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(54) Title: CONDUCTOR INTEGRATED MEMBRANE ELECTRODE ASSEMBLY

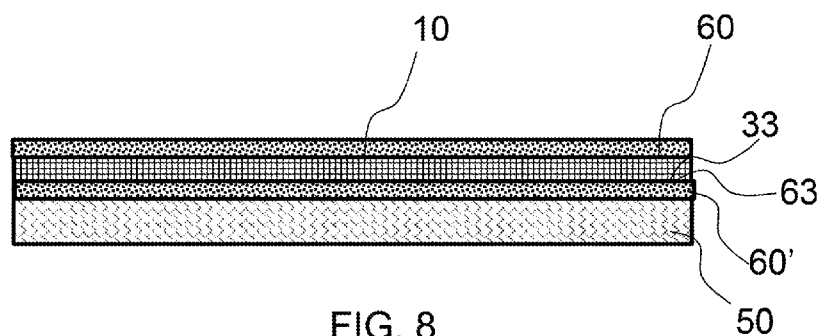


FIG. 8

(57) Abstract: A conductor integrated membrane electrode assembly includes a conductor coupled with and in contact with the electrode and forms a permeable network to enable flow of liquid and gases therethrough to improve performance as the electrons more freely available to accelerate reaction rates. The conductor may be coupled to an ion conducting membrane to form a composite membrane conductor or may be pre-formed and attached onto the membrane, or may be formed on the membrane or electrode by printing or vapor deposition. The conductor may be configured between the ion conducting membrane and the electrode and may be partially embedded into the ion conducting membrane and/or the electrode. The conductor may be a screen that is free-standing material, or may be printed or otherwise deposited on the electrode and/or on the ion conducting membrane.

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CONDUCTOR INTEGRATED MEMBRANE ELECTRODE ASSEMBLY

Cross Reference To Related Applications

[0001] This application claims the benefit of priority to U.S. provisional patent application No. 63/470,725, filed on June 2, 2023; the entirety of which is hereby incorporated by reference herein.

BACKGROUND

FIELD OF THE INVENTION

[0002] This invention is directed to conductor integrated membrane electrode assemblies, wherein the conductor is coupled with and in contact with the electrode and forms a permeable network to enable flow of liquid and gases therethrough.

BACKGROUND OF THE INVENTION

[0003] Membrane electrode assemblies produce power or form chemical reactions as a function of ion transport through the ion conducting membrane and there can be many rate limiting factors that reduce the power density or chemical conversion rates. The electrodes can become saturated with water or other liquid reactant solution and this can affect mass transport of compounds to the electrode sites. The ion conducting membrane can become dry and this can reduce the ion transport rate. The gas diffusion media, which is typically in contact with a circuit, which may connect the anode to the cathode, can have poor contact with the electrode and therefore create high electrical resistance for transferring electrons and this can further slow reactions and overall efficiency of the membrane electrode assembly. Electrons from the reactions on the electrode have to pass through the electrode to the gas diffusion media and current collector in traditional membrane electrode assemblies. The electrodes are typically not very electrically conductive as they comprise carbon or some other electrically conductive carrier with a catalyst coated thereon or mixed therewith.

SUMMARY OF THE INVENTION

[0004] The present invention is directed to a conductor integrated membrane electrode assembly, wherein the conductor is coupled with and in contact with the electrode and forms a permeable network to enable flow of liquid and gases therethrough. The conductor integrated with the electrode or between the electrode and membrane greatly improves performance of membrane electrode assemblies as the electrons more freely are available or drawn away from the electrode to accelerate reaction rates.

[0013] The conductor may be coupled to an ion conducting membrane to form a composite membrane conductor. The conductor may be pre-formed and attached onto the membrane, or may be formed on the membrane or electrode by printing or vapor deposition. An electrode may then be bonded to the composite membrane conductor to form a conductor integrated membrane electrode assembly. The conductor may be configured between the ion conducting membrane and the electrode and may be partially embedded into the ion conducting membrane and/or the electrode. The conductor has open area and the ion conducting polymer and/or electrode may extend into this open area and contact the strands within the open area.

[0014] A conductor may be coupled to an electrode on a catalyst decal sheet to form a composite catalyst conductor. The composite catalyst conductor may then be bonded to the ion conducting membrane to form the conductor integrated membrane electrode assembly. A conductor may be electrically coupled to the electrode and/or membrane which means that electrons produced by the electrode can flow to the conductor into the conductor.

[0015] A composite catalyst conductor may be coupled to an electrode that is already coupled to the ion conducting membrane to form an embedded conductor, with the conductor configured between a first layer or portion of the electrode and a second portion or layer of the electrode to form the half cell membrane electrode assembly. A first portion or layer of an electrode on a first side of the embedded conductor may be different from a second portion or layer of electrode on a second side of said embedded conductor. The catalyst concentration, aerial mass, may be substantially different, wherein the aerial mass (g/m^2) is at least 10% or 20% different, or the catalyst type may be different, or the concentration of ion conducting polymer by aerial mass may be substantially different, wherein the aerial mass (g/m^2) is at least 10% or 20% different. The conductor embedded in the electrode may provide improved performance with reduced electrical resistance.

[0016] An integrated conductor membrane electrode assembly may be configured with a conductor integrated with the electrode on one or on both the anode and cathode.

[0017] The conductor has open area to allow liquid and gases to pass therethrough and to allow the ion conducting membrane and/or electrode to advance into the open area to increase performance due to better charge transfer to the conductor. The open area percentage of the conductor may be 20% or more, 40% or more, 60% or more, 80% or more or even 90% or more. When the conductor incorporates strands that are highly electrically conductive, such as metal wires, the open area may be larger. When the conductor is made of a deposited material onto the ion conducting membrane and/or electrode, the electrical conductivity may not be as high as a wire grid, such as a metal screen and therefor the percent open area may be less. A deposited conductor may be vapor deposited metal, or a printed material, such as from an ink or paste. Alternatively, a conductor may be separate

free-standing material, such as a metal screen made of strands of metal that intersect or an apertured metal layer or foil, wherein the conductor has a consistent thickness with apertures therethrough.

[0018] A conductor may be a screen of metal having strands of metal wire that extend across the membrane electrode assembly and may intersect each other to form a grid or other suitable pattern. The screen may be a wire cloth, or a material having strands of metal wire, or may be pressed or otherwise process to engage the individual strands together. The strands of a metal wire conductor may be circular in cross-section or may be polygonal in cross-section, such as rectangular. A woven wire screen or wire cloth may have large variations in thickness, wherein the overlap areas of the wire forms high pressure zone when the membrane electrode assembly is assembled. Therefore, a conductor with a more consistent thickness may be preferred, and therefore polygonal shaped strands may be preferred. A sheet of metal foil with apertures may provide the most uniform thickness for the purpose of preventing damage due to variations in thickness. The conductor has open area 31 that enables the transport of liquids and gasses through the conductor. As described herein the open area of the conductor may be about 20% or more, about 30% or more, about 50% or more, about 75% or less and any range between and including the values provided.

[0019] An exemplary conductor may be metal and is preferably a metal that is highly electrically conductive, such a gold, silver, copper, aluminum, zinc, nickel, metal alloys and the like. A vapor deposited conductor may use a precious metal such as gold or silver as very little is required in a very thin printed conductor layer.

[0020] An exemplary conductor may have conductor strands coupled by conductor nodes, enlarged areas of conductor material, that shorten the length of the strands, which may have less electrical conductivity. As described herein the nodes may be much larger in dimension than the cross-length dimension of a strand, such as about 50% larger or more, about 75% larger or more, about 100% larger or more, about 150% larger or more, about 200% larger or more, about 500% larger or more, and any range between and including the percentages provide.

[0021] An ion conducting polymer or ion conducting membrane as described herein may be an anion conducting polymer or membrane or cation conducting polymer or membrane.

[0022] This application incorporates by reference the following applications: U.S. provisional patent application No. 63/249,000, filed on September 27, 2021, U.S. provisional patent application No. 63/274,702 filed on November 2, 2021, U.S. provisional patent application No. 63/278,780 filed on November 12, 2021, and to U.S. provisional patent application No. 63/395,577, filed on August 5, 2022; the entirety all prior applications are hereby incorporated by reference herein, International Patent Application no.

PCT/US2016/063699, filed on Nov. 23, 2016 which claims the benefit of U.S. provisional patent application No. 62/258,945, filed on Nov. 23, 2015, U.S. provisional patent application No. 62/300,074, filed on Feb. 26, 2016, U.S. provisional patent application No. 62/353, 545, filed on Jun. 22, 2016, U.S. provisional patent application No. 62/373,329, filed on Aug. 10, 2106 and U.S. provisional patent application No. 62/385,175, filed on Sep. 8, 2016, and this application claims the benefit of priority to.

[0023] The summary of the invention is provided as a general introduction to some of the embodiments of the invention, and is not intended to be limiting. Additional example embodiments including variations and alternative configurations of the invention are provided herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The accompanying drawings are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate embodiments of the invention, and together with the description serve to explain the principles of the invention.

[0023] Figure 1 shows a side view of a conductor being coupled to an ion conducting membrane to form a composite membrane conductor.

[0024] Figure 2 shows a side view of the composite membrane conductor shown in FIG. 1 being coupled to an electrode to form a half cell membrane electrode assembly.

[0025] Figure 3 shows the half cell membrane electrode assembly formed in FIG. 2.

[0026] Figure 4 shows a side view of a conductor being coupled to an electrode on a catalyst decal sheet.

[0027] Figure 5 shows a side view of the composite catalyst conductor formed in FIG. 4 being coupled to an ion conducting membrane to form a half cell membrane electrode assembly.

[0028] Figure 6 shows the half cell membrane electrode assembly formed in FIG. 5.

[0029] Figure 7 shows a side view of a composite catalyst conductor as shown in FIG. 5 being coupled to an electrode already coupled to the ion conducting membrane to form an embedded conductor with the electrode of the half cell membrane electrode assembly.

[0030] Figure 8 shows a side view of the half cell membrane electrode assembly formed in FIG. 7 having an embedded conductor.

[0031] Figure 9 shows an integrated conductor membrane electrode assembly with a conductor integrated with the electrode on both the anode and cathode.

[0032] Figure 10 shows a top view of a conductor having conductor strands that extend in a grid pattern.

[0033] Figure 11 shows a top view of an exemplary conductor having conductor strands coupled by conductor nodes, enlarged areas of conductor material that shorten the length of the strands, which may have less electrical conductivity.

[0034] Figure 12 shows a side view of an exemplary conductor comprising strands that are woven, one over another.

[0035] Figure 13 shows a side view of an exemplary conductor comprising strands that are wire configured orthogonal to each other.

[0036] Figure 14 shows a side view of an exemplary tape stand having a polygonal cross-sectional shape with a uniform thickness across the width.

[0037] Figure 15 shows a top view of an exemplary conductor that is a metal foil with apertures therethrough to create open areas through the metal foil.

[0038] Figure 16 is a side view of a metal foil conductor having apertures therethrough to produce open area in the metal foil.

[0039] Corresponding reference characters indicate corresponding parts throughout the several views of the figures. The figures represent an illustration of some of the embodiments of the present invention and are not to be construed as limiting the scope of the invention in any manner. Further, the figures are not necessarily to scale, some features may be exaggerated to show details of components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art to variously employ the present invention.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

[0040] Corresponding reference characters indicate corresponding parts throughout the several views of the figures. The figures represent an illustration of some of the embodiments of the present invention and are not to be construed as limiting the scope of the invention in any manner. Further, the figures are not necessarily to scale, some features may be exaggerated to show details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art to variously employ the present invention.

[0041] As used herein, the terms “comprises,” “comprising,” “includes,” “including,” “has,” “having” or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. Also, use of “a” or “an” are

employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

[0042] Certain exemplary embodiments of the present invention are described herein and are illustrated in the accompanying figures. The embodiments described are only for purposes of illustrating the present invention and should not be interpreted as limiting the scope of the invention. Other embodiments of the invention, and certain modifications, combinations and improvements of the described embodiments, will occur to those skilled in the art and all such alternate embodiments, combinations, modifications, improvements are within the scope of the present invention.

[0043] Referring now to FIGS. 1 to 3, a conductor 30 is coupled to an ion conducting membrane 50 to form a composite membrane conductor 53. As shown in FIG. 1 the conductor 30 may be pre-formed and attached onto the membrane, or as described herein, the conductor may be formed on the membrane or electrode by printing or vapor deposition. As shown in FIG. 2, an electrode 60 is bonded to the composite membrane conductor 53 to form the conductor integrated membrane electrode assembly 10, as shown in FIG. 3. The conductor has an inside surface 305 that is coupled to the ion conducting membrane 50 and an outside surface 306 that is configured to couple with the electrode, as shown in FIG. 3. A conductor may be an electrode integrated conductor and be integrated into the electrode wherein a portion of the electrode is on the inside surface 305 and the outside surface 306 and may be configured in the in the open area 31 of the conductor, such as in apertures 37 through the conductor. Also, a conductor may be a membrane integrated conductor wherein a portion of said ion conducting membrane extends into the apertures of the conductor.

[0024] A conductor may be a printed conductor 34 that is printed onto the electrode and/or the membrane and may be printed in a pattern of conductive traces that are interconnected by conductor nodes, the intersection of conductor strands. A conductor strand may be an elongated conductor trace having a length that is at least three times a width of the trace. A printed conductor may be a vapor deposited metal, or a printed material, such as from an ink or paste. A printed conductor, or a foil conductor, may be very thin, having a thickness of about 25 μ m or less, about 20 μ m or less, about 15 μ m or less, about 10 μ m or less, about 5 μ m or less, about 3 μ m or less, about 2 μ m or less and any range between and including the thickness values provided, such as from about 2 μ m to about 5 μ m.

[0044] Referring now to FIGS. 4 to 6, a conductor 30 is coupled to an electrode 60 on a catalyst decal sheet 66 to form a composite catalyst conductor 63 shown in FIG. 5. The composite catalyst conductor 63 is then bonded to the ion conducting membrane 50 in FIG.

5 to form the conductor integrated membrane electrode assembly 10, as shown in FIG. 6. The electrode includes a catalyst 62, which may be platinum and the like.

[0045] Referring to FIGS. 7 and 8, a composite catalyst conductor 63, as shown in FIG. 5, is being coupled to an electrode 60' already coupled to the ion conducting membrane 50 to form an embedded conductor 33 with the conductor 30 configured between electrode 60 and electrode 60' to form the half cell membrane electrode assembly shown in FIG. 8. The conductor integrated membrane electrode assembly 10, as shown in FIG. 8 has the conductor 30 embedded in the electrode which may provide improved performance with reduced electrical resistance.

[0046] As shown in FIG. 9, an integrated conductor membrane electrode assembly 10 is configured with a conductor 30, 30' integrated with the electrode 60, 60' respectively, on both the anode 20 and cathode 26

[0047] As shown in FIG.10, an exemplary conductor 30 has conductor strands 38 that extend in a grid pattern. The conductor has open area 31 that enables the transport of liquids and gasses through the conductor. As described herein the open area of the conductor may be about 20% or more, about 30% or more, about 50% or more, about 75% or less and any range between and including the values provided.

[0048] As shown in FIG.11, an exemplary conductor 30 has conductor strands 38 coupled by conductor nodes 36, enlarged areas of conductor material, that shorten the length of the strands, which may have less electrical conductivity. As described herein the nodes may be much larger in dimension than the cross-length dimension of a strand.

[0049] Referring now to FIGS. 12 to 16, a conductor 30 may be a free-standing conductor that is coupled with the ion conducting membrane and/or the electrode and may comprise strands that are coupled together to produce a screen 32 or cloth. As shown in FIG. 12, the woven strands of the woven conductor include a first strand extending over a second strand 40 and under a third strand 40'. The strands may be circular in cross-section as shown in FIGS. 12 and 13, having a stand diameter 41, and may be woven, as shown in FIG. 12, with a first set of strands 40 extending over and under a second set of strands 40'. A strand diameter or cross-length dimension, or width of a strand may be about 1mm or less, about 1mm or more, about 2mm or more, about 3mm or more about 4mm or more, about 5mm or more about 8mm or more and any range between and including the values provided. A small diameter may be preferred to keep the composite thin. As show in FIG. 13, the circular cross-sectional shaped strands 40, 40' are configured in a grid with a first set extending over a second set of strands. As shown in FIG. 14, a strand may be polygonal in shape, such as rectangular and be a tape strand having a thickness 45 that is uniform across the width. The thickness 35 of the conductor may be about 0.25mm or more, about 0.5mm or more, 1mm or less, about 1mm or more, about 2mm or more, about 3mm or more

about 4mm or more, about 5mm or more and any range between and including the values provided. A wider and thicker conductor or conductor strand will have lower resistance to a flow of current therethrough which may prevent heating from the electrical resistance. A tape strand may be preferred as it may provide better contact with the ion conducting membrane and/or electrode for electrical contact and reduce resistance. A circular cross-sectional strand when woven or layered as show in FIGS. 12 and 13 may provide pressure points in the membrane electrode assembly that may be undesirable for durability. As shown in FIGS. 15 and 16, a conductor 30 may be a metal foil 44 having a substantially uniform thickness 35 across the width, or within about 10% of uniform, and may have apertures 42 forming open area in the conductor. Figure 15 shows the “open area” of the of the conductor, or surface area of conductor that is open as determined by orthogonal “line of sight” through the plane of the conductor. A preferred conductor may be very thin and may be a foil or thin sheet of material to enable good contact with the electrode and high in-plane conductivity. A foil, or thin planar sheet of material, or printed conductor with apertures therethrough may be preferred for this reason.

[0050] It will be apparent to those skilled in the art that various modifications, combinations and variations can be made in the present invention without departing from the scope of the invention. Specific embodiments, features and elements described herein may be modified, and/or combined in any suitable manner. Thus, it is intended that the present invention cover the modifications, combinations and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A conductor integrated membrane electrode assembly comprising:
 - a) a conductor that is electrically conductive and comprising apertures therethrough;
 - b) an ion conducting membrane; and
 - c) an electrode;wherein the conductor is coupled with the electrode.
2. The conductor integrated membrane electrode assembly of claim 1, wherein the conductor is coupled to the ion conducting membrane.
3. The conductor integrated membrane electrode assembly of claim 2, wherein the conductor is coupled to the electrode and is configured between the ion conducting membrane and the electrode.
4. The conductor integrated membrane electrode assembly of claim 1, wherein the conductor is an electrode integrated conductor wherein a portion of said electrode is configured on both an inside surface and an outside surface of the conductor.
5. The conductor integrated membrane electrode assembly of claim 1, wherein the conductor is a membrane integrated conductor wherein a portion of said ion conducting membrane extends into the apertures of the conductor.
6. The conductor integrated membrane electrode assembly of claim 1, wherein the conductor is a printed conductor.
7. The conductor integrated membrane electrode assembly of claim 1, wherein the conductor is printed onto the electrode.
8. The conductor integrated membrane electrode assembly of claim 7, wherein the printed conductor has a thickness of no more than 5 μ m.
9. The conductor integrated membrane electrode assembly of claim 1, wherein the conductor is printed onto the ion conducting membrane.
10. The conductor integrated membrane electrode assembly of claim 9, wherein the printed conductor has a thickness of no more than 5 μ m.
11. The conductor integrated membrane electrode assembly of claim 6, wherein the printed conductor has an open area of at least 50%.
12. The conductor integrated membrane electrode assembly of claim 6, wherein the printed conductor includes conductor strands that have a length that is at least three times a width of said conductor strand and conductor nodes that are intersections of conductor strands.
13. The conductor integrated membrane electrode assembly of claim 1, wherein the conductor is a metal screen.

14. The conductor integrated membrane electrode assembly of claim 6, wherein the metal screen has an open area of at least 50%.
15. The conductor integrated membrane electrode assembly of claim 6, wherein the metal screen comprises stands that intersect.
16. The conductor integrated membrane electrode assembly of claim 15, wherein the metal screen includes conductor strands that have a length that is at least three times a width of said conductor strand and conductor nodes that are intersections of conductor strands.
17. The conductor integrated membrane electrode assembly of claim 16, wherein the conductor nodes are larger in area than the conductor strands.
18. The conductor integrated membrane electrode assembly of claim 13, wherein the conductor is a woven screen comprising strands that are woven with a first strand extending over a second strand and under a third strand.
19. The conductor integrated membrane electrode assembly of claim 13, wherein the conductor comprises a first set of strands extending over a second set of strands.
20. The conductor integrated membrane electrode assembly of claim 13, wherein the strands have a polygonal cross-sectional shape.
21. The conductor integrated membrane electrode assembly of claim 20, wherein the width of the stands is at least four times greater than a width.
22. The conductor integrated membrane electrode assembly of claim 1, wherein the conductor comprises a metal foil.
23. The conductor integrated membrane electrode assembly of claim 22, wherein the metal foil has apertures therethrough to produce an open area in the metal foil.
24. The conductor integrated membrane electrode assembly of claim 23, wherein the metal screen has an open area of at least 50%.

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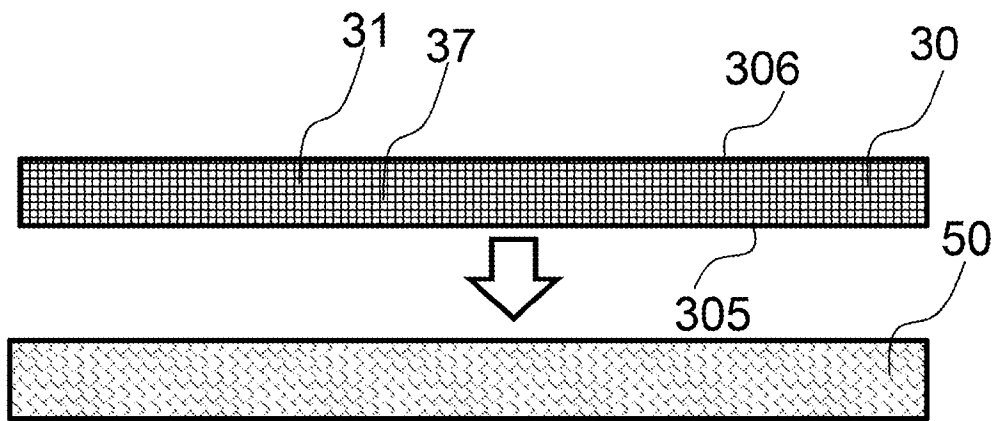


FIG. 1

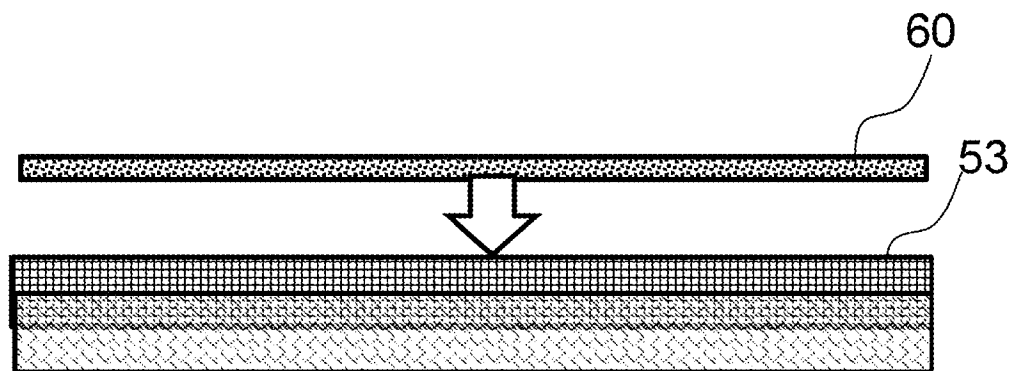


FIG. 2

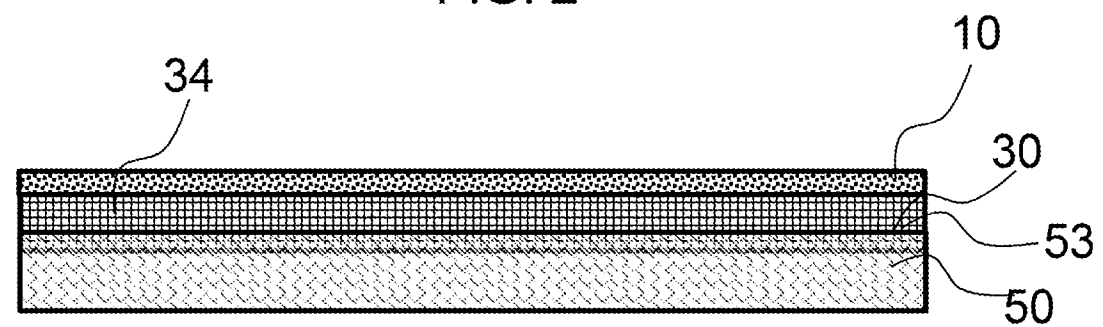


FIG. 3

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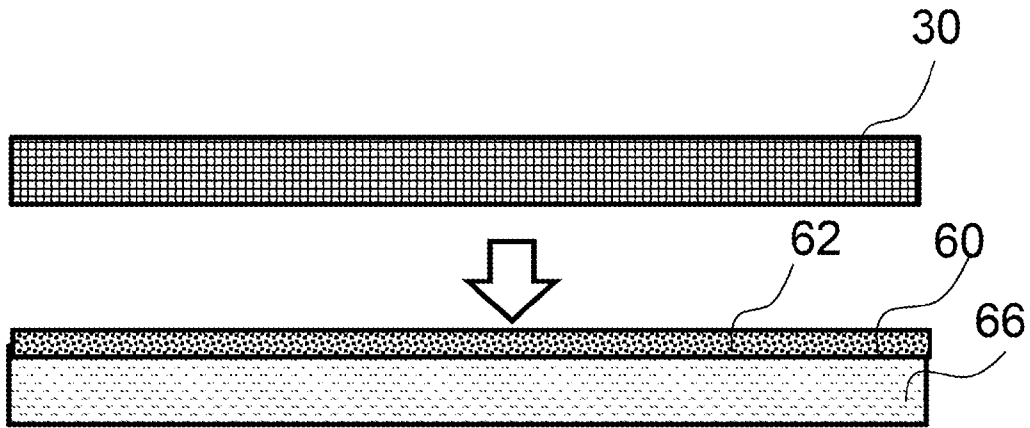


FIG. 4

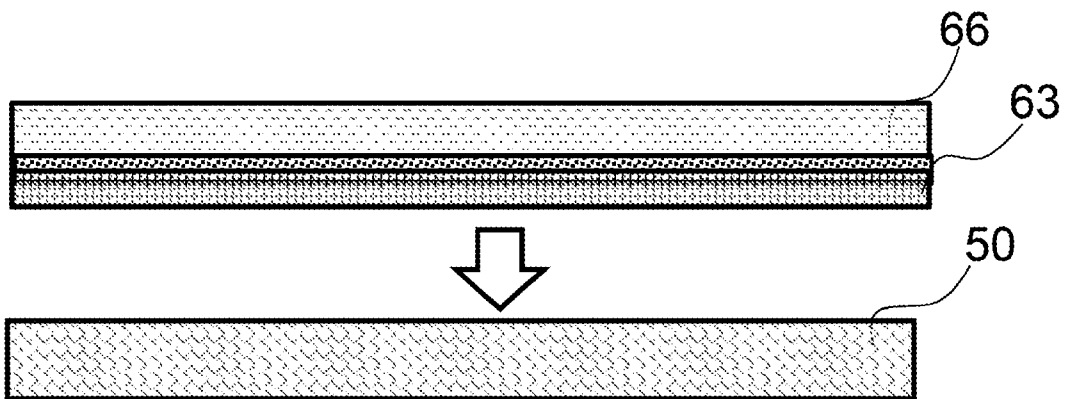


FIG. 5

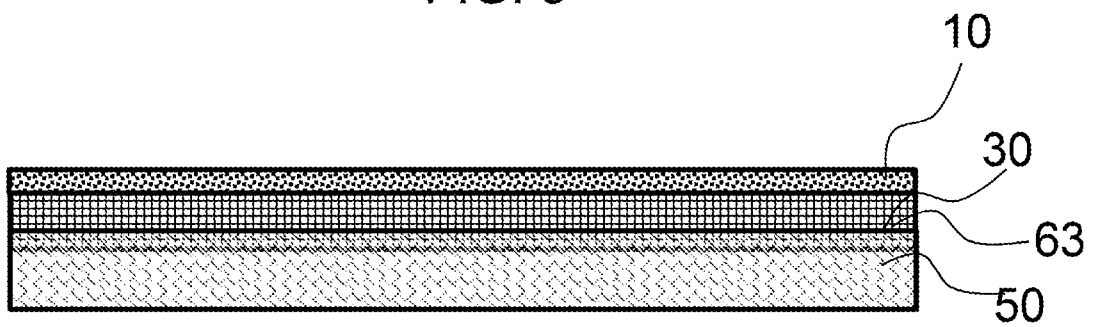


FIG. 6

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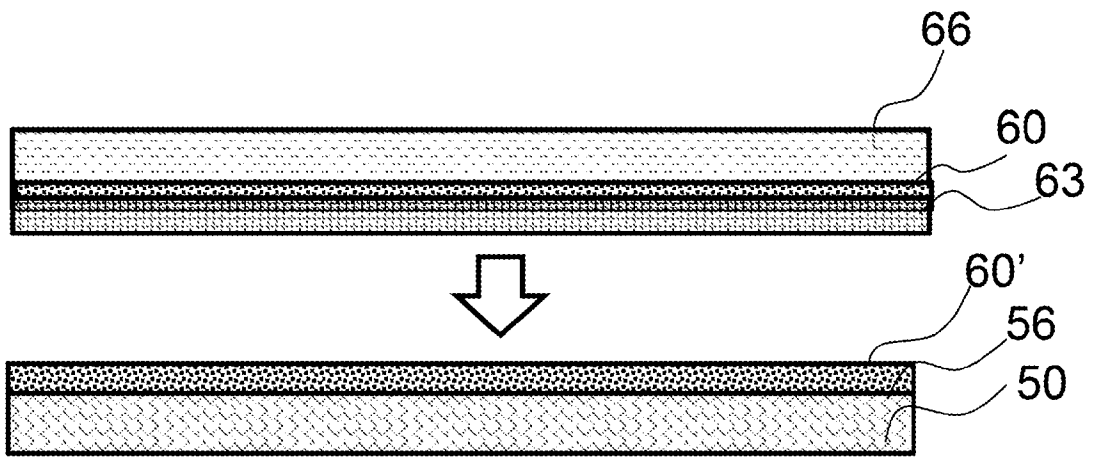


FIG. 7

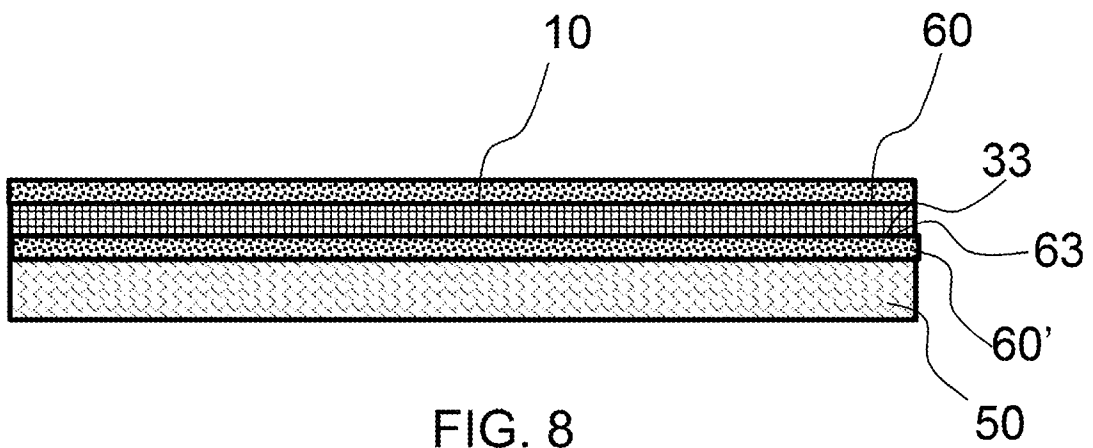


FIG. 8

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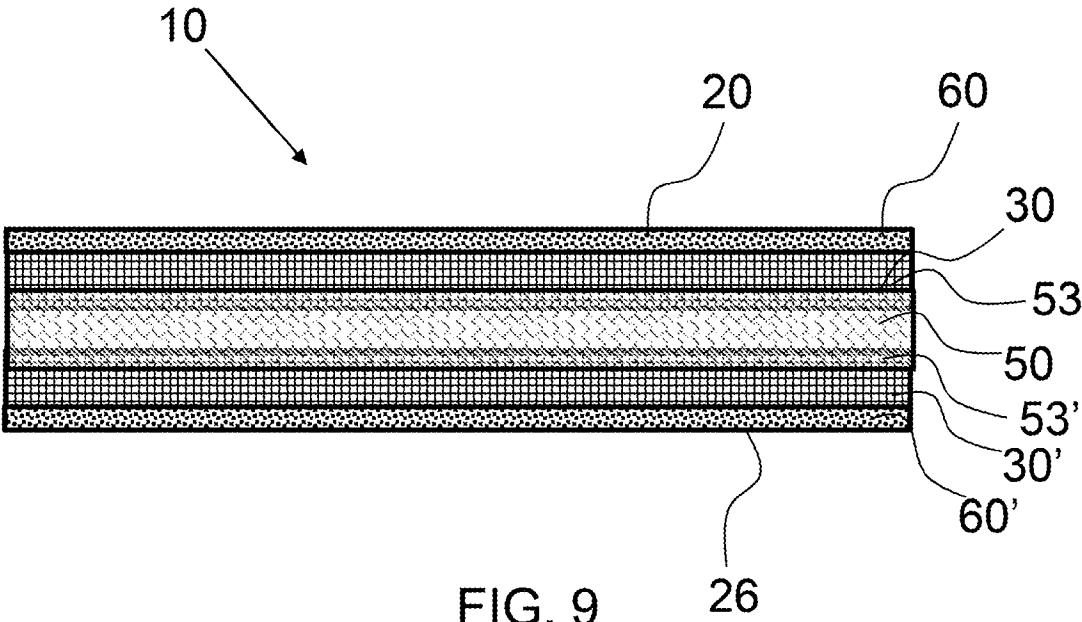


FIG. 9

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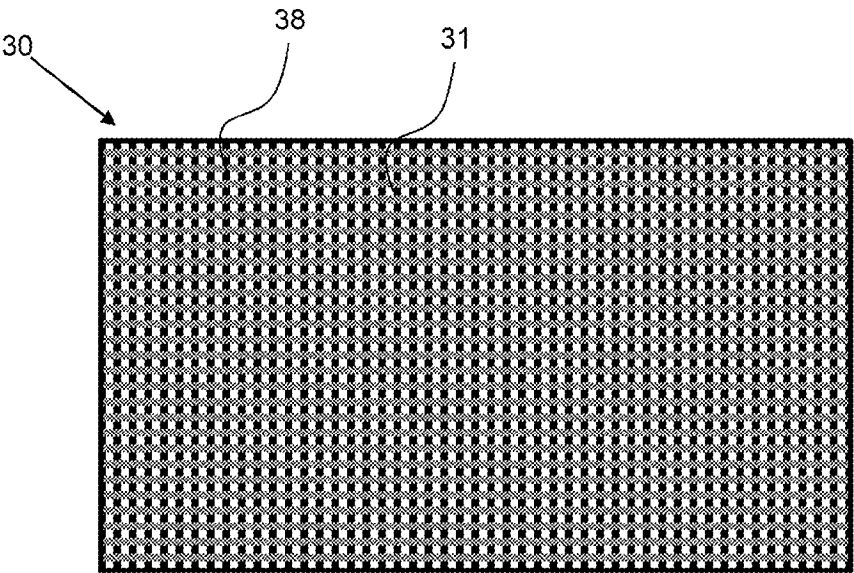


FIG. 10

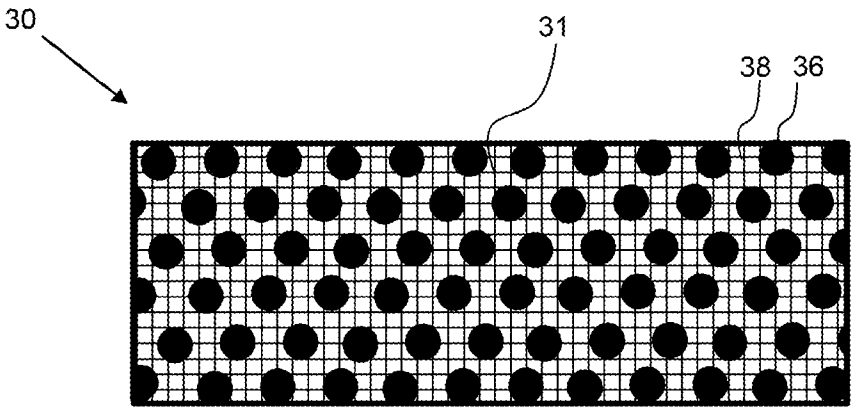
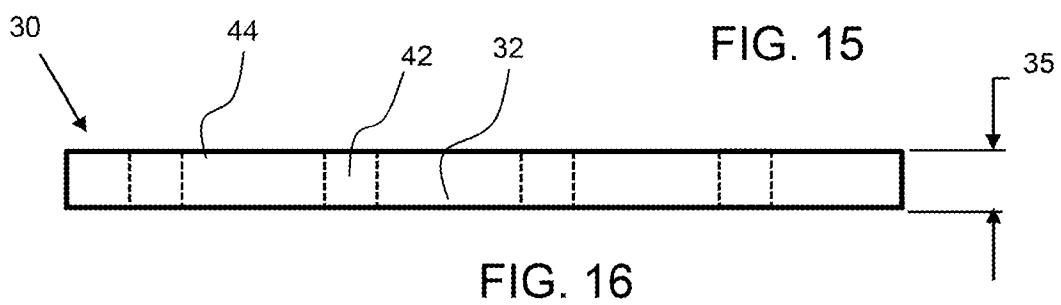
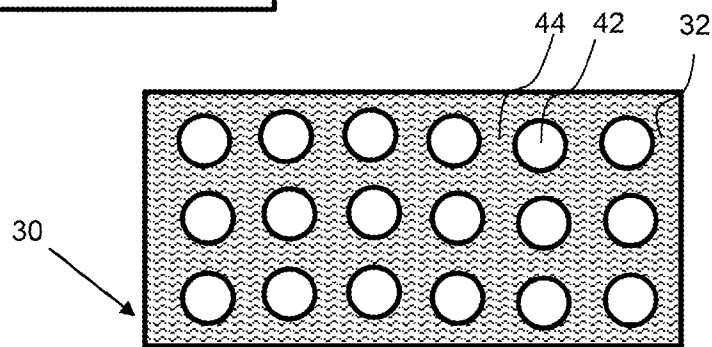
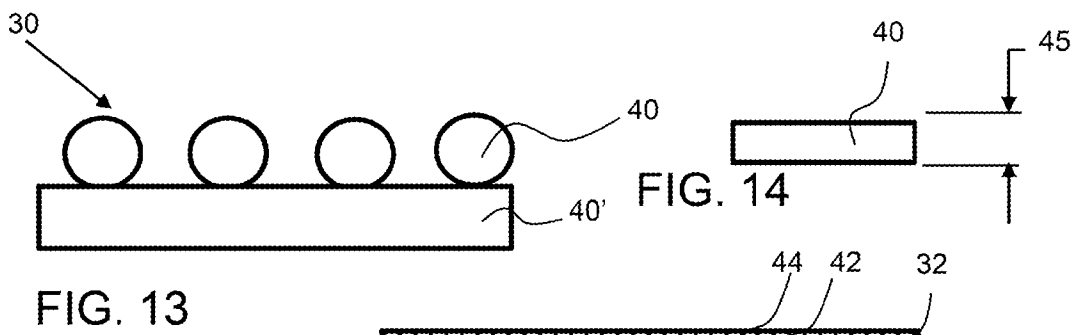
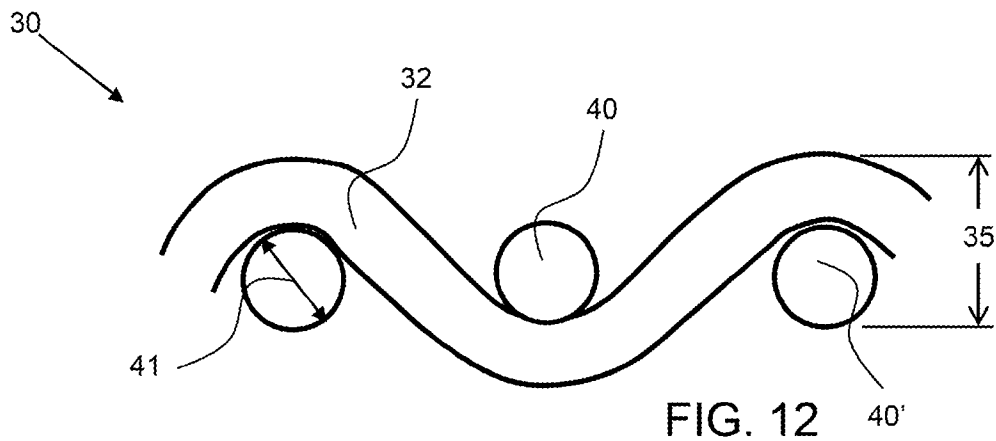


FIG. 11

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/032261

A. CLASSIFICATION OF SUBJECT MATTER H01B 1/12(2006.01)i; H01B 5/00(2006.01)i; B32B 7/025(2019.01)i According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H01B 1/12(2006.01); G01N 27/26(2006.01); G01N 27/30(2006.01); H01B 13/00(2006.01); H01B 5/14(2006.01); H01G 9/00(2006.01); H01G 9/004(2006.01); H01M 10/0525(2010.01); H01M 4/134(2010.01) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Korean utility models and applications for utility models Japanese utility models and applications for utility models Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) eKOMPASS(KIPO internal) & Keywords: conductor, apertures, ion conducting membrane, electrode, metal screen, metal foil		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 113933358 A (NANJING AGRICULTURAL UNIVERSITY) 14 January 2022 (2022-01-14) claims 1-3	1-5
Y		6-24
Y	CN 113409991 A (JIANGSU NAMEIDA PHOTOELECTRIC TECHNOLOGY CO., LTD.) 17 September 2021 (2021-09-17) claims 1-18; paragraphs [0118], [0119]	6-12
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Name and mailing address of the ISA/KR Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon 35208, Republic of Korea Facsimile No. +82-42-481-8578		Authorized officer JANG, Gi Jeong Telephone No. +82-42-481-8364

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