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AN ELECTROLYSIS DEVICE****Publication Classification**(76) Inventors: **Nicolas Guillet**, Pizancon (FR); **Eric
Mayousse**, Grenoble (FR)(51) **Int. Cl.**
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(2), (4) Date: **Dec. 16, 2013**(57) **ABSTRACT**

A membrane-electrode assembly for an electrolysis device includes a proton-exchange membrane, an anode and a cathode disposed on either side of the proton-exchange membrane, a first conductive catalyst disposed within the proton-exchange membrane, and a first conductive junction linking the first conductive catalyst and the cathode. The first conductive junction has an electrical resistance greater than a proton resistance of the membrane between the first conductive catalyst and the cathode.

(30) **Foreign Application Priority Data**

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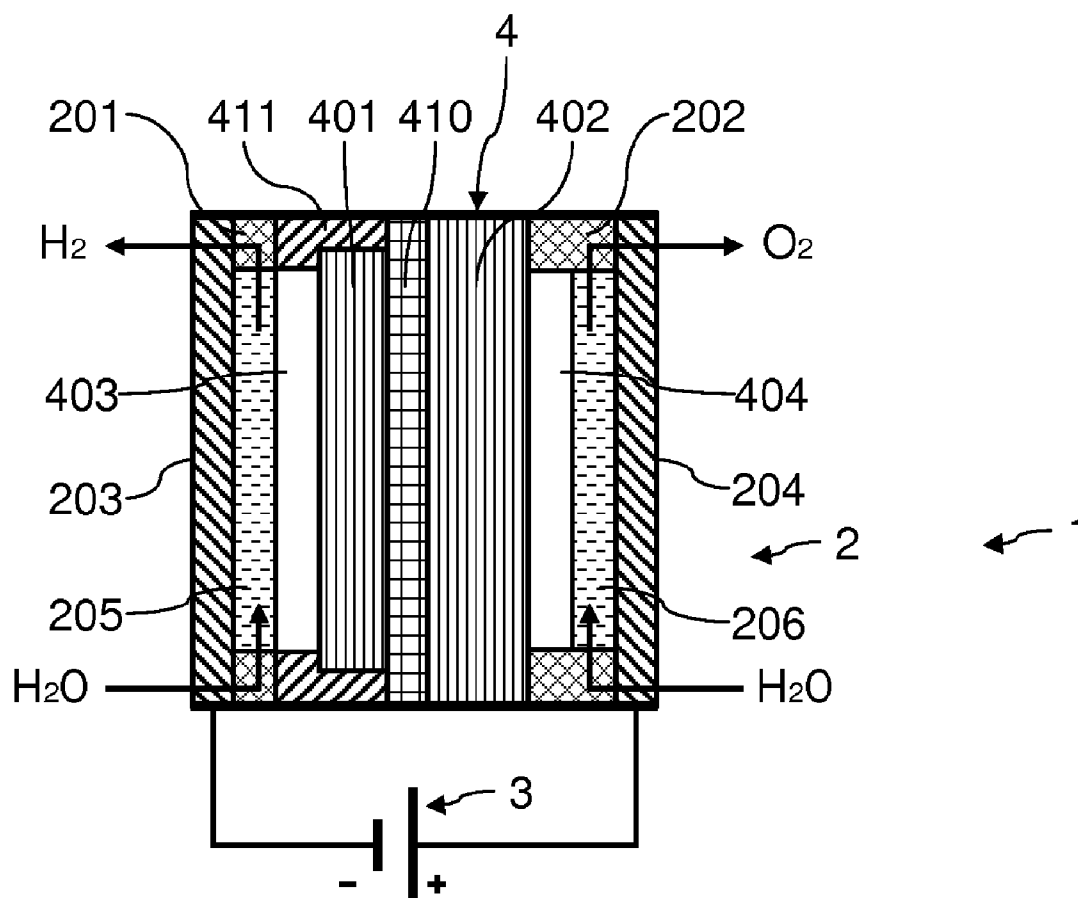


Fig. 1

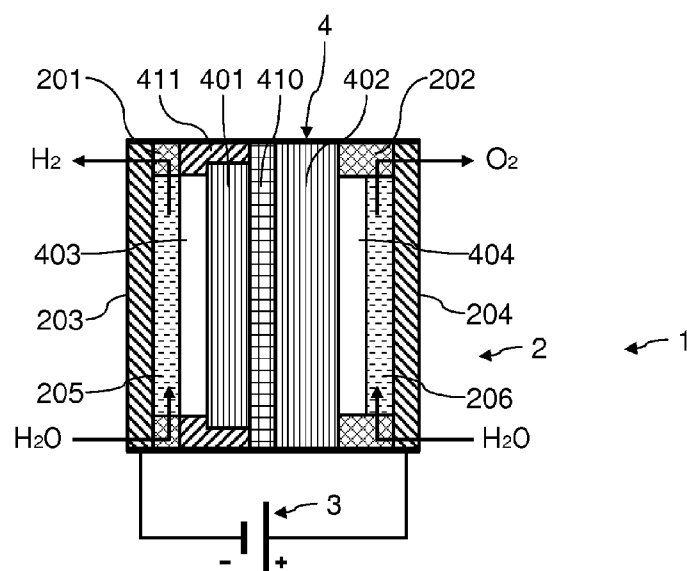
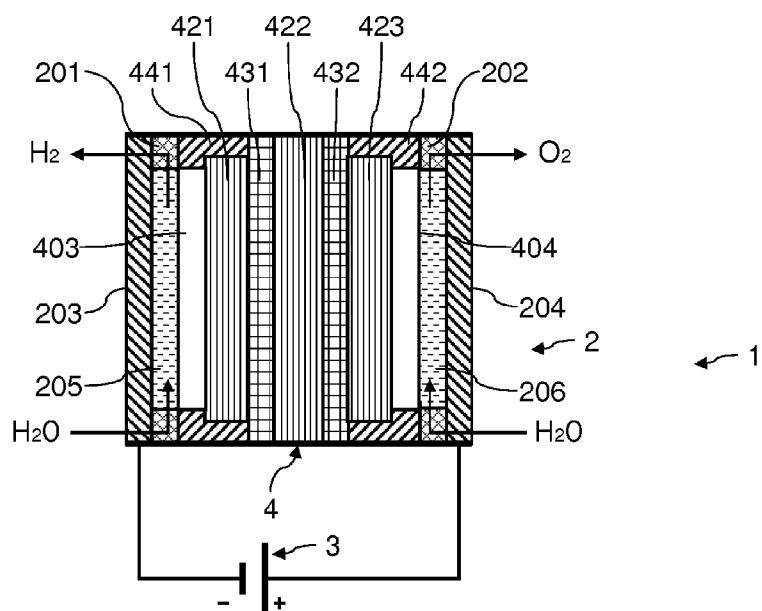


Fig. 2



MEMBRANE/ELECTRODE ASSEMBLY FOR AN ELECTROLYSIS DEVICE

RELATED APPLICATIONS

[0001] This applicant is the national stage under 35 USC 371 of PCT/EP2012/061118, filed on Jun. 12, 2012, which claims the benefit of the priority date of French application FR 1155351, filed on Jun. 17, 2011, the contents of which are herein incorporated by reference.

FIELD OF DISCLOSURE

[0002] The invention pertains to the production of gas by electrolysis and especially to devices for producing hydrogen using a proton-exchange membrane to implement electrolysis at low temperature of water.

BACKGROUND

[0003] Fuel cells are envisaged as an electric power supply system for future mass-produced motor vehicles as well as for a large number of applications. A fuel cell is an electrochemical device that converts chemical energy directly into electrical energy. Hydrogen (H₂) or molecular hydrogen is used as a fuel for the fuel cell. The molecular hydrogen is oxidized on an electrode of the cell and oxygen (O₂) or molecular oxygen from the air is reduced on another electrode of the cell. The chemical reaction produces water. The great advantage of the fuel cell is that it averts emissions of atmospheric pollutant compounds at the place where electricity is generated.

[0004] One of the major difficulties in the development of such fuel cells lies in the synthesis and supply of dihydrogen (or molecular hydrogen). On earth, hydrogen does not exist in great quantities except in combination with oxygen (in the form of water), sulphur (in the form of hydrogen sulphide) and nitrogen (as ammonia) or carbon (fossil fuels such as natural gas or petroleum). The production of molecular hydrogen therefore requires either the consumption of fossil fuels or the availability of large quantities of low-cost energy in order to obtain this hydrogen from the decomposition of water, by thermal or electrochemical means.

[0005] The most widespread method for producing hydrogen from water consists of the use of the principle of electrolysis. To implement such methods, electrolyzers provided with proton-exchange membranes (PEMs) are known. In such an electrolyzer, an anode and a cathode are fixed on either side on the proton-exchange membrane and put into contact with water. A difference in potential is applied between the anode and the cathode. Thus, oxygen is produced at the anode by oxidation of water. The oxidation at the anode also gives rise to H⁺ ions that pass through the proton-exchange membrane up to the cathode, and electrons that are sent back to the cathode by the electrical supply unit. At the cathode, the H⁺ ions are reduced at the level of the cathode to generate molecular hydrogen.

[0006] Such an electrolysis device comes up against undesirable effects. The proton-exchange membrane is not perfectly impermeable to gas. A part of the gases produced at the anode and the cathode thus passes through the proton-exchange membrane by diffusion. This induces problems of purity of the gas produced but also induces problems of security. The proportion of hydrogen in oxygen must especially remain absolutely below 4%, such a proportion being the lower limit of the explosivity of hydrogen in oxygen.

[0007] The permeability of the membranes to gas can be reduced by increasing the thickness of the proton-exchange membrane. This, however, causes an increase in the electrical resistance by making it more difficult for the H⁺ ions to pass through, and lowers the performance of the systems.

[0008] To limit the permeability of a proton-exchange membrane to gases, certain developments suggest a depositing of catalyst particles inside the proton-exchange membrane. The catalyst particles seek to recombine the molecular hydrogen passing through the membrane with molecular oxygen passing through the membrane. The quantities of molecular oxygen that reach the cathode and of molecular hydrogen that reach the anode are thus reduced.

[0009] However, the recombination reaction of the catalyst particles is exothermal and induces a loss of energy. Furthermore, such a solution is not optimized for industrial-scale applications since a part of the molecular hydrogen generated at the cathode is nevertheless lost inside the proton-exchange membrane. Furthermore, the permeability of the proton-exchange membrane to molecular hydrogen is greater than its permeability to molecular oxygen. Consequently, a part of the molecular hydrogen nevertheless reaches the anode since the quantity of molecular oxygen is insufficient in the catalyst particles disposed in the membrane.

SUMMARY

[0010] The invention seeks to resolve one or more of these drawbacks. The invention thus pertains to a membrane-electrode assembly for an electrolysis device comprising:

[0011] a proton-exchange membrane;

[0012] an anode and a cathode disposed on either side of the membrane;

[0013] a conductive catalyst disposed within the proton-exchange membrane;

[0014] a conductive junction linking the catalyst and the cathode, the conductive junction having electrical resistance greater than the proton resistance of the membrane between the catalyst and the cathode.

[0015] According to one variant, the electrical resistance of the junction is at least 20 times greater than the proton resistance between the catalyst and the cathode.

[0016] According to another variant, the junction forms a peripheral frame maintaining the proton-exchange membrane in position.

[0017] According to yet another variant, the junction comprises a structural part having electrical resistivity at 293.15K greater than 20 μΩ·cm.

[0018] According to yet another variant, the catalyst is capable of oxidizing molecular hydrogen.

[0019] According to one variant, the catalyst comprises titanium fixed to a conductive graphite support, the conductive graphite support being fixed to a first layer of the proton-exchange membrane fixedly attached to the cathode and to a second layer of the proton-exchange membrane fixedly attached to the anode.

[0020] According to another variant, the proton resistance of the first proton-exchange layer is lower than the proton resistance of the second proton-exchange layer.

[0021] According to yet another variant, the proton-exchange membrane comprises first, second and third proton-exchange layers, the cathode being fixed to the first proton-exchange layer and the anode being fixed to the third proton-exchange layer, said catalyst being a first catalyst, disposed

between the first and second proton-exchange layers, the assembly furthermore comprising:

[0022] a second catalyst disposed between the second and third proton-exchange layers;

[0023] another conductive junction connecting the second catalyst and the anode.

[0024] The invention also pertains to a device for the electrolysis of water, comprising a membrane-electrode assembly as described here above and an electrical power supply applying a difference in potential between the anode and the cathode of the membrane-electrode assembly, this difference in potential being appropriate for hydrolyzing water in contact with the anode.

[0025] According to one variant, the values of resistance of the junction between the catalyst and the cathode are configured in such a way that the voltage of the catalyst is below 0.8V.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Other features and advantages of the invention shall appear more clearly from the following description given by way of an indication that is in no way exhaustive, with reference to the appended drawings, of which:

[0027] FIG. 1 is a schematic view in section of an electrolysis device incorporating a membrane-electrode assembly according to a first embodiment of the invention;

[0028] FIG. 2 is a schematic view in section of an electrolysis device incorporating a membrane-electrode assembly according to a second embodiment of the invention.

DETAILED DESCRIPTION

[0029] The invention proposes to place a catalyst within the proton-exchange membrane of a membrane-electrode assembly. An electronic conductive junction links the catalyst to the cathode, with electric resistance 2 to 500 times greater than the proton resistance of the membrane between the catalyst and the cathode.

[0030] The invention enables the oxidation of the molecular hydrogen diffusing through the membrane from the cathode in order to limit the quantity of molecular hydrogen reaching the anode. The invention also enables molecular hydrogen to be reformed at the cathode by reducing protons with the electrons that come from the oxidation of the hydrogen and are collected by the catalyst. The energy efficiency of the catalyst is thus improved.

[0031] FIG. 1 is a view in section of an example of an electrolysis device 1 according to one embodiment of the invention. The electrolysis device 1 comprises an electrochemical cell 2 and an electrical supply 3.

[0032] The electrochemical cell 2 comprises a membrane-electrode assembly 4, electrical power supply plates 203 and 204, porous current collectors 205 and 206 and seals 201 and 202.

[0033] The membrane-electrode assembly 4 comprises a proton-exchange membrane as well as a cathode and an anode fixed to either side of this proton-exchange membrane. The proton-exchange membrane comprises a first layer 401 to which the cathode 403 is fixed. The proton-exchange membrane comprises a second layer 402 to which the anode 404 is fixed. A catalyst in the form of a catalytic layer or catalyst layer 410 is disposed within the proton-exchange membrane between the first layer 401 and the second layer 402. The membrane-electrode assembly 4 thus comprises a stack

formed by the cathode 403, the first layer 401, the catalyst layer 410, the second layer 402 and the anode 404. The membrane-electrode assembly 4 also comprises an electronically conductive junction 411 connecting the cathode 403 to the catalyst layer.

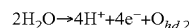
[0034] The porous current collector 205 is interposed between the cathode 403 and the power supply plate 203. The porous current collector 206 is interposed between the anode 404 and the power supply plate 204.

[0035] The electrical supply plate 203 has a water supply conduit, not shown, communicating with the cathode 403 by means of the porous current collector 205. The electrical power supply plate 203 also has a conduit for removing molecular hydrogen, not shown, in communication with the cathode 403 by means of the porous current collector 205.

[0036] The electrical power supply plate 204 has a water supply conduit, not shown, in communication with the anode 404 by means of the porous current collector 206. The electrical power supply plate 204 also has a conduit for removing molecular oxygen, not shown, in communication with the anode 404 by means of the porous current collector 206.

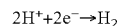
[0037] The electrical power supply 3 is configured to apply a DC voltage generally ranging from 1.3V to 3.0V with a current density at the power supply plates ranging from 10 to 40000 A/m², and advantageously from 500 to 40000 A/m². By applying such a voltage, a reaction of oxidation of the water at the anode produces molecular oxygen and, simultaneously, a proton reduction reaction at the cathode produces molecular hydrogen.

[0038] The reaction at the anode 404 is the following:



[0039] The protons generated by the anode reaction pass through the proton-exchange membrane up to the cathode 403. The power supply 3 conducts the electrons generated by the anode reaction up to the cathode 403.

[0040] The reaction at the cathode 403 is thus as follows:



[0041] The proton-exchange membrane has the function of being crossed by protons coming from the anode 404 towards the cathode 403 while at the same time blocking the electrons as well as the molecular oxygen and the molecular hydrogen generated. However, the prior-art proton-exchange membrane structures undergo a phenomenon of diffusion by a part of the gases produced at the cathode and at the anode.

[0042] The first function of the catalyst layer 410 is to oxidize the molecular hydrogen passing through the membrane to form protons. The protons thus formed return under the effect of the electrical field to the cathode 403. The quantity of molecular hydrogen that reaches the anode 404 is thus reduced. The second function of the catalyst layer 410 is to reduce the molecular oxygen passing through the membrane to form water. This reaction of reduction brings into play especially the protons present in the proton-exchange membrane.

[0043] The third function of the catalyst layer 410 is to collect the electrons generated by the oxidation of molecular hydrogen not compensated for by the reduction of molecular oxygen. For this purpose, the catalyst layer 410 is conductive.

[0044] The electrons collected by the catalyst layer 410 are conducted up to the cathode 403 by means of the conductive junction 411. These electrons enable an additional reduction of protons at the cathode 403. Thus, the efficiency of generation of molecular hydrogen by electrolysis is increased while,

at the same, an appreciable reduction is obtained in the diffusion of molecular hydrogen up to the anode **404**.

[0045] Advantageously, the electrical resistance of the junction **411** is at least two times greater than the proton resistance of the membrane between the layer **410** and the cathode **403**, advantageously at least 20 times greater, by preference at least 50 times greater and preferably at least 100 times greater. With such values, the creation of an excessively great leakage current is prevented.

[0046] The SHE standard potential (at 100 kPa and 298.15 K) of the pair H^+/H_2 is equal to 0V. The SHE standard potential of the pair O_2/H_2O is equal to 1.23V.

[0047] The potential of the layer **410** must therefore be greater than 0 to enable the oxidation of the molecular hydrogen and must advantageously be lower than 0.8V (RHE) to ensure optimal reduction of molecular oxygen.

[0048] The permeation of hydrogen measured on materials conventionally used as membranes corresponds to a maximum current density of 10 mA cm^{-2} (as a function of the thickness and conditions of temperature, pressure, etc.).

[0049] This value of current density is the maximum value that can pass through the junction **411**. Indeed, a part of the hydrogen passing through the membrane is directly recombined at the layer **410** with the oxygen (reduction) to form water.

[0050] The following notations will be used:

[0051] U_{cat} is the cathode potential, R_a is the proton resistance between the layer **410** and the cathode **403**, R_{sa} is the resistance of the junction **411**, S_a is the cross-section of the junction **411**, j_{junc} is the density of current passing through the junction, and U_{cou} is the potential of the layer **410**.

[0052] $U_{cou} - U_{cat} = S_a \times R_{sa} \times j_{junc}$ therefore $U_{cou} = S_a \times R_{sa} \times j_{junc} + U_{cat}$

For $U_{cou} > 0$

[0053] It is necessary for U_{cou} to be greater than $-U_{cat}$ (U_{cat} zero or negative). This is verified if $R_{sa} > R_a$.

For $U_{cou} < 0.8 \text{ V (RHE)}$

[0054] U_{cat} is zero or negative (potential of reduction of the proton). Therefore, it is necessary to compute R_{sa} for the maximum value of U_{cou} , i.e. when $U_{cat} = 0$.

[0055] Thus: $U_{cou} = S_a \times R_{sa} \times j_{junc}$ whence $R_{sa} = U_{cou} / j_{junc} / S_a$

[0056] For $U_{cou} = 0.8 \text{ V (ERH)}$, $S_a = 10 \text{ cm}^2$ and $j_{junc} = 10 \text{ mA cm}^{-2}$, we obtain $R_{sa} = 8 \Omega$.

[0057] The maximum value of the resistance of the junction **411** is thus 8Ω .

[0058] The proton resistance of the membrane between the layer **410** and the cathode **403** could, in this case, advantageously range from 6 to $32 \text{ m}\Omega$ according to its nature, its thickness, and the conditions of measurement (temperature, pressure), taking for example a cross-section of 25 cm^2 for the anode **404**.

[0059] Finally, the electrical resistance of the junction **411** is at least equal to twice the proton resistance of the membrane between the layer **410** and the cathode **403** and at most 1400 times greater than this resistance (when $R_a = 6 \text{ m}\Omega$).

[0060] The junction **411** can be obtained by means of a material with high resistivity such as a semi-conductive metal oxide (SnO_2 , oxide combined with antimony or indium for example) or an electronic conductive polymer. The junction **411** can for example be obtained by means of a structural

element having electrical resistivity at 293.15K greater than $20 \mu\Omega \cdot \text{cm}$. The junction **411** can also be obtained by means of a resistive electronic component connected to the layer **410** and the cathode **403** by means of electrical cables. Advantageously, as illustrated in FIG. 1, the junction **411** forms a peripheral frame holding the cathode **403** or the first layer **401** in position.

[0061] The cathode **403** can advantageously be formed by using an electronic conductive material formed by platinum particles supported by carbon. The anode **404** can advantageously be formed by using noble metal oxides such as iridium oxide or ruthenium oxide in order to resist high potentials.

[0062] The layer **410** is advantageously formed by a porous electronic conductive support on which a catalyst material such as platinum is fixed. This layer **410** is configured in a known manner to enable the passage of the protons. The layer **410** can be obtained in the form of a conductive carbon screen to which platinum particles are fixed. The layer **410** can also be made in the form of a carbon layer coated with a layer of platinum particles.

[0063] The layer **410** can be formed by the application of ink containing catalyst material on the conductive support. The layer **410** formed can be assembled with the layers **401** and **402** by any appropriate method such as a hot pressing.

[0064] The layer **410** can also be formed by the application of this ink directly on the first layer **401** or on the second layer **402** of the proton-exchange membrane. The application of ink can be obtained by any appropriate method, for example spraying, coating, silk-screen printing. The deposit of the layer **410** can also be obtained by any other technique such as physical vapor deposition (PVD) or by metal-oxide chemical vapor deposition (MOCVD).

[0065] The thickness of the layer **410** can, for example, be limited so as not to induce excessive resistance to the diffusion of protons through the membrane-electrode assembly **4**.

[0066] The layers **401** and **402** can be formed out of materials usually selected by those skilled in the art for proton-exchange membranes. A material such as the one commercially distributed under the reference Nafion **211** or the reference Nafion **212** can for example be used.

[0067] The permeability of the proton-exchange membrane to molecular hydrogen is greater than its permeability to molecular oxygen. The goal is to limit the direct recombination of hydrogen with oxygen at the layer **410**. The use of the junction **411** enabling the retrieval of permeation hydrogen at the cathode **403** can be preferred.

[0068] The quantity of oxygen present at the layer **410** must be limited by the sizing of the layers **401** and **402**. Advantageously, the thickness of the layer **402** is greater than the thickness of the layer **401**.

[0069] Using layers **401** and **402** made out of material commercially distributed under the reference Nafion **211**, it would be appropriate for these layers **401** and **402** to have respective thicknesses of $25 \mu\text{m}$ and $75 \mu\text{m}$.

[0070] Most of these cases will use a layer **401** whose proton resistance is smaller than the proton resistance of the layer **402**.

[0071] FIG. 2 is a view in section of an example of an electrolysis device **1** according to another embodiment of the invention. As in the example of FIG. 1, the electrolysis device **1** comprises an electrochemical cell **2** and an electric power

supply 3. The electric power supply 3 is identical to that of the previous embodiment and shall not be described in further detail.

[0072] The electrochemical cell 2 comprises electrical power supply plates 203 and 204, porous current collectors 205 and 206, and seals 201 and 202. These are components whose structure and configuration are identical to those described with reference to FIG. 1. The electrochemical cell 2 also comprises a membrane-electrode assembly 4.

[0073] The membrane-electrode assembly 4 comprises a proton-exchange membrane as well as a cathode and an anode fixed on either side of this proton-exchange membrane. The cathode 403 and the anode 404 are identical to those of the previous embodiment.

[0074] The proton-exchange membrane comprises a first layer 421 to which the cathode 403 is fixed. The proton-exchange membrane comprises a second layer 422. A first catalyst in the form of a catalyst layer 431 is disposed within the proton-exchange membrane between the first layer 421 and the second layer 422. The membrane-electrode assembly 4 furthermore comprises a conductive junction 441 connecting the cathode 403 to the catalyst layer 431.

[0075] The proton-exchange membrane comprises a third layer 423 to which the anode 404 is fixed. A second catalyst in the form of a catalyst layer 432 is disposed within a proton-exchange membrane between the second layer 422 and the third layer 423. The first catalyst layer 431 and the second catalyst layer 432 are thus separated by the third layer 423. The membrane-electrode assembly 4 furthermore comprises a conductive junction 442 connecting the anode 404 to the catalyst layer 432.

[0076] As in the above embodiment, the proton-exchange membrane has the function of being crossed by protons of the anode 404 going to the cathode 403 while at the same time blocking the electrons as well as the molecular oxygen and the molecular hydrogen generated.

[0077] The catalyst layer 431 has a function of oxidizing the molecular hydrogen passing through the membrane to form protons. The protons thus formed return to the cathode 403. The quantity of molecular hydrogen reaching the anode 404 is thus reduced.

[0078] The catalyst layer 431 also has the function of collecting electrons generated by the oxidation of the molecular hydrogen passing through the proton-exchange membrane. To this end, the catalyst layer 431 is conductive.

[0079] The electrons collected by the catalyst layer 431 are conducted up to the cathode 403 by means of the conductive junction 441. These electrons make it possible to obtain an additional reduction of protons at the cathode 403. Thus, the efficiency of generation of molecular hydrogen by electrolysis is increased while at the same time an appreciable reduction is fostered in the diffusion of molecular hydrogen up to the anode 404.

[0080] The catalyst layer 432 has the function of conducting electrons coming from the anode 404. To this end, the catalyst layer 432 is conductive.

[0081] The catalyst layer 432 also has the function of reducing the molecular oxygen passing through the membrane to form water. This reaction of reduction especially brings into action protons present in the proton-exchange membrane and electrons generated by the oxidation of the molecular oxygen at the anode 404 and conducted up to the catalyst layer 432 by means of the conductive junction 442.

[0082] In this embodiment, a direct reaction at the catalyst layers 431 or 432 between the molecular hydrogen and the molecular oxygen is almost non-existent because they are separated by the second layer 422. Thus, the major part of the molecular hydrogen diffused through the proton-exchange membrane is oxidized before reaching the catalyst layer 432 and, conversely, the major part of the molecular oxygen diffused through the proton-exchange membrane is reduced before it reaches the catalyst layer 431. The gases diffusing through the proton-exchange membrane are thus oxidized or reduced at an early stage of their diffusion.

[0083] The catalyst layers 431 and 432 can have the same structure as the catalyst layer 410 of the previous embodiment. Methods of manufacture equivalent to those described for the catalyst layer 410 can also be used for these catalyst layers 431 and 432.

[0084] The junctions 441 and 442 can have appreciably the same structure as the junction 411 of the previous embodiment.

[0085] The SHE standard potential (at 100 kPa and 298.15 K) of the pair H^+/H_2 is equal to 0V. The SHE standard potential of the pair O_2/H_2O is equal to 1.23V.

[0086] The potential U1 of the layer 431 must therefore be greater than 0 to enable the molecular hydrogen to be oxidized.

[0087] The potential U2 of the layer 432 must advantageously be lower than 0.8 V(SHE) to ensure optimum reduction of molecular oxygen.

[0088] The permeation of hydrogen measured on materials conventionally used as membranes corresponds to a maximum density of current $j_{junc\ H_2}$ of 10 mA cm^{-2} (depending on the thickness and conditions of temperature, pressure, etc.). The permeation of oxygen is half as great and corresponds to $j_{junc\ O_2}$.

[0089] It is possible to carry out the same type of evaluation of the values of resistances of the junctions as for the previous embodiment.

[0090] Rsa is defined as the resistance of the junction 441, Rsb the resistance of the junction 442, Ra the proton resistance between the layer 410 and the cathode, Rb the proton resistance between the layer 432 and the anode, Uan the anode potential and Ucat the cathode potential, Sa the cross-section of the junction 441 and Sb the cross-section of the junction 442

$$U1 - Ucat = S_{ax} R_{sa} j_{junc\ H_2}$$

$$Uan - U2 = S_{bx} R_{sb} j_{junc\ O_2}$$

For $U1 > 0$

[0091] It is necessary that U1 should be greater than $-Ucat$ ($Ucat$ is zero or negative). This is verified if $R_{sa} > R_a$.

[0092] Advantageously, the electrical resistance of the junction 441 is greater than the proton resistance of the membrane between the layer 421 and the cathode 403. Such values prevent the creation of a short circuit and limit the deterioration of the potential within the proton-exchange membrane.

For $U2 < 0.8\text{ V(ERH)}$

[0093] For a polarization curve classically encountered in PEM electrolysis, Uan is around 1.8 V(RHE).

[0094] Thus, for an anode voltage 1.8 V, a value of Sb of 10 cm^2 , $R_{sb} = (Uan - U2) / j_{junc\ O_2} / Sb$ giving $R_{sb} = 24\Omega$.

[0095] The proton resistance of the membrane **423** between the layer **432** and the anode **404** advantageously ranges from 6 to 32 mΩ depending on its nature, its thickness and the conditions of measurement (temperature, pressure), in taking for example a cross-section of 25 cm² for the cathode **403**.

[0096] Finally, in this example, the electrical resistance of the junction **442** is at least 750 times greater than the proton resistance of the membrane **423** between the layer **432** and the anode **404** and at most 4000 times greater than this resistance (when Rb=32 mQ).

[0097] The layers **421**, **422** and **423** can be made out of a material distributed under the trade reference Nafion **211**. Here, the presence of two junctions makes the two sides independent since there is no longer any direct recombination between hydrogen and oxygen on the central catalyst layer unlike in the previous embodiment. There is no longer any ratio of flow of diffusion (related to the thickness of the layers) to be complied with between the two gases as above. Respective thicknesses of 25, 25 and 75 μm can be proposed for the layers **421**, **422** and **423**.

[0098] The invention has been described with reference to a device for the electrolysis of water. It is however also possible to envisage a case where such a device is configured to carry out other types of electrolysis resulting in a generation of gases for which it is desirable to prevent their diffusion through a proton-exchange membrane.

1-10. (canceled)

11. An apparatus comprising a membrane-electrode assembly for an electrolysis device, said membrane-electrode assembly comprising a proton-exchange membrane, an anode and a cathode disposed on either side of said proton-exchange membrane, a first conductive catalyst disposed within said proton-exchange membrane, and a first conductive junction linking said first conductive catalyst and said cathode, said first conductive junction having an electrical resistance greater than a proton resistance of said membrane between said first conductive catalyst and said cathode.

12. The apparatus of claim **11**, wherein said electrical resistance of said first conductive junction is at least twenty

times greater than a proton resistance between said first conductive catalyst and said cathode.

13. The apparatus of claim **11**, wherein said first conductive junction forms a peripheral frame maintaining said proton-exchange membrane in position.

14. The apparatus of claim **11**, wherein said first conductive junction comprises a structural part having electrical resistivity at 293.15K greater than 20 μΩ·cm.

15. The apparatus of claim **11**, wherein said first conductive catalyst is selected to be capable of oxidizing molecular hydrogen.

16. The apparatus of claim **15**, wherein said first conductive catalyst comprises titanium fixed on a conductive graphite support, said conductive graphite support being fixed to a first layer of said proton-exchange membrane fixedly attached to said cathode and to a second layer of said proton-exchange membrane fixedly attached to said anode.

17. The apparatus of claim **16**, wherein a proton resistance of said first layer is lower than a proton resistance of said second layer.

18. The apparatus of claim **11**, wherein said proton-exchange membrane comprises first, second and third proton-exchange layers, said cathode being fixed to said first proton-exchange layer, and said anode being fixed to said third proton-exchange layer, wherein said first conductive catalyst is disposed between said first and second proton-exchange layers, wherein said membrane-electrode assembly further comprises a second catalyst disposed between said second and third proton-exchange layers, and a second conductive junction connecting said second catalyst and said anode.

19. The apparatus of claim **11**, further comprising an electrical power supply configured to apply a difference in potential between said anode and said cathode of said membrane-electrode assembly, said difference in potential being selected for hydrolyzing water in contact with said anode.

20. The apparatus of claim **19**, wherein a resistance of said junction between said catalyst and said cathode is configured in such a way that said voltage of said catalyst is below 0.8V (RHE).

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