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(54) **METAL-AIR BATTERY CELL, METAL-AIR BATTERY INCLUDING METAL-AIR BATTERY CELL AND METHOD OF FABRICATING THE SAME**

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(57) **ABSTRACT**

A metal-air battery cell includes: a negative electrode metal layer; a positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; a negative electrode electrolyte film disposed between the negative electrode metal layer and the positive electrode layer in a thickness direction; and a channel layer disposed on the positive electrode layer and comprising a plurality of channel structures, the channel structures each elongated to extend in an extension direction crossing the thickness direction.

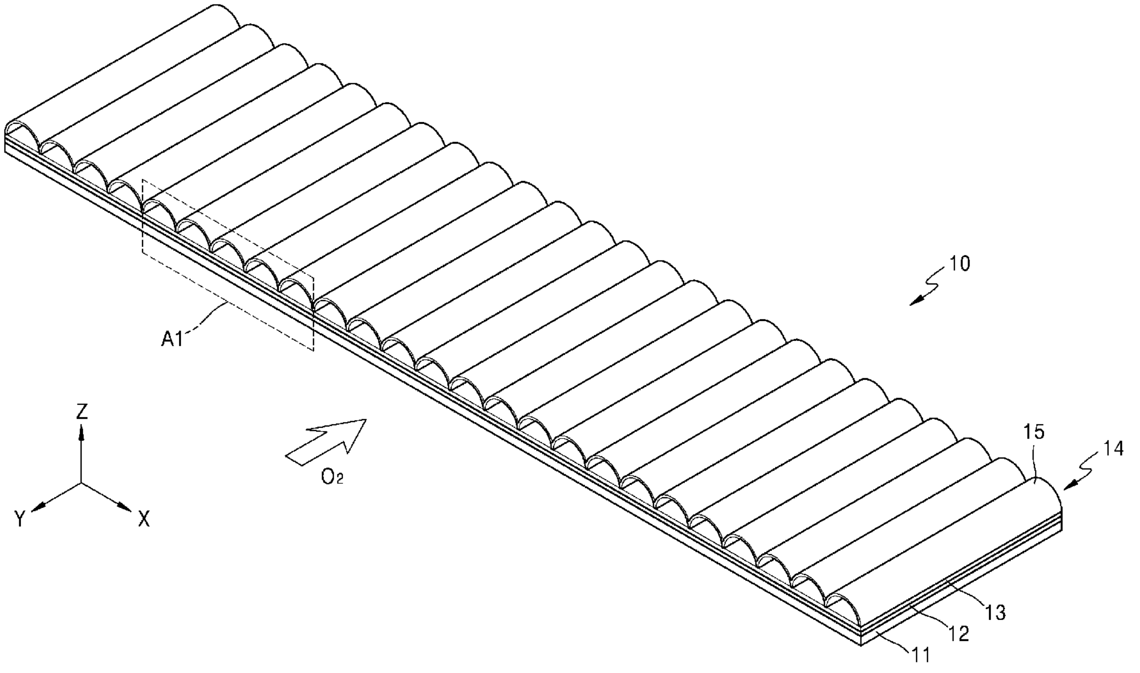


FIG. 1

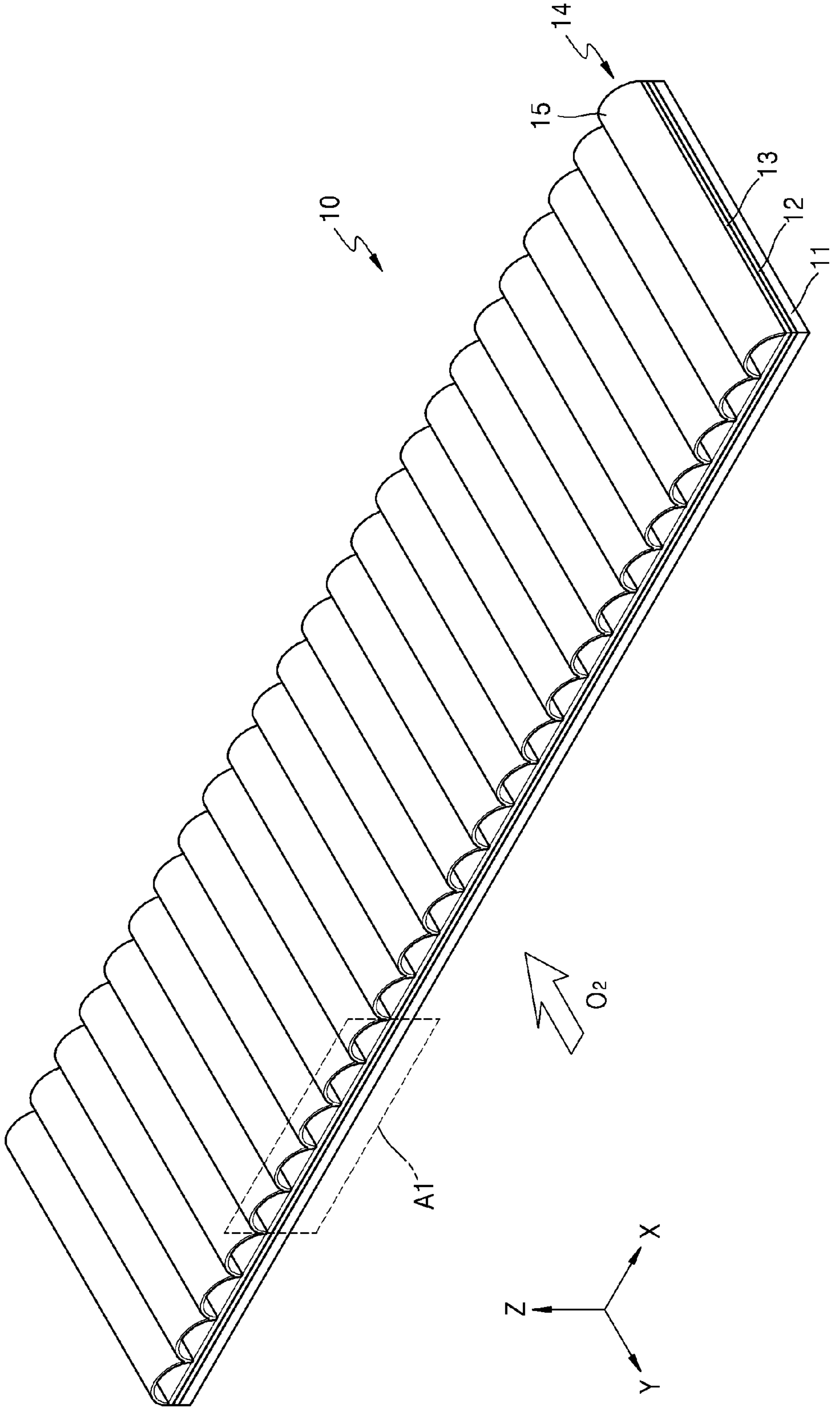


FIG. 2

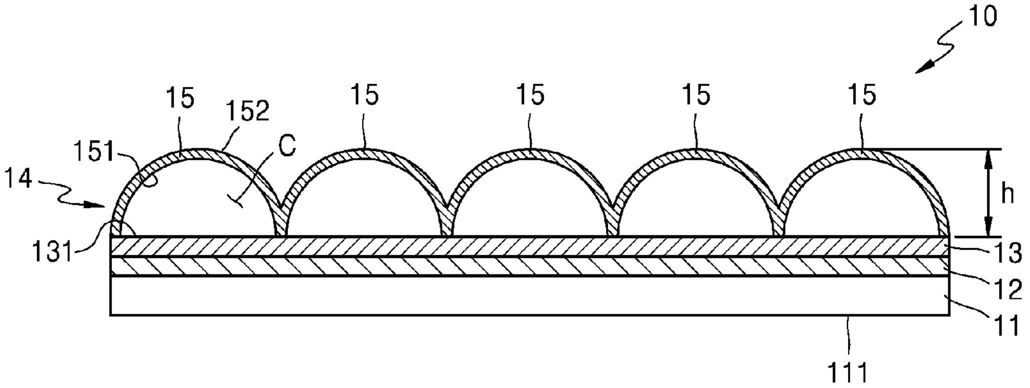


FIG. 3A

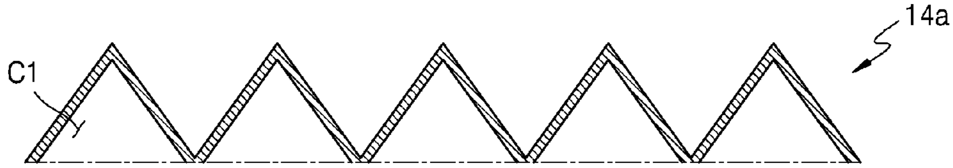


FIG. 3B

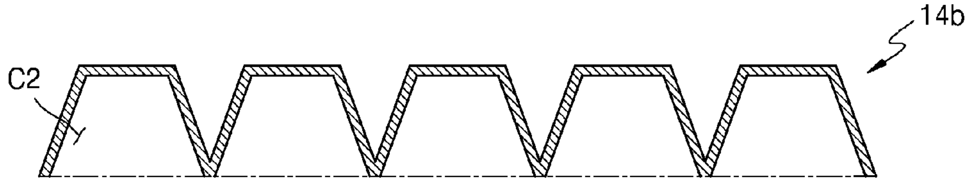


FIG. 3C

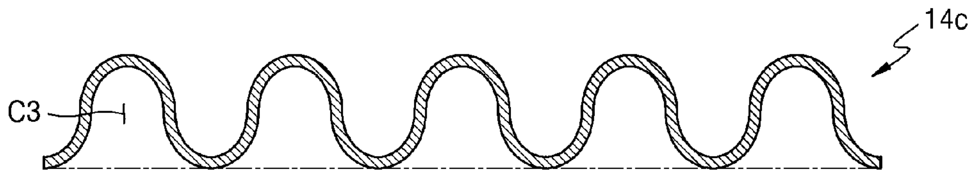


FIG. 4

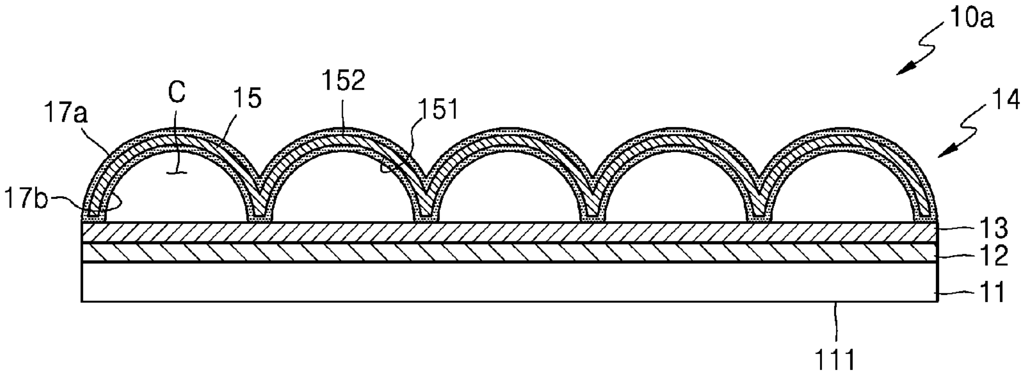


FIG. 5

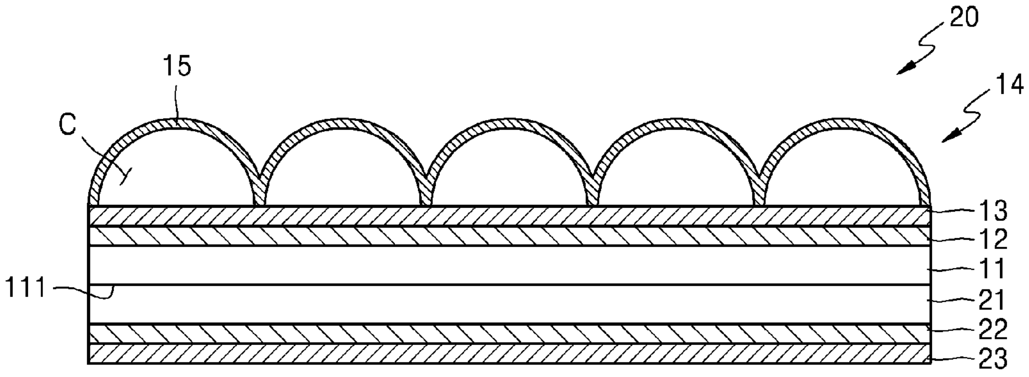


FIG. 6

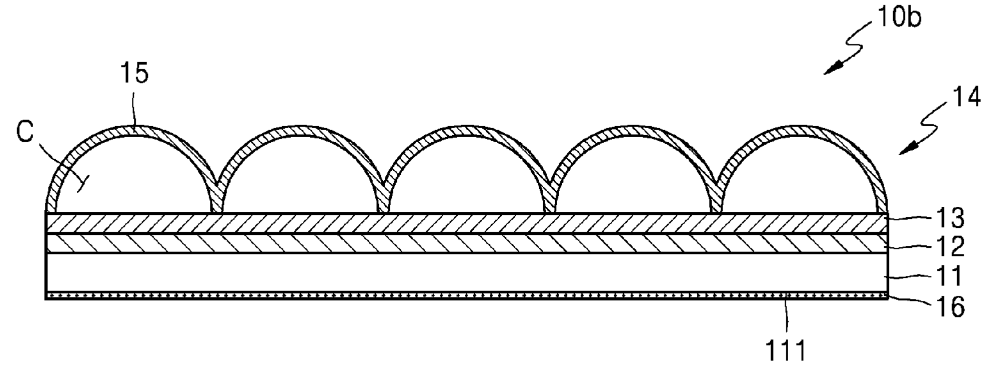


FIG. 7A-1

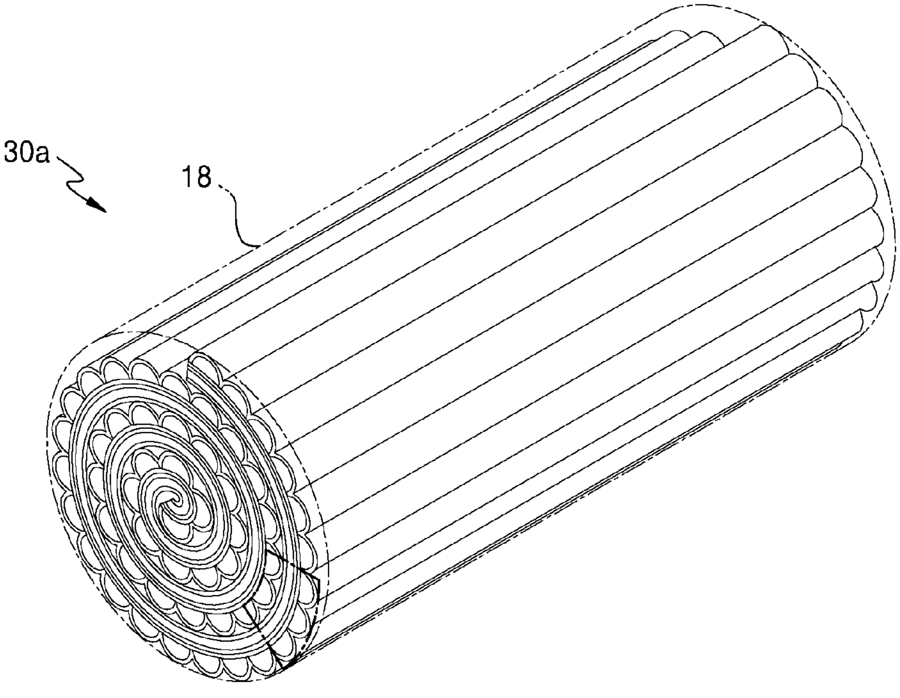


FIG. 7A-2

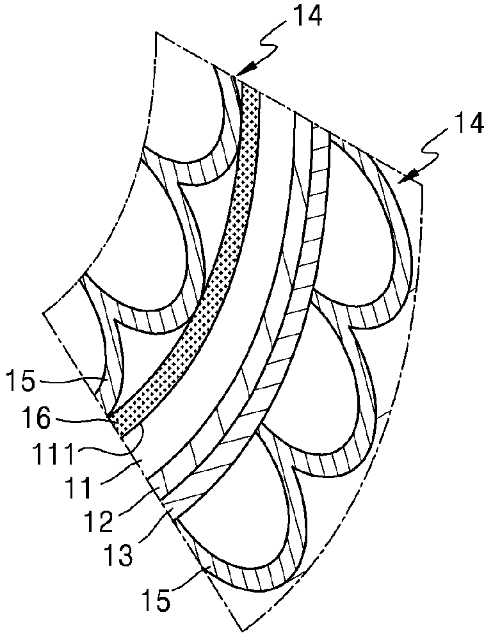


FIG. 7B-1

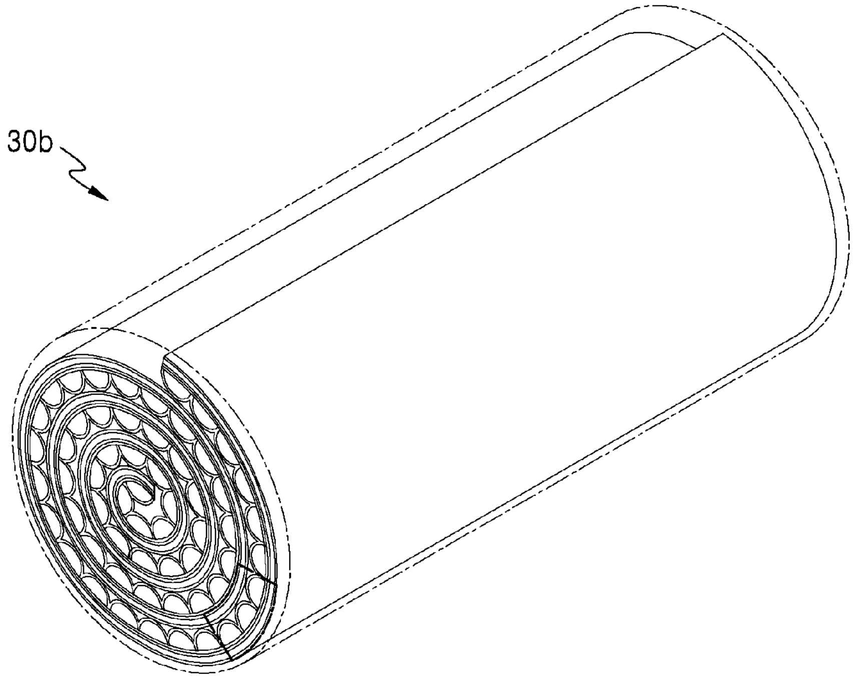


FIG. 7B-2

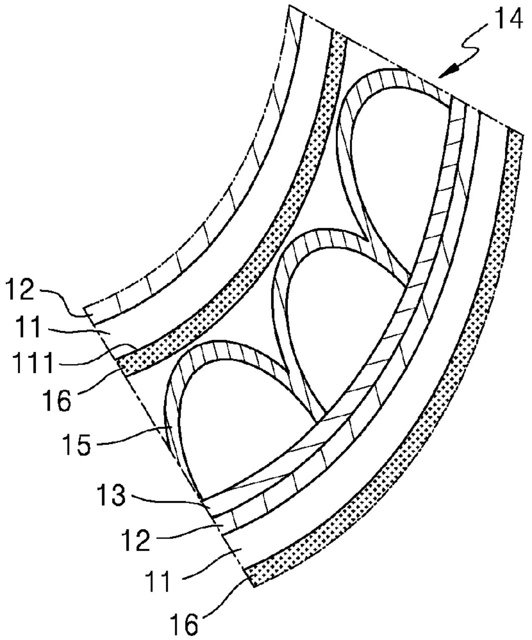


FIG. 8A

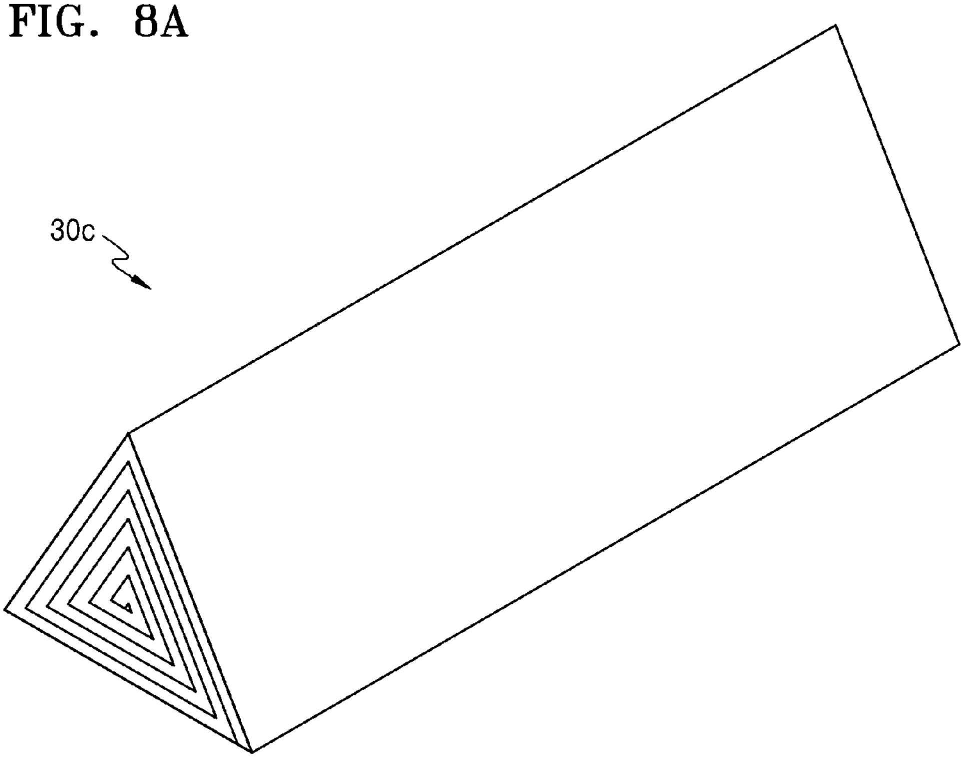


FIG. 8B

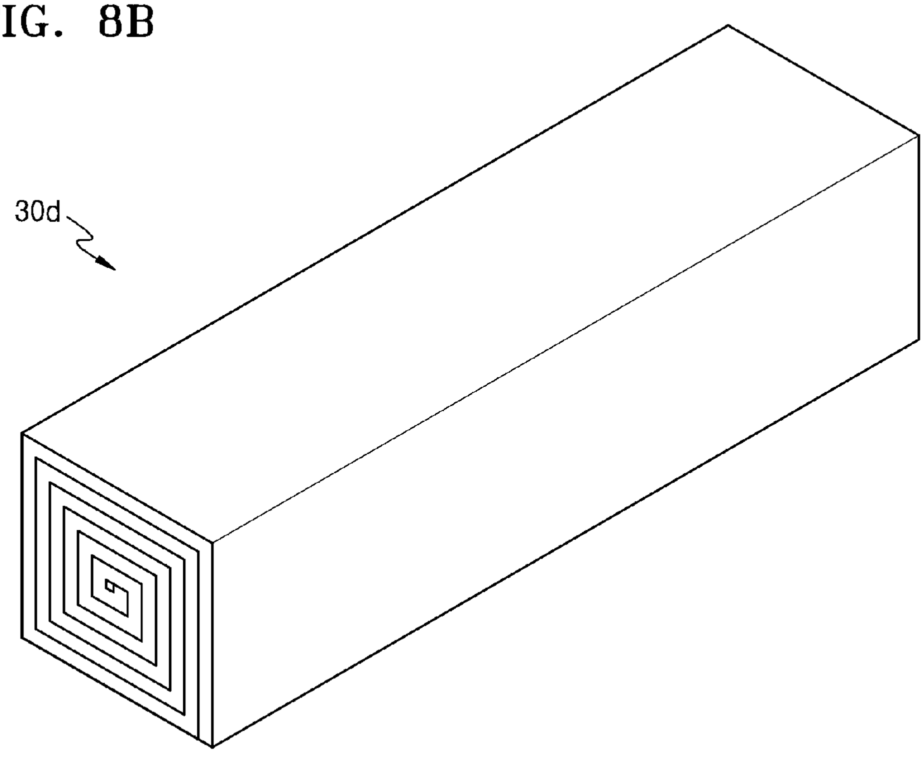


FIG. 9

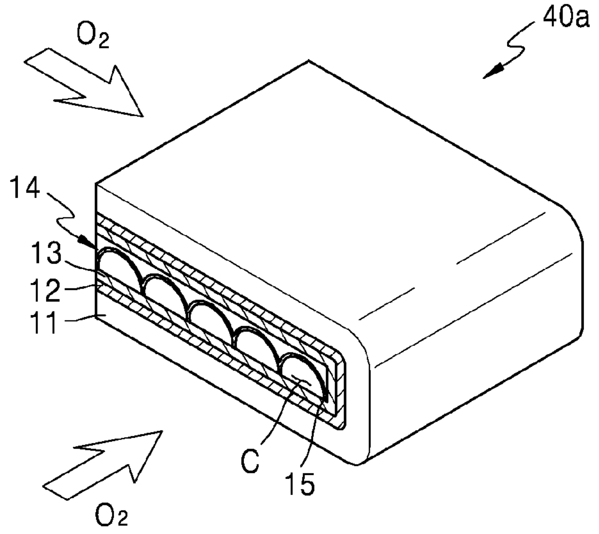


FIG. 10

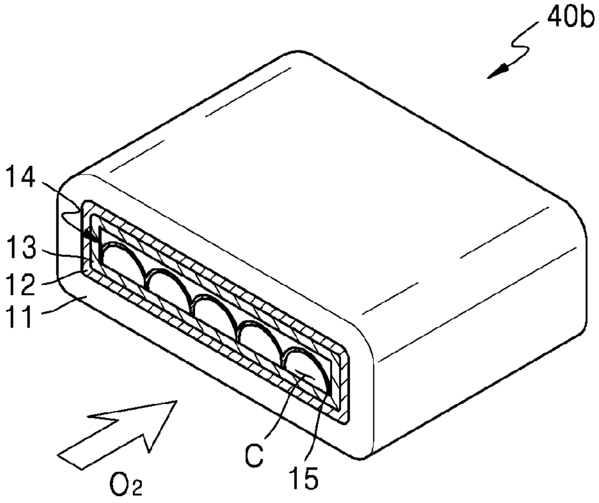


FIG. 11A

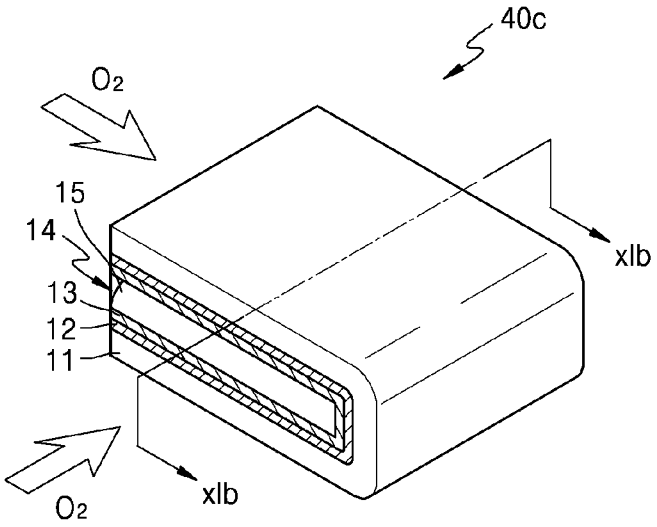


FIG. 11B

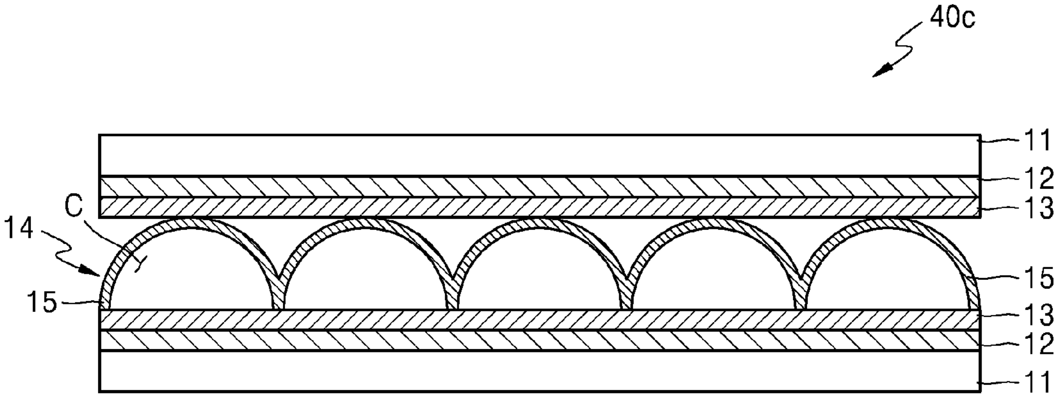


FIG. 12

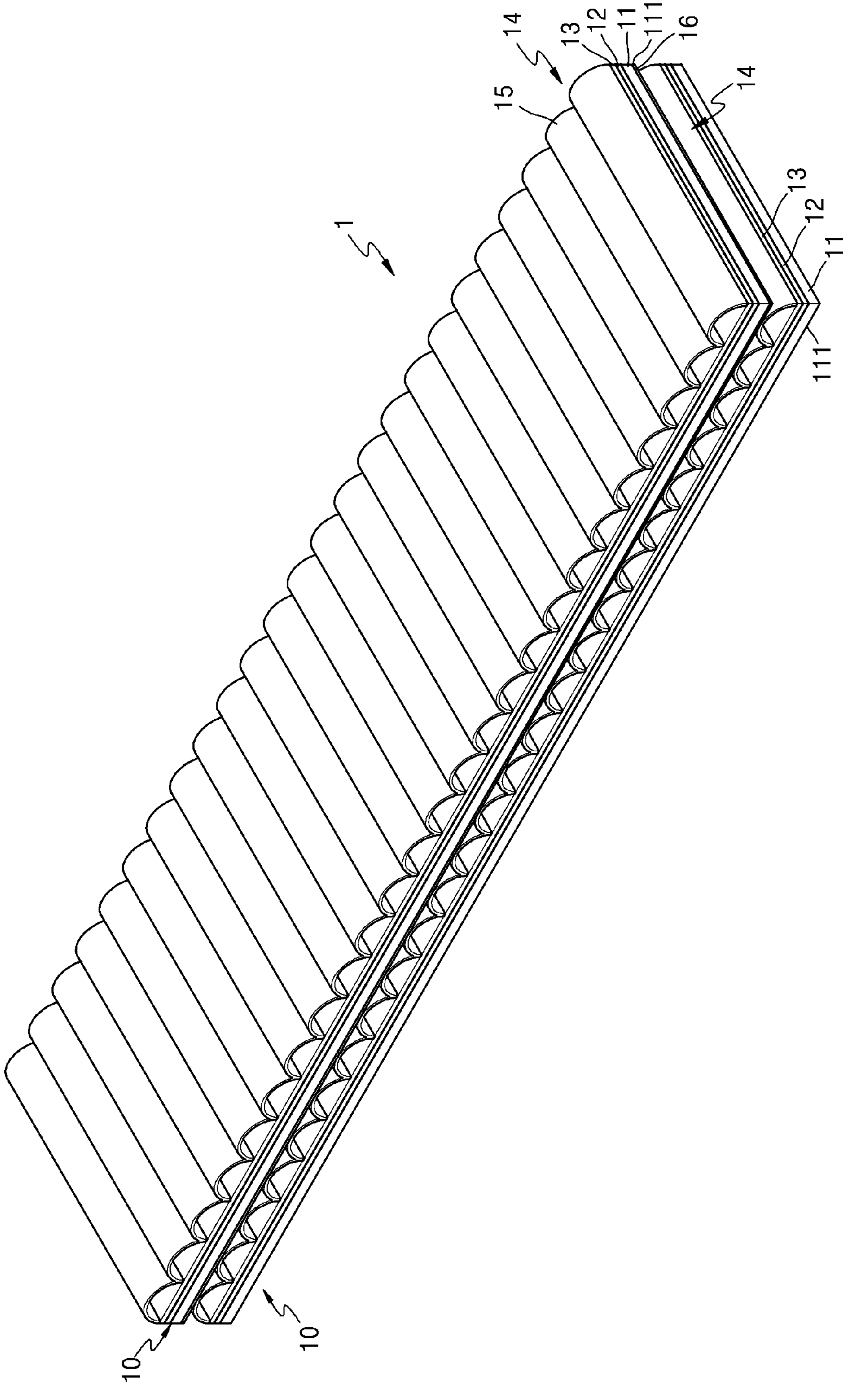


FIG. 13

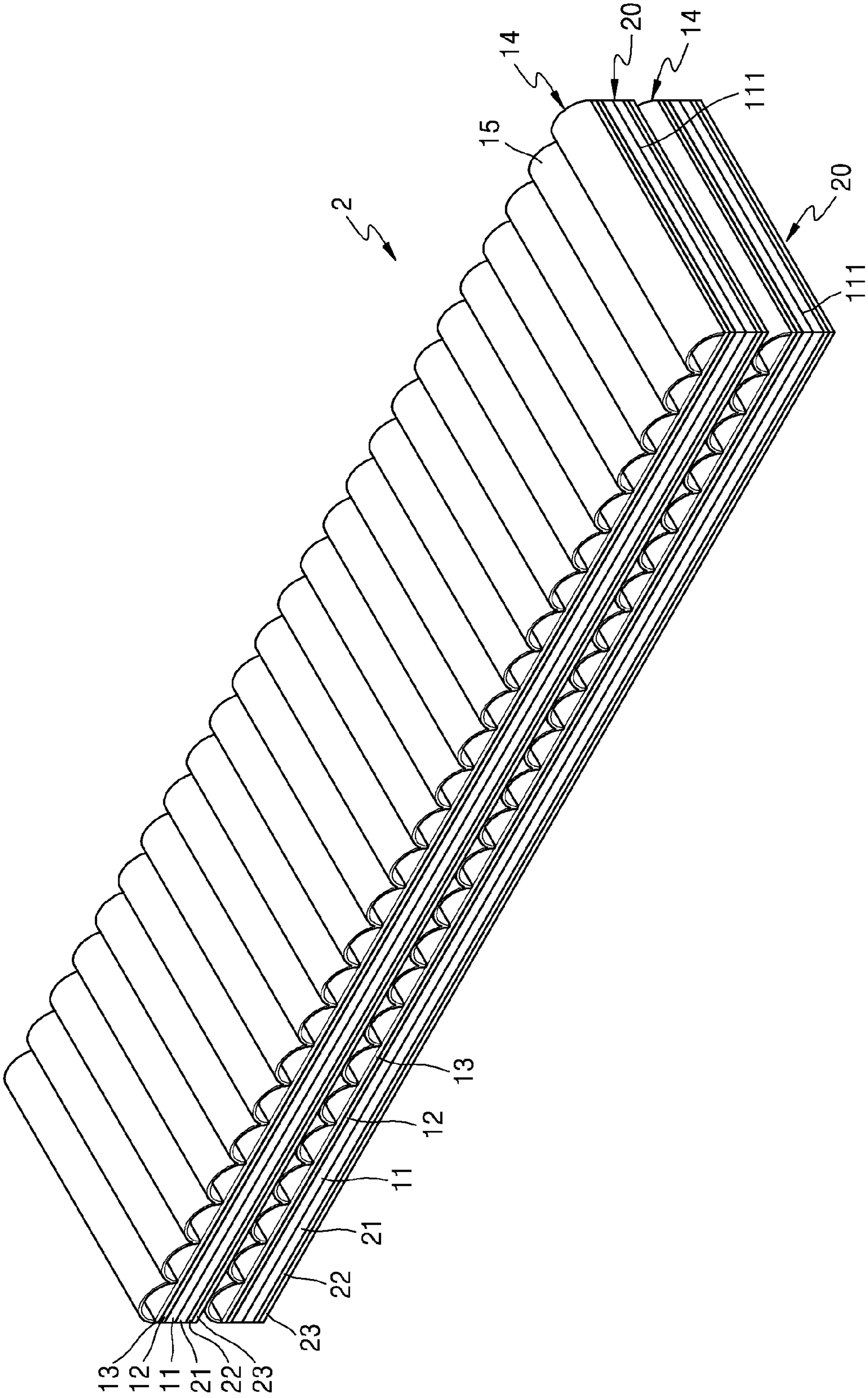


FIG. 14

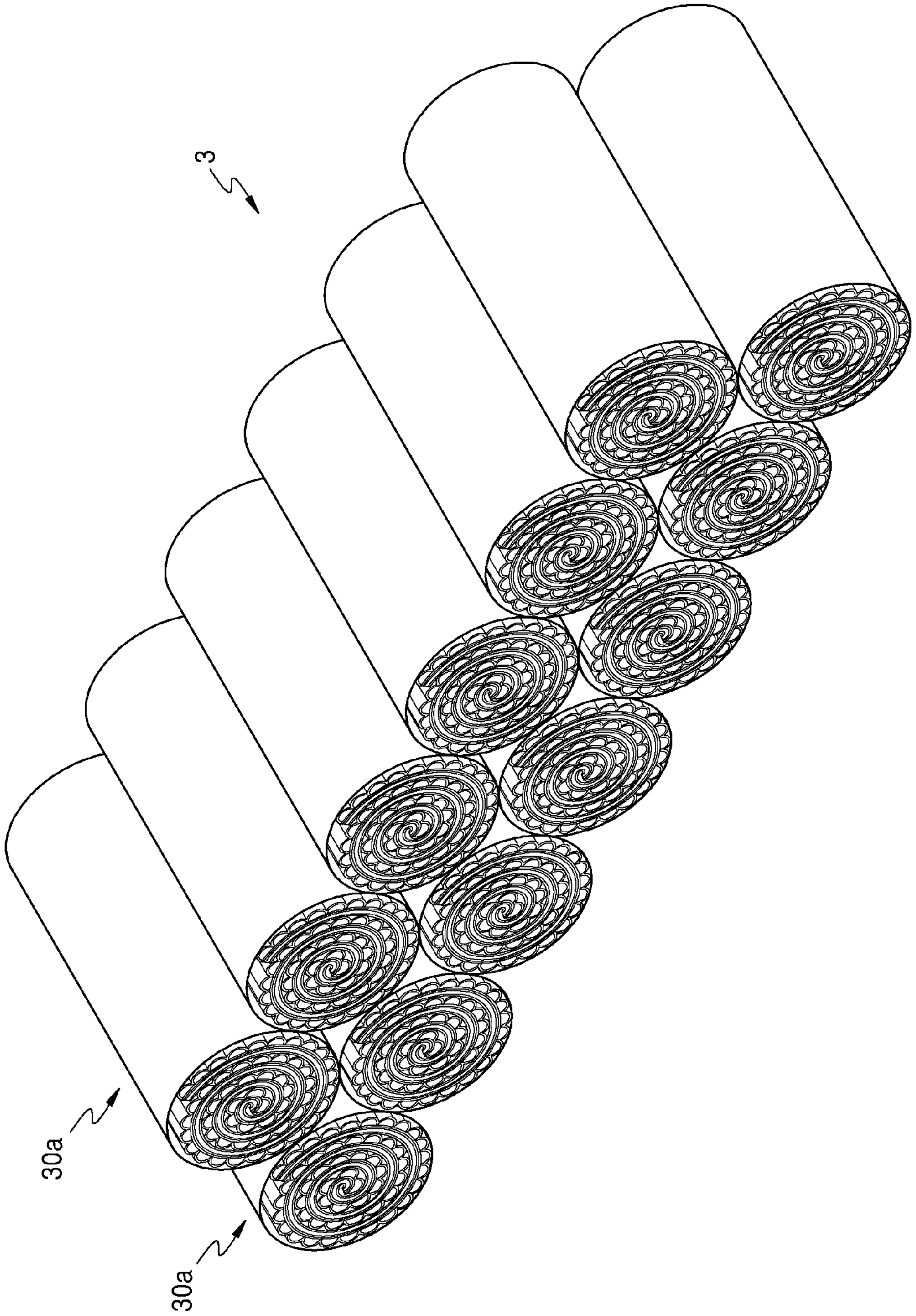


FIG. 15

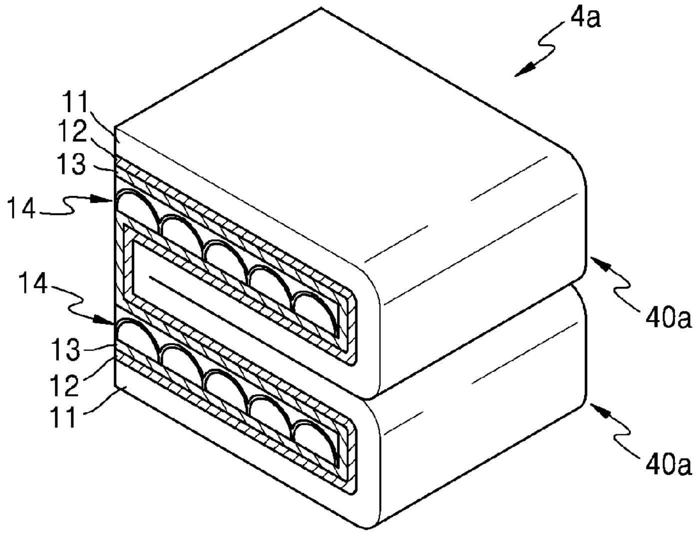

4a
11
12
13
14
14
13
12
11
40a
40a

FIG. 16

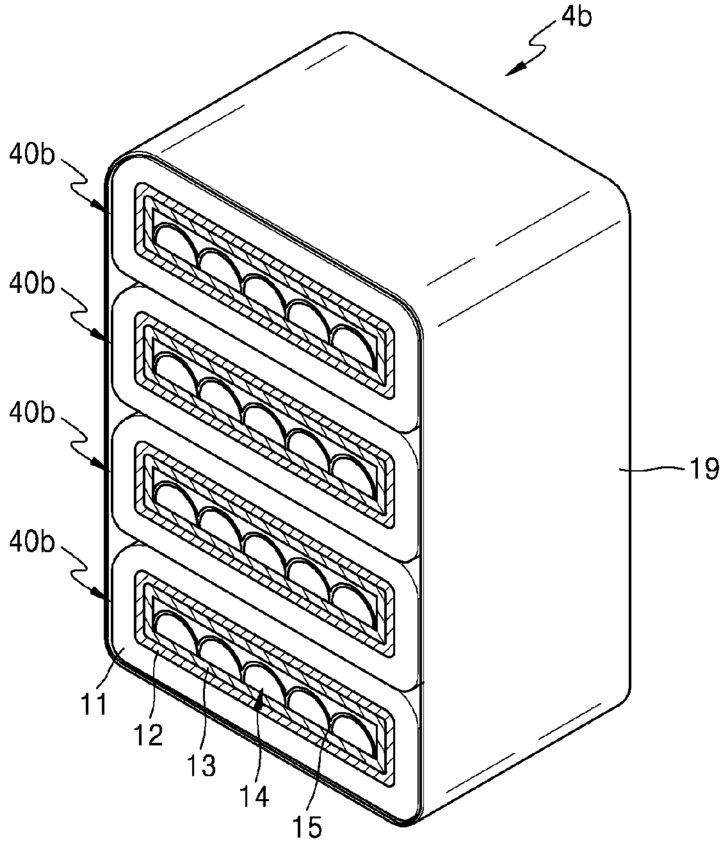

4b
40b
40b
40b
40b
19
11
12
13
14
15

FIG. 17A

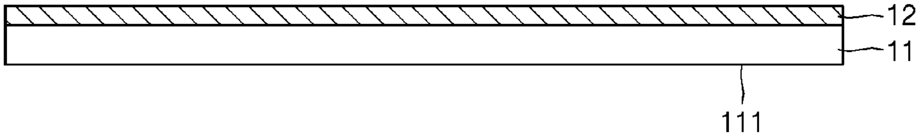


FIG. 17B

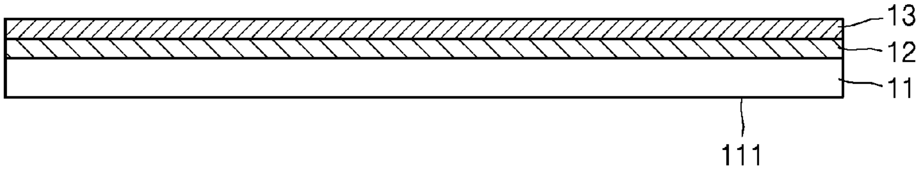


FIG. 17C

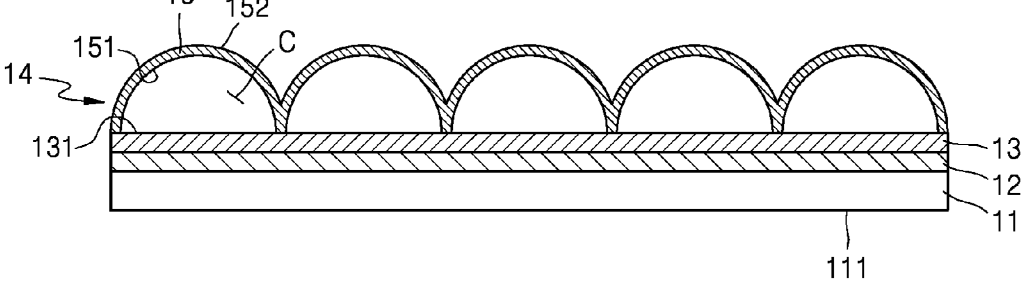


FIG. 18A

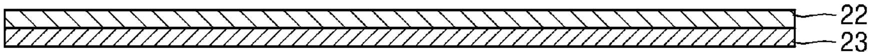


FIG. 18B

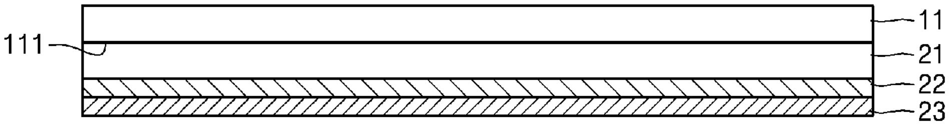


FIG. 18C

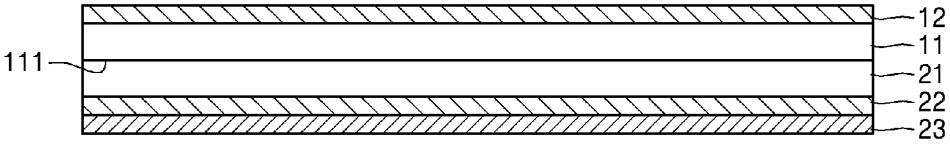


FIG. 18D

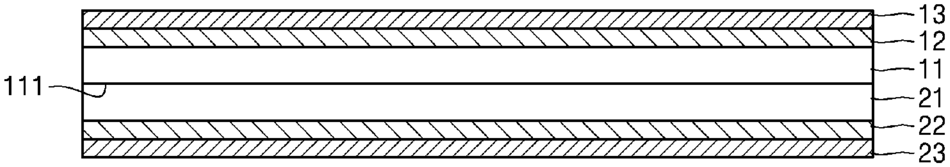


FIG. 18E

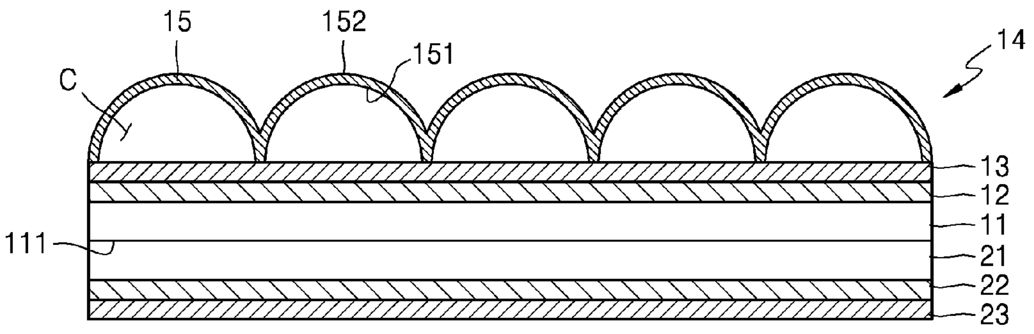


FIG. 19A

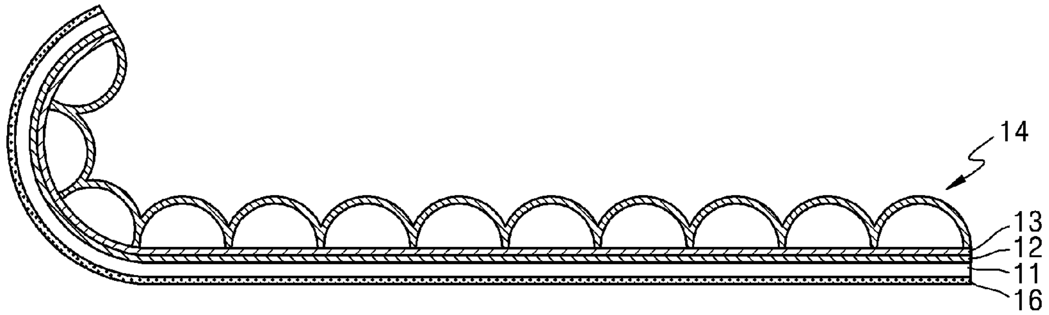
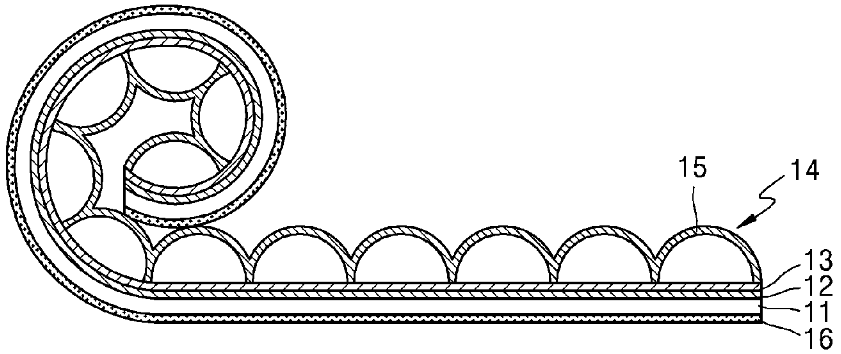


FIG. 19B



METAL-AIR BATTERY CELL, METAL-AIR BATTERY INCLUDING METAL-AIR BATTERY CELL AND METHOD OF FABRICATING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Korean Patent Application No. 10-2014-0063110, filed on May 26, 2014, and all the benefits accruing therefrom under 35 U.S.C. §119, the disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND

[0002] 1. Field

[0003] Provided is a metal-air battery cell, a metal-air battery including the metal-air battery cell, and a method of fabricating the metal-air battery cell, and more particularly, a metal-air battery cell that is configured to easily supply air to a positive electrode and is improved in terms of energy density, a metal-air battery including the metal-air battery cell, and a method of fabricating the metal-air battery cell.

[0004] 2. Description of the Related Art

[0005] Metal-air batteries each include a plurality of metal-air battery cells, and each metal-air battery cell includes a negative electrode capable of intercalating/deintercalating ions and a positive electrode using oxygen included in air as an active material. A reduction/oxidation reaction of introduced oxygen occurs at the positive electrode, and an oxidation/reduction reaction of metal occurs at the negative electrode. Electric energy is obtained from chemical energy generated by such reactions. For example, a metal-air battery absorbs oxygen when being electrically discharged and emits oxygen when being electrically charged. As described above, since metal-air batteries use oxygen included in air, the energy density of the metal-air batteries may be markedly increased. For example, the energy density of metal-air batteries may be several times the energy density of lithium ion batteries.

[0006] In addition, since there is a relatively low possibility of metal-air batteries catching on fire in abnormal high-temperature conditions, metal-air batteries may be stably used. Furthermore, since metal-air batteries are operated through absorption/release of oxygen without using a heavy metal material, metal-air batteries may cause relatively less environmental pollution compared to conventional batteries. Owing to the above-mentioned characteristics, much research into metal-air batteries has been conducted.

SUMMARY

[0007] Provided are a metal-air battery cell that is configured to easily supply air to a positive electrode and is improved in terms of energy density, a metal-air battery including the metal-air battery cell, and a method of fabricating the metal-air battery cell.

[0008] Additional features will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the presented embodiments.

[0009] Provided is a metal-air battery cell including: a first negative electrode metal layer; a first positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; a first negative electrode electrolyte film disposed between the first negative electrode metal layer and the first positive electrode layer in a thickness direction; and a first channel layer disposed on the first positive electrode layer and including a plurality of first channel structures, the first channel structures each elongated to extend in an extension direction crossing the thickness direction.

[0010] Each first channel structure among the plurality of first channel structures among the channel structures may be convex in a direction away from an upper surface of the positive electrode layer.

[0011] First cavities of the first channel layer may be defined by the upper surface of the first positive electrode layer and inner surfaces of the convex first channel structures, respectively.

[0012] The first cavities of the first channel layer may have a polygonal cross-sectional shape, a semicircular cross-sectional shape or a wave-form cross-sectional shape.

[0013] The metal-air battery cell may further include: a second negative electrode metal layer disposed under the first negative electrode metal layer; a second positive electrode layer disposed under the second negative electrode metal layer and configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; and a second negative electrode electrolyte film disposed between the second negative electrode metal layer and the second positive electrode layer in the thickness direction.

[0014] The first negative electrode metal layer, the first negative electrode electrolyte film and the first positive electrode layer may each be continuously extended and disposed at opposing sides of the first channel layer in the thickness direction.

[0015] The first negative electrode metal layer, the first negative electrode electrolyte film, the first positive electrode layer and the first channel layer may each be continuously extended and bent about an axis to define the metal-air battery cell in a roll form.

[0016] The first negative electrode metal layer, the first negative electrode electrolyte film and the first positive electrode layer may each be continuously extended and bent upward toward the first channel layer to define the metal-air battery cell in a flat form, and in the flat form of the metal-air battery cell, the first positive electrode layer may contact apexes of the convex first channel structures of the first channel layer.

[0017] An end of the channel layer in an extension direction of the channel structures may be exposed outside the metal-air battery cell.

[0018] The metal-air battery cell may further include: a sub positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs, disposed on a surface of the first channel structures of the first channel layer.

[0019] The negative electrode electrolyte film may include: a separator which is impermeable with respect to oxygen and conductive with respect to metal ions; and an electrolyte configured to conduct the metal ions.

[0020] The first channel structures of the first channel layer may have a porous structure.

[0021] Provided is a metal-air battery including a first metal-air battery cell and a second metal-air battery cell. Each of the first and second metal-air battery cells includes: a first negative electrode metal layer; a first positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; a first negative electrode electrolyte film disposed between the first negative electrode metal layer and the first positive electrode layer in a thickness direction; and a first channel layer disposed on the first positive electrode layer and including a plurality of first channel structures, the first channel structures each elongated to extend in an extension direction crossing the thickness direction.

[0022] The first channel layer of the first metal-air battery cell may be disposed between the first negative electrode metal layers of the first and second metal-air battery cells in the thickness direction.

[0023] The metal-air battery may further include an oxygen blocking layer disposed between the first channel layer of the first metal-air battery cell and the first negative electrode metal layer of the second metal-air battery cell in the thickness direction.

[0024] Each of the first and second metal-air battery cells may further include: a second negative electrode metal layer disposed under the first negative electrode metal layer; a second positive electrode layer disposed under the second negative electrode metal layer and configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; and a second negative electrode electrolyte film disposed between the second negative electrode metal layer and the second positive electrode layer in the thickness direction.

[0025] For each of the first and second metal-air battery cells, the first negative electrode metal layer, the first negative electrode electrolyte film and the first positive electrode layer are each continuously extended and disposed at opposing sides of the first channel layer in the thickness direction.

[0026] Provided is a method of fabricating a metal-air battery cell, including: disposing a first negative electrode electrolyte film between a first negative electrode metal layer and a first positive electrode layer in a thickness direction, the first positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; and disposing a first channel layer on the first positive electrode layer, the first channel layer including a plurality of first channel structures each elongated to extend in an extension direction crossing the thickness direction.

[0027] The method may further include: disposing a second negative electrode electrolyte film between a second negative electrode metal layer and a second positive electrode layer, the second positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; and disposing the second negative electrode metal layer and the first negative electrode metal layer facing each other.

[0028] The first negative electrode metal layer, the first negative electrode electrolyte film and the first positive electrode layer may each be continuously extended and the method may further include bending the continuously extended first negative electrode metal layer, first negative electrode electrolyte film and first positive electrode layer to be disposed at opposing sides of the first channel layer in the thickness direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] These and/or other features will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings in which:

[0030] FIG. **1** is a perspective view schematically illustrating a metal-air battery cell according to an embodiment of the present invention;

[0031] FIG. **2** is an enlarged cross-sectional view illustrating portion A1 of the metal-air battery cell illustrated in FIG. **1**;

[0032] FIGS. **3**A to **3**C are enlarged cross-sectional views illustrating modified examples of cavities of the metal-air battery cell illustrated in FIG. **2**;

[0033] FIG. **4** is a cross-sectional view illustrating a metal-air battery cell in which sub positive electrode layers are disposed on a channel layer according to an embodiment of the present invention;

[0034] FIG. **5** is a cross-sectional view illustrating a metal-air battery cell according to another embodiment of the present invention;

[0035] FIG. **6** is a cross-sectional view illustrating a metal-air battery cell configured to prevent oxygen from making contact with a negative electrode metal layer according to another embodiment of the present invention;

[0036] FIGS. **7A_1** and **7B_1** are perspective views illustrating examples in which the metal-air battery cell illustrated in FIG. **1** is bent, and FIGS. **7A_2** and **7B_2** are enlarged cross-sectional views of the metal-air battery cells illustrated in FIGS. **7A_1** and **7B_1**, respectively;

[0037] FIGS. **8**A and **8**B are perspective views illustrating other examples in which the metal-air battery cell illustrated in FIG. **1** is bent;

[0038] FIGS. **9**, **10** and **11**A are perspective views illustrating metal-air battery cells each including a negative electrode metal layer, a negative electrode electrolyte film and a positive electrode layer that are bent according to embodiments of the present invention, and FIG. **11**B is a cross-sectional view of the metal-air battery cell illustrated in FIG. **11**A taken along xlb-xlb;

[0039] FIG. **12** is a perspective view illustrating a metal-air battery including a plurality of metal-air battery cells such as the metal-air battery cell illustrated in FIG. **1**, according to an embodiment of the present invention;

[0040] FIG. **13** is a perspective view illustrating a metal-air battery including a plurality of metal-air battery cells such as the metal-air battery cell illustrated in FIG. **5**, according to an embodiment of the present invention;

[0041] FIG. **14** is a perspective view illustrating a metal-air battery including a plurality of metal-air battery cells such as the metal-air battery cell **30***a* illustrated in FIGS. **7A_1** and **7A_2**, according to an embodiment of the present invention;

[0042] FIG. **15** is a perspective view illustrating a metal-air battery including a plurality of metal-air battery cells such as the metal-air battery cell illustrated in FIG. **9**, according to an embodiment of the present invention;

[0043] FIG. **16** is a perspective view illustrating a metal-air battery including a plurality of metal-air battery cells such as the metal-air battery cell illustrated in FIG. **10**, according to an embodiment of the present invention;

[0044] FIGS. **17**A to **17**C are schematic cross-sectional views illustrating a method of fabricating the metal-air battery cell illustrated in FIG. **1**, according to an embodiment of the present invention;

[0045] FIGS. **18**A to **18**E are schematic cross-sectional views illustrating a method of fabricating the metal-air battery cell illustrated in FIG. **5**, according to an embodiment of the present invention; and

[0046] FIGS. **19**A and **19**B are schematic cross-sectional views illustrating an exemplary process of deforming the metal-air battery cell illustrated in FIG. **17**C, according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0047] Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings. In this regard, the present embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the embodiments are merely described below, by referring to the figures, to explain features of the present description.

[0048] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. As used herein, the singular forms "a," "an," and "the" are intended to include the plural forms, including expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list. It will be further understood that the terms "comprises" and/or "comprising," or "includes" and/or "including" when used in this specification, specify the presence of stated features, regions, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, regions, integers, steps, operations, elements, components, and/or groups thereof.

[0049] In the drawings, like reference numbers refer to like elements, and also the size of each element may be exaggerated for clarity of illustration. The embodiments described herein are for illustrative purposes only, and various modifications may be made therefrom. In the following description, when an element is referred to as being "above" or "on" another element in a layered structure, it may be directly on the other element while making contact with the other element or may be above the other element without making contact with the other element.

[0050] It will be understood that, although the terms "first," "second," "third" etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer or section from another element, component, region, layer or section. Thus, "a first element," "component," "region," "layer" or "section" discussed below could be termed a second element, component, region, layer or section without departing from the teachings herein.

[0051] Furthermore, relative terms, such as "lower" or "bottom" and "upper" or "top," may be used herein to describe one element's relationship to another elements as illustrated in the Figures. It will be understood that relative terms are intended to encompass different orientations of the device in addition to the orientation depicted in the Figures. For example, if the device in one of the figures is turned over, elements described as being on the "lower" side of other elements would then be oriented on "upper" sides of the other elements. The exemplary term "lower," can therefore, encompasses both an orientation of "lower" and "upper," depending on the particular orientation of the figure. Similarly, if the device in one of the figures is turned over, elements described as "below" or "beneath" other elements would then be oriented "above" the other elements. The exemplary terms "below" or "beneath" can, therefore, encompass both an orientation of above and below.

[0052] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and the present disclosure, and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0053] Embodiments are described herein with reference to cross section illustrations that are schematic illustrations of idealized embodiments. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, embodiments described herein should not be construed as limited to the particular shapes of regions as illustrated herein but are to include deviations in shapes that result, for example, from manufacturing. For example, a region illustrated or described as flat may, typically, have rough and/or nonlinear features. Moreover, sharp angles that are illustrated may be rounded. Thus, the regions illustrated in the figures are schematic in nature and their shapes are not intended to illustrate the precise shape of a region and are not intended to limit the scope of the present claims.

[0054] Hereinafter, a metal-air battery cell, a metal-air battery including the metal-air battery cell, and a method of fabricating the metal-air battery cell will be described in detail with reference to the accompanying drawings.

[0055] FIG. **1** is a perspective view schematically illustrating a metal-air battery cell **10**, and FIG. **2** is an enlarged cross-sectional view illustrating portion A1 of the metal-air battery cell **10** illustrated in FIG. **1**. FIGS. **3**A to **3**C are enlarged cross-sectional views illustrating modified examples of cavities of the metal-air battery cell illustrated in FIG. **2**.

[0056] Referring to FIGS. **1** and **2**, the metal-air battery cell **10** may include a negative electrode metal layer **11**, a negative electrode electrolyte film **12** disposed on the negative electrode metal layer **11**, a positive electrode layer **13** disposed on the negative electrode electrolyte film **12**, and a channel layer **14** disposed on the positive electrode layer **13**.

[0057] The negative electrode metal layer **11** may intercalate/deintercalate metal ions. In embodiments, for example, the negative electrode metal layer **11** may include or be formed of lithium (Li), sodium (Na), zinc (Zn), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), aluminum (Al) or an alloy thereof.

[0058] The negative electrode electrolyte film **12** may deliver metal ions to the positive electrode layer **13**. The negative electrode electrolyte film **12** may include an electrolyte. In an embodiment of forming the electrolyte, a metal salt may be dissolved in a solvent. The electrolyte may be a solid electrolyte including a polymer electrolyte, an inorganic electrolyte, or a combination thereof, and may be prepared in such a manner that the electrolyte has flexibility. In embodiments, for example, the metal salt may be a lithium salt such as $LiN(SO_2CF_2CF_3)_2$, $LiN(SO_2C_2F_5)_2$, $LiClO_4$, $LiBF_4$, $LiPF_6$, $LiSbF_6$, $LiAsF_6$, $LiCF_3SO_3$, $LiN(SO_2CF_3)_2$, $LiC(SO_2CF_3)_3$,

$LiN(SO_3CF_3)_2$, $LiC_4F_9SO_3$, $LiAlCl_4$ or LiTFSI (Lithium bis (trifluoromethanesulfonyl)imide). In addition to the lithium salt, the metal salt may further include another metal salt such as $AlCl_3$, $MgCl_2$, NaCl, KCl, NaBr, KBr, or $CaCl_2$. The solvent may be any of a number of solvents capable of dissolving the above-listed lithium salts and metal salts.

[0059] In addition, the negative electrode electrolyte film **12** may further include a separator impermeable with respect to oxygen and conductive with respect to metal ions. The separator may be a flexible polymer separator. In embodiments, for example, the separator may be a nonwoven polymer fabric such as a nonwoven polypropylene fabric or a nonwoven polyphenylene sulfide fabric, or may be a porous olefin-containing film such as a porous polyethylene film or a porous polypropylene film.

[0060] The separator and the electrolyte may form different layers within the negative electrode electrolyte film **12**, or the separator (e.g., porous separator) may be impregnated with the electrolyte to form a single layer within the negative electrode electrolyte film **12**. In an embodiment of forming the negative electrode electrolyte film **12**, for example, pores of a porous separator may be impregnated with an electrolyte and the electrolyte may include a combination of polyethylene oxide ("PEO") and LiTFSI.

[0061] The positive electrode layer **13** may include an electrolyte configured for conducting metal ions, a catalyst configured for oxidation/reduction of oxygen, a conductive material, and a binder. In an embodiment of forming the positive electrode layer **13**, for example, the electrolyte, the catalyst, the conductive material and the binder may be combined with each other, and a solvent may be added to the combination to form a positive electrode slurry. Thereafter, the positive electrode slurry may be applied to the negative electrode electrolyte film **12** and dried to form the positive electrode layer **13**.

[0062] The electrolyte of the positive electrode layer **13** may include the above-described lithium salt or metal salt. In embodiments, for example, the conductive material of the positive electrode layer **13** may be a porous material such as a carbon-containing material, a conductive metal material, a conductive organic material or a combination thereof. In embodiments, for example, the carbon-containing material may be carbon black, graphite, graphene, active carbon, carbon fiber or carbon nanotubes. In embodiments, for example, the conductive metal material may be metal powder. In embodiments, for example, the catalyst of the positive electrode layer **13** may be platinum (Pt), gold (Au) or silver (Ag). Alternatively, the catalyst may be an oxide of manganese (Mn), nickel (Ni), or cobalt (Co). In embodiments, for example, the binder of the positive electrode layer **13** may be polytetrafluoroethylene ("PTFE"), polypropylene, polyvinylidene fluoride ("PVDF"), polyethylene, or styrene-butadiene rubber ("SBR").

[0063] The channel layer **14** is configured to cause air to flow on and be incident to the positive electrode layer **13**. The channel layer **14** may include a plurality of channel structures **15** which defines the channel layer **14**. Each of the channel structures **15** may form an independent channel through which air flows and may be elongated to extend in a direction crossing a direction (z-axis direction) in which the positive electrode layer **13** is disposed relative to other layers. The z-axis direction may otherwise be referred to as a laminating direction or a thickness direction. In an embodiment, for example, the channel structures **15** may be linearly elongated to extend in a y-axis direction as shown in FIG. **1**. However, the channel structures **15** are not limited thereto. In another embodiment, for example, the channel structures **15** may be elongated to extend in a curved (e.g., non-linear) shape. The channel structures **15** may be arranged in a direction (x-axis direction) perpendicular to both the laminating direction (z-axis direction) of the positive electrode layer **13** and the extension direction (y-axis direction) of the channel structures **15**. In an embodiment, for example, the channel layer **14** may be considered as having a corrugated shape defined by alternating ridges and grooves.

[0064] Each of the channel structures **15** may be convex in a direction (z-axis direction) taken away from an upper surface **131** of the positive electrode layer **13**. Cavities C are defined by inner surfaces **151** of the convex channel structures **15** and the upper surface **131** of the positive electrode layer **13**. The cavities C are elongated to extend in the same direction as the extension direction of the channel structures **15**. Ambient air may be introduced into the cavities C through at least one of front and rear ends of each of the cavities C in the extension direction of the cavities C. Each of the front and rear ends of the cavity C may be open to outside the metal-air battery cell **10**. In addition, ambient air may be introduced into the cavities C via the channel layer **14** depending on a material used to form the channel layer **14**. In an embodiment, for example, the ambient air may be introduced into the cavities C by traveling through a thickness of the material forming the convex channel structure **15**, such as into an outer surface **152**, through the thickness and out of the inner surface **151** thereof.

[0065] Air introduced into the cavities C may make direct contact with the upper surface **131** of the positive electrode layer **13**. Oxygen (O_2) included in the air is introduced into the cavities C. That is, the positive electrode layer **13** may smoothly make contact with oxygen (O_2) included in air which is introduced via the channel layer **14** to the positive electrode layer **13**.

[0066] As described above, since oxygen (O_2) is smoothly supplied to the positive electrode layer **13** through the channel layer **14**, an additional space for generating air flow is not required at a position above the channel layer **14** (e.g., further in the direction away from an upper surface **131** of the positive electrode layer **13**). That is, a second metal-air battery cell **10** may be brought into contact with an upper side of the channel layer **14** of an underlying first metal-air battery cell **10**. Therefore, since a plurality of metal-air battery cells **10** can be disposed in the z-axis direction, a larger number of metal-air battery cells **10** may be disposed in a given planar area defined in the x-axis and y-axis directions.

[0067] In addition, the metal-air battery cell **10** may be cooled more efficiently owing to the channel layer **14**. During operation of the metal-air battery cell **10**, heat may be generated when the positive electrode layer **13** is oxidized. According to the illustrated embodiment, since air making direct contact with the positive electrode layer **13** flows in the cavities C of the channel layer **14**, overheating of the positive electrode layer **13** may be reduced or effectively prevented.

[0068] The cavities C may have various cross-sectional shapes or profiles as long as the cavities C are convex with reference to the upper surface **131** of the positive electrode layer **13**.

[0069] In an embodiment, for example, the cavities C may have a semicircular cross-sectional shape as shown in FIG. **2**. In other embodiments, cavities C**1**, C**2** and C**3** of channel layers **14***a*, **14***b* and **14***c* may have a polygonal triangular shape, a polygonal rectangular shape, or a wave-form shape as shown in FIGS. **3**A, **3**B and **3**C, respectively. Within each of the embodiments of the channel layers **14**, **14***a*, **14***b* and **14***c*, each group of the cavities C, C**1**, C**2** and C**3** have the same shape. However, the present invention is not limited thereto. In alternative embodiments, for example, a portion of the group of cavities C, C**1**, C**2** and C**3** within a channel layer **14**, **14***a*, **14***b* and **14***c* may have a size and/or shape different from a remainder of the group.

[0070] The channel layer **14** may include or be formed of any of a number of materials as long as a convex profile and the shape of the channel structures **15** is maintained. In an embodiment, for example, the channel layer **14** may include a material including one selected from porous metals, porous ceramic materials, porous polymers, porous carbon materials, porous light metals and combinations thereof. Since the channel layer **14** has a porous structure, the channel layer **14** may absorb oxygen (O_2) included in the air and smoothly diffuse the oxygen (O_2) into the cavities C. Examples of the porous metals may include foam metals having a sponge shape, and metal fiber mats. Examples of the porous carbon materials may include carbon paper, carbon cloth, and carbon felt that are formed of carbon fibers. Examples of the porous ceramic materials may include magnesium-aluminum silicate. Examples of the porous polymers may include porous polyethylene and porous polypropylene. Examples of the porous light metals may include nickel meshes, and flexible composite materials made of polymers and nickel meshes.

[0071] FIG. **4** is a cross-sectional view illustrating a metal-air battery cell in which sub positive electrode layers are disposed on a channel layer according to an embodiment of the present invention.

[0072] Sub positive electrode layers **17***a* and **17***b* configured to use oxygen (O_2) as an active material may be disposed on surface portions of the channel layer **14**. FIG. **4** illustrates a metal-air battery cell **10***a* in which sub positive electrode layers **17***a* and **17***b* are disposed on a channel layer **14** according to an embodiment. Referring to FIG. **4**, the sub positive electrode layers **17***a* and **17***b* using oxygen (O_2) as an active material may be respectively disposed on the outer surface **152** and the inner surface **151** of the channel layer **14**. Owing to the sub positive electrode layers **17***a* and **17***b*, a larger total planar area of the metal-air battery cell **10***a* may be structurally brought into contact with oxygen (O_2).

[0073] The sub positive electrode layers **17***a* and **17***b* may make direct contact with a positive electrode layer **13** and may be electrically connected to the positive electrode layer **13**. In an embodiment, for example, the sub positive electrode layer **17***b* may be disposed between the channel structure **15** and the positive electrode layer **13**. The sub positive electrode layer **17***b* may extend between adjacent cavities C and/or extend from endmost cavities C to be connected to the sub positive electrode layer **17***a*.

[0074] The sub positive electrode layers **17***a* and **17***b* may include an electrolyte configured for conducting metal ions, a catalyst configured for oxidation/reduction of oxygen (O_2), a conductive material, and a binder. The channel layer **14** and the sub positive electrode layers **17***a* and **17***b* may collectively form a single layer (e.g., monolayer) or may define a plurality of different layers as shown in FIG. **4**. In an embodiment of forming a sub positive electrode layer, for example, the electrolyte, the catalyst, the conductive material and the binder may be combined, and a solvent may be added to the combination to form a positive electrode slurry. Thereafter, the positive electrode slurry may be applied to the channel layer **14** and dried to form the sub positive electrode layers **17***a* and **17***b*. The sub positive electrode layers **17***a* and **17***b* may include the same material as each other and/or as the positive electrode layer **13**. In an embodiment of forming the sub positive electrode layers **17***a* and **17***b*, a same material as that used to form the positive electrode layer **13** may form the sub positive electrode layers **17***a* and **17***b*.

[0075] Referring back to FIG. **2**, the channel layer **14** may function as a buffer when an overall thickness of the metal-air battery cell **10** is changed during a charging/discharging operation thereof.

[0076] In the metal-air battery cell **10**, at least one selected from the positive electrode layer **13** and the negative electrode metal layer **11** may vary in thickness during a charging/discharging operation of the metal-air battery cell **10**. A thickness of the negative electrode metal layer **11** may decrease during a discharging operation and may increase during a charging operation. A thickness of the positive electrode layer **13** may increase during a discharging operation and may decrease during a charging operation.

[0077] When the thickness of at least one of the negative electrode metal layer **11** and the positive electrode layer **13** varies during a charging or discharging operation as described above, an overall height h (refer to FIG. **1**) of the channel layer **14** may vary according to thickness variations of the negative electrode metal layer **11** and the positive electrode layer **13** within the metal-air battery cell **10**. The overall height h of the channel layer **14** refers to the distance between the upper surface **131** of the positive electrode layer **13** and an apex of the channel layer **14**, or a maximum distance between the positive electrode layer **13** and the channel layer **14**. Since the overall height h of the channel layer **14** is variable, the formation of metal dendrites in the negative electrode metal layer **11** may be suppressed.

[0078] The overall height h of the channel layer **14** may easily vary during a charging or discharging operation as described above owing to the structure thereof. Since the channel layer **14** includes the channel structures **15** forming the cavities C, the overall height h of the channel layer **14** may easily vary during a charging or discharging operation as described above as compared with a flat structure during a charging or discharging operation.

[0079] The channel layer **14** may include or be formed of an elastic material. Where the channel layer **14** includes elastic material, the overall height h of the channel layer **14** may vary more easily during a charging or discharging operation as described above owing to the elasticity thereof. Examples of the elastic material may include elastic polymers. Examples of the elastic polymers may include polyvinylidene fluoride ("PVDF"), a copolymer of vinylidene fluoride and hexafluoro propylene ("PVDF-HFP"), a copolymer of styrene/butadiene ("SBR"), polyethylene oxides ("PEO"), copolymers of ethylene oxides, and copolymers thereof. In addition, any of a number materials (such as metal wires (formed of shape memory alloys), metal meshes, or rubber) usable to form an elastic structure may be unlimitedly used to form the channel layer **14**.

[0080] FIG. **5** is a cross-sectional view illustrating a metal-air battery cell **20** according to another embodiment of the present invention. Elements of the metal-air battery cell **20** of FIG. **5** identical to those of the metal-air battery cell **10** of FIG. **2** are denoted by the same reference numerals, and descriptions thereof are not repeated.

[0081] Referring to FIG. **5**, the metal-air battery cell **20** may further include a second negative electrode metal layer **21** disposed under a negative electrode metal layer **11**, a second negative electrode electrolyte film **22** disposed under the second negative electrode metal layer **21**, and a second positive electrode layer **23** disposed under the second negative electrode electrolyte film **22**.

[0082] The second negative electrode metal layer **21** may intercalate/deintercalate metal ions. In embodiments, for example, the second negative electrode metal layer **21** may include or be formed of lithium (Li), sodium (Na), zinc (Zn), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), aluminum (Al), or an alloy thereof. The second negative electrode metal layer **21** and the negative electrode metal layer **11** may form and define different distinct layers within the metal-air battery cell **20**. However, the invention is not limited thereto. In an alternative embodiment, for example, the second negative electrode metal layer **21** and the negative electrode metal layer **11** may collectively form a single layer (e.g., monolayer) among layers of the metal-air battery cell **20**.

[0083] The second negative electrode electrolyte film **22** may deliver metal ions to the second positive electrode layer **23**. The second negative electrode electrolyte film **22** may include an electrolyte. In an embodiment of forming the electrolyte, a metal salt may be dissolved in a solvent. The electrolyte may be a solid electrolyte including a polymer electrolyte, an inorganic electrolyte, or a combination thereof, and may be prepared in such a manner that the electrolyte has flexibility. In embodiments, for example, the metal salt may be a lithium salt such as $LiN(SO_2CF_2CF_3)_2$, $LiN(SO_2C_2F_5)_2$, $LiClO_4$, $LiBF_4$, $LiPF_6$, $LiSbF_6$, $LiAsF_6$, $LiCF_3SO_3$, $LiN(SO_2CF_3)_2$, $LiC(SO_2CF_3)_3$, $LiN(SO_3CF_3)_2$, $LiC_4F_9SO_3$, $LiAlCl_4$ or LiTFSI (Lithium bis(trifluoromethanesulfonyl)imide). In addition to the lithium salt, the metal salt may further include another metal salt such as $AlCl_3$, $MgCl_2$, NaCl, KCl, NaBr, KBr, or $CaCl_2$. The solvent may be any of a number of solvents capable of dissolving the above-listed lithium salts and metal salts.

[0084] In addition, the second negative electrode electrolyte film **22** may further include a separator impermeable with respect to oxygen (O_2) and conductive with respect to metal ions. The separator may be a flexible polymer separator. In embodiments, for example, the separator may be a nonwoven polymer fabric such as a nonwoven polypropylene fabric or a nonwoven polyphenylene sulfide fabric, or may be a porous olefin-containing film such as a porous polyethylene film or a porous polypropylene film.

[0085] The separator and the electrolyte may form different layers within the negative electrode electrolyte film **22**, or the separator (e.g., porous separator) may be impregnated with the electrolyte to form a single layer within the negative electrode electrolyte film **22**. In an embodiment of forming the second negative electrode electrolyte film **22**, for example, pores of a porous separator may be impregnated with an electrolyte and the electrolyte may include a combination of polyethylene oxide (“PEO”) and LiTFSI. In an embodiment, for example, the second negative electrode electrolyte film **22** may include and/or be formed of the same material used to form the (first) negative electrode electrolyte film **12**.

[0086] The second positive electrode layer **23** may include an electrolyte configured for conducting metal ions, a catalyst configured for oxidation/reduction of oxygen (O_2), a conductive material, and a binder. In an embodiment of forming the second positive electrode layer **23**, for example, the electrolyte, the catalyst, the conductive material and the binder may be combined with each other, and a solvent may be added to the combination to form a positive electrode slurry. Thereafter, the positive electrode slurry may be applied to the second negative electrode electrolyte film **22** and dried to form the second positive electrode layer **23**.

[0087] A (first) negative electrode electrolyte film **12** is disposed on top of the (first) negative electrode metal layer **11**, and the second negative electrode metal layer **21** and the second negative electrode electrolyte film **22** are disposed under the (first) negative electrode metal layer **11**. Therefore, contact of the (first) negative electrode metal layer **11** with oxygen (O_2) may be reduced or effectively prevented.

[0088] FIG. **6** is a cross-sectional view illustrating a metal-air battery cell **10*b*** in which contact of a lower side of a negative electrode metal layer **11** with oxygen (O_2) is reduced or effectively prevented according to another embodiment of the present invention.

[0089] Referring to FIG. **6**, an oxygen blocking layer **16** may be disposed under the negative electrode metal layer **11**. The oxygen blocking layer **16** may reduce or effectively prevent permeation of oxygen (O_2) into the negative electrode metal layer **11**. That is, the oxygen blocking layer **16** disposed under the negative electrode metal layer **11** may reduce or effectively prevent contact between oxygen (O_2) and the lower side of the negative electrode metal layer **11**. The oxygen blocking layer **16** may include or be formed of polyethylene terephthalate.

[0090] In the embodiments shown in FIGS. **1** to **6**, the metal-air battery cells **10**, **10*a***, **10*b*** and **20** have a substantially flat shape. However, the metal-air battery cells **10**, **10*a***, **10*b*** and **20** are not limited thereto. In embodiments, for example, one or more layers within the metal-air battery cells **10**, **10*a***, **10*b*** and **20** may be deformed or bent such that the metal-air battery cells **10**, **10*a***, **10*b*** and **20** in a deformed or bent state do not have a flat shape.

[0091] The one or more layers that may be deformed or bent may include, but are not limited to, the negative electrode metal layer **11**, the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layer **14**.

[0092] FIGS. **7A_1**, **7A_2**, **7B_1** and **7B_2** illustrate examples in which the metal-air battery cell **10** illustrated in FIG. **1** is bent. Referring to FIGS. **7A_1** and **7B_1**, the negative electrode metal layer **11**, the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layer **14** of a metal-air battery cell (denoted by reference numerals **30*a*** and **30*b*** in FIGS. **7A_1** and **7B_1**, respectively) may be rolled up. The metal-air battery cells **30*a*** and **30*b*** may represent any one of the above-described metal-air battery cells **10**, **10*a***, **10*b*** and **20** in a rolled-up state. FIGS. **1**, **4**, **5** and **6** illustrate the metal-air battery cells **10**, **10*a***, **10*b*** and **20** in a flat (e.g., un-bent or un-rolled state).

[0093] Referring to FIGS. **7A_2** and **7B_2**, for example, the negative electrode metal layer **11**, the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layer **14** of the metal-air battery cell **30*a*** and **30*b*** may be bent from a flat state thereof in such a manner that the negative electrode metal layer **11** is disposed on top of the channel layer **14** in a direction away from a center of the roll. An axis of the metal-air battery cell **30*a*** and **30*b*** may be defined at the center of the roll. The continuously extended negative electrode metal layer **11**, the negative electrode electrolyte film

12, the positive electrode layer **13** and the channel layer **14** may be bent about such axis to form the metal-air battery cell **30***a* and **30***b* in a rolled state. In the bent or rolled state of the metal-air battery cell **30***a*, a lower surface **111** of the negative electrode metal layer **11** may be disposed on top of the channel layer **14** and further from the center of the roll one or more times along the direction away from the center of the roll.

[0094] The metal-air battery cell may be rolled up in such a manner that the channel layer **14** is disposed outward and further from the center of the roll than the negative electrode layer **11** as shown in FIGS. **7**A_**1** and **7**A_**2** (denoted by reference numeral **30***a*). Alternatively, the negative electrode metal layer **11** is disposed outward and further from the center of the roll than the channel layer **14** as shown in FIGS. **7**B_**1** and **7**B_**2** (denoted by reference numeral **30***b*).

[0095] The negative electrode metal layer **11**, the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layer **14** may be rolled up into a roll. That is, the metal-air battery cells **30***a* and **30***b* illustrate the form of a roll. The roll may have an overall cylindrical shape as shown in FIGS. **7**A_**1** and **7**B_**1**. However, the present invention is not limited thereto. In alternative embodiments, for example, metal-air battery cells **30***c* and **30***d* having a polygonal pillar shape such as a triangular or rectangular pillar shape may be formed as shown in FIGS. **8**A and **8**B. The metal-air battery cells **30***c* and **30***d* may represent any one of the above-described metal-air battery cells **10**, **10***a*, **10***b* and **20** in a rolled-up state. The metal-air battery cells **30***c* and **30***d* shown in FIGS. **8**A and **8**B have the same layers as those shown in FIG. **7**A_**1**, **7**A_**2**, **7**B_**1** and **7**B_**2**, and thus each individual or discrete layer thereof is not specifically illustrated.

[0096] Referring to back FIG. **7**A_**1**, **7**A_**2** **7**B_**1** and **7**B_**2**, an oxygen blocking layer **16** (refer to FIG. **6**) may be disposed between the negative electrode metal layer **11** and the channel layer **14**. Owing to the oxygen blocking layer **16**, contact of oxygen (O_2) included in air introduced into the channel layer **14** with the negative electrode metal layer **11** may be reduced or effectively prevented. The oxygen blocking layer **16** may be disposed within any one of the above-described metal-air battery cells **10**, **10***a* and **10***b*.

[0097] Referring again to FIGS. **7**A_**1** and **7**A_**2**, a shape maintaining film **18** may be wound around the metal-air battery cell **30***a* that is in the form of a roll. The shape maintaining film **18** may maintain the shape of the metal-air battery cell **30***a* even though the thicknesses of the negative electrode metal layer **11** and the positive electrode layer **13** vary during a charging/discharging operation. Since the shape of the metal-air battery cell **30***a* is maintained by the shape maintaining film **18**, the formation of dendrites in the negative electrode metal layer **11** may be suppressed. The shape maintaining film **18** may be disposed around any one of the rolled-up metal-air battery cells **30***a*, **30***b*, **30***c* and **30***d*, such that the shape thereof is maintained even though thicknesses of layers therein vary during a charging/discharging operation thereof.

[0098] Metal-air battery cells having only a portion of the layers thereof in a bent state illustrate other examples of metal-air battery cells in which less than all layers are in a bent state. In embodiments, for example, among layers of a metal-air battery cells, a negative electrode metal layer **11**, a negative electrode electrolyte film **12** and a positive electrode layer **13** may be bent while remaining layers may be in an un-bent state.

[0099] FIGS. **9**, **10** and **11**A are perspective views illustrating metal-air battery cells each including a negative electrode metal layer, a negative electrode electrolyte film and a positive electrode layer that are bent according to embodiments of the present invention, and FIG. **11**B is a cross-sectional view of the metal-air battery cell illustrated in FIG. **11**A taken along xlb-xlb.

[0100] Referring to FIGS. **9**, **10** and **11**A, the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** among layers of each of the metal-air battery cells **40***a*, **40***b* and **40***c* are in a bent state according to embodiments of the present invention. FIG. **11**B is a cross-sectional view illustrating the metal-air battery cell **40***c* illustrated in FIG. **11**A taken along xlb-xlb. In each of FIGS. **9**, **10** and **11**A, the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** are bent upward toward the channel layer **14** such that the positive electrode layer **13** may make contact with an upper side of a channel layer **14**.

[0101] Referring to FIG. **9**, in the metal-air battery cell **40***a*, the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** may be continuously extended and bent to cover lower, right and upper sides of the channel layer **14**. The lower side of the channel layer **14** refers to an imaginary plane connecting lowermost points of channel structures **15** of the channel layer **14**, and the upper side of the channel layer **14** refers to an imaginary plane connecting uppermost points of the channel structures **15** of the channel layer **14**.

[0102] In a flat state of the metal-air battery cell **40***a*, the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** may extend further than the channel layer **14**, such that portions thereof are exposed from the channel layer **14**. In an embodiment of forming the bent-state metal-air battery cell **40***a* illustrated in FIG. **9**, after the channel layer **14** is disposed on top of a portion of the positive electrode layer **13**, the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** may be bent upward such as toward the channel layer **14** such that the positive electrode layer **13** may make contact with the upper side of the channel layer **14**. The above-described forming method may be applied to any one of the metal-air battery cells **40***a*, **40***b* and **40***c*.

[0103] Referring to FIG. **9**, in this bent-state structure, front and rear ends of the channel layer **14** in an extension direction of the channel layer **14**, and a left side of the channel layer **14** may be exposed to outside the metal-air battery cell **40***a*. At the exposed ends and sides of the bent-state metal-air battery cell **40***a*, air may be incident to a layer thereof.

[0104] Referring to FIG. **10**, the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** may be bent to cover lower, right, upper and left sides of the channel layer **14**. In this bent-state structure, only the front and rear ends of the channel layer **14** in an extension direction of channel structures **15** of the channel layer **14** may be exposed to outside the metal-air battery cell **40***b*. An extension direction of each of the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** is perpendicular to the extension direction of the channel structures **15**. That is, sides of the channel layer **14** are not exposed to outside the metal-air battery cell **40***b*.

[0105] Refers to FIGS. **11**A and **11**B, the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** may be bent to cover upper and lower sides of the channel layer **14** and a first end of the channel layer **14** in an extension direction of channel structures **15** of the channel layer **14**. An extension direction of each of the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** is parallel to the extension direction of the channel structures **15**. In this bent-state structure of the metal-air battery cell **40***c*, an opposing second end of the channel layer **14** in the extension direction of the channel structures **15** may be exposed to outside the metal-air battery cell **40***c*.

[0106] According to an embodiment of the present invention, a metal-air battery includes a plurality of metal-air battery cells. The energy density of the metal-air battery may be determined according to the number of the metal-air battery cells integrated in a given area. An explanation will now be given of how the metal-air battery cells are integrated in the metal-air battery according to embodiments of the present invention. The metal-air battery cells are not limited to the metal-air battery cell **10** illustrated in FIG. **2**. In embodiments, for example, the metal-air battery cells of the metal-air battery may be any one of the metal-air battery cells **10***a*, **10***b*, **20**, **30***a*, **30***b*, **30***c*, **30***d*, **40***a*, **40***b* or **40***c* illustrated in FIGS. **4** to **11**A.

[0107] FIG. **12** is a perspective view illustrating a metal-air battery **1** including a plurality of metal-air battery cells **10** such as the metal-air battery cell **10** illustrated in FIG. **1** according to an embodiment of the present invention, and FIG. **13** is a perspective view illustrating a metal-air battery **2** including a plurality of metal-air battery cells **20** such as the metal-air battery cell **20** illustrated in FIG. **5** according to an embodiment of the present invention. In FIGS. **12** and **13**, two metal-air battery cells **10** and two metal-air battery cells **20** are illustrated. However, the number of the metal-air battery cells **10** and **20** are not limited thereto. In an embodiment, for example, three or more metal-air battery cells **10** and three or more metal-air battery cells **20** may be arranged in similar manners for the metal-air battery **1** and **2**, respectively.

[0108] Referring to FIG. **12**, the metal-air battery **1** includes a first (lower) metal-air battery cell **10** and a second (upper) metal-air battery cell **10**. The second metal-air battery cell **10** is disposed on top of the first metal-air battery cell **10**. As described above, each of the first and second metal-air battery cells **10** includes a negative electrode metal layer **11**, a negative electrode electrolyte film **12**, a positive electrode layer **13** and a channel layer **14**.

[0109] The second metal-air battery cell **10** may be disposed on the channel layer **14** of the first metal-air battery cell **10**. Since it is unnecessary to form an additional space above the channel layer **14** of the first metal-air battery cell **10**, the second metal-air battery cell **10** may be directly disposed on the channel layer **14** of the first metal-air battery cell **10**.

[0110] An oxygen blocking layer **16** may be disposed between the channel layer **14** of the first metal-air battery cell **10** and the negative electrode metal layer **11** of the second metal-air battery cell **10**, but the invention is not limited thereto. The oxygen blocking layer **16** reduces or effectively prevents oxygen-containing air from moving from the channel layer **14** of the first metal-air battery cell **10** to the negative electrode metal layer **11** of the second metal-air battery cell **10**. Therefore, the negative electrode metal layer **11** may make contact with a minimal amount of oxygen (O_2).

[0111] Referring to FIG. **13**, a second (upper) metal-air battery cell **20** may be disposed on top of a first (lower) metal-air battery cell **20**. Each of the first and second metal-air battery cells **20** includes a channel layer **14**, a positive electrode layer **13**, a negative electrode electrolyte film **12**, a negative electrode metal layer **11**, a second negative electrode metal layer **21**, a second negative electrode electrolyte film **22** and a second positive electrode layer **23**. Since the second negative electrode electrolyte film **22** and the second positive electrode layer **23** are disposed under the (first) negative electrode metal layer **11** and second negative electrode metal layer **21**, the (first) negative electrode metal layer **11** and the second negative electrode metal layer **21** do not make direct contact with oxygen (O_2) included in air flowing through the channel layer **14**. Therefore, unlike the embodiment shown in FIG. **12**, oxidation of the negative electrode metal layer **11** may be reduced or effectively prevented without using an oxygen blocking layer **16**.

[0112] FIG. **14** is a perspective view illustrating an exemplary metal-air battery **3** including a plurality of metal-air battery cells **30***a* such as the metal-air battery cell **30***a* illustrated in FIGS. **7**A_**1** and **7**A_**2**. Referring to FIG. **14**, the metal-air battery cells **30***a* may be stacked in such a manner that at least one of front and rear ends of each of the metal-air battery cells **30***a* in an extension direction of channel structures **15** is exposed to the outside. In an embodiment, for example, the metal-air battery cells **30***a* that are each in the form of a roll may be arranged in such a manner that at least portions of lateral sides of the metal-air battery cells **30***a* are in contact with each other.

[0113] FIG. **15** is a perspective view illustrating an exemplary metal-air battery **4***a* including a plurality of metal-air battery cells **40***a* such as the metal-air battery cell **40***a* illustrated in FIG. **9**. Referring to FIG. **15**, the metal-air battery **4***a* may include a plurality of channel layers **14**, for example, two individual channel layers **14**. A continuously extended single negative electrode metal layer **11**, single negative electrode electrolyte film **12** and single positive electrode layer **13** may each be bent to cover three sides of each of the channel layers **14**.

[0114] In an embodiment of forming the metal-air battery **4***a*, for example, among the plurality of channel layers **14**, a first channel layer **14** may be disposed on top of a portion of the positive electrode layer **13**, and the negative electrode metal layer **11**, the negative electrode electrolyte film **12**, and the positive electrode layer **13** may be bent upward to the first channel layer **14** such that the positive electrode layer **13** may make contact with an upper side of the first channel layer **14**.

[0115] Thereafter, the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** are bent 180 degrees in an opposite direction such that the positive electrode layer **13** may face upward. Then, among the plurality of channel layers **14**, a second channel layer **14** is disposed on top of the bent positive electrode layer **13** facing upward, and the negative electrode metal layer **11**, the negative electrode electrolyte film **12** and the positive electrode layer **13** are bent upward to the second channel layer **14** such that the positive electrode layer **13** may make contact with an upper side of the second channel layer **14**.

[0116] In the metal-air battery **4***a* only the negative electrode metal layer **11** may be exposed at the right side of the metal-air battery **4***a*, and each of the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layers **14** may be exposed at the left side opposite to the right side of the metal-air battery **4***a*. Therefore, oxygen (O_2) necessary for oxidation/reduction at the positive electrode layer

13 may be absorbed into front and rear ends of the channel layers **14** in an extension direction of the channel layers **14** and into the left sides of the channel layers **14**, and the absorbed oxygen (O_2) may be supplied to the entirety of the positive electrode layer **13**.

[0117] FIG. **16** is a perspective view illustrating an exemplary metal-air battery **4***b* including a plurality of metal-air battery cells **40***b* such as the metal-air battery cell **40***b* illustrated in FIG. **10**. Referring to FIG. **16**, the metal-air battery **4***b* includes the metal-air battery cells **40***b*. The individual metal-air battery cells **40***b* may be stacked in such a manner that outer negative electrode metal layers **11** may make contact with each other.

[0118] The collection of individual metal-air battery cells **40***b* may be surrounded with an outer casing **19**. The outer casing **19** may prevent oxidation of the negative electrode metal layers **11** disposed at an outermost portion of each of the individual metal-air battery cells **40***b*. The metal-air battery cells **40***b* may be disposed with the outer casing **19** in such a manner that all sides of the metal-air battery cells **40***b* are enclosed with the outer casing **19** except for front and rear ends thereof in an extension direction of channel structures **15** of channel layers **14**. Therefore, according to the illustrated embodiment, oxygen (O_2) may be easily supplied to positive electrode layers **13** even though the number of the metal-air battery cells **40***b* having the outermost negative electrode metal layers **11** is increased.

[0119] FIGS. **17**A to **17**C are schematic cross-sectional views illustrating a method of fabricating the metal-air battery cell **10** illustrated in FIG. **1**.

[0120] Referring to FIG. **17**A, a negative electrode electrolyte film **12** is disposed on top of a negative electrode metal layer **11**. The negative electrode metal layer **11** and the negative electrode electrolyte film **12** may be individually fabricated and may then be attached to each other, or the negative electrode electrolyte film **12** may directly be formed on top of the negative electrode metal layer **11**.

[0121] The negative electrode metal layer **11** is configured for intercalation/deintercalation of metal ions. In an embodiment, for example, the negative electrode metal layer **11** may be formed from lithium (Li), sodium (Na), zinc (Zn), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), aluminum (Al), or an alloy thereof.

[0122] The negative electrode electrolyte film **12** is configured to deliver metal ions to a positive electrode layer **13**. To this end, the negative electrode electrolyte film **12** may include an electrolyte prepared by dissolving a metal salt in a solvent. The electrolyte may be a solid electrolyte including a polymer electrolyte, an inorganic electrolyte, or a combination thereof. The electrolyte may be prepared in such a manner that the electrolyte has flexibility in a process described later. In embodiments, for example, the metal salt may be a lithium salt such as $LiN(SO_2CF_2CF_3)_2$, $LiN(SO_2C_2F_5)_2$, $LiClO_4$, $LiBF_4$, $LiPF_6$, $LiSbF_6$, $LiAsF_6$, $LiCF_3SO_3$, $LiN(SO_2CF_3)_2$, $LiC(SO_2CF_3)_3$, $LiN(SO_3CF_3)_2$, $LiC_4F_9SO_3$, $LiAlCl_4$ or LiTFSI (Lithium bis(trifluoromethanesulfonyl) imide). In addition to the lithium salt, the metal salt may further include another metal salt such as $AlCl_3$, $MgCl_2$, NaCl, KCl, NaBr, KBr, or $CaCl_2$. The solvent may be any of a number of solvents capable of dissolving the above-listed lithium salts and metal salts.

[0123] In addition, the negative electrode electrolyte film **12** may further include a separator impermeable with respect to oxygen (O_2) but permeable with respect to metal ions. The separator may be a flexible polymer separator. In an embodiment, for example, the separator may be a nonwoven polymer fabric such as a nonwoven polypropylene fabric or a nonwoven polyphenylene sulfide fabric, or may be a porous olefin-containing film such as a porous polyethylene film or a porous polypropylene film.

[0124] The separator and the electrolyte may form different layers within the negative electrode electrolyte film **12**, or the separator (e.g., porous separator) may be impregnated with the electrolyte to form a single layer within the negative electrode electrolyte film **12**. In an embodiment of forming the negative electrode electrolyte film **12**, for example, pores of a porous separator may be impregnated with an electrolyte prepared by combining polyethylene oxide ("PEO") and LiTFSI.

[0125] Referring to FIG. **17**B, the positive electrode layer **13** is formed on top of the negative electrode electrolyte film **12**. The positive electrode layer **13** may include an electrolyte for conducting metal ions, a catalyst for oxidation/reduction of oxygen (O_2), a conductive material, and a binder. In an embodiment of forming the positive electrode layer **13**, for example, the electrolyte, the catalyst, the conductive material, and the binder may be combined with each other, and a solvent may be added to the combination to form a positive electrode slurry. Thereafter, the positive electrode slurry may be applied to the negative electrode electrolyte film **12** and dried to form the positive electrode layer **13**.

[0126] The electrolyte of the positive electrode layer **13** may include the above-described lithium salt or metal salt. In embodiments, for example, the conductive material of the positive electrode layer **13** may be a porous material such as a carbon-containing material, a conductive metal material, a conductive organic material, or a combination thereof. In embodiments, for example, the carbon-containing material may be carbon black, graphite, graphene, active carbon, carbon fiber, or carbon nanotubes. In embodiments, for example, the conductive metal material may be metal powder. In embodiments, for example, the catalyst of the positive electrode layer **13** may be platinum (Pt), gold (Au), or silver (Ag). Alternatively, the catalyst may be an oxide of manganese (Mn), nickel (Ni), or cobalt (Co). In embodiments, for example, the binder of the positive electrode layer **13** may be polytetrafluoroethylene ("PTFE"), polypropylene, polyvinylidene fluoride ("PVDF"), polyethylene, or styrene-butadiene rubber ("SBR").

[0127] Referring to FIG. **17**C, a channel layer **14** including a plurality of channel structures **15** is disposed on top of the positive electrode layer **13**.

[0128] The channel layer **14** is formed to cause air incident thereinto to flow on the positive electrode layer **13**, and for this purpose, the channel layer **14** may include the channel structures **15** which define the channel layer **14**. Each of the channel structures **15** may be elongated to extend in a direction (for example, a y-axis direction) crossing the laminating direction (z-axis direction) of the positive electrode layer **13**. The channel structures **15** may be arranged in a direction (x-axis direction) perpendicular to both the laminating direction (z-axis direction) of the positive electrode layer **13** and the extension direction (y-axis direction) of the channel structures **15**. In an embodiment, for example, the channel layer **14** may have a corrugated shape defined by alternating ridges and grooves.

[0129] Each of the channel structures **15** may be convex in a direction opposite to an upper surface **131** of the positive electrode layer **13**. Cavities C are defined by inner surfaces **151** of the convex channel structures **15** and the upper surface **131** of the positive electrode layer **13**. The cavities C are elongated to extend in the same direction as the extension direction of the channel structures **15**. Ambient air may be introduced into the cavities C through at least one of front and rear ends of each of the cavities C in the extension direction of the cavities C. In addition, ambient air may be introduced into the cavities C through a thickness of the channel layer **14** depending on a material used to form the channel structures **15** of the channel layer **14**.

[0130] The cavities C may have a semicircular cross-sectional shape. The cavities C are not limited thereto and may have various cross-sectional shapes as long as the cavities C are convex with reference to the upper surface **131** of the positive electrode layer **13**. In embodiments, for example, cavities C**1**, C**2** and C**3** having a polygonal shape such as a triangular shape or a rectangular shape, or a wave-form shape as shown in FIGS. **3**A to **3**C may be formed by the channel structures **15**.

[0131] The channel layer **14** may be formed of any of a number of materials as long as a convex profile and the shape of the channel structures **15** is maintained. In an embodiment, for example, the channel layer **14** may be formed of a porous material including one selected from metals, ceramic materials, polymers, carbon materials, light metals and combinations thereof. Since the channel layer **14** has a porous structure, the channel layer **14** may absorb oxygen (O_2) included in the air and smoothly diffuse the oxygen (O_2) into the cavities C. Examples of the porous metals include foam metals in the form of a sponge, and metal fiber mats. Examples of the porous carbon materials may include carbon paper, carbon cloth, and carbon felt that are formed of carbon fibers. Examples of the porous ceramic materials may include magnesium-aluminum silicate. Examples of the porous polymers may include porous polyethylene and porous polypropylene. Examples of the porous light metals may include nickel meshes, and flexible composite materials made of polymers and nickel meshes.

[0132] In a method of fabricating the metal-air battery cell **10** illustrated in FIG. **1**, an oxygen blocking layer **16** may be disposed on a lower surface **111** of the negative electrode metal layer **11**, such as shown in FIG. **6**. Owing to the oxygen blocking layer **16**, the negative electrode metal layer **11** may not be exposed to the atmosphere outside the metal-air battery cell **10**.

[0133] FIGS. **18**A to **18**E are schematic cross-sectional views illustrating a method of fabricating the metal-air battery cell **20** illustrated in FIG. **5**.

[0134] Referring to FIG. **18**A, a second negative electrode electrolyte film **22** is disposed on top of a second positive electrode layer **23**.

[0135] The second positive electrode layer **23** may include an electrolyte configured for conducting metal ions, a catalyst for oxidation/reduction of oxygen (O_2), a conductive material, and a binder. In an embodiment of forming the second positive electrode layer **23**, for example, the electrolyte, the catalyst, the conductive material, and the binder may be combined with each other, and a solvent may be added to the combination to form a positive electrode slurry. Thereafter, the positive electrode slurry may be applied to the second negative electrode electrolyte film **22** and dried to form the second positive electrode layer **23**.

[0136] The second negative electrode electrolyte film **22** may include an electrolyte prepared by dissolving a metal salt in a solvent. The electrolyte may be a solid electrolyte including a polymer electrolyte, an inorganic electrolyte, or a combination thereof, and may be prepared in such a manner that the electrolyte has flexibility. In embodiments, for example, the metal salt may be a lithium salt such as $LiN(SO_2CF_2CF_3)_2$, $LiN(SO_2C_2F_5)_2$, $LiClO_4$, $LiBF_4$, $LiPF_6$, $LiSbF_6$, $LiAsF_6$, $LiCF_3SO_3$, $LiN(SO_2CF_3)_2$, $LiC(SO_2CF_3)_3$, $LiN(SO_3CF_3)_2$, $LiC_4F_9SO_3$, $LiAlCl_4$ or LiTFSI (Lithium bis(trifluoromethanesulfonyl)imide). In addition to the lithium salt, the metal salt may further include another metal salt such as $AlCl_3$, $MgCl_2$, NaCl, KCl, NaBr, KBr, or $CaCl_2$. The solvent may be any of a number of solvents capable of dissolving the above-listed lithium salts and metal salts.

[0137] In addition, the second negative electrode electrolyte film **22** may further include a separator impermeable with respect to oxygen (O_2) and conductive with respect to metal ions. The separator may be a flexible polymer separator. In embodiments, for example, the separator may be a nonwoven polymer fabric such as a nonwoven polypropylene fabric or a nonwoven polyphenylene sulfide fabric, or may be a porous olefin-containing film such as a porous polyethylene film or a porous polypropylene film.

[0138] The separator and the electrolyte may form different layers in the negative electrode electrolyte film **22**, or the separator (e.g., porous separator) may be impregnated with the electrolyte to form a single layer within the negative electrode electrolyte film **22**. In an embodiment of forming the second negative electrode electrolyte film **22**, for example, the second negative electrode electrolyte film **22** may be formed by impregnating pores of a porous separator with an electrolyte prepared by combining polyethylene oxide ("PEO") and LiTFSI. In an embodiment, for example, the second negative electrode electrolyte film **22** may be formed of the same material used to form the (first) negative electrode electrolyte film **12**.

[0139] Referring to FIG. **18**B, a second negative electrode metal layer **21** and a (first) negative electrode metal layer **11** are sequentially disposed on top of the second negative electrode electrolyte film **22**.

[0140] The second negative electrode metal layer **21** and the (first) negative electrode metal layer **11** are formed for intercalation/deintercalation of metal ions. In embodiments, for example, the second negative electrode metal layer **21** and the (first) negative electrode metal layer **11** may be formed from lithium (Li), sodium (Na), zinc (Zn), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), aluminum (Al), or an alloy thereof. The second negative electrode metal layer **21** and the (first) negative electrode metal layer **11** may form different distinct layers within the metal-air battery cell **20**. However, the invention is not limited thereto. In an alternative embodiment, for example, the second negative electrode metal layer **21** and the negative electrode metal layer **11** may collectively form a single layer (e.g., monolayer) among layers of the metal-air battery cell **20**.

[0141] As shown in FIGS. **18**C to **18**E, a (first) negative electrode electrolyte film **12**, a (first) positive electrode layer **13**, and a channel layer **14** may be sequentially disposed on top of the (first) negative electrode metal layer **11**. This is similar to the description with reference to FIGS. **17**A to **17**C, and thus a description thereof will not be repeated.

[0142] After the metal-air battery cells **10** and **20** are fabricated by performing the processes described with reference to FIGS. **17**A to **17**C and **18**A to **18**E, the metal-air battery cells **10** and **20** may be deformed through an additional process.

[0143] FIGS. **19**A and **19**B are schematic cross-sectional views illustrating an exemplary process of deforming the metal-air battery cell **10** illustrated in FIG. **17**C. With reference to FIGS. **19**A and **19**B, a description will now be given of how the negative electrode metal layer **11**, the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layer **14** are rolled to dispose the negative electrode metal layer **11** on top of the channel layer **14**.

[0144] The negative electrode metal layer **11**, the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layer **14** of the formed metal-air battery cell **10** are bent together so that portions of the channel layer **14** may make contact with each other, as illustrated at the left of FIG. **19**A. With the portions of the channel layer **14** in contact with each other, the negative electrode metal layer **11**, the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layer **14** are further bent so that the channel layer **14** and the negative electrode metal layer **11** may make contact with each other, as illustrated at the left of FIG. **19**B. Further bending of the negative electrode metal layer **11**, the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layer **14** may dispose the channel layer **14** and the negative electrode metal layer **11** in direct contact with each other. If the oxygen blocking layer **16** is disposed at the lower surface **111** of the negative electrode metal layer **11**, further bending of the negative electrode metal layer **11**, the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layer **14** may dispose the channel layer **14** and the negative electrode metal layer **11** in indirect contact with each other with the oxygen blocking layer **16** being disposed therebetween.

[0145] In this way, the metal-air battery cell **10** is continuously rolled to bring the channel layer **14** and the negative electrode metal layer **11** into contact with each other at multiple locations. Then, by the continuous rolling of the metal-air battery cell **10**, the metal-air battery cell **30***b* of FIGS. 7B_**1** and 7B_**2** having a roll shape may be fabricated. However, the rolling direction of the metal-air battery cell **30***b* may be varied. In an alternative embodiment, for example, the negative electrode metal layer **11**, the negative electrode electrolyte film **12**, the positive electrode layer **13** and the channel layer **14** may be rolled in a direction in which portions of the negative electrode metal layer **11** are first brought into contact with each other and then continuously rolled, so as to form the metal-air battery cell **30***a* shown in FIGS. **7**A_**1** and **7**A_**2**.

[0146] The above-described process illustrated in FIGS. **19**A and **19**B of deforming the shape of the metal-air battery cell **10** may be applied to the second metal-air battery cell **20** illustrated in FIG. **18**E.

[0147] In the embodiments of FIGS. **2**, **4**, **5** and **6**, the channel layer **14** is formed to be disposed on the entirety of the positive electrode layer **13**. However, the invention is not limited thereto. In alternative embodiments, for example, as shown in FIGS. **9** to **11**A, a channel layer **14** may be formed on top of a portion of a single continuous positive electrode layer **13** to expose a remaining portion of the positive electrode layer **13**. Then, each of a negative electrode metal layer **11**, a negative electrode electrolyte film **12** and the positive electrode layer **13** which is continuous extended may be bent to cover at least three sides of the channel layer **14**, so as to form a metal-air battery cell **40***a*, **40***b* or **40***c*.

[0148] As described above, in one or more embodiment of a metal-air battery cell of the present invention, the channel layer including a plurality of channel structures extending in a direction crossing the laminating direction of the positive electrode layer is disposed on top of the positive electrode layer. Therefore, oxygen (O_2) may smoothly contact the positive electrode layer, and an increase in the thickness of the metal-air battery cell may be minimized. Accordingly, more metal-air battery cells may be disposed in a given planar area, and thus a metal-air battery having a high energy density may be provided.

[0149] The metal-air battery cells **10**, **10***a*, **10***b*, **20**, **30***a*, **30***b*, **30***c*, **30***d*, **40***a*, **40***b* and **40***c*, the metal-air batteries **1**, **2**, **3**, **4***a* and **4***b*, and the methods of manufacturing the same have been described according to embodiments of the present invention with reference to the accompanying drawings. However, it should be understood that the embodiments described herein should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or elements within each embodiment should typically be considered as available for other similar features or elements in other embodiments.

[0150] While one or more embodiments of the present invention have been described with reference to the figures, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the following claims.

What is claimed is:

1. A metal-air battery cell comprising:

a first negative electrode metal layer;

a first positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs;

a first negative electrode electrolyte film disposed between the first negative electrode metal layer and the first positive electrode layer in a thickness direction; and

a first channel layer disposed on the first positive electrode layer and comprising a plurality of first channel structures, the first channel structures each elongated to extend in an extension direction crossing the thickness direction.

2. The metal-air battery cell of claim **1**, wherein each first channel structure among the plurality of first channel structures is convex in a direction away from an upper surface of the first positive electrode layer.

3. The metal-air battery cell of claim **2**, wherein first cavities of the first channel layer are defined by the upper surface of the first positive electrode layer and inner surfaces of the convex first channel structures, respectively.

4. The metal-air battery cell of claim **3**, wherein the first cavities of the first channel layer have a polygonal cross-sectional shape, a semicircular cross-sectional shape or a wave-form cross-sectional shape.

5. The metal-air battery cell of claim **1**, further comprising:

a second negative electrode metal layer disposed under the first negative electrode metal layer;

a second positive electrode layer disposed under the second negative electrode metal layer and configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; and a second negative electrode electrolyte film disposed between the second negative electrode metal layer and the second positive electrode layer in the thickness direction.

6. The metal-air battery cell of claim **1**, wherein the first negative electrode metal layer, the first negative electrode electrolyte film and the first positive electrode layer are each continuously extended and disposed at opposing sides of the first channel layer in the thickness direction.

7. The metal-air battery cell of claim **1**, wherein the first negative electrode metal layer, the first negative electrode electrolyte film, the first positive electrode layer and the first channel layer are each continuously extended and bent about an axis to define the metal-air battery cell in a roll form.

8. The metal-air battery cell of claim **1**, wherein

the first negative electrode metal layer, the first negative electrode electrolyte film and the first positive electrode layer are each continuously extended and bent upward toward the first channel layer to define the metal-air battery cell in a flat form, and

in the flat form of the metal-air battery cell, the first positive electrode layer contacts apexes of the convex first channel structures of the first channel layer.

9. The metal-air battery cell of claim **1**, wherein an end of the first channel layer in the extension direction of the first channel structures is exposed outside the metal-air battery cell.

10. The metal-air battery cell of claim **1**, further comprising:

a sub positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs, disposed on a surface of the first channel structures of the first channel layer.

11. The metal-air battery cell of claim **1**, wherein the first negative electrode electrolyte film comprises:

a separator which is impermeable with respect to oxygen and conductive with respect to metal ions; and

an electrolyte configured to conduct the metal ions.

12. The metal-air battery cell of claim **1**, wherein the first channel structures of the first channel layer have a porous structure.

13. A metal-air battery comprising:

a first metal-air battery cell and a second metal-air battery cell,

wherein each of the first and second metal-air battery cells comprises:

a first negative electrode metal layer;

a first positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs;

a first negative electrode electrolyte film disposed between the first negative electrode metal layer and the first positive electrode layer in a thickness direction; and

a first channel layer disposed on the first positive electrode layer and comprising a plurality of first channel structures, the first channel structures each elongated to extend in an extension direction crossing the thickness direction.

14. The metal-air battery of claim **13**, wherein the first channel layer of the first metal-air battery cell is disposed between the first negative electrode metal layers of the first and second metal-air battery cells in the thickness direction.

15. The metal-air battery of claim **14**, further comprising an oxygen blocking layer disposed between the first channel layer of the first metal-air battery cell and the first negative electrode metal layer of the second metal-air battery cell in the thickness direction.

16. The metal-air battery of claim **13**, wherein each of the first and second metal-air battery cells further comprises:

a second negative electrode metal layer disposed under the first negative electrode metal layer;

a second positive electrode layer disposed under the second negative electrode metal layer and configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; and

a second negative electrode electrolyte film disposed between the second negative electrode metal layer and the second positive electrode layer in the thickness direction.

17. The metal-air battery of claim **13**, wherein for each of the first and second metal-air battery cells,

the first negative electrode metal layer, the first negative electrode electrolyte film and the first positive electrode layer are each continuously extended and disposed at opposing sides of the first channel layer in the thickness direction.

18. A method of fabricating a metal-air battery cell, the method comprising:

disposing a first negative electrode electrolyte film between a first negative electrode metal layer and a first positive electrode layer in a thickness direction, the first positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; and

disposing a first channel layer on the first positive electrode layer, the first channel layer comprising a plurality of first channel structures each elongated to extend in an extension direction crossing the thickness direction.

19. The method of claim **18**, further comprising:

disposing a second negative electrode electrolyte film between a second negative electrode metal layer and a second positive electrode layer, the second positive electrode layer configured to use oxygen as an active material for which a reduction/oxidation reaction of oxygen introduced thereto occurs; and

disposing the second negative electrode metal layer and the first negative electrode metal layer facing each other.

20. The method of claim **18**, wherein the first negative electrode metal layer, the first negative electrode electrolyte film and the first positive electrode layer are each continuously extended,

further comprising bending the continuously extended first negative electrode metal layer, first negative electrode electrolyte film and first positive electrode layer to be disposed at opposing sides of the first channel layer in the thickness direction.

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