FUEL CELL SYSTEM AND METHOD OF OPERATING IT

159159

FIELD OF THE INVENTION

The invention relates to a fuel cell system comprising at least one fuel cell having an anode compartment, a membrane, catalyst layers, a cathode compartment comprising a gas diffusion layer, a cooling layer partially covering the gas diffusion layer and a device for generating an airflow, the cooling layer being adapted to split the airflow into fractions, at least one cooling airflow fraction and at least one reaction airflow fraction, the reaction airflow fraction contacting the gas diffusion layer; and a method of operating the fuel cell system.

BACKGROUND OF THE INVENTION

Fuel cell systems of the kind mentioned above are known e.g. from US2010/0119914 A1. Such fuel cell systems allow an optimization of the conditions of cooling and wetting the membrane. However still some difficulties exist with reference to sufficient supply of oxygen for the reaction to the membrane and at the same time keeping the membrane in an optimum status of humidity. Since a high penetration of oxygen through the diffusion layer also leads to a high discharge of water vapour, with the consequence of drying out the membrane and enhancing the electrical resistance thereof.

SUMMARY OF THE INVENTION

The fuel cell system of the invention is characterised in that the gas diffusion layer and the covering percentage of the cooling layer are adapted to adjust the water vapour and oxygen diffusion resistances so as to result in a mass transport limitation of the current density in the fuel cell, which is the short circuit current density, of 2.5 A/cm², preferably of 1.4 A/cm² and more preferably of 0.8 A/cm². The short circuit current density is a measure for the penetrability of oxygen and water vapour through the gas diffusion layer of the cathode compartment. The claimed limits provide for an optimum of the equilibrium between oxygen supply and water vapour discharge.

G00001

According to a known structure of the cooling layer, this is an undulated layer, preferably of metal and coated with a protective coating against corrosion, so lowering the electrical contact resistance between the metal layer and the gas diffusion layer. Such undulated layer allows a mutual adjustment of oxygen supply and cooling characteristics, both by the percentage of covering the gas diffusion layer and by the resulting enlarged cooling surface. This adjustment can advantageously be obtained by the construction that the structure of the undulated layer varies its shape in one and the same layer and/or that the structures of the undulated layers vary their shapes in different fuel cells of the fuel cell system, taking into account the differences in the operation temperature of one fuel cell and/or the complete stack. For easily stacking, the undulated layer can be connected with the bipolar plate.

According to a further embodiment, the cooling layer can be a plate comprising through holes parallel to the layer extension for the cooling airflow fraction and tunnels opened to the gas diffusion layer for the reaction airflow fraction, and serving as the bipolar plate. To simplify the fabrication process and therewith safe costs, the through holes for the cooling airflow fraction can be built from two grooving layers that comprise, in a cross sectional view, semi circles and are brazed together.

For fine tuning the water vapour and oxygen diffusion resistances, the gas diffusion layer has a pore structure suitable for resulting in the above mass transport limitation of the current density.

According to further refinements, the gas diffusion layer can comprise a varying pore structure in one and the same layer and/or the gas diffusion layers can vary their pore structures in different fuel cells of the fuel cell system. In a further preferred embodiment the gas diffusion layer comprises a stack of more than one layer, i.e. gas diffusion partial layers, having different water vapour and oxygen diffusion resistances; in a special form, one of the gas diffusion partial layers is a dense sheet with through holes orthogonal to the sheet extension, e.g. a perforated metal plate.

The fuel cell system of the invention can be operated with an airflow, which is taken from the surrounding atmosphere and which comprises no additional humidification besides the atmospheric moisture, and preferably the pressure difference of the airflow to atmospheric pressure is not more than 10 mbar, even more preferably not more than 3 mbar. Due to the effective cooling, the device for generating the airflow can be small dimensioned, with respect to both, electric consumption and size, thereby minimizing the peripheral losses, the size and the weight of the complete system.

For an effective protection against a drying out of the membrane, especially in case of a high environment temperature, the reaction airflow fraction is not more than 50% of the total airflow and preferably not more than 10%.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and further objects, features and advantages of the present invention will become apparent from the following description of preferred embodiments with reference to the accompanying drawings.

Fig.1 schematically shows a partial cross section through an embodiment of one fuel cell of the system

Fig.2 shows a partial cross section through another embodiment of one fuel cell of the system

Fig.2a shows in a reduced scale a top view of a component of the embodiment of Fig 2

Fig.3 shows a partial cross section through still another embodiment of one fuel cell of the system

DETAILED DESCRIPTION OF PREFERRED EMBOMENTS

One fuel cell 1 of a fuel cell system is depicted in Fig 1. The single cell shown can as well be a double cell or a stack or any other arrangement of a plurality of fuel cells. The fuel cell 1, schematically shown in section, contains an anode

compartment 2, receive as fuel hydrogen, and a cathode compartment 3, receiving atmospheric air, the oxygen of which is exploited. Typically, the compartments 2 and 3 are separated by a membrane 4 comprising catalyst layers on the both sides, not shown in the drawing. As usual, the membrane 4 is covered on both sides by gas diffusion layers 5 and 6. Current collectors not shown and allow the connection of a load.

On the surface 11 of the gas diffusion layer 5, opposite to the membrane 4, a cooling layer 12 is arranged, which at its other side is covered by a bipolar plate 13. The cooling layer 12 consists of an undulated metal sheet, e.g. of titanium covered with a noble metal like ruthenium to avoid corrosion and lower the contact resistance to the gas diffusion layer 5 and to the bipolar plate 13. The cooling layer 12 has a corrugated shape, its section consisting of U-shaped rectangles so as to constitute channels or notches which are open at alternating sides.

The base faces 14 of the cooling layer 12, contacting the gas diffusion layer surface 11 cover the respective parts of the surface 11 in a gas tight manner, thereby reducing the water vapour and oxygen exchange area of the surface 11. By selecting a proper reduction proportion, this exchange and thereby the diffusion volume of oxygen and water vapour are adjusted so that an optimal compromise between oxygen supply which should be high and water vapour escape, which should be low is obtained. The top faces 15 of the cooling layer 12 are bonded to the bipolar plate 13 thus allowing a simple stacking.

An airflow provided by a fan not shown, is split in two fractions by the cooling layer 12. One of the fractions is used as reaction airflow fraction; it flows through channels 20, between two base faces 14 and at one side limited by one top face 15. Channels 20 have direct contact to the surface 11 of the gas diffusion layer 5 and serve for supplying the electrochemical reaction with oxygen. The other airflow fraction flows through channels 21, between two top faces 15 and at one side limited by one base face 14. Thus, the total airflow serves for cooling the fuel cell 1, but the airflow fraction through channels 21, i.e. the cooling airflow fraction, provides no oxygen to the membrane and does not withdraw any water vapour. The phrase "reaction airflow fraction" was used for simplicity; the correct term would be "airflow fraction that serves for

cooling purposes as well as for supplying the reaction gas oxygen the fuel cell 1". The effective cooling properties of the undulated layer with its large surface allows an operation of the fuel cell system without additional humidification besides the atmospheric moisture and furthermore, the average pressure difference between channels 20, 21 and the atmosphere can be as small as 10 mbar or even less.

In the present example, the base faces 14 and the respective channels 21 have different width. The base face 14 have a higher width in the middle of the cell, e.g. the relation of the sectional areas of channels 21 to 20 is 9 to 1, and smaller width in the marginal areas, e.g. the relation of the sectional areas of channels 21 to 20 is 1 to 1, thereby providing for a smaller oxygen and water vapour exchange in the middle and a higher exchange in the marginal areas, also providing for a higher cooling effect in the middle of the cell. Such variations in the base faces 14 allow a compensation of the temperature differences in the membrane. In a fuel cell stack the negative effects of temperature differences between the single cells can be reduced by using different cooling layers 12 in different single cells.

The gas diffusion layers 5 and 6 consist of a conductive carbon microporous material that has a pore structure suitable for resulting in a mass transport limitation of the current density of not more than 2.5A/cm^2. The current density is proportional to the oxygen input and therewith to the water vapour output; the latter has to be limited to keep the membrane in an optimum status of conductivity. The maximum possible current density is the short-circuit current density; by a proper tuning of the features influencing the oxygen input and water vapour output, such as the porosity characteristics of layer 5 and the sizes of faces 14, the resulting operational optimum is obtained, which can be defined by the short-circuit current density.

Similarly as the described variation of the faces 14 or 15, or respectively of channels 21 or 20, it is also possible to have a variation in the porosity through the gas diffusion layer 5, thereby considering the temperature differences across the membrane 4 and adjusting the water vapour and oxygen diffusion resistances. In a fuel cell stack the negative effects of temperature differences

between the single cells can be reduced by using different porosities in the gas diffusion layers 5 in different single cells.

In the embodiment of Fig 2, where the anode compartment is not shown, compared to Fig 1, the gas diffusion layer 5 and the cooling layer 12 are modified. The gas diffusion layer 5 consists of two partial layers 25 and 26. Partial layer 25 has a high and uniform porosity, partial layer 26 is a dense, conductive sheet, e.g. of stainless steel coated with carbon and a polymer, to protect the metal against corrosion and to lower the contact resistances to the adjacent layers 25 and 12. The partial layer 26, as shown in a top view in Fig 2a, has through holes 27 orthogonal to its extension. The adjustment of the water vapour and oxygen diffusion resistance is carried out by the selection of appropriate holes, i.e. diameter, arrangement and number per area thereof. The cooling layer 12, e.g. of stainless steel, has a sinusoidal section, in the depicted example with constant periodicity and thus having equal sizes of channels 20 and 21. For lowering the electrical resistance to the gas diffusion partial layer 26 and to the bipolar plate 13, the stainless steel is coated with appropriate materials. In the depicted example the chosen cooling layer 12 splits the total airflow in only two airflow fractions; other known designs of an undulated sheet, not shown, comprise more than two airflow fractions.

In the embodiment of Fig 3, the gas diffusion layer 5 consists of three gas diffusion partial layers 30, 31 and 32. While the partial layers 30 and 32 have a high porosity, the middle layer 31 is relatively dense and thus obtains the adjusted water vapour and oxygen diffusion resistance. The cooling layer 12 is gastight and also serves as bipolar plate. To simplify the fabrication, cooling layer 12 consists of two grooving layers 33, 34. The first grooving layer 33 comprises, from a top view, one plane surface and on the surface that contacts the second grooving layer 34, parallel tunnels. The second grooving layer 34 comprises parallel tunnels on both surfaces; on the face contacting the first grooving layer 33 and on the face contacting the partial layer 32. When the two grooving layers 33 and 34 are assembled, e.g. by brazing using as soldering agents nickel or argent, the resulting channels 21 are in a cross sectional view through holes or bores parallel to the extension of the cooling layer 12 and

have a diameter of 1.5 mm with 0.5 mm between two channels 21. The face of the second grooving layer 34 contacting the partial layer 32 contains the channels 20, which, in this case, have a diameter of 0.8 mm with 1.2 mm between two channels 20.

To give a specific example, with reference to Fig 2, the cooling layer 12 has a wave length of 3.2 mm and an amplitude p-p of 1.6 mm and consists of stainless steel coated with graphite and polymer. The partial layer 26, also a coated stainless steel, the holes have a diameter of 250 µm, the total open hole fraction of partial layer 26 is 12%. The partial layer 25 and the anode gas diffusion layer 6, not shown in Fig 2, consist of Sigracet ® GDL 34 BC from SGL Carbon. As membrane 4 a Gore™ Primea ® MEA is used with a thickness of 18µm and an equivalent weight of 850 to 950 g/molH^+. In operation, the ambient temperature being 42°C, the stoichiometric rate is 120 and the current density at 0.6V per cell is 0.65 A/cm². The mass transport limitation of the current density is 0.95 A/cm²

REFERENCE LIST

1	fuel cell
2	anode compartment
3	cathode compartment
4	membrane
5	gas diffusion layer
6	gas diffusion layer
11	surface
12	cooling layer
13	bipolar plate
14	base face of 12
15	top face of 12
20	channels
21	channels
25	gas diffusion partial layer
26	gas diffusion partial layer
27	through holes
30	gas diffusion partial layer
31	gas diffusion partial layer
32	gas diffusion partial layer
33	first grooving layer
34	second grooving layer

CLAIMS

1. A fuel cell system comprising at least one fuel cell (1) having an anode compartment (2), a membrane (4), catalyst layers, a cathode compartment (3) comprising a gas diffusion layer (5), a cooling layer (12) partially covering the gas diffusion layer (5) and a device for generating an airflow, the cooling layer (12) being adapted to split the airflow into fractions, at least one cooling airflow fraction and at least one reaction airflow fraction, the reaction airflow fraction contacting the gas diffusion layer (5), characterized in that the gas diffusion layer (5) and the covering percentage of the cooling layer (12) are adapted to adjust the water vapour and oxygen diffusion resistances so as to result in a mass transport limitation of the current density in the fuel cell of 2.5 A/cm².

2. The fuel cell system according to claim 1, characterized in that the gas diffusion layer (5) and the covering percentage of the cooling layer (12) are so adapted that the limit current density is 1.4 A/cm².

3. The fuel cell system according to claim 2, characterized in that the gas diffusion layer (5) and the covering percentage of the cooling layer (12) are so adapted that the limit current density is 0.8 A/cm².

4. The fuel cell system according to any of claims 1 to 3, characterized in that the cooling layer (12) is an undulated layer.

5. The fuel cell system according to claim 4, characterized in that the undulated layer is of metal.

6. The fuel cell system according to claim 5, characterized in that the undulated metal layer is coated with a coating material protecting the metal layer against corrosion and lowering the contact resistance between the metal layer and the gas diffusion layer (5).

7. The fuel cell system according to any of claims 4 to 6, characterized in that the structure of the undulated layer varies its shape in one and the same layer.

8. The fuel cell system according to any of claims 4 to 7, characterized in that the structures of the undulated layers vary their shapes in different fuel cells (1) of the fuel cell system.

9. The fuel cell system according to any of claims 4 to 8, characterized in that the undulated layer is connected with a bipolar plate (13).

10. The fuel cell system according to any of claims 1 to 3, characterized in that the cooling layer (12) comprises through holes parallel to the layer extension for the cooling airflow fraction and tunnels opened to the gas diffusion layer for the reaction airflow fraction.

11. The fuel cell system according to claim 10, characterized in that the cooling layer (12) also serves as bipolar plate (13).

12. The fuel cell system according to claim 11, characterized in that the cooling layer (12) comprises two grooving layers (33, 34), in a cross sectional view comprising half circles that are assembled on top of each other, so as to build the channels (21) for the cooling airflow fraction.

13. The fuel cell system according to any of claims 1 to 12, characterized in that the gas diffusion layer (5) has a pore structure suitable for resulting in the above maximum current density.

14. The fuel cell system according to claim 13, characterized in that the gas diffusion layer (5) comprises a varying pore structure in one and the same layer.

15. The fuel cell system according to claims 13 or 14, characterized in that the gas diffusion layers (5) vary their pore structures in different fuel cells of the fuel cell system.

16. The fuel cell system according to any of claims 1 to 15, characterized in that the gas diffusion layer (5) comprises a stack of more than one layer, i.e. gas diffusion partial layers (25, 26 and 30, 31, 32) having different water vapour and oxygen diffusion resistances.

17. The fuel cell system according to claim 16, characterized in that one of the gas diffusion partial layers (26) is a dense, conductive sheet with through holes (27) orthogonal to the sheet extension.

18. A method of operating the fuel cell system according to any of claims 1 to 17, characterized in that an airflow is used, which is taken from the surrounding atmosphere and which comprises no additional humidification besides the atmospheric moisture.

19. The method according to claim 18, characterized in that the device for generating the airflow generates a pressure difference of the airflow to atmospheric pressure of not more than 10 mbar.

20. The method according to claim 19, characterized in that the generated pressure difference is not more than 3 mbar.

21. The method according to any of claims 18 to 20, characterized in that the airflow is split so that the reaction airflow fraction is not more than 50% of the total airflow.

22. The method according to claim 21, characterized in that the reaction airflow fraction is not more than 10% of the total airflow.