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(54) **ELECTROLYTE MEMBRANE**

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(57) **ABSTRACT**

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In an electrolyte membrane that is disposed between an electrolytic solution in an oxidation tank and a reduction electrode in a reduction tank in contact with the electrolytic solution and the reduction electrode, and is used in a carbon dioxide reduction device that performs a reduction reaction of carbon dioxide by bringing the carbon dioxide into direct contact with the reduction electrode, fibers are woven in a network shape inside the electrolyte membrane.

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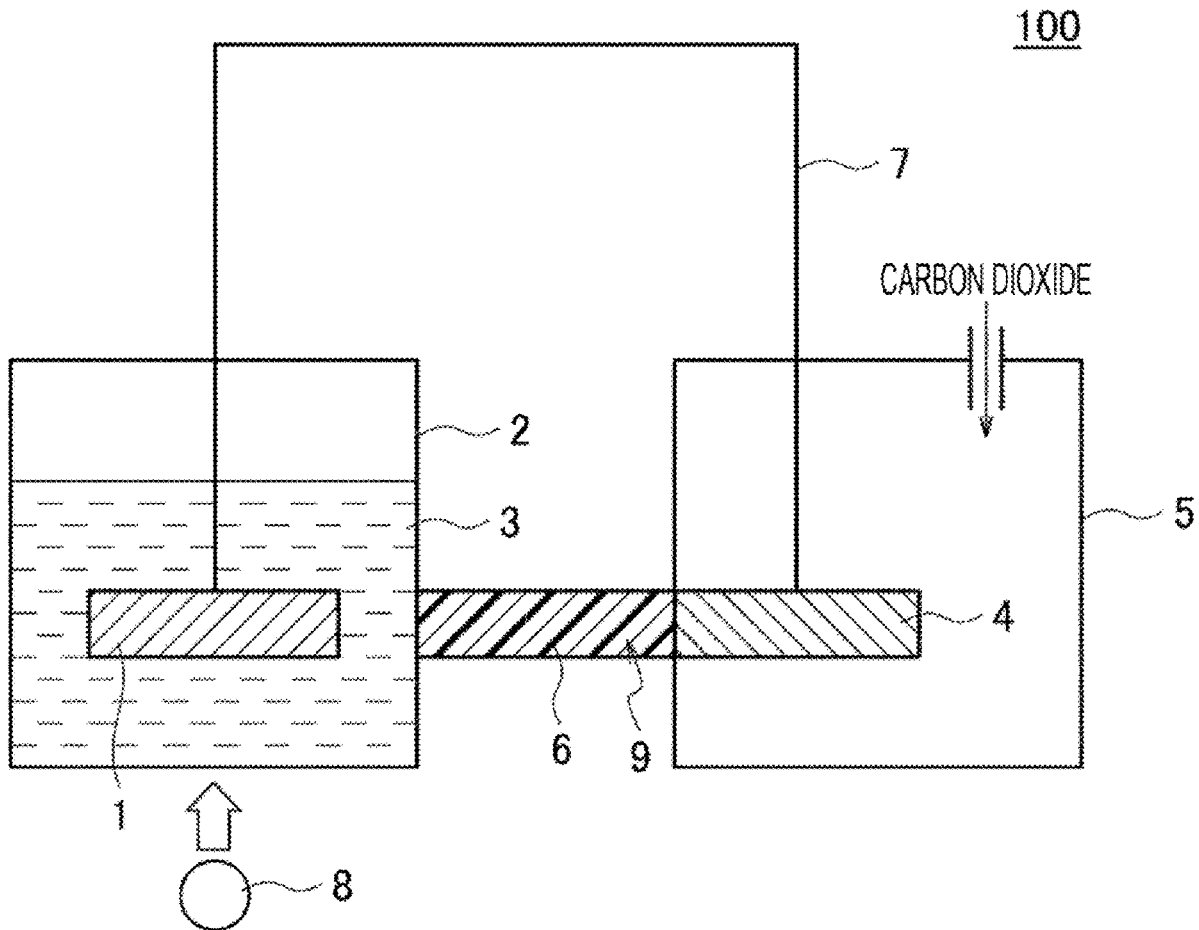


Fig. 1

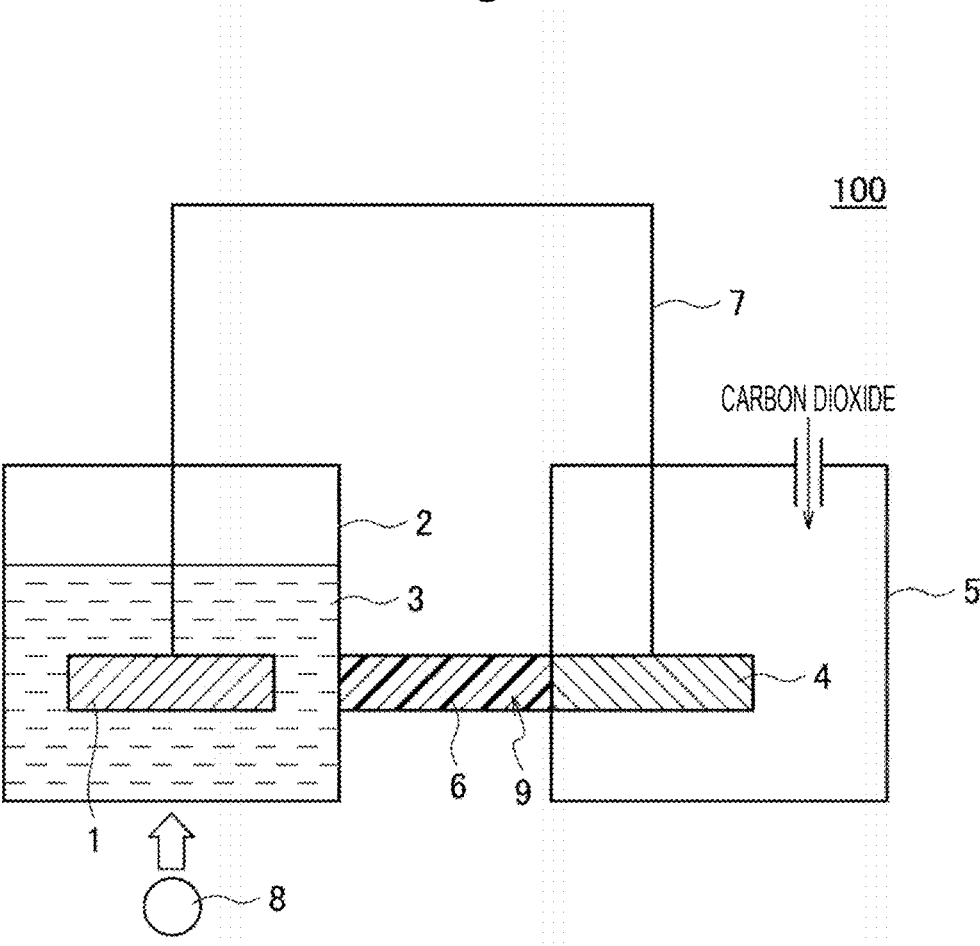


Fig. 2(a)

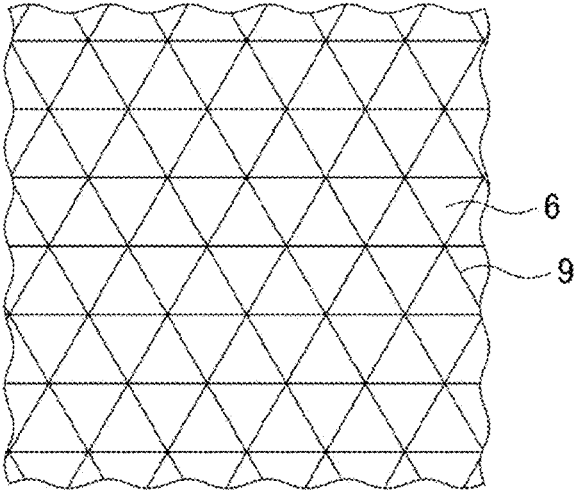


Fig. 2(b)

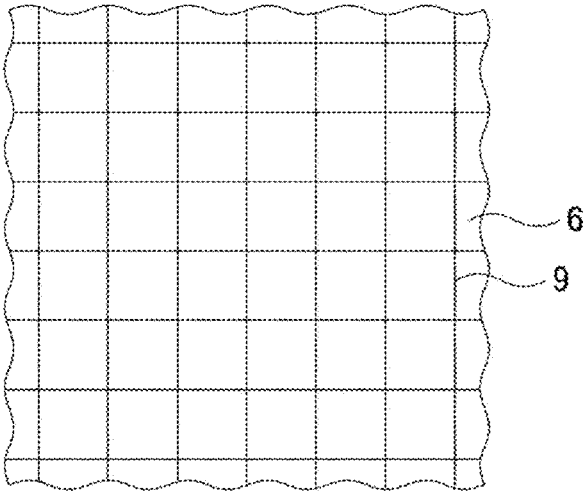


Fig. 2(c)

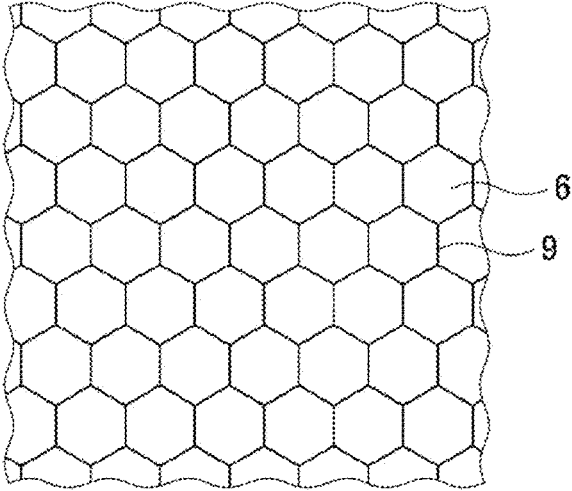


Fig. 3

| | NETWORK STRUCTURE | FIBER LENGTH REQUIRED FOR AREA OF 1 cm ² | FIBER DIAMETER |
|---------------------|-------------------|---|----------------|
| EXAMPLE 1 | REGULAR HEXAGON | 3.7cm | 100um |
| EXAMPLE 2 | SQUARE | 4.0cm | 100um |
| EXAMPLE 3 | REGULAR TRIANGLE | 4.6cm | 100um |
| COMPARATIVE EXAMPLE | - | - | - |

Fig. 4

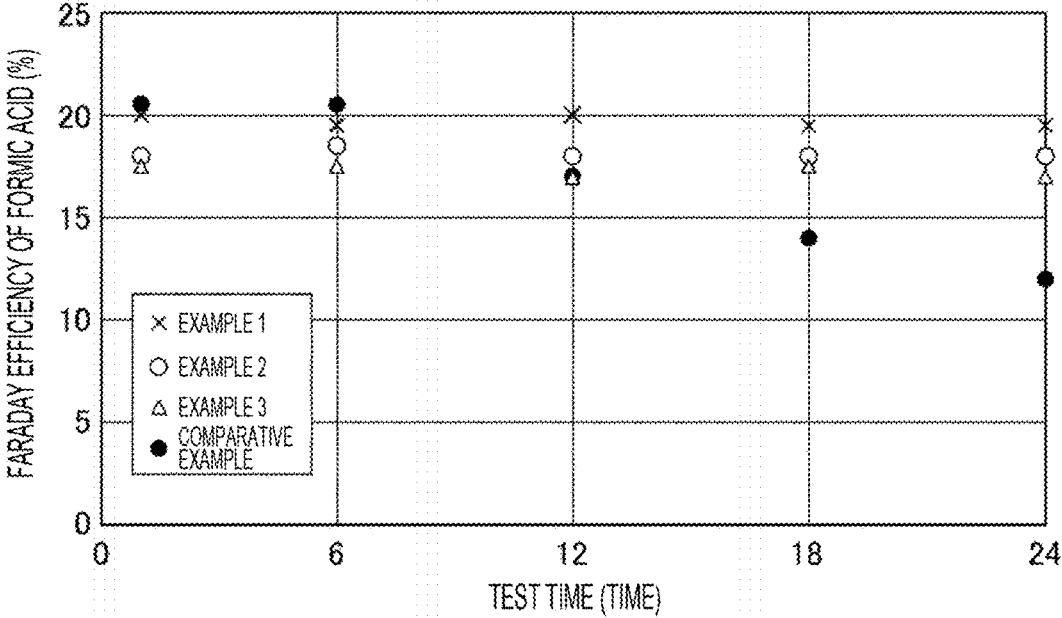


Fig. 5

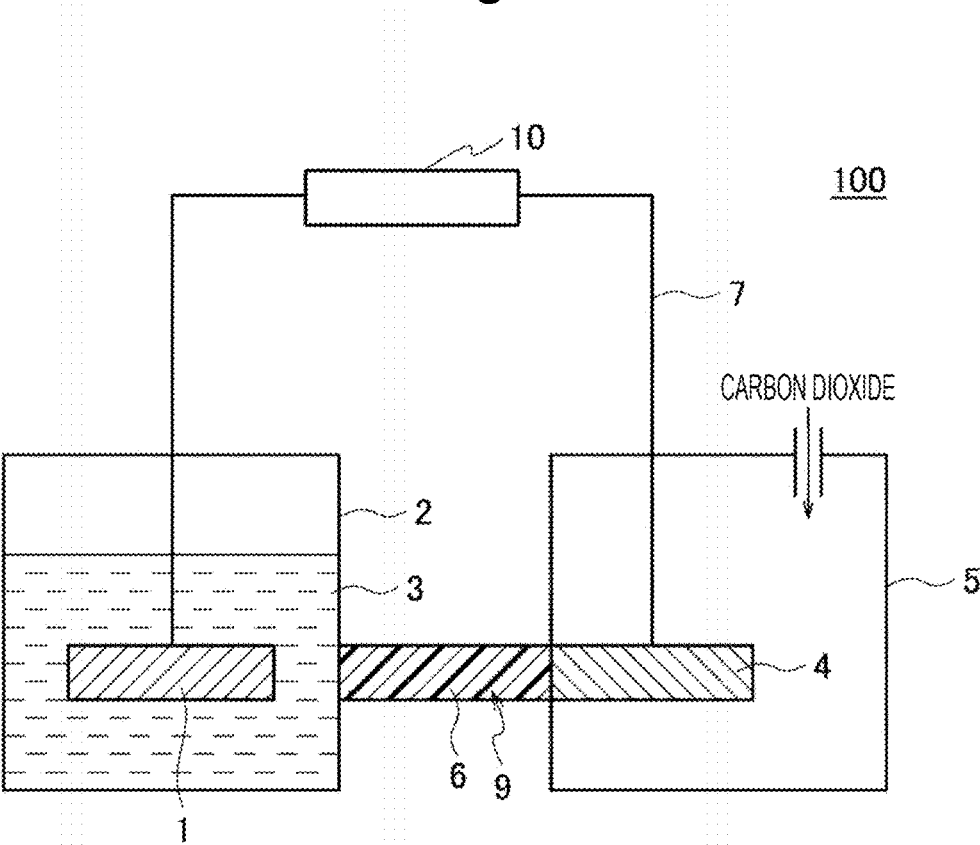
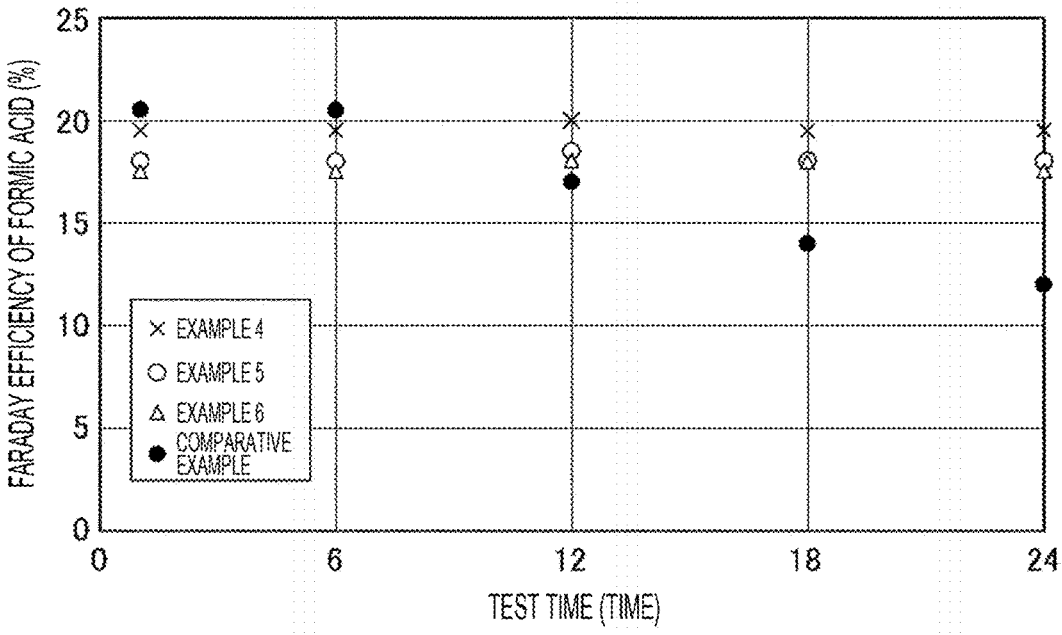


Fig. 6



ELECTROLYTE MEMBRANE

TECHNICAL FIELD

[0001] The present invention relates to an electrolyte membrane.

BACKGROUND ART

[0002] An increase in the concentration of carbon dioxide in the atmosphere is mentioned as a main cause of global warming. Reduction of carbon dioxide emissions has become a long-term challenge on a global scale. Meanwhile, energy supply relying on fossil fuels is to be reviewed in the medium and long term as an energy problem, and creation of a next-generation energy supply source is awaited.

[0003] As a way of suppressing emission of carbon dioxide and obtaining energy, technologies have been developed for utilizing unused energy such as exhaust heat, snow and ice heat, vibration, and electromagnetic waves and renewable energy such as sunlight. These power generation technologies enable only creation of electrical energy, and storage of energy is impossible with these technologies. Creation of chemical products using fossil fuels as raw materials is also impossible.

[0004] As a method of simultaneously solving these issues, a technology of reducing carbon dioxide using light energy has attracted attention. For example, Non Patent Literature 1 discloses a carbon dioxide reduction device by light irradiation. In the oxidation tank, when the oxidation electrode is irradiated with light, electron-hole pairs are generated and separated at the oxidation electrode, and oxygen and protons (H^+) are generated by the oxidation reaction of water in the electrolytic solution. The protons pass through the electrolyte membrane and reach the reduction tank, and the electrons flow to the reduction electrode through the conductive wire. In the reduction tank, a reduction reaction of carbon dioxide by protons, electrons, and carbon dioxide dissolved in the solution is caused at the reduction electrode in the solution. This reduction reaction generates carbon monoxide, formic acid, methane, and the like that can be used as energy resources.

[0005] In the carbon dioxide reduction device of Non Patent Literature 1, the reduction electrode is immersed in a solution, and carbon dioxide is dissolved in the solution to supply the carbon dioxide to the reduction electrode. However, in this method for reducing carbon dioxide, since the reduction electrode is immersed in the solution, there are limitations on the concentration of carbon dioxide dissolved in the solution and the diffusion coefficient of carbon dioxide in the solution, and the amount of carbon dioxide supplied to the reduction electrode is limited.

[0006] Therefore, in order to increase the amount of carbon dioxide supplied to the reduction electrode, studies have been conducted to eliminate the solution in the reduction tank and directly supply carbon dioxide to the reduction electrode. In Non Patent Literature 2, by using a reduction tank having structure in which carbon dioxide in a gas phase is directly supplied to the reduction electrode, the amount of carbon dioxide supplied to the reduction electrode is increased, and reduction reaction of carbon dioxide is promoted.

CITATION LIST

Non Patent Literature

- [0007] Non Patent Literature 1: Satoshi Yotsuhashi, and six others, "CO₂ Conversion with Light and Water by GaN Photo electroade", Japanese Journal of Applied Physics, 51, 2012, p. 02BP07-1-p. 02BP07-3
- [0008] Non Patent Literature 2: Qingxin Jia, and two others, "Direct Gas-phase CO₂ reduction for Solar Methane Generation Using a Gas Diffusion Electrode with a BiVO₄: Mo and a Cu-In-e Photoanode", Chem. Lett., 47, Jan. 13, 2018, p. 436-p. 439

SUMMARY OF INVENTION

Technical Problem

[0009] However, when an acid or alkali solution is used as an electrolytic solution in the oxidation tank and a Nafion membrane (registered trademark) is used as the electrolyte membrane, the electrolyte membrane swells with the lapse of time, and the electrolytic solution in the oxidation tank gradually exudes into the reduction tank through the electrolyte membrane. Therefore, the reaction surface (reaction site) of the reduction electrode is covered with the electrolytic solution, and the reduction reaction of carbon dioxide does not proceed. Therefore, the conventional carbon dioxide reduction device has a problem in that the reduction reaction efficiency of carbon dioxide decreases in several tens of hours.

[0010] The present invention has been made to address the problem above, and an object of the present invention is to provide a technology capable of improving the reduction reaction efficiency of carbon dioxide.

Solution to Problem

[0011] An electrolyte membrane according to an aspect of the present invention is an electrolyte membrane that is disposed between an electrolytic solution in an oxidation tank and a reduction electrode in a reduction tank in contact with the electrolytic solution and reduction electrode, and is used in a carbon dioxide reduction device that performs a reduction reaction of carbon dioxide by bringing carbon dioxide into direct contact with the reduction electrode, in which fibers are woven in a network shape.

Advantageous Effects of Invention

[0012] According to the present invention, the reduction reaction efficiency of carbon dioxide can be improved.

BRIEF DESCRIPTION OF DRAWINGS

[0013] FIG. 1 is a diagram showing a configuration example of a carbon dioxide reduction device according to a first embodiment.

[0014] FIG. 2 is a diagram showing a formation example of fibers.

[0015] FIG. 3 is a diagram showing an example of fibers.

[0016] FIG. 4 is a diagram showing a measurement result of the Faraday efficiency of formic acid according to the first embodiment. FIG. 5 is a diagram showing a configuration example of a carbon dioxide reduction device according to a second embodiment.

[0017] FIG. 6 is a diagram showing a measurement result of the Faraday efficiency of formic acid according to the second embodiment.

DESCRIPTION OF EMBODIMENTS

[0018] Hereinafter, embodiments of the present invention will be described with reference to the drawings. In the drawings, the same portions are denoted by the same reference signs, and description thereof is omitted.

First Embodiment

[0019] FIG. 1 is a diagram showing a configuration example of a carbon dioxide reduction device 100 according to a first embodiment. As shown in FIG. 1, the carbon dioxide reduction device 100 includes an oxidation electrode 1, an oxidation tank 2, an electrolytic solution 3, a reduction electrode 4, a reduction tank 5, an electrolyte membrane 6, a conductive wire 7, a light source 8, and fibers 9.

[0020] The oxidation electrode 1 is immersed in the electrolytic solution 3 in the oxidation tank 2. The oxidation electrode 1 is formed by forming a semiconductor on a substrate having a predetermined area. The oxidation electrode 1 is formed, for example, by forming a film of a compound exhibiting photoactivity, redox activity, or the like such as a nitride semiconductor, titanium oxide, amorphous silicon, a ruthenium complex, or a rhenium complex, on a surface of the sapphire substrate.

[0021] The oxidation tank 2 holds the electrolytic solution 3 in which the oxidation electrode 1 is immersed.

[0022] The electrolytic solution 3 is placed in the oxidation tank 2. Examples of the electrolytic solution 3 include a potassium hydrogen carbonate aqueous solution, a sodium hydrogen carbonate aqueous solution, a potassium chloride aqueous solution, a sodium chloride aqueous solution, a potassium hydroxide aqueous solution, a rubidium hydroxide aqueous solution, and a cesium hydroxide aqueous solution.

[0023] The reduction electrode 4 is disposed in the reduction tank 5. The reduction electrode 4 is formed on a substrate having predetermined area similarly to the oxidation electrode 1. The reduction electrode 4 is, for example, a porous body of copper, platinum, gold, silver, indium, palladium, gallium, nickel, tin, cadmium, or an alloy thereof. In addition, the reduction electrode 4 may be a compound such as silver oxide, copper oxide, copper (II) oxide, nickel oxide, indium oxide, tin oxide, tungsten oxide, tungsten (VI) oxide, or copper oxide, or a porous metal complex having a metal ion and an anionic ligand.

[0024] The reduction tank 5 has the reduction electrode 4 disposed inside thereof, and holds gas phase carbon dioxide supplied from the outside through a pipe.

[0025] The electrolyte membrane 6 is disposed between the oxidation tank 2 and the reduction tank 5. To be precise, the electrolyte membrane 6 is disposed between the electrolytic solution 3 and the reduction electrode 4 in contact with the electrolytic solution 3 and the reduction electrode 4. The electrolyte membrane 6 is, for example, Nafion (registered trademark), FORBLUE, or Aquivion each of which is an electrolyte membrane having a carbon-fluorine skeleton, or SELEMION or NEOSEPTA that is an electrolyte membrane having a carbon-hydrogen skeleton.

[0026] The conductive wire 7 physically and electrically connects the oxidation electrode 1 and the reduction electrode 4.

[0027] The light source 8 is disposed close to the oxidation tank 2. The light source 8 is, for example, a light source of sunlight, a xenon lamp, a pseudo sunlight source, a halogen lamp, a mercury lamp, or a combination thereof.

[0028] The reduction electrode 4 and the electrolyte membrane 6 may be formed of an integrated material. For example, the reduction electrode 4 and the electrolyte membrane 6 can be realized by using a gas diffusion electrode (GDE (registered trademark)) including porous equipment and a catalyst. Since the gas diffusion electrode can separate liquid and gas, and allows cations to move in the electrode, the gas diffusion electrode has an action equivalent to the action of both the reduction electrode 4 and the electrolyte membrane 6.

[0029] In addition, in FIG. 1, the reduction electrode 4 and the electrolyte membrane 6 are drawn so as to have a large width in the lateral direction of the paper surface, but the width in the lateral direction of the paper surface may be reduced to have a thin plate shape with a flat surface in the depth direction of the paper surface. By bonding the reduction electrode 4 and the electrolyte membrane 6 to each other in their planes, the reaction field of the contact surface can be maximized.

[0030] In the carbon dioxide reduction device 100 described above, in the oxidation tank 2, the oxidation reaction of water in the electrolytic solution 3 is performed by irradiation light (light energy) from the light source 8 using the electrolytic solution 3 and the oxidation electrode 1 of the semiconductor immersed in the electrolytic solution 3. In the reduction tank 5, the reduction reaction of carbon dioxide is performed using the reduction electrode 4 connected to the oxidation electrode 1 via the conductive wire 7 and carbon dioxide brought into direct contact with the reduction electrode 4.

[0031] Specifically, when the light source 8 emits light from the bottom of the oxidation tank 2, electron-hole pairs are generated and separated at the oxidation electrode 1 within the oxidation tank 2 that has received the emitted light, and oxygen and protons are generated by the oxidation reaction of water in the electrolytic solution 3. The protons pass through the electrolyte membrane 6 and reach the reduction electrode 4 in the reduction tank 5 from the electrolytic solution 3 in the oxidation tank 2. The electrons flow from the oxidation electrode 1 in the oxidation tank 2 to the reduction electrode 4 in the reduction tank 5 via the conductive wire 7. In the reduction tank 5, a reduction reaction of carbon dioxide by protons, electrons, and carbon dioxide in a gas phase brought into direct contact with the reduction electrode 4 is caused in the reduction electrode 4. This oxidation-reduction reaction generates carbon monoxide, formic acid, methane, and the like that can be used as energy resources.

[0032] At this time, when a strong alkaline aqueous solution, for example, a 1.0 mol/L aqueous solution of sodium hydroxide is used as the electrolytic solution 3 in the oxidation tank 2, the electrolyte membrane 6 swells, and the electrolytic solution 3 passes through the pores of the electrolyte membrane 6 and exudes to the surface of the reduction electrode 4 in the reduction tank 5. In order to prevent such exudation of the electrolytic solution 3 from

the electrolyte membrane 6, fibers 51 may be incorporated into the electrolyte membrane 6 so as to prevent swelling of the electrolyte membrane 6.

[0033] Therefore, in the present embodiment, the fibers 9 are woven in a network shape inside the electrolyte membrane 6. For example, as shown in FIG. 2, the fibers 9 are woven into the electrolyte membrane 6 so as to form a regular triangular, square, and regular hexagonal network shape when viewed from the side of the paper surface of FIG. 1. At this time, it is more preferable to maintain the strength with as few fibers as possible. That is, it is preferable to fill the area with the shortest possible side length.

[0034] For example, in a case where the lengths of the sides of a regular triangle, a square, and a regular hexagon are x cm, and the area to be filled is A cm², the length of the side of the regular triangle is $\sqrt{(4A/\sqrt{3})} \times 3$, the length of the side of the square is $\sqrt{A} \times 4$, and the length of the side of the regular hexagon is $\sqrt{(2A/3\sqrt{3})} \times 6$. Therefore, it can be seen that the necessary lengths of the sides of the regular triangle, the square, and the regular hexagon are shortened in this order. Therefore, it is desirable that the fibers 9 are woven into the electrolyte membrane 6 so as to have structure of regular hexagonal network (regular hexagonal network structure, honeycomb structure).

[0035] The polymer material of the fibers 9 is preferably, for example, polytetrafluoroethylene (PTFE), polyvinylidene chloride (PVdC), acrylonitrile-butadiene-styrene (ABS), polyethylene (PE), or polypropylene (PP) which does not swell even in an acid or an alkaline solution.

[0036] As described above, since the fibers 9 are woven into the inside of the electrolyte membrane 6 in a network shape, it is possible to suppress the electrolytic solution 3 in the oxidation tank 2 from entering the inside of the electrolyte membrane 6, it is possible to suppress liquid leakage of the electrolytic solution 3 to the reduction electrode 4, and the reaction site of the reduction electrode 4 is not filled with the electrolytic solution 3. In addition, it is possible to maintain a state in which protons can pass through the electrolyte membrane 6. As a result, the reduction reaction of carbon dioxide can proceed, and a decrease in the reduction reaction efficiency can be suppressed.

[0037] Next, electrochemical measurement by the carbon dioxide reduction device 100 and a measurement result thereof will be described.

[0038] First, a thin film of gallium nitride (GaN) as an n-type semiconductor and aluminum gallium nitride (Al-GaN) were epitaxially grown in this order on a sapphire substrate, and nickel (Ni) was vacuum-deposited thereon to perform heat treatment, so that a cocatalyst thin film of nickel oxide (NiO) was formed. Then, the cocatalyst thin film was used as the oxidation electrode 1, and the oxidation electrode 1 was immersed in the electrolytic solution 3 of a 1.0 mol/L aqueous potassium hydroxide solution in the oxidation tank 2.

[0039] In addition, the reduction electrode 4 was formed using a porous body of copper, the formed reduction electrode 4 was connected to the oxidation electrode 1 by the conductive wire 7, and the reduction electrode 4 was installed in the reduction tank 5.

[0040] In addition, Nafion was used for the electrolyte membrane 6 physically separating the oxidation tank 2 and the reduction tank 5. As Nafion, the fibers 9 of PTFE having a fiber length and a fiber diameter shown in FIG. 3 were used. In Example 1, Nafion having PTFE fibers having

regular hexagonal network structure was used. In Example 2, Nafion having PTFE fibers having square network structure was used. In Example 3, Nafion having PTFE fibers having regular triangular network structure was used. In Comparative Example, Nafion into which no PTFE fibers were introduced was used as it was as the electrolyte membrane 6.

[0041] As the light source 8, a 300 W xenon lamp was used. A wavelength of 450 nm or more was cut with a filter, and the illuminance was set to 6.6 mW/cm². A light irradiation surface of the oxidation electrode 1 was set to 2.5 cm².

[0042] Then, nitrogen and carbon dioxide were supplied to the oxidation tank 2 and the reduction tank 5 at a flow rate of 5 ml/min and a pressure of 0.5 MPa, respectively. The bubbling of nitrogen into the oxidation tank 2 was carried out for the purpose of analyzing the reaction products. The inside of each of the oxidation tank 2 and the reduction tank 5 was sufficiently replaced with nitrogen and carbon dioxide, respectively, and light was emitted from the light source 8. Thereafter, the reduction reaction of carbon dioxide proceeded on the surface of the copper porous body as the reduction electrode 4.

[0043] At this time, the current flowing between the oxidation electrode 1 and the reduction electrode 4 by the irradiation light was measured by an electrochemical measurement apparatus (Model 1287 Potentiogalvanostat manufactured by Solartron). Gases and liquids generated in the oxidation tank 2 and the reduction tank 5 were collected, and the reaction products were analyzed using a gas chromatograph, a liquid chromatograph, and a gas chromatograph mass spectrometer.

[0044] In particular, in the present embodiment, the effect of the fibers 9 woven into the electrolyte membrane 6 was examined by determining the Faraday efficiency of the carbon dioxide reduction reaction. A method for calculating the Faraday efficiency of the carbon dioxide reduction reaction will be described later.

[0045] FIG. 4 is a diagram showing a measurement result of the Faraday efficiency of formic acid according to the first embodiment. In Comparative Example in which the fibers 9 were not woven, the Faraday efficiency decreased after 6 hours. On the other hand, in Examples 1 to 3 in which the fibers 9 were woven, the Faraday efficiency did not decrease even after 6 hours. This is because as a result of introducing PTFE fibers into the Nafion film, swelling of the Nafion film was suppressed, liquid leakage of the electrolytic solution 3 to the reduction electrode 4 was suppressed, and the reaction site of the reduction electrode 4 was not filled with the electrolytic solution 3.

[0046] In addition, comparing the Faraday efficiency after one hour, which is the initial stage of the reaction, the Faraday efficiency is in descending order of the Faraday efficiency as Comparative Example, Example 1, Example 2, and Example 3. This is because the PTFE fibers inhibit the movement of protons, and it can be understood that the order of the introduction amount of the PTFE fibers and the order of the Faraday efficiency coincide with each other as described above.

[0047] Here, a method for calculating the Faraday efficiency of the carbon dioxide reduction reaction will be described. The Faraday efficiency of carbon dioxide indicates the ratio of the number of electrons used in the carbon dioxide reduction reaction to the number of electrons moved

between the oxidation electrode **1** and the reduction electrode **4** by light irradiation or application of a current voltage, and can be calculated by Formula (1).

$$\text{Faraday efficiency} = \frac{\{\text{number of electrons in reduction reaction}\}}{\{\text{number of electrons transferred between electrodes}\}} \quad (1)$$

[0048] The “number of electrons in reduction reaction” in Formula (1) is determined by converting the measured value of the integrated amount of the generated carbon dioxide reduction product into the number of electrons required for the production reaction. For example, the “number of electrons in the reduction reaction” when the reduction product is a gas can be calculated by Formula (2).

$$\text{Number of electrons in each reduction reaction (C)} = \frac{\{(A \times B \times Z \times F \times T \times 10^{-6})\}}{V_g} \quad (2)$$

[0049] A is a concentration (ppm) of the reduction reaction product. B is a flow rate (L/sec) of the carrier gas. Z is the number of electrons required for the reduction reaction. F is the Faraday constant (C/mol). T is a light irradiation time or a current voltage application time (sec). V_g is a molar volume of the gas (L/mol).

[0050] The “number of electrons in the reduction reaction” when the reduction product is a liquid can be calculated by Formula (3).

$$\text{Number of electrons in each reduction reaction (C)} = C \times V_l \times Z \times F \quad (3)$$

[0051] C is a concentration (mol/L) of the reduction reaction product. V_l is a volume (L) of the liquid sample. Z is the number of electrons required for the reduction reaction. F is the Faraday constant (C/mol).

[0052] The first embodiment has been described above. According to the carbon dioxide reduction device **100** of the first embodiment, it is possible to provide the carbon dioxide reduction device **100** capable of allowing the carbon dioxide reduction reaction to proceed without reducing the Faraday efficiency.

[0053] That is, in the first embodiment, in the carbon dioxide reduction device **100** including the oxidation tank **2** in which the oxidation reaction of water is performed by the irradiation light from the light source **8** using the electrolytic solution **3** and the oxidation electrode **1** of a semiconductor to be immersed in the electrolytic solution **3**, the reduction tank **5** in which the reduction reaction of carbon dioxide is performed using the reduction electrode **4** connected to the oxidation electrode **1** via the conductive wire **7** and carbon dioxide brought into direct contact with the reduction electrode **4**, and the electrolyte membrane **6** disposed between the electrolytic solution **3** in the oxidation tank **2** and the reduction electrode **4** in the reduction tank **5** in contact with the electrolytic solution **3** and the reduction electrode **4**, the fibers **9** are woven in a network shape inside the electrolyte membrane **6**.

[0054] Therefore, it is possible to suppress the electrolytic solution **3** in the oxidation tank **2** from entering the inside of

the electrolyte membrane **6**, it is possible to suppress liquid leakage of the electrolytic solution **3** to the reduction electrode **4**, and the reaction site of the reduction electrode **4** is not filled with the electrolytic solution **3**. In addition, it is possible to maintain a state in which protons pass through the electrolyte membrane **6**. As a result, the reduction reaction of carbon dioxide can proceed, and a decrease in the reduction reaction efficiency can be suppressed.

[0055] In the above experiment, light is generated by a xenon lamp in order to quantitatively manage the irradiation amount of light with respect to the oxidation electrode **1**, but it is also possible to cause an oxidation reaction using sunlight or the like.

Second Embodiment

[0056] In the first embodiment, the case where the light source **8** and the oxidation electrode **1** including a semiconductor are used has been described. In the second embodiment, instead of the light source **8** and the oxidation electrode **1**, an oxidation/reduction reaction is allowed to proceed using an external power supply and the oxidation electrode **1** including a metal.

[0057] FIG. 5 is a diagram showing a configuration example of a carbon dioxide reduction device **100** according to the second embodiment. The oxidation electrode **1** is platinum. In addition, the oxidation electrode **1** may be, for example, gold or silver. The external power supply **10** is an electrochemical measurement device, and is connected in series to the conductive wire **7** connecting the oxidation electrode **1** and the reduction electrode **4**. The power supply **10** may be another power supply device. Other components are the same as those of the first embodiment.

[0058] In the carbon dioxide reduction device **100** according to the present embodiment, in the oxidation tank **2**, the oxidation reaction of water in the electrolytic solution **3** is performed by the current voltage (electrical energy) from the power supply **10** using the electrolytic solution **3** and the oxidation electrode **1** of platinum (metal) immersed in the electrolytic solution **3**. In the reduction tank **5**, the reduction reaction of carbon dioxide is performed using the reduction electrode **4** connected to the power supply **10** (source of electric energy) and carbon dioxide brought into direct contact with the reduction electrode **4**.

[0059] Specifically, when the power supply **10** applies a current voltage to the conductive wire **7**, electron-hole pairs are generated and separated at the oxidation electrode **1** in the oxidation tank **2**, and oxygen and protons are generated by the oxidation reaction of water in the electrolytic solution **3**. The protons pass through the electrolyte membrane **6** and reach the reduction electrode **4** in the reduction tank **5** from the electrolytic solution **3** in the oxidation tank **2**. The electrons flow from the power supply **10** to the reduction electrode **4** in the reduction tank **5** via the conductive wire **7**. In the reduction tank **5**, a reduction reaction of carbon dioxide by protons, electrons, and carbon dioxide in a gas phase brought into direct contact with the reduction electrode **4** is caused in the reduction electrode **4**.

[0060] Also in the second embodiment, similarly to the first embodiment, the fibers **9** are woven into the electrolyte membrane **6** in a network shape. For example, the fibers **9** are woven into the electrolyte membrane **6** so as to have a regular triangular shape, a square shape, or a regular hexagonal shape.

[0061] FIG. 6 is a diagram showing a measurement result of the Faraday efficiency of formic acid according to the second embodiment. Examples using the same electrolyte membrane 6 as in Example 1 to Example 3 described in the first embodiment are referred to as Example 4 to Example 6, respectively. Comparative Example in which Nafion in which the fibers 9 are not woven is used as it is as the electrolyte membrane 6 is also described.

[0062] In Examples 4 to 6, the Faraday efficiency did not decrease even after the lapse of 6 hours. This is because as a result of introducing PTFE fibers into the Nafion film, swelling of the Nafion film was suppressed, liquid leakage of the electrolytic solution 3 to the reduction electrode 4 was suppressed, and the reaction site of the reduction electrode 4 was not filled with the electrolytic solution 3.

[0063] The second embodiment has been described above. According to the carbon dioxide reduction device 100 of the second embodiment, it is possible to provide the carbon dioxide reduction device 100 capable of allowing the carbon dioxide reduction reaction to proceed without reducing the Faraday efficiency.

[0064] That is, in the second embodiment, in the carbon dioxide reduction device 100 including the oxidation tank 2 in which the oxidation reaction of water is performed by the current voltage from the power supply 10 using the electrolytic solution 3 and the oxidation electrode 1 of platinum (metal) to be immersed in the electrolytic solution 3, the reduction tank 5 in which the reduction reaction of carbon dioxide is performed using the reduction electrode 4 connected to the power supply 10 and carbon dioxide brought into direct contact with the reduction electrode 4, and the electrolyte membrane 6 disposed between the electrolytic solution 3 in the oxidation tank 2 and the reduction electrode 4 in the reduction tank 5 in contact with the electrolytic solution 3 and the reduction electrode 4, the fibers 9 are woven in a network shape inside the electrolyte membrane 6.

[0065] Therefore, it is possible to suppress the electrolytic solution 3 in the oxidation tank 2 from entering the inside of the electrolyte membrane 6, it is possible to suppress liquid leakage of the electrolytic solution 3 to the reduction electrode 4, and the reaction site of the reduction electrode 4 is not filled with the electrolytic solution 3. In addition, it is possible to maintain a state in which protons pass through the electrolyte membrane 6. As a result, the reduction reaction of carbon dioxide can proceed, and a decrease in the reduction reaction efficiency can be suppressed.

Others

[0066] The present invention can be widely used in the field related to the recycling of carbon dioxide. Although light energy is used in the first embodiment and electric energy is used in the second embodiment, other renewable energy may be used. In addition, the first embodiment and the second embodiment can be combined.

[0067] The present invention can be also applied to any electrolyte membrane as long as it is the electrolyte membrane 6 used in the carbon dioxide reduction device 100 that is disposed between the electrolytic solution 3 in the oxidation tank 2 and the reduction electrode 4 in the reduction tank 5 in contact with the electrolytic solution 3 and the reduction electrode 4 and that performs the reduction reaction of carbon dioxide by bringing carbon dioxide into contact with the reduction electrode 4.

REFERENCE SIGNS LIST

- [0068]** 1 Oxidation electrode
- [0069]** 2 Oxidation tank
- [0070]** 3 Electrolytic solution
- [0071]** 4 Reduction electrode
- [0072]** 5 Reduction tank
- [0073]** 6 ELECTROLYTE MEMBRANE
- [0074]** 7 Conductive wire
- [0075]** 8 Light source
- [0076]** 9 Fibers
- [0077]** 10 Power supply
- [0078]** 100 Carbon dioxide reduction device

1. An electrolyte membrane that is disposed between an electrolytic solution in an oxidation tank and a reduction electrode in a reduction tank in contact with the electrolytic solution and the reduction electrode, and is used in a carbon dioxide reduction device that performs a reduction reaction of carbon dioxide by bringing the carbon dioxide into direct contact with the reduction electrode, wherein fibers are woven in a network shape inside the electrolyte membrane.

2. The electrolyte membrane according to claim 1, wherein the fibers includes

triangular, square, or hexagonal network structure.

3. The electrolyte membrane according to claim 1, wherein the oxidation tank performs an oxidation reaction of water by light energy using the electrolytic solution and an oxidation electrode of a semiconductor to be immersed in the electrolytic solution, and

the reduction tank performs a reduction reaction of carbon dioxide using the reduction electrode connected to the oxidation electrode via a conductive wire and the carbon dioxide brought into direct contact with the reduction electrode.

4. The electrolyte membrane according to claim 1, wherein the oxidation tank performs an oxidation reaction of water by electric energy using the electrolytic solution and an oxidation electrode of metal to be immersed in the electrolytic solution, and

the reduction tank performs a reduction reaction of carbon dioxide using the reduction electrode connected to a source of the electric energy and carbon dioxide brought into direct contact with the reduction electrode.

* * * * *