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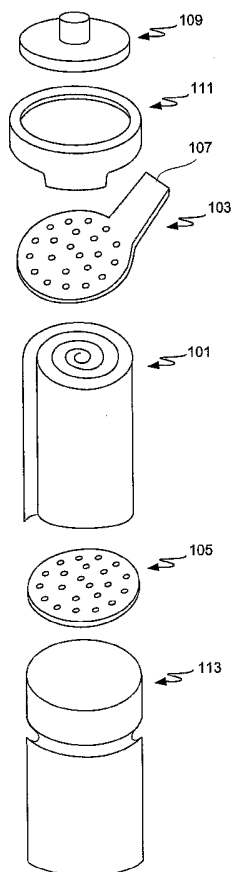
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(54) Title: NICKEL ZINC BATTERY DESIGN



(57) Abstract: Nickel zinc cylindrical battery cell designs are described. The designs provided limit dendrite formation and prevent build up of hydrogen gas in the cell. The present invention also provides low-impedance cells required by rapid discharge applications. The cylindrical battery cells may have polarity opposite of that of conventional power cells, with a negative cap and positive can. The cylindrical cells may include a gel electrolyte reservoir.



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NICKEL ZINC BATTERY DESIGN

BACKGROUND

Field of the Invention

5 **[0001]** The present invention relates to the rechargeable battery arts and more particularly to nickel zinc rechargeable battery design.

Description of the Related Art

10 **[0002]** The advent of portable communication and computation devices that allow diverse mobile connectivity has fueled growth and innovation in the rechargeable battery field. Increased capacity and power has made possible the entry of rechargeable power sources in various fields including the power tool arena. Because power tools typically have large current demands, rechargeable power sources have necessarily evolved to accommodate rapid discharge characteristics. It can be
15 appreciated that the present invention will also find use in applications other than power tools such as Uninterruptible Power Supplies (UPS), Electric Vehicles, and high demand consumer electronics – all of which require high carrying capacity and current discharging ability. Of course, the invention also applies to relatively lower discharge rate applications such as many mainstream consumer electronics
20 applications.

25 **[0003]** Because of the hazardous nature of some of the commonly used materials for conventional rechargeable power sources, it would be desirable to manufacture a rechargeable power source that reduces the quantity of any potentially hazardous materials. In particular, it would be desirable to find a substitute for the widely used nickel cadmium (NiCd) battery cell.

30 **[0004]** The rechargeable nickel zinc (NiZn) cells provide a power-to-weight ratio comparable to and even exceeding nickel cadmium cells at a reasonable cost. However, nickel zinc battery technology has not been widely deployed in part because it has been found to have a relatively limited cycle life. In other words, a given nickel zinc cell can only charge and discharge for a fraction of the cycles typically attained with a comparable nickel cadmium cell. This is due to zinc distribution and dendrite formation. Various advances in electrolyte composition and other chemistry

improvements have reduced these issues, but they remain an important consideration in cell design.

[0005] The negative thermodynamic potential of zinc relative to cadmium and the metal hydride electrode, while allowing NiZn batteries to provide more power density than NiCd and Ni-metal hydride batteries, presents additional issues that are not addressed by conventional battery designs. First, nickel zinc batteries are more likely to evolve hydrogen. In addition, the main conductive paths associated with the negative electrode in conventional NiCd batteries are nickel plated steel. Nickel plated steel is not compatible with the negative zinc electrode.

[0006] There is a need therefore for a nickel zinc battery design that takes advantage of the improved performance offered by the battery chemistry, yet has a long cycle life, is able to prevent hydrogen build-up, and address various other challenges.

SUMMARY

[0007] The present invention realizes the advantages described above by providing a nickel zinc battery design that, in one or more aspects, limits dendrite formation, allows for low impedance copper conductive paths and limits build up of hydrogen gas in the cell. The present invention also provides low impedance cells required by rapid discharge applications.

[0008] In certain embodiments, the battery cells of the present invention comprise a cylindrical assembly of a zinc negative electrode, a nickel positive electrode, a separator that separates the positive and negative electrodes, and an electrolyte.

[0009] The battery cells of the present invention include a negative electrode comprising zinc and a positive electrode comprising nickel. In preferred embodiments, low carbonate zinc oxide is used in the zinc electrode. Also in preferred embodiments, the positive electrode is a low carbonate positive electrode. In some embodiments, the low carbonate positive electrode is a dry processed electrode. In some embodiments, low carbonate components contain not more than about 1% by weight carbonate.

[0010] In preferred embodiments, the separator comprises a barrier layer to prevent zinc dendrite formation and a wetting layer to maintain hydration at the positive electrode. In some embodiments the barrier layer is adjacent to the positive electrode and the wetting layer is adjacent to the negative electrode. In other

embodiments the barrier layer is adjacent to the negative electrode and the wetting layer is adjacent to the positive electrode. In some embodiments, a single separator material is used to both prevent zinc dendrite formation and serve as a wetting layer.

[0011] In certain embodiments, the battery cells of the present invention also include negative and positive current collector elements, which are typically disks in the case of cylindrical format cells. In some embodiments the negative current collectors that electrically connect the negative collector disk to the negative electrode are bent or crimped to form a substantially flat and/or continuous surface for attaching the negative collector disk. This may be facilitated by the removal of some of the material from the area to be bent such that an improved fold may be achieved. The surface created provides for better attachment of the current collector and the collector disk, which improves reliability and lowers cell impedance.

[0012] In certain embodiments, the negative collector disk is made from at least one of copper, brass and tin. In a preferred embodiment, the negative collector disk is made from copper. In one embodiment, the negative collector disk comprises a copper disk the bottom of which is coated in tin. In this embodiment, the tin-coated copper disk may be heat bonded or soldered to the negative current collectors.

[0013] The collector disks should be shaped to allow attachment to the current collectors and addition of electrolyte to the cylindrical assembly. According to various embodiments, the collector disks may be perforated or unperforated circular disks. In one embodiment, the negative collector disk is a disk with triangular notches in the perimeter. In another embodiment, the negative collector disk is donut-shaped with a center hole to permit electrolyte to reach the center of the cylindrical assembly. In this embodiment, the positive collector disk may be perforated to allow uniform electrolyte distribution. In one arrangement the disk is slotted with radial open sections and associated vertical energy directors that make intimate contact with the edge of the spiral wound electrodes. By using, for example, an inverter based millisecond pulse welding technique it is possible to make strong bonds to both the nickel and the copper current collectors. In some embodiments, vertical extensions protrude above a flat section of the collector disk, and the collector disk is aligned in the cell such that the flat section makes electrical contact with the current collector in the rolled electrodes and the vertical extensions make electrical contact with the end terminal (cap or can).

[0014] In some cases, a non-welded pressure contact is employed. In certain embodiments, two circular disks (copper or other appropriate material) are connected together with a bent strip of metal (e.g., copper). The upper disk is resistance welded to the cap of the cylindrical cell (e.g., a sub-C cell) and the lower disk is pressurized (by spring action of the copper strip) to make electrical contact to the jellyroll. In certain embodiments, the spring may be a steel spring that has been plated with copper, tin, or another protective metal that has high hydrogen overpotential. Alternatively the spring may be substituted for with a pressurized rubber annulus or “o” ring that is resistant to the alkaline media.

10 [0015] A similar contact mechanism may be applied to the positive electrode. In this case the contact surface may employ two interconnected nickel disks pressurized by a similar spring arrangement. A contact surface may be formed by folding over the uncoated nickel foam current collector toward the center of the electrode roll to create a high surface area plane that facilitates either welded or pressurized contact of the collector disk. In certain embodiments, the disks are electroplated with cobalt. It should be understood that when the term “collector disk” is used herein, it is intended to cover various shapes of collectors, some of which deviate only slightly from disk shape and others of which deviate more strongly (e.g., collectors used with electrodes in prismatic cells).

20 [0016] The battery cells of the present invention may include a gel electrolyte reservoir. In certain embodiments, the reservoir is located at the bottom of cell, below the lower extent of an electrode/separator jellyroll.

[0017] In preferred embodiments, the cells of the present invention are of polarity opposite of that of conventional cylindrical power cells, with the cap negative and the can positive.

25 [0018] The battery cells of the present invention may facilitate recombination of hydrogen and oxygen by various mechanisms. In a preferred embodiment, the oxygen recombination rate supports at least about 150 mA. In some embodiments, recombination is facilitated by adding catalysts to various recombination surfaces. In some embodiments, recombination is facilitated by operating cells at starved conditions.

30 [0019] These and other features and advantages of the present invention will be described in more detail below with reference to the associated drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The invention may be understood more fully by reference to the following description taken in conjunction with the accompanying drawings in which:

5 Fig. 1a shows an exploded view of a battery cell according to one embodiment of the present invention.

Fig. 1b is a cross-sectional view of the battery cell shown in Fig. 1a

Fig. 2 is a representation of electrode and separator layers prior to winding.

Fig. 3 is a representation of electrode and separator layers in a cylindrical “jellyroll” assembly.

10 Fig. 4 is a cross-sectional representation of one set of electrode and separator layers in cylindrical assembly.

Fig. 5a and 5b are representations of bent current collectors at the negative end of a cylindrical assembly according to various embodiments of the present invention.

15 Figs. 6a and 6b are representations of collector disks according to various embodiments of the present invention.

Fig. 7a is a representation of a positive collector disk according to one embodiment of the present invention.

20 Fig. 7b is a representation of a cylindrical electrode/separator assembly and collector disks in a can according to one embodiment of the present invention.

Fig. 8 is a representation of a cylindrical assembly and gel reservoir in a can according to one embodiment of the present invention.

Fig. 9 is a representation of a cylindrical assembly, can and cap during the electrolyte fill process.

25 Fig. 10 is a representation of a cap and vent mechanism according to one embodiment of the present invention.

[0021] In the drawings like reference numerals designate like structural elements. Also, it is understood that the depictions in the figures are not necessarily to scale.

30

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0022] The present invention relates to nickel zinc battery designs. As indicated above, nickel zinc battery design presents several challenges that are not addressed by

conventional rechargeable battery design. These include zinc dendrite formation and redistribution of the zinc electrode ("shape change"), the use of copper conductive paths, and the propensity for hydrogen evolution at the zinc electrode.

[0023] Embodiments of this aspect of the invention are discussed below with reference to Figs. 1-10. However, those skilled in the art will readily appreciate that the detailed description given herein with respect to these figures is for explanatory purposes as the invention extends beyond these limited embodiments.

[0024] Figs. 1a and 1b are graphical representations of the main components of a cylindrical power cell according to one embodiment of the present invention, with Fig. 1a showing an exploded view of the cell. Electrode and electrolyte layers are in cylindrical assembly 101 (also called a "jellyroll"). Negative collector disk 103 and positive collector disk 105 are attached to opposite ends of cylindrical assembly 101. The negative and positive collector disks function as internal terminals, with the negative collector disk electrically connected to the negative electrode and the positive collector disk electrically connected to the positive electrode. Cap 109 and can 113 are external terminals. Negative collector disk 103 includes tab 107 to connect the negative collector disk 103 to cap 109. Positive collector disk 105 is electrically connected to cap 113. The embodiment shown in Figs. 1a and 1b has a polarity reverse of that in a conventional NiCd cell, in that the cap is negative and the can positive. In other embodiments, the polarity remains the same as in conventional designs – with a positive cap. Returning to the figures, a gasket 111 rests on a bead 115 and electrically insulates cap 109 from can 113. Note that although a cylindrical cell design is shown in Figs. 1a and 1b, the invention is certainly not limited to cylindrical cells. With minor modifications, apparent to those of skill in the art, the various designs depicted and described herein can be extended to prismatic cells.

[0025] Fig. 2 is a representation of electrode and separator layers prior to winding. Negative electrode 201 is separated from positive electrode 221 by separator 211. Negative electrode 201 includes a suitable electrochemically active zinc compound, typically zinc oxide and/or zinc metal, on a carrier sheet. Other electrochemically active zinc compounds such as calcium zincate may be used as well. As discussed above, zinc and zinc compounds are significantly less hazardous than the more commonly used cadmium compounds.

[0026] In certain embodiments, the zinc oxide is a low carbonate zinc oxide. The presence of carbonate neutralizes the electrolyte and can impede high rate discharge. US Patent Application No. 10/921,062 (J. Phillips), filed August 17, 2004, hereby incorporated by reference, describes manufacturing a low carbonate zinc electrode.

5 As indicated, the carbonate content in such compositions is preferably not greater than about 1 percent by weight.

[0027] In addition to the zinc oxide or other electrochemically active zinc source, the negative electrode may include other materials that facilitate certain processes within the electrode such as ion transport, electron transport, wetting, porosity, structural integrity, active material solubility etc. For example, in some embodiments, the negative electrode includes another oxide such as bismuth oxide, indium oxide, and/or aluminum oxide. Bismuth oxide and indium oxide tend to mix with zinc and reduce gassing at the electrode.

[0028] US Patent Application No. 10/921,062, referred to above, describes a method of manufacturing a negative electrode from a slurry containing additives in addition to zinc oxide. In a specific embodiment the slurry contains bismuth oxide, aluminum oxide, hydroxyethyl cellulose (HEC), and a dispersant. Indium oxide is also included in some embodiments. Various other formulations are possible, including those that employ other forms of zinc, such as calcium zincate or precursors thereof (e.g., calcium oxide and zinc oxide). Other electrode formulations include various inorganic fluorides, inorganic fibers such as alumina-silica fibers, and organic fibers such as cotton flock etc.

[0029] Other negative electrode compositions are described in the following documents, each of which is incorporated herein by reference: PCT Publication No. WO 02/39517 (J. Phillips), PCT Publication No. WO 02/039520 (J. Phillips), PCT Publication No. WO 02/39521, PCT Publication No. WO 02/039534 and (J. Phillips), US Patent Publication No. 2002182501. Negative electrode additives in the above references include, for example, silica and fluorides of various alkaline earth metals, transition metals, heavy metals, and noble metals.

30 [0030] The carrier for the negative electrode (which may also serve as a current collector) should be electrochemically compatible with the negative electrode materials. The carrier sheet can be provided in various structural forms including a perforated metal sheet, an expanded metal, and a metal foam. Among the criteria

employed to select a particular structural form are cost, ease of coating, and ability to facilitate electron transport between the electrochemically active electrode material and the current collector. For a zinc electrode, for example, the carrier material is preferably copper or an alloy of copper in the form of a perforated sheet or an expanded metal. In some embodiments, the current collector may be coated with a layer of tin, lead, or other material that is more compatible with zinc, in that it does not promote corrosion of zinc. Further, it may be desirable that the coating material has a high hydrogen evolution overpotential. These materials may be coated on the current collector by any of various means such as plating, dipping in molten metal, laminating, etc. In a specific embodiment, the negative current collector is copper or a copper alloy coated with tin or a tin alloy to a thickness of between about 0.00005 and 0.001 inches.

[0031] In a preferred embodiment, the thickness of the carrier is between about 2 and 5 mils for a perforated sheet but may be between 2 and 20 mils for expanded metal. Metal foam substrates may be between 15 and 60 mils. In a particularly preferred embodiment, the carrier is 3- 4 mils thick perforated copper. A specific range for the thickness of the negative electrode, including the carrier metal, zinc oxide and other negative electrode materials is about 10 to 24 mils.

[0032] Positive electrode 221 preferably has a composition similar to that employed to fabricate the nickel electrode in a conventional nickel cadmium battery, although there may be some important optimizations for the nickel zinc battery system. The electrochemically active material is preferably nickel hydroxide ($\text{Ni}(\text{OH})_2$), although a nickel oxide or nickel oxyhydroxide may also be used.

[0033] Zinc oxide and cobalt oxide may be employed in the positive electrode to improve charge transfer efficiency by creating conductive channels through the positive electrode materials. In a specific example, these oxides may be coprecipitated with or otherwise locked into the matrix of insoluble nickel material to prevent their leaching out of the positive electrode.

[0034] If cobalt metal is employed in the positive electrode, it is preferably present in a concentration of between about 1% to 10% by weight. This concentration range is appropriate for a wide range of discharge rates (e.g., about 0.001 to 0.4 A/cm^2 of zinc electrode surface area). In a typical high rate application (e.g., discharge is conducted at about 0.01 to 0.4 A/cm^2 of zinc electrode surface area), the

concentration of cobalt metal is between about 4-10% by weight in the positive electrode. In a typical low rate application, the concentration of cobalt metal is between about 1-5% by weight, and the discharge is conducted at about 0.001 to 0.01 $\text{\AA}/\text{cm}^2$ of zinc electrode surface area. Additives may be provided in the electrolyte and/or the electrode to reduce the migration of cobalt.

[0035] As suggested above, cobalt oxide may also (or alternatively) be added to the material to enhance conductivity. Note that in commercial nickel cadmium cells, free cobalt oxide is commonly employed in the positive electrode mixture.

[0036] A nickel foam matrix is preferably used to support the electroactive nickel (e.g., $\text{Ni}(\text{OH})_2$) electrode material. In one example, commercially available nickel foam by Inco, Ltd. may be used. The diffusion path to the $\text{Ni}(\text{OH})_2$ (or other electrochemically active material) through the nickel foam should be short for applications requiring high discharge rates. At high rates, the time it takes ions to penetrate the nickel foam is important. The width of the positive electrode, comprising nickel foam filled with the $\text{Ni}(\text{OH})_2$ (or other electrochemically active material) and other electrode materials, should be optimized so that the nickel foam provides sufficient void space for the $\text{Ni}(\text{OH})_2$ material while keeping the diffusion path of the ions to the $\text{Ni}(\text{OH})_2$ through the foam short. The foam substrate thickness may be may be between 15 and 60 mils. In a preferred embodiment, the thickness of the positive electrode, comprising nickel foam filled with the electrochemically active and other electrode materials, ranges from about 16 - 24 mils. In a particularly preferred embodiment, positive electrode is about 20 mils thick.

[0037] The density of the nickel foam should be optimized to ensure that the electrochemically active material uniformly penetrates the void space of the foam. In a preferred embodiment, nickel foam of density ranging from about 300 – 500 g/m^2 is used. An even more preferred range is between about 350 – 500 g/m^2 . In a particularly preferred embodiment nickel foam of density of about 350 g/m^2 is used. As the width of the electrode layer is decreased, the foam may be made less dense to ensure there is sufficient void space. In a preferred embodiment, a nickel foam density of about 350 g/m^2 and thickness ranging from about 16 – 18 mils is used.

[0038] A few positive electrode compositions are described in the following documents, each of which is incorporated herein by reference: PCT Publication No. WO 02/039534 (J. Phillips) (co-precipitated $\text{Ni}(\text{OH})_2$, CoO and finely divided cobalt

metal) and (J. Phillips) US Patent Publication No. 20020192547 filed March 15, 2002 (fluoride additives).

[0039] In some embodiments, the positive electrode may be coated with a material to prevent it from spalling, flaking, or otherwise mechanically degrading.

5 The coating may be a polymeric or elastomeric material in some embodiments. Examples include polyvinyl alcohol (PVA) and polystyrene sulfonates. The coating may be applied by dipping in a solution containing the coating material, brushing on the material, or spraying a solution of the material etc.

[0040] Methods of making electrodes include wet and dry processes. Wet
10 processes are described in US Patent Application No. 10/921,062, referred to above. However, wet processes may introduce organic materials into the nickel foam matrix. The presence of these organic materials are undesirable as they reduce conductivity. In a preferred embodiment, the positive electrode is made by a dry process which does not employ substantial water or other liquid. The component materials of nickel
15 hydroxide, nickel and cobalt powders are dry blended together with a suitable binder and are introduced into a hopper. A continuous strip of foam nickel is drawn through the powder while rotating brushes force material into the foam pores. A compression roller step sizes the foam to the appropriate porosity.

[0041] Separator 211 serves to mechanically isolate the positive and negative
20 electrodes, while allowing ionic exchange to occur between the electrodes and the electrolyte. The separator also blocks zinc dendrite formation. Dendrites are crystalline structures having a skeletal or tree-like growth pattern ("dendritic growth") in metal deposition. In practice, dendrites form in the conductive media of a power cell during the lifetime of the cell and effectively bridge the negative and positive
25 electrodes causing shorts and subsequent loss of battery function.

[0042] Typically, a separator will have small pores. In certain embodiments described herein, the separator includes multiple layers. The pores and/or laminate structure may provide a tortuous path for zinc dendrites and therefore effectively bar penetration and shorting by dendrites. Preferably, the porous separator has a
30 tortuosity of between about 1.5 and 10, more preferably between about 2 and 5. The average pore diameter is preferably at most about 0.2 microns, and more preferably between about 0.02 and 0.1 microns. Also, the pore size is preferably fairly uniform in the separator. In a specific embodiment, the separator has a porosity of between

about 35 and 55% with one preferred material having 45% porosity and a pore size of 0.1 micron.

[0043] In a preferred embodiment, the separator comprises at least two layers (and preferably exactly two layers) - a barrier layer to block zinc penetration and a wetting layer to keep the cell wet with electrolyte, allowing ionic exchange. This is generally not the case with nickel cadmium cells, which employ only a single separator material between adjacent electrode layers.

[0044] Performance of the cell may be aided by keeping the positive electrode as wet as possible and the negative electrode relatively dry. Thus, in some embodiments, the barrier layer is located adjacent to the negative electrode and the wetting layer is located adjacent to the positive electrode. This arrangement improves performance of the cell by maintaining electrolyte in intimate contact with the positive electrode.

[0045] In other embodiments, the wetting layer is placed adjacent to the negative electrode and the barrier layer is placed adjacent to the positive electrode. This arrangement aids recombination of oxygen at the negative electrode by facilitating oxygen transport to the negative electrode via the electrolyte.

[0046] The barrier layer is typically a microporous membrane. Any microporous membrane that is ionically conductive may be used. Often a polyolefin having a porosity of between about 30 and 80 per cent, and an average pore size of between about 0.005 and 0.3 micron will be suitable. In a preferred embodiment, the barrier layer is a microporous polyethylene. Examples of commercially available materials for the barrier layer include the UBE U-PORE UP3138 (Ube Industries, Ltd., Tokyo, Japan), the SOLUPORE™ products from Solutech of Heerlen, Netherlands, the CELGARD™ line of separators from Celgard Inc. of Charlotte, North Carolina, and AMS products from Advanced Membrane Systems. The barrier layer is typically about 0.5 - 4 mils thick, more preferably between about 2 and 4 mils thick. Specific examples of barrier layer membranes include a 4 mil AMS separator, 2 layers of a 1 mil thick SOLUPORE™ separator and 2 layers of 1 mil thick CELGARD™ separator.

[0047] The wetting layer may be made of any suitable wettable separator material. Typically the wetting layer has a relatively high porosity e.g., between about 50 and 85% porosity. Examples include polyamide materials such as nylon-based as well as

wettable polyethylene and polypropylene materials. In certain embodiments, the wetting layer is between about 1 and 10 mils thick, more preferably between about 3 and 6 mils thick. Examples of separate materials that may be employed as the wetting material include NKK VL100 (NKK Corporation, Tokyo, Japan), Freudenberg
5 FS2213E, Scimat 650/45 (SciMAT Limited, Swindon, UK), and Vilene FV4365.

[0048] Other separator materials known in the art may be employed. As indicated, nylon-based materials and microporous polyolefins (e.g., polyethylenes and polypropylenes) are very often suitable.

[0049] In an alternate embodiment, a single separator material may be used to
10 block zinc penetration and to keep the cell wet with electrolyte. The single separator material may be a separator used in a conventional lithium ion cell but modified for use in the nickel zinc cell. For example, the lithium ion-type separator may be impregnated with a gel to improve its wettability characteristics. One such example is the polyethylene Teklon material available from Entek Membranes LLC, Lebanon,
15 Oregon. This material is 20 microns thick with approximately 40% porosity. Gel may be provided to the separator directly or indirectly by, for example, adding it to the zinc electrode. Gel electrolytes are employed in some embodiments as explained below.

[0050] In certain embodiments, the separator may be treated with a surfactant
20 prior to incorporating into the anode/cathode structure. This serves to enhance the wettability and promote uniform current density. In a specific example, the separator is first treated with a solution of about .5 – 5% of a surfactant such as a Triton surfactant (e.g., X100) available from Dow Chemical Corporation of Midland Michigan. The time of contact with the surfactant as well as the drying time, choice
25 of surfactant, and concentration of surfactant are all factors that can impact the effectiveness of the treatment. Soaking for several hours in a dilute aqueous solution and subsequent air-drying can produce excellent results; additionally the use of other solvents such as methanol has been found to accelerate the uptake of the surfactant.

[0051] Another consideration in the electrode/separator design is whether to
30 provide the separator as simple sheets of approximately the same width as the electrode and currently collector sheet (e.g., Fig. 2) or to encase one or both electrodes in separator layers. In the latter example, the separator serves as a “bag” for one of the electrode sheets, effectively encapsulating an electrode layer. In some

embodiments, encapsulating the negative electrode in a separator layer will aid in preventing dendrite formation. In other embodiments, however, use of a barrier layer sheet without encapsulating an electrode is sufficient protection against dendrite penetration.

5 [0052] Fig. 3 is a representation of electrode and separator layers in a cylindrical or jellyroll-like assembly. The jellyroll is formed from the cut electrode and separator sheets described above. Negative electrode 301 and positive electrode 321 are separated by separator 313. A winding apparatus draws the various sheets in at the same time and rolls them into the jellyroll-like structure. After a cylinder of sufficient
10 thickness is produced, the apparatus cuts the layers of separator and electrodes to produce the finished cell assembly. A hollow core 315 extends through the center of the assembly. The radius and shape of the core may be controlled by the winding tool which holds the sheets of electrode and separator during winding.

[0053] Fig. 4 is a vertical cross-sectional representation of one set of electrode
15 and separator layers in a cylindrical assembly. These layers are wound together in a spiral to form the jellyroll. A negative electrode 401 includes the electrochemically active material 403, e.g. zinc oxide, and any other negative electrode materials, and a current collector 405. Similarly, a positive electrode 421 includes a current collector 423 (e.g., a nickel foam substrate in this embodiment) filled with $\text{Ni}(\text{OH})_2$ and other
20 positive electrode materials. Note that a metal tab 425 is attached the nickel foam positive current collector 423.

[0054] Negative current collector 405 extends past separator 413 at one axial end of the assembly and positive current collector tab 425 extends past separator 413 at the other axial end. As discussed above, the carrier for the electrochemically active
25 material in this embodiment serves as the negative current collector. Thus, as shown in Fig. 3, the negative current collector is co-extensive with the other negative electrode materials at the positive end of the assembly. In a preferred embodiment, the negative current collector is copper of thickness of about 3 - 4 mils. The positive current collector is typically nickel. In a preferred embodiment, shown in Fig. 4, the
30 positive current collector tab 425 is a nickel strip of about 3 mils thickness spot-welded or otherwise attached to the nickel foam substrate.

[0055] Fig. 5a shows a cross-sectional view of the negative end of a cylindrical assembly 510 prior to attaching the disk (e.g., collector disk 103 in Fig. 1A) to the

assembly according to one embodiment of the present invention, with negative electrode layers 501, separator layers 503, positive electrode layers 505 and negative current collectors 507. As indicated above, a negative collector disk is attached to the negative end of the cylindrical assembly and is electrically connected to the negative electrode via the current collectors. Fig. 5a shows one embodiment in which the current collectors 501 are bent at acute angles (e.g., about 90 degrees) prior to attaching the collector disk to form a substantially flat and continuous surface. Bending the current collectors increases the surface area available for attachment. It is important that the negative current collectors do not contact the positive electrode 505. In some embodiments, it may be necessary to cover or protect the ends of the positive electrode at the negative end of the cylindrical assembly.

[0056] Fig. 5b shows another embodiment in which the bent current collectors are separated from the positive electrode by separator layers 503. In this embodiment, the separator layers extend further than the positive electrodes at the negative end of the cylindrical assembly. Although negative and/or positive current collectors may be bent prior to attaching the collector disks, in a specific embodiment, only the negative current collectors are bent to improve attachment to the negative collector disk. As explained below, the copper-to-copper contact presents particular challenges. Hence, configurations such as those shown in Figs. 5a and 5b are particularly desirable for the negative electrode. The current collectors may be bent toward the center of the assembly as shown in Fig. 5a, or facing one direction as shown if Fig. 5b. In some embodiments, the current collectors may be predisposed in the desired direction before being pressed flat, e.g., by scoring at or near the bending point. In other embodiments, the current collectors are predisposed to bending while being wound in the jellyroll. In order to provide unimpeded bending, sections of the current collectors (from the area to be bent) may be removed to create a saw-tooth or battlement configuration. This may be most conveniently done during the slitting process of individual electrode fabrication. The surface created provides for better attachment of the current collector and the collector disk, which improves reliability and lowers cell impedance.

[0057] Among the main considerations for collector disks are conductivity, attachability to the current collectors, and allowing uniform distribution of electrolyte. The latter point can be understood by recognizing that electrolyte must normally be

added after at least one of the current disks has been properly placed in the cell and attached to the electrode current collector. In a specific embodiment, positive collector disks are perforated nickel disks. In one arrangement, the disk (positive or negative) is slotted with radial open sections and associated vertical energy directors (extensions or protrusions) that make intimate contact with the edge of the spiral wound electrodes, or alternatively with the cap or can, in which case the flat portion of the disk is electrically connected with the wound electrodes. By using, for example, an inverter based millisecond pulse welding technique it is possible to make strong bonds to both the nickel and the copper current collectors. The vertical extensions may serve as a spring to help resist damage to the battery caused by shock or vibration, effectively allowing the electrode roll to "float" with respect to the can.

[0058] Negative collector disks may be made of any material that will not corrode at the potential of the zinc electrode and may be electrically connected to the current collectors. The material should possess a high conductivity so that collector disk does not contribute a large impedance that reduces the power efficiency of the battery.

[0059] According to various embodiments, the negative collector disk comprises a material selected from copper, a copper alloy, e.g. brass, and tin. These metals are preferred in part because they do not readily evolve hydrogen at the potential of the zinc electrode and they have low resistivity. In a particularly preferred embodiment, the negative collector disk is copper or a copper alloy. Another embodiment employs tin coated copper or copper alloy. When the collector disk serves as a spring, it may be made from a beryllium-copper alloy, a spring steel alloy, etc.

[0060] The disk may be attached to the current collector by various methods known in the art such as spot welding, ultrasonic welding, laser welding, soldering, and other types of electro-conductive bonding appropriate for the terminal and current collector materials. While copper is favored in some embodiments for its low resistivity and other properties, it presents a particular challenge for attachment to the negative current collector of the jellyroll. A copper disk is typically attached to the copper current collectors by resistance welding or laser welding. In some embodiments, the copper disk also comprises tin to improve attachability and reduce gassing. For example, the bottom of the disk may be coated with tin or a tin alloy, which can serve as a solder bonding to the negative current collectors. The collector

disk may also be brass. Brass collector disks are less conductive than copper but may have superior attachability.

[0061] After the collector disks are attached, the entire jellyroll assembly is inserted into a retaining vessel, such as a can. In certain processes, electrolyte is then added to the cylindrical assembly. Thus, the disks should be shaped to allow electrolyte to enter the body of the cell and be evenly distributed through the cylindrical assembly as well as to allow attachment to the current collectors. According to various embodiments, the disks may or may not be perforated or slotted. In another embodiment, the collector disks comprise H-shaped structures. Fig. 6a shows a collector disk that is a circular disk with a center hole and triangular notches or "cake slices" removed from the perimeter. The design shown in Fig. 6a has been found to be relatively easy to weld. Fig. 6b shows a disk with holes spaced to permit uniform distribution of the electrolyte. Providing a collector disk that permits uniform electrolyte distribution becomes increasingly important as the amount of electrolyte used is decreased. Uniform distribution is important during fill as well as for reincorporation of any electrolyte that leaks out of the assembly during normal operation. For example, some electrolyte may make its way above the collector disk during operation and then must then find its way back into the jellyroll. When this occurs, the disk design may facilitate uniform distribution of the electrolyte as it flows back into the jellyroll. The holes may be uniformly spaced or otherwise arranged to optimize uniform distribution. For example, the holes may be spaced in a spiral arrangement so that they overlay the separator layers when the disk is attached to the electrode.

[0062] In conventional power cell manufacturing, the polarity of the cell is such that the cap is positive and the can or vessel is negative. That is, the positive electrode of the cell assembly is electrically connected with the cap and the negative electrode of the cell assembly is electrically connected with the can that retains the cell assembly. In a preferred embodiment of this invention, the polarity of the cell is opposite of that of a conventional cell. Thus, the negative electrode is electrically connected with the cap and the positive electrode is electrically connected to the can. As discussed above with reference to Figs. 1a and 1b, the cap is a normally connected with the collector disk by a tab. The collector disk connected with the can is normally welded or otherwise attached to the can.

[0063] Fig. 7a shows a perforated collector disk 701 with a U-shaped indent 703. Part of the U-shaped indented portion of the disk is attached to the can while the rest of the disk rests above the bottom of the can. In this way, the U-shaped portion functions as a spring that provides stability to the assembly if vibrated. In certain
5 embodiments, the distance between the rest of the disk (i.e. the un-indented portion) and the bottom of the can is about 5 – 10 mils.

[0064] Various techniques may be employed to fill the vessel with electrolyte. In one example, the electrolyte may be added prior to cap application and the cell is then spun to distribute the fluid. In other cases, the electrolyte is introduced via an
10 injection process in which electrolyte enters the cell via a fill port located in the base of the cell after the cap is applied.

[0065] Fig. 7b shows positive collector disk 701 and negative collector disk 705 attached to cylindrical assembly 707 in can 709. Positive collector disk 701 has a U-shaped indent 703 attached to one end of can 709. In a preferred embodiment,
15 positive collector disk 701 is perforated and negative collector disk 705 is a donut-shaped disk containing a center hole. Most of the electrolyte added through the center hole of the negative collector disk is then forced down the assembly, through the center hole of the positive disk to the bottom of the can where it is forced upward on the cell perimeter and then reaches the electrodes in the jellyroll assembly through the
20 perforations in the positive collector disk. As only the center hole of the negative collector is used for electrolyte fill, the structure or shape of remainder of the disk may be determined solely by attachability requirements. In one embodiment, the surface of the remainder of the negative collector disk is unperforated to maximize the surface area available for attachment to the current collectors. See e.g., the disk
25 structure in Fig. 6a.

[0066] In another embodiment, the negative collector disk is solid and the electrolyte is not added through the negative collector disk but only through the positive collector disk. This embodiment may require a fill port. In a related approach, a negative can design can be employed.

30 [0067] The electrolyte should possess a composition that limits dendrite formation and other forms of material redistribution in the zinc electrode. Such electrolytes have generally eluded the art. But one that appears to meet the criterion is described in U.S. Patent No. 5,215,836 issued to M. Eisenberg on June 1, 1993,

which is hereby incorporated by reference. A particularly preferred electrolyte includes (1) an alkali or earth alkali hydroxide present in an amount to produce a stoichiometric excess of hydroxide to acid in the range of about 2.5 to 11 equivalents per liter, (2) a soluble alkali or earth alkali fluoride in an amount corresponding to a concentration range of about 0.01 to 1 equivalents per liter of total solution, and (3) a borate, arsenate, and/or phosphate salt (e.g., potassium borate, potassium metaborate, sodium borate, sodium metaborate, and/or a sodium or potassium phosphate). In one specific embodiment, the electrolyte comprises about 4.5 to 10 equiv/liter of potassium hydroxide, from about 2 to 6 equiv/liter boric acid or sodium metaborate and from about 0.01 to 1 equivalents of potassium fluoride. A specific preferred electrolyte for high rate applications comprises about 8.5 equiv/liter of hydroxide, about 4.5 equivalents of boric acid and about 0.2 equivalents of potassium fluoride.

[0068] The invention is not limited to the electrolyte compositions presented in the Eisenberg patent. Generally, any electrolyte composition meeting the criteria specified for the applications of interest will suffice. Assuming that high power applications are desired, then the electrolyte should have very good conductivity. Assuming that long cycle life is desired, then the electrolyte should resist dendrite formation. In the present invention, the use of borate and/or fluoride containing KOH electrolyte along with appropriate separator layers reduces the formation of dendrites thus achieving a more robust and long-lived power cell.

[0069] In a specific embodiment, the electrolyte composition includes an excess of between about 3 and 5 equiv/liter hydroxide (e.g., KOH, NaOH, and/or LiOH). This assumes that the negative electrode is a zinc oxide based electrode. For calcium zincate negative electrodes, alternate electrolyte formulations may be appropriate. In one example, an appropriate electrolyte for calcium zincate has the following composition: about 15 to 25% by weight KOH, about 0.5 to 5.0% by weight LiOH.

[0070] According to various embodiments, the electrolyte may comprise a liquid and a gel. The gel electrolyte may comprise a thickening agent such as CARBOPOL® available from Noveon of Cleveland, OH. In a preferred embodiment, a fraction of the active electrolyte material is in gel form. In a specific embodiment, about 5-25% by weight of the electrolyte is provided as gel and the gel component comprises about 1-2% by weight CARBOPOL®.

[0071] Fig. 8 shows the positive end of a cylindrical assembly 801 and can 807 according to one embodiment of the present invention. A portion 803 of positive collector disk 805 is attached to the end of can 807 as described above with reference to Figs. 7a and 7b. Some of the electrolyte is in the form of a gel which serves as a non-spillable reservoir 809 for electrolyte that may decompose (e.g., through hydrogen evolution). As indicated by the arrows, electrolyte from reservoir 809 moves up through the perforated collector disk 805 to the cylindrical assembly as needed. The gel may be added to the cylindrical assembly before, during or after the liquid electrolyte is added. In one embodiment, the liquid electrolyte is added through the center hole of the negative collector disk. Liquid electrolyte travels down the center portion the assembly, under the positive collector disk and wicks up through the perforated collector disk to uniformly fill the assembly. Gel electrolyte is then added through the center hole in the negative collector disk, displacing liquid electrolyte remaining in the center of the assembly or base.

[0072] The can or other vessel serves as the outer housing or casing of the final cell. In conventional NiCd cells, the can is often nickel-plated steel. As indicated above, the can may either be positive or negative. In embodiments wherein the can is negative, the can material may be a composition similar to that employed in a conventional nickel cadmium battery, such as steel, as long as the material is coated with another material compatible with the potential of the zinc electrode. In some embodiments that employ a negative can, the can is coated with a zinc-compatible material such as copper to prevent corrosion. As mentioned, in certain embodiments, the can is positive and the cap negative. The can may be a composition similar to that used in convention nickel-cadmium cells, typically nickel-plated steel. In some embodiments, the interior of the can may be coated with a material to aid hydrogen recombination. Any material that catalyzes hydrogen recombination may be used. An example of such a material is silver oxide.

[0073] After the can or other containment vessel is filled with electrolyte, the vessel is sealed to isolate the electrodes and electrolyte from the environment as shown in Fig 1b. The cylindrical assembly or jellyroll 101 is located inside can 113. Positive collector disk 105 is welded or otherwise attached to can 113 as discussed above with respect to Figs. 7a and 7b. Negative collector disk 103 is electrically connected to cap 109 through tab 107. Cap 109 is electrically isolated from can 113

through the use of flexible gasket 111. Gasket 111 resides on a circumferential bead 115 in the upper portion of can 113.

5 [0074] In a preferred embodiment, the bead 115 on which gasket 111 rests is coated with a polymer coating. The gasket may be any material that electrically isolates the cap from the can. Preferably the material does not appreciably distort at high temperatures; one such material is nylon. In other embodiments, it may be desirable to use a less wettable material to reduce the driving force that causes the alkaline electrolyte to creep and ultimately leak from the cell at seams or other available egress points. An example of a less wettable material is polypropylene.

10 [0075] The gasket is typically sealed by a crimping process. In a preferred embodiment, the gasket a sealing agent is used to prevent leakage. Examples of suitable sealing agents include bituminous sealing agents, tar and VERSAMID® available from Cognis of Cincinnati, OH. The cap may be made of any suitable conductive material that inhibits the evolution of hydrogen. These may include tin
15 plated or silver plated steel. In a preferred embodiment, the cap is tin plated steel.

[0076] Fig. 9 presents a representation of a cylindrical cell during electrolyte fill. Tab 911 electrically connects collector disk 913. In this embodiment, tab 911 is long enough to allow cap 909 to be open during the filling process. Because of its length, it is important to use a highly conductive material for tab 911 to minimize impedance.
20 Thus, in a preferred embodiment, cap 909 is negative and tab 911 is made of a highly conductive material such as copper. In conventional NiCd cells, the cap is positive and the conductive paths typically comprise nickel.

[0077] Although the cell is generally sealed from the environment, the cell may be, in some embodiments, permitted to vent gases from the battery that are generated
25 during charge and discharge. A typical nickel cadmium cell vents gas at approximately 200 PSI. In some embodiments, a nickel zinc cell of this invention is designed to operate at this pressure and even higher (e.g., up to about 300 PSI) without the need to vent. This may encourage recombination of any oxygen and hydrogen generated within the cell. Preferably the cell is constructed to maintain an
30 internal pressure of not greater than about 600 PSI and more preferably not greater than about 450 PSI. In other embodiments, a nickel zinc cell is designed to vent gas at relatively lower pressures. This may be appropriate when the design encourages

release of hydrogen and/or oxygen gases over their recombination within the nickel zinc cell.

[0078] Fig. 10 is a representation of a cap and vent mechanism according to one embodiment of the invention. The vent mechanism is preferably designed to allow gas escape but not allow electrolyte passage that may interfere with the reproducible function of the vent and raise safety concerns. Cap 1001 includes disk 1008 that rests on the gasket, vent 1003 and upper portion 1005. Disk 1008 includes a hole 1007 that permits gas to escape. - - Vent 1003 covers hole 1007 and is displaced by escaping gas. Vent 1003 is typically rubber, though it may be made of any material that permits gas to escape and withstands high temperatures. A square vent has been found to work well. Upper portion 1005 is welded to disk 1008 at weld spots 1009 and includes holes 1011 to allow the gas to escape. The locations of weld spots 1009 and 1011 shown are purely illustrative and these may be at any suitable location. In a preferred embodiment, the vent mechanism includes a vent cover 1013 made of a hydrophobic gas permeable membrane. Examples of vent cover materials include microporous polypropylene, microporous polyethylene, microporous PTFE, microporous FEP, microporous fluoropolymers, and mixtures and co-polymers thereof (see e.g., US Patent Application No. 10/098,193, "Leak Proof Pressure Relief Valve for Secondary Batteries," filed March 15, 2002 for J. Phillips, which is incorporated herein by reference for all purposes). The material should be able to withstand high temperatures.

[0079] Hydrophobic gas permeable membranes may be used alone or in conjunction with a tortuous gas escape route. Many other battery venting mechanisms are known in the art and are suitable for use with this invention. In certain embodiments, a cell's materials of construction are chosen to provide regions of hydrogen egress. For example, the cells cap or gasket may be made from a hydrogen permeable polymeric material. In one specific example, the outer annular region of the cell's cap is made from a hydrogen permeable material such as an acrylic plastic or one or more of the polymers listed above. Only the actual terminal (provided in the center of the cap and surrounded by the hydrogen permeable material) need be electrically conductive.

[0080] The battery cells of this invention can have any of a number of different shapes and sizes. For example, cylindrical cells of this invention may have

the diameter and length of conventional AAA cells, AA cells, A cells, C cells, etc. Custom cell designs are appropriate in some applications. In a specific embodiment, the cell size is a sub-C cell size of diameter 22 mm and length 43 mm. Often the profile of a battery pack for, e.g., a power tool will dictate the size and shape of the battery cells. This invention also pertains to battery packs including one or more nickel zinc battery cells of this invention and appropriate casing, contacts, and conductive lines to permit charge and discharge in an electric device.

Nickel Zinc Battery Design Considerations

10 [0081] Nickel zinc battery designs must take into account several design considerations. Some apply to conventional NiCd or other battery designs, but require designs optimized for NiZn cells, and some challenges are unique to NiZn batteries. The present invention addresses these issues as discussed below.

15 Electrolyte Leakage

[0082] The battery design should minimize leaking of caustic electrolyte from the cell. Electrolyte leakage may be minimized by operating at starved conditions (i.e. low amount of electrolyte). Thus, in some embodiments of the present invention, battery cells are provided that are capable of operating at starved conditions. As discussed below, operating at starved conditions presents design considerations that the NiZn batteries of the present invention address. Regardless of whether a cell is operated under starved conditions, electrolyte leakage may be further minimized by providing a liquid impermeable/gas permeable vent cover as discussed above with reference to Fig 10.

25

Uniform Electrolyte Distribution

[0083] In preferred embodiments, the electrolyte is uniformly distributed through the separator layer. Uniform electrolyte distribution is desirable as it provides uniform current density and thereby helps minimize shape change of the zinc electrode. Uniform distribution is especially important for starved cells.

30 [0084] In some embodiments, uniform electrolyte distribution is facilitated by providing collector disks with uniformly spaced holes through which the electrolyte is added to the cell. However, as discussed above, it is often desirable to provide a

collector disk for the zinc electrode that is not perforated in order to improve the attachability of the collector disk, usually copper, to the negative current collectors. Thus, according to various embodiments, the negative collector disk may be unperforated except for a center hole through which electrolyte is added and the positive collector uniformly perforated to provide uniform distribution. In this embodiment, the electrolyte is added through the center hole in the negative collector disk and is then reaches the cylindrical assembly or jellyroll from the holes in the perforated positive collector disk.

[0085] Operating under starved conditions also increases the likelihood of battery failure from electrolyte leakage. In some embodiments, a gel reservoir is added to replenish the electrolyte supply as needed as discussed above with respect to Fig. 7.

Hydrogen Evolution/Recombination

[0086] The relatively negative electric potential of zinc in zinc electrodes makes it particularly susceptible to hydrogen evolution and corrosion of the negative electrode. In particular, it is more susceptible to hydrogen evolution than cadmium and metal hydride cells. Hydrogen evolution is undesirable because of electrode corrosion, pressure build-up in the cell and potential cell dry-out through electrolyte decomposition. In addition, recombination of hydrogen and oxygen is challenging in a nickel zinc battery. In nickel - cadmium cells, in which dendrite formation is not a great concern, there is a clear path through the separator for gases to travel between electrodes for the recombination reaction. Unlike with conventional nickel cadmium or nickel metal hydride cells, the nickel zinc cells of the present invention may include a barrier separator layer that blocks zinc dendrite formation. This barrier layer prevents a clear path for evolved oxygen and hydrogen to access the appropriate recombination electrode in the cell. The gases instead must go around the jellyroll assembly to recombine.

[0087] According to various embodiments, the batteries of the present invention may be designed to minimize hydrogen evolution at the zinc electrode. In some embodiments, the negative electrode may include materials that reduce gassing at the negative electrode, such as certain metal oxides.

- [0088] In some embodiments, the nickel zinc battery design facilitates recombination. As discussed above, recombination in the nickel zinc battery design of the present invention is hindered by the existence of a barrier layer to prevent zinc dendrite penetration. However recombination by other mechanisms can be facilitated in a number of ways. In some embodiments, a catalyst for recombination may be added to the electrodes and/or interior of the can to aid recombination. An example of such a catalyst for hydrogen recombination is silver oxide. In another embodiment, a catalyst such as bismuth is added to the negative electrode to facilitate oxygen recombination.
- 10 [0089] Recombination is also facilitated by even electrolyte distribution. Thus, as described above some embodiments employ perforated collector disks and/or gel reservoirs to improve the uniformity of electrolyte distribution and aid recombination. Recombination is also improved by providing void space for the gases to recombine. In some embodiments, the batteries of the present invention are
- 15 suitable for operating at starved conditions. As discussed above, the separator layer comprises a barrier layer and a wetting layer. In some embodiments, the wetting layer is adjacent to the zinc electrode. The more open poer structure of the wetting vs. barrior layer facilitates oxygen transport to the zinc electrode for recombination.
- [0090] In a preferred embodiment, the oxygen recombination rate in a sub-C
- 20 cell is at least 150 mA.

Zinc Shape Change/Dendrite Formation

- [0091] As mentioned, zinc electrodes are susceptible to shape change. During charge/discharge cycling, formation of soluble zincate ion causes redistribution of zinc over the face of the electrode. Shape change results in a dramatic decrease in battery capacity with successive cycles. In addition, zinc electrodes are susceptible to zinc dendrites. Dendrites are crystalline structures having a skeletal or tree-like growth pattern ("dendritic growth") in metal deposition. During cycling, dendrites form in the zinc electrode and, if unchecked, penetrate the separator and reach the
- 25 positive electrode causing shorts and subsequent loss of battery function.
- [0092] In some embodiments, the batteries of the present invention include an electrolyte of a composition that limits dendrite formation and other forms of material
- 30

redistribution in the zinc electrode as discussed above. In some embodiments, the separator layer includes a barrier layer to impede dendrite formation and penetration.

Carbonate

5 **[0093]** The presence of carbon dioxide in the battery cell neutralizes the alkaline electrolyte and can impede high rate discharge through formation of carbonate. Further, many commercial sources of zinc oxide have significant carbonate content. In a preferred embodiment, zinc employed to fabricate the negative electrode has a relatively low-carbonate content, e.g., not more than about
10 1% by weight. In addition, it is believed carbonate may form during wet processing using organic compounds. Thus, in a preferred embodiment, the positive electrode is formed by a dry-processing method. In some embodiments, the amount of electrolyte in the cell may be required to be boosted to account for electrolyte that is taken out of solution by a certain amount of carbonate.

15

Copper Conductive Paths and Impedance Reduction

[0094] Copper and copper alloys are particularly preferred materials for the conductive paths associated with the zinc electrode. Copper is preferred because of its low resistivity, relatively low price, and electrochemical compatibility with the
20 zinc electrode. Notably, nickel plated steel is the conductive path for the cadmium electrode in commercial nickel cadmium cells.

[0095] In a preferred embodiment, the polarity of the nickel zinc cell is opposite that of a conventional power cell, that is the cap of the nickel zinc cell is negative and the can positive. Approximately 0.5 mΩ of the overall impedance in a
25 conventional C size power cell may be attributed to the positive current collector and the resistance weld to the cap. This is due in part to the compositional requirements of the terminal given the electrochemistry of conventional power cells. In the present embodiment, the use of copper in the manner described results in a significant impedance reduction at the now negative terminal thus achieving a more power
30 efficient cell.

[0096] While copper has better electronic conductivity than steel, it can present fabrication issues. For example, attaching a current collecting copper disk to

the copper sheet may require specific laser welding settings and the appropriate jigs to provide continuous pressure during the weld.

[0097] As such, the electrical attachment of the collector disk with the negative electrode requires specific manufacturing techniques. In an example
5 embodiment, the copper collector is perforated and attached at multiple points along the negative electrode so that the electrode is attached to the current collector at multiple points along its length. By activating a greater area, the charge efficiency is further enhanced. The perforations also serve to locate the electrode and allow electrolyte to penetrate the stack uniformly during the electrolyte fill operation. In
10 another embodiment, the collector disk is slotted to achieve the named advantages. In another embodiment, the copper collector disk requires only center hole for the electrolyte to enter. The structure of the rest of the disk is then determined by the requirements of the method of attachment (i.e. unperforated, perforated or slotted as required). In another embodiment, the copper collector disk is covered with tin or a
15 tin alloy and attached to the current collectors by soldering. In a preferred embodiment, the current collectors are bent as described above with reference to Fig. 4a to improve attachment of the collector disk to the current collectors.

[0098] One disadvantage associated with the welding of current collector disks to the active-material-supporting conductor (current collectors) is that the heat input can
20 damage thin heat sensitive separator membranes. This can promote short circuits and significantly curtail service life. A non-welded pressure contact can mitigate this problem. In certain embodiments, two circular copper disks are connected together with a bent strip of copper. The upper disk is resistance welded to the cap of the cylindrical cell (e.g., a sub-C cell) and the lower disk is pressurized to make electrical
25 contact to the jellyroll.

[0099] When the cap (and vent assembly) is mated to the cell body during cell assembly the electrical contact to the jellyroll is maintained by the pressure created by a "spring" that has been inserted between the two parallel copper disks. The spring
30 may be a steel spring that has been plated with copper, tin, or another protective metal that has high hydrogen overpotential. Alternatively the spring may be substituted for with a pressurized rubber annulus or "o" ring that is resistant to the alkaline media. Such materials may be EPDM (Ethylene Propylene Diene Monomer) or Viton® (fluoroelastomer family from DuPont Dow Elastomers, L.L.C.). In either case

sufficient pressure is maintained such that low impedance electrical resistance is maintained between the cap and jellyroll. In certain embodiments, the pressure exerted by the o-ring presses downward through or from a crimp in the cell can. In some cases, it is desirable to provide a reinforced bottom of the can.

5 **[00100]** While this method is particularly useful for the negative electrode contact where there is minimal oxidation of the metal parts and minimal oxidation of organic-based rubber compounds it may nevertheless also be applied to the positive electrode. In such cases, the contact surface may be two interconnected nickel disks that are pressurized by a similar spring arrangement. However, there may be some
10 degradation over time associated with the formation of resistive nickel oxides on the nickel contact area. In order to prevent the progressive build up of resistance the disks may be electroplated with cobalt. Although still subject to oxidation the cobalt oxides provide much better conductivity than nickel oxides.

[00101] One skilled in the art will appreciate that the foregoing advantages may
15 be achieved by coating or plating the interior surface of the can with copper in a nickel zinc power cell with conventional polarity.

[00102] The battery cells of the present invention have low overall impedance, due in part to the negative cap arrangement discussed above. In a preferred embodiment, a nickel-zinc sub-C cell has an overall AC impedance of between about
20 3 and 5 mΩ. In an even more preferred embodiment, the cell has an AC impedance of between about 3.5 and 4.5 mΩ. By comparison the overall AC impedance of Sanyo's power tool sub-C cell NiCd battery is 5.3 mΩ

[00103] The foregoing describes the instant invention and its presently preferred embodiments. Numerous modifications and variations in the practice of this
25 invention are expected to occur to those skilled in the art. For example, while the above specification describes cylindrical cells, certain aspects of the invention apply to other cell designs as well, such as prismatic cell designs. Such modifications and variations are encompassed within the following claims.

[00104] The entire disclosures of all references cited herein are incorporated by
30 reference for all purposes.

CLAIMS

What is claimed is:

1. A cylindrical nickel zinc battery cell comprising:
 - a) a negative electrode layer comprising zinc;
 - 5 b) a positive electrode layer comprising nickel;
 - c) a separator layer to separate the positive and negative electrode layers, the separator layer comprising a barrier layer to substantially prevent zinc dendrite formation and a wetting layer; and
 - d) an electrolyte.
- 10 2. The battery cell of claim 1 wherein the negative electrode layer is between 16 and 24 mils thick and the positive electrode is between 16 and 24 mils thick.
3. The battery cell of claim 1 wherein the barrier layer and the wetting layer are different materials.
- 15 4. The battery cell of claim 1, wherein the barrier layer and the wetting layer are the same material.
5. The battery cell of claim 1, wherein the barrier layer is between 1 and 4 mils thick.
- 20 6. The battery cell of claim 1, wherein the negative electrode layer comprises a negative current collector, and wherein the end of the negative current collector is bent to form a substantially flat surface at one end of the cylindrical cell.
7. The battery cell of claim 1, wherein the end of the negative current collector that is bent to form a substantially flat surface at one end of the cylindrical cell has material removed to facilitate bending.
- 25 8. The battery cell of claim 1 further comprising a copper negative collector disk, and wherein one side of the copper disk is coated with tin or a tin alloy.
- 30 9. The battery cell of claim 7 further comprising copper negative current collectors and wherein the disk is soldered to the current collectors.
10. The battery cell of claim 1 wherein at least some of the electrolyte is in gel form.

11. The battery cell of claim 1 further comprising:
- a) a can electrically connected to the positive electrode layer;
 - b) a positive collector disk electrically connected to the positive electrode layer; and
 - 5 c) an electrolyte gel reservoir located between the positive collector disk and one end of the can.
12. The battery cell of claim 1 further comprising:
- a) a positive collector disk electrically connected to the positive electrode layer; wherein the positive collector disk is perforated; and
 - 10 b) a negative collector disk electrically connected to the negative electrode.
13. The battery cell of claim 1 further comprising:
- a) a positive collector disk electrically connected to the positive electrode layer; wherein the positive collector disk is slotted; and
 - 15 b) a negative collector disk electrically connected to the negative electrode.
14. The battery cell of claim 1 wherein the wetting layer is adjacent to the negative electrode and the barrier layer is adjacent to the positive electrode.
- 20 15. The battery of cell of claim 1 wherein the overall AC impedance is between about 3 and 5.0 mΩ.
16. The battery cell of claim 15, wherein at least one of the positive and negative collector disks comprises a spring element.
17. The battery cell of claim 1, further comprising a cell can and a cell cap, and wherein the cell cap comprises the battery cell's negative terminal.
- 25 18. The battery cell of claim 1, wherein the cell cap comprises an annular polymeric region that is permeable to hydrogen.
19. The battery cell of claim 1, wherein the negative electrode comprises a perforated tin-coated copper strip.

30

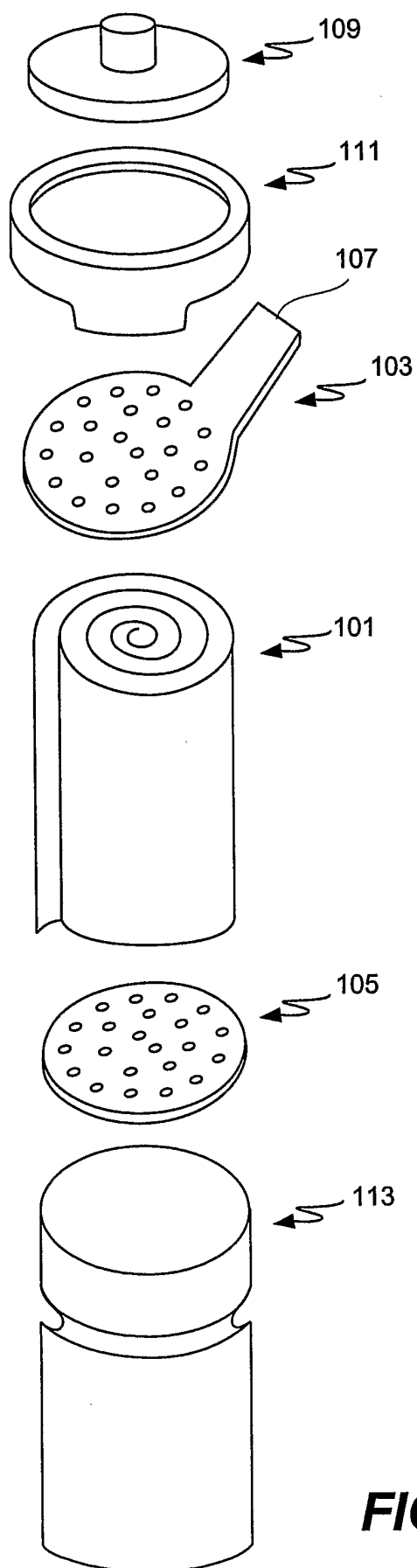


FIG. 1a

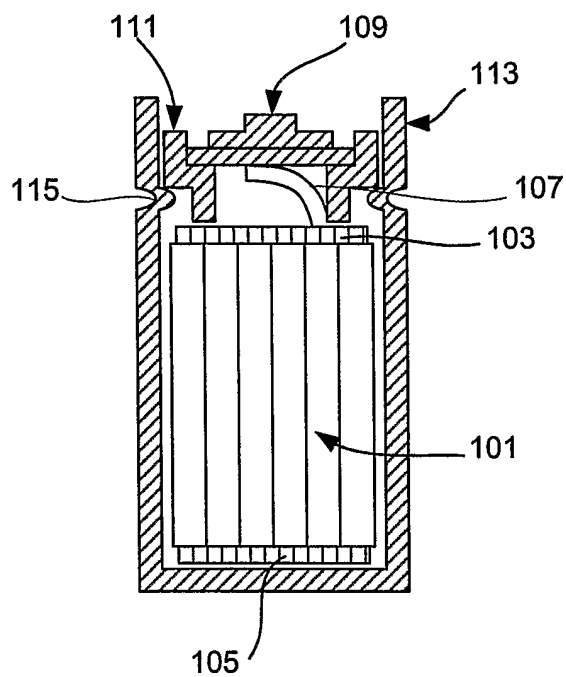


FIG. 1b

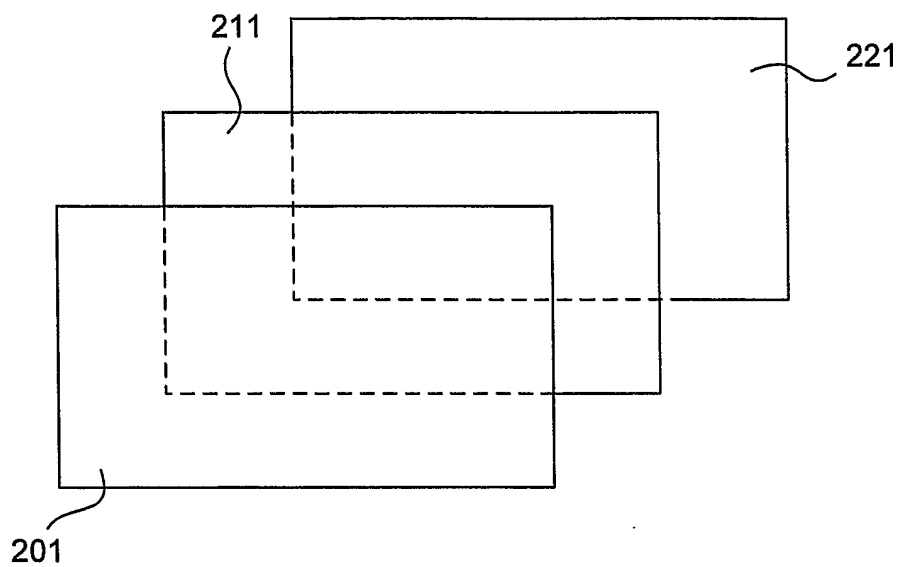


FIG. 2

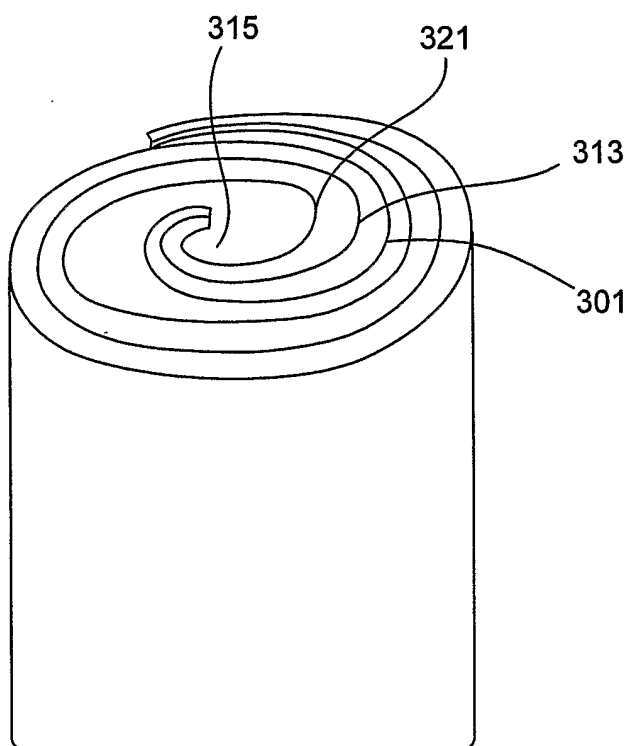
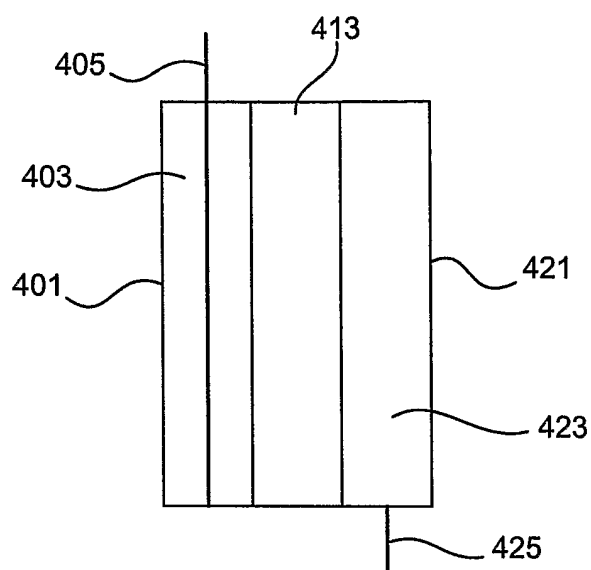
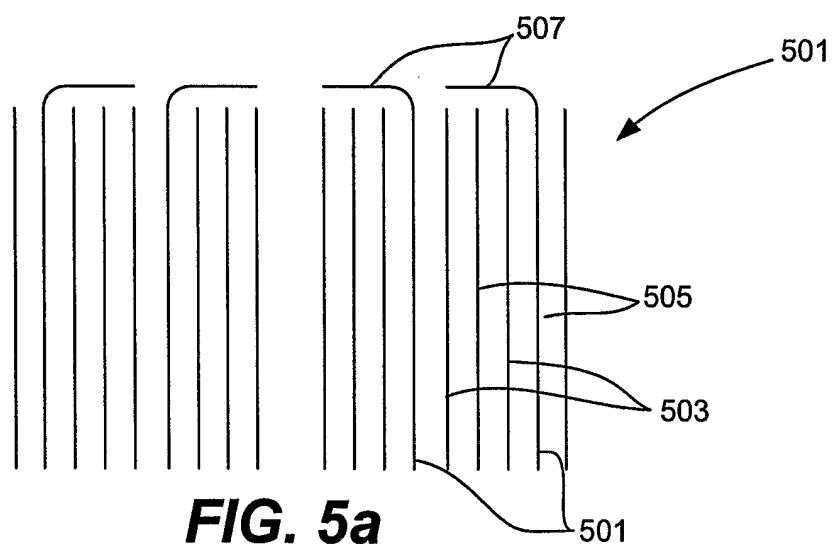
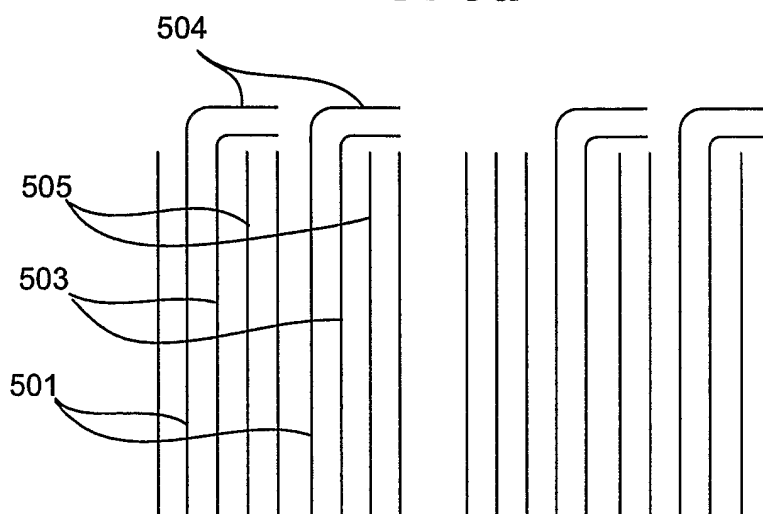


FIG. 3

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**FIG. 4****FIG. 5a****FIG. 5b**

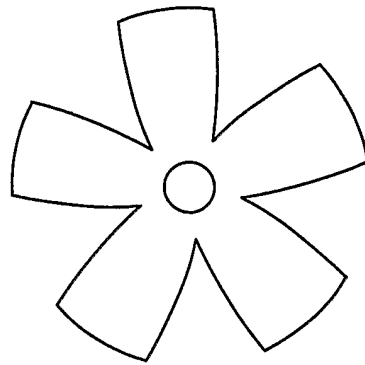


FIG. 6a

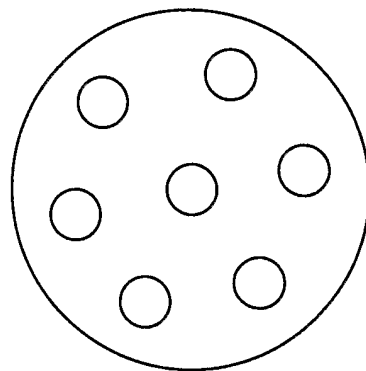
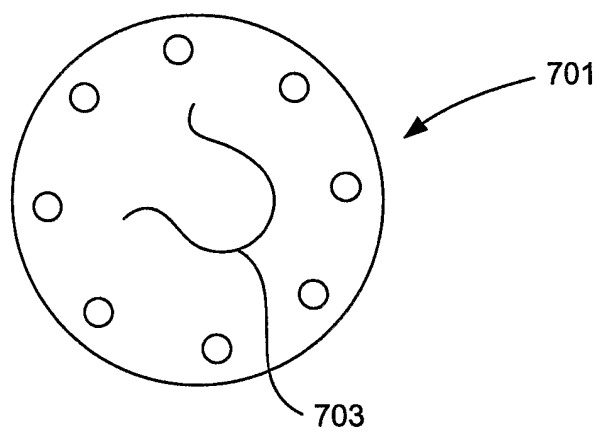
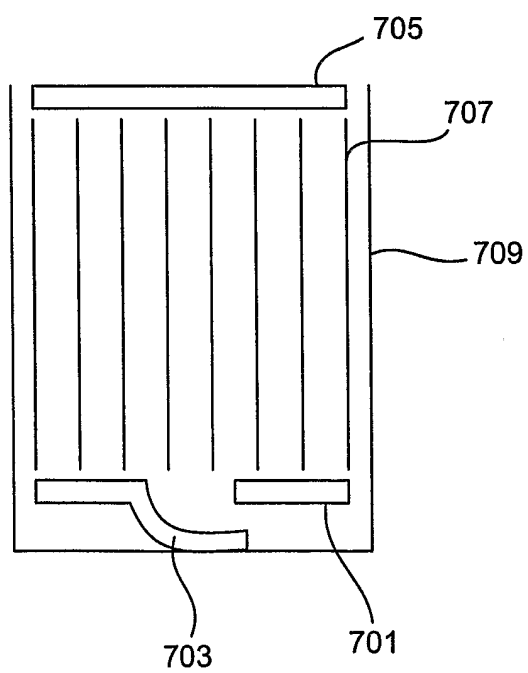


FIG. 6b

**FIG. 7a****FIG. 7b**

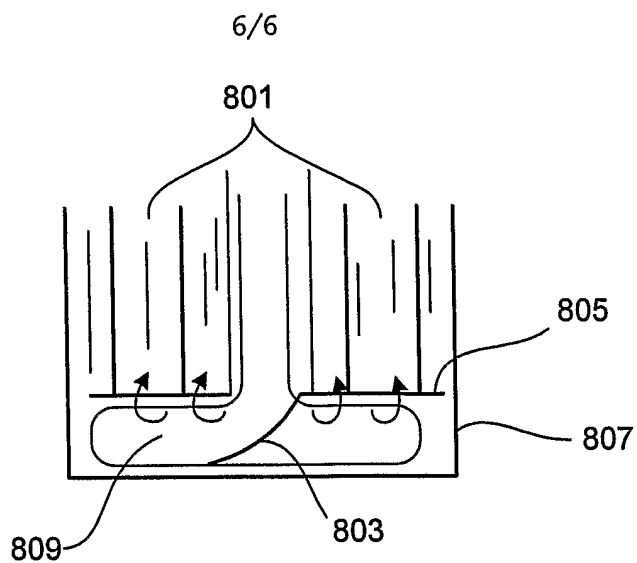


FIG. 8

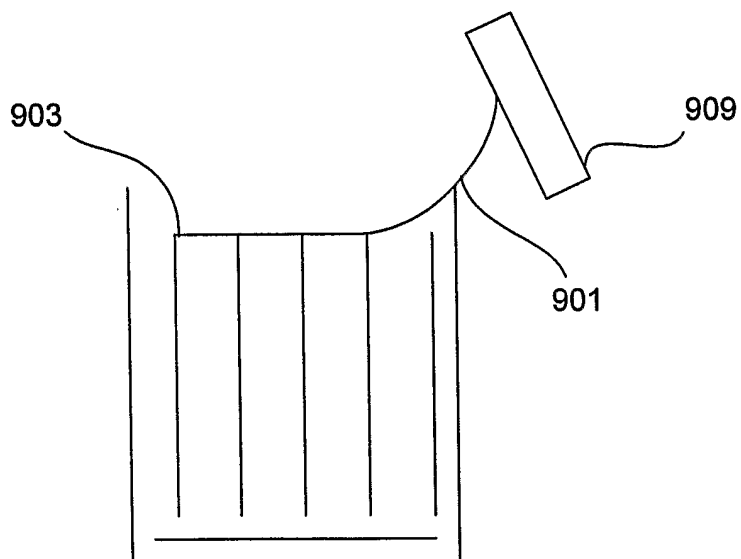


FIG. 9

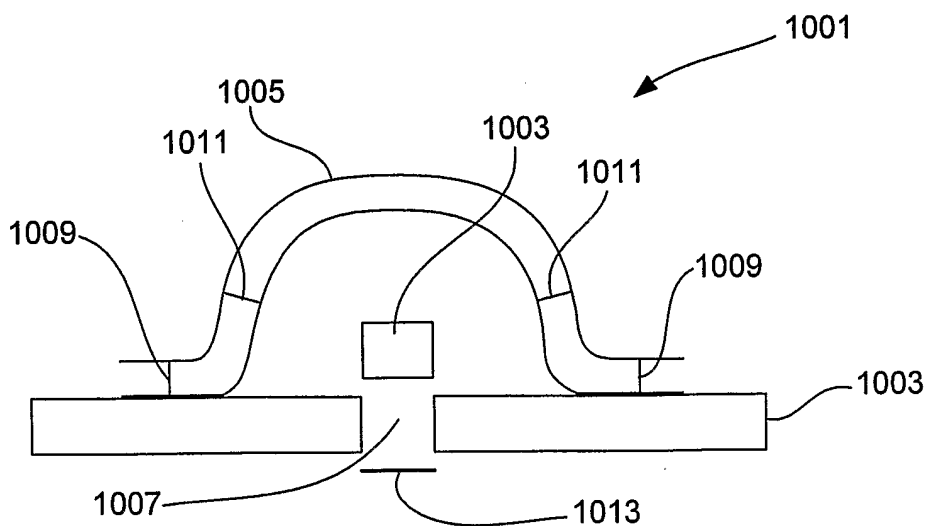


FIG. 10