(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 April 2025 (17.04.2025)

WIPO | PCT

(10) International Publication Number
WO 2025/080121 A2

(51) International Patent Classification:
C25B 1/04 (2021.01) *C25B 11/091* (2021.01)
C25B 9/19 (2021.01) *C25B 9/65* (2021.01)
C25B 15/08 (2006.01) *C25B 9/60* (2021.01)
C25B 11/061 (2021.01) *C25B 13/02* (2006.01)
C25B 11/075 (2021.01)

(21) International Application Number:
PCT/MY2024/050098

(22) International Filing Date:
12 December 2024 (12.12.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PI 2023006251 11 October 2023 (11.10.2023) MY

(71) Applicant: **UNIVERSITY OF MALAYA** [MY/MY]; University of Malaya Centre of Innovation & Enterprise (UMCIE), Level 5, Research Management & Innovation Complex, University of Malaya, Wilayah Persekutuan Kuala Lumpur, 50603 (MY).

(72) Inventors: **AHMAD, Muhammad Shakeel**; UM Power Energy Dedicated Advanced Centre (UMPEDAC), Level 4, Wisma R&D UM, Jalan Pantai Baharu, Wilayah Persekutuan Kuala Lumpur, 59990 (MY). **ABD RAHIM, Nasrudin**; UM Power Energy Dedicated Advanced Centre (UMPEDAC), Level 4, Wisma R&D UM, Jalan Pantai Baharu, Wilayah Persekutuan Kuala Lumpur, 59990 (MY).

(74) Agent: **AWANG, Muhammad Irfan Mustaqim**; Patentsworth International Sdn Bhd, A-SG-11A, Sunway GEO Avenue, Jalan Lagoon Selatan, Sunway South Quay, Sunway City, Subang Jaya, 47500 (MY).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY,

(54) Title: ZERO-GAP, MEMBRANE-LESS ELECTROLYSER FOR WATER SPLITTING IN HYDROGEN/OXYGEN PRODUCTION AND METHODS THEREOF

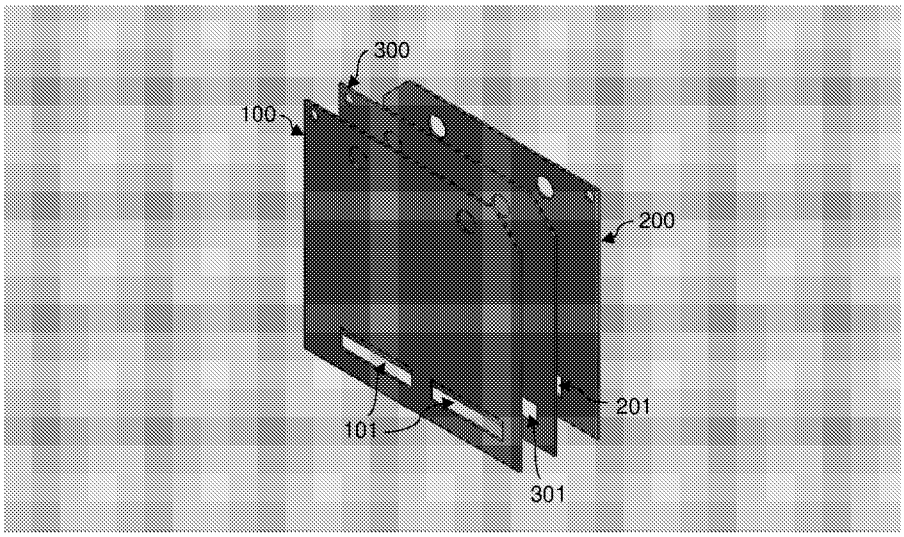


FIGURE 1

(57) Abstract: The present invention discloses an electrolyser for water splitting in hydrogen/oxygen production and methods thereof. The electrolyser comprises a first electrode plate (100) coated with a first catalyst comprising a first ion transfer opening (101) formed therethrough along a first lateral axis of the first electrode plate (100); a second electrode plate (200) coated with a second catalyst comprising a second ion transfer opening (201) formed therethrough along a second lateral axis of the second electrode plate (200); and an electrically insulative adhesive layer (300) configured for securing together the first electrode plate (100) and the second electrode plate (200) in a face-to-face manner or a back-to-face manner, forming separate compartments each for a hydrogen gas and an oxygen gas resulting from the water splitting that provide immunity against any mixing of the hydrogen gas and the oxygen gas at any level of an electrical power supply.

WO 2025/080121 A2

[Continued on next page]

MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

— *with information concerning request for restoration of the right of priority in respect of one or more priority claims (Rules 26bis.3 and 48.2(b)(vii))*

— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

ZERO-GAP, MEMBRANE-LESS ELECTROLYSER FOR WATER SPLITTING IN HYDROGEN/OXYGEN PRODUCTION AND METHODS THEREOF

FIELD OF THE INVENTION

The present invention generally relates to the field of water splitting by electrolysis. More particularly, the present invention relates to an electrolyser for water splitting in hydrogen/oxygen production and methods thereof.

BACKGROUND OF THE INVENTION

The subject matter discussed in the background section should not be assumed to be prior art merely as a result of its mention in the background section. Similarly, a problem mentioned in the background section or associated with the subject matter of the background section should not be assumed to have been previously recognised in the prior art. The subject matter in the background section merely represents different approaches, which in and of themselves may also correspond to implementations of the claimed technology.

Electrolysis of water is an important technology for the production of hydrogen to be used as an energy carrier. With fast dynamic response times, large operational ranges, and high efficiencies, water electrolysis is a promising technology for energy storage coupled with renewable energy sources. Electrolyser uses electricity to split water molecules into their constituent elements that are hydrogen and oxygen gases through electrolysis. The hydrogen gas can be stored as either compressed gas or liquefied. The oxygen created may be released back into the air or captured and stored to supply to other industrial processes. The components of an electrolyser are rather straightforward. This device typically consists of a stack of electrodes that is separated by a thin membrane. A high voltage current is then passed through the stack of electrodes; causing water molecules to break down into hydrogen and oxygen atoms.

Conventional electrolysers include a proton exchange membrane (PEM) electrolyser, an alkaline water electrolyser, and a solid oxide electrolyser. The conventional PEM electrolyser involves the electrolysis of water in a cell equipped with a solid polymer electrolyte responsible for the conduction of protons, separation of product gases, and electrical insulation of the electrodes. The performance of

conventional PEM electrolysers is however limited due to the thickness of the proton exchange membrane (about 175 µm), causing resistance to proton flow and therefore heat losses. Besides difficulty in maintaining the high efficiency, conventional PEM electrolysers also have higher capital costs due to the use of expensive materials, and hence, relatively expensive to produce which can be a barrier to widespread adoption. The conventional alkaline water electrolyser exhibits low conductivity, which makes its performance subpar compared to PEM electrolysers. This type of electrolyser further suffers from the degradation at high temperatures causing the conversion of membranes to carbonate and emit carbon dioxide. The alkaline water electrolyser also has chemical and mechanical stability concerns that usually result in unstable lifetime profiles. The conventional solid oxide electrolyser, disadvantageously, requires high operating temperature which results in longer start-up times and issues pertaining to mechanical and chemical stability. While the electrolysis devices and systems described above have been somewhat satisfactory in the past, there is a continuing need in the art to improve such electrolysers. More particularly, it would be desirable to provide a zero-gap and membrane-less electrolyser for producing a high purity hydrogen that is inexpensive and easy to use, and yet directly couplable with any intermittent electrical power source.

By way of background, United States Patent Application Publication No. US 2018/0195185 A1 (hereinafter “the ‘185 publication”) discloses a PEM electrolyser for breaking down water to hydrogen and oxygen that comprises a titanium anode, a catalyst-coated membrane, a titanium cathode, and a power source. The titanium anode is configured to receive water from a water source. The titanium anode liberates oxygen and protons. According to the ‘185 publication, the catalyst-coated membrane is operably connected to the titanium anode via gas diffusion layer (titanium frits and titanium mesh). The catalyst-coated membrane is configured to permit protons to permeate from the anode to the cathode. The titanium cathode is configured to receive the protons that have migrated through the membrane. The received protons accept electrons from the power source to form hydrogen. The power source is electrically connected across the titanium anode and the titanium cathode. The power source completes an electric circuit between the cathode and the anode for breaking down the water to hydrogen and oxygen.

For the reasons stated above and for other reasons which will become apparent to those skilled in the art upon reading and understanding the

specification, there is a need in the art for a zero-gap and membrane-less electrolyser for water splitting. Although there may be similar approaches for the same in the prior art, there is still considerable room for improvement for many practical purposes.

SUMMARY OF THE INVENTION

The following presents a simplified summary of the invention in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. Its sole purpose is to present some concepts of the invention in a simplified form as a prelude to the more detailed description that is presented later.

Accordingly, the present invention provides an electrolyser for water splitting in hydrogen/oxygen production. The electrolyser of the present invention may be characterised by a first electrode plate coated with a first catalyst comprising a first ion transfer opening formed therethrough along a first lateral axis of the first electrode plate; a second electrode plate coated with a second catalyst comprising a second ion transfer opening formed therethrough along a second lateral axis of the second electrode plate; and an electrically insulative adhesive layer configured for securing together the first electrode plate and the second electrode plate in a face-to-face manner or a back-to-face manner, forming separate compartments each for a hydrogen gas and an oxygen gas resulting from the water splitting that provide immunity against any mixing of the hydrogen gas and the oxygen gas at any level of an electrical power supply.

Preferably, the first electrode plate comprises a substrate made from a stainless steel and a surface enhancer comprising an alloy selected from a group comprising a nickel aluminium alloy, a nickel cobalt alloy, a nickel chromium alloy, a cobalt aluminium alloy, a cobalt chromium alloy, and any combinations thereof.

Preferably, the first catalyst comprises a molybdenum compound selected from a group comprising oxyhydroxyhalides of molybdenum and a molybdenum compound having a formula of MMoX, wherein M is an alkali metal selected from a group comprising a sodium, a potassium, a lithium, a rubidium, and a caesium, and X is a halogen.

Preferably, the first ion transfer opening includes a pair of first ion transfer openings spaced apart from each other along a first longitudinal axis of the first electrode plate.

Preferably, the second electrode plate comprises a substrate made from a stainless steel and a surface enhancer comprising an alloy selected from a group comprising a nickel aluminium alloy, a nickel cobalt alloy, a nickel chromium alloy, a cobalt aluminium alloy, a cobalt chromium alloy, and any combinations thereof.

Preferably, the second catalyst comprises a cobalt compound.

Preferably, the second ion transfer opening includes a pair of second ion transfer openings spaced apart from each other along a second longitudinal axis of the second electrode plate.

Preferably, the first ion transfer opening and the second ion transfer opening are identical in configuration and position.

Preferably, the electrically insulative adhesive layer comprises a phenolic prepreg comprising a nitrile phenolic resin, an epoxy resin, a curing-agent-containing epoxy resin, a polyimide resin, or any combinations thereof.

Preferably, the electrically insulative adhesive layer comprises a third ion transfer opening identical to that of the first ion transfer opening and the second ion transfer opening.

Preferably, the electrolyser further comprises a first gasket and a second gasket each comprising a circular through hole and a semicircular through hole arranged in an alternate manner configured for sealing a connection between a first end plate and the first electrode plate and between the second electrode plate and a second end plate, respectively.

Preferably, the electrolyser further comprises a first gasket, a second gasket, and a third gasket each comprising a circular through hole and a semicircular through hole arranged in an alternate manner configured for sealing a connection between a first end plate and the first electrode plate, between the

second electrode plate and another second electrode plate, and between another first electrode plate and a second end plate, respectively.

Preferably, the first end plate comprises a first gas outlet for discharging the hydrogen gas thereof and a water intake port.

Preferably, the second end plate comprises a second gas outlet for discharging the oxygen gas thereof and a water intake port.

In accordance with another aspect of the invention, a method of fabricating an electrolyser for water splitting in hydrogen/oxygen production is provided. The method of the present invention may be characterised by the steps of providing a first electrode plate coated with a first catalyst comprising a first ion transfer opening formed therethrough along a first lateral axis of the first electrode plate; providing a second electrode plate coated with a second catalyst comprising a second ion transfer opening formed therethrough along a second lateral axis of the second electrode plate; and providing an electrically insulative adhesive layer configured for securing together the first electrode plate and the second electrode plate in a face-to-face manner or a back-to-face manner, forming separate compartments each for a hydrogen gas and an oxygen gas resulting from the water splitting that provide immunity against any mixing of the hydrogen gas and the oxygen gas at any level of an electrical power supply.

In accordance with another aspect of the invention, a method of hydrogen/oxygen production is provided. The method of the present invention may be characterised by the steps of generating a hydrogen gas and an oxygen gas by water splitting in an electrolyser comprising a first electrode plate coated with a first catalyst comprising a first ion transfer opening formed therethrough along a first lateral axis of the first electrode plate; a second electrode plate coated with a second catalyst comprising a second ion transfer opening formed therethrough along a second lateral axis of the second electrode plate; and an electrically insulative adhesive layer configured for securing together the first electrode plate and the second electrode plate in a face-to-face manner or a back-to-face manner, forming separate compartments each for the hydrogen gas and the oxygen gas resulting from the water splitting that provide immunity against any mixing of the hydrogen gas and the oxygen gas at any level of an electrical power supply; and discharging the hydrogen gas and the oxygen gas from the said separate compartments.

The foregoing and other objects, features, aspects and advantages of the present invention will become better understood from a careful reading of a detailed description provided herein below with appropriate reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

Figure 1 is an isometric view of an electrolyser for water splitting in hydrogen/oxygen production comprising a first electrode plate, a second electrode plate, and an electrically insulative adhesive layer sandwiched therebetween according to one embodiment of the present invention;

Figure 2 is an isometric view of an electrolyser deployed with gaskets and end plates forming a single cell assembly according to one embodiment of the present invention;

Figure 3 is an isometric view of an electrolyser deployed with gaskets and end plates forming a stacked cell assembly according to one embodiment of the present invention;

Figure 4 is a flow diagram depicting a method of fabricating an electrolyser for water splitting in hydrogen/oxygen production according to one embodiment of the present invention;

Figure 5 is a flow diagram depicting a method of hydrogen/oxygen production according to one embodiment of the present invention;

Figure 6 is a cross-sectional view of an electrolyser deployed with gaskets and end plates forming a stacked cell assembly according to one embodiment of the present invention;

Figure 7 shows a gasket for use with an electrolyser for water splitting in hydrogen/oxygen production according to one embodiment of the present invention;

Figure 8 is a schematic diagram illustrating the production of a hydrogen gas and an oxygen gas resulting from water splitting by an electrolyser according to one embodiment of the present invention; and

Figure 9 shows an electrolyser in a stacked cell assembly according to another embodiment of the present invention.

It is noted that the drawings may not be to scale. The drawings are intended to depict only typical aspects of the invention, and therefore should not be considered as limiting the scope of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention discloses an electrolyser for water splitting in hydrogen/oxygen production, a method of fabricating an electrolyser for water splitting in hydrogen/oxygen production, and a method of hydrogen/oxygen production that can be made, used, and maintained in a highly specific and compact, cost-effective, quick, and simple manner, without the use of complicated and sophisticated steps, components, or parts.

Advantageously, the present invention provides a zero-gap and membrane-less alkaline electrolyser for producing a high purity hydrogen. The said electrolyser operatively does not require and demand any membrane or diaphragm and/or any gas separator. The present invention eliminates the current collector and costly micro-designed bipolar plates. No bipolar plate is employed in the present invention. More advantageously, the zero-gap and membrane-less alkaline electrolyser of the present invention allows for about a 14% reduction in a capital cost compared to any conventional alkaline electrolysers, and for ease of assembly, reducing about 70% of stacking costs. The engineered alkaline electrolyser of the present invention comes with the capability of directly coupling with an intermittent energy source, e.g., solar, wind, with an expected design load range of about 1% to 100%, allowing more significant power load variability without compromising on hydrogen purity.

The term “zero-gap”, as used herein, generally refers to the concept of substantially or almost eliminating any gap between electrode plates of an electrolyser. The term also encompasses the direct contact between the electrode plates. The term is expanded to mean that all structures between the electrode plates are in mechanical contact with no space for a liquid electrolyte to congregate.

The term “membrane-less”, as used herein, generally refers to an electrolyser that does not include a membrane, or other non-porous or ion-selective barrier, positioned between the electrodes.

The term “water splitting”, as used herein, generally relates to any process that generates elemental hydrogen and/or oxygen from water as the starting material in the presence of an electric potential. In an embodiment, water splitting is achieved by many different technologies of which electrolysis is an example. Water splitting by electrolysis is achieved by applying electric energy on two electrodes, termed anode and cathode.

The term “face-to-face”, as used herein, generally implies that the faces of electrode plates will be bonded so as to face each other. The term also means that two substantially identical electrode plates are bonded together such that they are substantially symmetrically arranged.

The term “back-to-face”, as used herein, generally implies that the back of one electrode plate will be bonded to the face of another electrode plate.

The term “lateral axis”, as used herein, refers to a side-to-side axis extending a width of an electrode substrate. Thus, a “lateral direction”, as used herein, refers to a direction aligned with a lateral axis.

The term “longitudinal axis”, as used herein, refers to an axis extending a length of an electrode substrate. Thus, a “longitudinal direction”, as used herein, refers to a direction aligned with a longitudinal axis. The longitudinal axis and the lateral axis are oriented perpendicularly relative to one another.

In accordance with one preferred embodiment of the present invention, the electrolyser comprises a first electrode plate **100**, a second electrode plate **200** and an electrically insulative adhesive layer **300**. It is preferred that the first electrode

plate **100** and the second electrode plate **200** are secured together or bonded in a direct contact manner by the said electrically insulative adhesive layer **300** sandwiched therebetween. The electrolyser preferably comprises an electrolyte media. The electrolyte media is an ionically conductive and electrically insulating material that allows ions to migrate or conduct therethrough, but which does not allow electrons to conduct therethrough. In an embodiment, the electrolyte media comprises an alkaline electrolyte. The alkaline electrolyte may be a potassium hydroxide or sodium hydroxide.

The first electrode plate **100** is preferably an electrode device or substrate that includes both a length dimension and a width dimension to some substantive degree. The said substrate may be a mesh substrate, structure, or sheet. The first electrode plate **100** preferably includes not only a rigid plate-like member, but also a flexible sheet and film. It is preferred that the first electrode plate **100**, which is a planar or substantially planar sheet or plate, is alignable in a substantially face-to-face or back-to-face manner, orientation or alignment with one or more adjacent electrode plates. In an embodiment, the substrate of the first electrode plate **100** is rectangular in shape and has a proximal end and a distal end as well as sides. In the depicted embodiment, the substrate is rectangular, but it may also be, for example, cylindrical, oval, square, triangular, or any other suitable shape or configuration.

The said substrate of the first electrode plate **100** is preferably made from a stainless steel. The stainless steel is preferably an alloy of iron and carbon (referred to in the art as “steel”) which further comprises chromium at a concentration of at least 10 weight percents. The concentration of carbon is typically in a range of from 0.002 to 2.14 weight percents. The stainless steel may include austenitic alloy steels, such as stainless and acid-proof steels. The first electrode plate **100** further comprises a surface enhancer comprising an alloy. The alloy can be selected from a group comprising a nickel aluminium alloy (e.g., Raney nickel), a nickel cobalt alloy, a nickel chromium alloy, a cobalt aluminium alloy, a cobalt chromium alloy, and any combinations thereof. The surface enhancer preferably modifies the surface of the substrate to improve its electrocatalytic activity. In an embodiment, the substrate is coated with the surface enhancer thereof.

The first electrode plate **100** preferably comprises a first ion transfer opening **101**. The first ion transfer opening **101** is preferably disposed towards the proximal

end of the substrate thereof. The first ion transfer opening **101** is formed through a body of the substrate along a first lateral axis of the first electrode plate **100**. The first ion transfer opening **101** preferably includes a slit, orifice, crevice, or gap of a configuration including a size and a shape through which the ion can pass. More preferably, the first ion transfer opening **101** is a through hole or perforation, that is an opening that breaks in a straight line through the body of the substrate and any coating applied to the substrate thereof. In the depicted embodiment, the said first ion transfer opening **101** is rectangular, but it may also be, for example, cylindrical, oval, square, triangular, or any other suitable shape or configuration.

In one preferred embodiment, the first ion transfer opening **101** includes a pair of first ion transfer openings spaced apart from each other along a first longitudinal axis of the first electrode plate **100**. The pair of first ion transfer openings are preferably arranged in series with each other and in parallel with the proximal end of the substrate thereof. In a different embodiment, there may be more than a pair of first ion transfer openings formed therethrough.

The first electrode plate **100** preferably has the substrate coated or disposed with a first catalyst. The first catalyst preferably comprises a molybdenum compound. The molybdenum compound is preferably selected from a group comprising oxyhydroxyhalides of molybdenum and a molybdenum compound having a formula of MMoX, wherein M is an alkali metal selected from a group comprising a sodium, a potassium, a lithium, a rubidium, and a caesium, and X is a halogen. In an embodiment, the first catalyst is a molybdenum catalyst. The term “molybdenum compound” includes, but is not limited to, elemental molybdenum. Other metal catalysts based on a material, such as, but not limited to, tungsten, scandium, vanadium, titanium, zirconium, praseodymium, neodymium, samarium, europium, terbium, disprosium, holmium, erbium, yttrium and lutetium may be used.

The first electrode plate **100** is preferably an anode or positive electrode plate.

The second electrode plate **200** is preferably an electrode device or substrate that includes both a length dimension and a width dimension to some substantive degree. The said substrate may be a mesh substrate, structure, or sheet. The second electrode plate **200** preferably includes not only a rigid plate-like member, but also a flexible sheet and film. It is preferred that the second electrode

plate **200**, which is a planar or substantially planar sheet or plate, is alignable in a substantially face-to-face or back-to-face manner, orientation or alignment with one or more adjacent electrode plates. In an embodiment, the substrate of the second electrode plate **200** is rectangular in shape and has a proximal end and a distal end as well as sides. In the depicted embodiment, the substrate is rectangular, but it may also be, for example, cylindrical, oval, square, triangular, or any other suitable shape or configuration.

The said substrate of the second electrode plate **200** is preferably made from a stainless steel. The stainless steel is preferably an alloy of iron and carbon (referred to in the art as “steel”), which further comprises chromium at a concentration of at least 10 weight percents. The concentration of carbon is typically in a range of from 0.002 to 2.14 weight percents. The stainless steel may include austenitic alloy steels, such as stainless and acid-proof steels. The second electrode plate **200** further comprises a surface enhancer comprising an alloy. The alloy can be selected from a group comprising a nickel aluminium alloy (e.g., Raney nickel), a nickel cobalt alloy, a nickel chromium alloy, a cobalt aluminium alloy, a cobalt chromium alloy, and any combinations thereof. The surface enhancer preferably modifies the surface of the substrate to improve its electrocatalytic activity. In an embodiment, the substrate is coated with the surface enhancer thereof.

The second electrode plate **200** preferably comprises a second ion transfer opening **201**. The second ion transfer opening **201** is preferably disposed towards the proximal end of the substrate thereof. The second ion transfer opening **201** is formed through a body of the substrate along a second lateral axis of the second electrode plate **200**. The second lateral axis is preferably parallel with the first lateral axis thereof. The second ion transfer opening **201** preferably includes a slit, orifice, crevice, or gap of a configuration, including a size and a shape through which the ion can pass. More preferably, the second ion transfer opening **201** is a through hole or perforation, that is an opening that breaks in a straight line through the body of the substrate and any coating applied to the substrate thereof. In the depicted embodiment, the said second ion transfer opening **201** is rectangular, but it may also be, for example, cylindrical, oval, square, triangular, or any other suitable shape or configuration. The second ion transfer opening **101** and the first ion transfer opening **201** are preferably identical in configuration and position. For the

purposes of the present invention, the term “identical” refers to being similar in every detail; exactly alike.

In one preferred embodiment, the second ion transfer opening **201** includes a pair of second ion transfer openings spaced apart from each other along a second longitudinal axis of the second electrode plate **200**. The second longitudinal axis is preferably parallel with the first longitudinal axis thereof. The pair of second ion transfer openings are preferably arranged in series with each other and in parallel with the proximal end of the substrate thereof. In a different embodiment, there may be more than a pair of second ion transfer openings formed therethrough.

The second electrode plate **200** preferably has the substrate coated or disposed with a second catalyst. The second catalyst preferably comprises a cobalt compound. The term “cobalt compound” includes, but is not limited to, elemental cobalt. In an embodiment, the second catalyst is a cobalt catalyst, which means a catalyst containing elemental cobalt as an active ingredient and is not particularly limited. Examples thereof include cobalt powder, cobalt (II) chloride, and cobalt (II) bromide), cobalt (II) iodide, cobalt (II) fluoride, cobalt (II) acetate, cobalt (III) acetate, cobalt formate (II), cobalt (II) oxalate, cobalt (II) benzoate, cobalt (II) stearate, cobalt (II) borate, cobalt (II) acetylacetonate, cobalt (III) acetylacetonate, cobalt carbonate (II), compounds such as cobalt (II) sulphate, cobalt (II) nitrate and cobalt (II) phosphate, hydrates of these compounds, and various complex catalysts derived from these compounds. Other metal catalysts based on a material, such as, but not limited to, tungsten, scandium, vanadium, titanium, zirconium, praseodymium, neodymium, samarium, europium, terbium, disprosium, holmium, erbium, yttrium and lutetium may be used.

The second electrode plate **200** is preferably a cathode or negative electrode plate.

The electrically insulative adhesive layer **300** is preferably configured for securing together the first electrode plate **100** and the second electrode plate **200** in a face-to-face manner or a back-to-face manner, forming separate compartments each for a hydrogen gas and an oxygen gas resulting from the water splitting thereof. Surprisingly, such separate compartments provide immunity against any gas mixing of the hydrogen gas and the oxygen gas at any level of an electrical power supply. In an embodiment, the separate compartments include partitions,

regions, channels, volumes, passages, enclosed sections, delimited zones, and the like (with a containing function) that separate or isolate the hydrogen gas and the oxygen gas from each other, thus preventing gas mixing. The electrically insulative adhesive layer **300** essentially refers to a layer containing an adhesive as a main component that is on the surface of the first electrode plate **100** used to adhere the first electrode plate **100** to the second electrode plate **200**, and vice versa. It is preferred that the electrically insulative adhesive layer **300** is an intermediate layer or film. The term “electrically insulative” refers to a material, a reconfiguration of a material, and/or a combination of materials in relation to the electrically insulative adhesive layer **300** that inhibits current or does not allow current to be transferred or passed through the material.

In an embodiment, the electrically insulative adhesive layer **300,** having a proximal end and a distal end as well as sides, is a bond adhesive panel that is rigid and dimensionally stable. The electrically insulative adhesive layer **300** is preferably rigid enough to be shaped as a panel having a dimension (e.g., shape and size) that is the same or similar to that of the first electrode plate **100** and/or the second electrode plate **200**. In relation to the aforesaid, the electrically insulative adhesive layer **300** preferably comprises a third ion transfer opening **301** formed therethrough along a third lateral axis of the electrically insulative adhesive layer **300**. The third lateral axis is preferably parallel with the first lateral axis and the second lateral axis thereof.

The third ion transfer opening **301** is preferably disposed towards the proximal end of the electrically insulative adhesive layer **300** thereof. The third ion transfer opening **301** is formed through a body of the electrically insulative adhesive layer **300** along the third lateral axis of the electrically insulative adhesive layer **300**. The third ion transfer opening **301** preferably includes a slit, orifice, crevice, or gap of a configuration, including a size and a shape through which the ion can pass. More preferably, the third ion transfer opening **301** is a through hole or perforation that is an opening that breaks in a straight line through the body of the electrically insulative adhesive layer **300**. In the depicted embodiment, the said third ion transfer opening **301** is rectangular, but it may also be, for example, cylindrical, oval, square, triangular, or any other suitable shape or configuration. The third ion transfer opening **301**, the second ion transfer opening **101** and the first ion transfer opening **201** are preferably identical in configuration and position. The third ion transfer opening **301** is preferably identical to that of the first ion transfer opening

101 and the second ion transfer opening **201**. For the purposes of the present invention, the term "identical" refers to being similar in every detail; exactly alike.

In one preferred embodiment, the third ion transfer opening **301** includes a pair of third ion transfer openings spaced apart from each other along a third longitudinal axis of the electrically insulative adhesive layer **300**. The third longitudinal axis is preferably parallel with the first longitudinal axis and the second longitudinal axis thereof. The pair of third ion transfer openings are preferably arranged in series with each other and in parallel with the proximal end of the electrically insulative adhesive layer **300** thereof. In a different embodiment, there may be more than a pair of third ion transfer openings formed therethrough.

The adhesive being the main component of the electrically insulative adhesive layer **300** preferably comprises a phenolic prepreg comprising a nitrile phenolic resin, an epoxy resin, a curing-agent-containing epoxy resin, a polyimide resin, or any combinations thereof.

The electrically insulative adhesive layer **300** may be regarded as a spacer material inserted between the first electrode plate **100** and the second electrode plate **200** and so forth (e.g., another first electrode plate(s) **100a/100b/100c** and another second electrode plate(s) **200a/200b/200c** with respective electrically insulative adhesive layer **300a/300b/300c**), and the overall structure would still be considered a "zero-gap architecture", as that term is being used herein, so long as there is not a liquid electrolyte gap between any of the electrodes.

Essentially, the electrolyser of the present invention comprises the first electrode plate **100** coated with the first catalyst and the second electrode plate **200** coated with the second catalyst joined back-to-back by or via an electrically insulative rigid adhesive layer, with end or compression plates **500, 600** flanking thereof. A gasket or sealant **400, 401, 402** is employed and used in the present invention to arrange multiple cells in a stack where the arrangement of positive and negative connections and gasket/sealant arrangement is critical and crucial.

The end plates preferably include a first end plate **500** and a second end plate **600** that are preferably a rigid support material for flanking, clamping and compressing the first electrode plate **100** and the second electrode plate **200** and so forth, and the electrically insulative adhesive layer **300** sandwiched

therebetween. The end plates **500, 600** include both flat and curved compression elements and cover both a frame plate and a pressure plate. It is preferred that each of the end plates **500, 600** includes a plurality of screw holes (threaded) for receiving fastening means, such as screws, nuts and bolts, and the like, although the described embodiment includes only twelve screw holes on each of them and where the location of the screw holes corresponds screw holes of opposing end plate **500, 600**. The functions of the end plates **500, 600** include, for example, ensuring sufficient stability and sealing functions.

In one embodiment, the first end plate **500** preferably comprises a first gas outlet **501** for discharging the hydrogen gas thereof and a water intake port **502** for receiving water. The second end plate **600** preferably comprises a second gas outlet **601** for discharging the oxygen gas thereof and a water intake port **602** for receiving water.

The gasket **400, 401, 402** is preferably configured for sealing a connection or providing a mechanical seal and a watertight seal between the first electrode plate **100** and the second electrode plate **200** and so forth (e.g., another first electrode plate(s) **100a/100b/100c** and another second electrode plate(s) **200a/200b/200c** with respective electrically insulative adhesive layer **300a/300b/300c**). The gasket **400, 401, 402** blocks, reduces or prevents fluid leakage around the first electrode plate **100** and the second electrode plate **200** and so forth (e.g., another first electrode plate(s) **100a/100b/100c** and another second electrode plate(s) **200a/200b/200c** with respective electrically insulative adhesive layer **300a/300b/300c**). The gasket **400, 401, 402** is preferably compressible and can be made of a silicon rubber, rubber, or foam material.

It is preferred that the gasket **400, 401, 402** comprises a frame portion having a proximal end and a distal end as well as sides forming an inner cavity. The frame portion is preferably in alignment with the first electrode plate **100** and the second electrode plate **200** and so forth (e.g., another first electrode plate(s) **100a/100b/100c** and another second electrode plate(s) **200a/200b/200c** with respective electrically insulative adhesive layer **300a/300b/300c**).

The gasket **400, 401, 402** further comprises a circular through hole and a semicircular through hole formed towards the distal end of the frame portion thereof. The circular through hole and the semicircular through hole are spaced apart from

each other along a longitudinal axis of the gasket **400, 401, 402**. It is preferred that the circular through hole and the semicircular through hole are in alignment with perforations of the electrodes **100/100a/100b/100c** and **200/200a/200b/200c**, respectively. Preferably, the circular through hole is centrally provided in the width section of the proximal end of the frame portion and the semicircular through hole is, at a distance from the circular through hole, provided in the lower section of the proximal end of the frame portion. The term "semicircular" widely includes an arc shape having a certain radius of curvature and a shape curved in one direction from the middle portion toward both ends, and, for example, also includes a shape having a straight-line portion in the middle portion and curved lines extending from both ends of the straight portion.

Preferably, the circular through hole and the semicircular through hole are configured for channelling the hydrogen gas and the oxygen gas separately. There is no independent gas separator in the present invention. The gasket **400, 401, 402** is used in a single cell assembly and a stacked cell assembly.

According to one embodiment of the present invention, with respect to the single cell assembly, a first gasket **400** and a second gasket **401** are employed and arranged in an alternate manner configured for sealing a connection between the first end plate **500** and the first electrode plate **100** and between the second electrode plate **200** and the second end plate **600**, respectively.

According to another embodiment of the present invention, with respect to the stacked cell assembly, a first gasket **400**, a second gasket **401**, and a third gasket **402** are employed and arranged in an alternate manner configured for sealing a connection between the first end plate **500** and the first electrode plate **100**, between the second electrode plate **200** and another second electrode plate **200a**, and between another first electrode plate **100a** and the second end plate **600**, respectively.

The intermittent energy source employed herein from which the electrolyser of the present invention gains the electrical power supply preferably refers to any source of energy which fluctuates in terms of its availability. In an embodiment, the intermittent energy source includes a natural renewable energy source, including but not limited to wind, wave or solar power, which, due to the vagaries of nature, are not consistent in the power they provide. The electrolyser of the present

invention can be powered by the usual electrical power supply, e.g., power grid, battery and the like.

According to the present invention, a 200-mV reduction in overpotential (i.e., from 2.4V to 2.2V) is recorded compared to conventional alkaline electrolysers with a 2-2.5mm gap between electrodes separated by a diaphragm. A high purity hydrogen can be produced at power ratings between 0-100% using the developed electrolyser of the present invention, which is not possible when using the Zirfon diaphragm-based alkaline type electrolyser. The electrolyser of the present invention includes the following specifications:

- Operational pressure: Atmospheric pressure
- Power factor: 0-100
- Power supply requirement: Intermittent energy source
- Electrocatalyst: Earth-abundant materials
- Net production rate (Nm^3/H): 50 Nm^3/H & 200 Nm^3/H
- Production capacity dynamic range (%): 1%-100%
- Power consumption at stack (kWh/NM^3): Approximately 4.5-4.8 kWh/NM^3
- H2 purity: 99.999%
- Delivery pressure (barg): <10 barg (or <1000 kPa)
- Full load hours per year (Hrs): 5256 Hrs – 6132 Hrs
- Level of cost of energy (USD/kW): Around 300-500 USD/kW
- Stock lifetime (Yrs): 20 years

For clarity, the method of fabricating an electrolyser for water splitting in hydrogen/oxygen production described in conjunction with the electrolyser in the preceding paragraphs will be summarised as follows:

(a) providing a first electrode plate **100** coated with a first catalyst comprising a first ion transfer opening **101** formed therethrough along a first lateral axis of the first electrode plate **100**;

(b) providing a second electrode plate **200** coated with a second catalyst comprising a second ion transfer opening **201** formed therethrough along a second lateral axis of the second electrode plate **200**; and

(c) providing an electrically insulative adhesive layer **300** configured for securing together the first electrode plate **100** and the second electrode plate **200** in a face-to-face manner or a back-to-face manner, forming separate compartments each for a hydrogen gas and an oxygen gas resulting from the water splitting that provide immunity against any mixing of the hydrogen gas and the oxygen gas at any level of an electrical power supply.

Although the method is depicted as a sequence of numbered steps for clarity, the numbering does not necessarily dictate the order of the steps. It should be understood that some of these steps may be skipped, performed in parallel, or performed without the requirement of maintaining a strict order of sequence.

For clarity, the method of fabricating an electrolyser for water splitting in hydrogen/oxygen production described in conjunction with the electrolyser in the preceding paragraphs will be summarised as follows:

(a) generating a hydrogen gas and an oxygen gas by water splitting in an electrolyser comprising a first electrode plate **100** coated with a first catalyst comprising a first ion transfer opening **101** formed therethrough along a first lateral axis of the first electrode plate **100**; a second electrode plate **200** coated with a second catalyst comprising a second ion transfer opening **201** formed therethrough along a second lateral axis of the second electrode plate **200**; and an electrically insulative adhesive layer **300** configured for securing together the first electrode plate **100** and the second electrode plate **200** in a face-to-face manner or a back-to-face manner, forming separate compartments each for the hydrogen gas and the oxygen gas resulting from the water splitting that provide immunity against any mixing of the hydrogen gas and the oxygen gas at any level of an electrical power supply; and

(b) discharging the hydrogen gas and the oxygen gas from the said separate compartments.

Although the method is depicted as a sequence of numbered steps for clarity, the numbering does not necessarily dictate the order of the steps. It should

be understood that some of these steps may be skipped, performed in parallel, or performed without the requirement of maintaining a strict order of sequence.

Although an overview of the inventive subject matter has been described with reference to specific example embodiments, various modifications and changes may be made to these embodiments without departing from the broader scope of embodiments of the present disclosure. Such embodiments of the inventive subject matter may be referred to herein, individually or collectively, by the term “invention” merely for convenience and without intending to voluntarily limit the scope of this application to any single disclosure or inventive concept if more than one is, in fact, disclosed.

The embodiments illustrated herein are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed. Other embodiments may be used and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. The Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

As used herein, the term “or” may be construed in either an inclusive or exclusive sense. Moreover, plural instances may be provided for resources, operations, or structures described herein as a single instance. Additionally, boundaries between various resources, operations, modules, engines, and data stores are somewhat arbitrary, and particular operations are illustrated in a context of specific illustrative configurations. Other allocations of functionality are envisioned and may fall within a scope of various embodiments of the present disclosure. In general, structures and functionality presented as separate resources in the example configurations may be implemented as a combined structure or resource. Similarly, structures and functionality presented as a single resource may be implemented as separate resources. These and other variations, modifications, additions, and improvements fall within a scope of embodiments of the present disclosure as represented by the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

The foregoing description, for the purpose of explanation, has been described with reference to specific example embodiments. However, the

illustrative discussions above are not intended to be exhaustive or to limit the possible example embodiments to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The example embodiments were chosen and described in order to best explain the principles involved and their practical applications, to thereby enable others skilled in the art to best utilise the various example embodiments with various modifications as are suited to the particular use contemplated.

It will also be understood that, although the terms “first”, “second”, and so forth may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first contact could be termed a second contact, and, similarly, a second contact could be termed a first contact, without departing from the scope of the present example embodiments. The first contact and the second contact are both contacts, but they are not the same contact.

The terminology used in the description of the example embodiments herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used in the description of the example embodiments and the appended examples, the singular forms “a”, “an”, and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term “and/or” as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms “comprises” and/or “comprising” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

As used herein, the term “if” may be construed to mean “when” or “upon” or “in response to determining” or “in response to detecting” depending on the context. Similarly, the phrase “if it is determined” or “if [a stated condition or event] is detected” may be construed to mean “upon determining” or “in response to determining” or “upon detecting [the stated condition or event]” or “in response to detecting [the stated condition or event]” depending on the context.

CLAIMS

1. An electrolyser for water splitting in hydrogen/oxygen production, **characterised in that**, the electrolyser comprising:

   a first electrode plate (100) coated with a first catalyst comprising a first ion transfer opening (101) formed therethrough along a first lateral axis of the first electrode plate (100);

   a second electrode plate (200) coated with a second catalyst comprising a second ion transfer opening (201) formed therethrough along a second lateral axis of the second electrode plate (200); and

   an electrically insulative adhesive layer (300) configured for securing together the first electrode plate (100) and the second electrode plate (200) in a face-to-face manner or a back-to-face manner, forming separate compartments each for a hydrogen gas and an oxygen gas resulting from the water splitting that provide immunity against any mixing of the hydrogen gas and the oxygen gas at any level of an electrical power supply.

2. The electrolyser according to Claim 1, wherein the first electrode plate (100) comprises a substrate made from a stainless steel and a surface enhancer comprising an alloy selected from a group comprising a nickel aluminium alloy, a nickel cobalt alloy, a nickel chromium alloy, a cobalt aluminium alloy, a cobalt chromium alloy, and any combinations thereof.

3. The electrolyser according to Claim 1, wherein the first catalyst comprises a molybdenum compound selected from a group comprising oxyhydroxyhalides of molybdenum and a molybdenum compound having a formula of MMoX, wherein M is an alkali metal selected from a group comprising a sodium, a potassium, a lithium, a rubidium, and a caesium, and X is a halogen.

4. The electrolyser according to Claim 1, wherein the first ion transfer opening (101) includes a pair of first ion transfer openings spaced apart from each other along a first longitudinal axis of the first electrode plate (100).

5. The electrolyser according to Claim 1, wherein the second electrode plate (200) comprises a substrate made from a stainless steel and a surface enhancer comprising an alloy selected from a group comprising a nickel aluminium alloy,

a nickel cobalt alloy, a nickel chromium alloy, a cobalt aluminium alloy, a cobalt chromium alloy, and any combinations thereof.

6. The electrolyser according to Claim 1, wherein the second catalyst comprises a cobalt compound.

7. The electrolyser according to Claim 1, wherein the second ion transfer opening (201) includes a pair of second ion transfer openings spaced apart from each other along a second longitudinal axis of the second electrode plate (200).

8. The electrolyser according to Claims 1, 4, and 7, wherein the first ion transfer opening (101) and the second ion transfer opening (201) are identical in configuration and position.

9. The electrolyser according to Claim 1, wherein the electrically insulative adhesive layer (300) comprises a phenolic prepreg comprising a nitrile phenolic resin, an epoxy resin, a curing-agent-containing epoxy resin, a polyimide resin, or any combinations thereof.

10. The electrolyser according to Claim 1, wherein the electrically insulative adhesive layer (300) comprises a third ion transfer opening (301) identical to that of the first ion transfer opening (101) and the second ion transfer opening (201).

11. The electrolyser according to Claim 1 further comprising a first gasket (400) and a second gasket (401) each comprising a circular through hole and a semicircular through hole arranged in an alternate manner configured for sealing a connection between a first end plate (500) and the first electrode plate (100) and between the second electrode plate (200) and a second end plate (600), respectively.

12. The electrolyser according to Claim 1 further comprising a first gasket (400), a second gasket (401), and a third gasket (402) each comprising a circular through hole and a semicircular through hole arranged in an alternate manner configured for sealing a connection between a first end plate (500) and the first electrode plate (100), between the second electrode plate (200) and another

second electrode plate (200a), and between another first electrode plate (100a) and a second end plate (600), respectively.

13. The electrolyser according to Claims 11 and 12, wherein the first end plate (500) comprises a first gas outlet (501) for discharging the hydrogen gas thereof and a water intake port (502).

14. The electrolyser according to Claims 11 and 12, wherein the second end plate (600) comprises a second gas outlet (601) for discharging the oxygen gas thereof and a water intake port (602).

15. A method of fabricating an electrolyser for water splitting in hydrogen/oxygen production, **characterised in that**, the method comprising the steps:

providing a first electrode plate (100) coated with a first catalyst comprising a first ion transfer opening (101) formed therethrough along a first lateral axis of the first electrode plate (100);

providing a second electrode plate (200) coated with a second catalyst comprising a second ion transfer opening (201) formed therethrough along a second lateral axis of the second electrode plate (200); and

providing an electrically insulative adhesive layer (300) configured for securing together the first electrode plate (100) and the second electrode plate (200) in a face-to-face manner or a back-to-face manner, forming separate compartments each for a hydrogen gas and an oxygen gas resulting from the water splitting that provide immunity against any mixing of the hydrogen gas and the oxygen gas at any level of an electrical power supply.

16. A method of hydrogen/oxygen production, **characterised in that**, the method comprising the steps:

generating a hydrogen gas and an oxygen gas by water splitting in an electrolyser comprising:

a first electrode plate (100) coated with a first catalyst comprising a first ion transfer opening (101) formed therethrough along a first lateral axis of the first electrode plate (100);

a second electrode plate (200) coated with a second catalyst comprising a second ion transfer opening (201) formed therethrough along a second lateral axis of the second electrode plate (200); and

an electrically insulative adhesive layer (300) configured for securing together the first electrode plate (100) and the second electrode plate (200) in a face-to-face manner or a back-to-face manner, forming separate compartments each for the hydrogen gas and the oxygen gas resulting from the water splitting that provide immunity against any mixing of the hydrogen gas and the oxygen gas at any level of an electrical power supply; and

discharging the hydrogen gas and the oxygen gas from the said separate compartments.

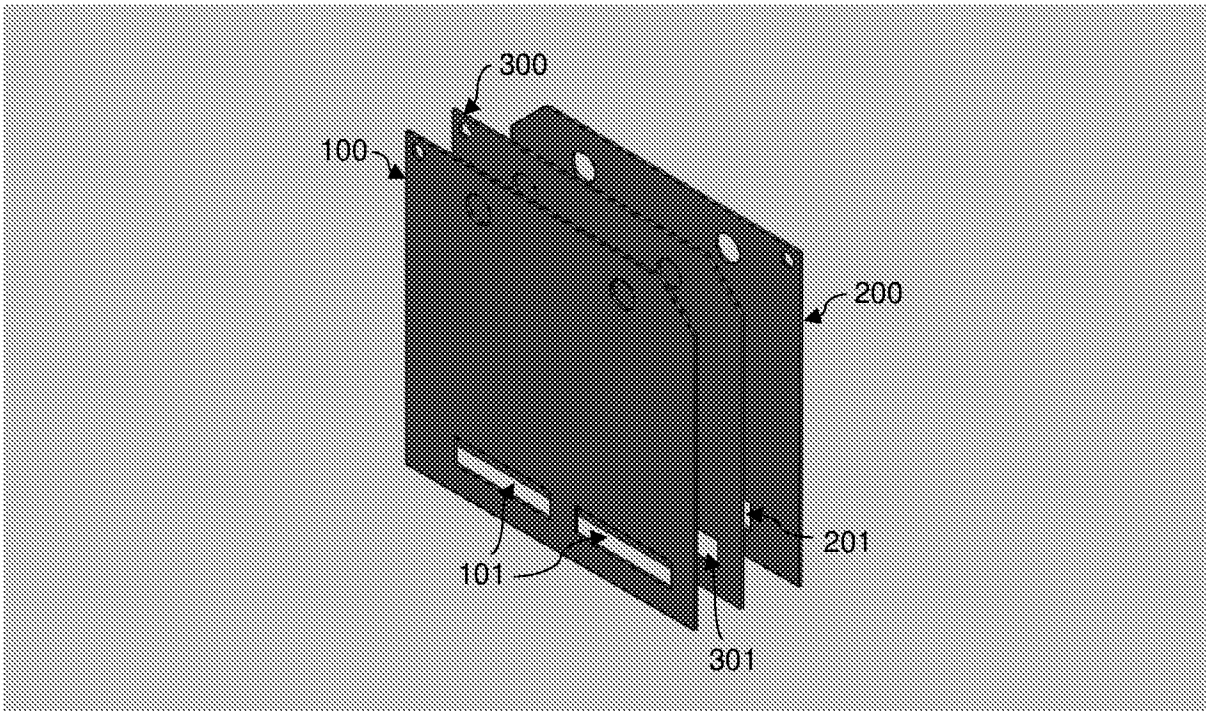


FIGURE 1

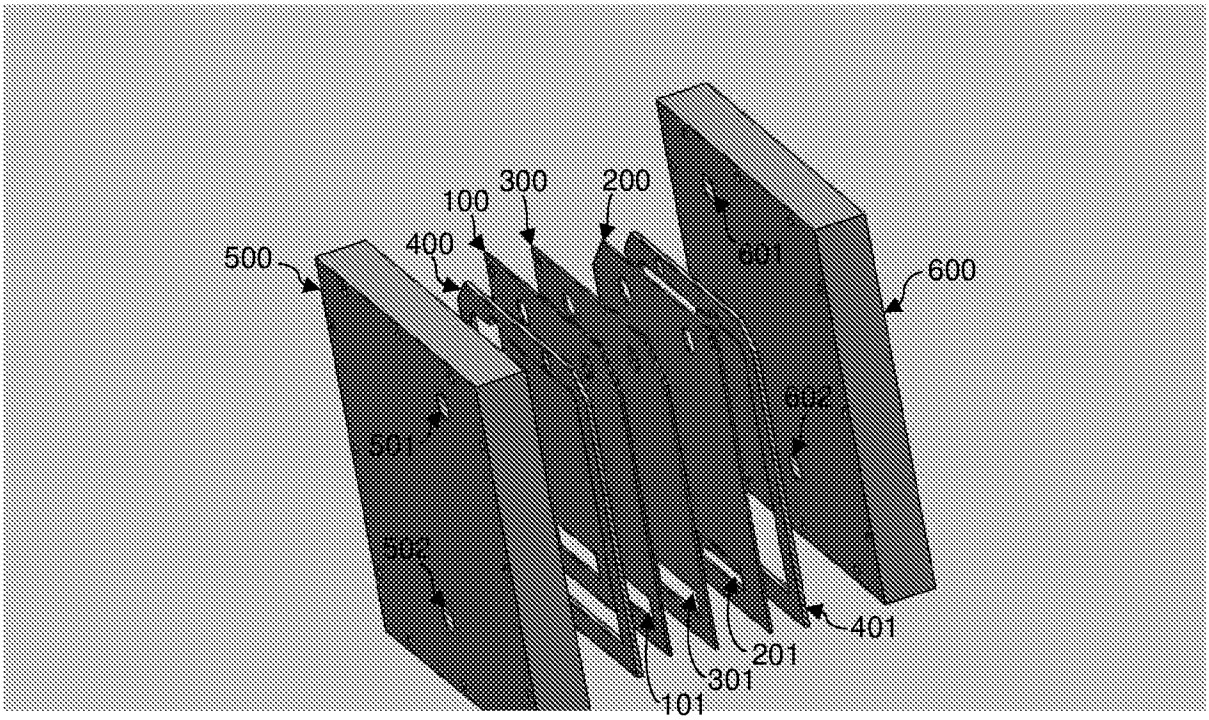


FIGURE 2

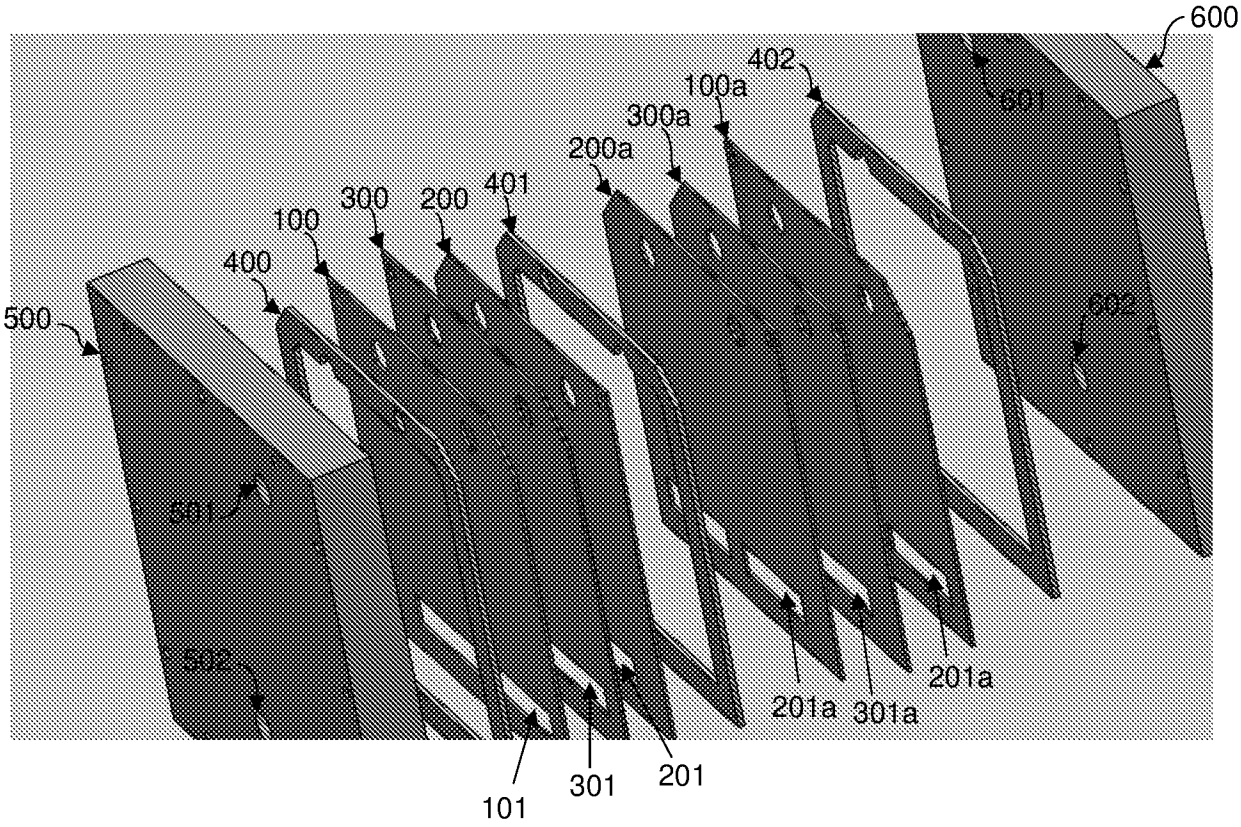


FIGURE 3

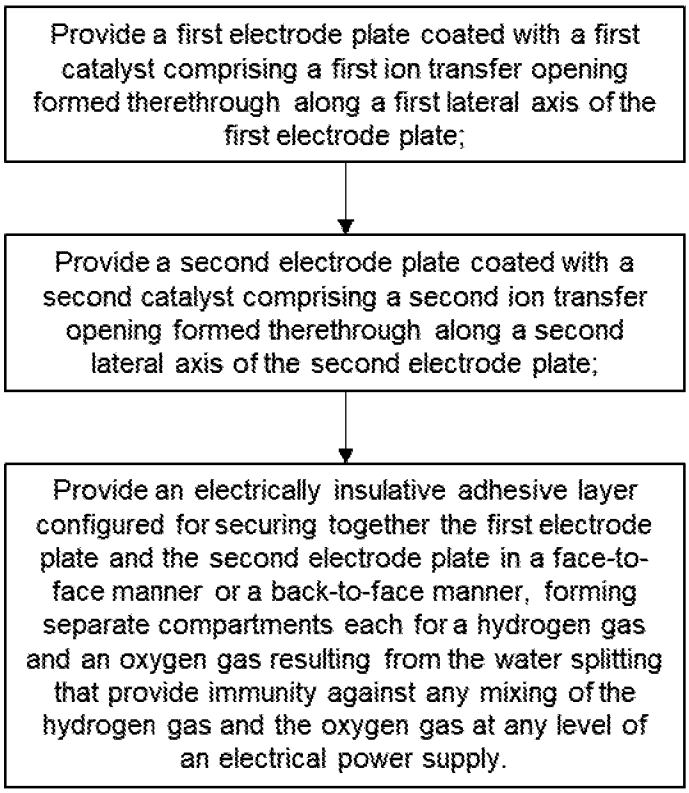


FIGURE 4

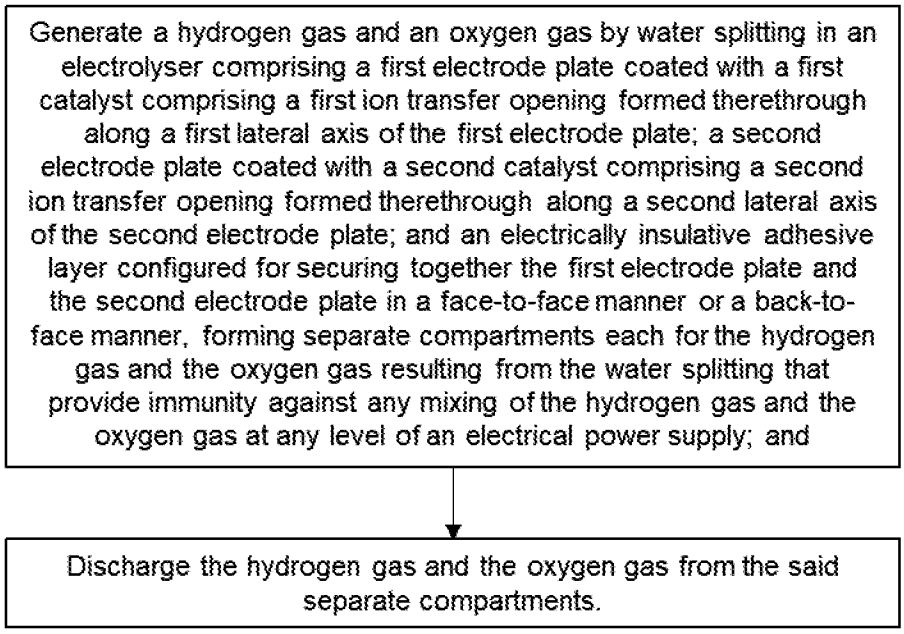


FIGURE 5

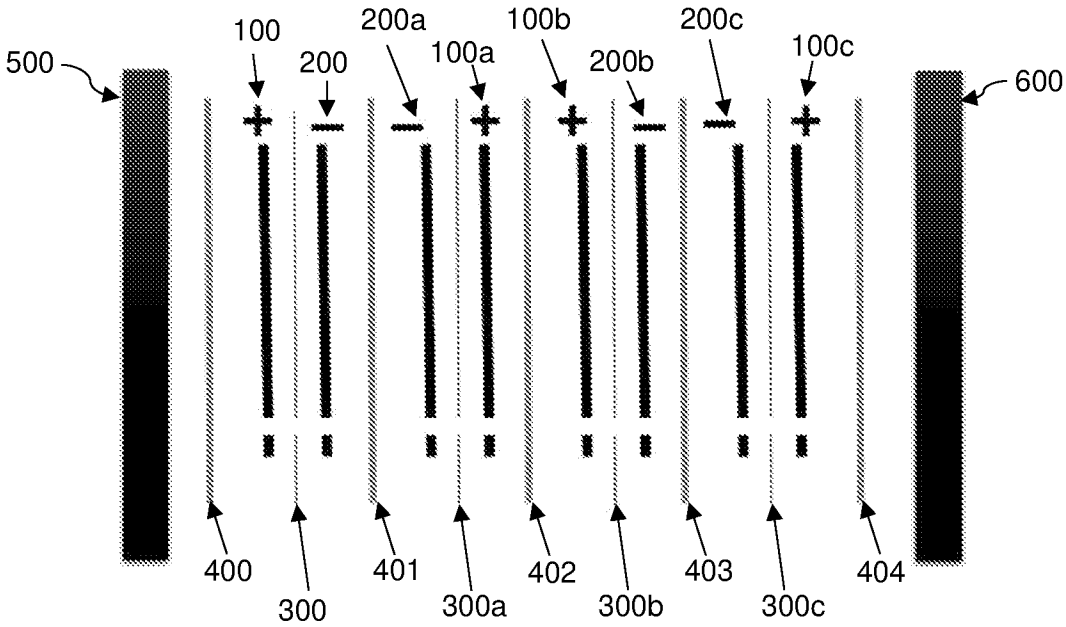


FIGURE 6

400/401/402/403/404

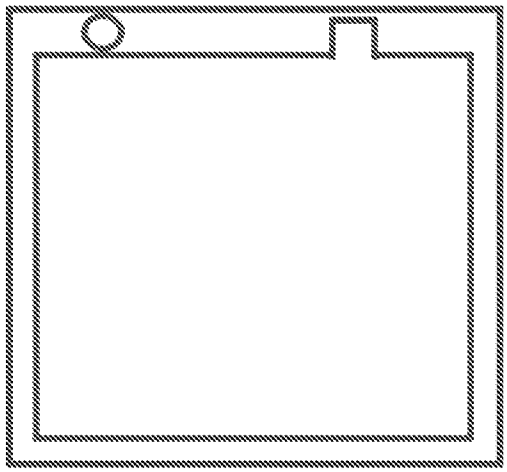


FIGURE 7

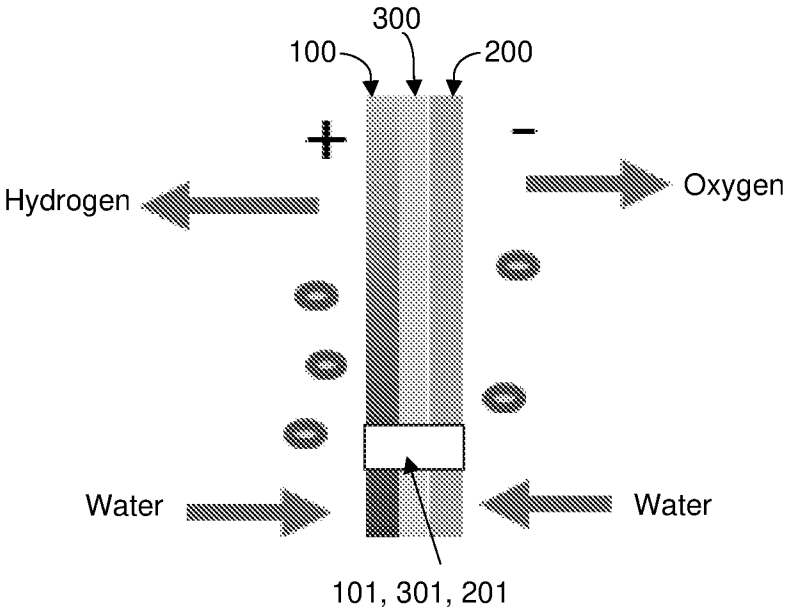


FIGURE 8

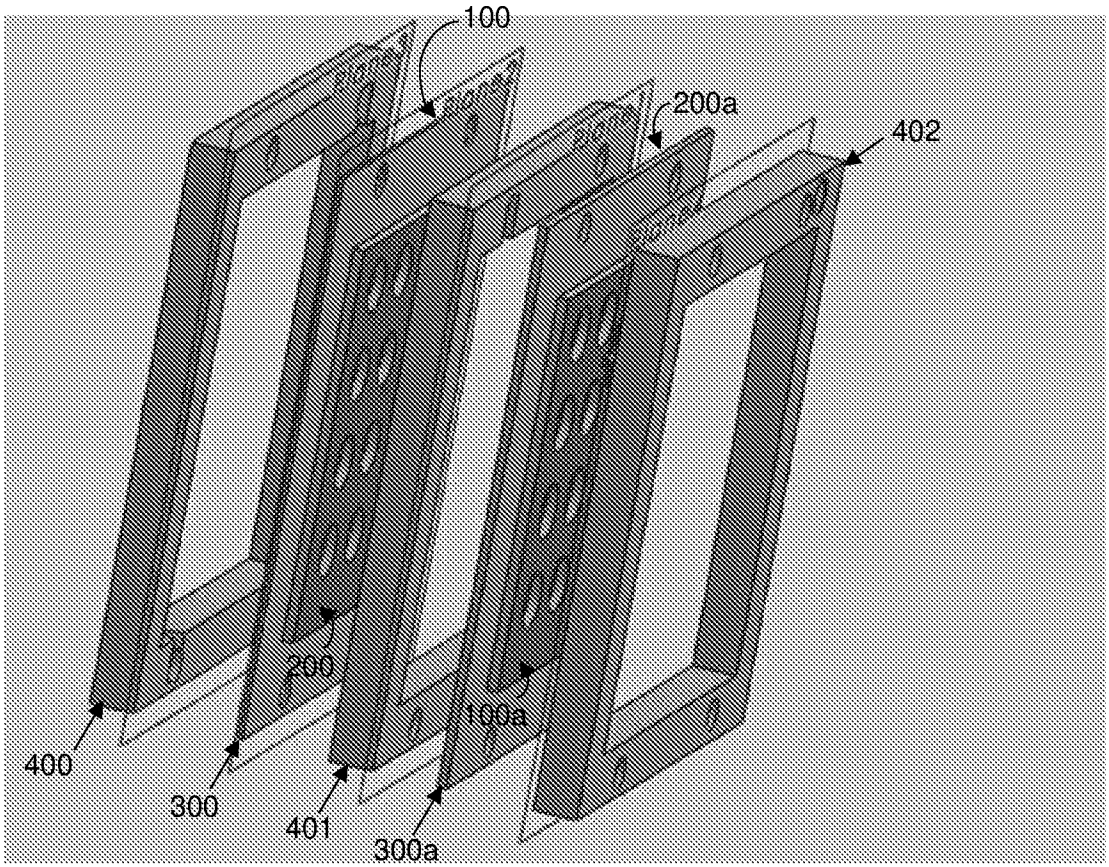


FIGURE 9