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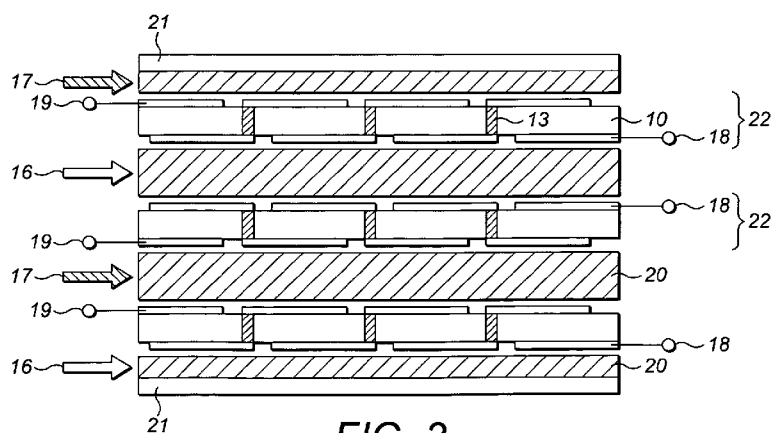


FIG. 3

(57) Abstract: A fuel cell comprising at least two stacked fuel cell boards (22) which each comprise a membrane of substantially gas impervious electrolyte material and at least two electrode pairs wherein the anode and cathode of each said electrode pair are arranged on respective faces of said membrane. An electrode of each pair of electrodes is connected to an electrode of an adjacent pair of electrodes by a through-membrane connection (13) or by an external connection on a Printed Circuit Board, comprising an electrically conductive region of said electrolyte material. A method for forming the through-membrane electrical connections in the electrolyte membrane is also disclosed.

FUEL CELL COMPRISING AT LEAST TWO STACKED PRINTED CIRCUIT BOARDS WITH A PLURALITY OF INTERCONNECTED FUEL CELL UNITS

Technical Field

5 This invention relates to fuel cells, for example solid polymer electrolyte fuel cells. This invention also relates to the use of Printed Circuit Board (PCB) technology in the manufacture of fuel cells of the present invention, the use of corrosion-resistant coatings, and the use of a Shape Memory Alloy (SMA) in low profile valves in fuel cells.

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Background Art

A fuel cell is an electrochemical device which generates electrical energy and heat from an oxidant (e.g. pure oxygen or air) and a fuel (e.g. hydrogen or a hydrogen-containing mixture, or a hydrocarbon or hydrocarbon derivative). Fuel cell technology
15 finds application in portable, mobile and stationary applications, such as power stations, vehicles and laptop computers.

Typically, a cell comprises two electrodes, an anode and a cathode, which are separated by an electrolyte membrane that allows ions (e.g. hydrogen ions) but not
20 free electrons to pass through from one electrode to the other. A catalyst layer on the electrodes accelerates a reaction with the fuel (on the anode electrode) and oxidant (on the cathode electrode) to create or consume the ions and electrons. The electrons freed at the anode form an electrical current, which is used to perform work and then flows to the cathode where the electrons are consumed.

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A single pair of electrodes separated by an electrolyte membrane is called a Membrane Electrode Assembly (MEA). A fuel cell MEA operating under a moderate load produces an output voltage of about 0.7 V, which is too low for many practical considerations. Conventionally, in order to increase this voltage, MEAs are assembled
30 into a stack as shown in Figure 1. Each MEA **1** has a layer of “electrolyte membrane” **1a**, which is an ion-permeable membrane sandwiched between two electrolyte layers, and an anode **2** and a cathode **3** on opposite faces of the electrolyte membrane. Adjacent MEAs can be separated by an electrically conducting bipolar separator plate **4** and hydrogen fuel **5** and oxygen gas **6** flow through the channels provided on

opposed faces of the bipolar plate. End plates 9 are connected to an external circuit via an electrical connection 7, 8. The number of these MEAs in a stack in a fuel cell determines the total voltage, and the surface area of each membrane electrode determines the total current.

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A problem with current fuel cell geometry is that when fuel cells are stacked in this manner, the electrical current flows perpendicular to the face of an MEA. Hence, this stacking requires separator plates to conduct the current from the positive electrode of one cell to the negative electrode of the next. Furthermore, failure of an MEA, for example due to pinhole formation through the membrane electrolyte or short-circuiting of electrodes across the membrane, results in the entire stack needing to be shut down. Yet further, if a single MEA is not performing as well as the others, current will be driven through it, which results in its rapid degradation. If one MEA is destroyed then the whole fuel cell stack becomes unusable.

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In the known arrangement the bipolar plates are commonly made of graphite carbon or stainless steel and must be electrically conductive, gas impervious and incorporate the flow-field channels for the distribution of reactants, and possibly also of coolant, across the faces of the MEA in their surface. Thus, the material composition of the bipolar plates is constrained and the plates are complex and expensive to manufacture. Furthermore, maintaining the correct water content in the electrolyte membrane is essential to optimising its performance. The membrane requires a certain level of moisture to operate and conduct the ionic current efficiently so that the cell current does not drop. Water produced by the cell is removed by the flow of gas along the cathode, or wicked away. Accordingly, corrosion of metallic bipolar plates in the humid environment of the cell is a common problem, limiting the materials from which the bipolar plate can be made. Overheating of the fuel cell stack is a further problem and cooling is necessary. This is usually achieved by the provision of further plates comprising channels to circulate coolant water through the middle of the stack, which is cumbersome and impractical for many applications. Further still, the electrical output of a stack is modulated and regulated by using monolithic power electronics. This is expensive and point failure of these power electronics also leads to failure of the whole fuel cell system.

One known alternative is described in “New SPFC-Technology with Plastics”, by K. Ledjeff and R. Nolte, Proceedings of the First International Symposium on New Materials for Fuel Cell Systems, 1995, p128-134. The authors describe a banded structure of a single electrolyte membrane to generate a high output voltage, without
5 employing stack technology. The electrodes and bipolar plates of a standard construction fuel cell are mounted in a co-planar configuration, with each fuel cell MEA present as a band joined to a second adjacent MEA band. A problem with this approach is that the membrane structure requires careful assembly and sealing of the adjacent bands to avoid mixing of oxidant and fuel.

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The invention is set out in the claims. The construction of a stacked fuel cell is greatly simplified, as plastic or other non-electrically conductive spacers may be used between adjacent MEAs as opposed to complicated and expensive bipolar plates. Because of the layout of the fuel cell of the present invention, there is low risk of fuel
15 mixing with oxygen. Individual MEAs or fuel cell boards in the fuel cell stack may also be incorporated with an independent switch which provides additional control of the fuel cell.

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In the following discussion the invention is described by reference to three embodiments. The description of these embodiments is not to be understood to limit the scope of the present invention and is merely exemplifying the invention.

Brief Description of the Figures

25

Specific embodiments of the invention will now be described by reference to the accompanying Figures in which:

Figure 1 shows a schematic side view of a stacked fuel cell of the known type.

Figure 2 (a) shows a cross-sectional side view of a fuel cell board according to the first embodiment of the present invention.

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Figure 2 (b) shows a perspective view of a fuel cell board according to the first embodiment of the present invention.

Figure 3 shows a sectional side view of a fuel cell comprising a stack of fuel cell boards according to the first embodiment of the present invention.

Figure 4 shows a perspective view of a fuel cell system according to the first embodiment of the present invention.

Figure 5 (a) shows a cross-sectional side view of a spacer with surface channels.

Figure 5 (b) shows a perspective view of a spacer with surface channels.

- 5 Figure 5 (c) shows a plastic spacer viewed from above or below, having an internal conduit provided for a coolant.

Figure 6 shows a partially exploded perspective view to show the internal structure of a section of the fuel cell stack of the first embodiment.

- 10 Figure 7 shows a perspective, partial cut-away view of a fuel cell stack of the second embodiment of the present invention.

Figure 8 shows an exploded view of a section of the fuel cell detailing the MEA layout of the second embodiment of the present invention.

Figure 9 shows an exploded view of the individual layers of the PCB board and MEAs of the second embodiment of the present invention.

- 15 Figures 10 (a) and 10 (b) show a plan view of a current collection and distribution layer of the second embodiment of the present invention.

Figure 11 shows a plan view of a reactant distribution layer of the second embodiment of the present invention.

- 20 Figure 12 shows an exploded view of the individual layers of the PCB board with reactant flow of the second embodiment of the present invention.

Figures 13 (a) and 13 (b) show a cross sectional view of the third embodiment of the present invention.

Figure 13 (c) shows a plan view of the individual layers of a fuel cell board of the third embodiment of the present invention.

- 25 Figure 14 shows the lower half of a reactant channel and illustrates the use of a Shape Memory Alloy (SMA) as a low profile valve.

A first embodiment of the invention can be understood referring to Figure 2 (a) and 2 (b) in which electrode pairs are arranged in a series along either side of a single layer of polymer electrolyte **10**, such as a Nafion™ membrane, to form a membrane or sheet, termed here a fuel cell board **22**. Anodes **11**, separated by gaps **15**, are situated on one face of this membrane and cathodes **12**, separated by gaps **15**, are situated on the other face of this membrane. The anode and cathode respectively of two adjacent electrode pairs may partially overlap. Through-membrane electronic connections **13**

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connect the electrodes across the membrane in the overlapping region and are produced by a homogeneous chemical deposition process described in more detail below. A catalyst layer **14** adjacent to the electrodes encourages the reactions at the electrodes. A fuel **16**, such as hydrogen gas, flows along the face of the fuel cell board **22** supporting the anodes; an oxidant **17**, such as oxygen gas or air, flows along the face of the fuel cell board supporting the cathodes. One electrode at the edge of the upper face and one electrode at another edge of the lower face of a fuel cell board are connected to an external circuit via an electrical connection **18, 19**. In this series arrangement, the surface area of an electrode pair determines the size of the current for a fuel cell board **22**, but the voltage builds up corresponding to the number of electrode pairs on that fuel cell board **22**.

In the preferred embodiment, the thickness of the electrolyte membrane layer **10** is between 1-200 μ m, and preferably between 5-100 μ m. The electrode bands **11, 12** are 1mm – 5cm in width, preferably 2mm-1cm in width. The gaps **15** between the electrode bands are between 0.1mm – 1.5cm wide, preferably between 0.2mm and 1cm wide. The width of the through-membrane electronic connectors **13** is 1 μ m - 2mm, and preferably 10 μ m-1mm.

Figures 3 and 4 show a fuel cell, wherein multiple fuel cell boards **22** are stacked between two endplates **21** in order to provide increased current. Electrically insulating spacers **20** are integrated into the stack between each of the fuel cell boards each comprising an spacer composed of electrically insulating material, which can incorporate a reactant distribution system as well as optionally containing channels or conduits associated with the cooling system and optionally containing a distribution system for delivering or removing water. The spacers **20** may be arranged in any suitable layout, as well as possibly containing channels or conduits associated with the provision of water required for the hydration of the membranes or the extraction of product water, as discussed in more detail below. The size of a single cell (that is, the surface area of a pair of electrodes) determines the size of the current for a fuel cell board. The number of these single cells on a fuel cell board determines the voltage produced. The number of fuel cell boards in a stack determines the size of the total current of the fuel cell stack. Manifolds of any appropriate form (not shown in Figures 3 and 4) supply and collect the reactants respectively at the inlets and outlets

of the cell; and may incorporate further inlets and outlets for the coolant and the hydration/product water.

As there is no requirement for electrical contact between the fuel cell boards in the present invention, the bipolar plate used in current fuel cell designs can be replaced by a simple plastic spacer which is easily manufactured and hence cheap. Similarly, as it is no longer necessary to stack the anode of one fuel cell board next to the cathode of the next, adjacent fuel cell boards may have their anode sides (or cathode sides) facing each other in which case porous spacers **20** can be provided as there is no risk of the gases mixing. This results in a significant increase in packing density of the fuel cell as one gas flow can serve two fuel cell boards, reducing the number of seals, and increasing the power density. Repeat distances (i.e. the thickness of the combined fuel cell board and feed region) may be as low as about 0.2 mm. Hence a far higher volumetric power density of the fuel cell system is achievable. Further, the channels in the surface are easily formed for gas circulation and internal conduits are easily integrated into the spacer, allowing coolant and/or water to circulate and providing a cooling and water distribution system for the stack. Channels provided for the reactant gases and channels or conduits associated with the cooling and/or water distribution system are separate as discussed in more detail below.

The end cathodes **12** and anodes **11** on each fuel cell board are connected to respective first and second output lines **23**, **24** via electrical connections **18**, **19**. The connection between each fuel cell board in the stack and the second output line **24** can be controlled by a switch mechanism **25** such as a field-effect transistor (FET) switch providing power handling and control directly at the cell. Each of these switches can be controlled by individual control lines **26**. For this reason, failure of a fuel cell board is not serious, as each individual fuel cell board can be “switched off” or its loading may be reduced, allowing power handling and control at the cell using cheap low-current switches.

Figures 5 (a) to (c) show in more detail an insulating spacer **20** with channels **27** etched into its surface for the reactants to flow through and one possible layout of an internal cooling channel **28** (shown by dotted lines), which allows a cooling gas or liquid to circulate between the layers of the fuel cell boards. For most efficient

cooling, these channels may be provided in the spacers between every layer, or between multiple layers such as every 2nd, 3rd or 4th fuel cell board layer in the fuel cell stack.

- 5 Alternatively, as shown in Figure 7, cooling may be provided by means of a fan **46** situated at one or more edges of the fuel cell stack, blowing air through the stack in channels. This leads to effective cooling being achieved, as the single channel necessary for reactants allows faster flow of gas through the layers of the stack than a bipolar plate or a further separate plate used for a cooling system. Further, a larger
10 volume of gas may be used, which also improves cooling. Coolant is pumped through the cooling channels to maintain the stack at a desired operating temperature.

Figure 6 shows a partially exploded cross sectional view of the internal structure of a section of the fuel cell stack. Banded MEAs **30** are arranged with the anodes of (in
15 this illustration) vertically adjacent MEAs facing each other and the cathodes of vertically adjacent MEAs also facing each other. Oxygen or air **A** is delivered to the cathodes, while fuel **B**, such as hydrogen, is delivered to the anodes. The porous, electrically non-conductive spacer **31** having gas distribution channels forms a gas distribution layer using ribs **32** of a flexible electrically non-conductive material. The
20 ribs are positioned along the gaps **33** between the bands of electrodes. Each fuel cell board is sealed from the atmosphere with a seal **34** and is attached to an external circuit, or bus bar **35**, for example via an FET switch **36**.

The porous, electrically non-conductive spacer **31** may be made of a rigid plastics
25 material. Preferably the ribs **32** and seals **34** are made of polydimethylsiloxane (PDMS), or a similar flexible material that provides a tight seal.

In order to fabricate the fuel cell stack, multiple bands of electrodes are, for example, screen printed onto both the upper and lower face of a membrane, the anodes and
30 cathodes being in the form of bands running in the same direction as, and connected in pairs by, through-membrane connections. The through-membrane electronic connections are created in bands along the electrolyte membrane, as described below. Each membrane is coated with a plurality of electrodes in this way forms a fuel cell

board. When complete, these fuel cell boards are stacked alternately with insulating spacers formed of moulded plastics.

In order to deposit through-membrane electrical conductors, it is necessary to chemically deposit a metal or other electrically conductive material within the membrane. This material must be chemically stable within the membrane under fuel cell operating conditions, and may typically be a precious metal (e.g. Pt, Au, Ru, Ir, Rh, Pd) or an oxide of a precious metal. The general approach involves placing the membrane in a mask and exposing it to a precursor to the electrically conductive material. The precursor is allowed to diffuse into the membrane, following which the membrane is exposed to a reactant species which reacts with the precursor so as to cause the deposition of particles within the membrane material. This reactant species may be an acid or base, it may be an oxidant or reductant, or it may destabilize the complex containing the precursor. This second step 'fixes' the position of the through membrane conductor. The fixing step may also be electrochemical – two electrodes may be placed on either side of the membrane, and a current passed so as to induce reduction or oxidation of the precursor at the point at which the through-membrane electrical conductors are to be placed. The particles produced in the "fixing step" may or may not be electrically conducting. A post-treatment involving a further chemical species or treatment step may optionally be used to render those particles deposited in the membrane conductive or to improve the conductivity of the particles deposited (for instance, a chemical reductant may be applied to reduce a non-conducting precursor particle to a conducting state). The precursor introduction-fixing-post-treatment process may be repeated more than once to improve the conductivity of the through membrane connection.

A preferred method used to deposit conductive bands in the membrane will now be described. The membrane is placed into a mask before immersing it in a solution or allowing a solution to flow over it. The solution contains a metal complex, for example a gold- or platinum-complex (e.g. $\text{Pt}(\text{NH}_3)_4\text{Cl}_2$ or AuCl_2), in a high concentration. The metal ions / complex diffuse(s) into the membrane, in the regions where it is not protected by the mask. The metal-complex solution is then replaced by a solution containing a strong reductant in a high concentration (e.g. NaBH_4 , or HCOOH). The reducing agent reduces the metal ions to their metallic state, leaving

metal particles deposited in the membrane. These metal particles aggregate and are able to conduct electrical current.

Impregnation of the precious metal complex or salt into the membrane is dependent upon the concentration of the ions in the solution next to the membrane material, the diffusion coefficient of the molecule in the membrane material and the thickness of the membrane material. The temperature of the impregnation affects the diffusion coefficient of the ion which increases with increasing temperature.

- 10 The characteristic diffusion time for a distance L is: $\tau = L^2 / D$, where D is the diffusion coefficient of the molecule in the ion exchange polymer. Therefore, assuming a diffusion coefficient of $10^{-6} \text{ cm}^2 \text{ s}^{-1}$, a membrane thickness of $200 \text{ }\mu\text{m}$, and allowing the metal complex solution to diffuse in from both sides of the membrane, yields a characteristic time of 100 seconds. The membrane would normally be left for
- 15 a multiple of the characteristic time in order to allow the system to reach equilibrium, therefore it would take approximately 250 seconds for the metal ions to impregnate the membrane material.

- There is significant benefit in using a thinner membrane, as halving the membrane thickness quarters the characteristic time τ . Using the thin Nafion™ membranes which are common in modern fuel cell systems gives a characteristic time of around 20 seconds. Diffusion of the subsequent reactant requires an equivalent length of time to that required for the precious metal precursor, resulting in the cycle of impregnation, reduction and washing taking between 2 and 3 minutes. This process
- 25 may be repeated several times in order to produce improved through-membrane contact.

- To avoid the creation of very diffuse through-membrane connections, the metal complex may alternatively be reduced with an electron beam or a visible or UV light beam directed onto the electrolyte membrane, in the location where the through-membrane connection is required, resulting in a very well defined and precisely located through-membrane connection. This method has the added benefit that a mask is not necessary, as one could immerse the entire electrolyte membrane in the metal-complex solution, and selectively create the conducting through-connections.
- 30

Another alternative is to allow a composition containing a reducing agent, which is activated by visible or UV light, and the metal complex to diffuse into the electrolyte membrane. Thus when visible or UV light is shone onto the membrane, the metal ions
5 are reduced. Precise, well-defined through-membrane connections can be formed either by placing the membrane into a mask before directing visible or UV light onto it, or without using a mask, by beam geometry.

Because electronic connectors are integrated into the membrane without
10 compromising the integrity of the membrane, there is low risk of fuel mixing with oxygen.

In a second embodiment of the present invention, a fuel cell stack **40** is provided. A perspective, partial cut-away view is shown in Figure 7 and is described in more
15 detail in reference to Figure 8. Figure 8 shows an exploded view of a section of the fuel cell detailing the MEA layout. Each fuel cell board **41** of the fuel cell stack comprises a plurality of polymer electrolyte membranes **50a**, **50b**, **50c**, etc., each of these membranes supporting an anode **51** and a cathode **52**. Alternatively, each fuel cell board may comprise one single polymer electrolyte membranes, which supports a
20 plurality of anodes and cathodes. This does not alter the mode of operation described below.

For clarity, the construction of the fuel cell boards and the fuel cell stack is described herein in terms of 'horizontal' and 'vertical' planes, in accordance with the
25 embodiments illustrated in the Figures. However, these terms are used for clarity only, and are not limiting on the scope of the invention. It will be clear to the reader that the fuel cell boards can be arranged in any plane, not just the horizontal plane. Further, the term 'directly opposite' is not limited to the electrodes being in register.

30 The anode lies on one face of the polymer electrolyte and lies directly opposite a cathode on the opposite face of the same electrolyte membrane layer. Together, the anode, cathode and electrolyte layer form an MEA **59**. In one (horizontal) plane, anodes on one face of a polymer electrolyte layer **50a** are adjacent to cathodes on the same face of the adjacent electrolyte layer **50b**. That is, in a horizontal plane, the

sequence of anode and cathode positioning in adjacent MEAs alternates for each MEA. If one single polymer electrolyte membrane is used, the sequence of anodes and cathodes along each face alternates, with the respective cathodes and anodes on the opposite face also alternating.

5

Thus, each fuel cell board comprises an alternating sequence of anodes and cathodes on its two opposing faces. Anodes and cathodes on each face of the electrolyte membrane in a horizontal plane are separated by gaps **55**. In the corresponding vertical plane, anodes on one MEA **54a** face anodes of the adjacent MEA **54b**, and cathodes on one MEA **54b** face cathodes of the adjacent MEA **54c**. Thus when a plurality of fuel cell boards are stacked together, pairs of adjacent anodes and pairs of adjacent cathodes alternate in the plane vertical to the singly alternating anodes and cathodes.

10

As shown in Figure 9, between each planar layer of MEAs **59**, is a PCB board **60** that is made up of three individual layers. This PCB board comprises a first current collection and distribution layer **61**, a reactant distribution layer **62**, and a second current collection and distribution layer **63**. These three layers are bonded together to form a single PCB board **60**. By virtue of the current collection and distribution layer, current does not cross the electrolyte layer, but moves laterally from anode to cathode parallel to the horizontal plane of electrodes. Consequently, no through-membrane connections are necessary for the current to flow.

20

The individual layers of the PCB boards, i.e. the first and second current collection and distribution layers and the reactant distribution layers, are adhered together into a solid structure using an epoxy-containing glass fibre composite. The PCBs may be fabricated from pre-impregnated composite fibres, such that they contain an amount of the material used to bond the individual layers together and to bond the MEAs to the PCBs, or a pre-impregnated composite fibre mask may be applied to the PCBs. The MEAs may be laser bonded onto a PCB, thereby creating a fuel cell board **41**. To create the fuel cell stack, a plurality of boards are laminated together. The gaps between the electrodes, and the sealing achieved in these gaps by the epoxy resin, prevent the fuel and oxidant gas flows from mixing, and prevent the fuel coming into contact with the cathode and the oxidant coming into contact with the anode, as

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described in more detail below. As this lamination step results in a solid structure, with good contact between the individual layers, the usually necessary heavy end boards become redundant. Accordingly, a monolithic, light, and completely sealed structure is produced. A simple PCB can be used as the end board.

5

When assembled into a fuel cell stack, an anode of a first MEA on a first fuel cell board lies vertically directly opposite an anode of a second MEA on a second fuel cell board, wherein the first and second fuel cell board are horizontally adjacent in the fuel cell stack. Similarly, a cathode of a first MEA, on a first fuel cell board, lies
10 vertically directly opposite a cathode of a second MEA on a second fuel cell board, wherein the first and second fuel cell board are horizontally adjacent in the fuel cell stack.

The structure of a current collection and distribution layer **61** is shown in more detail
15 in Figure 9. Figure 9 shows a section of the layer **61**, corresponding to two adjacent MEAs **59**. Referring to Figure 9, the layer **61** consists of a frame **65**, with panels of electrical distribution tracks **66** that link the anode **59a** of one MEA to the cathode **59b** of the vertically adjacent MEA. By virtue of the electrical distribution tracks of the current collection and distribution layer, the MEAs on each individual fuel cell
20 board are connected in electrical series. As indicated by the arrows in Figure 9, the anode **59a** and cathode **59b** are located on the underside of the MEA shown. The upper side of the MEA carries the corresponding cathode **59c** and anode **59d**, respectively.

Figures 10a and 10b show a plan view of a current collection and distribution layer **61**
25 for a planar layer of 16 MEAs. In Figure 10b (and at the left hand side end of the layer shown in Figure 10a), the plan view of a first and second current collection and distribution layer bonded together is shown. That is, the tracks **66** of the first and second current collection and distribution layer are visible. Figure 10a (with the
30 exception of the left hand side end of the layer) shows a plan view of only one current collection and distribution layer. Only a single layer of tracks is visible.

Holes **67** may be provided at regular intervals in the frame **65** to form part of an integral cooling system. These holes may form vertical cooling channels **42**, as

shown in Figure 7. One or more fans **46** may be included to force the air into the cooling system.

5 The current collection and distribution layer **61** also includes holes **68** forming part of vertical reactant channels **43** (shown in Figure 7), at the two opposed edges of the current distribution layer, adjacent to the narrow ends of the electrode bands.

10 These vertical channels **42**, **43** are formed when the fuel cell boards **41** are stacked. In the embodiment shown in Figure 7, the vertical fuel inlet and outlet channels run close to one edge **44** of the layer, and the vertical oxidant inlet and outlet channels run close to the opposite edge **45** of the layer. In the embodiment shown in Figures 7-12, there are two vertical fuel and oxidant channels per electrode. These vertical reactant channels connect with the channels provided in the reactant distribution layer.

15 The structure of a reactant distribution layer **62** is shown in detail in Figures 9 and 11, where a section of this layer **62**, corresponding to two adjacent MEA **59** electrode pairs, is shown. This section is repeated, such that the number of reactant distribution channels corresponds to the number of MEAs or electrode pairs in the plane. The reactant distribution layer **62** comprises a frame **70**, with two channels **71**, **72**, each
20 forming a planar reactant distribution loop, and holes located close to two opposed edges of the frame, at the narrow ends of the distribution loops, forming vertical reactant channels.

The holes along one edge of the frame **70** are sequentially inlet **73a**, **74a** and outlet **73b**, **74b** channels for a reactant, for example, a fuel, such as hydrogen and the holes
25 along the opposite edge of the frame are sequentially inlet **75a**, **76a** and outlet **75b**, **76b** channels for a reactant, for example, an oxidant, such as oxygen or air. This is shown in Figures 9 and 12. The holes **73**, **74**, **75**, **76** on the reactant distribution layer **62** line up with the holes **68** in the current collection and distribution layer **61** to create
30 the vertical reactant distribution channels **43** shown in Figure 7.

In the reactant distribution layer shown in Figure 12, a reactant, for example a fuel, flows through the vertical channels **80** on one edge of the frame **70**. When the location of the vertical channel corresponds to the location between two anodes **59a**,

59a', the vertical channel is connected to the reactant distribution loop **72** of the reactant distribution layer **62**. Accordingly, the fuel will flow from the vertical inlet channel **73a**, into the entrance **81** of the distribution loop **72** of the reactant distribution layer, and along the faces of the anodes **59a**, **59a'** in the planes directly above and below the reactant distribution layer. The exit **82** of the distribution loop connects with the vertical fuel outlet channel **73b**. The vertical channels **76a**, **76b** at the opposite edge of the frame, for example carrying the oxidant, are holes in the frame **70** that are not connected to the distribution loop **72**.

In the planar adjacent MEA, the electrodes facing the distribution channel **71** are both cathodes **59b**, **59b'**. Accordingly, the layout of the distribution channel **71** associated with these electrodes is reversed: In the reactant distribution layer shown in Figures 9, 11 and 12, the oxidant flows through the vertical channels **90** on the right hand edge of the frame. When the location of the vertical channel corresponds to the location in the reactant distribution layer **62** between two cathodes **59b**, **59b'**, the vertical channel is connected to the reactant distribution loop **71** of the reactant distribution layer **62**. Accordingly, the oxidant flows from the vertical inlet channel **75a**, into the entrance **91** of the distribution loop of the reactant distribution layer, and along the faces of the cathodes in the planes directly above and below the reactant distribution layer. The exit **92** of the distribution loop is adjacent to the entrance **91** of the distribution loop, and is connected to the vertical fuel outlet channel **75b** that is adjacent to the vertical inlet channel **75a**. The vertical channels **74a**, **74b** at the opposite edge of the frame, carrying the fuel, are not connected to the distribution loop **71**.

In the adjacent fuel cell boards of the fuel cell stack, the sequence of anodes and cathodes is reversed. The reactant distribution channel layout thus alternates in sequence both in the horizontal and vertical plane, in order to supply vertically positioned pairs of anodes and cathodes with fuel and oxidant, respectively.

As in the first embodiment of the invention, the polymer electrolyte layer may be any electrolyte membrane, which allows ions (e.g. hydrogen ions) but not free electrons to pass through from one electrode to the other, for example, a sheet of NafionTM membrane. The same preferred dimensions as described above for the first embodiment apply.

The reactant gas flows are kept separated by virtue of seals in the gaps between the electrodes of adjacent MEAs. These seals are achieved by impregnating the PCB boards with epoxy compounds, which are activated to create a tight seal upon lamination and bonding with the MEA. If appropriate, further sealing may be incorporated by using seals made of PDMS, for example at the outer edges of a fuel cell board.

The vertical channels are connected to one or more reactant manifolds along the two opposed edges of the stack, which supplies and collects the reactants.

The frame of the reactant distribution layer may also comprise a series of holes **100** at regular intervals in the frame to form part of an integral cooling system, as described below.

The holes **67**, **100** provided for the cooling system may be positioned between every electrode in a horizontal plane, or between every second, third, fourth, fifth, sixth, seventh, eighth, ninth or tenth electrode, depending on the cooling required. The holes need not be at regular intervals between electrodes, but can be at any suitable interval.

In a third embodiment of the present invention, each fuel cell board **41** of the fuel cell stack comprises one or a plurality of polymer electrolyte membranes arranged in a plane. In a first alternative embodiment a) for each fuel cell board a series of individual membranes is aligned in a plane, with an anode on one face of the membrane and a cathode on the opposite side of the membrane. In a second alternative embodiment b) a single membrane is provided for each fuel cell board, with a series of anodes on one face of the membrane and a series of cathodes on the opposite side of the membrane. In both embodiments a) and b), all the anodes are positioned on one face of the one or more polymer electrolyte membranes in a horizontal plane, and all the cathodes are positioned on the opposite face of the one or more polymer electrolyte membranes in a horizontal plane. As in the second embodiment, anodes and cathodes lie directly opposite each other.

As in the first embodiment, in the third embodiment the fuel cell boards are stacked so that the anode-side faces of two adjacent fuel cell boards face each other, and the cathode-side faces of two adjacent fuel cell boards face each other. In this manner, the fuel can be delivered to all the anodes on two adjacent fuel cell boards, and the oxidant can be delivered to all the cathodes on two adjacent fuel cell boards, in a simple manner.

As in the second embodiment, in the third embodiment the MEAs are bonded onto a PCB board made of three separate layers, to form a fuel cell board. In the fuel cell stack, each planar series of MEAs is located between two PCB boards. Reactant delivery to the electrodes is achieved by the reactant distribution layer of the PCB board, as described for the second embodiment. Thus, the electrically insulating spacer of the first embodiment (by reference to Figures 3 and 4, each spacer **20**) is replaced by a PCB layer.

15

As for the second embodiment, in the third embodiment, heavy end plates are not necessary, as the fuel cell boards are laminated together into a solid structure. A simple PCB can be used instead of the heavy end board.

In embodiment a) of the third embodiment, in which each fuel cell board comprises a series of individual membranes, the electrical connections between anodes and cathodes are made either through the gaps between the membranes, as holes can easily be machined into the PCB boards, or by externally connecting the current collection layer of the PCB board of the anode side to the current distribution layer of the PCB board of the cathode side.

25

In embodiment b) of the third embodiment, in which a single membrane is provided for each fuel cell board, the electrical connections between anodes and cathodes are made either by through-membrane connections, as described for embodiment 1, or by externally connecting the current collection layer of the PCB board of the anode side to the current distribution layer of the PCB board of the cathode side.

30

The PCB reactant distribution layer is described in more detail with reference to the second embodiment of this invention. However, due to the different layout of anodes and cathodes in the third embodiment, the current collection and distribution layers

are not required when the electrical connection is made via through-membrane connections or when electrical connections are made through the PCB board. When the electrical connection is made by externally connecting the PCB boards of the anode side to the PCB boards of the cathode side, the PCB boards facing the anodes will have a first and a second current collection layer, separated by a reactant distribution layer and the PCB boards facing the cathodes will have a first and a second current distribution layer, separated by a reactant distribution layer. The connections are made between the anode of a first MEA and the cathode of a second MEA, between the anode of a second MEA and the cathode of a third MEA, and so forth, depending on the number of electrode pairs on the fuel cell board.

Figure 13 (a) shows two layers of a fuel cell stack, comprising an MEA **110**, PCB material **111**, an electrically conducting layer **112** that conducts the current from the anode of a first cell to the cathode of the next cell, and reactant distribution channels **113** to carry the reactants to the electrodes.

Figure 13 (b) shows an alternative layout.

Figure 13 (c) shows an extract of the fuel cell structure, with one set of fuel cell electrodes sandwiched between two sets of three separate boards. The individual subsections are laminated together. Four fuel cell electrodes **120** are configured in electrical series. Adjacent to the cathode side is a lower cathode contact board **121** and an upper anode contact board **122**. The contact boards have slots cut into them so that reactant from the inlet channel can flow to the outlet channel. The boards carry conducting bars **123**, **124** that carry the current laterally. In Figure 13 (c) the cathode board is shown with the conductor layer facing up, whereas in reality the conductors would face towards the electrodes **120**. Adjacent to the lower cathode contact board **121** is an inner air distribution layer **125**. This layer has sets of inlet and outlet channels **127** for the air (oxygen), and holes for the hydrogen inlet and outlet channels **128**. Each channel flows to the corresponding reactant plenum. Adjacent to the upper anode contact board **122** is an inner hydrogen distribution layer **126**, comprising hydrogen inlet and outlet channels **129** and air inlet and outlet channels **130**. Adjacent to the inner air distribution layer **125** is an upper cathode contact board **131** and Adjacent to the inner hydrogen distribution layer **126** is a lower anode contact layer **132**. The contacts on the lower side of the lower cathode contact board **121** are

designed to connect to the connectors of the upper anode contact board **122**, placing the MEAs **120** in electrical series.

As in the first embodiment of the invention, the polymer electrolyte layer may be any electrolyte membrane that allows ions (e.g. hydrogen ions) but not free electrons to pass through from one electrode to the other, for example, a sheet of NafionTM membrane, and the same preferred dimensions apply, with the proviso that the membrane may be provided in individual sections, rather than in one complete piece.

PCB technology (or other similar technology) is used to manufacture elements of the fuel cell stack of the second and third embodiment. This enables the elements to be manufactured in large quantities and at low cost. For example, multiple flow field boards can be manufactured at the same time, by using thin laminate boards which are stacked and then simultaneously routed. Individually routed boards are then stacked and laminated together.

PCBs for the present invention are produced in the known way. Insulating layers may be made of dielectric substrates such as FR-1, FR-2, FR-3, FR-4, FR-5, FR-6, CEM-1, CEM-2, CEM-3, CEM-4, CEM-5, polytetrafluoroethylene, and G-10, which are laminated together with an epoxy resin prepreg. In order to yield conductive areas, a thin layer of copper is either applied to the whole insulating substrate and etched away using a mask to retain the desired conductive pattern, or applied by electroplating.

Each individual layer of the PCB board is 30µm-2mm thick, preferably 50 µm-1mm thick, more preferably 0.1mm-0.8mm thick, most preferably about 0.4mm thick. Each PCB board is thus 90µm-6mm thick, preferably 150 µm-3mm thick, more preferably 0.3mm-2.4cm thick, most preferably about 1.2cm thick. The electrode layer is 0.1mm-1mm thick, preferably 0.3-0.6mm thick, more preferably 0.4mm thick. Thus the cell pitch is preferably 1.6mm thick (1.2+0.4mm), thus allowing 16 cells per inch.

30

For the first, second and third embodiment of the present invention, the electrode bands are 1mm – 5cm in width, preferably 5mm-15mm in width, more preferably about 1cm in width. The size of the gaps between the electrode bands is dependent on

whether they accommodate cooling channels. The gaps between the electrode bands with a cooling channel are between 1mm – 1.5cm wide, preferably between 2mm and 1,2cm wide, more preferably between 5mm and 1cm wide. The gaps between the electrode bands without a cooling channel are between 0.5mm – 1cm wide, preferably
5 between 2mm and 8mm wide, more preferably between 3mm and 6mm wide.

For the first, second and third embodiment of the present invention, a catalyst layer is preferably provided on the electrodes. This layer may be made of suitable catalytic material for the reactions of interest, as is commonly understood by a researcher
10 skilled in the art of producing fuel cells. For example, the catalyst layer may be composed of platinum nanoparticles deposited on carbon and bound with an proton conducting polymer (e.g. NafionTM), as described in "PEM Fuel Cell Electrocatalysts and Catalyst Layers Fundamentals and Applications", JiuJun Zhang (Ed.), 1st Edition., 2008, XXII, 1137 p. 489 illus., Springer-Verlag London, ISBN: 978-1-
15 84800-935-6.

A gas diffusion layer may be included adjacent to the catalyst layer. The gas diffusion layer may be fabricated or deposited in any appropriate manner as will be familiar to the skilled reader. For example, the gas diffusion layer in a typical fuel
20 cell is composed of carbon in one of a number of forms mixed with a number of binders and additives to modify the wetting characteristics of the layers. Typically the gas diffusion layer adjacent to the catalyst layer is composed of a microporous layer of carbon powder bound with PolyTetraFluoroEthylene (PTFE) (this layer has very small pores). Adjacent to this microporous layer is a further backing layer, typically
25 composed of carbon fibers – either woven into a cloth, or bound together in some form of non-woven material, such as a paper. This layer has pores of a larger size. The combination of these two layers provides a gradation in pore size in moving from the gas-channel to the catalyst layer. Sometimes rather than two discrete layers, the microporous layer and the porous backing layer interpenetrate.

30

Typically the thickness of the gas diffusion layer is around 100-1000 μm . In commonly used modern fuel cells, the choice of carbon as the major constituent of the gas diffusion layer is dictated by the further constraint that electrical current must be conducted from the catalyst layer to the ribs of the bipolar plate. Most other materials

that might be used are either not sufficiently corrosion resistant (many other metals), or are too expensive (gold, platinum etc.)

5 In the design of the current invention, the gas diffusion layer may be composed of the same materials i.e. carbon powder and/or fibers bound together with a suitable binder and treated with a suitable chemical to modify its hydrophilicity. However, because transport to electrons in a direction normal to the surface of the electrode is not required, the gas diffusion layer may alternatively be composed of non electrically conducting materials which nonetheless have suitable properties. The exact nature and
10 electrical conducting properties are dictated by the electrical conductivity requirements of the surface layer – because current must be conducted along the surface of the MEA, requiring a high enough value of the electrical conductivity so that ohmic loss (surface current · layer resistance) is small (i.e. < 10-20 mV).

15 Examples of material out of which the gas diffusion layer can be composed are porous forms of the following: inorganic oxides (Al_2O_3 , SiO_2); plastics: (ptfe, poly ethylene, poly sulfones, etc); other inorganic materials: nitrides, carbides, phosphates, sulphates etc. In some cases, e.g. for thick catalyst layers, the catalyst layer may provide sufficient electrical conduction itself – in this case the gas diffusion layer does not
20 need to be electrically conducting and may even be omitted. In other cases it may be necessary to have some of the current carried through the gas diffusion layer, in which case it would need to be composed (at least partially) from carbon or other electrically conducting material. In all cases, the gas diffusion layer can be made to be quite thin, for example, less than 100 μm , more preferably less than 25 μm . A thinner gas
25 diffusion layer enhances transport of reactants to and from the catalyst layer.

Under typical operating conditions, it is necessary to provide a cooling mechanism to prevent the fuel cell from overheating. Cooling plates are used in some known fuel cells and can be incorporated into the fuel cell stacks of the present invention.
30 However, the thickness of these plates limits the density of the fuel cell. Cooling of the fuel cell stacks of the first, second and third embodiment of the invention may be effected by inclusion of one or more of cooling plates, cooling channels and/or heat pipes. Further, the PCB boards of the second and third embodiments may further incorporate a coolant channel.

In the second and third embodiments of the present invention, integral cooling of the fuel cell stack is simple due to PCB technology (holes). Air or water cooling, or heat pipes can be used. For example, fans for air cooling may be provided, pushing air
5 into a plenum, which forces air into, for example, vertical channels running through the fuel cell stack. These cooling channels are the result of horizontally stacking the boards with holes in their frames, as described above. Heat pipes may be used in combination with, or in place of, the cooling channels.

10 Heat pipes are described in detail in "An introduction to heat pipes: modeling, testing, and applications", G. P. Peterson, Wiley, New York, 1994, ISBN 047130512X. A heat pipe is a sealed hollow tube made of a material with high thermal conductivity at both ends, filled with a fraction of a percent by volume of a working fluid (or
15 coolant), forming a closed-loop capillary recirculation system. Heat pipes operate when there is a temperature difference between the two ends of the pipe, by employing evaporative cooling to transfer thermal energy from one end of the pipe to the other by the evaporation and condensation of a working fluid or coolant. Alternatively, flat, planar heat pipes may be used.

20 Each fuel cell board of the first, second and third embodiment of the present invention is connected via its first cathode and its last anode to an external circuit. These electrical connections are fabricated by known means. The switching mechanism, such as an FET switch, and possibly a voltage measuring apparatus of any appropriate
25 known type, are incorporated into the fuel cell board. The voltage measuring apparatus allows quick and simple monitoring of the voltage output of each fuel cell board when it is either connected or disconnected from the stack bus-bar. This voltage measurement is then used to adjust the load pattern of the fuel cell boards, as described below. The switch is located between the electrical connection of an electrode and the stack bus bar and the voltage measuring apparatus is connected to
30 the first cathode and the last anode of each fuel cell board. Individual control lines are used to operate each of the switches.

In operation, the fuel cell is enclosed in a housing and is sealed from the atmosphere. Reactants are fed into the fuel cell channels through sealed connections. Seals may,

for example, be made of PDMS. In particular, fuel (e.g. H₂) and oxidant (e.g. O₂) are fed into appropriate channels of the fuel cell stack, with fuel being supplied to the anodes and oxidant to the cathodes. The electrical current thus formed can be taken directly or the output of the fuel cell board can be modulated utilising the
5 aforementioned switch. Modulating the output of the fuel cell board may result in a significantly improved performance when the cell is operating on reformat or methanol (in a Direct Methanol Fuel Cell) or other fuels which result in poisoning of the fuel cell over time.

10 A constant power output of the stack may be achieved in a variety of ways. For example, all fuel cell boards may be loaded at all times. Alternatively, the fuel cell boards may be divided into groups and these groups may be “switched on” in turn in a synchronous manner (i.e. switching occurs at a defined time for all fuel cell boards). The fuel cell boards may also be switched in an asynchronous or quasi-asynchronous
15 manner – i.e. each fuel cell board is connected and disconnected to the load for a defined period and frequency individually specified for each fuel cell board. By switching the fuel cell boards so that they are only connected to the load for a proportion of the time according to a duty cycle, the output power of the stack can be continuously modified. For example, if over a given sample period of time only 50%
20 of the fuel cell boards are connected to the load, then the output power of the fuel cell stack will be similarly reduced. The manner in which this 50% is achieved may be brought about in a multitude of ways – for example half of the fuel cell boards may be disconnected from the load and half connected for the entire period; alternatively all fuel cell boards may be connected to the load, but each connected for only half of the
25 sample period. Alternatively again, half of the fuel cell boards may be connected to the load for one quarter of the sample period, and the other half for three quarters of the sample period etc. The choice of the specific scheme or duty cycle used may depend on the performance of individual fuel cell boards, the need to avoid localized heating or ‘hot spots’, the need to avoid flooding of cathode sites with product water,
30 the need to prevent dehydration of the membrane, or the need to counteract poisoning of the electrodes. It will be noted that the duty cycle may be predetermined or may be controlled in real time based on monitored performance of the fuel cell, for example in a closed feedback loop with the voltage measuring apparatus described above. Part-time use of fuel cell boards may also improve efficiency as one can achieve

optimum load conditions and power conversion for each individual fuel cell board rather than for the fuel cell stack which is a limitation of current designs. By including additional switching and filtering components on the fuel cell boards, a smoothly varying output, for example a sinusoidal wave, may be obtained, in addition
5 to simple “changeovers” or steps from one potential to another.

In the case of failure of a fuel cell board, the failed fuel cell board may be switched out altogether. This may also be performed in advance of the failure on the basis of diagnostics or predictive models.

10

Each fuel cell board can carry its own electronic circuitry, with each module feeding the power into an electrical bus. That is, each board contains its own power electronics and controller. The latter monitors the performance of the fuel cell electrodes, local humidity and temperature. It can also control the shape memory alloy
15 (SMA) valves to throttle the flow of reactant to the electrodes on that board, as described in more detail below. Thus the power electronics can be put directly onto each horizontal board. In this manner, the status of each electrode can be monitored for degradation. This information gives feedback to enable the electronics to be modulated so a particular board of electrodes can be used less, thereby slowing the
20 degradation process, or by completely shutting down a board of electrodes. This control enables the protection of underperforming boards, thereby increasing the longevity of the entire fuel cell stack.

A further benefit of having electronics directly on each board is that they can each be
25 configured to convey power in a different way. One example is to use the fuel cell to work multiphase electric motors and provide current to different coils at different times, thereby increasing the efficiency, increasing control of performance and increasing control at low torque. Each of the horizontal boards comprising the series of electrodes would drive one phase.

30

If, for example, an electrode is underperforming or has become faulty, it is not only possible to switch out the affected board using the individual electronics, but it is also possible to stop the fuel or oxidant supply to specific electrodes. In such a case, it is preferable to particularly stop the flow of hydrogen through cells that have been shut

off. Stopping the gas flow is difficult, due to the low profile gas inlet. However, it has been found that the gas flow through the inlet may be blocked by using a Shape Memory Alloy (SMA) as a low profile valve. A Shape Memory Alloy is a metal alloy that deforms in response to the application of temperature (e.g. heat) or an electromagnetic field (e.g. application of current), and returns to its original shape after the application of e.g. heat or current ceases. This is described in reference to Figure 14, which shows three views of the lower half of a reactant channel (the top half is not shown for clarity). Figure 14(a) shows the reactant-inlet valve open. The arrow indicates where reactant flow occurs. The SMA may be either a foil which distorts on heating to close off the channel, as shown in Figure 14(b), or it may be in the form of a wire attached to a flap, where the wire changes shape upon heating, thereby drawing an object, for example a flap, which closes the channel, as shown in Figure 14(c). SMAs that may be used in the present invention include nickel-titanium, copper-aluminium-nickel, copper-zinc-aluminium, and iron-manganese-silicon alloys. Preferably the SMA used is a nickel-titanium alloy.

The fuel cell of the present invention comprises at least two fuel cell boards, each fuel cell board may comprise either

- a) one membrane of substantially gas impervious electrolyte material supporting at least two anodes on a first face of the membrane and two cathodes on a second face of the membrane; or
- b) at least two membranes of substantially gas impervious electrolyte material, each supporting one anode on a first face of the membrane and one cathode on a second face of the membrane.

Preferably, the fuel cell comprises at least three fuel cell boards. More preferably the fuel cell comprises between four and fifty fuel cell boards, for example, eight, ten, sixteen or twenty fuel cell boards.

Preferably each fuel cell board comprises either

- a) one membrane of substantially gas impervious electrolyte material supporting at least three anodes on a first face of the membrane and three cathodes on a second face of the membrane; or

b) at least three membranes of substantially gas impervious electrolyte material, each supporting one anode on a first face of the membrane and one cathode on a second face of the membrane.

5 More preferably each fuel cell board comprises either

a) one membrane of substantially gas impervious electrolyte material supporting at least three anodes on a first face of the membrane and three cathodes on a second face of the membrane; for example, at least four anodes on a first face of the membrane and four cathodes on a second face of the membrane, for example, at least ten anodes
10 on a first face of the membrane and ten cathodes on a second face of the membrane, for example, at least sixteen anodes on a first face of the membrane and sixteen cathodes on a second face of the membrane, for example, at least twenty anodes on a first face of the membrane and twenty cathodes on a second face of the membrane;

or

15 b) at least three membranes of substantially gas impervious electrolyte material, each supporting one anode on a first face of the membrane and one cathode on a second face of the membrane; for example, at least four membranes of substantially gas impervious electrolyte material, each supporting one anode on a first face of the membrane and one cathode on a second face of the membrane, for example, at least
20 ten membranes of substantially gas impervious electrolyte material, each supporting one anode on a first face of the membrane and one cathode on a second face of the membrane, for example, at least sixteen membranes of substantially gas impervious electrolyte material, each supporting one anode on a first face of the membrane and one cathode on a second face of the membrane, for example, at least twenty
25 membranes of substantially gas impervious electrolyte material, each supporting one anode on a first face of the membrane and one cathode on a second face of the membrane.

When the current is conducted by means of a current collection and distribution layer,
30 the surface area of an electrode on a membrane, or on the at least two membranes, should substantially correspond to the dimensions of a reactant distribution channel on a reactant distribution layer, and to the size of a panel of electrical distribution tracks on the current collection and distribution layer, or to the size of a panel on the current collection layer and the current distribution layer, depending on the specific

embodiment. Preferably, the surface area of an electrode will be such that as much of its surface area as possible is in contact with a reactant distribution channel.

The flexible characteristics of the present invention make it suitable for use in applications which require a high degree of resilience and fault tolerance, along with a high power density. For instance it may be used within a stationary power supply system which is required to work for long periods without manual intervention, or for applications which require operation under degraded conditions due to partial damage.

Because of the ability to monitor the fuel cell for degradation and switch out a whole plate containing a faulty electrode, electrodes can be built to a lower tolerance than possible for known fuel cells. This in turn lowers the cost of manufacturing the fuel cells of the present invention compared to known fuel cells.

Thus all embodiments of the present invention have the advantages of easily separating the fuel and air flows, resulting in a simpler, cheaper system, and the ability to monitor the operating status (e.g. degradation) of each element of the fuel cell stack and to independently control elements of the fuel cell stack.

It will be appreciated that aspects of the invention can be interchanged or juxtaposed as appropriate. The fuel used is not restricted to hydrogen, but may be any suitable fuel. For example, the new geometry fuel cell stack described herein is also applicable to methanol used in Direct Methanol fuel cells. The electrodes deposited on the membrane need not be straight bands, but may be any appropriate shape e.g. they may be curved, or their width may vary with position. Similarly, any of the cooling or gas diffusion channels need not be straight, and may for example be of a serpentine design. Also, the first embodiment of the invention is not limited to having only one cooling or gas diffusion channel in each spacer.

The membrane material is not limited to Nafion™, and any suitable ion-exchange electrolyte, such as a fluoropolymer sulfonic acid membrane may be employed.

In the first embodiment, the spacer between the stacked sheets may be plastic, but any suitable electrically insulating material may be used. Channels in the surface on either face of the spacer need not line up or be of equal dimensions.

- 5 The switch mechanism for controlling the electronics of the fuel cell board is not restricted to FET-type switches; any suitable switch, such as a junction transistor, may be used.

- 10 Whereas gold or platinum metal complex containing solutions are preferred for the fabrication of the through-membrane electronic connectors, any suitable precious-metal or suitable compound may be used. The catalyst is preferably Pt or a Pt-alloy and is optionally supported onto carbon, but is not limited to these examples.

- 15 A further aspect of the present invention relates to a corrosion resistant coating that may be applied in the first, second and third embodiments of the invention. This coating is used to passivate the copper surface of the PCB and stop the copper layer from corroding. This is important because the conditions in a fuel cell are very acidic and oxidizing, under which conditions copper corrodes. If the copper is oxidized from Cu^0 to Cu^{2+} , this leads to the disintegration of the copper surface of the PCB,
20 and the consequently, the fuel cell.

- Accordingly, a coating is needed that prevents H_2O from reaching the copper surface of the PCB, but still allows good electrical conduction. The copper surface of the PCB may for example be the current collection and/or distribution layer or 'plate'.
25 The coating must be stable and must not undergo any electrochemical or chemical degradation within the fuel cell environment. At the same time the material must be hard-wearing, as it must not become detached from the copper surface. It is important that the coating does not have any cracks or holes in it that would allow water ingress.
- 30 Three different approaches to achieve these effects are detailed below. A combination of two or all three approaches is also considered herein, in order to achieve the best performance.

In a first approach, the copper layer is coated with an ink or paint composed of electrically conductive particles. These particles must be passive and must not undergo significant oxidative or acidic corrosion.

- 5 Examples of suitable particles include carbon (in the form of graphite particles) or electrically conductive titanium suboxide, for example, Ti_4O_7 , obtainable commercially as Ebonex®. Other materials may also be considered, for instance $Ti_{0.9}Nb_{0.1}O_2$, which may be more resistant to corrosion, doped tin oxide (doped with antimony, fluorine, or indium to improve conductivity), or an ink composed of
- 10 electrically conductive polymer particles. Examples of suitable polymers include polyaniline, polypyrrole, polythiophene and poly(3,4-ethylenedioxythiophene) (PEDOT).

Carbon inks for coating copper tracks for PCBs are known and commercially

15 available.

An ink is obtained by mixing the conductive compound, for example graphite, or the titanium, or tin compounds described above, with a solvent and a polymeric binder to form a slurry, or ink. The concentration of particles used in the ink is typically a

20 volume fraction of greater than 20 vol %, for example, between 20 vol % and 70 vol %, for example, between 20 vol % and 60 vol %. This volume fraction is selected in order to enable good particle-particle contact, for conductivity, and also to contain sufficient binder to create a stable coating layer. The particles make up the

25 conductive phase of the coating layer when the ink is coated onto a substrate. The polymeric binder may be any suitable polymer, for example, polyethylene, or an epoxide polymer, such as a thermosetting epoxy polymer.

Inks containing conductive polymers are used in the electronics industry for displays, although they have not previously been used in fuel cell current collection plates. The

30 term 'current collection plate' is used to encompass a range of components in the fuel cell which may also be called bipolar plate, monopolar or unipolar current collector, gas diffusion layer, gas transport layer etc.

The other materials exemplified above are not known in the field of inks or passivating coating layers for PCBs and fuel cell current collection and/or distribution layers or plates.

5 A second approach involves direct electrodeposition of an electrically conducting polymer onto the copper surface of the PCB. There are many possible polymers which can be considered including polyaniline, polypyrrole, polythiophene and poly(3,4-ethylenedioxythiophene) (PEDOT).

10 Stabilisation of the polymer to electrochemical oxidation and reduction and improvement in electrical conductivity may be achieved by incorporating a polymeric anionically charged polymer such as poly(styrenesulfonate) or Nafion®.

The use of such electrically conducting polymers has been considered within fuel
15 cells before, predominantly within the catalyst layer. The use of these materials as corrosion protection layers in general has been disclosed in the literature, but there has been no disclosure regarding the use of these materials as corrosion protection layers in fuel cells.

20 The Applicant has examined the use of fluorinated polymer derivatives as an electrically conductive corrosion resistant layer and discovered that fluorinating the polymer by adding a pendant pefluoro alkyl chain increases the surface energy of the resulting coating and makes it water repellent. This reduces the likelihood of corrosion. Higher surface energies also lead to better wear resistance due to decreased
25 friction.

In a preferred embodiment, the conducting polymer is chosen such that it has a high fluorine content, for example, wherein the polymer comprises a perfluorinated alkyl chain.

30

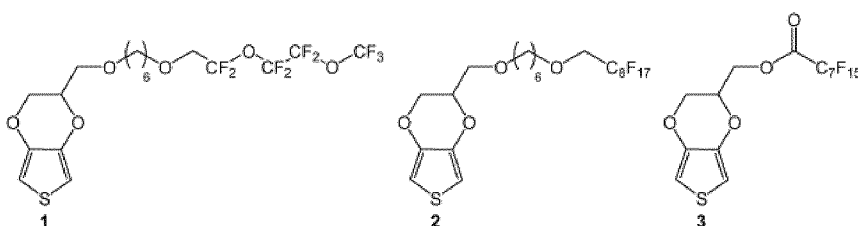
PEDOT has previously been considered as a passivating layer because of its stability and high electrical conductivity. The Applicant has examined fluorinated PEDOT as

a passivating layer directly electrodeposited onto a fuel cell current collection and/or distribution layer or plate.

A method of producing the EDOT monomer and its polymerisation are described in

5 *Benedetto et al., Electrochimica Acta, Vol 53, 11, 20 April 2008, 3779-3788.*

Examples of EDOT monomers are shown below:



10 A third approach involves the direct attachment of an organic group to the copper surface to reduce water adsorption and increase the surface energy of the surface. A number of different approaches are possible including the reaction of a silyl-chloride with a hydrophobic backbone, a silyl alkoxide with a hydrophobic backbone, or a perfluorinated alkoxy silane, with the surface. Example materials are shown in Table 1 below. An example of this approach, used for organic electronics purposes, is given

15 in *Lee, Relationship between the chemical nature of silanes and device performance of polymer light emitting diodes, Thin Solid Films, Vol 515, 4, 5 December 2006, 2705-2708.*

Table 1

(1) 1H,1H,2H,2H-Perfluorooctyltriethoxysilane	(2) Trichloro (1H,1H,2H,2H-perfluorooctyl) silane	(3) Trichloro(3,3,3-trifluoropropyl) silane	(4) Trimethoxy-methyl(3,3,3-trifluoropropyl) silane
(5) (Pentafluorophenyl) triethoxysilane			

20

This approach has not been previously disclosed for use with fuel cell current collection and/or distribution layers or plates.

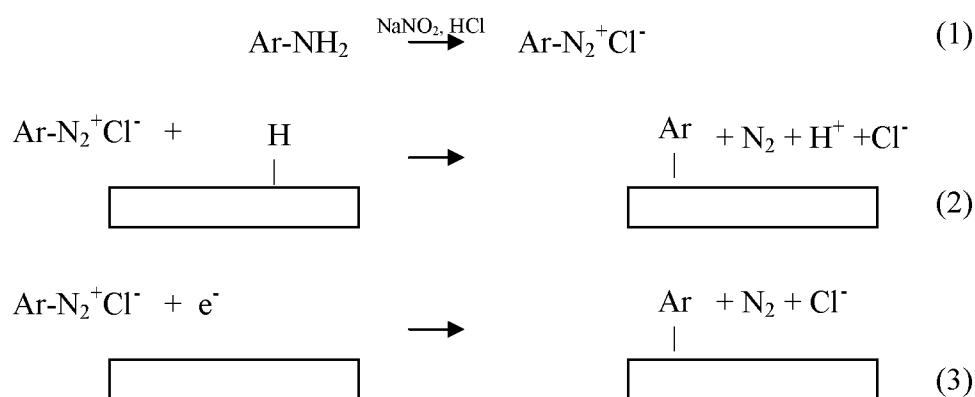
For example, one possibility in this approach is to use the formation of a diazo compound from a functionalised aniline followed by reaction of the diazo compound with the substrate or electrochemical reduction to lead to direct electrochemical deposition of the material.

5

A Scheme showing the production of diazo derivative followed by derivatisation of a surface either by direct reduction due to surface hydrogen (1) or electrochemical reduction (2), or direct electrochemical deposition (3) is outlined below:

10

Scheme



15

Other approaches for producing the diazo salt are possible, and there are a range of possible reaction conditions.

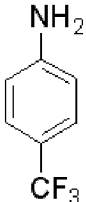
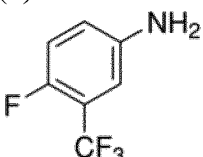
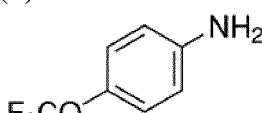
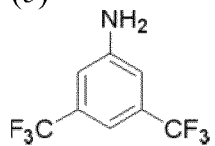
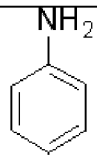
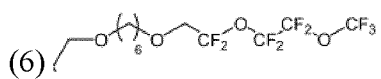
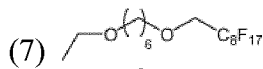
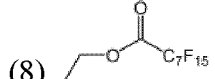
20

A chemical process has been disclosed for fuel cell catalyst layers in which the penta fluoro aryl group is bonded to a carbon surface by *Xu et al., Electrochem. Solid-State Lett., Vol 8, 10, pA492-A494, (2005)*. However, there is no disclosure on the application of this process to fuel cell current collection and/or distribution layers or plates.

25

Examples of perfluoro aniline derivatives for use with the diazo approach are shown in Table 2 below. Other examples include aniline with the same pendant chains as those shown for the EDOT monomers (1)-(3), above.

Table 2

	(2)  4-(Trifluoromethyl)aniline	(3)  4-Fluoro-3-(trifluoromethyl)aniline	(4)  4-(Trifluoromethoxy)aniline
(5)  3,5-Bis(trifluoromethyl)aniline	 Derivatised on the aryl ring by any of the groups on the right		(6)  (7)  (8) 

5 In this approach, it is also possible to use a chemical process to coat the copper surface with perfluoro derivatised aryl groups on silicon. Whilst this process has been described in *Stewart et al., J. Am. Chem. Soc. 126 (1): 370*, the application of this approach to fuel cell current collector and/or distribution layers or plates has not been described.

10 An electrochemical process described in *Lyskawa and Bélanger, Chem. Mater., 2006, 18 (20), 4755–4763*, has been used to derivatise both metal and carbon, but has not been applied to fuel cell current collector and/or distribution layers or plates.

15 There is no disclosure of the deposition of fluorinated materials using the electrochemical approach, as is described by the present invention.

20 The electrochemical approach devised by the Applicant to deposit the perfluoro group on a surface is different from normal approaches, because of the instability of the intermediate azo compound.

The following are examples of use that are intended to illustrate the invention, and not intended to limit the scope of the claims:

5 (a) A conductive carbon ink is screen printed onto the copper electrode surface and dried in an oven at 120°C. Examples of suitable inks are

1. Carbon conductive ink XZ302-1 manufactured by Sun Chemical Corporation.
2. Carbon conductive ink SD 2843HAL manufactured by Peters Lackwerke GmbH.

10

(b) Synthesis of compound (1) of the EDOT monomers was undertaken as described in *Benedetto et al.*. A 10 mM solution of (1) in acetonitrile containing 0.1 M Bu₄N PF₆ was electropolymerised onto the copper surface by sweeping the electrochemical potential to a value of 1.1 V.

15

(c) (Pentafluorophenyl) triethoxysilane was dissolved in 0.5 mol dm⁻³ HCl to a concentration of 10 mmol dm⁻³. NaNO₃ was added to this solution in an ice bath to a concentration of 20 mmol dm⁻³. A copper surface was placed in this solution and held at a potential of -0.2 V vs. a saturated calomel electrode for
20 five minutes.

20

(d) A copper surface was cleaned and coated with tridecafluoro-1,1,2,2-tetrahydrooctyl-1-siloxane. The silane solution was prepared by dissolving 1H,1H,2H,2H-Perfluorooctyltriethoxysilane in 100 ml of butanol/H₂O (95/5) solution containing a few drops of acetic acid at a concentration of 0.2 wt.%.
25 The solution was stirred for 60 minutes to hydrolyze silane materials and then the cleaned copper surface was dip coated with the hydrolysed silane solution. After dip coating, the silane treated copper substrates were washed with toluene several times to get a layer of silane. The silane coated substrate was
30 dried at 160 °C for 5 minutes to remove residual solvents after toluene washing.

30

The following examples relate to combinations of coating techniques, to achieve more than one corrosion resistant coating layer:

(e) The method of example (a) is followed by the method of example (b), in which electropolymerisation occurs on the surface produced in (a), rather than on the “copper surface” referred to in example (b).

5

(f) The method of example (a) is followed by the method of example (c), in which (pentafluorophenyl) triethoxysilane is coated onto the surface produced in (a), rather than on the “copper surface” referred to in example (c).

10

(g) The method of example (a) is followed by the method of example (d), in which tridecafluoro-1,1,2,2-tetrahydrooctyl-1-siloxane is coated onto the surface produced in (a), rather than on the “copper surface” referred to in example (d).

15

(h) The method of example (b) is followed by the method of example (c), in which (pentafluorophenyl) triethoxysilane is coated onto the surface produced in (b), rather than on the “copper surface” referred to in example (c).

Claims

1. A fuel cell comprising
 - a) at least two fuel cell boards, each fuel cell board comprising at
5 least one ion permeable membrane and a plurality of anodes and a plurality of
cathodes, wherein the anodes and the cathodes are arranged in pairs such that
each anode is located on the opposite side of a membrane to a cathode;
 - b) gas flow channels arranged between adjacent fuel cell boards
for supplying an oxidisable gas to each anode and a reducible gas to each
10 cathode; and
 - c) electrical connectors for connecting adjacent pairs of anodes
and cathodes on the same fuel cell board;
wherein each fuel cell board is arranged so that the anodes and cathodes on
one board are located opposite to anodes and cathodes (respectively) on an
15 adjacent board.
2. A fuel cell as claimed in claim 1, wherein the electrical connectors consist of
 - i) a through-membrane connection comprising at least one electrically
conductive region located in the membrane, or
 - 20 ii) an external connection provided by a printed circuit board,
3. A fuel cell as claimed in claim 1 or claim 2, wherein the fuel cell comprises at
least three fuel cell boards.
- 25 4. A fuel cell as claimed in any one of claims 1 to 3, wherein each fuel cell board
comprises
 - a) one ion permeable membrane supporting at least two anodes on a
first face of the membrane and two cathodes on a second face of the
membrane; or
 - 30 b) at least two ion permeable membranes, each supporting one anode
on a first face of the membrane and one cathode on a second face of the
membrane.

5. A fuel cell as claimed in any one of claims 1 to 4, wherein each fuel cell board comprises
- a) one ion permeable membrane supporting at least three anodes on a first face of the membrane and at least three cathodes on a second face of the membrane; or
 - b) at least three ion permeable membranes, each supporting one anode on a first face of the membrane and one cathode on a second face of the membrane.
6. A fuel cell as claimed in any one of claims 1 to 5, wherein connected electrodes of adjacent pairs of electrodes partially overlap.
7. A fuel cell as claimed in any one of claims 1 to 5, wherein the membrane of the fuel cell board is bonded to a multilayer Printed Circuit Board.
8. A fuel cell as claimed in claim 7, wherein the Printed Circuit Board (PCB) comprises
- a) a first current collection and distribution layer, a reactant distribution layer, and a second current collection and distribution layer,
 - b) a first and a second current collection layer, separated by a reactant distribution layer, or
 - c) first and a second current distribution layer, separated by a reactant distribution layer,
- wherein the individual layers are bonded together to form a single Printed Circuit Board.
9. A fuel cell as claimed in any one of claims 1 – 8, wherein each layer of each PCB comprises holes that, on stacking of the fuel cell boards, line up to form a conduit through the fuel cell, said conduit running substantially perpendicular to the planar surfaces of the fuel cell boards.
10. A fuel cell as claimed in claim 9, each layer of each PCB comprises a plurality of holes that, on stacking of the fuel cell boards, line up to form a plurality of conduits through the fuel cell.

11. A fuel cell as claimed in claim 10, wherein the conduit acts as an inlet or outlet channel for a reactant.
- 5 12. A fuel cell as claimed in claim 10, wherein the conduit acts as an inlet or outlet for a coolant.
13. A multilayer Printed Circuit Board wherein the Printed Circuit Board comprises
- 10 a) a first current collection and distribution layer, a reactant distribution layer, and a second current collection and distribution layer,
- b) a first and a second current collection layer, separated by a reactant distribution layer, or
- c) a first and a second current distribution layer, separated by a reactant
- 15 distribution layer,
- wherein the individual layers are bonded together to form a single Printed Circuit Board.
14. A multilayer Printed Circuit Board, as claimed in claim 13, wherein the
- 20 current collection and distribution layer comprises a frame that carries panels of electrical distribution tracks to link the anode of a first pair of electrodes to the cathode of an adjacent pair of electrodes, in order to connect the electrodes on a fuel cell board in electrical series.
- 25 15. A multilayer Printed Circuit Board, as claimed in claim 13 or 14, wherein the current collection and distribution layer comprises holes capable of forming a conduit that runs substantially perpendicular to the planar surfaces of the fuel cell boards when a plurality of fuel cell boards are stacked together.
- 30 16. A multilayer Printed Circuit Board, as claimed in any one of claims 13 - 15, wherein the reactant distribution layer comprises a frame defining a plurality of reactant distribution channels, and holes capable of forming a conduit that runs substantially perpendicular to the planar surfaces of the fuel cell boards when a plurality of fuel cell boards are stacked together.

17. A multilayer Printed Circuit Board, as claimed in any one of claims 13 - 16, wherein either
- 5 a) one membrane of substantially gas impervious electrolyte material supporting at least two anodes on a first face of the membrane and two cathodes on a second face of the membrane; or
- b) at least two membranes of substantially gas impervious electrolyte material, each supporting one anode on a first face of the membrane and one cathode on a second face of the membrane;
- 10 is bonded to the Printed Circuit Board, and
- wherein one anode a first face of the membrane and one cathode on the second face of the membrane are located substantially opposite one another and form a pair of electrodes.
- 15 18. A multilayer Printed Circuit Board, as claimed in any one of claims 12 - 17, wherein the membrane is, or the at least two membranes are, bonded to the Printed Circuit Board such that the surface area of each pair of electrodes corresponds to a panel of electrical distribution tracks on the current collection and distribution layer, and a reactant distribution channel.
- 20 19. A fuel cell, as claimed in any of claims 1-12, wherein a reactant is delivered to the electrodes by means of a conduit formed by stacking the fuel cell boards, wherein the conduit runs substantially perpendicular to the planar surfaces of the fuel cell boards.
- 25 20. A fuel cell, as claimed in claim 19, wherein said conduit is connected to a reactant distribution channel on a reactant distribution layer of a fuel cell board.
- 30 21. A fuel cell, as claimed in claim 19 or 20, wherein for each pair of electrodes on a fuel cell board, there is provided a first conduit that serves to provide a first reactant to a first end of a first reactant distribution channel, a second conduit that serves to accept said first reactant from a second end of said first reactant distribution channel, a third conduit that serves to provide a second

reactant to a first end of a second reactant distribution channel, and a fourth conduit that serves to accept said second reactant from a second end of said second reactant distribution channel.

- 5 22. A fuel cell, as claimed in claim 21, wherein said first conduit provides a first reactant to a first end of at least two first reactant distribution channels, said second conduit accepts said first reactant from a second end of said at least two first reactant distribution channels, said third conduit provides a second reactant to a first end of at least two second reactant distribution channels, and
10 said fourth conduit accepts said second reactant from a second end of said at least two second reactant distribution channels.
- 15 23. A fuel cell, as claimed in any one of claims 1-12 and 19-22, wherein each fuel cell board is connected to an electronic circuit to produce an electrical output.
24. A fuel cell as claimed in claim 23, wherein each of said fuel cell boards connected to said electronic circuit is individually switchable.
- 20 25. A fuel cell comprising at least two fuel cell boards, each individually switchable by providing at least one switch on each of said fuel cell boards.
26. A fuel cell as claimed in any one of claims 1-12 or 19-22, wherein a catalyst layer is provided adjacent to the electrodes.
- 25 27. A fuel cell as claimed in claim 26, wherein the catalyst layer is electrically conductive and comprises an outer layer adjacent a reactant conduit.
28. A fuel cell as claimed in claim 26 or 27, wherein a gas diffusion layer is provided as an outer layer, adjacent on one side to a reactant conduit and on
30 the other to the catalyst layer.
29. A fuel cell as claimed in claim 28, wherein the gas diffusion layer is composed of one or more of an electrically conductive or non-conductive material.

30. An electrically insulating spacer for separating adjacent stacked fuel cell boards.
31. A spacer as claimed in claim 30, having integrated coolant conduits
- 5 32. A spacer as claimed in claim 30 or 31, shaped to assist the distribution of reactants.
- 10 33. A spacer as claimed in any one of claims 30-32, further comprising water supply or extraction conduits.
- 15 34. A fuel cell as claimed in any one of claims 1-12 or 19-29, wherein adjacent fuel cell boards in the stack are separated by an insulating spacer as claimed in any of claims 30-33.
- 20 35. A fuel cell as claimed in any one of claims 1-12 or 19-29, wherein on each face of each fuel cell board, the sequence of anodes and cathodes alternates such that each anode, except the anode on edge of the fuel cell board, lies between two cathodes, and each cathode, except the cathode on edge of the fuel cell board, lies between two anodes, and the fuel cell boards in the fuel cell are stacked such that the anodes of two adjacent fuel cell boards lie substantially opposite each other, and the cathodes of two adjacent fuel cell boards lie substantially opposite each other.
- 25 36. A fuel cell as claimed in claim 35, wherein a first reactant is delivered to a pair of anodes on a first and second adjacent fuel cell boards by means of a single first reactant distribution channel on one reactant distribution layer, and a second reactant is delivered to a pair of cathodes on said first and second adjacent fuel cell boards by means of a single second reactant distribution
- 30 channel on said reactant distribution layer.
37. A fuel cell as claimed in any one of claims 1-12 or 19-29, wherein each face of each fuel cell board carries either only anodes or only cathodes, and the fuel cell boards in the fuel cell are arranged so that the anodes of two adjacent fuel

cell boards lie substantially opposite each other, and the cathodes of two adjacent fuel cell boards lie substantially opposite each other.

38. A method of forming a through membrane electrical connection in a
5 membrane composed of electrolyte material comprising exposing a selected area of said membrane to a solution containing a precursor of an electrically conductive material followed by at least one of a reactant species containing solution, or by electrochemical reduction or by electrochemical oxidation of a selected area of said membrane.
- 10 39. A method as claimed in claim 38, comprising a further step of treating the membrane to achieve or increase conductivity of the electrical connection.
40. A method as claimed in claims 38 or 39, wherein said solution containing a
15 precursor of an electrically conductive material contains a gold, platinum, ruthenium, iridium, rhodium or palladium complex.
41. A method of controlling the power output profile of a fuel cell having at least
20 two fuel cell boards comprising selectively switching one or more fuel cell board.
42. A method as claimed in claim 41 comprising the step of switching fuel cell boards according to a duty cycle.
- 25 43. A method of fabricating a fuel cell comprising the steps of stacking a plurality of fuel cell boards each having at least one through membrane electrical connection interleaved with insulating spacers.
- 30 44. A method of fabricating a fuel cell comprising manufacturing and machining individual layers of Printed Circuit Board, laminating these together into a multi-layer Printed Circuit Board, and bonding at least one membrane supporting at least one anode and at least one cathode to said multi-layer Printed Circuit Board.

45. A method as claimed in claim 44, wherein the multi-layer Printed Circuit Board comprises
- a) a first current collection and distribution layer, a reactant distribution layer, and a second current collection and distribution layer,
 - 5 b) a first and a second current collection layer, separated by a reactant distribution layer, or
 - c) a first and a second current distribution layer, separated by a reactant distribution layer.
- 10 46. A method as claimed in claim 44 or 45, wherein the method comprises bonding
- a) one membrane supporting at least two anodes and at least two cathodes; or
 - b) at least two membranes, each membrane supporting one anode and one
 - 15 cathode;
- to said multi-layer Printed Circuit Board.
47. A method as claimed in claim 46, wherein the method comprises bonding
- c) one membrane supporting at least three anodes and at least three
 - 20 cathodes; or
 - d) at least three membranes, each supporting one anode and one cathode;
- to said multi-layer Printed Circuit Board.
48. The use of a shape memory alloy as a valve to close the reactant inlet to a
- 25 reactant distribution channel on the reactant distribution layer of a fuel cell board.
49. A fuel cell as claimed in any one of claims 1-12, and 19-37, comprising a
- 30 shape memory alloy capable of controlling or preventing the entry of gas into a gas flow channel in the fuel cell.
50. A multilayer PCB, as claimed in any one of claims 16-18, comprising a shape memory alloy capable of controlling or preventing the entry of gas into a reactant distribution channel.

51. A method of depositing a corrosion resistant layer onto the surface of a current collection and/or distribution layer of a fuel cell.
- 5
52. The method of claim 51, wherein a corrosion resistant layer is deposited onto a current collection and/or distribution layer of a fuel cell as claimed in any one of claims 7-12, 34-37, or is deposited onto a Printed Circuit Board according to claims any one of claims 13-18.
- 10
53. The method of any one of claims 43-47, wherein the method additionally comprises the step of depositing a corrosion resistant layer onto the surface of a current collection and/or distribution layer of the fuel cell.
- 15
54. The method of any one of claims 51-53, wherein the corrosion resistant layer is formed by applying an ink comprising a conducting polymer or a conductive metal oxide, or carbon conductive ink, to the surface of a current collection and/or distribution layer.
- 20
55. The method of claim 54, wherein the conducting polymer is selected from polyaniline, polypyrrole, polythiophene and poly(3,4-ethylenedioxythiophene) (PEDOT).
- 25
56. The method of claim 54, wherein the conductive metal oxide is selected from Ti_4O_7 ; $\text{Ti}_{0.9}\text{Nb}_{0.1}\text{O}_2$; or tin oxide doped with antimony, fluorine, or indium.
- 30
57. The method of any one of claims 51-53, wherein a conductive polymer is electrodeposited onto the surface of a current collection and/or distribution layer, followed by thermal annealing to melt the film to form a corrosion resistant layer.
58. The method of claim 57, wherein the conductive polymer has a perfluorinated substituent, especially where that perfluorinated substituent is a perfluorinated aliphatic chain, or contains perfluorinated aliphatic chains.

59. The method of claim 58, wherein the monomers forming the conductive polymer comprise a perfluorinated alkyl chain.
- 5 60. The method of any one of claims 51-53, wherein the surface of a current collection and/or distribution layer undergoes direct derivatisation of its surface, utilising a silane or diazo reagent to form a corrosion resistant layer.
61. The method of claim 60, wherein the silane or diazo reagent comprises
10 perfluoro properties.
62. The method of claim 61, wherein the silane or diazo reagent comprises a pefluorinated benzene, or an aryl ring further comprising a perfluorinated alkyl chain.
- 15 63. The method of any one of claims 51-53, wherein a combination of corrosion resistant layers is applied to the surface of a current collection and/or distribution layer, the method comprising the step of applying an ink to the surface of a current collection and/or distribution layer according to claim 54,
20 and/or electrodepositing a conductive polymer onto the surface of a current collection and/or distribution layer according to claim 54, 55, or 57, and/or direct derivatisation of the surface of a current collection and/or distribution layer, with a silane or diazo reagent, according to claim 60.
- 25 64. A corrosion resistant coating comprising a conductive polymer, a conductive metal oxide, a carbon conductive ink, or a perfluorinated silane or diazo reagent.
- 30 65. The corrosion resistant coating of claim 64, wherein the conductive polymer is selected from polyaniline, polypyrrole, polythiophene and poly(3,4-ethylenedioxythiophene) (PEDOT), and the conductive metal oxide is selected from Ti_4O_7 ; $Ti_{0.9}Nb_{0.1}O_2$; or tin oxide doped with antimony, fluorine, or indium, and the silane or diazo compound is selected from 1H,1H,2H,2H-Perfluorooctyltriethoxysilane, Trichloro (1H,1H,2H,2H-perfluorooctyl) silane,

Trichloro(3,3,3-trifluoropropyl) silane, Trimethoxy-methyl(3,3,3-trifluoropropyl) silane, or (Pentafluorophenyl) triethoxysilane.

- 5 66. The corrosion resistant coating of claim 64 or 65, wherein the coating is applied to a fuel cell current collection and/or distribution layer.
67. A multilayer Printed Circuit Board, as claimed in any one of claims 13-18, wherein the current collection layers comprise a corrosion resistant coating according to any one of claims 64-66.
- 10 68. The invention substantially as described herein and in Figures 2 to 14.

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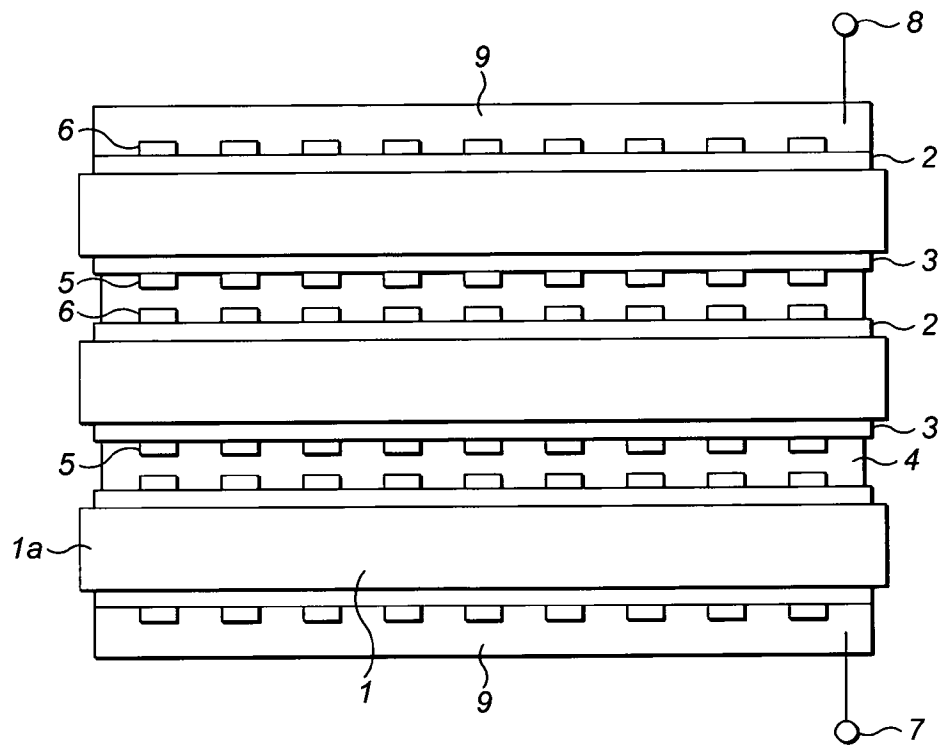


FIG. 1

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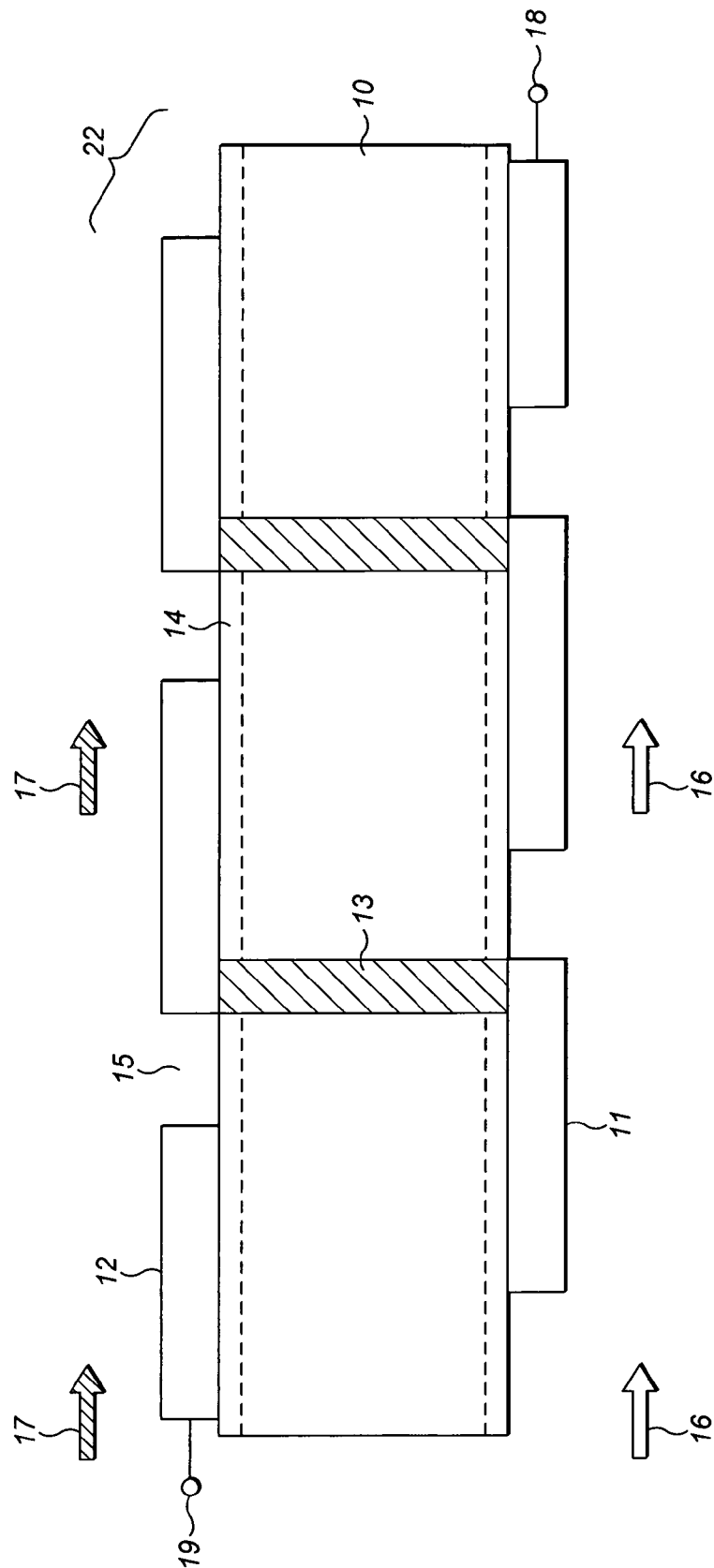


FIG. 2a

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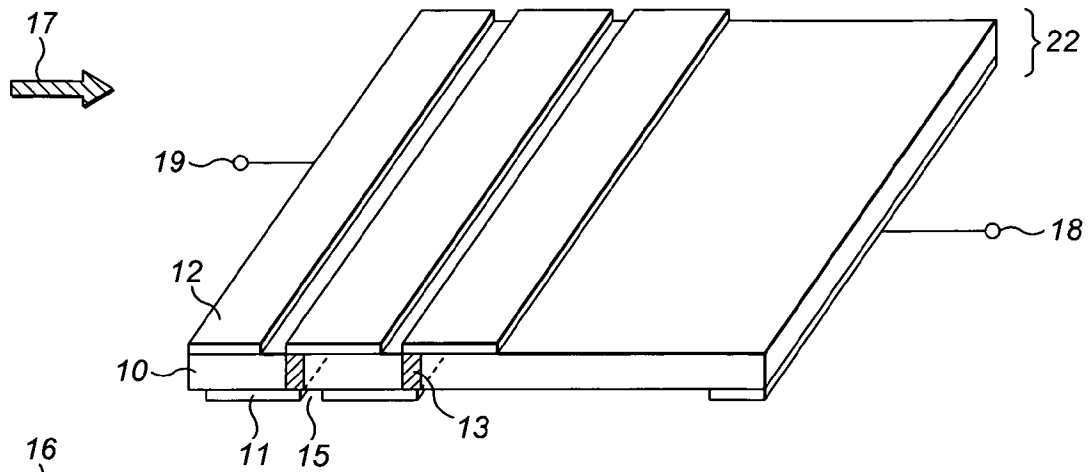


FIG. 2b

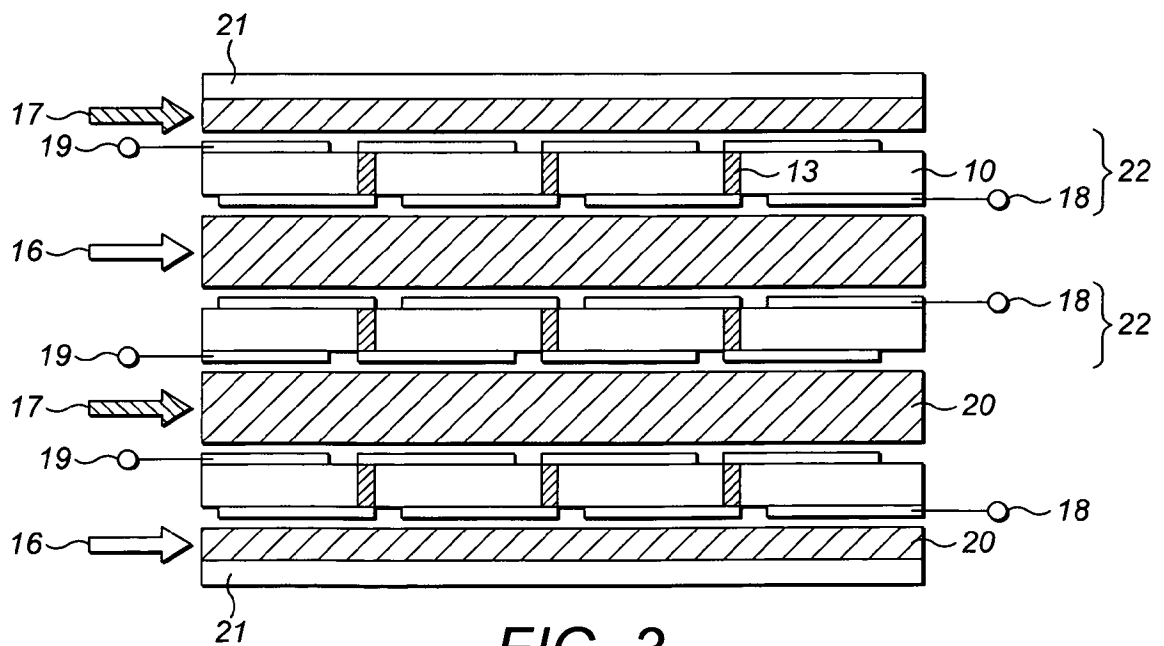
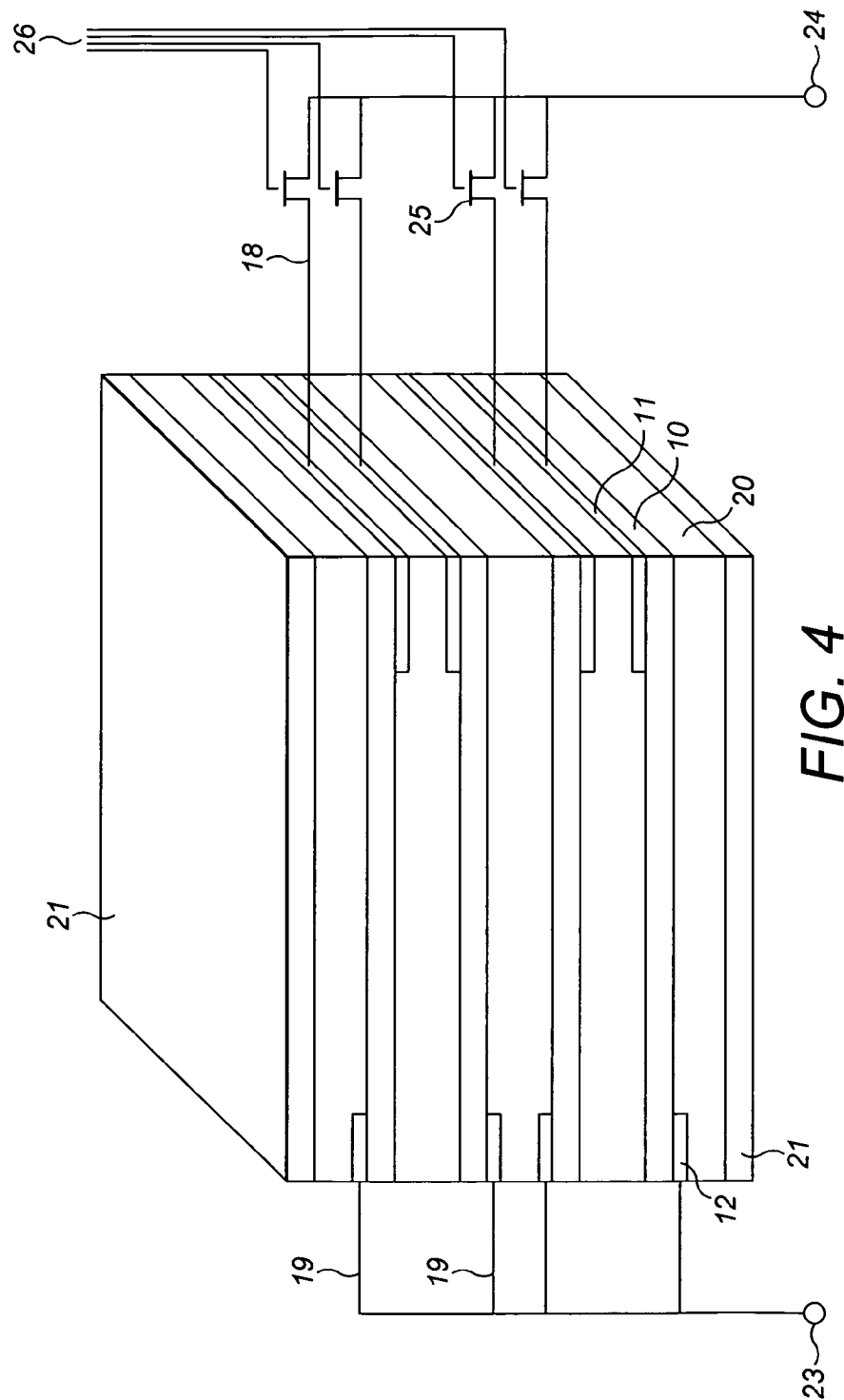


FIG. 3



5 / 17

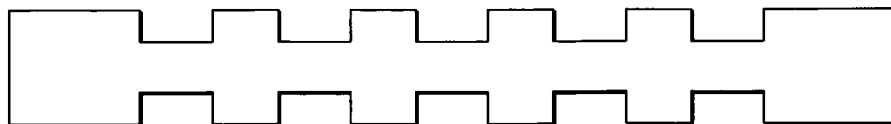


FIG. 5a

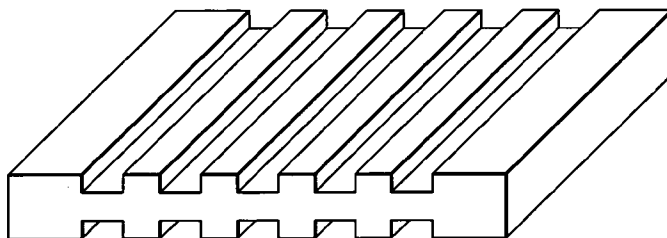


FIG. 5b

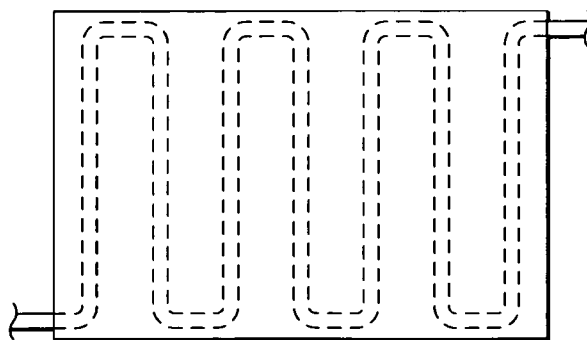


FIG. 5c

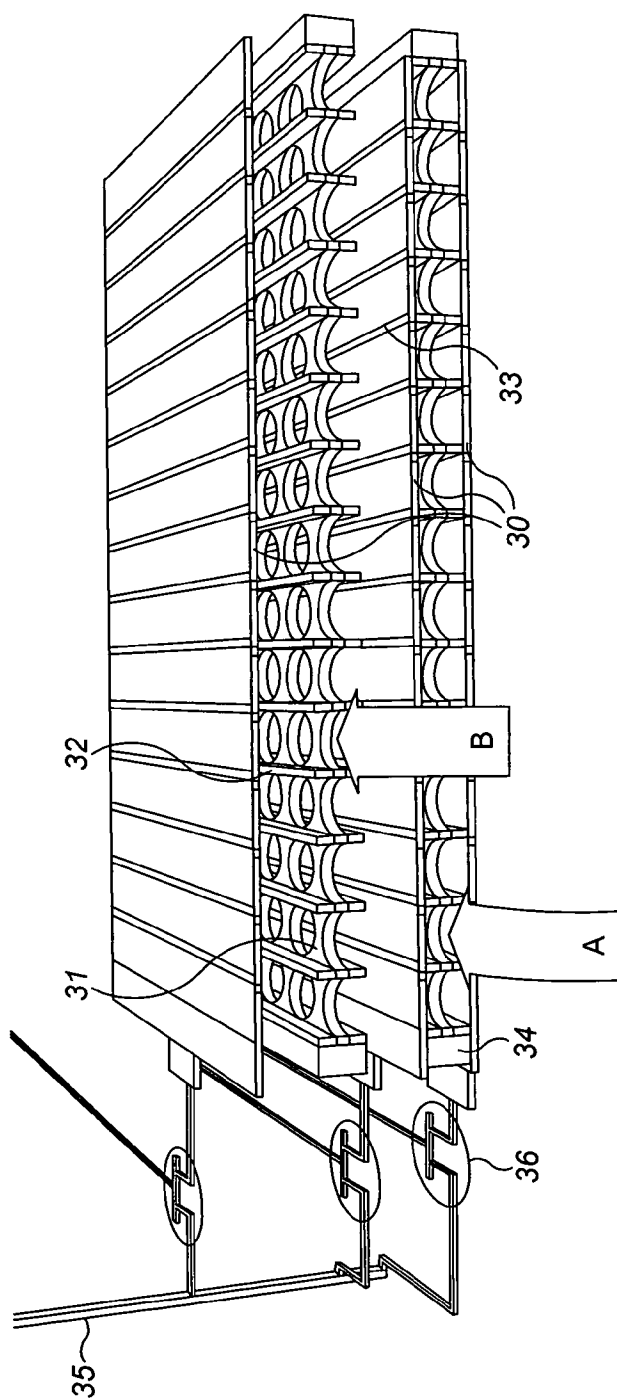


FIG. 6

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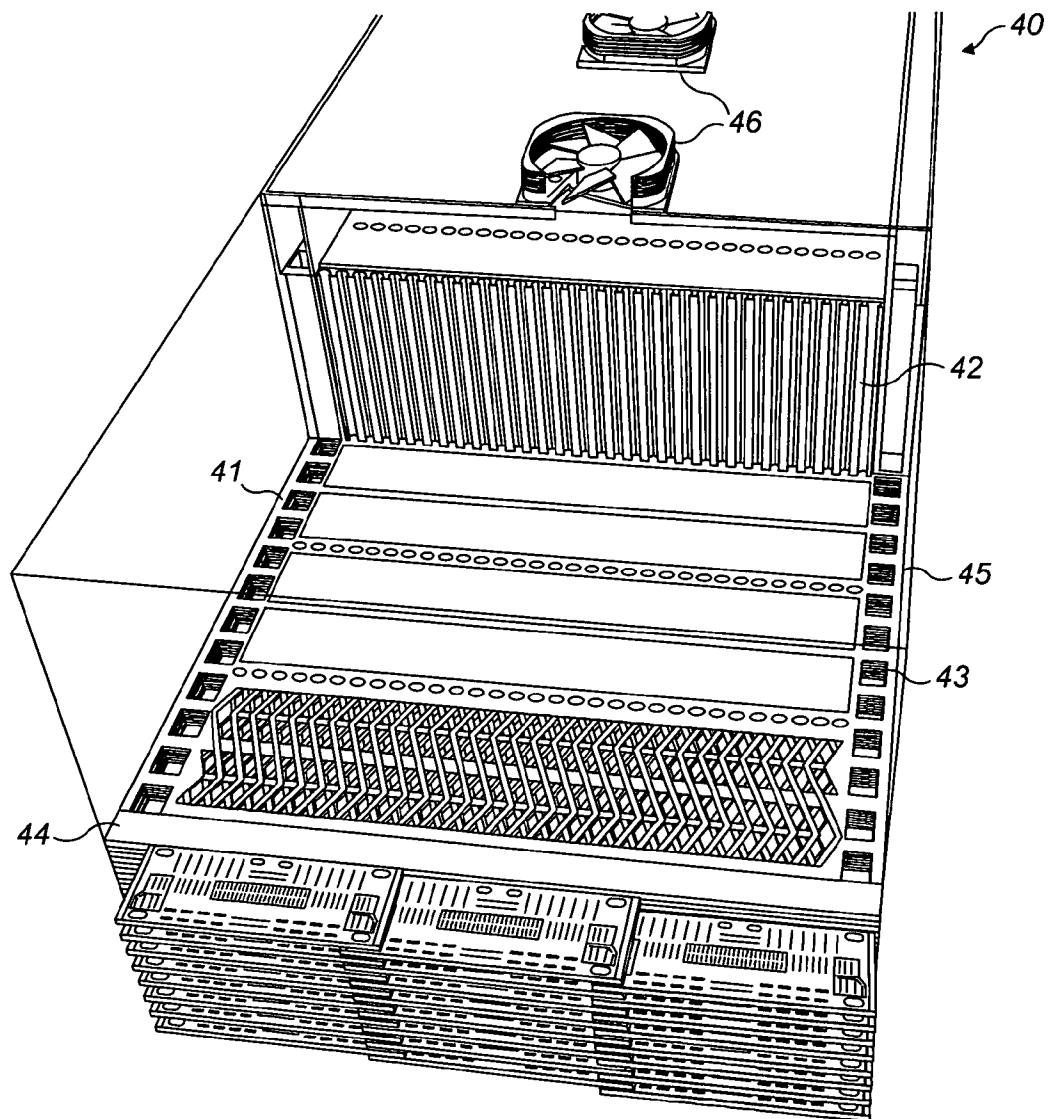


FIG. 7

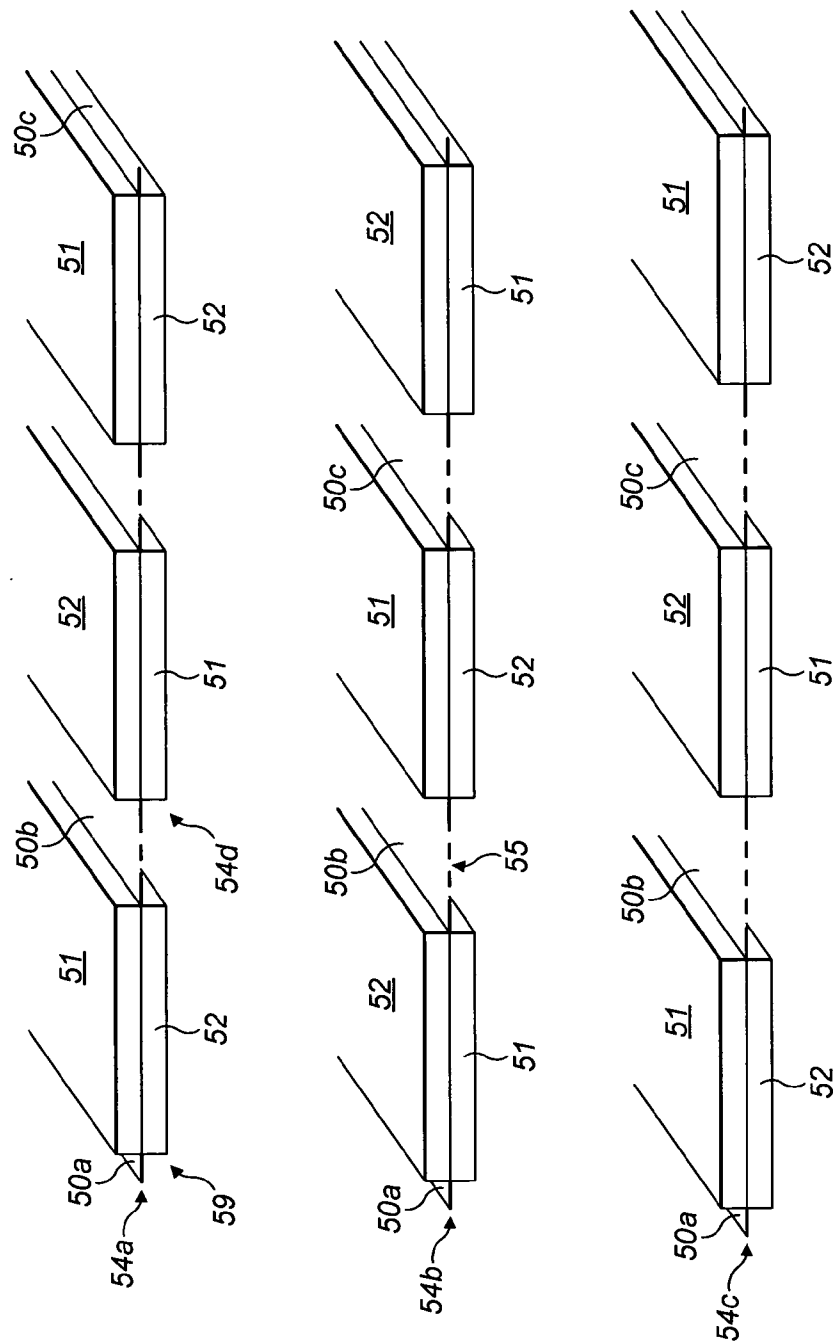


FIG. 8

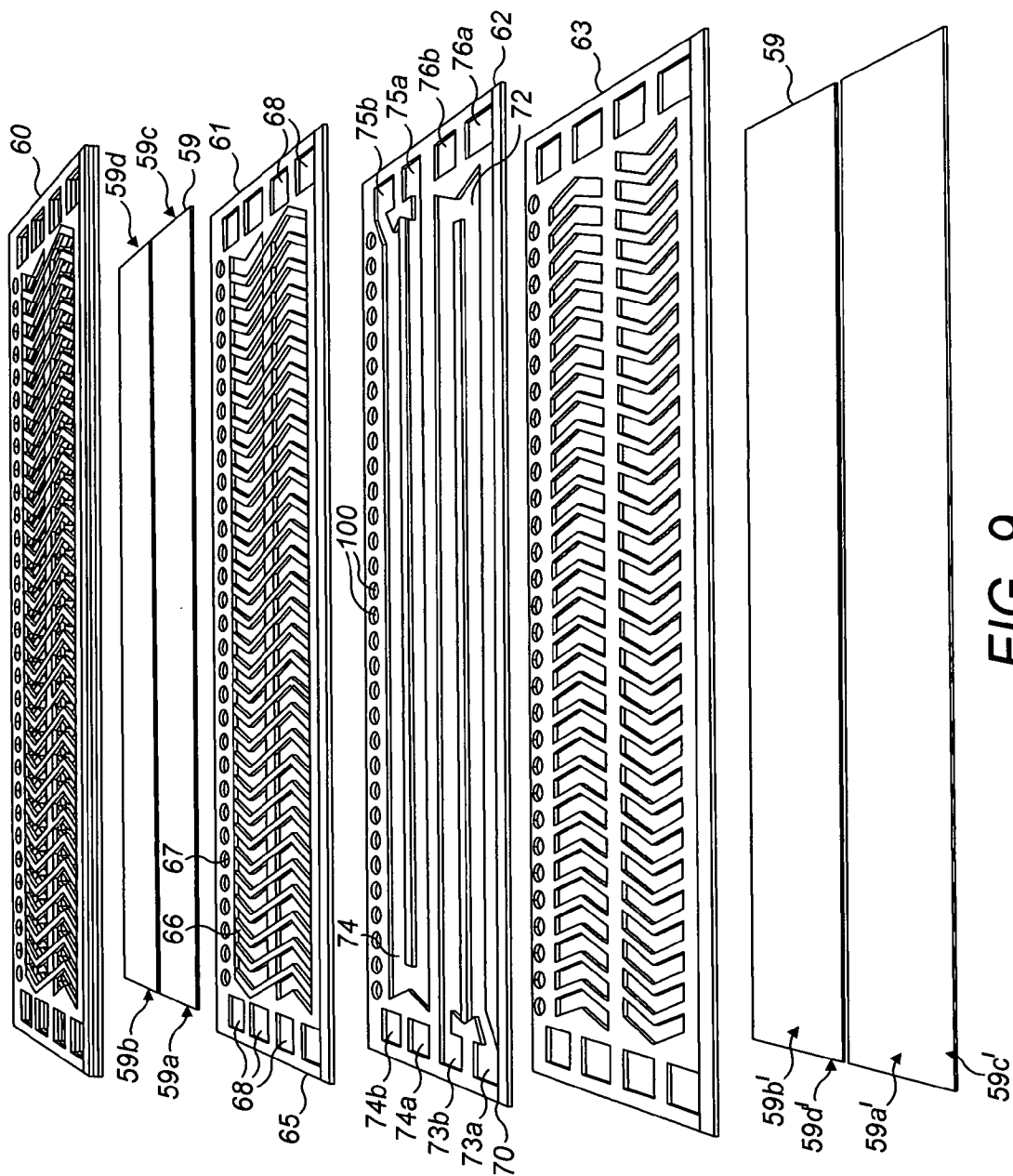


FIG. 9

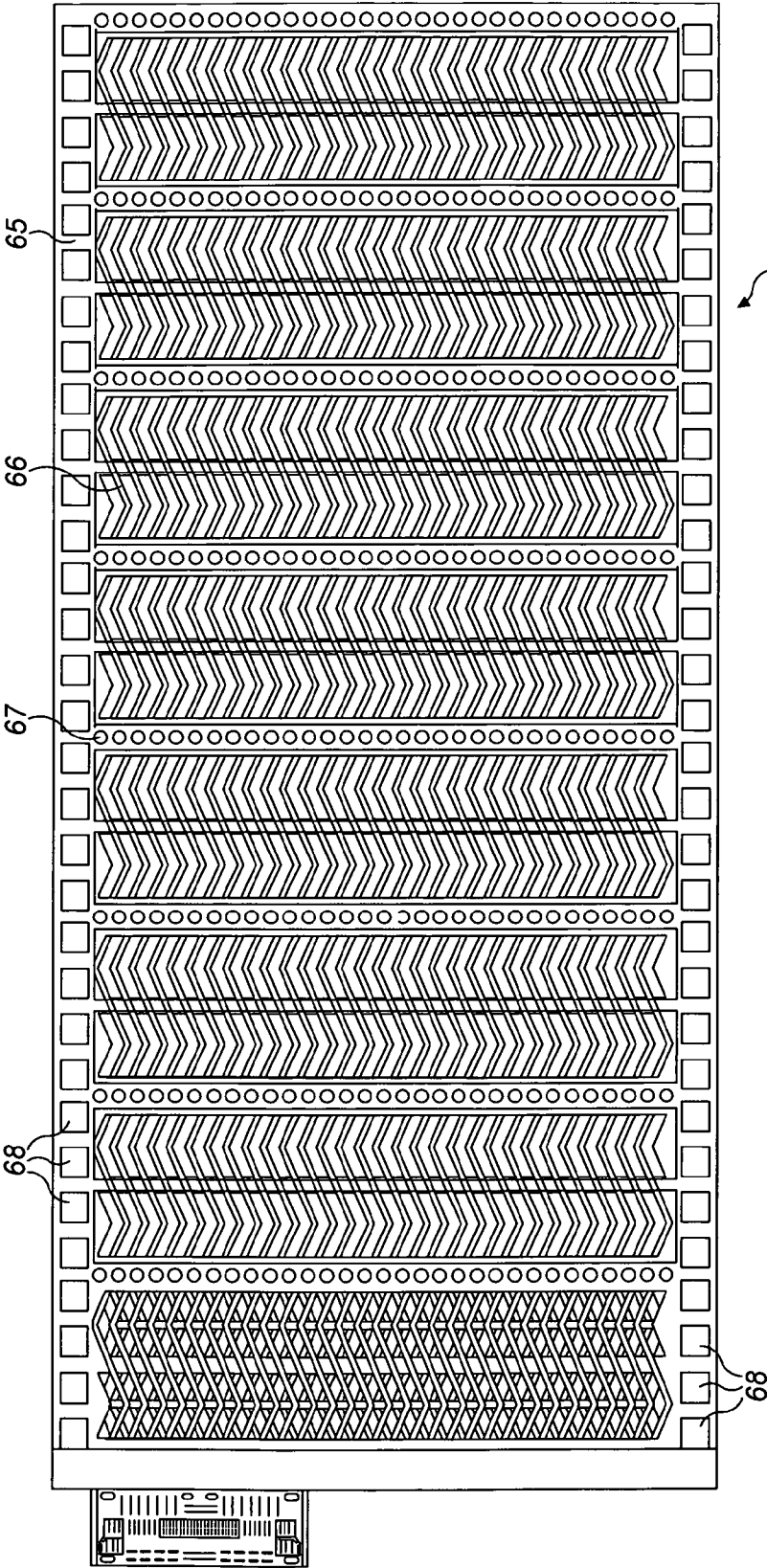


FIG. 10a

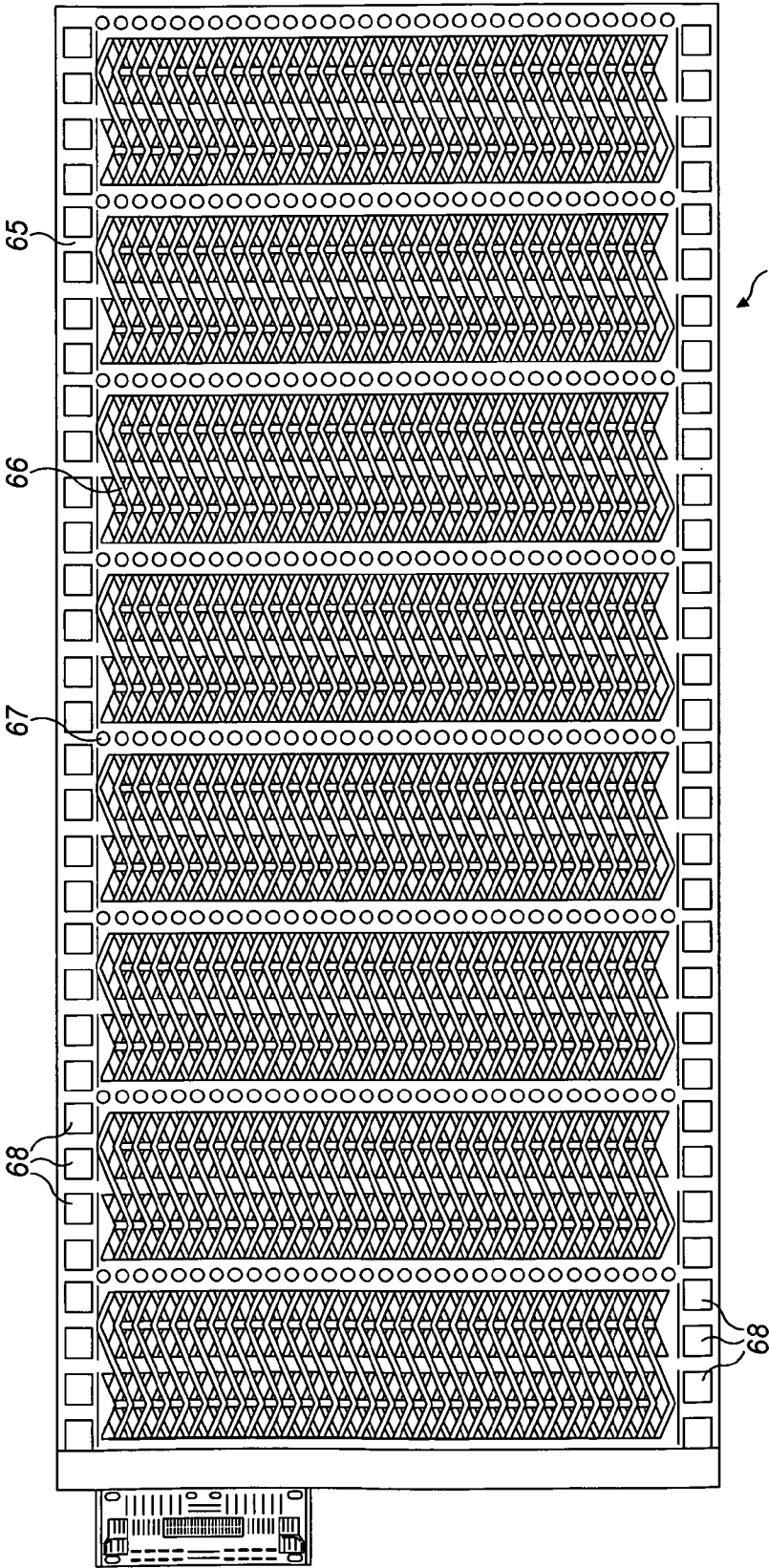
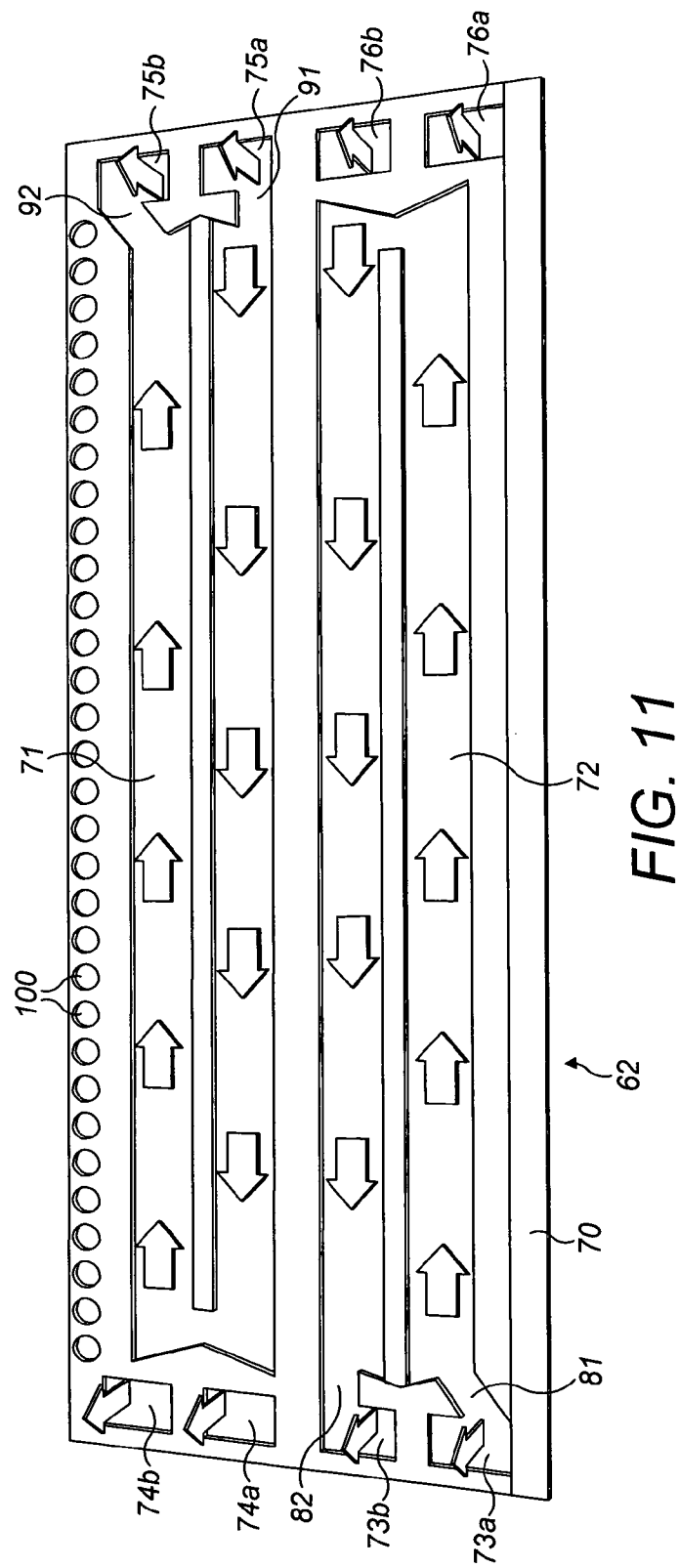


FIG. 10b



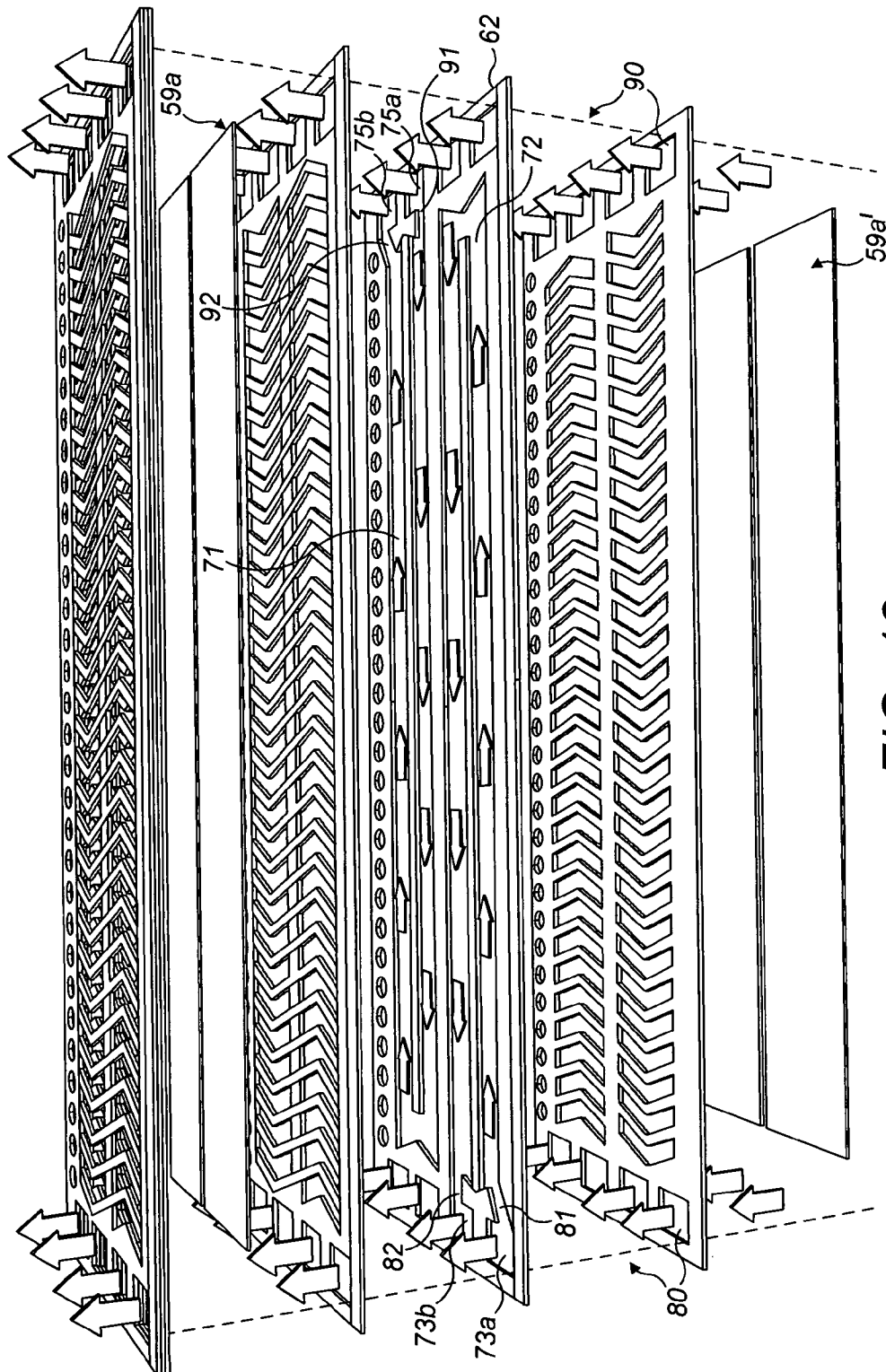


FIG. 12

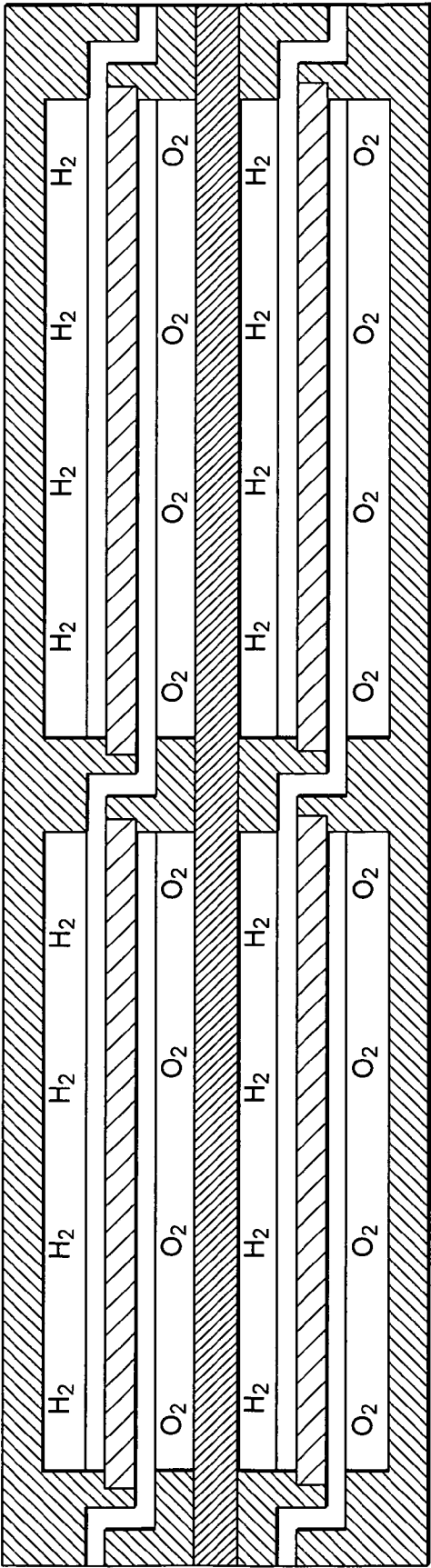


FIG. 13b

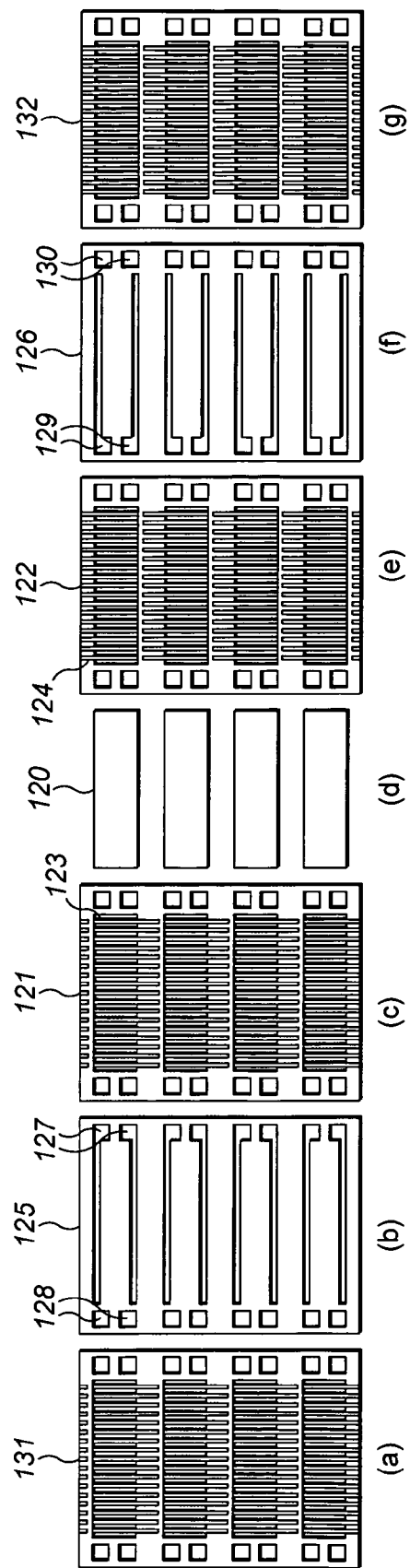


FIG. 13C

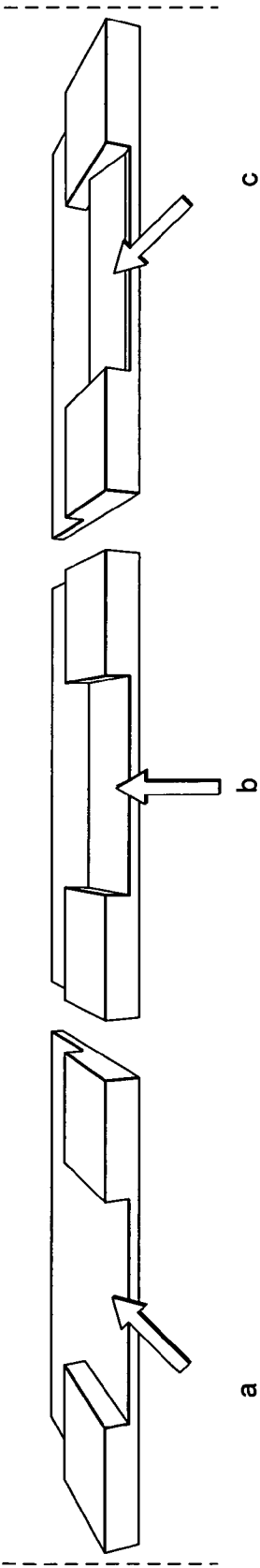


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2012/053479

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 68
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-12, 19-24, 26-29, 34-37, 49(completely); 30-33, 52, 54-63(partially)

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/053479

A. CLASSIFICATION OF SUBJECT MATTER INV. H01M8/02 H01M8/04 H01M8/10 H01M8/24 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H01M		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 127 058 A (PRATT STEVEN D [US] ET AL) 3 October 2000 (2000-10-03)	1-5,7,8, 23, 26-29, 34,37 6,49
Y	figures 2,4,5 column 5, lines 8-38 -----	
X	US 2004/185319 A1 (ENJOJI NAOYUKI [JP] ET AL) 23 September 2004 (2004-09-23)	1,3-5, 19-24, 26-29, 34-36 6,49
Y	paragraphs [0055] - [0066]; figures 1-6, 10, 11 ----- -/-	
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 26 April 2012	Date of mailing of the international search report 10/07/2012	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Jacquinot, Patrick	

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2012/053479

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/031926 A1 (SUGIMASA MASATOSHI [JP] ET AL) 10 February 2005 (2005-02-10)	1,4,5, 23, 26-29, 34,37, 52,54 6,49
Y	figures 2,3 paragraphs [0018], [0020], [0023], [0029] -----	
X	US 2008/280183 A1 (EUN YEONG-CHAN [KR] ET AL) 13 November 2008 (2008-11-13)	1,2,4,5, 7-12,23, 26-29, 34,37, 52,54 6,49
Y	figures 1a,2, 4a-4c paragraphs [0032], [0050], [0051], [0060] -----	
X,P	EP 2 337 132 A1 (IND TECH RES INST [TW]) 22 June 2011 (2011-06-22) figures 2B, 2c, 5A, 6A,6B -----	1,4,5, 23, 26-29,37
Y	GB 1 091 303 A (GEN ELECTRIC) 15 November 1967 (1967-11-15) figures 3-6 page 2, lines 12-16,52-54 page 3, lines 17-19 -----	6
Y	US 2008/233446 A1 (ZIMMERMANN JOERG [CA] ET AL) 25 September 2008 (2008-09-25) figure 6 paragraph [0092] -----	49

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2012/053479

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6127058	A	03-10-2000	AU 1313800 A 22-05-2000 US 6127058 A 03-10-2000 WO 0026980 A1 11-05-2000
US 2004185319	A1	23-09-2004	NONE
US 2005031926	A1	10-02-2005	JP 2005087989 A 07-04-2005 US 2005031926 A1 10-02-2005 US 2005158611 A1 21-07-2005
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US 2008233446	A1	25-09-2008	CA 2684583 A1 25-09-2008 CN 101680557 A 24-03-2010 EP 2140182 A1 06-01-2010 JP 2010522851 A 08-07-2010 KR 20100015783 A 12-02-2010 US 2008233446 A1 25-09-2008 WO 2008113180 A1 25-09-2008

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-12, 19-24, 26-29, 34-37, 49(completely); 30-33, 52, 54-63(partially)

a fuel cell comprising at least two fuel cell boards, gas flow channels arranged there between and electrical connectors for connecting adjacent pairs of anodes and cathodes on the same fuel cell board

2. claims: 13-18, 50, 67(completely); 52, 54-66(partially)

a multilayer printed circuit board

3. claims: 25, 34-37, 41, 42, 49(completely); 30-33, 52, 54-63(partially)

a fuel cell comprising at least two fuel cell boards being individually switchable, and a method of controlling the power thereof

4. claims: 30-33

an electrically insulating spacer

5. claims: 38-40

a method of forming a through membrane electrical connection

6. claim: 43

a method of fabricating a fuel cell comprising the steps of stacking a plurality of (undefined) fuel cell boards each having at least one (undefined) through membrane electrical connection interleaved with (undefined) insulating spacers

7. claims: 44-47, 53

a method of fabricating a fuel cell with (undefined) printed circuit boards

8. claim: 48

use of a shape memory alloy as a valve in a fuel cell board

9. claims: 51-63

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

a method of depositing a corrosion resistant layer

10. claims: 64-66

a corrosion resistant coating

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 68

The scope of claim 68 merely being defined by reference to the description and the Figures is unclear under Article 6 PCT to such an extent that a meaningful search of said claim cannot be carried out.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guideline C-VI, 8.2), should the problems which led to the Article 17(2) declaration be overcome.