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(54) **Title**: BI-POLAR ELECTROCHEMICAL CELL

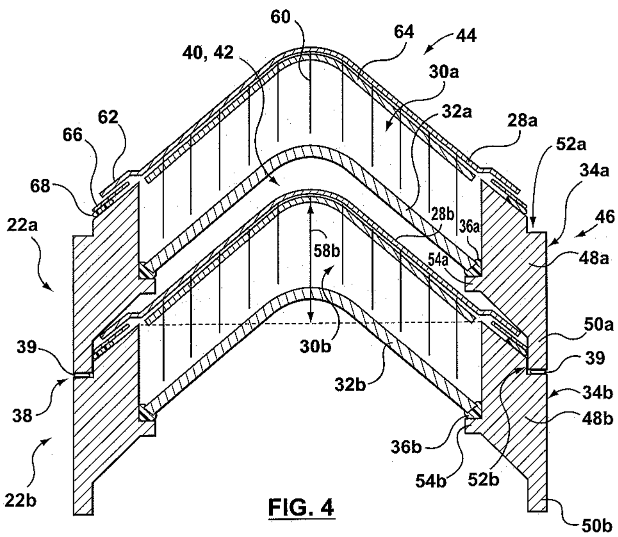

FIG. 4

(57) **Abstract**: A modular electrochemical cell for axial assembly with a corresponding electrochemical cell to form a stack, which includes a conductive separating member, a cathode material, a solid electrolyte, and a cell wall sealed around the solid electrolyte. The cell wall is configured to join axially at an interface with a corresponding cell wall of the corresponding electrochemical cell in the stack, the cell wall and corresponding cell wall being dimensioned to surround collectively an entire perimeter of the interface. The solid electrolyte may be shaped to include a dome shape having a basal radius and a height dimensioned to be at least the basal radius.

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BI-POLAR ELECTROCHEMICAL CELL

TECHNICAL FIELD

[0001] Example embodiments relate generally to the field of electrochemical cells, and in particular to bi-polar electrochemical cells having a solid electrolyte.

BACKGROUND

[0002] There are some existing electrochemical cells which use a solid electrolyte as a separator between the cathode and anode components. In many of these cases the cells are comprised of single, self-contained or stand-alone cells each having stand-alone components, and a cell case which contains all these parts. In some systems, these very same stand-alone cells are stacked with little or no modification. In particular, this can result in some cell stacks having protruding conductive leads between each of the cells in the stack. Some cell stacks may also utilize conductive metallic cans as the housing. Some disadvantages which such existing cells have are a high proportion of parts that are not contributors to energy or power production, high probability for quality non-conformance issues due to complexity and processing sensitivities, risk of external short circuit paths emanating from inside the cell through protruding metallic paths, and/or high production cost.

[0003] During manufacture of some conventional electrochemical cells, it is common to subject the cell to high pressures and temperatures. However, such environments may result in hazardous, costly and inefficient manufacturing conditions.

[0004] The reliability and performance of high temperature cells based on solid electrolytes such as sodium-sulfur and sodium metal chloride can be appreciated as being dependent on materials compatibility and strength, seal integrity and leak-tightness, and resistance to corrosion at operating temperatures. The solid electrolyte in particular is a brittle ceramic which is prone to fracture causing premature failure of the cell and results in loss of capacity and poor battery life.

[0005] Other difficulties with conventional cells may be appreciated in view of the description herein.

SUMMARY

[0006] Example embodiments generally relate to a modular electrochemical cell including a solid electrolyte and an electrochemical cell stack assembled from same.

[0007] In accordance with an example embodiment, there is provided a modular electrochemical cell for axial assembly with a corresponding electrochemical cell to form a stack, which includes a conductive separating member, a cathode material, a solid electrolyte, and a cell wall sealed around the solid electrolyte. The cell wall is configured to join axially at an interface with a corresponding cell wall of the corresponding electrochemical cell in the stack, the cell wall and corresponding cell wall being dimensioned to surround collectively an entire perimeter of the interface. The cell walls may define an anode compartment when joined. The solid electrolyte may be shaped to include a three-dimensional dome shape having a basal radius and a height dimensioned to be at least the basal radius.

BRIEF DESCRIPTION OF THE FIGURES

[0008] Embodiments will now be described by way of example with reference to the accompanying drawings, in which like reference numerals are used to indicate similar features, and in which:

[0009] Figure 1A shows a perspective view of a bi-polar electrochemical cell stack in accordance with an example embodiment;

[0010] Figure 1B shows a side cross-section of the cell stack of Figure 1A;

[0011] Figure 1C shows a perspective section of the cell stack of Figure 1A;

[0012] Figure 2A shows a side cross-section of a cathode unit in accordance with an example embodiment;

[0013] Figure 2B shows an exploded perspective view of the cathode unit of Figure 2A;

[0014] Figure 3A shows a side cross-section of a sealing unit in accordance with an example embodiment;

[0015] Figure 3B shows an exploded perspective view of the sealing unit of Figure 3A;

[0016] Figure 4 shows a side cross-section of stacked interior cells, in accordance with an example embodiment;

[0017] Figure 5 shows a side cross-section of an anode end unit in accordance with an example embodiment;

[0018] Figure 6 shows a side cross-section of a cathode end unit in accordance with an example embodiment;

[0019] Figure 7A shows a side view of a sealing unit in accordance with another example embodiment;

[0020] Figure 7B shows a top view of the sealing unit of Figure 7A;

[0021] Figure 7C shows a sectional view of the sealing unit taken along 7C-7C of Figure 7B; and

[0022] Figure 7D shows a perspective view of the sealing unit of Figure 7A.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0023] Example embodiments generally relate to a modular electrochemical cell including a solid electrolyte and an electrochemical cell stack assembled from same.

[0024] Generally, in accordance with example embodiments, modular electrochemical cells can be formed from prefabricated components in an assembly. Further, the cells may be each configured for axially assembling with a corresponding or adjacent cell in a stack. In one aspect of some example embodiments, the cells may be dimensioned to assemble flushly with the adjacent cell to surround an interface between the cells. In another aspect of some example embodiments, the cells may include components which are dome shaped at a curvature or having a height to assist in facilitating structural integrity, power distribution or stacking alignment.

[0025] In accordance with an example embodiment, there is provided an electrochemical cell for axial assembly with a corresponding electrochemical cell to form a stack, which includes a conductive separating member, a cathode material adjoined to the conductive separating member, a solid electrolyte adjoined to the cathode material, and an electrically insulating cell wall sealed around the solid electrolyte. The cell wall is configured to join axially at an interface with a corresponding cell wall of the corresponding electrochemical cell in the stack, the cell wall and corresponding cell wall being dimensioned to surround collectively an entire perimeter of the interface. The solid electrolyte may be shaped to include a three-dimensional dome shape having a basal radius and a height dimensioned to be at least the basal radius.

[0026] In accordance with another example embodiment, there is provided an electrochemical cell, which includes a conductive separating member, a cathode material adjoined to the conductive separating member, a solid electrolyte adjoined to the cathode material, the solid electrolyte being shaped to include a three-dimensional dome shape having a basal radius and a height dimensioned to be at least the basal radius, and a cell wall sealed around said solid electrolyte at the basal radius.

[0027] In accordance with another example embodiment, there is provided a method of assembling an electrochemical cell, which includes forming a solid cathode material, adjoining said solid cathode material to a conductive separating member, sealing an electrically insulating cell wall around a solid electrolyte, and assembling the conductive separating member to the cell wall to adjoin the solid cathode material to the solid electrolyte.

[0028] For convenience of reference, individual cells may be referred to hereinafter as "cells" while a stack of such cells may be referred to as a "cell stack" or merely "stack", as it may be appreciated in the art that a cell stack can also often be referred to in the art as merely a "cell".

[0029] Reference is first made to Figures 1A to 1C, which show a bi-polar electrochemical cell stack 20 in accordance with an example embodiment. As best shown in Figure 1B, the cell stack 20 includes at least one, or a plurality of, modular interior electrochemical cells 22a, 22b, ..., 22g (each or collectively referred to as 22) which are axially stacked in series. A cathode end unit 24 is assembled at a cathode end of the cell stack 20. An anode end unit 26 is assembled at an anode end of the cell stack 20. In example embodiments, the cells 22 are cylindrically symmetrical about a central axis. It can be appreciated that the configuration may be optimized for strength, sealing or cell stacking.

[0030] Generally, in accordance with example embodiments each cell 22 may each be formed from prefabricated components in an assembly. Further, each cell may be each configured for axially assembling with a corresponding or adjacent cell in the stack 20. In one aspect of some example embodiments, each cell 22 may be dimensioned to assemble with an adjacent cell to prevent hazardous or unnecessary protruding electrically conductive leads between each of the cells 22. In another aspect of some example embodiments, each cell 22 may include components which are dome shaped at a height or a curvature to assist in facilitating structural integrity, power distribution or stacking alignment.

[0031] Reference is now made to Figure 4, which shows a first interior cell 22a and a neighbouring second interior cell 22b axially assembled together in a stack in accordance with an example embodiment. In the embodiment shown, the interior cells 22a, 22b are modular and are of like construction. Generally, in example embodiments the interior cells 22a, 22b may each be assembled from prefabricated components in an assembly. For example, referring briefly to Figures 2A and 2B, a prefabricated cathode unit 44, as shown, may be used in the assembly of the interior cell 22a. Similarly, referring briefly to Figures 3A and 3B, a prefabricated sealing unit 46, as shown, may be used in the assembly of the interior cell 22a.

[0032] Referring again to Figure 4, as shown, the first interior cell 22a includes a conductive separating member 28a which may be formed of an electron-conductive material. The separating member 28a may also be referred to as a cathode backplane or a bipolar plate, as is understood in the art. A cathode material 30a contained within a cathode compartment is axially adjoined to the separating member 28a during assembly. A solid electrolyte 32a, which can be a solid electrolyte membrane, may be formed from sodium beta double prime (β")-alumina, as is understood in the art, is adjoined axially to the cathode material 30a. Thus, the cathode compartment is defined as between the separating member 28a and the solid electrolyte 32a. A first cell wall 34a in the form of a shell or sealing ring is sealed around the solid electrolyte 32a, for example, using a glass seal 36a. The cell wall 34a may be formed from a suitable electrical and ionic insulating material, for example alpha (α) – alumina. The cell wall 34a accordingly acts as an insulating housing for the cell 22a (and therefore for the stack 20 of Figure 1A). The particular recipe, elements or materials which form the alpha alumina is understood in the art and not described in detail herein. In example embodiments, the cathode material 30a is typically in solid form for assembly but liquefies within the cathode compartment at operating temperature. The cathode compartment is defined between the separating member 28a and the solid electrolyte 32a. Similarly, the second interior cell 22b includes a separating member 28b, a solid cathode material 30b axially adjoined to the separating member 28b, and a solid electrolyte 32b axially adjoined to the solid cathode material 30b. A second cell wall 34b is sealed around the solid electrolyte 32b using, for example, a glass seal 36b.

[0033] Referring still to Figure 4, each cell wall 34a, 34b is generally configured and dimensioned to join axially to each other at an interface 38. Generally, when joined at the interface 38 the cell walls 34a, 34b are dimensioned to surround collectively an entire perimeter (e.g., a circumference in this example) of the interface 38. When the cell walls 34a, 34b are joined together, anode compartment 42 is defined between the solid electrolyte 32a and the separating member 28b. Generally, the anode compartment 42 is evacuated and, on charge, an anode material 40 becomes filled within the anode compartment 42 (as is understood in the art). Inside the anode compartment 42, a simplex or multiplex carbon felt can be included for wicking of the anode material 40 (e.g. sodium) in order to ensure complete wetting between the anode material 40 and the electrolyte 32a (independent from the status of charge).

[0034] Referring still to Figure 4, the interface 38 will now be described in greater detail. As shown, the first cell wall 34a overlaps with the second cell wall 34b, wherein cell wall 34a includes a cell wall body 48a, and a flange member 50a which extends there from towards the second cell wall 34b. Second cell wall 34b also includes a cell wall body 48b, and which defines a groove 52b which corresponds to the shape of the flange member 50a. Accordingly, cell walls 34a, 34b interlock to surround collectively the entire circumference at the interface 38. The interface 38 may include a glass seal 39 (as best shown in Figure 3B) with laser sealing or other suitable corrosion resistant material glass or recipes. It can be appreciated that such a configuration assists to prevent or minimize hazardous or unnecessary protruding conductive leads between the cell walls 34a, 34b. In some example embodiments, cell walls 34a, 34b engage flushly each other at interface 38.

[0035] In an alternate embodiment, not shown, the first cell wall 34a defines the groove (not shown) while the second cell wall 34b includes the flange (not shown) for interlocking there between.

[0036] Referring still to Figure 4, first cell wall 34a also defines a groove 52a for assembly with another cell (e.g., cathode end unit 24 as shown in Figure 1B). Second cell wall 34b also includes a flange member 50b for assembly with yet another cell (e.g. third interior cell 22c as shown in Figure 1B).

[0037] Referring still to Figure 4, a dome shape feature will now be described in greater detail. For example, some other existing conventional cells include a thin flat disc or slightly domed beta alumina solid electrolytes. These were aimed at improvements over the traditional tubular single cells, but many may suffer from the various disadvantages of mechanical weakness and a reduced ability to withstand the stresses occurring during cell charge-discharge cycling (as is understood in the art), and in particular to the changes in pressure between cathode and anode that occur during charge-discharge cycling. For example, in discharge, cations are transferred from an anode chamber, across an electrolyte, to a cathode chamber. This transfer depletes the amount of active material in the anode chamber and tends increasingly to fill the cathode chamber, so that an increasing pressure differential is created across the electrolyte. In conventional existing cells, there also may be disadvantages of low electrolyte/electrode interfacial surface area which contributes to high cell resistance and restricted battery power.

[0038] As shown in Figure 4, the solid electrolyte 32a, solid cathode material 30a, and separating member 28a are each three-dimensional dome shaped. The particular height 57 (Figure 3A) or curvature may be used to assist in facilitating structural integrity, power distribution or stacking alignment. As shown, the cathode material 30a is located on a convex side of the solid electrolyte 32a and the anode compartment 42 is located on a concave side of the solid electrolyte 32a. The anode compartment 42 pressure after assembly is typically low ambient pressure (less than one bar or one bar) or evacuated. This pressure is less than the cathode compartment pressure and creates a differential force with the more positive value on the cathode side under operating conditions. The dome shape having its convex side at the cathode side results in minimum bending stress and a compressive preload in the solid electrolyte 32a. On charge, the anode compartment 42 fills with anode material 40, as is understood in the art.

[0039] An interior of the first cell wall body 48a includes a radially inward protruding lip 54a for sealing with and supporting of the solid electrolyte 32a. Similarly, the second cell wall body 48b includes a radially inward protruding lip 54b for sealing with and supporting of the solid electrolyte 32b.

[0040] In some example embodiments, as shown in Figure 3A, the dome shape of the solid electrolyte 32a defines a basal radius 56 and a height 57. In some example embodiments, the height 57 is dimensioned to be at least the basal radius 56. In other example embodiments, the height 57 is dimensioned to be at least two times the basal radius 56. It is recognized herein that the height 57 can be much larger than the basal radius 56. The non-circular bases, the basal radius 56 can be appreciated as being a length from its center at the base to the periphery.

[0041] In another aspect, still referring to Figure 3A, the solid electrolyte 32a includes a radius of curvature at the apex 59 of the solid electrolyte 32a which is at least a same or smaller than the basal radius 56. In another example embodiment, the radius of curvature is at least two times smaller than said basal radius 56 of said solid electrolyte 32a. In another example embodiment, the radius of curvature is at least ten times smaller than said basal radius 56.

[0042] Referring again to Figure 4, the cell wall 34a may also be shaped to continue generally the dome shape of the solid electrolyte 32a. Thus, as shown, the flange member 50a may also act as a leg member to continue generally the dome shape to support the solid electrolyte 32a from the lip 54a. Thus, as shown, the load from the solid electrolyte 32a and thereabove is generally axially distributed to the second cell wall 34b of the second interior cell 22b via the flange member 50a.

[0043] Referring still to Figure 4, it can be appreciated that the dome shape may also assist in stacking. For example, at least a portion 58b of the separating member 28b and the cathode material 30b are shaped to protrude axially beyond the cell wall 34b. As shown, an apex of this protrusion assists in axially aligning the second cell wall 34b to a concave side of the first cell wall 34a. This feature may be used in combination with the flange and groove interlocking of the cell walls 34a, 34b. Further, referring still to Figure 4, note that the first cell wall 34a surrounds the at least a portion 58b which is protruding from the second cell wall 34b, when the cell walls 34a, 34b are joined at the interface 38.

[0044] In various example embodiments, the three-dimensional dome shape or two-dimensional profile can be shaped as a rounded cone, arch, semicircular, segmental, parabolic, catenary, lancet and/or elliptical. The choice of design and the degree of arching may be suitably determined by practical considerations such as strength, surface area, and ease of stacking. Ease of stacking may be important in order to allow for electrodes whose depth is acceptably uniform from the outer edge to the centre, for operation during charge-discharge cycling. Example embodiments allow for arching of considerable depth, with may result in greatly increased surface area and high strength, with minimal loss of electrode uniformity.

[0045] An example of a cross-section for a relatively high-strength stackable shape is a catenary section described by the hyperbolic function y = a cosh (r/a) wherein "y" is the axial or longitudinal profile, "r" is the basal radius 56 or transverse axis, and "a" is a constant. For example, "a" is a large number of the order of at least 10. Such a shape and radius of curvature of the solid electrolyte is able to withstand large differential electrode pressures during cycling and assists in stacking.

[0046] Referring now to Figure 2A, the prefabricated cathode unit 44 used to assemble the interior cell 22a will now be described in greater detail. As shown, the prefabricated cathode unit 44 includes the solid cathode material 30a which includes an active cathode mass. The cathode material 30a may include a porous structure of a metal powder like nickel or/and iron mixed with NaCl and additives and impregnated with the molten salt NaAlCl4, or suitable sodium metal chloride. The cathode mass may be formed or moulded in the dome shape of the cathode compartment as shown in Figure 2A. This step typically occurs at a high temperature and/or pressure. Alternatively, the active cathode mass can be produced by pressing a mixture of the suitable components which may include the metal powder of Ni and/or Fe, NaCl, AlCl3 and additives in the shape of the cathode compartment as shown in Figure 2A.

[0047] The cathode unit 44 further includes a plurality of longitudinal current collectors 60 for providing an electrical current pathway, and which are positioned within the cathode mass and axially extend from the separating member 28a. The longitudinal current collectors 60 are shaped as needle-like members which provide an electrical current pathway to the separating member 28a. Note that, the separating member 28a provides conductivity as well as serving as the separation between the anode compartment 42 (Figure 4) and the cathode material 30a. In example embodiments, the separating member 28a may be formed of a conductive material which includes nickel or nickel-plated steel which is corrosion resistant against the cathode material 30a and may be metallurgically joined for the junction 62, for example by welding. Alternatively, the multiple current collectors 60 can also be formed of a fibre structured carbon which is connected to the separating member 28a either directly (as shown) or alternatively through an electrically conducting and NaAlCl4 chemically resistant layer such as graphite foil 64. It can therefore be appreciated that the cathode unit 44 and the solid cathode material 30a may be preformed prior to stacking, and assembly with the sealing unit 46. It can also be appreciated that the cathode material 30a typically liquefies during operating temperature of the cell 22a (i.e., after assembly).

[0048] Referring now to Figure 3A, the sealing unit 46 used to assemble the interior cell 22a will now be described in greater detail. The sealing unit 46 may be prefabricated and includes a thin solid electrolyte 32a of β”-alumina or other ionically conductive ceramic and a cell wall 34a in the form of an α–alumina sealing ring (or other ceramic) which are sealed together using glass joint 36a. A weld ring 66 is also sealed to ceramic ring 48a by means of a glassed joint 68. The weld ring 66 is glass joined 68 to the cell wall 34a. In example embodiments, the glass joints 36a, 68 are joined in a glassing process which may be performed in a single curing or heating step.

[0049] Referring again to Figure 4, the prefabricated cathode unit 44 is assembled to the sealing unit 46. During assembly the separating member 28a is metallurgically joined to the weld ring 66 by welding at joint 62, using for example a laser beam. This step may for example be performed at a ambient temperature and/or under vacuum or low pressure. It can be appreciated that this step may avoid manufacturing conditions which require high temperature and/or high pressure, which could cause damage to the cathode material 30a. In example embodiments, at a subsequent stage the anode compartment 42 is evacuated.

[0050] The dimensions, the radius of curvature, and the support by the α–alumina cell wall 34a are designed to minimize bending stress in the electrolyte 32a so that the electrolyte 32a may have a minimal wall thickness. This minimal wall thickness allows a minimum contribution to cell internal resistance by the β”-alumina electrolyte. An example wall thickness of the electrolyte 32a is in the order of 0.1 millimetres. The glass joint 36a forms a hermetically leak-tight seal between the β”-alumina electrolyte 32a and cell wall 34a. In this configuration, the joint 36a is also exposed to the liquid anode material 40 and the cathode material 30a which has a liquid component, NaAlCl4, at operating temperature. The interface 38 may also include a glass seal 39 which during operation is exposed to a liquid anode material 40, for example liquid sodium, at operating temperature. For optimization of the corrosion resistance the joints 36a, 36b, 39 and 68 may use different material glass or recipes.

[0051] Reference is now made to Figure 5, which shows an anode end unit 26 in accordance with an example embodiment. As shown, the anode end unit 26 includes a cathode unit having the same construction as cathode unit 44 (Figure 2A). A sealing unit 73 is similar to sealing unit 46 in Figure 3A, except for the cell wall, wherein the cell wall 72 includes an α–alumina sealing ring and includes a flattened bottom. The cathode unit 44 is metallurgically joined (e.g. welded) via ring 66 and glass joint 68 to the cell wall 72 as described above. An insulating or ceramic end plate 74 (which may be formed of α-alumina) is glass joined to the cell wall 72 using a seal 76, which can be effected by laser, glassing or other suitable joint. The ceramic end plate 74 and the sealing unit 73 define an anode compartment 78 for housing of anode material 80. A positive terminal 82 formed of conductive material provides conductivity between the anode material 80 and external leads (not shown). The cathode end plate 74 is glass-joined to the cell wall 72 followed by welding of the cathode assembly 44 followed by insertion of the positive terminal 82 (which allows evacuation of the anode compartment 78).

[0052] Reference is now made to Figure 6, which shows a cathode end unit 24 in accordance with an example embodiment. As shown, the cathode end unit 24 includes the same cathode unit 44 (Figure 2A) and sealing unit 46 (Figure 3A). An insulating or ceramic end plate 92 is joined to the cathode unit 44 at seal 96, which can be effected by laser, glassing or other suitable joint. A negative terminal 94 formed of conductive material provides conductivity between the separating member 28a and external leads (not shown).

[0053] Referring now to Figure 1B, an assembly of the illustrated cell stack 20 will now be described. Referring to Figure 5, the assembly of the cell stack 20 is started with the anode end unit 26, having the ceramic end plate 74 and positive terminal 82. The sealing unit 73 is joined to the ceramic end plate 74 at seal 76. The cathode end unit 44 is then stacked to the sealing unit 73. Referring now to

Figure 4, the assembly is built up from interior cells 22 and repeated for "n" number of pre-determined cells 22. Finally, referring to Figure 6, the cathode end unit 24 is assembled at the cathode end of the stack 20. The alignment of the cell stack 20 is facilitated by the shapes and corresponding alignment features of the cell walls 34a, 34b. Accordingly, it can be appreciated that "n" can be a relatively large number because of these features.

[0054] Continuing with the assembly, the cell stack 20 may then be moved into a protective chamber having low and/or ambient pressure with one or more lasers positioned relative to the glass seals 39 at interface 38. Thus, it can be appreciated that this stage of the assembly process may avoid unnecessarily high surrounding temperature and/or pressures. At this stage the anode compartment 42 is evacuated. Multiple seals of the interface 38 may then be simultaneously or in a short sequence completed by the laser beams. Alternatively, cement can be applied to each seal at each interface 38 and cured simultaneously. In some example embodiments, no protruding cell connections are required between individual cells 22 and no voltage potential occurs outside the cell stack 20 except at the positive and negative terminals. The current flows through all cells 22 in the direction of the stack axis which is low resistive because of the large electric contact surface areas in each cell 22. It can be appreciated that the height and curvature of the electrolyte 32a, 32b offers a relatively larger surface area compared to a flat or slightly domed disc, thereby reducing the internal resistance.

[0055] In example embodiments, the cell wall 34a is formed as a unitary component. In other example embodiment, the cell wall 34a is formed from two or more separate parts which are attached or formed together.

[0056] Reference is now made to Figures 7A to 7D, which show a sealing unit 100 in accordance with another example embodiment. The sealing unit 100 may for example be assembled with a cathode unit (e.g., cathode unit 44 as shown in Figure 2A), and form a stack with other like units, in a manner similar to those example embodiments as described above. Generally, the sealing unit 100 includes a solid electrolyte 102 which includes a wave shape or wave shape surface area.

[0057] Referring to Figure 7C, as shown, the sealing unit 100 includes a cell wall 104 in the form of a shell or sealing ring which is sealed around the solid electrolyte 102, for example, using a glass seal 106. The cell wall 104 may be formed of electrical and/or ionic insulating material. An anode compartment 110 can contain a simplex or multiplex carbon felt, as described above.

[0058] As best shown in Figure 7D, the solid electrolyte 102 may include a three-dimensional dome shape, including an apex 108. The solid electrolyte 102 further includes a wave shape or surface area. In the example embodiment shown, the wave shape proceeds angularly around the three-dimensional dome shape, with respect to the apex 108. The wave shape may also be periodic, as shown. The wave shape may also have either a constant amplitude (as shown) or have varying amplitudes.

[0059] In an alternate embodiment (not shown), the wave shape extends radially outward from the apex 108 of the solid electrolyte 102, similar to a ripple caused by a stone in a puddle.

[0060] It can be appreciated that the wave shape of the solid electrolyte 102 increases the amount of electric contact surface area exposed to the cathode material (not shown), and therefore assists in increased power production and distribution during cell cycling. The wave shape yields a larger surface area and can provide lower ionic resistance.

[0061] In some example embodiments, referring still to Figure 7D, the solid electrolyte 102 includes a relatively high angular frequency (low period) when compared to the main curvature of the three-dimensional dome shape. Accordingly, the main curvature primarily provides the structural integrity of the solid electrolyte 102 during cell charge-discharge cycling, especially when the anode compartment 110 (Figure 7C) or concave side has relatively low pressure.

[0062] In some example embodiments, the wave shape of the solid electrolyte 102 may be fluted (as shown), zig-zag, sinusoidal, rippled, corrugated, triangular-wave, etc.

[0063] Variations may be made to example embodiments. In various example embodiments, suitable materials for the solid electrolyte include sodium beta-alumina, sodium beta"-alumina, and NaSICON and/or conductive glass.

[0064] In various example embodiments, suitable materials for the separating member include nickel, nickel-plated steel, and/or chromized steel.

[0065] In various example embodiments, suitable materials for the cathode material include NaCl/Fe-Ni, and sulfur materials.

[0066] Although example embodiments have been described as being cylindrically symmetrical, it can be appreciated that other cross-sectional shapes may be used in other example embodiments, for example rounded-cornered square or rectangle. Accordingly, reference to "radial" herein can likewise apply to any transverse axis or direction, as would be understood in the art.

[0067] It can be appreciated that some example embodiments described herein may simplify the cell design, reduce the number of components to a functional minimum, to apply simplified and reliable ceramic to ceramic, ceramic to metal, and metal to metal joining processes, and to improve the safety of the cell by eliminating voltage carrying parts on the outside of the cell. Example embodiments may provide a strong robust cell assembly that is capable of withstanding the stresses of battery operation and of cell charge-discharge cycling. Example embodiments may further provide for a substantially increased electrolyte/electrode interfacial surface area in a bipolar cell configuration.

[0068] It can further be appreciated that in some example embodiments battery safety is increased since each cell of the cell stack is formed from sealed and/or interlocking insulating outer cell walls with no exposed metal parts.

[0069] It can further be appreciated that in some example embodiments ease of assembly may be facilitated by the use of glass joining and laser-welding, and construction from prefabricated cell components and solid cathode structures.

[0070] It can further be appreciated that in some example embodiments cell performance may be improved by the use of sharply arched solid electrolyte and bipolar separator plates that result in high surface areas in relation to the volume enclosed.

[0071] It can further be appreciated that in some example embodiments cell reliability may be provided by the use of a mechanically strong design for the solid electrolyte assembly that withstands the varying electrode pressures during charge-discharge cycling.

[0072] It can further be appreciated that in some example embodiments the described cell is orientation agnostic, i.e., it can operate similarly in horizontal or vertical orientations.

[0073] Certain adaptations and modifications of the described embodiments can be made. Therefore, the above discussed embodiments are considered to be illustrative and not restrictive.

[0074] Variations may be made to some example embodiments, which may include combinations and sub-combinations of any of the above. The various embodiments presented above are merely examples and are in no way meant to limit the scope of this disclosure. Variations of the innovations described herein will be apparent to persons of ordinary skill in the art, such variations being within the intended scope of the present disclosure. In particular, features from one or more of the above-described embodiments may be selected to create alternative embodiments comprised of a sub-combination of features which may not be explicitly described above. In addition, features from one or more of the above-described embodiments may be selected and combined to create alternative embodiments comprised of a combination of features which may not be explicitly described above. Features suitable for such combinations and sub-combinations would be readily apparent to persons skilled in the art upon review of the present disclosure as a whole. The subject matter described herein intends to cover and embrace all suitable changes in technology.

WHAT IS CLAIMED IS:

1. An electrochemical cell for axial assembly with a corresponding electrochemical cell to form a stack, comprising:

a conductive separating member;

a cathode material adjoined to said conductive separating member;

a solid electrolyte adjoined to said cathode material; and

an electrically insulating cell wall sealed around said solid electrolyte and configured to join axially at an interface with a corresponding cell wall of said corresponding electrochemical cell in said stack, said cell wall and corresponding cell wall being dimensioned to surround collectively an entire perimeter of said interface.

2. The electrochemical cell as claimed in claim 1, wherein said cell wall and said corresponding cell wall overlap at said interface.

3. The electrochemical cell as claimed in claims 1 or 2, wherein at said interface said cell wall or said corresponding cell wall includes a flange member and the other of said cell wall or said corresponding cell wall defines a corresponding groove.

4. The electrochemical cell as claimed in any one of claims 1 to 3, wherein said interface includes a glass seal.

5. The electrochemical cell as claimed in any one of claims 1 to 4, wherein said solid electrolyte and said corresponding electrochemical cell define an anode compartment there between when said cell wall and corresponding cell wall are joined.

6. The electrochemical cell as claimed in any one of claims 1 to 5, wherein an interior of said cell wall includes a protruding lip for sealing with said solid electrolyte.

7. The electrochemical cell as claimed in any one of claims 1 to 6, further comprising a plurality of longitudinal current collectors for providing an electrical current pathway positioned within said cathode material and which are axially extending from said conductive separating member.

8. The electrochemical cell as claimed in any one of claims 1 to 7, wherein the electrochemical cell is assembled from an assembly, said assembly including:

a cathode unit including said conductive separating member and said cathode material; and

a sealing unit for assembly with said cathode unit including said solid electrolyte and said cell wall.

9. The electrochemical cell as claimed in claim 8, wherein said cathode material includes a solid cathode material preformed prior to assembly with said sealing unit.

10. The electrochemical cell as claimed in claim 9, wherein said sealing unit includes a weld member joined to said cell wall at said interface, wherein said cathode unit is sealed at said interface to said sealing unit by welding said conductive separating member to said weld member.

11. The electrochemical cell as claimed in claim 10, wherein said welding is performed at low pressure, ambient pressure or evacuated.

12. The electrochemical cell as claimed in any one of claims 1 to 11, wherein said solid electrolyte is shaped to include a dome shape.

13. The electrochemical cell as claimed in claim 12, wherein said solid electrolyte includes a basal radius and a height dimensioned to be at least the basal radius.

14. The electrochemical cell as claimed in any one of claims 1 to 13, wherein said cell wall includes an alpha alumina material.

15. A method of assembling an electrochemical cell, comprising:

forming a solid cathode material;

adjoining said solid cathode material to a conductive separating member;

sealing an electrically insulating cell wall around a solid electrolyte; and

assembling said conductive separating member to said cell wall to adjoin said solid cathode material to said solid electrolyte.

16. The method as claimed in claim 15, further comprising axially joining said cell wall to a corresponding electrochemical cell to define an anode compartment between said solid electrolyte and said corresponding electrochemical cell.

17. The method as claimed in claim 16, further comprising evacuating said anode compartment.

18. The method as claimed in claim 16, wherein said axially joining is performed at low ambient pressure or vacuum.

19. The method as claimed in any one of claims 15 to 18, wherein said assembling of said conductive separating member to said cell wall is performed at low ambient pressure or vacuum.

20. An electrochemical cell, comprising:

a conductive separating member;

a cathode material adjoined to said conductive separating member;

a solid electrolyte adjoined to said cathode material, said solid electrolyte being shaped to include a dome shape having a basal radius and a height dimensioned to be at least said basal radius; and

a cell wall sealed around said solid electrolyte at said basal radius.

21. An electrochemical cell as claimed in claim 20, wherein said solid electrolyte includes, at an apex of said dome shape, a radius of curvature at least a same or smaller than said basal radius of said solid electrolyte.

22. An electrochemical cell as claimed in claim 20, wherein said dome shape includes a profile of the function $y = a \cosh(r/a)$, wherein "r" is said basal radius and "a" is a constant.

23. An electrochemical cell as claimed in claim 22, wherein said constant "a" is at least 10.

24. An electrochemical cell as claimed in any one of claims 20 to 23, wherein an interior of said cell wall includes a protruding lip for sealing with said solid electrolyte.

25. An electrochemical cell as claimed in any one of claims 20 to 24, wherein said cell wall is shaped to continue generally said dome shape of said solid electrolyte.

26. An electrochemical cell as claimed in claim 25, wherein said cell wall includes a leg member to continue generally said dome shape.

27. An electrochemical cell as claimed in any one of claims 20 to 26, wherein said conductive separating member and cathode material are dome shaped to correspond generally to said dome shape of said solid electrolyte.

28. An electrochemical cell as claimed in claim 27, wherein at least a portion of said conductive separating member and cathode material are shaped to protrude axially beyond said cell wall.

29. An electrochemical cell as claimed in claim 28, wherein said cell wall is configured to join axially at an interface with a corresponding cell wall of a corresponding electrochemical cell to form a stack, said corresponding cell wall surrounding said at least a portion of said conductive separating member and said cathode material when joined at said interface.

30. An electrochemical cell as claimed in claim 29, wherein said at least a portion of said conductive separating member protrudes to assist in aligning axially said cell wall to said corresponding cell wall.

31. An electrochemical cell as claimed in any one of claims 20 to 30, wherein the solid electrolyte includes a wave shape.

32. An electrochemical cell as claimed in claim 31, wherein the wave shape proceeds angularly around said dome shape of the solid electrolyte.

33. An electrochemical cell as claimed in claim 31, wherein the wave shape includes a wave shaped surface area facing the cathode material.

34. An electrochemical cell as claimed in claim 31, wherein the wave shape is periodic.

AMENDED CLAIMS
received by the International Bureau on
21 July 2011 (21.07.11)

WHAT IS CLAIMED IS:

1. An electrochemical cell for axial assembly with a corresponding electrochemical cell to form a stack, comprising:

a conductive separating member;

a cathode material adjoined to said conductive separating member;

a solid electrolyte adjoined to said cathode material; and

an electrically insulating cell wall sealed around said solid electrolyte and configured to join axially at an interface with a corresponding cell wall of said corresponding electrochemical cell in said stack, said cell wall and corresponding cell wall being dimensioned to surround collectively said conductive separating member and an entire perimeter of said interface.

2. The electrochemical cell as claimed in claim 1, wherein said cell wall and said corresponding cell wall overlap at said interface.

3. The electrochemical cell as claimed in claims 1 or 2, wherein at said interface said cell wall or said corresponding cell wall includes a flange member and the other of said cell wall or said corresponding cell wall defines a corresponding groove.

4. The electrochemical cell as claimed in any one of claims 1 to 3, wherein said interface includes a glass seal.

5. The electrochemical cell as claimed in any one of claims 1 to 4, wherein said solid electrolyte and said corresponding electrochemical cell define an anode compartment there between when said cell wall and corresponding cell wall are joined.

6. The electrochemical cell as claimed in any one of claims 1 to 5, wherein an interior of said cell wall includes a protruding lip for sealing with said solid electrolyte.

7. The electrochemical cell as claimed in any one of claims 1 to 6, further comprising a plurality of longitudinal current collectors for providing an electrical current pathway positioned within said cathode material and which are axially extending from said conductive separating member.

8. The electrochemical cell as claimed in any one of claims 1 to 7, wherein the electrochemical cell is assembled from an assembly, said assembly including:

a cathode unit including said conductive separating member and said cathode material; and

a sealing unit for assembly with said cathode unit including said solid electrolyte and said cell wall.

9. The electrochemical cell as claimed in claim 8, wherein said cathode material includes a solid cathode material preformed prior to assembly with said sealing unit.

10. The electrochemical cell as claimed in claim 9, wherein said sealing unit includes a weld member joined to said cell wall at said interface, wherein said cathode unit is sealed at said interface to said sealing unit by welding said conductive separating member to said weld member.

11. The electrochemical cell as claimed in claim 10, wherein said welding is performed at low pressure, ambient pressure or evacuated.

12. The electrochemical cell as claimed in any one of claims 1 to 11, wherein said solid electrolyte is shaped to include a dome shape.

13. The electrochemical cell as claimed in claim 12, wherein said solid electrolyte includes a basal radius and a height dimensioned to be at least the basal radius.

14. The electrochemical cell as claimed in any one of claims 1 to 13, wherein said cell wall includes an alpha alumina material.

15. A method of assembling an electrochemical cell, comprising:

forming a solid cathode material;

adjoining said solid cathode material to a conductive separating member;

sealing an electrically insulating cell wall around a solid electrolyte, wherein the electrically insulating cell wall surrounds the solid electrolyte;

assembling said conductive separating member to said cell wall to adjoin said solid cathode material to said solid electrolyte; and

axially joining said cell wall to a corresponding electrochemical cell to form a stack.

16. The method as claimed in claim 15, wherein said axially joining defines an anode compartment between said solid electrolyte and said corresponding electrochemical cell.

17. The method as claimed in claim 16, further comprising evacuating said anode compartment.

18. The method as claimed in claim15, wherein said axially joining is performed at low ambient pressure or vacuum.

19. The method as claimed in any one of claims 15 to 18, wherein said assembling of said conductive separating member to said cell wall is performed at low ambient pressure or vacuum.

20. An electrochemical cell, comprising:

a conductive separating member;

a cathode material adjoined to said conductive separating member;

a solid electrolyte adjoined to said cathode material, said solid electrolyte being shaped as a dome shape having a basal radius and a height dimensioned to be at least said basal radius; and a cell wall sealed around said solid electrolyte at said basal radius.

21. An electrochemical cell as claimed in claim 20, wherein said solid electrolyte includes, at an apex of said dome shape, a radius of curvature at least a same or smaller than said basal radius of said solid electrolyte.

22. An electrochemical cell as claimed in claim 20, wherein said dome shape includes a profile of the function y = a cosh(r/a), wherein "r" is said basal radius and "a" is a constant.

23. An electrochemical cell as claimed in claim 22, wherein said constant "a" is at least 10.

24. An electrochemical cell as claimed in any one of claims 20 to 23, wherein an interior of said cell wall includes a protruding lip for sealing with said solid electrolyte.

25. An electrochemical cell as claimed in any one of claims 20 to 24, wherein said cell wall is shaped to continue generally said dome shape of said solid electrolyte.

26. An electrochemical cell as claimed in claim 25, wherein said cell wall includes a leg member to continue generally said dome shape.

27. An electrochemical cell as claimed in any one of claims 20 to 26, wherein said conductive separating member and cathode material are dome shaped to correspond generally to said dome shape of said solid electrolyte.

28. An electrochemical cell as claimed in claim 27, wherein at least a portion of said conductive separating member and cathode material are shaped to protrude axially beyond said cell wall.

29. An electrochemical cell as claimed in claim 28, wherein said cell wall is configured to join axially at an interface with a corresponding cell wall of a corresponding electrochemical cell to form a stack, said corresponding cell wall

surrounding said at least a portion of said conductive separating member and said cathode material when joined at said interface.

30. An electrochemical cell as claimed in claim 29, wherein said at least a portion of said conductive separating member protrudes to assist in aligning axially said cell wall to said corresponding cell wall.

31. An electrochemical cell as claimed in any one of claims 20 to 30, wherein the solid electrolyte includes a wave shape.

32. An electrochemical cell as claimed in claim 31, wherein the wave shape proceeds angularly around said dome shape of the solid electrolyte.

33. An electrochemical cell as claimed in claim 31, wherein the wave shape includes a wave shaped surface area facing the cathode material.

34. An electrochemical cell as claimed in claim 31, wherein the wave shape is periodic.

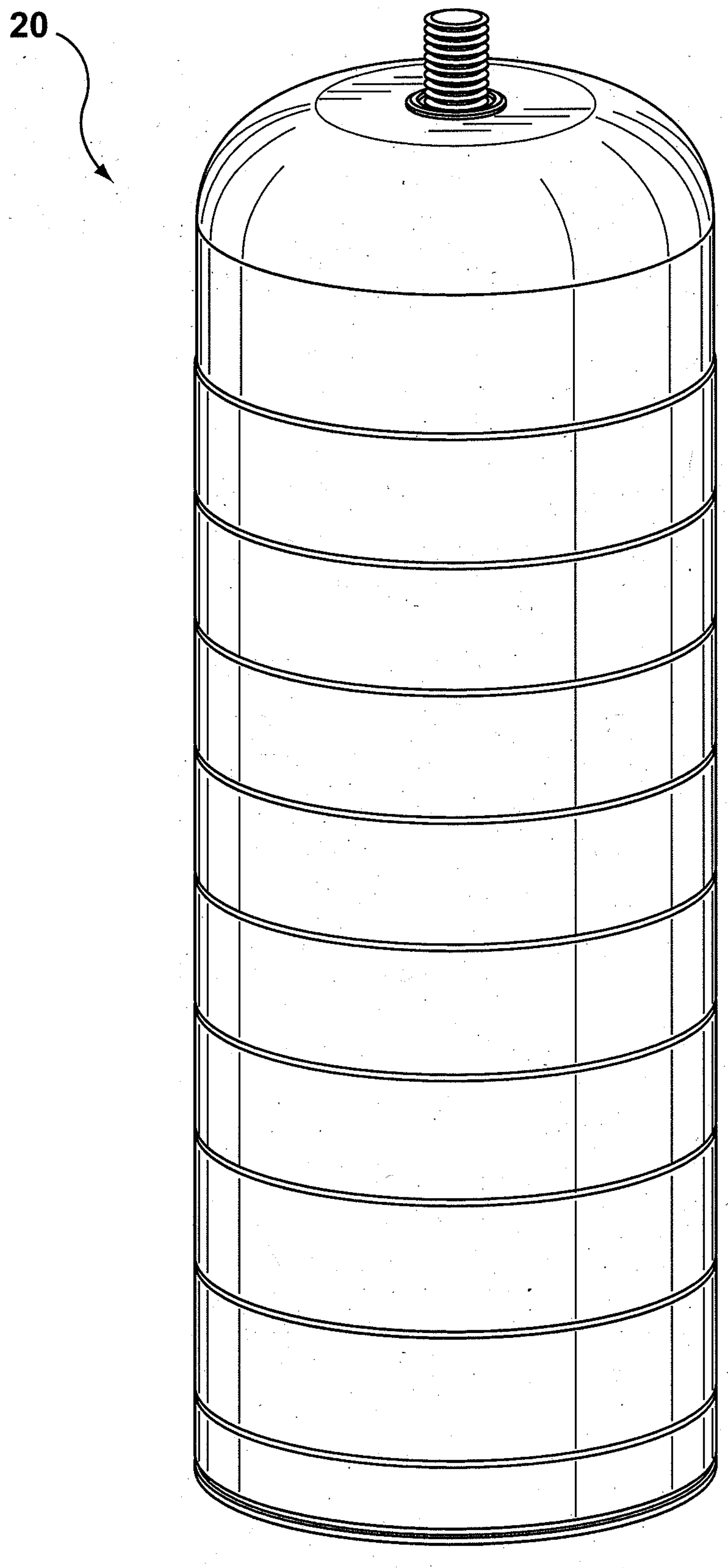


FIG. 1A

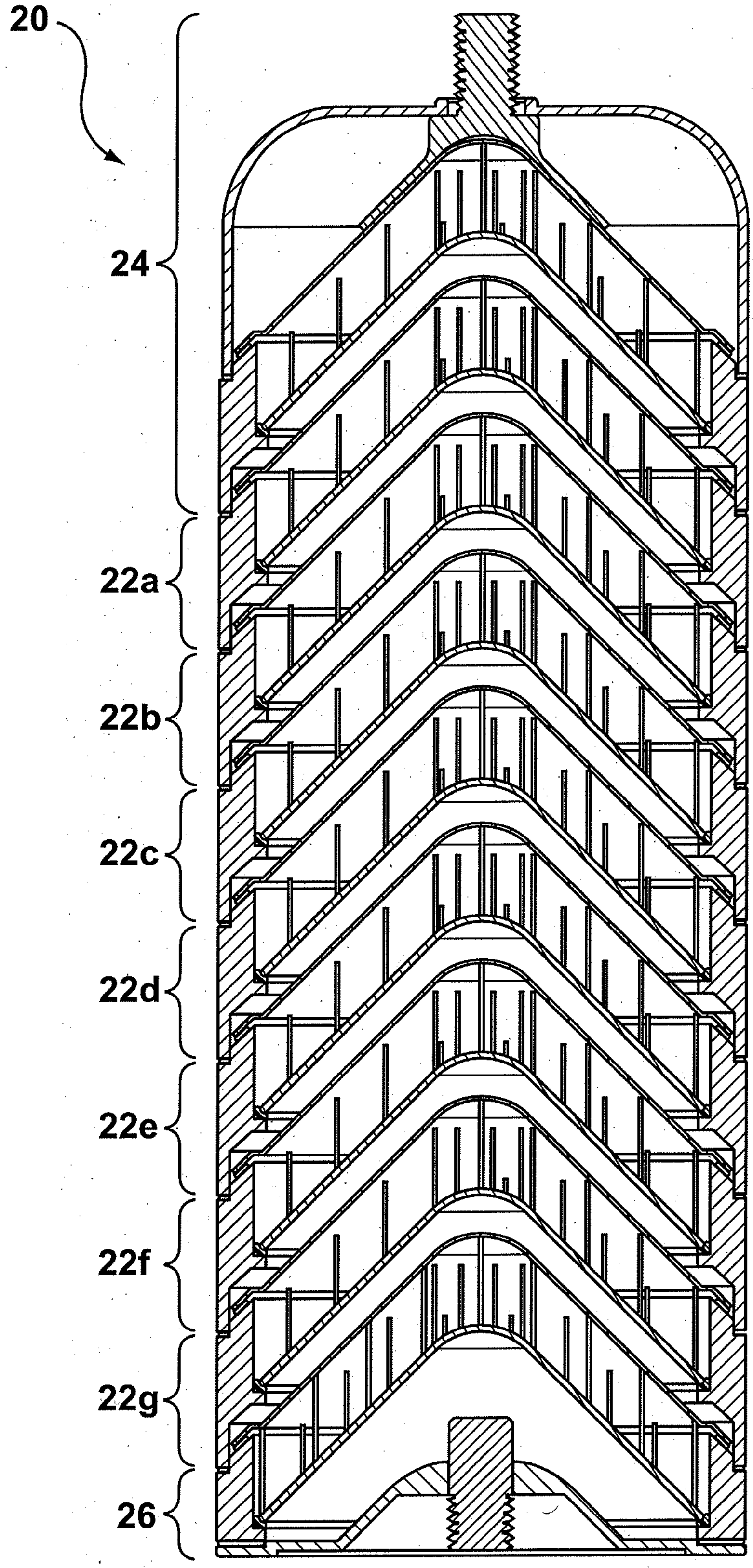


FIG. 1B

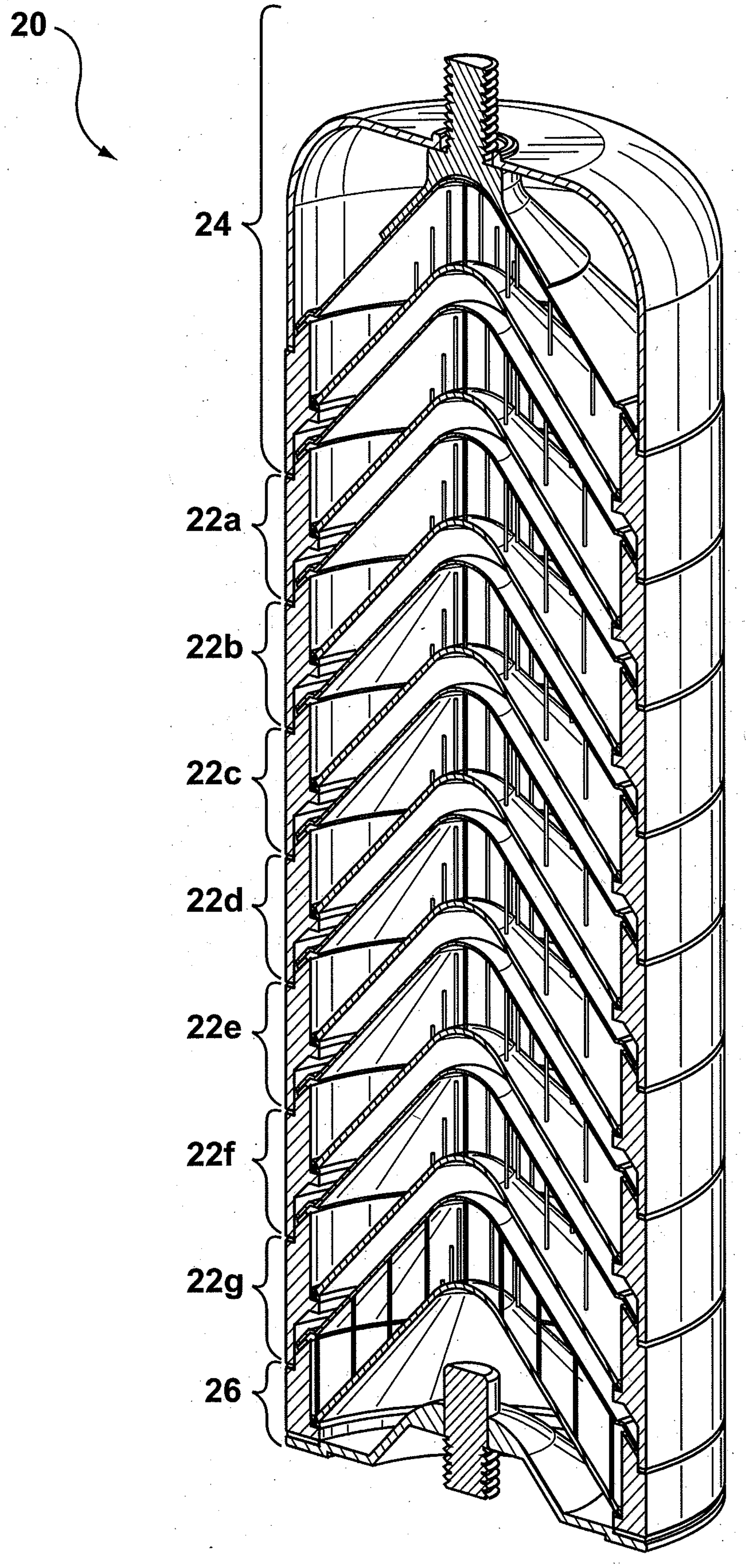


FIG. 1C

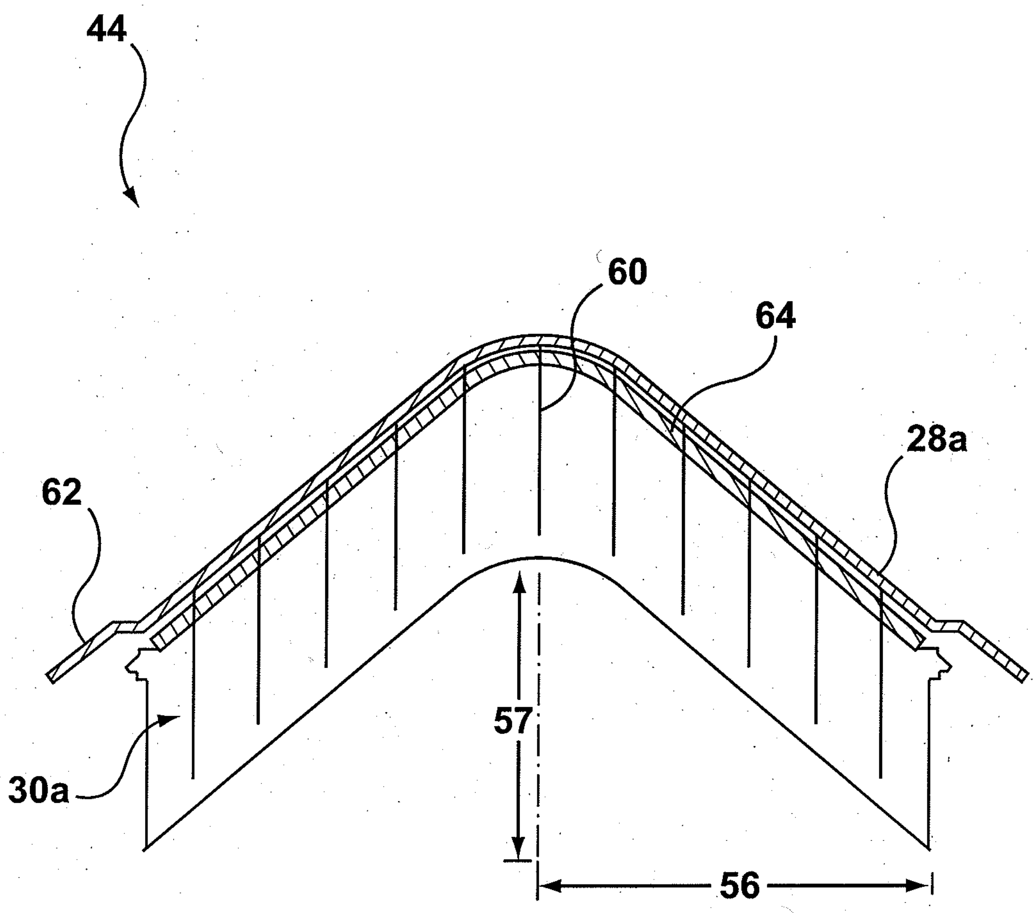


FIG. 2A

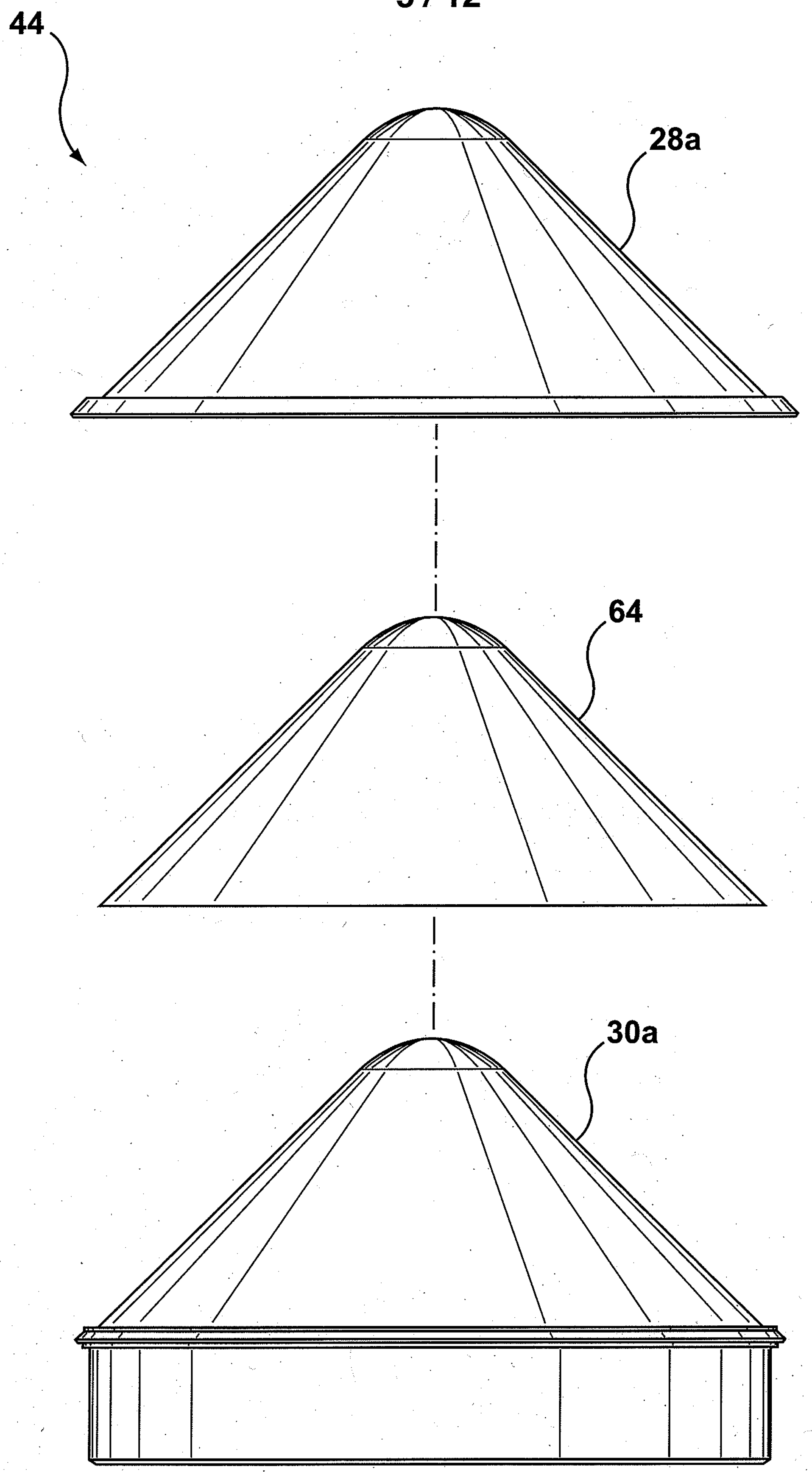


FIG. 2B

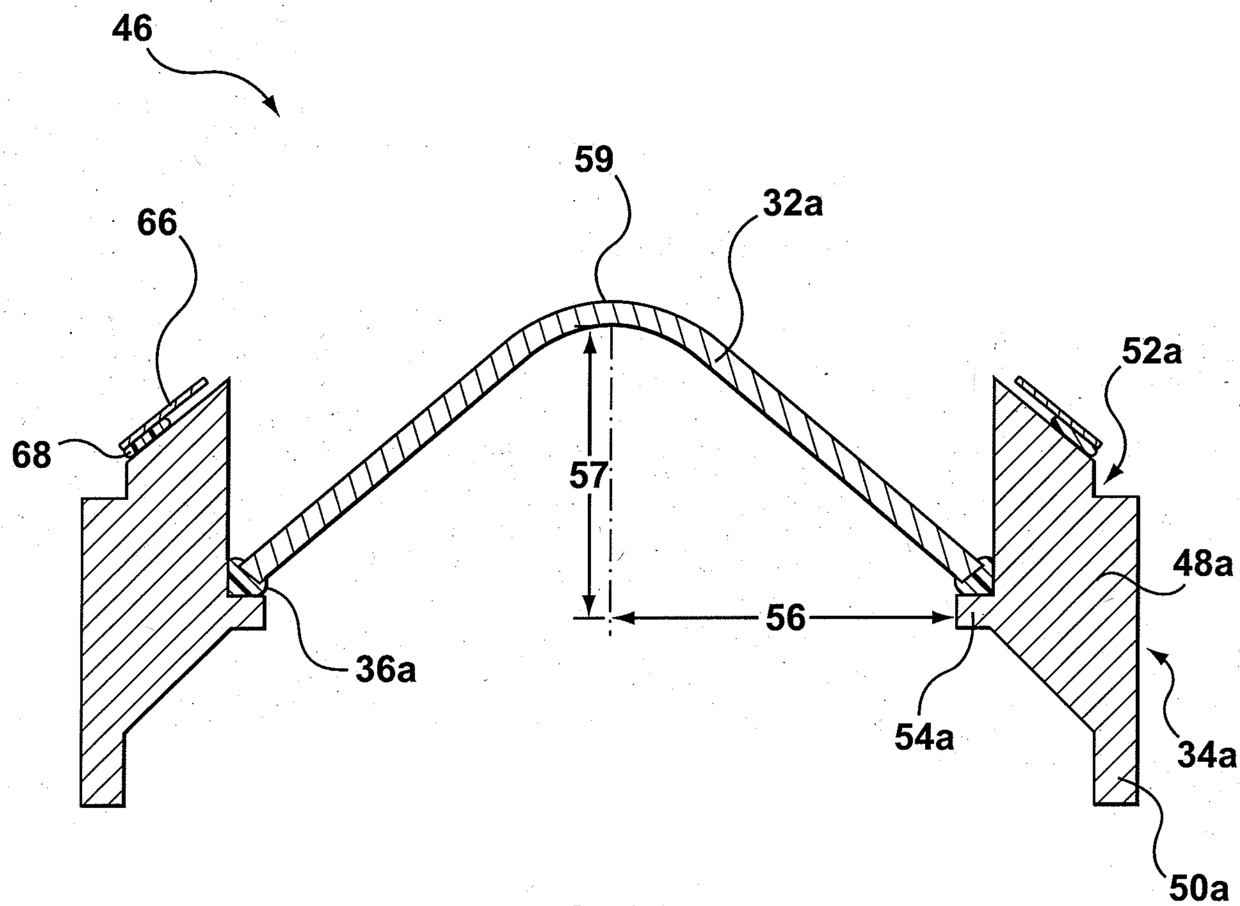


FIG. 3A

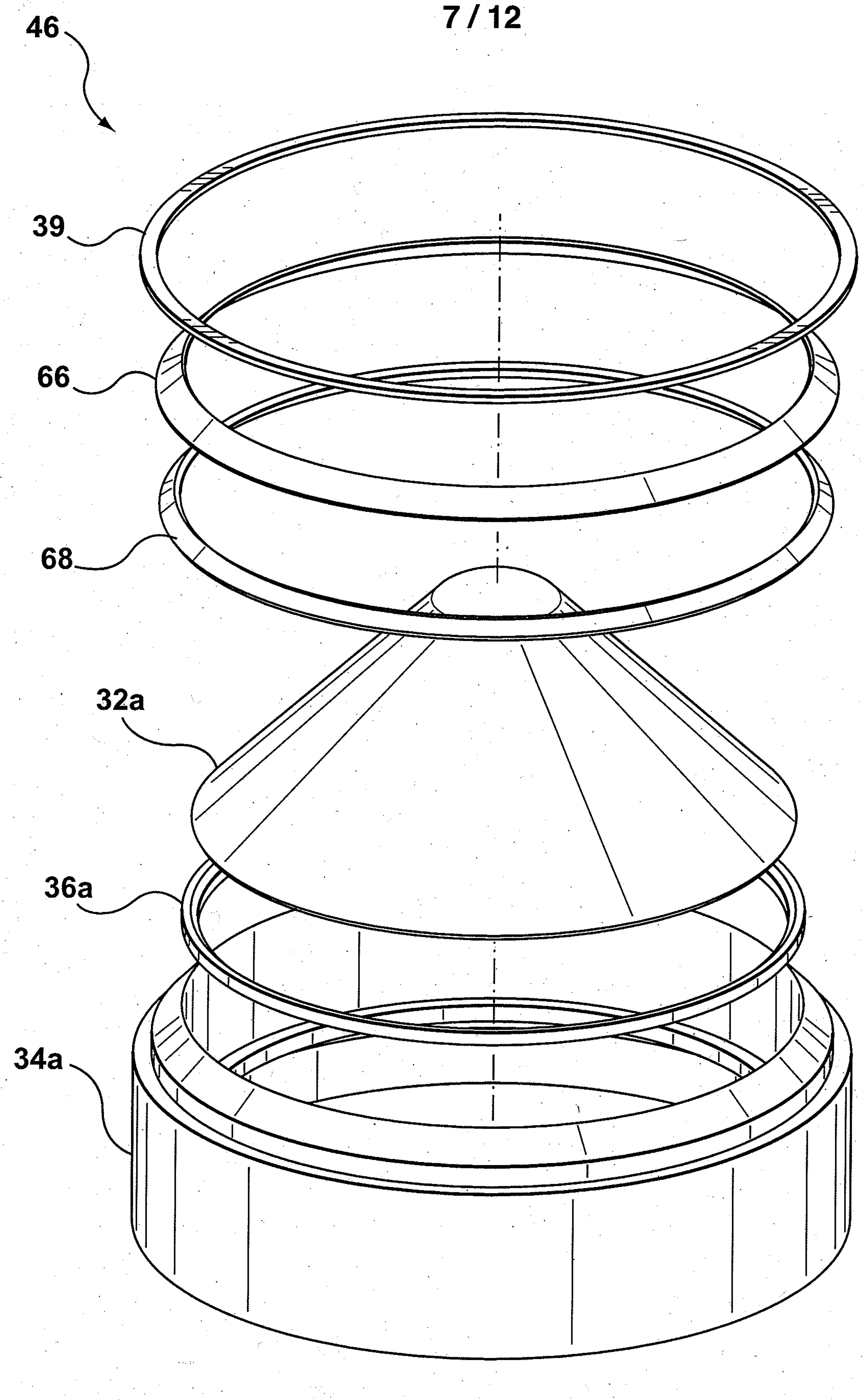
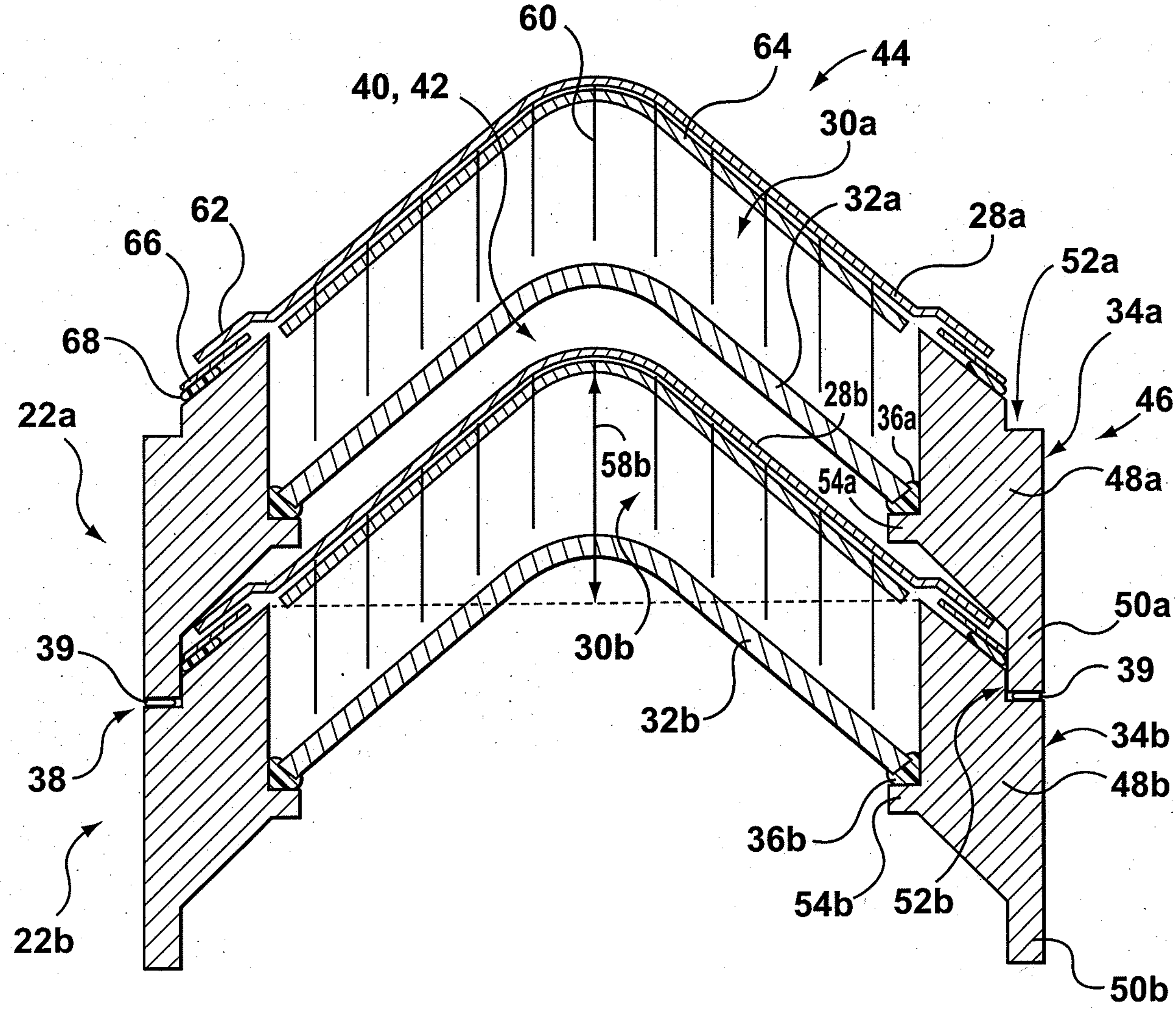


FIG. 3B


60
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58b
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54b
52b
50b

FIG. 4

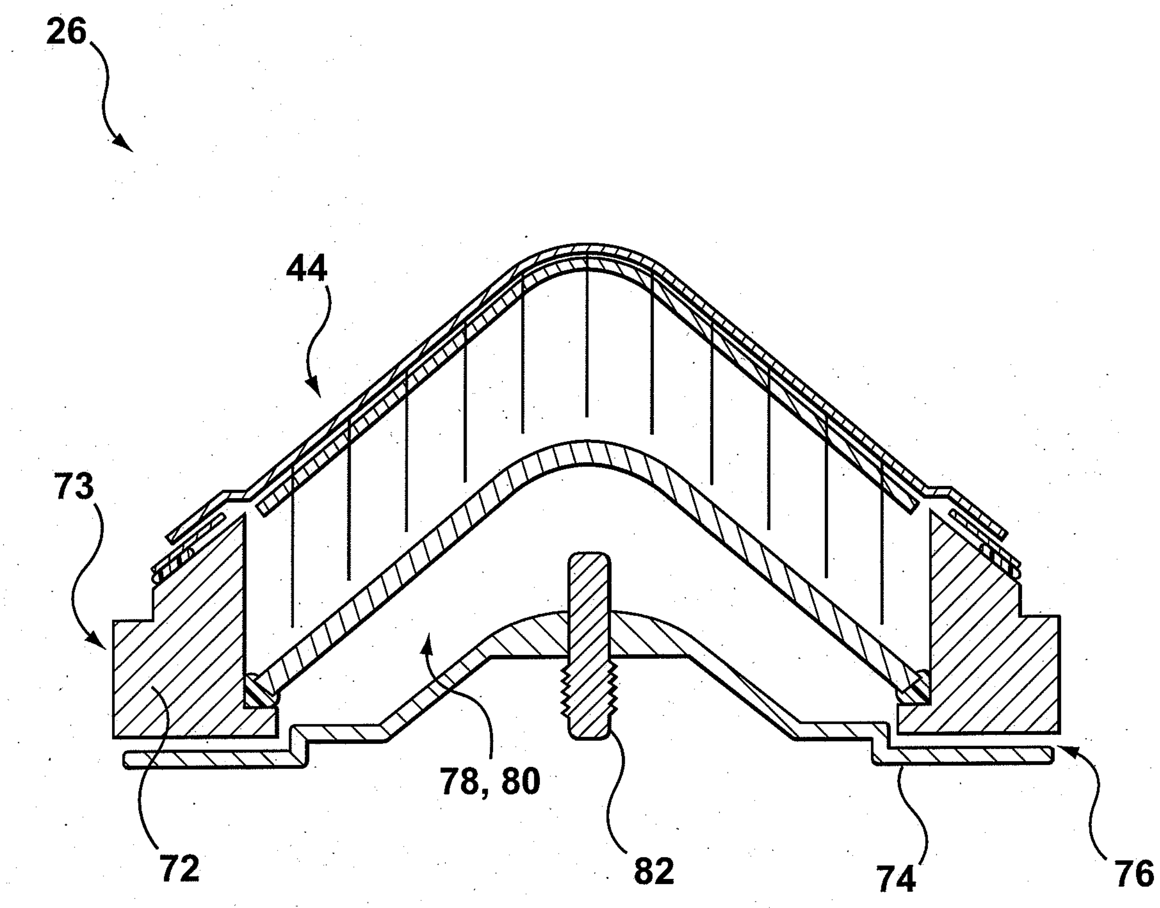

FIG. 5

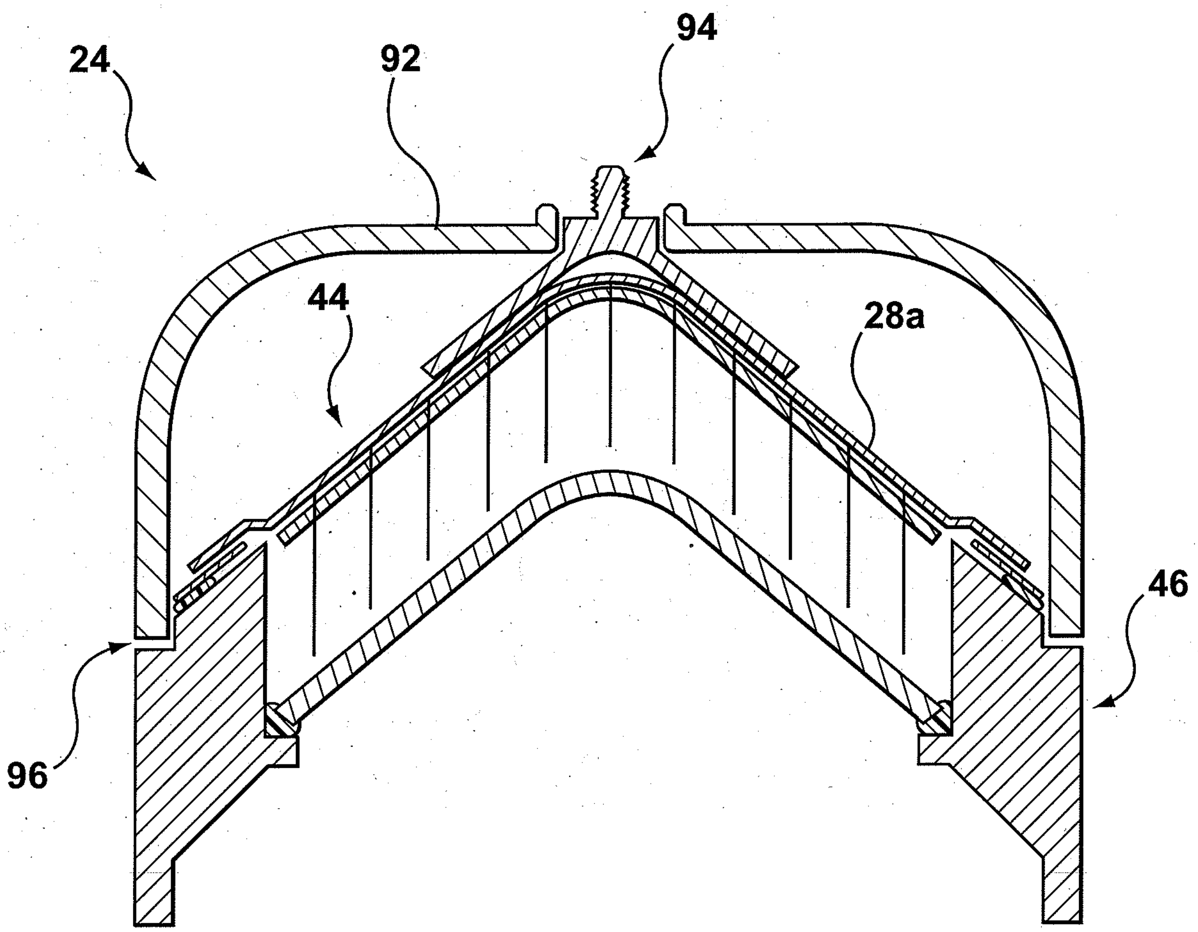

FIG. 6

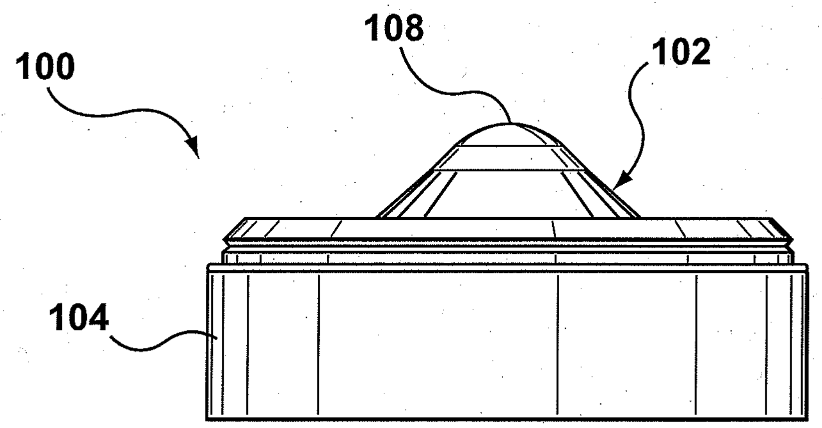

FIG. 7A

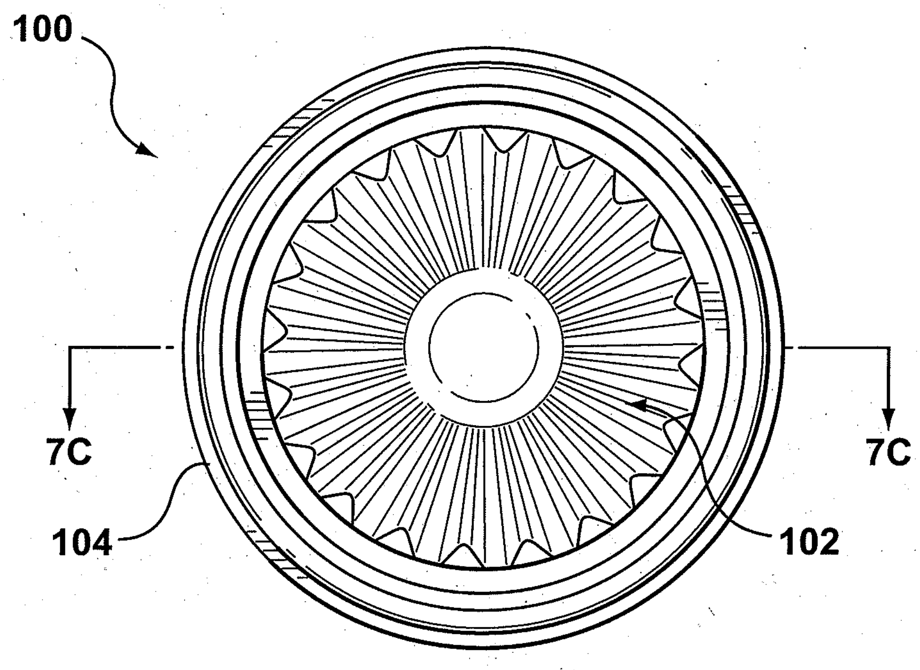

FIG. 7B

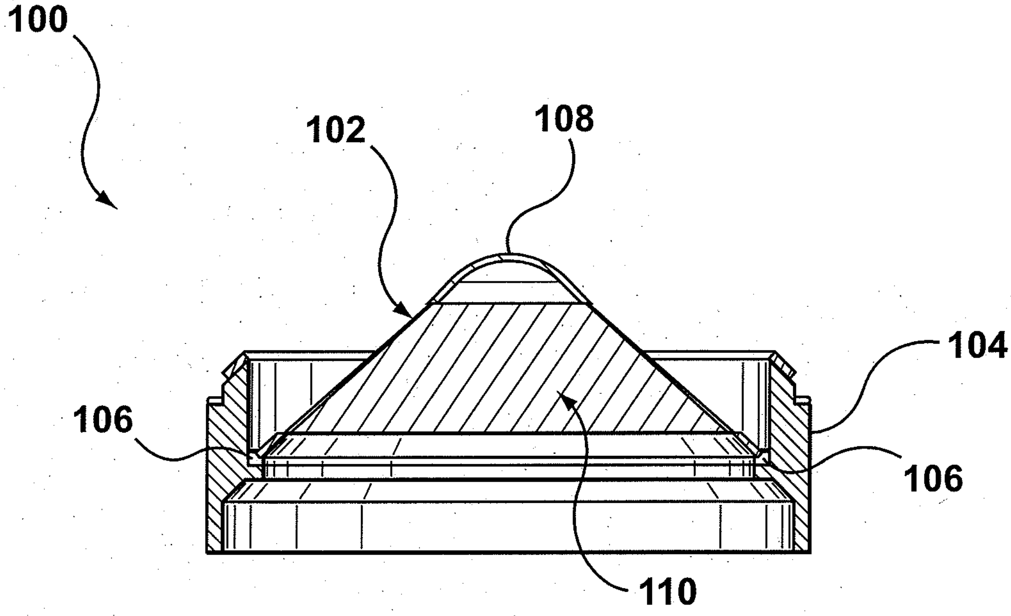

FIG. 7C

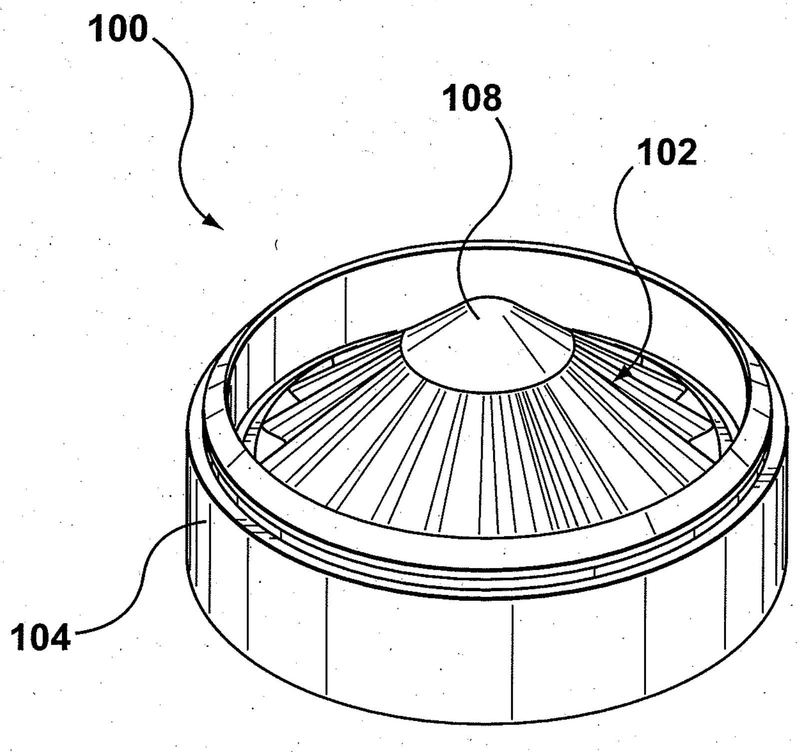

FIG. 7D

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2010/001355

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***H01M 10/058*** (2010.01) , ***H01M 6/18*** (2006.01) , ***H01M 6/44*** (2006.01)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (2010.01): H01M 10/058
IPC (2006.01): H01M 6/18, H01M 6/44, H01M 10/38

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Databases: EPOQUE (Epodoc, English Full-Text), TotalPatent, Canadian Patent Database, SCOPUS
Keywords: cell, battery, stack, separating member, bipolar, bi-polar, cathode, positive, solid electrolyte, wall, case, dome, cone

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5,053,294 (SERNKA et al.) 1 October 1991 (01-10-1991) *whole document*	1-14 15-34
X A	US 3,783,024 (GIBSON et al.) 1 January 1974 (01-01-1974) *whole document*	1-14 15-34
X A	US 4,894,299 (MORSE) 16 January 1990 (16-01-1990) *whole document*	1-14, 20-34 15-19
X	GB 1,508,803 (EVANS et al.) 26 April 1978 (26-04-1978) *whole document*	1-34
X A	US 2009/0233164 A1 (SHIMAMURA et al.) 17 September 2009 (17-09-2009) *whole document*	1-19 20-34
A	GB 617,669 (JOHNSON) 9 February 1949 (09-02-1949) *whole document*	1-34

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

*	Special categories of cited documents :	"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
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent but published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
10 May 2011 (10-05-2011)	24 May 2011 (24-05-2011)

Name and mailing address of the ISA/CA	Authorized officer
Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Philip Gbor (819) 934-9091

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 726,008 (PERTRIX-UNION G.M.B.H.) 16 March 1955 (16-03-1955) *whole document*	1-34
A	GB 2,050,042 (CATTLE) 31 December 1980 (31-12-1980) *whole document*	1-34
A	US 5,837,110 (DEAN) 17 November 1998 (17-11-1998) *whole document*	1-34
A	US 2009/0142655 A1 (WEST et al.) 4 June 2009 (04-06-2009) *whole document*	1-34

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

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

1. [ ] Claim Nos. :
   because they relate to subject matter not required to be searched by this Authority, namely :

2. [ ] Claim Nos. :
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically :

3. [ ] Claim Nos. :
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

See extra sheet

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

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

Continuation of Box No. III

The International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims 1-14

Invention 1 concerns an electrochemical cell for axial assembly with a corresponding electrochemical cell to form a stack, comprising: a conductive separating member; a cathode material adjoined to said conductive separating member; a solid electrolyte adjoined to said cathode material; and an electrically insulating cell wall sealed around said solid electrolyte and configured to join axially at an interface with a corresponding cell wall of said corresponding electrochemical cell in said stack, said cell wall and corresponding cell wall being dimensioned to surround collectively an entire perimeter of said interface.

2. Claims 15-19

Invention 2 concerns a method of assembling an electrochemical cell, comprising: forming a solid cathode material; adjoining said solid cathode material to a conductive separating member; sealing an electrically insulating cell wall around a solid electrolyte; and assembling said conductive separating member to said cell wall to adjoin said solid cathode material to said solid electrolyte.

3. Claims 20-34

Invention 3 concerns an electrochemical cell, comprising: a conductive separating member; a cathode material adjoined to said conductive separating member; a solid electrolyte adjoined to said cathode material, said solid electrolyte being shaped to include a dome shape having a basal radius and a height dimensioned to be at least said basal radius; and a cell wall sealed around said solid electrolyte at said basal radius.

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		DE2157939C3	07 November 1974 (07-11-1974)
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		WO2006062204A1	15 June 2006 (15-06-2006)
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		NL177738B	
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		GB2050042B	20 October 1982 (20-10-1982)

Continued in Extra Sheet.

Continuation of patent family annex

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		CN101971406A	09 February 2011 (09-02-2011)
		EP2215683A2	11 August 2010 (11-08-2010)
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		WO2009055073A2	30 April 2009 (30-04-2009)
		WO2009055073A3	13 August 2009 (13-08-2009)