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ELECTROCHEMICAL CELL

Abstract

An electrochemical cell according to a first aspect of the present invention includes a support body, a first electrode layer, an electrolyte layer, and a second electrode layer. The first electrode layer is disposed on the support body. The electrolyte layer is disposed on the first electrode layer. The second electrode layer is disposed on the side opposite to the first electrode layer with respect to the electrolyte layer. The support body has a current collecting layer and a beam portion embedded in the current collecting layer. The first electrode layer includes an overlapping portion that overlaps the beam portion in a stacking direction, and a non-overlapping portion that does not overlap the beam portion in the stacking direction. The average particle size of Ni particles contained in the overlapping portion is smaller than the average particle size of Ni particles contained in the non-overlapping portion.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This is a continuation of PCT/JP2023/041814, filed Nov. 21, 2023, which claims priority from Japanese Application No. 2022-195067, filed Dec. 6, 2022 the entire content of which is hereby incorporated by reference.

TECHNICAL FIELD
[0002] The present invention relates to an electrochemical cell.
BACKGROUND ART
[0003] There have been conventionally known electrode-supported electrochemical cells (electrolytic cells, fuel cells, and the like) that have an electrolyte layer interposed between two electrode layers, one of which functions as a support body.
[0004] For example, JP 2014-049322A discloses an anode-supported fuel cell in which, out of the anode, the cathode, and the electrolyte, the anode is the thickest, and the anode functions as a support body.
SUMMARY
[0005] However, even if the thickness of the electrode layer functioning as a support body is increased, it is difficult to obtain sufficient rigidity because the electrode layer is porous. Therefore, the electrochemical cell may become warped as the temperature rises and falls during reduction treatment or operation.
[0006] An object of the present invention is to provide an electrochemical cell that is capable of suppressing warping.
[0007] An electrochemical cell according to a first aspect of the present invention includes a support body, a first electrode layer, an electrolyte layer, and a second electrode layer. The first electrode layer is disposed on the support body. The electrolyte layer is disposed on the first electrode layer. The second electrode layer is disposed on the side opposite to the first electrode layer with respect to the electrolyte layer. The support body has a current collecting layer and a beam portion embedded in the current collecting layer. The first electrode layer includes an overlapping portion that overlaps the beam portion in a stacking direction, and a non-overlapping portion that does not overlap the beam portion in the stacking direction. The average particle size of Ni particles contained in the overlapping portion is smaller than the average particle size of Ni particles contained in the non-overlapping portion.
[0008] An electrochemical cell according to a second aspect of the present invention relates to the electrochemical cell according to the first aspect, wherein a first surface of the beam portion on the side opposite to the first electrode layer is covered with the current collecting layer.
[0009] An electrochemical cell according to a third aspect of the present invention relates to the electrochemical cell according to the first or second aspect, wherein a second surface of the beam portion facing the first electrode layer is covered with the current collecting layer.
[0010] An electrochemical cell according to a fourth aspect of the present invention relates to the

electrochemical cell according to any one of the first to third aspects, wherein the support body has a frame body that surrounds a side periphery of the current collecting layer and to which the beam portion is coupled.
[0011] An electrochemical cell according to a fifth aspect of the present invention relates to the electrochemical cell according to any one of the first to fourth aspects, wherein the support body has a beam structural body constituted by a plurality of the beam portions.
[0012] An electrochemical cell according to a sixth aspect of the present invention relates to the electrochemical cell according to the fifth aspect, wherein the beam structural body has lattice structure.
[0013] An electrochemical cell according to a seventh aspect of the present invention relates to the electrochemical cell according to any one of the first to sixth aspects, wherein the porosity of the overlapping portion is greater than the porosity of the non-overlapping portion.
[0014] According to the present invention, it is possible to provide an electrochemical cell that is capable of suppressing warping.

Description

BRIEF DESCRIPTION OF DRAWINGS
[0015] FIG. **1** is a cross-sectional view of an electrolytic cell according to an embodiment.
[0016] FIG. **2** is a perspective view of a support body according to the embodiment.
[0017] FIG. **3** is a cross-sectional view of an electrolytic cell according to Modification 1.
[0018] FIG. **4** is a cross-sectional view of an electrolytic cell according to Modification 2.
DESCRIPTION OF EMBODIMENTS
Configuration of Electrolytic Cell **10**
[0019] FIG. **1** is a cross-sectional view of an electrolytic cell **10** according to an embodiment. FIG. **2** is a perspective view of a support body **11** according to the embodiment. The electrolytic cell **10** is an example of an “electrochemical cell” according to the present invention.
[0020] As shown in FIG. **1**, the electrolytic cell **10** includes a support body **11**, a hydrogen electrode active layer **12**, an electrolyte layer **13**, a reaction prevention layer **14**, and an oxygen electrode layer **15**. The hydrogen electrode active layer **12** is an example of a “first electrode layer” according to the present invention. The oxygen electrode layer **15** is an example of a “second electrode layer” according to the present invention.
[0021] In the electrolytic cell **10**, the support body **11**, the hydrogen electrode active layer **12**, the electrolyte layer **13**, and the oxygen electrode layer **15** are essential components, whereas the reaction prevention layer **14** is an optional component.
[0022] The support body **11**, the hydrogen electrode active layer **12**, the electrolyte layer **13**, the reaction prevention layer **14**, and the oxygen electrode layer **15** are stacked in this order in a Z-axis direction. The Z-axis direction is perpendicular to an X-axis direction and a Y-axis direction. The Z-axis direction is an example of the “stacking direction” according to the present invention.
Support Body **11**
[0023] As shown in FIGS. **1** and **2**, the support body **11** is formed in a plate shape. The support body **11** has a first main surface P**1**, a second main surface P**2**, and a side surface P**3**. The first main surface P**1** is electrically connected to a separator not shown. The first main surface P**1** faces a hydrogen electrode-side space S**1** into which a raw material gas is supplied. The second main surface P**2** is provided on the side opposite to the first main surface P**1** in the Z-axis direction. The second main surface P**2** is connected to the hydrogen electrode active layer **12**. The side surface P**3** is continuous with the first main surface P**1** and the second main surface P**2**. The side surface P**3** may be perpendicular to the first main surface P**1** and the second main surface P**2**, or may be inclined with respect to the first main surface P**1** and the second main surface P**2**.

[0024] The thickness of the support body **11** is not particularly limited, but may be 150 μm or more and 1000 μm or less, for example. In the Z-axis direction, the thickness of the support body **11** may be greater than the thicknesses of the hydrogen electrode active layer **12**, the electrolyte layer **13**, the reaction prevention layer **14**, and the oxygen electrode layer **15**.
[0025] As shown in FIGS. **1** and **2**, the support body **11** has a hydrogen electrode current collecting layer **20**, a beam structural body **30**, and a frame body **40**. The hydrogen electrode current collecting layer **20** is an example of a "current collecting layer" according to the present invention.
Hydrogen Electrode Current Collecting Layer **20**
[0026] The beam structural body **30** is embedded in the hydrogen electrode current collecting layer **20**. In the present embodiment, the hydrogen electrode current collecting layer **20** is divided into small compartments by the beam structural body **30**.
[0027] The hydrogen electrode current collecting layer **20** is supported by the beam structural body **30**. In the present embodiment, the hydrogen electrode current collecting layer **20** is also supported by the frame body **40**. The hydrogen electrode current collecting layer **20** functions as a support body for the electrolytic cell **10**, together with the beam structural body **30** and the frame body **40**. The electrolytic cell **10** according to the present embodiment is an electrode-supported electrochemical cell.
[0028] In addition to the current collecting function, the hydrogen electrode current collecting layer **20** has a gas diffusing function of diffusing the raw material gas supplied to the hydrogen electrode-side space S**1** toward the hydrogen electrode active layer **12**.
[0029] The hydrogen electrode current collecting layer **20** is a porous body having electron conductivity. The hydrogen electrode current collecting layer **20** contains nickel (Ni). In the case of co-electrolysis, Ni functions as an electron conductor and also functions as a thermal catalyst that promotes thermal reaction between H**2** generated in the hydrogen electrode active layer **12** and CO.sub.2 contained in the raw material gas to maintain a gas composition suitable for methanation and Fischer-Tropsch (FT) synthesis. The Ni contained in the hydrogen electrode current collecting layer **20** is basically present in the form of metallic Ni during the operation of the electrolytic cell **10**, but a portion of it may be present in the form of nickel oxide (NiO).
[0030] The hydrogen electrode current collecting layer **20** may contain an ion conductive material. The ion conductive material may be any of yttria-stabilized zirconia (YSZ), calcia-stabilized zirconia (CSZ), scandia-stabilized zirconia (ScSZ), gadolinium-doped ceria (GDC), samarium-doped ceria (SDC), and a mixture of two or more of these materials.
[0031] The porosity of the hydrogen electrode current collecting layer **20** is not particularly limited, but can be 20% or more and 40% or less, for example.
[0032] The method for forming the hydrogen electrode current collecting layer **20** is not particularly limited, and may be any of sintering, spray coating (thermal spraying, aerosol deposition, aerosol gas deposition, powder jet deposition, particle jet deposition, cold spraying, and the like), PVD (sputtering, pulsed laser deposition, and the like), CVD, extrusion molding, tape molding, printing lamination, casting, dry pressing, and the like.
Beam Structural Body **30**
[0033] The beam structural body **30** supports the hydrogen electrode current collecting layer **20**. The beam structural body **30** functions as a support body for the electrolytic cell **10**, together with the hydrogen electrode current collecting layer **20** and the frame body **40**.
[0034] The beam structural body **30** is embedded in the hydrogen electrode current collecting layer **20**. In the present embodiment, the beam structural body **30** being embedded in the hydrogen electrode current collecting layer **20** means that at least a portion of the beam structural body **30** is buried in the hydrogen electrode current collecting layer **20**.
[0035] The beam structural body **30** has a first surface Q**1** and a second surface Q**2**.
[0036] The first surface Q**1** is the surface of the beam structural body **30** opposite to the hydrogen electrode active layer **12**. Specifically, the first surface Q**1** is the surface of a first beam portion **31**

and a second beam portion **32**, which will be described later, opposite to the hydrogen electrode active layer **12**. In the present embodiment, the first surface Q**1** is not covered with the hydrogen electrode current collecting layer **20**. That is, the first surface Q**1** is exposed from the hydrogen electrode current collecting layer **20**. Therefore, in the present embodiment, the first surface Q**1** forms a portion of the first main surface P**1** of the support body **11**.
[0037] The second surface Q**2** is the surface of the beam structural body **30** facing the hydrogen electrode active layer **12**. Specifically, the second surface Q**2** is the surface of the first beam portion **31** and the second beam portion **32**, which will be described later, facing the hydrogen electrode active layer **12**. In the present embodiment, the second surface Q**2** is not covered with the hydrogen electrode current collecting layer **20**. That is, the second surface Q**2** is exposed from the hydrogen electrode current collecting layer **20**. Therefore, in the present embodiment, the second surface Q**2** forms a portion of the second main surface P**2** of the support body **11**, and is in direct contact with the hydrogen electrode active layer **12**.
[0038] In the present embodiment, the beam structural body **30** has lattice structure in which a plurality of beam portions are arranged in a lattice pattern in the planar direction in planar view from the Z-axis direction. The lattice structure is structure in which a plurality of beam portions are periodically arranged in planar view from the Z-axis direction. Since the beam structural body **30** has lattice structure, the support body **11** as a whole can be improved in rigidity.
[0039] Although the beam structural body **30** according to the present embodiment has tetragonal lattice structure, the shape of the lattice structure is not particularly limited. The lattice structure may be vertical lattice structure, horizontal lattice structure, hexagonal lattice structure, or the like, for example.
[0040] The beam structural body **30** can be made of forsterite (Mg.sub.2SiO.sub.4), magnesium silicate (MgSiO.sub.3), zirconia (ZrO.sub.2, including partially stabilized zirconia), magnesia (MgO), magnesium alumina spinel (MgAl.sub.2O.sub.4), or a mixed material of two or more of these.
[0041] The porosity of the beam structural body **30** may be lower than the porosity of the hydrogen electrode current collecting layer **20**. The porosity of the beam structural body **30** may be 0.1% or more and 15% or less, for example. The porosity of the beam structural body **30** is preferably 5% or less. This improves the strength of the beam structural body **30**, thereby improving the rigidity of the support body **11** as a whole.
[0042] The electron conductivity of the beam structural body **30** may be lower than the electron conductivity of the hydrogen electrode current collecting layer **20**. The beam structural body **30** may have electron insulation. The electron conductivity of the beam structural body **30** is not particularly limited, but may be 0.1 S/m or less.
[0043] As shown in FIG. **2**, the beam structural body **30** is constituted by a plurality of beam portions. In the present embodiment, the beam structural body **30** is constituted by four first beam portions **31** and four second beam portions **32**.
[0044] The first beam portions **31** and the second beam portions **32** are embedded in the hydrogen electrode current collecting layer **20**. In the present embodiment, the first beam portions **31** being embedded in the hydrogen electrode current collecting layer **20** means that the first beam portions **31** are at least partially embedded in the hydrogen electrode current collecting layer **20**. Similarly, the second beam portions **32** being embedded in the hydrogen electrode current collecting layer **20** means that the second beam portions **32** are at least partially embedded in the hydrogen electrode current collecting layer **20**.
[0045] The first beam portions **31** and the second beam portions **32** are formed in a columnar shape. The first beam portions **31** and the second beam portions **32** extend along planar directions perpendicular to the Z-axis direction (stacking direction). In the present embodiment, the first beam portions **31** extend along the Y-axis direction, and the second beam portions **32** extend along the X-axis direction. Therefore, in planar view from the Z-axis direction, the angle formed by the second

beam portions **32** with respect to the first beam portions **31** is 90 degrees. However, the angle formed by the second beam portions **32** with respect to the first beam portions **31** may be less than 90 degrees.

[0046] Both ends of each first beam portion **31** in the Y-axis direction are coupled to the frame body **40**. The first beam portions **31** may be formed integrally with the frame body **40**. Both ends of each second beam portion **32** in the X-axis direction are coupled to the frame body **40**. The second beam portions **32** may be formed integrally with the frame body **40**.

[0047] The beam structural body **30** according to the present embodiment has four first beam portions **31** and four second beam portions **32**, but the number of first beam portions **31** and the number of second beam portions **32** are not particularly limited as long as they are one or more. The beam structural body **30** may have only either the first beam portions **31** or the second beam portions **32**.

[0048] The method for forming the beam structural body **30** is not particularly limited, and may be extrusion molding, tape molding, printing lamination, casting, dry pressing, or the like.

[0049] As described above, since the support body **11** has at least either the first beam portions **31** or the second beam portions **32**, the rigidity of the electrolytic cell **10** can be improved. Accordingly, it is possible to suppress warping of the electrolytic cell **10** caused by temperature rise and fall during reduction treatment or operation.

Frame Body **40**

[0050] The frame body **40** is formed in a frame shape. The frame body **40** surrounds the side peripheries of the hydrogen electrode current collecting layer **20** and the beam structural body **30**. The side peripheries of the hydrogen electrode current collecting layer **20** and the beam structural body **30** refer to the peripheries of the side surfaces along the thickness direction. The frame body **40** functions as a support body for the electrolytic cell **10**, together with the hydrogen electrode current collecting layer **20** and the beam structural body **30**. In the present embodiment, the frame body **40** covers the entire side surfaces of the hydrogen electrode current collecting layer **20**.

[0051] In the present embodiment, as shown in FIG. **2**, the planar shape of the frame body **40** is rectangular. However, the planar shape of the frame body **40** may be circular, elliptical, or polygonal with three or more corners, in accordance with the planar shape of the hydrogen electrode current collecting layer **20**.

[0052] The frame body **40** is coupled to the beam structural body **30**. The frame body **40** may be formed integrally with the beam structural body **30**.

[0053] The frame body **40** can be made of forsterite, magnesium silicate, zirconia, magnesia, magnesium alumina spinel, or a mixed material of two or more of these.

[0054] The porosity of the frame body **40** may be lower than the porosity of the hydrogen electrode current collecting layer **20**. The porosity of the frame body **40** can be 0.1% or more and 15% or less, for example. The porosity of the frame body **40** is preferably 5% or less. This imparts gas sealing properties to the frame body **40**, so as to suppress the case where the raw material gas flowing from the hydrogen electrode-side space S**1** to the hydrogen electrode active layer **12** passes through the frame body **40** and returns to the hydrogen electrode-side space S**1**. This improves the efficiency of gas supply from the hydrogen electrode-side space S**1** to the hydrogen electrode active layer **12**.

[0055] The electron conductivity of the frame body **40** may be lower than the electron conductivity of the hydrogen electrode current collecting layer **20**. The frame body **40** may have electron insulation. The electron conductivity of the frame body **40** is not particularly limited, but can be 0.1 S/m or less.

[0056] The method for forming the frame body **40** is not particularly limited, and may be extrusion molding, tape molding, printing lamination, casting, dry pressing, or the like.

Hydrogen Electrode Active Layer **12**

[0057] The hydrogen electrode active layer **12** functions as a cathode. The hydrogen electrode active layer **12** is disposed on the support body **11**. The hydrogen electrode active layer **12** is covered with the electrolyte layer **13**.

[0058] A raw material gas is supplied to the hydrogen electrode active layer **12** mainly via the hydrogen electrode current collecting layer **20** of the support body **11**. In the present embodiment, the raw material gas contains at least H_2O.

[0059] If the raw material gas contains only H_2O, the hydrogen electrode active layer **12** generates H_2 from the raw material gas in accordance with the electrochemical reaction of water electrolysis shown in the following formula (1):

Hydrogen electrode active layer 12: $H_2O+2e^- \rightarrow H_2+O^{2-}$ (1)

[0060] If the raw material gas contains CO_2 in addition to H_2O, the hydrogen electrode active layer **12** generates H_2, CO, and O^{2-} from the raw material gas in accordance with the co-electrochemical reactions shown in the following formulas (2), (3), and (4):

Hydrogen electrode active layer 12: $CO_2+H_2O+4e^- \rightarrow CO+H_2+2O^{2-}$ (2)

Electrochemical reaction of H_2O: $H_2O+2e^- \rightarrow H_2+O^{2-}$ (3)

Electrochemical reaction of CO_2: $CO_2+2e^- \rightarrow CO+O^{2-}$ (4)

[0061] The hydrogen electrode active layer **12** is a porous body having electron conductivity. The hydrogen electrode active layer **12** contains nickel (Ni). In the case of co-electrolysis, Ni functions as an electron conductor and also functions as a thermal catalyst that promotes the thermal reaction between the generated H_2 and the CO_2 contained in the raw material gas to maintain a gas composition suitable for methanation and Fischer-Tropsch (FT) synthesis. The Ni contained in the hydrogen electrode active layer **12** is basically present in the form of metallic Ni during the operation of the electrolytic cell **10**, but a portion of the Ni may be present in the form of nickel oxide (NiO).

[0062] The hydrogen electrode active layer **12** may contain an ion conductive material. The ion conductive material may be YSZ, CSZ, ScSZ, GDC, SDC, (La, Sr) (Cr, Mn) O_3, (La, Sr) TiO_3, Sr_2 (Fe, Mo) $_2O_6$, (La, Sr) VO_3, (La, Sr) FeO_3, or a mixture of two or more of these.

[0063] The thickness of the hydrogen electrode active layer **12** is not particularly limited, but can be 5 μm or more and 50 μm or less, for example.

[0064] The method for forming the hydrogen electrode active layer **12** is not particularly limited, and may be sintering, spray coating (thermal spraying, aerosol deposition, aerosol gas deposition, powder jet deposition, particle jet deposition, cold spraying, and the like), PVD (sputtering, pulsed laser deposition, and the like), CVD, extrusion molding, tape molding, printing lamination, casting, dry pressing, or the like.

[0065] As shown in FIG. **1**, the hydrogen electrode active layer **12** includes overlapping portions **12***a* and non-overlapping portions **12***b*.

[0066] The overlapping portions **12***a* are regions of the hydrogen electrode active layer **12** that overlap the first beam portions **31** or the second beam portions **32** of the beam structural body **30** in the Z-axis direction (stacking direction). In the planar directions perpendicular to the Z-axis direction, the positions of the overlapping portions **12***a* correspond to the positions of the first beam portions **31** or the second beam portions **32** of the beam structural body **30**. In the present embodiment, the overlapping portions **12***a* are in direct contact with the second surface Q**2** of the beam structural body **30**.

[0067] The non-overlapping portions **12***b* are regions of the hydrogen electrode active layer **12** that do not overlap the first beam portions **31** or the second beam portions **32** of the beam structural body **30** in the Z-axis direction (stacking direction). In the planar direction perpendicular to the Z-axis direction, the positions of the non-overlapping portions **12***b* are away from the positions of the first beam portions **31** or the second beam portions **32** of the beam structural body **30**. The non-overlapping portions **12***b* are not in contact with the second surface Q**2** of the beam structural body **30**.

[0068] As described above, since the support body **11** has at least either the first beam portions **31** or the second beam portions **32**, the occurrence of warping in the electrolytic cell **10** can be suppressed. However, the raw material gas flowing from the hydrogen electrode-side space S**1** toward the hydrogen electrode active layer **12** is blocked by the first beam portions **31** or the second beam portions **32**. Therefore, the raw material gas is easily supplied to the non-overlapping portions **12***b*, but is relatively not easily supplied to the overlapping portions **12***a*. Accordingly, the electrode reaction occurs less easily in the overlapping portions **12***a*, thereby decreasing the overall performance.

[0069] In view of this, in the present embodiment, the average particle size of Ni particles contained in the overlapping portions **12***a* is made smaller than the average particle size of Ni particles contained in the non-overlapping portions **12***b*. This improves the electrode activity of the Ni particles, and the electrode activity in the overlapping portions **12***a* can be enhanced compared to the electrode activity in the non-overlapping portions **12***b*, so that it is possible to suppress a difference in the electrode reaction between the overlapping portions **12***a* and the non-overlapping portions **12***b*. Accordingly, the electrode reaction of the hydrogen electrode active layer **12** can be made uniform in the planar direction.

[0070] The average particle size of the Ni particles contained in the overlapping portions **12***a* is not particularly limited, but may be 3 μm or more and 10 μm or less. The average particle size of the Ni particles contained in the non-overlapping portions **12***b* is not particularly limited, but may be 2.4 μm or more and 8 μm or less.

[0071] The average particle sizes of the Ni particles contained in the overlapping portions **12***a* and the non-overlapping portions **12***b* are each calculated by the following method. First, a cross section of the hydrogen electrode active layer **12** along the thickness direction is exposed. Then, a composition mapping image of Ni on the cross section is obtained at 5000 to 10000-fold magnification using an SEM device (FE-SEM JSM-7900F manufactured by JEOL Ltd.) and an EDS device (JED-2300) attached to the SEM device. Next, the Ni composition mapping image is subjected to binarization processing in image analysis using image analysis software Image-Pro produced by Media Cybernetics, Inc., to thereby identify Ni particle portions in the Ni composition mapping image. Next, the diameter of a circle having the same area as that of each Ni particle in the binarized image is taken as the particle size of each Ni particle. The above processing is performed on **10** Ni particles randomly selected from each of five fields of view of the overlapping portions **12***a*, and the particle sizes of the **10** Ni particles are averaged to calculate the average particle size of the Ni particles contained in the overlapping portions **12***a*. Similarly, the particle sizes of **10** Ni particles randomly selected from one field of view of the non-overlapping portions **12***b* are averaged to calculate the average particle size of the Ni particles contained in the non-overlapping portions **12***b*.

[0072] The Ni content of the overlapping portions **12***a* is not particularly limited, but may be 20 vol % or more and 50 vol % or less. The Ni content of the non-overlapping portions **12***b* is not particularly limited, but may be 20 vol % or more and 50 vol % or less.

[0073] The porosity of the overlapping portions **12***a* is preferably greater than the porosity of the non-overlapping portions **12***b*. This improves gas diffusion in the overlapping portions **12***a* to which the raw material gas is less easily supplied from the hydrogen electrode current collecting layer **20** compared to the non-overlapping portions **12***b* to which the raw material gas is more easily supplied from the hydrogen electrode current collecting layer **20**, and thus improves the electrode reaction at the overlapping portions **12***a*.

[0074] The porosity of the overlapping portions **12***a* is not particularly limited, but may be 25% or more and 45% or less, for example. The porosity of the non-overlapping portions **12***b* is not particularly limited, but may be 20% or more and 40% or less, for example.
[0075] The porosities of the overlapping portion **12***a* and the non-overlapping portion **12***b* are each calculated by the following method. First, a cross section of each hydrogen electrode active layer **12** along the thickness direction is exposed. Then, using the above-mentioned SEM device, backscattered electron images of the cross sections of the overlapping portion **12***a* and the non-overlapping portion **12***b* are obtained at 10,000-fold magnification. Next, using the image analysis software HALCON produced by MVTec Software GmbH, the parts displayed in black in the backscattered electron images (corresponding to pores) are identified. Then, the total area of the pores is divided by the total area of the backscattered electron image of the overlapping portion **12***a* to calculate the porosity of the overlapping portion **12***a*. Similarly, the total area of the pores is divided by the total area of the backscattered electron image of the non-overlapping portion **12***b* to calculate the porosity of the non-overlapping portion **12***b*.
Electrolyte Layer **13**
[0076] The electrolyte layer **13** is interposed between the hydrogen electrode active layer **12** and the oxygen electrode layer **15**. In the present embodiment, the reaction prevention layer **14** is interposed between the electrolyte layer **13** and the oxygen electrode layer **15**, so that the electrolyte layer **13** is interposed between the hydrogen electrode active layer **12** and the reaction prevention layer **14** and is connected to both the hydrogen electrode active layer **12** and the reaction prevention layer **14**.
[0077] The electrolyte layer **13** covers the hydrogen electrode active layer **12**. As shown in FIG. **1**, the electrolyte layer **13** preferably covers the entire surface of the hydrogen electrode active layer **12**.
[0078] The electrolyte layer **13** has the function of transmitting O.sup.2− generated in the hydrogen electrode active layer **12** to the oxygen electrode layer **15**. The electrolyte layer **13** is a dense body that has ion conductivity and has no electron conductivity. The electrolyte layer **13** can be made of YSZ, GDC, ScSZ, SDC, lanthanum gallate (LSGM), or the like, for example.
[0079] The porosity of the electrolyte layer **13** is not particularly limited, but may be 0.1% or more and 7% or less, for example. The thickness of the electrolyte layer **13** is not particularly limited, but may be 1 μm or more and 100 μm or less, for example.
[0080] The method for forming the electrolyte layer **13** is not particularly limited, and may be sintering, spray coating, PVD, CVD, or the like.
Reaction Prevention Layer **14**
[0081] The reaction prevention layer **14** is interposed between the electrolyte layer **13** and the oxygen electrode layer **15**. The reaction prevention layer **14** is disposed on the side opposite to the hydrogen electrode active layer **12** with respect to the electrolyte layer **13**. The reaction prevention layer **14** suppresses reaction of the constituent elements of the electrolyte layer **13** with the constituent elements of the oxygen electrode layer **15** to form a layer with high electrical resistance.
[0082] The reaction prevention layer **14** is made of an ion conductive material. The reaction prevention layer **14** can be made of GDC, SDC, or the like.
[0083] The porosity of the reaction prevention layer **14** is not particularly limited, but may be 0.1% or more and 50% or less, for example. The thickness of the reaction prevention layer **14** is not particularly limited, but may be 1 μm or more and 50 μm or less, for example.
[0084] The method for forming the reaction prevention layer **14** is not particularly limited, and may be sintering, spray coating, PVD, CVD, or the like.
Oxygen Electrode Layer **15**
[0085] The oxygen electrode layer **15** functions as an anode. The oxygen electrode layer **15** is disposed on the side opposite to the hydrogen electrode active layer **12** with respect to the electrolyte layer **13**. In the present embodiment, since the reaction prevention layer **14** is interposed

between the electrolyte layer **13** and the oxygen electrode layer **15**, the oxygen electrode layer **15** is connected to the reaction prevention layer **14**. If the reaction prevention layer **14** is not interposed between the electrolyte layer **13** and the oxygen electrode layer **15**, the oxygen electrode layer **15** is connected to the electrolyte layer **13**.

[0086] The oxygen electrode layer **15** generates O.sub.2 from O.sup.2−0 transmitted from the hydrogen electrode active layer **12** through the electrolyte layer **13** according to the chemical reaction in Formula (5) below. The O.sub.2 generated in the oxygen electrode layer **15** is released into the oxygen electrode-side space S**2**.

Oxygen electrode layer 15: 2O.sup.2−.fwdarw.O.sub.2+4e.sup.−   (5)

[0087] The oxygen electrode layer **15** is a porous body having ion conductivity and electron conductivity. The oxygen electrode layer **15** can be made of a composite material of one or more of (La, Sr) (Co, Fe) O.sub.3, (La, Sr) FeO.sub.3, La (Ni, Fe) O.sub.3, (La, Sr) CoO.sub.3, and (Sm, Sr) CoO.sub.3 with an ion conductive material (such as GDC).

[0088] The porosity of the oxygen electrode layer **15** is not particularly limited, but may be 20% or more and 60% or less, for example. The thickness of the oxygen electrode layer **15** is not particularly limited, but may be 1 μm or more and 100 μm or less, for example.

[0089] The method for forming the oxygen electrode layer **15** is not particularly limited, and may be sintering, spray coating, PVD, CVD, or the like.

Modifications of Embodiments

[0090] Although embodiments of the present invention have been described above, the present invention is not limited to these, and various modifications are possible without departing from the spirit of the present invention.

Modification 1

[0091] In the above-described embodiments, the first surface Q**1** of the beam structural body **30** (specifically, the first and second beam portions **31** and **32**) is not covered with the hydrogen electrode current collecting layer **20**. However, as shown in FIG. **3**, the first surface Q**1** may be covered with the hydrogen electrode current collecting layer **20**. Accordingly, a portion of the hydrogen electrode current collecting layer **20** is formed as an outer layer-shaped portion **20***a* on the side opposite to the hydrogen electrode active layer **12** with respect to the beam structural body **30**. This suppresses the blocking of a flow of electrons between the hydrogen electrode current collecting layer **20** and the separator (not shown) by the beam structural body **30**.

Modification 2

[0092] In the above-described embodiments, the second surface Q**2** of the beam structural body **30** (specifically, the first and second beam portions **31** and **32**) is not covered with the hydrogen electrode current collecting layer **20** but is in direct contact with the hydrogen electrode active layer **12** (specifically, the overlapping portions **12***a*). However, as shown in FIG. **4**, the second surface Q**2** may be covered with the hydrogen electrode current collecting layer **20**. Accordingly, a portion of the hydrogen electrode current collecting layer **20** is formed as an inner layer-shaped portion **20***b* between the beam structural body **30** and the hydrogen electrode active layer **12**. This improves the function of gas diffusion from the hydrogen electrode current collecting layer **20** to the hydrogen electrode active layer **12**.

Modification 3

[0093] In the above-described embodiments, the frame body **40** surrounds the side peripheries of the hydrogen electrode current collecting layer **20** and the beam structural body **30**. In addition, the frame body **40** may also surround the side periphery of the hydrogen electrode active layer **12**, and may further surround the side periphery of the electrolyte layer **13**.

Modification 4

[0094] In the above-described embodiments, the support body **11** has the frame body **40**. However, the support body **11** may not have the frame body **40**. In this case, the hydrogen electrode current collecting layer **20** and the beam structural body **30** function as the support body for the electrolytic cell **10**.

Modification 5

[0095] In the above-described embodiments, the hydrogen electrode active layer **12** functions as the cathode, and the oxygen electrode layer **15** functions as the anode. Alternatively, the hydrogen electrode active layer **12** may function as the anode, and the oxygen electrode layer **15** may function as the cathode. In this case, the constituent materials of the hydrogen electrode active layer **12** and the oxygen electrode layer **15** are interchanged, and the raw material gas is passed over the outer surface of the hydrogen electrode active layer **12**. The hydrogen electrode current collecting layer **20** functions as the oxygen electrode current collecting layer, but the configuration and function of the oxygen electrode current collecting layer are the same as those of the hydrogen electrode current collecting layer **20** in the above-described embodiments.

Modification 6

[0096] In the above-described embodiments, the electrolytic cell **10** is an example of an electrochemical cell. However, the electrochemical cell is not limited to an electrolytic cell. “Electrochemical cell” is a general term for elements in which a pair of electrodes are arranged such that an electromotive force is generated from an overall oxidation-reduction reaction in order to convert electrical energy into chemical energy, and elements that convert chemical energy into electrical energy. Therefore, electrochemical cells include fuel cells that use oxide ions or protons as carriers, for example.

REFERENCE SIGNS LIST

[0097] **10** Electrolytic cell [0098] **11** Support body [0099] **12** Hydrogen electrode active layer [0100] **12***a* Overlapping portion [0101] **12***b* Non-overlapping portion [0102] **13** Electrolyte layer [0103] **14** Reaction prevention layer [0104] **15** Oxygen electrode layer [0105] **20** Hydrogen electrode current collecting layer [0106] **30** Beam structural body [0107] **40** Frame body [0108] **50** Through hole [0109] P**1** First main surface of support body [0110] P**2** Second main surface of support body [0111] Q**1** First surface of beam portion [0112] Q**2** Second surface of beam portion

Claims

1. An electrochemical cell comprising: a support body; a first electrode layer disposed on the support body; an electrolyte layer disposed on the first electrode layer; and a second electrode layer disposed on a side opposite to the first electrode layer with respect to the electrolyte layer, wherein the support body has a current collecting layer and a beam portion embedded in the current collecting layer, the first electrode layer includes an overlapping portion and a non-overlapping portion, the overlapping portion overlapping the beam portion in a stacking direction, and the non-overlapping portion not overlapping the beam portion in the stacking direction, and an average particle size of Ni particles contained in the overlapping portion is smaller than an average particle size of Ni particles contained in the non-overlapping portion.

2. The electrochemical cell according to claim 1, wherein a first surface of the beam portion on a side opposite to the first electrode layer is covered with the current collecting layer.

3. The electrochemical cell according to claim 1, wherein a second surface of the beam portion facing the first electrode layer is covered with the current collecting layer.

4. The electrochemical cell according to claim 1, wherein the support body has a frame body, the frame body surrounding a side periphery of the current collecting layer and being coupled to the beam portion.

5. The electrochemical cell according to claim 1, wherein the support body has a beam structural body constituted by a plurality of the beam portions.

6. The electrochemical cell according to claim 5, wherein the beam structural body has lattice structure.

7. The electrochemical cell according to claim 1, wherein a porosity of the overlapping portion is greater than a porosity of the non-overlapping portion.