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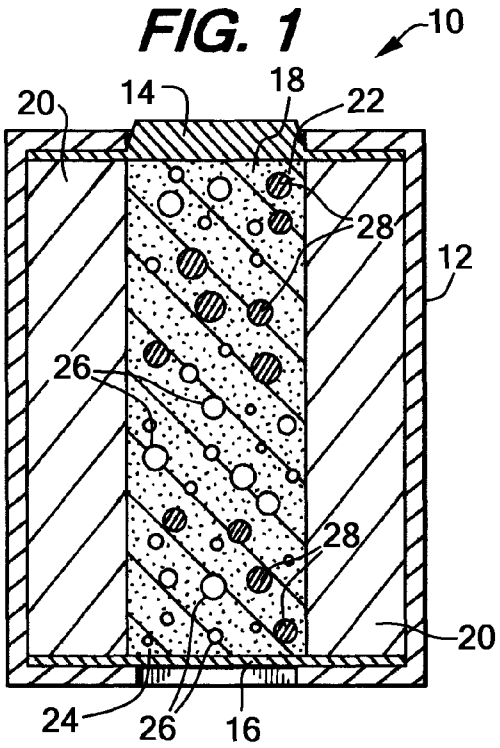
(54) Title: LITHIUM ION BATTERY AND METHODS OF MANUFACTURING SAME



(57) Abstract: Lithium ion battery cells using metallic foam. One electrode may include a metallic foam that is coated with electrode material allowing some of the electrode material to be disposed within open pores of the metallic foam. An electrode may also be electrically connected to a terminal of the battery with a metallic foam. The electrode has an exposed edge across its length wherein no electrode material is present on the current collector.

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TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

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

TITLE OF THE INVENTION

LITHIUM ION BATTERY AND METHODS OF MANUFACTURING SAME

RELATED APPLICATIONS

[0001] This application claims priority to United States Provisional Application No. 61/598,518 filed on February 14, 2012, the entirety of which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present inventions generally relates to lithium ion batteries and methods of manufacturing same.

BACKGROUND OF THE INVENTION

[0003] Lithium ion battery electrodes are generally produced using a slurry (or paste). This slurry generally includes an electrode active material, a binder material, and an electrical conductive additive material all dispersed in a solvent (such as NMP). This slurry is coated onto both surfaces of a thin metallic current collector foil (typically between 30 and 100 micrometers thick). Typically, the current collector is copper for the negative electrode and aluminum for the positive electrode. After the slurry dries, the electrodes are cut to the desired dimensions using rotary knife slitters.

[0004] The process for making these batteries is slow. Specifically, this production process requires slurries with controlled rheology, as well as requires the application of these slurries onto the metal foil current collector, generally one side at the time. Further, the slurry must be allowed to dry. Finally, the dried layers are calendared to increase in density. All of these require steps increase the time of the production process.

[0005] This relatively slow process is required because the resulting electrode layer has a relatively low electrical conductivity which needs to be in close proximity with the metallic foil current collector. Typically, if the distance between any active electrode material particle

and the metallic current collect exceeds approximately 100 microns, the electrical resistance associated with this separation is too large to permit an efficient utilization of the electrode material. This deficiency is accentuated at high rate of utilization of the battery.

[0006] This process also requires that an entire section (or sections) of the current collector foil to be left uncoated. Subsequent to the electrode coating and calendaring, at least one tab (per electrode) is welded to the current collector foil within the uncoated area. This tab is necessary to make and secure electrical contact between the electrodes and the terminals in the cell packaging material or housing (*e.g.*, a cylindrical can, a soft prismatic pouch or a hard prismatic can).

[0007] In addition, the tab may need to be welded to the packaging material in order to provide a continuous electrical link between the cell and its housing. This is typically done by electrically welding the anode tab to the bottom of the steel can, in an 18650 format, or by laser welding the cathode tab to the CID/Cap plate.

[0008] These welding steps can be complex and require constant attention. In addition, they can contribute to longer production time and low production yield, cell defects, and cell failures. In sum, the production process is long and complex for these types of batteries.

[0009] While these batteries and methods are effective, the present invention seeks to provide a battery cell that improves on the prior designs, as well as a providing a more efficient method of making the battery.

BRIEF DESCRIPTION OF THE PRESENT INVENTION

[0010] In one embodiment of the present invention, the invention relates to a process for the production of lithium ion battery electrodes that have high electrical conductivity, and which provides an easier method of production, and which provides a construction for the electrode in which the average maximum distance between an active material particle and a metallic current collector point is less then 100 microns--preferably less then approximately 50 microns. As a result, a thicker electrode can be produced, without compromising its performance, and, thus enabling the fabrication of a cell with improved energy and power density at a lower cost.

[0011] Some embodiments of the present invention utilize a 3-dimensionally electrically conducting porous current collector material, filled with a paste-like electrode material composition and compressed after being filled by the electrode material. Preferably, the porous current collector material is open celled porous metallic foam.

[0012] Such a current collector material has a high electrical conductivity and will result in a maximum distance between active material particle and current collector of 100 microns or less.

[0013] Typically, the open celled porous metallic foam includes nickel when used in association with the negative electrode and aluminum or graphite/carbon when used in association with the positive electrode. These foams may be approximately (*i.e.*, +/-10%) 3 to 5 mm in thickness and have a porosity in excess of 60% (***by volume or weight?***), preferably a porosity in excess of 90%.

[0014] The electrodes may be made using a paste containing little, if any, solvent and which is applied to the foam in a manner so as to enable filling of a significant fraction of the foam porosity. Subsequent to pasting the foam with the electrode paste, the electrode-foam is compressed to about one-third to one-fifth of its original thickness. The compressed electrode-foam can be further processed in to a plate, a strip, a ribbon or any other required shapes prior to its final assembly into a battery.

[0015] The AC IR of the resulting battery is less than 5 mOhms/Ah, preferably less then 1 mOhm/Ah based on an equivalent 18650 cylindrical format. A typical "energy" cell battery design made according to these known methods has an AC IR value in excess of 20 mOhms/Ah. Similarly, a typical "power" cell battery design according to these known methods has an AC IR value in excess of 10 mOhms/Ah.

[0016] In another embodiment of the present invention, the present invention provides a new cell design that does not include a tab, and therefore does not require tab welding or a tab connection between the electrodes and the terminals. This design utilizes a continuous (or non-interrupted) electrode coating process for the production of electrodes. In addition, such electrodes do not require any further material removal, cleaning, or scratching as required with prior art designs and methods of manufacture. Further, such electrodes have lower calendaring defects and can be process faster which increases production yield.

[0017] Embodiments of the present invention may include offset electrode alignment, which results in a tab-less construction for the production of a low AC IR lithium ion battery. This is achieved by using an edge connection between the cell current collector and a conductive pad that is made of a first 3D metallic electrically conductive open structure and second component made of a compressible polymer. This composite structured pad allows for the pad to be maintained under compression, thus securing electrical continuity, while preventing the metallic 3D structure from breaking, losing electrical continuity, or losing contact due to permanent or non-reversible compression.

[0018] A preferred embodiment of the invention includes a negative electrode made with a full width coated electrode and a positive electrode made out of an electrode that has one edge uncoated. This uncoated edge is useful to prevent local capacity unbalance and to prevent lithium metal deposition on the opposite surface of the negative electrode.

[0019] Embodiments of the present invention allow for a method to accurately and reliably cut or trim the uncoated excess edge aluminum foil. In the present invention, this foil can be very thin, approximately 10 micrometers (compared to approximately 20 micrometers for some conventional battery cells), and as such can be difficult to cut/trim accurately using traditional rotary knife slitting equipment. Therefore, some embodiments allow for the use of a low power laser to cut the uncoated aluminum excess.

[0020] Certain embodiments of the present invention provide low resistance and continuous electrical contact between the edges of a cell (jelly roll or prismatic) and its packaging material (can or soft pouch) by utilizing a porous and compressible electrically conducting foam (nickel, aluminum and/or carbon are preferred) to make the electrical connections. Further, in preferred embodiments, the porous compressible electrically conducting foam is filled with an elastomeric material in order to allow this component to reversibly deform to best adapt to the jelly roll dimension variations.

[0021] Such a cell may have a low AC IR, and will increase performance because of the lack of any tab, tab welding, and because it does not require interrupted coating. Moreover, the fabrication process may have improved yield and improved quality, thus allowing a lower cost. Further, cells assembled using certain embodiments of the present invention may show no variation or degradation of their AC IR value due to mechanical vibration. Further, such cells may have a lower temperature increase at high discharge rates compared with

conventional cells assembled using tabs. Finally, such cells may have a more uniformly cut/trim uncoated edge of the positive electrode which will provide a uniform and stable contact with the current collecting conductive foam.

[0022] In some embodiments, at least one of its current collectors may be coated with an electrically enhancing primer layer. The primer layer is preferably inorganic and basic and lithium polysilicates are one contemplated primer. The continuous coating allows for use of the primer and there is no need for overlaying electrode coating registration. The use of a primer is a result of the electrode coating onto the metallic substrate being non-interrupted and electrode tab welding not being required.

[0023] In some embodiments of the present invention, the uncoated edge of the electrode is covered with a rubber type material that will flow in between the electrode layer without covering the edges of the electrode. Thus, electrical contact still can be made, while the ends of the electrode may be mechanically reinforced.

[0024] It is to be understood that the aspects and objects of the present invention described above may be combinable and that other advantages and aspects of the present invention will become apparent upon reading the following description of the drawings and detailed description of the invention.

DESCRIPTION OF THE DRAWINGS

[0025] As one of ordinary skill in the art would appreciate, none of the drawings are to scale, and are merely used to better understand the various embodiments and features of the present invention in which:

[0026] FIG. 1 is a side elevation cut away view of a battery cell according to one or more embodiments of the present invention;

[0027] FIG. 2 is a side elevation cut away view of a battery cell according to one or more embodiments of the present invention;

[0028] FIG. 3 is a front perspective view of an embodiment of an electrode used in a battery cell according to one or more embodiments of the present invention;

[0029] FIG. 4 is a side elevation view of the electrode of FIG. 3; and,

[0030] FIG. 5 is a side elevation view of two electrodes in an offsetting configuration.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

[0031] While this invention is susceptible of embodiment in many different forms, there is shown in the drawings and will herein be described in detail one or more embodiments with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the invention to the embodiments illustrated.

[0032] Turning to FIG. 1, in one embodiment of the invention, the invention relates to lithium ion battery cell 10 having housing 12 with first terminal 14 and second terminal 16.

[0033] First electrode 18 is in electrical communication with first terminal 14 and second electrode 20 is in electrical communication with second terminal 16.

[0034] At least first electrode 18 comprises current collector 22 which is metallic foam 24 having a plurality of open pores 26. First electrode 18 also includes electrode material 28. In this manner, a portion of electrode material 28 is disposed within the open pores 26 of the metallic foam 24. If first electrode 18 is an anode, it is contemplated that that the metallic foam 24 includes nickel. Alternatively, if first electrode 18 is a cathode, it is contemplated that the metallic foam 24 includes aluminum and/or carbon.

[0035] It is preferred, although not required, that the metallic foam 24 have a porosity of at least 60%, and most preferred that the porosity is at least 90%. It is also preferred that in battery cell 10, a maximum distance between electrode material 28 and metallic foam 24 is approximately 100 microns. Moreover, it is preferred that the metallic foam 24 has a thickness of approximately 3 to 5 mm.

[0036] A preferred method of making battery cell 10 includes a step of pasting electrode material 28 onto current collector 22 to form first electrode 18. Again, current collector 22 comprises metallic foam 24 which includes a plurality of open pores 26. After the step of pasting, first electrode 18 is compressed such that it has a thickness of between 1/3 and 1/5 of an original thickness. Thereafter, first electrode 18 may be inserted into housing 12.

[0037] It is also contemplated that first electrode 18 is processed into a desired shape after compressing first electrode 18 and before inserting first electrode 18 into housing 12.

[0038] As discussed above, battery cell 10 and the method of making same provide benefits for the battery based upon the use of the metallic foam. For example, a thicker electrode can be produced, without compromising its performance. Accordingly, an improved battery cell can be made with improved energy and power density at a lower cost.

[0039] Turning to FIG. 2, the present invention also relates to a battery 50 with a "spiral wound" or "jelly roll" type electrode configuration.

[0040] As shown, battery 50 includes housing 52 having first terminal 54 connected to first electrode 56 and a second terminal 58 connected to second electrode 60. Metallic foam 62 is used at least to electrically connect first terminal 54 to first electrode 56, and preferably also to connect second terminal 58 to second electrode 60. It is contemplated that the metallic foam 62 includes a compressible material, such as rubber, etc.

[0041] It is preferred that first electrode 56 has the configuration of electrode 100 in FIGS. 3 and 4. Moreover, if metallic foam 62 is used to connect second electrode 60 to second terminal 58, it is also preferred that second electrode 60 has the configuration of electrode 100 (from FIGS. 3 and 4).

[0042] As can be seen in FIGS. 3 and 4, electrode 100 comprises a current collector 102 and an electrode material 104. Current collector 102 includes an exposed edge 106 across its length L, and exposed edge 106 is in contact with metallic foam 60. Exposed edge 106 can be either top edge 108 or bottom edge 110 of current collector 102. *See, e.g.*, FIG. 5.

[0043] By "exposed edge" 106 it is meant that there is no electrode material 104 disposed on that portion (the exposed edge 106) of current collector 102. As discussed herein, it is contemplated that current collector 102 include and/or be coated with, primers, rubber material, and other substances to increase its strength and electrical connectivity to the metallic foam 60. Thus, "exposed edge" 106 merely means that there is no electrode material 104 on exposed edge 106, but other substances may be present on exposed edge 106 of current collector 102.

[0044] As can be seen in FIGS. 3 and 4, current collector 102 has a height H extending from top edge 108 to bottom edge 110, a length L extending from first edge 112 to second edge 114. The length L is greater than the height H (preferably the length is at least two times the height).

[0045] Electrode material 104 is disposed on at least first side 116 of current collector 102 continuously from first edge 112 to the second edge 114 and from the bottom edge 110 to a distance shorter than the height H, such that exposed edge 106 is formed along the top edge 108 along the length L of the current collector 102.

[0046] Retuning to FIG. 2, exposed edge 64 of first electrode 56 is disposed within metallic foam 62. Further, although not required, exposed edge 66 of second electrode 60 is also disposed in electrical contact within metallic foam 62. In this manner, metallic foam 62 electrically connects each electrode 56, 60, with its respective terminal 54, 58 of battery cell 50.

[0047] Turning to FIG. 5, when making such a battery it is preferred that both electrodes 100a, 100b used in a battery utilize the construction shown in FIGS. 3 and 4. In such a manner, electrodes 100a, 100b will be offset during winding. *See*, FIG. 5. Thus, exposed edge 106a of electrode 100a extends downward and exposed edge 106b of electrode 100b extends upwards. Of course, one of ordinarily skill in the art would understand that the terms upward and downward, as well as top and bottom, are used merely for reference, and one could simply rotate the electrode to change top to bottom and still be within the scope of the present invention.

[0048] A battery having such an electrode configuration is believed to beneficial for many reasons. With the elimination of the welding typically required in such batteries, the time and effort needed to make the battery decreases—which in turn decrease the cost. Moreover, the lack of welding results in less opportunity for failure of the battery due to calendaring or other welding mistakes. Further, with a thinner current collector, a low power laser can be used to cut the current collector to the appropriate size or to trim the exposed edge.

[0049] It is to be understood that additional embodiments of the present invention described herein may be contemplated by one of ordinary skill in the art and that the scope of the present invention is not limited to the embodiments disclosed. While specific embodiments

of the present invention have been illustrated and described, numerous modifications come to mind without significantly departing from the spirit of the invention, and the scope of protection is only limited by the scope of the accompanying claims.

5

CLAIMS

What is claimed is:

1. A lithium ion battery cell comprising:

a housing having a first terminal and a second terminal;

a first electrode in electrical communication with the first terminal;

a second electrode in electrical communication with the second terminal;

wherein the first electrode comprises a current collector being a metallic foam having a plurality of open pores and a electrode material, and wherein a portion of the electrode material is disposed within the open pores of the metallic foam.

2. The lithium ion battery cell of claim 1 wherein the metallic foam is compressed.

3. The lithium ion battery cell of claim 1 or 2 wherein the metallic foam has a porosity of at least 60%.

4. The lithium ion battery cell of any one of claims 1 to 3 wherein the metallic foam has a porosity of at least 90%.

5. The lithium ion battery cell of any one of claims 1 to 4 wherein the maximum distance between the electrode material and the metallic foam is 100 microns.

6. The lithium ion battery cell of any one of claims 1 to 5 wherein the first electrode comprises an anode and the metallic foam includes nickel.

7. The lithium ion battery cell of any one of claims 1 to 5 wherein the first electrode comprises a cathode and the metallic foam includes aluminum.

8. The lithium ion battery cell of any one of claims 1 to 5 wherein the first electrode comprises a cathode and the metallic foam includes carbon.

9. The lithium ion battery cell of anyone of claims 1 to 8 wherein the metallic foam has a thickness of approximately 3 to 5 mm.

10. A method of making a lithium ion battery cell comprising the steps of:

pasting an electrode material onto a current collector to form an electrode, wherein the current collector comprises a metallic foam having a plurality of open pores,

compressing the electrode such that it has a thickness of between 1/3 and 1/5 of an original thickness; and,

inserting the electrode into a housing after it has been compressed.

11. The method of claim 10, further comprising the steps of:

processing the electrode into a desired shape after compressing the electrode and before inserting the electrode into the housing.

12. The method of claim 10 or 11 wherein the metallic foam has a porosity of at least 60%.

13. The method of any one of claims 10 to 12 wherein the metallic foam has a porosity of at least 90%.

14. The method of claim 10 wherein the maximum distance between the electrode material and the metallic foam is 100 microns.

15. The method of any one of claims 10 to 14 wherein the first electrode comprises an anode and the metallic foam includes nickel.

16. The method of any one of claims 10 to 14 wherein the first electrode comprises a cathode and the metallic foam includes aluminum.

17. The method of any one of claims 10 to 14 wherein the first electrode comprises a cathode and the metallic foam includes carbon.

18. A lithium ion battery comprising:

a housing having a first terminal and a second terminal,

a first electrode having a current collector and a electrode material disposed in the housing and electrically connected to the first terminal; and,

a second electrode disposed in the housing and electrically connected to the second terminal;

wherein, at least the first electrode is electrically connect to the first terminal with a metallic foam.

19. The lithium ion battery of claim 18 further comprising the current collector including an exposed edge across its length, and the exposed edge being in contact with the metallic foam.

20. The lithium ion battery of claim 18 or 19 further comprising the metallic foam includes a compressible material.

21. The lithium ion battery of any one of claims 18 to 20 further comprising the metallic foam includes nickel, aluminum or carbon.

22. A lithium ion battery comprising:

a housing having a first terminal and a second terminal,

a first electrode disposed in the housing and electrically connected to the first terminal, the first electrode comprising:

a current collector having a height extending from a bottom to a top, a length extending from a first edge to a second edge, a first side and a second side, the length being greater than the height, and,

an electrode material disposed on at least the first side of the current collector continuously from the first side edge to the second side edge and from the bottom to a distance less than the height such that an exposed edge is formed along the length of the current collector; and,

a second electrode disposed in the housing and electrically connected to the second terminal;

wherein, at least the first electrode is electrically connect to the first terminal with a metal foam.

23. The lithium ion battery of claim 22 further comprising the metallic foam including a compressible material.

24. The lithium ion battery of claim 22 or 23 further comprising the metallic foam includes nickel, aluminum or carbon.

FIG. 1

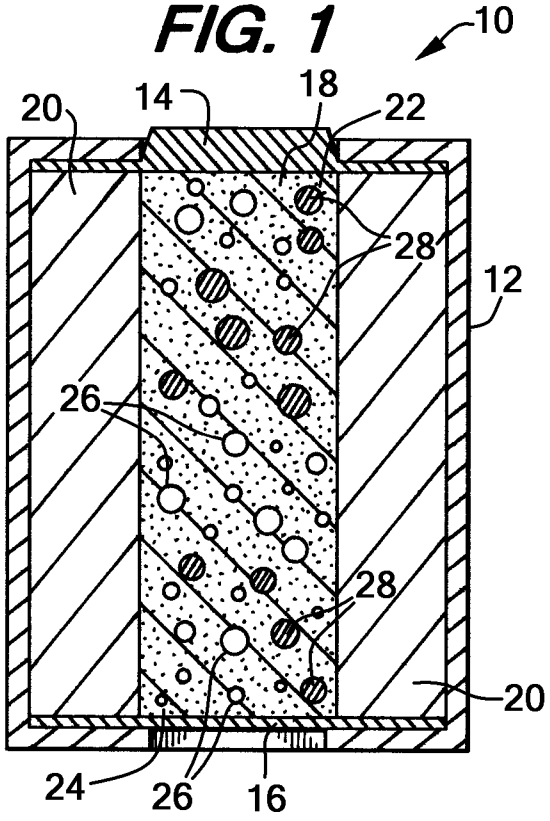
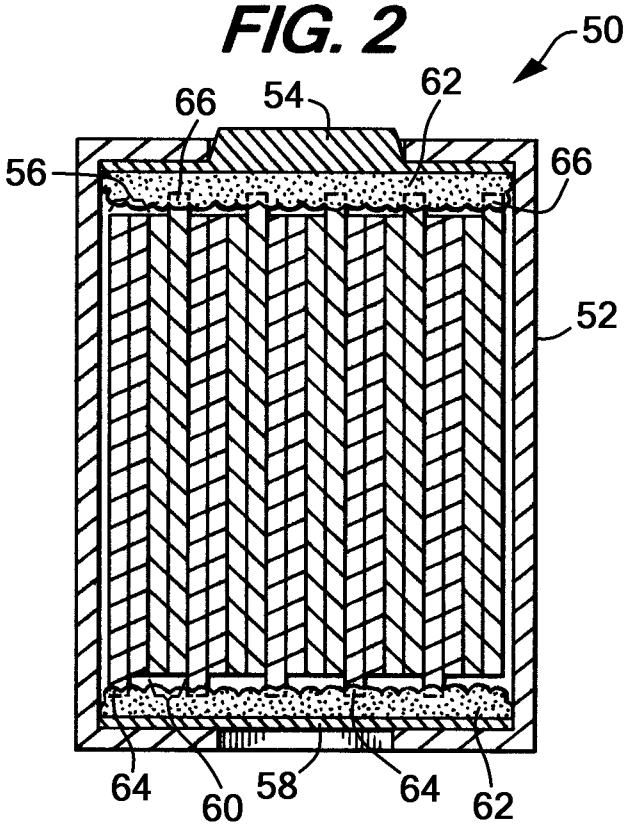


FIG. 2



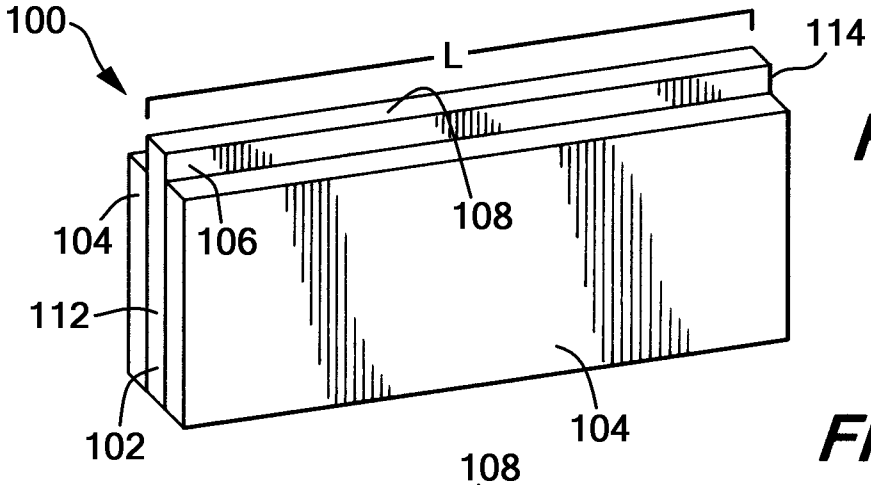


FIG. 3

FIG. 4

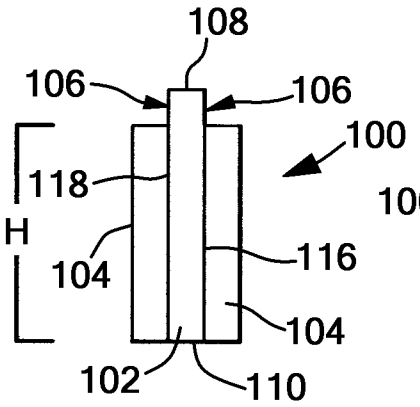
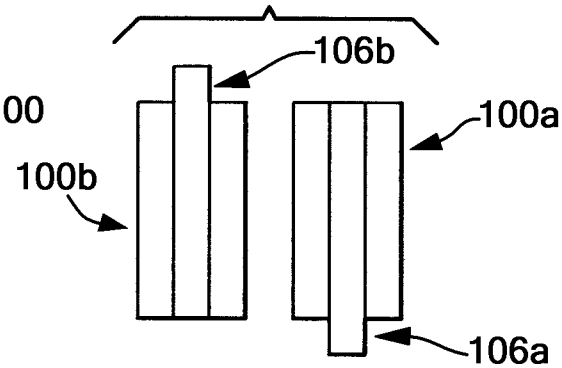


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/026046

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H01M 4/80 (2013.01)
USPC - 429/235
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(8) - H01M 4/13, 4/58, 4/64, 4/80, 6/04, 6/12, 6/44 (2013.01)
USPC - 429/206, 218.1, 233, 235, 236, 243

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - H01M 4/06, 4/661, 4/76, 4/762 (2013.01)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, Google Patent Search, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/0305131 A1 (KUMAR et al) 10 December 2009 (10.12.2009) entire document	10-12, 14
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Y		1-3, 18-20
Y	US 5,554,918 A (HARATS et al) 10 September 1996 (10.09.1996) entire document	1-3, 18-20
Y	US 6,238,819 B1 (CAHILL et al) 29 May 2001 (29.05.2001) entire document	19
A	US 2008/0268338 A1 (LEE et al) 30 October 2008 (30.10.2008) entire document	1-3, 10-12, 14, 18-20
A	US 2011/0052997 A1 (KIM et al) 03 March 2011 (03.03.2011) entire document	1-3, 10-12, 14, 18-20

☐ Further documents are listed in the continuation of Box C. ☐

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

Date of the actual completion of the international search	Date of mailing of the international search report
28 March 2013	19 APR 2013

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/026046

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

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

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

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

3. ☒ Claims Nos.: 4-9, 13, 15-17, 21
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:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.