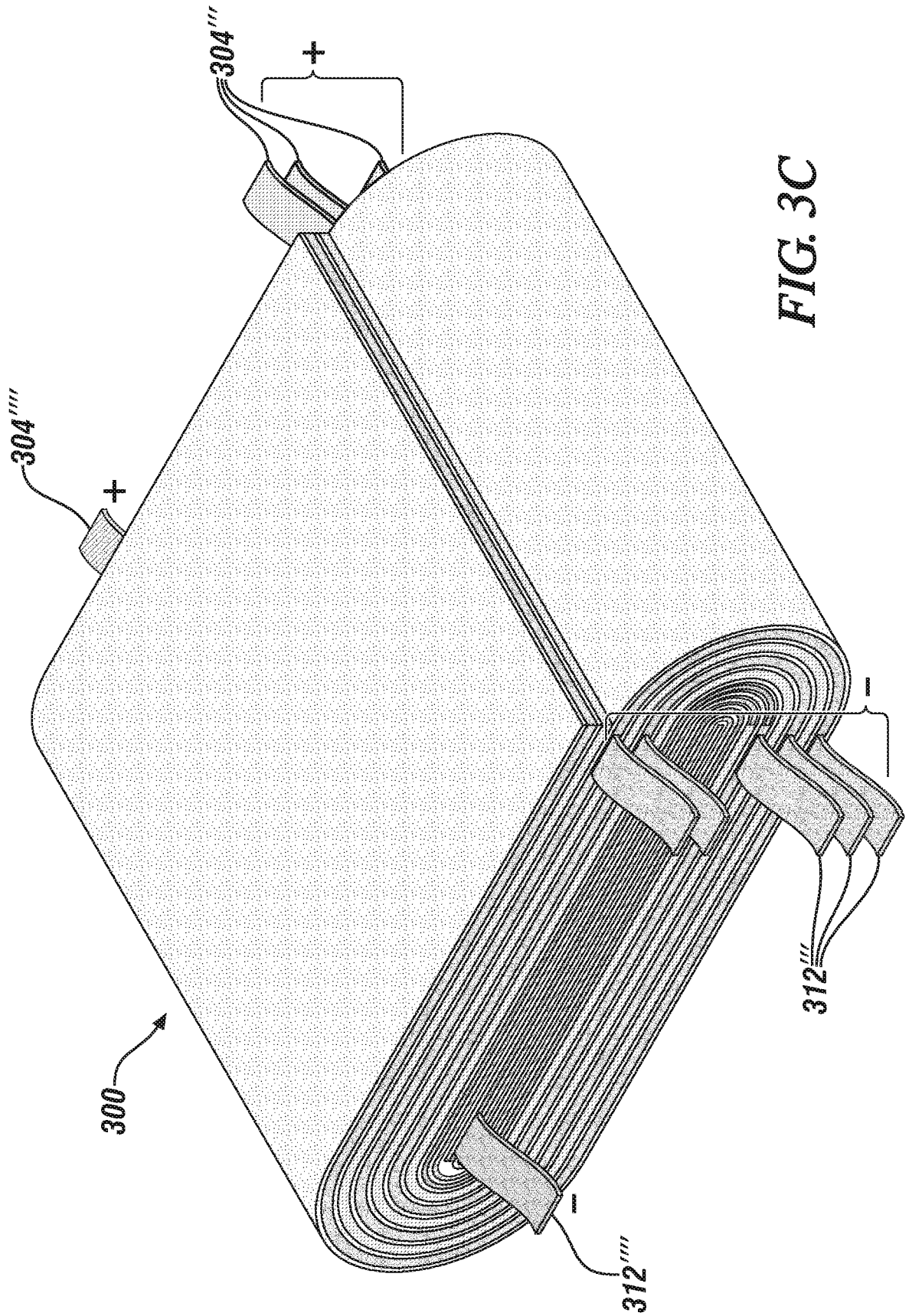


FIG. 3B



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/023506**A. CLASSIFICATION OF SUBJECT MATTER****H01M 10/654(2014.01)i, H01M 4/66(2006.01)i, H01M 10/0587(2010.01)i, H01M 10/615(2014.01)i, H01M 10/052(2010.01)i, H01M 10/054(2010.01)i, H01M 2/26(2006.01)i, H01G 11/10(2013.01)i, H01G 11/06(2013.01)i, H01G 11/06(2013.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01M 10/654; H01M 2/16; H02J 7/04; H01M 10/46; H02J 7/00; H01M 10/04; H01M 2/02; H01M 4/66; H01M 10/0587; H01M 10/615; H01M 10/052; H01M 10/054; H01M 2/26; H01G 11/10; H01G 11/06; H01G 11/68

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: self heating, anode, cathode, separator, connector tab, metallic current collector foil, uncoated portion**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008-0280197 A1 (MACHIDA, MASAKI) 13 November 2008 See paragraphs [0003], [0027], [0030]-[0034], [0043], [0048], [0053], [0055]-[0059], [0067], [0070]; claim 1; figure 3.	1-20
A	US 2006-0012342 A1 (KAMENOFF, ROBERT) 19 January 2006 See paragraphs [0005], [0033], [0037]; claim 1.	1-20
A	KR 10-2015-0054702 A (LG CHEM, LTD.) 20 May 2015 See paragraphs [0043], [0045], [0047]-[0049]; claims 1, 2; figure 3.	1-20
A	US 2013-0230749 A1 (LG CHEM, LTD.) 05 September 2013 See paragraph [0044]; claim 1; figure 2.	1-20
A	US 2016-0043447 A1 (MOTOROLA SOLUTIONS, INC.) 11 February 2016 See paragraphs [0011]-[0014]; claims 1, 3; figure 1.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"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)

"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

21 December 2017 (21.12.2017)

Date of mailing of the international search report

21 December 2017 (21.12.2017)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

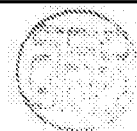


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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/023506

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