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(54) Title: INTERNAL SUPPORT STRUCTURE FOR AN UNDULATE MEMBRANE ELECTRODE ASSEMBLY IN AN ELECTROCHEMICAL FUEL CELL

(57) Abstract

A support structure for an undulate membrane electrode assembly in an electrochemical fuel cell including a stacked series of membrane layers extending generally in dimensions perpendicular to the stack dimension and alternating with support structures. The support structure has a reactant gas–impermeable separator stratum extending generally in dimensions perpendicular to the stack dimension and a pair of reactant gas–permeable electrically conductive current collectors lying adjacent the separator stratum on opposite sides thereof. Each collector is in non–continuous physical and electrical contact with the separator stratum and is attached to the separator stratum so as to form, when a membrane layer is sandwiched between two such skeletons so that the membrane layer is conformed to surfaces of the collectors and is in general physical and electrical contact with the collectors, at least one discrete conduit between each separator stratum and the membrane layer for flow of a discrete reactant gas therethrough. The separator stratum provides at least one electrically conductive path between current collectors, and the current collectors have sufficient rigidity when installed in an MEA fuel cell stack between two membrane layers to retain their shape when the support structure is placed under sufficient pressure in the stacking direction to maintain physical and electrical contact between each current collector and the adjacent membrane layer.

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INTERNAL SUPPORT STRUCTURE FOR AN UNDULATE MEMBRANE ELECTRODE ASSEMBLY IN AN ELECTROCHEMICAL FUEL CELL

RELATED APPLICATION

This application includes subject-matter incorporated from applicant's British Patent Application Serial No. No. 9814123.7 filed on 1 July 1998.

FIELD OF THE INVENTION

The present invention relates to electrochemical cells and particularly to fuel cells incorporating a proton exchange membrane. More particularly, the present invention relates to the preferred internal support structure of such fuel cells.

BACKGROUND

Electrochemical fuel cells convert fuel and oxidant to electricity and reaction product. In electrochemical fuel cells employing hydrogen as the fuel and oxygen as the oxidant, the reaction product is water. Conventional proton exchange membrane ("PEM") fuel cells generally employ a planar, layered structure known as a membrane electrode assembly ("MEA"), comprising a solid polymer electrolyte or ion exchange membrane, which is neither electrically conductive nor porous, disposed between an anode electrode layer and a cathode electrode layer. The electrode layers are typically comprised of porous, electrically conductive sheets with electro-catalyst particles at each membrane-electrode interface

to promote the desired electrochemical reaction.

In conventional fuel cells, the MEA is interposed between two rigid, planar, substantially fluid-impermeable, electrically conductive plates, commonly referred to as separator plates. The plate in contact with the anode electrode layer is referred to as the anode plate and the plate in contact with the cathode electrode layer is referred to as the cathode plate. The separator plates (1) serve as current collectors, (2) provide structural support for the MEA, and (3) typically provide reactant channels for directing the fuel and oxidant to the anode and cathode electrode layers, respectively, and for removing products, such as water, formed during operation of the fuel cell. Fuel channels and oxidant channels are typically formed in the separator plates; the plates are then normally referred to as fluid flow field plates. Herein, "fluid" shall include both gases and liquids; although the reactants are typically gaseous, the products may be liquids or liquid droplets as well as gases.

During operation of the fuel cell, hydrogen from a fuel gas stream moves from fuel channels through the porous anode electrode material and is oxidized at the anode electro-catalyst to yield electrons to the anode plate and hydrogen ions which migrate through the electrolyte membrane. At the same time, oxygen from an oxygen-containing gas stream moves from oxidant channels through the porous electrode material to combine with the hydrogen ions that have migrated through the electrolyte membrane and electrons from the cathode plate to form water. A useful current of electrons travels from the anode plate through an external circuit

to the cathode plate to provide electrons for the reaction occurring at the cathode electro-catalyst.

Multiple unitary fuel cells can be stacked together to form a conventional fuel cell stack to increase the overall power output. Stacking is typically accomplished by the use of electrically conductive bipolar plates which act both as the anode separator plate of one fuel cell and as the cathode separator plate of the next fuel cell in the stack. One side of the bipolar plate acts as an anode separator plate for one fuel cell, while the other side of the bipolar plate acts as a cathode separator plate for the next fuel cell in the stack. The bipolar plates combine the functions of anode and cathode plates referred to above and are provided with the fuel channels and oxidant channels.

Fluid reactant streams are typically supplied to channels in the flow field plates via external inlet manifolds connected to the sides of the stack or by internal inlet manifolds formed by aligning openings formed in the bipolar plates and each MEA. Similarly, fluid stream exhaust manifolds may be external or internal exhaust manifolds. Typically the stack also has coolant passageways extending through the bipolar plates and each MEA for circulating a coolant fluid to absorb heat generated by the fuel cell reaction.

A typical conventional bipolar plate has a plurality of parallel open-faced oxidant channels on one side and a plurality of parallel open-faced fuel channels on the other side. The oxidant channels extend between an oxidant inlet manifold opening and an oxidant outlet manifold opening in the bipolar plate and

typically traverse the central area of one plate surface in a plurality of passes, that is, in a serpentine manner, between the inlet manifold opening and the outlet manifold opening. Similarly, the fuel channels extend between a fuel inlet manifold opening and a fuel outlet manifold opening in the bipolar plate and traverse the central area of the other plate surface in a similar plurality of passes between the fuel inlet manifold opening and the fuel outlet manifold opening. Channel patterns other than serpentine may be used in conventional fuel cell plates, but serpentine channel patterns have generally been found to work the best.

In conventional fuel cell designs only a portion of the porous electrode structure is exposed directly to the flow of reactants in the flow channels. The remainder of the porous electrode structure is in contact with the material of the typically non-porous, but electrically conducting flow field plates. In practice, conventional fuel cell design has involved a trade-off between (1) increasing the electrode area directly exposed to reactant flow thus increasing the current and power which can be produced by a given area of electrode material and (2) increasing the electrode area in contact with the flow field plates thus reducing the contact resistance between the electrode material and the conducting flow field plate material and increasing physical support for the somewhat fragile MEA.

The MEA needs physical support in a conventional fuel cell stack as it is exposed to the compression forces needed to prevent fluid leaks between adjacent fluid flow channels in the fuel cell stack. In

conventional fuel cell designs such leakage is undesirable, particularly if the channels are serpentine, as some of the fluid may move directly from the inlet manifold opening across the channels to the outlet manifold opening without passing through the passes of the channels and so missing most of the MEA. To prevent such fluid movement, separator plates with extremely flat surfaces are required in conventional fuel cell stacks, necessitating either the grinding of the surfaces of the separator plates or the molds used to form the separator plates to exacting specific tolerances.

The compression needed to prevent leakage and reduce contact resistance is conventionally obtained by clamping the fuel cell stack together. Clamping is undesirable as fuel cell layers must be strong to resist crushing and the clamping hardware is bulky and adds weight to the fuel cell stack. Significantly higher power density could be obtained if clamping forces could be reduced or eliminated.

Watkins, U.S. Patents Nos. 4,988,583 and 5,108,849, issued 29 January 1991 and 28 April 1992, respectively, describe fluid flow field plates in which continuous open-faced fluid flow channels formed in the surface of the plate traverse the central area of the plate surface in a plurality of passes, that is, in a serpentine manner, between an inlet manifold opening and an outlet manifold opening formed in the plate. Flow field plates such as those described are typical of prior art designs. The separator is formed from bulk material by either removing material to form the open faced fluid reactant channels or by compressing a pliable material

to form the appropriate three dimensional structure. Such methods of manufacture result in comparatively heavy structures created through comparatively expensive manufacturing techniques.

Wilkinson et al., U.S. Patent No. 5,252,410 proposes the formation of reactant flow channels formed in the surfaces the porous gas diffusion electrode layers of the MEA, facilitating the use of simplified separator layers that are single sheets of conductive, gas impermeable material. The design relies on the application of compressive forces to reduce internal resistance and mitigate against inter-channel gas leakage.

A number of designs for complex bi-polar separator plates formed by the physical interaction of multiple sheet and corrugated components have been proposed. Typical of these are Fujiwara Naoki et al., Japanese Patent Publication No. 10154519 A, published June 9, 1998, Spear, et al., U.S. Patent No. 5,683,828, and Marianowski, U.S. Patent No. 4,702,973. While these patents propose a bi-polar plate design that is built up, and therefore lighter and potentially cheaper than the dominant graphite based design, they continue to rely on planar MEA layers and simple compressive forces to reduce internal contact resistance.

The simplest bipolar separator layers for use with convnentional planar MEA layers are based on single sheet corrugated structures, as in Tsuru Atsushi et al., Japanese Patent Publication No. 9063599 A, published March 7, 1997, Koga, et. al., U.S. Patent No. 4,933,242 or Petri, et. al., U.S. Patent No. 5,362,578. These

designs also rely on simple compression to reduce contact resistance and disclose no means of obtaining complex serpentine flowpaths over the MEA layer.

All of the prior art discussed above is based on the use of planar MEA layers with simple mechanical contact as a means of reducing internal resistance.

A number of designs exist that recognize the inherent gains that can be made through the use of non-planar MEA layers in which the fluid reactant channels for distribution of fuel and oxidant gas to the MEA are formed implicitly with the non-planar MEA forming substantially the wall of the reactant gas channels.

Mitsuda, U.S. Patent No. 4,981,763, issued 1 January 1991, discloses the use of a static undulate electrolyte configuration, but his complete MEA (Figure 2) incorporates the undulate electrolyte layer within a conventional planar electrode structure. Note that in Figure 14, although the electrolyte and adjoining catalytic layers are undulate, the electrode structure remains planar, and conventional.

McIntyre, U.S. Patent No. 4,826,554, issued 2 May 1989, discloses a sinuously-formed "electrically conductive, hydraulically permeable matrix 130, which is also embedded into the membrane sheet 120" (column 2, lines 33-35) and at line 40 we read that "The membrane may be a singular layer membrane of a composite layer membrane". However, there is no disclosure of alternating layers in a stack that contact one another to form interior flow conduits or channels.

Japanese Patent Publication No. 50903/1996, Futoshi et al., 20 February 1996, discloses a solid polymer fuel cell having generally planar separators with alternating protruding parts serving to clamp a power generation element (apparently an MEA) into a non-planar but piecewise linear shape. The area of the MEA exposed to reactants is increased relative to planar MEA designs, but the portions of the MEA clamped between the protruding parts and the planar portion of each separator do not appear to be exposed to reactants. Further, significant clamping force appears to be required to reduce contact resistance. Such force, together with the abrupt changes in direction at the corners of the protruding parts, may introduce kinks and very large stresses in the MEA.

Fischer, et al., German Laid-Open Specification 25 14 034, Lemoine, German Laid-Open Specification No. 38 12813 A1 and Hiroshi Mihara, Japanese Patent Publication No. 1-292759, present designs in which a non-planar electrolyte layer for use in molten carbonate fuel cells is formed between planar separator layers. The designs are based on the use of high temperature sintering techniques for the creation of the internal structure and do not create internal structures suitable for use with PEM type fuel cells, neither do they propose the means of obtaining complex flowfields over the electrolyte region.

The object of this invention is to provide an internal structure serving nominally the function of the conventional bi-polar separator plate but for use with non-planar MEA layers. An ideal structure for use in such a stack would have the following characteristics:

1. Be as lightweight as possible, i.e. be made from simple thin sheet materials formed into required three dimensional structures.

2. Provide a conductive path from anode side of the membrane layer to cathode side of the neighbouring membrane layer in the stack with a minimum minimum contact resistance.

3. Interact with the MEA layers in such a way that large clamping forces are not required to prevent gas leaks between neighbouring flow channels or to obtain low internal electrical resistance.

4. Be conducive for continuous manufacture in large quantities to facilitate high volume manufacturing methods.

SUMMARY OF THE INVENTION

In the following description and in the claims: (i) the "flow dimension" or "axial dimension" is perpendicular to the plane of each drawing; (ii) the "stack dimension" is the direction of assembly of the series of fuel cells in the stack, perpendicular to the planes of the end plates of the stack; and (iii) the "transverse dimension" is perpendicular to both the flow and stack dimensions. Also, the undulate or wavy shape of various non-planar strata within fuel cells according to the invention is in part described using terminology normally used to describe wave motion, such as "waveform", "phase", "amplitude", and "period". The use of such terminology is not meant to suggest motion; the

waveform of an undulate stratum or layer is that of a static structure.

For use in an MEA fuel cell stack including a stacked series of membrane layers extending generally in dimensions perpendicular to the stack dimension and alternating with support structures, a support structure according to an embodiment of the invention comprises (i) a reactant gas-impermeable separator stratum extending generally in dimensions perpendicular to the stack dimension; and (ii) a pair of reactant gas-permeable electrically conductive current collectors, preferably of undulate configuration, lying adjacent the separator stratum on opposite sides thereof. The current collectors may be made, for example, of expanded metal mesh or of carbon cloth, and may be stitched or otherwise mechanically fastened or bonding to the separator stratum. Each collector is in non-continuous physical and electrical contact with the separator stratum and is attached to the separator stratum so as to form, when a membrane layer is sandwiched between two such skeletons so that the membrane layer is conformed to surfaces of the collectors and is in general physical and electrical contact with the collectors, at least one discrete conduit between each separator stratum and the membrane layer for flow of a discrete reactant gas therethrough. Each of the separator strata provides at least one electrically conductive path between current collectors and may be a thin electrically conductive plate. The separator strata may be planar or undulate, with undulate strata providing an improvement in the volumetric power density of the stack. The support structure has sufficient rigidity to retain its shape when installed in an MEA fuel cell stack between two

membrane layers.

A primary consequence of a fuel cell having non-planar MEA strata is that instead of relying primarily upon channels in the separator plates to provide reactant gas flow conduits, relatively large portions of the MEA strata may be shaped to serve as walls for reactant gas flow conduits, thereby exposing a relatively large surface area of the MEA electrocatalytic layer to reactant gases. In its simplest aspect, the resulting structure geometrically resembles corrugated cardboard, the MEAs being configured as corrugated strata sandwiched between planar separator strata.

When constructing cells of this nature, the general reliance on planar contact regions is reduced, and so is the need for precisely manufactured plates that are clamped within the stack to provide planar-planar interface layers. As a result, rigid, structurally strong separator plates are no longer needed and it becomes possible to construct lightweight, flexible separators that provide the necessary strength only when inserted into the overall structure. Each separator stratum has a unique current collector attached to each of its two sides ("side" meaning one of the two working surfaces lying generally perpendicular to the stack dimension, although separators may be designed and used, as will be described below).

The current collectors are each either (1) a separate rigid structure in intimate contact with the MEA or (2) one element of an integral bonded layered structure also comprising a current collector attached

to the next separator stratum in the stack, an ion exchange membrane, and electro-catalyst particles (and possibly porous material) between the membrane and the current collectors. In the former case, conventional flexible MEA sheet material may be placed between facing sides of successive separator strata and formed into ana non-planar configuration by squeezing the current collectors together in the stacking dimension as the stack is assembled. In the latter case, the composite layered MEA structure is formed in place and is the electrochemical equivalent of conventional MEA material. The current collectors in the layered MEA structure may replace the electrode layers of a conventional MEA. In the following discussion, the phrase "layered MEA structure" means either (1) a conventional sheet of MEA material sandwiched between two non-planar current collectors or (2) an ion exchange membrane, electro-catalyst particles, and possibly porous material sandwiched between two non-planar current collectors so as to form the electrochemical equivalent of a conventional MEA.

The cell skeleton is the core element from which the fuel cell stack is made. Successive cell skeletons support between them a sheet of conventional MEA material or an ion exchange membrane, electro-catalyst particles, and possibly porous material. Hence the terms "cell skeleton" and "support structure" should be taken as equivalent in the following discussion. The skeleton can be fabricated using continuous manufacturing processes and then cut to exact dimensions for stack assembly. The skeleton is formed from sheet materials into three distinct layers that interact to provide a gas impermeable separator and two gas

permeable current collectors. Flow channels are implicitly formed within the structure and a conductive path from one side to the other is provided. The skeleton structure provides a permanent bonding of the three conceptual layers to reduce contact resistance and eliminate the need for global stack clamping to achieve reasonable cell performance.

As in a conventional fuel cell stack, in embodiments of the present invention each separator plate or stratum must also provide electrical connection between the sites of electrochemical activity on opposed sides of the separator stratum. In a conventional fuel cell, the separator plate is conductive and is in electrical contact with the MEAs on its opposed sides. In accordance with the present invention, each current collector is conductive, collects electrons from one side of the layered MEA structure, and conveys the electrons to the separator stratum to which it is attached. The separator strata are either electrically conductive or otherwise provide electrically conductive paths between attachment points of the current collectors on their opposed sides so as to electrically connect those current collectors.

The resulting stacked configuration of separator strata alternating with attached non-planar layered MEA structures will produce a flow of electrical current through an external circuit connected between current collectors at the ends of the stack that are opposed in the stack dimension if reactant gases flow through the conduits formed between the separator strata and the non-planar layered MEA structures. One end of each conduit must be connected to a source of reactant gas

and the other to a sink of reactant gas to provide the necessary flows of reactant gas through the conduit. The preferred manifolding of reactant gas into and out of the conduits is within the designer's discretion and not *per se* a part of this invention.

The conduits on opposed sides of each layered MEA structure carry the reactant gases, fuel on one side and oxidant on the other side. As the layered MEA structures and separator strata are both reactant gas-impermeable, conduits having any desirable configuration may be formed by patterns of attachment of the layered MEA structures and the separator strata. For example, if the layered MEA structures are corrugated in the transverse dimension and attached along their parallel ridges and hollows to the separator strata, then an array of parallel conduits are consequently formed running (oriented) in the axial or flow dimension.

It is also an aspect of the invention to use hydrogen in a fuel cell stack made up of fuel cells having internal support structures as heretofore described and that is connectable via an anode terminal and a cathode terminal to an external load. Each fuel cell has an MEA layer and two discrete associated reactant-gas impermeable separator layers. The MEA layer has a porous anode electrode, a porous cathode electrode, an electrolytic membrane layer disposed between the two electrodes, an anode electro-catalyst layer disposed between the electrolytic membrane layer and the anode electrode, and a cathode electro-catalyst layer disposed between the electrolytic membrane layer and the cathode electrode. One side of one separator layer in conjunction with the MEA layer provides at

least one flowpath of a flow field for hydrogen and one side of the other separator layer in conjunction with the MEA layer provides at least one flowpath of a flow field for a selected oxidant. The flowpaths are constituted over their greater length by parallel transversely spaced and longitudinally extending flow channels interconnected in the vicinity of their ends to form the flowpaths. The MEA layer is installed in the stack between the associated separator layers so that the side of the separator layer that in conjunction with the MEA layer provides flow channels of a flow field for hydrogen faces and is in contact with the anode side of the MEA layer, whilst the side of the separator layer providing flow channels of a flow field for oxidant faces and is in contact with the cathode side of the MEA layer, so that the hydrogen flow channels are closed to form a conduit for supplying hydrogen to the MEA layer and the oxidant flow channels are closed to form a conduit for supplying oxidant to the MEA layer. The fuel cells are stacked in sequence, the anode electrode of the fuel cell at one extremity of the stack being electrically connected to the anode terminal, the cathode electrode of the fuel cell at the other extremity of the stack being electrically connected to the cathode terminal, and the anode electrode of each of the other fuel cells in the stack being electrically connected to the cathode electrode of the next adjacent fuel cell. When the anode terminal and cathode terminal are electrically connected through an external load and for each fuel cell hydrogen is supplied to the hydrogen conduit and oxygen is supplied to the oxidant conduit, then in each fuel cell hydrogen moves from the hydrogen flow field through the anode electrode and is ionized at the anode electro-catalyst layer to yield electrons and

hydrogen ions, the hydrogen ions migrate through the electrolytic membrane layer to react with oxygen that has moved from the oxidant flow field through the cathode to the cathode electro-catalyst layer and with electrons that have moved from the anode electrode electrically connected to the cathode electrode, thereby to form water as a reaction product, and a useful current of electrons is thereby produced through the load.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic cross-sectional view of a portion of a undulate MEA fuel cell stack that includes an embodiment of the present invention, taken perpendicular to the direction of reactant flow, in which alternate screens are out of phase with each other.

Figure 2 is a fragmentary schematic cross-sectional view of a cell skeleton of the fuel cell stack of Figure 1.

Figure 3 is a fragmentary schematic cross-sectional view of a portion of the cell skeleton of Figure 2 illustrating a first method of attachment of the screens to the separator strata.

Figure 4 is a fragmentary schematic cross-sectional view of a portion of the cell skeleton of Figure 2 illustrating a second method of attachment of the screens to the separator strata.

Figure 5 is a fragmentary schematic cross-sectional

view of a portion of the cell skeleton of Figure 2 illustrating a third method of attachment of the screens to the separator strata.

Figure 6 is a fragmentary schematic cross-sectional view of a portion of the cell skeleton of Figure 2 illustrating a fourth method of attachment of the screens to the separator strata.

Figure 7 is a schematic cross-sectional view of a portion of an undulate MEA fuel cell stack that includes an embodiment of the present invention, taken perpendicular to the direction of reactant flow, in which alternate screens are in phase with each other.

Figure 8 is a schematic cross-sectional view of a portion of an undulate MEA fuel cell stack that includes an embodiment of the present invention, taken perpendicular to the direction of reactant flow, in which both the separator strata and the screens are undulate.

DETAILED DESCRIPTION OF THE INVENTION

To provide a working fuel cell stack incorporating an MEA strata, it is necessary to (1) maintain the dimensional stability of the MEA strata, (2) separate flowing oxidant on the cathode side of one MEA from flowing fuel on the anode side of the next MEA in the stack, and (3) provide electrical connection between the cathode side of one MEA and the anode side of the next MEA in the stack. British application Serial No. 9814123.7 (McLean *et al.*, assigned to the applicant herein) filed on 1 July 1998 and derivatives and

divisionals thereof, describe the overall structural configuration of a class of non-planar MEA fuel cells that satisfy those criteria. The present application describes a structural skeleton, one embodiment of which may be used in fuel cells of that class, and a method of fabricating such skeletons.

The overall structure of a fuel cell stack in which an embodiment of the present invention may be used to advantage is illustrated in Figure 1, which provides a schematic axial cross-sectional fragmentary view of a portion of a fuel cell stack, generally indicated by reference numeral 10. The stack 10 comprises a plurality of undulate reactant gas-impermeable layered MEA structures, generally referred to by reference numeral 25 in the following discussion, and a plurality of reactant gas-impermeable conductive separator strata, generally referred to by reference numeral 20 in the following discussion. The layered MEA structures 25 and separator strata 20 are alternately disposed in the stack 10 so that each layered MEA structure 25 is disposed between an associated pair of separator strata 20. Where necessary for clarity of exposition separator strata 20 and layered MEA structures 25 are individually indicated in the drawings by reference numerals with appended letters.

The separator strata 20 and the layered MEA structures 25 extend in the axial dimension (perpendicular to the plane of Figure 1), maintaining throughout such extension the cross-sectional configuration shown in Figure 1. As the separator strata 20 and the layered MEA structures 25 are each impermeable to reactant gases, parallel oxidant conduits

28 and fuel conduits 30, whose axial or reactant flow dimension is perpendicular to the plane of Figure 1, are formed through which the respective reactant gases may be circulated.

Some of the internal structures of the layered MEA structure 25 have been omitted in Figure 1; alternative such structures 25 are described in British application Serial No. 9814123.7 (McLean *et al.*, assigned to the applicant herein) filed on 1 July 1998. Two elements common to each alternative structure 25 are reactant gas-impermeable ion-exchange membranes 14 and reactant gas-permeable conductive current collectors such as thin undulate screens 22, 24. Each membrane 14 has a cathode side or surface 16 and an anode side or surface 18 and is constrained in an undulate shape by the screens 22, 24. Each of the screens 22, 24 is attached at attachment points 26 to a unique one of the pair of separator strata 20 between which the membrane 14 is disposed.

The screens 22, 24 are treated as part of the layered MEA structure 25 for the purposes of description of the fuel cell stack 10 above, but the inventors have found that it is advantageous to assemble the fuel cell stack 10 by first constructing a plurality of cell skeletons, examples of which are shown in detail in Figure 2 and generally indicated by reference numeral 12, each comprising a separator stratum 20 and two attached screens 22, 24, and then either inserting layers of conventional MEA material between the skeletons 12 or forming the MEAs in-situ as described in British application Serial No. 9814123.7 (McLean *et al.*, assigned to the applicant herein) filed on 1 July 1998

and derivatives and divisionals thereof.

As is the case with the separator strata 20 and the layered MEA structure 25, the membranes 14 and screens 22, 24 extend in the axial dimension, maintaining throughout such extension the cross-sectional configuration and relative attachment position shown in Figure 1. Where necessary for clarity of exposition, the membranes 14 and the screens 22, 24 are individually indicated in the drawings by reference numerals with appended letters. For example, in Figure 1, membrane 14A is disposed between screen 24A, which is attached to separator stratum 20A, and screen 22A, which is attached to separator stratum 20B. Here the exemplary separator strata 20 are planar. In the following discussion, the current collectors are generally referred to as "screens" by way of example and for convenience of exposition, but it should be understood that other reactant gas-permeable structures may be used as well.

The separator strata 20 can be comprised of graphite plate, graphite foil, metal plate, metal foil, or non-conductive material such as conventional printed circuit board material. If printed circuit board material or other non-conductive material is used, electrical connection between the screens 22, 24 on opposite sides of a given separator 20 must be arranged.

The separator strata 20 can be rigid or flexible, conductive or non-conductive, homogeneous or composite. Typical materials that could be considered for this purpose include graphite and carbon sheets and composites, TEFLON™ or other polymer sheets, various forms of metals in which the metal is either inert in a

fuel cell environment or made to be inert through the application of appropriate surface coatings or composite materials of glass fibre or carbon fibre and epoxy construction.

The screens 22, 24 can be made of expanded metal mesh, preferably made of 316L stainless steel or noble metals. Other materials may also be used, such as carbon cloth or woven metal screen for the screens 22, 24. Structurally similar materials that are non-conductive may also be used for the interior of screens 22, 24 so long as they remain permeable to reactant gases when made conductive through the application of an exterior conductive surface coating by metal plating, carbon coating, or the application of conducting polymers.

Screens 22, 24 must be (1) gas permeable, (2) electrically conductive, and (3) rigid at the scale over which the screen is used. Rigidity in this context is relative to the dimensions of the undulations. For instance, a thin carbon paper formed into a 0.5mm x 0.5mm sinusoidal wave will be rigid enough to support a membrane layer. However, the same material formed into a 5mm x 5mm wave would probably not support the structure. Thus the definition of rigidity is scale dependent. Any material capable of supporting the MEA layer at the scale of construction is thus deemed to be rigid. This invention is not directed at any particular scale of fuel cell stack construction.

The sheet material out of which the screens 22, 24 are formed can be made into an undulate layer of the desired wavelength and amplitude by stamping, rolling, pressing or other manufacturing method suited to forming

a particular thin sheet material into a three dimensional structure.

In all embodiments of the invention the screens are mechanically bonded to the gas impermeable separator to provide a low resistance electrical connection as well as providing structural rigidity to support the undulate MEA layer. The local mechanical bond takes the place of the large overall clamping forces used in conventional cells.

In a preferred design for cell skeleton 12 using printed circuit board for the separator stratum 20, the substrate 21 of the printed circuit board separator stratum 20 illustrated in Figure 3 is made of rigid fibreglass, resin, or of flexible plastics materials such as TEFLON™ or MYLAR™. Electric circuit traces are formed on the surface of the substrate 21 using standard methodology and practice for the construction of printed circuit boards. As illustrated in Figure 3, the circuit traces 36, 37 on each surface of the substrate 21 are electrically connected with each other through a conductively filled hole or via 38, which is first drilled and then plated and filled with conductive material 40. The undulate screens 22, 24 are soldered, welded, stitched, stapled, riveted or otherwise electrically and physically connected to the circuit traces 36, 37 on either side of the substrate 21, the trace 36 providing the required electrically conductive path from screen 24 through the conductive material 40 in the via 38 to the trace 37 to the other screen 22.

If materials other than conventional printed circuit board are used for the separator strata 20,

several techniques may be used for attachment of the screens 22, 24 to the separator strata 20. For example, the screens 22, 24 may be attached to the separator 20 by stitching the screens 22, 24 together through the separator 20 as illustrated in Figure 4. The screens 22, 24 are preferably placed 180° out of phase with each other on either side of the separator 20 and a thread 44 is stitched from one side to the other to provide the desired mechanical connection of the screens 22, 24 to the separator 20. In the case of a conducting separator 20 made of material like graphite plate or foil or metal, the thread 44 may be chosen to provide the best mechanical bond and need not be conductive. In the case of a non-conducting separator 20 made of material like TEFLON™, fibreglass or MYLAR™, the thread 44 should provide electrical conductivity as well as mechanical bonding, and accordingly should be made of conductive filamentary material such as a carbon fibre material.

The task of assembling the cell skeleton 12 is greatly eased by placing the undulate screens 22, 24 out of phase with each other, as illustrated in Figures 1, 2, 4, 5 and 6. When placed out of phase the screens 22, 24 on either side of the separator 20 touch the separator at the same point. It is therefore possible to bond all three components at the same time, working simultaneously from both sides of the separator 20. However, it is possible to construct the cell skeleton 12 by connecting together in-phase screens or screens less than 180° out of phase as shown in figures 3, 7 and 8 , but the task in these last cases is more difficult, because the connecting apparatus must work from one side of the cell skeleton 12 and through what will become the

flow conduits 28, 30 rather than from both sides of the cell skeleton 12.

No matter what material or what phase is used to create the cell skeleton 12 by stitching or the use of mechanical fasteners, the separator 20 must be punctured. Thus, for the separator 20 to be fluid-impermeable, a seal 46 must be provided around the stitches 44. The seal 46 may be comprised of simple silicon sealant or such sealing compositions as liquid NAFION™. A conductive (carbon-filled) epoxy sealant may be particularly useful if the separator 20 is non-conducting.

If metallic fasteners are used to bond the current collectors to the separator then the sealant can serve the secondary function of providing electro-chemical isolation between the metal components and the active region of the cell to render the metallic fastener inert in the fuel cell environment.

In Figure 5, another method of constructing cell skeletons 12 is illustrated in which non-metallic screens 22, 24 made of materials such as carbon cloth are bonded to a non-metallic separator stratum 20 such as a graphite sheet by means of conductive bonds 48 comprised of a bonding agent such as conductive epoxy or other carbon-filled (and therefore conductive) adhesive substance. This approach has the advantage of avoiding puncturing of the separator stratum 20. The method has the further advantage that each undulate screen 22, 24 may be attached by working from only one side of the separator stratum 20 at a time as there is no need to have access to the other side of the separator stratum

20 as is the case in stitching or using mechanical fasteners. This method greatly facilitates the construction of cell skeletons 12 with undulate screens 22, 24 that are in phase with each other. The screens 22, 24 in Figure 5 are out-of-phase with each other, but this method may be used for screens 22, 24 in any phase relationship with each other. However, some conductive adhesives tend to have low conductivities that result in relatively high internal resistance within the resulting cell structure, so care must be taken to use an adhesive with as high a conductivity as possible.

When both the screens 22, 24 and the separator stratum 20 contain metallic components, then the cell skeleton 12 can be constructed using welding, brazing or soldering techniques. Spot welding requires the contact of an electrode structure with the cell skeleton components from both sides, and thus favours designs in which the two screens are 180° out of phase. Diffusion welding requires the entire cell skeleton 12 to be assembled and clamped into a jig, whereupon the clamped assembly can be placed in a high-temperature oven and subsequently welded.

If the screens 22, 24 are non-metallic, but the separator stratum 20 contains metallic components, the cell skeleton 12 can nevertheless be assembled using welding, brazing or soldering techniques by adding auxiliary metal plates or the like. Figure 6 shows the use of a metallic separator stratum 20 with carbon screens 22, 24. In order to create the desired electronic and mechanical bond, thin plates 50 of metallic material are laid on top of the screens 22, 24 and are each welded, brazed or soldered through the

screens 22, 24 to the separator stratum 20.

It is preferable to gold- or platinum-plate the metallic components of the completed cell skeleton 12 after attachment of the screens 22, 24 to the separator stratum 20 to reduce the risk of corrosion. Alternatively, a thin layer of conductive polymer material, such as polyaniline, may be applied to the metallic components of the completed cell skeleton 12 to provide a corrosion-resistant protective layer. Metallic cell skeletons which have not been treated with appropriate coatings will have reduced lifetimes compared to their coated counterparts, but will still work acceptably well in certain applications due to their simpler construction and reduced costs.

Cell skeletons in accordance with the present invention may be used in a variety of MEA fuel cell stack structures, for example, as illustrated in Figures 7 and 8. In Figure 7, the collector screens 22, 24 attached to each separator 20 are in phase, rather than out of phase as illustrated in Figures 1 and 2. In Figure 8, the separators 20 as well as the collector screens 22, 24 are undulate and in phase.

The cell skeletons 12 and layered MEA structures 25 may be assembled together into the fuel cell stack 10 either (1) by inserting sheets of conventional MEA material between the cell skeletons 12 and clamping the cell skeletons 12 together under pressure to conform the MEA material to the surfaces of the associated screens 22, 24 or (2) by forming the MEA strata *in situ* between cell skeletons 12 to form the layered MEA structures as described in detail British application Serial No.

9814123.7 (McLean *et al.*, assigned to the applicant herein) filed on 1 July 1998 and derivatives and divisionals thereof.

The cell skeletons are built up in an appropriate and continuous manufacturing process without the presence of any electro-chemically reactive substances. This means the skeleton can be exposed to high temperatures, pressures and "hostile environments" to facilitate manufacture prior to integration as part of a fuel cell stack.

The skeleton can be built from any number of materials ranging from more expensive but known conventional fuel cell materials (carbon, graphite, TEFLON™) to metals to combinations of these materials. The skeleton is of built up construction and does not rely on the use of bulk materials, thus minimizing filled volume and hence weight.

Hydrogen may be used as a fuel gas in a fuel cell stack incorporating the internal support structures 12 described above. In Figure 1 a portion of an exemplary fuel cell stack 10 is shown as made up of fuel cells 32A and 32B and includes separator plates 20A, 20B, and 20C. Stack 10 is connectable via a cathode terminal (not shown) and an anode terminal (not shown) to an external load (not shown). Using as an example the fuel cell indicated by reference numeral 32A, each fuel cell has a discrete MEA layer 25A and is associated with two of the reactant-gas impermeable separator layers 20A, 20B. Each MEA layer 25A has a porous anode electrode 18, a porous cathode electrode 16, an electrolytic membrane

layer 14 disposed between the two electrodes, an anode electro-catalyst layer (not shown) disposed between the electrolytic membrane layer 14 and the anode electrode 18, and a cathode electro-catalyst layer (not shown) disposed between the electrolytic membrane layer 14 and the cathode electrode 16. One side of one associated separator layer 20A in conjunction with the MEA layer 25A provides at least one flowpath of a flow field for hydrogen and one side of the other associated separator layer 20B in conjunction with the MEA layer 25A provides at least one flowpath of a flow field for a selected oxidant. The flowpaths are constituted over their greater length by parallel transversely spaced and longitudinally extending flow channels interconnected in the vicinity of their ends to form the flowpaths. Each MEA layer 25A, 25B is installed in the stack between the associated separator layers 20A, 20B, 20C so that the side of the separator layer that in conjunction with the MEA layer provides flow channels of a flow field for hydrogen faces and is in contact with the anode side of the MEA layer 25A, 25B, whilst the side of the separator layer providing flow channels of a flow field for oxidant faces and is in contact with the cathode side of the MEA layer 25A, 25B, so that the hydrogen flow channels are closed to form a conduit for supplying hydrogen to the MEA layer 25A, 25B and the oxidant flow channels are interconnected in the manner described above to form a conduit for supplying oxidant to the MEA layer 25A, 25B. For example, in the fuel cell having reference numeral 32A, the oxidant flow channels are indicated by reference numeral 28 and the hydrogen flow channels by reference numeral 30. The fuel cells 32A, 32B are stacked in sequence and the anode electrode 18 of the fuel cell, say 32A, at one extremity of the stack

electrically connected to the anode terminal, the cathode electrode 16 of the fuel cell 32B at the other extremity of the stack 10 electrically connected to the cathode terminal, and the anode electrode of each of the other fuel cells in the stack electrically connected to the cathode electrode of the next adjacent fuel cell. When the anode terminal and cathode terminal are electrically connected through an external load and for each fuel cell hydrogen is supplied to the hydrogen conduit and oxygen is supplied to the oxidant conduit, then in each fuel cell hydrogen moves from the hydrogen flow field through the anode electrode and is ionized at the anode electro-catalyst layer to yield electrons and hydrogen ions, the hydrogen ions migrate through the electrolytic membrane layer to react with oxygen that has moved from the oxidant flow field through the cathode to the cathode electro-catalyst layer and with electrons that have moved from the anode electrode electrically connected to the cathode electrode, thereby to form water as a reaction product, and a useful current of electrons is thereby produced through the load.

While particular elements, embodiments and applications of the present invention have been shown and described, it will be understood, of course, that the invention is not limited thereto, since modifications may be made by those skilled in the applicable technologies, particularly in light of the foregoing description. The appended claims include within their ambit such modifications and variants of the exemplary embodiments of the invention described herein as would be apparent to those skilled in the applicable technologies.

What is claimed is:

1. For use in an MEA fuel cell stack including a stacked series of membrane layers extending generally in dimensions perpendicular to the stack dimension and alternating with support structures, a support structure comprising:

a reactant gas-impermeable separator stratum extending generally in dimensions perpendicular to the stack dimension; and

a pair of reactant gas-permeable electrically conductive current collectors lying adjacent the separator stratum on opposite sides thereof, each collector in non-continuous physical and electrical contact with the separator stratum and attached to the separator stratum so as to form, when a membrane layer is sandwiched between two such skeletons so that the membrane layer is conformed to surfaces of the collectors and is in general physical and electrical contact with the collectors, at least one discrete conduit between each separator stratum and the membrane layer for flow of a discrete reactant gas therethrough,

the separator stratum providing at least one electrically conductive path between current collectors, and

the support structure having sufficient rigidity to retain its shape when installed in an MEA fuel cell stack between two membrane layers.

2. A support structure as defined in claim 1, wherein the separator stratum is planar.

3. A support structure as defined in claim 2, wherein the current collectors are undulate.

4. A support structure as defined in any of claims 1 - 3, wherein the separator stratum is an uninterrupted layer of uniform thickness.

5. A support structure as defined in any of claims 1 - 4, wherein each separator stratum is a thin electrically conductive plate.

6. A support structure as defined in any of claims 1 - 5, wherein the current collectors are made of expanded metal mesh.

7. A support structure as defined in any of claims 1 - 5, wherein the current collectors are made of carbon cloth.

8. A support structure as defined in any of claims 1 - 7, wherein the current collectors stitched to the separator stratum.

9. A support structure as defined in any of claims 1 - 8, wherein the support structure has sufficient rigidity to retain its shape when installed in an MEA fuel cell stack between two membrane layers and the stack is placed under sufficient pressure in the stacking direction to maintain physical and electrical contact between each current collector and the adjacent membrane layer.

10. A support structure as defined in any of claims 1 - 9, wherein each current collector is bonded to the adjacent membrane layer.

11. An MEA fuel cell stack comprising:

a stacked series of membrane layers extending generally in dimensions perpendicular to the stack dimension; and

a stacked series of support structures extending generally in dimensions perpendicular to the stack dimension and alternating with the membrane layers in the stack,

each support structure including:

a reactant gas-impermeable separator stratum extending generally in dimensions perpendicular to the stack dimension; and

a pair of reactant gas-permeable electrically conductive current collectors lying adjacent the separator stratum on opposite sides thereof, each collector in non-continuous physical and electrical contact with the separator stratum and attached to the separator stratum,

so that in the stack each membrane layer is sandwiched between a discrete pair of skeletons so that it conforms to surfaces of the collectors of those skeletons and is in general physical and electrical contact with those surfaces and at least

one discrete conduit is formed between the separator stratum of each skeleton and the membrane layer for flow of a discrete reactant gas therethrough,

each separator stratum providing at least one electrically conductive path between the current collectors attached to it, and

the support structure having sufficient rigidity to retain its shape when installed in the stack.

12. An MEA fuel cell stack as defined in claim 11, wherein each separator stratum is planar.

13. An MEA fuel cell stack as defined in claim 12, wherein the current collectors are undulate.

14. An MEA fuel cell stack as defined in any of claims 11 - 13, wherein the separator stratum is an uninterrupted layer of uniform thickness.

15. An MEA fuel cell stack as defined in any of claims 11 - 14, wherein each separator stratum is a thin electrically conductive plate.

16. An MEA fuel cell stack as defined in any of claims 11 - 15, wherein the current collectors are made of expanded metal mesh.

17. An MEA fuel cell stack as defined in any of claims 11 - 15, wherein the current collectors are made of carbon cloth.

18. An MEA fuel cell stack as defined in any of claims 11 - 17, wherein the current collectors stitched to the separator stratum.

19. An MEA fuel cell stack as defined in any of claims 11 - 18, wherein the support structure has sufficient rigidity to retain its shape when installed in an MEA fuel cell stack between two membrane layers and the stack is placed under sufficient pressure in the stacking direction to maintain physical and electrical contact between each current collector and the adjacent membrane layer.

20. An MEA fuel cell stack as defined in any of claims 11 - 19, wherein each current collector is bonded to the adjacent membrane layer.

21. The use of hydrogen as a fuel gas in fuel cells in a fuel cell stack connectable via an anode terminal and a cathode terminal to an external load, each said fuel cell having:

(i) an MEA layer having a porous anode electrode, a porous cathode electrode, an electrolytic membrane layer disposed between the two electrodes, an anode electro-catalyst layer disposed between the electrolytic membrane layer and the anode electrode, and a cathode electro-catalyst layer disposed between the electrolytic membrane layer and the cathode electrode; and

(ii) two discrete associated reactant-gas

impermeable support structures, one side of one support structure in conjunction with the MEA layer providing at least one flowpath of a flow field for hydrogen and one side of the other support structure in conjunction with the MEA layer providing at least one flowpath of a flow field for a selected oxidant, the flowpaths are constituted over their greater length by parallel transversely spaced and longitudinally extending flow channels interconnected in the vicinity of their ends to form the flowpaths;

the MEA layer being installed in the stack between the associated support structures so that the side of the support structure that in conjunction with the MEA layer provides flow channels of a flow field for hydrogen faces and is in contact with the anode side of the MEA layer, whilst the side of the support structure providing flow channels of a flow field for oxidant faces and is in contact with the cathode side of the MEA layer, so that the hydrogen flow channels are closed to form a conduit for supplying hydrogen to the MEA layer and the oxidant flow channels are closed to form a conduit for supplying oxidant to the MEA layer; and

the fuel cells being stacked in sequence, the anode electrode of the fuel cell at one extremity of the stack being electrically connected to the anode terminal, the cathode electrode of the fuel cell at the other extremity of the stack being electrically connected to the cathode terminal, and the anode

electrode of each of the other fuel cells in the stack being electrically connected to the cathode electrode of the next adjacent fuel cell,

so that when the anode terminal and cathode terminal are electrically connected through an external load and for each fuel cell hydrogen is supplied to the hydrogen conduit and oxygen is supplied to the oxidant conduit, then in each fuel cell hydrogen moves from the hydrogen flow field through the anode electrode and is ionized at the anode electro-catalyst layer to yield electrons and hydrogen ions, the hydrogen ions migrate through the electrolytic membrane layer to react with oxygen that has moved from the oxidant flow field through the cathode to the cathode electro-catalyst layer and with electrons that have moved from the anode electrode electrically connected to the cathode electrode, thereby to form water as a reaction product, and a useful current of electrons is thereby produced through the load

characterized in that

each support structure is provided with:

a reactant gas-impermeable separator stratum extending generally in dimensions perpendicular to the stack dimension; and

a pair of reactant gas-permeable electrically conductive current collectors lying adjacent the separator stratum on opposite sides thereof, each collector in non-continuous

physical and electrical contact with the separator stratum and attached to the separator stratum so as to form, when an MEA layer is sandwiched between two such support structures so that the MEA layer is conformed to surfaces of the collectors and is in general physical and electrical contact with the collectors, at least one discrete conduit between each separator stratum and the MEA layer for flow of a discrete reactant gas therethrough,

the separator stratum providing at least one electrically conductive path between current collectors, and

the support structure having sufficient rigidity to retain its shape when installed in the fuel cell stack between two MEA layers.

22. The use of hydrogen as defined in claim 21, wherein the separator strata are planar.

23. The use of hydrogen as defined in claim 22, wherein the current collectors are undulate.

24. The use of hydrogen as defined in any of claims 21 - 23, wherein the separator strata are uninterrupted layers of uniform thickness.

25. The use of hydrogen as defined in any of claims 21 - 24, wherein each separator stratum is a thin electrically conductive plate.

26. The use of hydrogen as defined in any of claims 21 - 25, wherein the current collectors are of expanded metal mesh.

27. The use of hydrogen as defined in any of claims 21 - 25, wherein the current collectors are made of carbon cloth.

28. The use of hydrogen as defined in any of claims 21 - 27, wherein the current collectors stitched to the separator stratum.

29. The use of hydrogen as defined in any of claims 21 - 28, wherein the support structure has sufficient rigidity to retain its shape when installed in an MEA fuel cell stack between two membrane layers and the stack is placed under sufficient pressure in the stacking direction to maintain physical and electrical contact between each current collector and the adjacent membrane layer.

30. The use of hydrogen as defined in any of claims 21 - 29, wherein each current collector is bonded to the adjacent membrane layer.

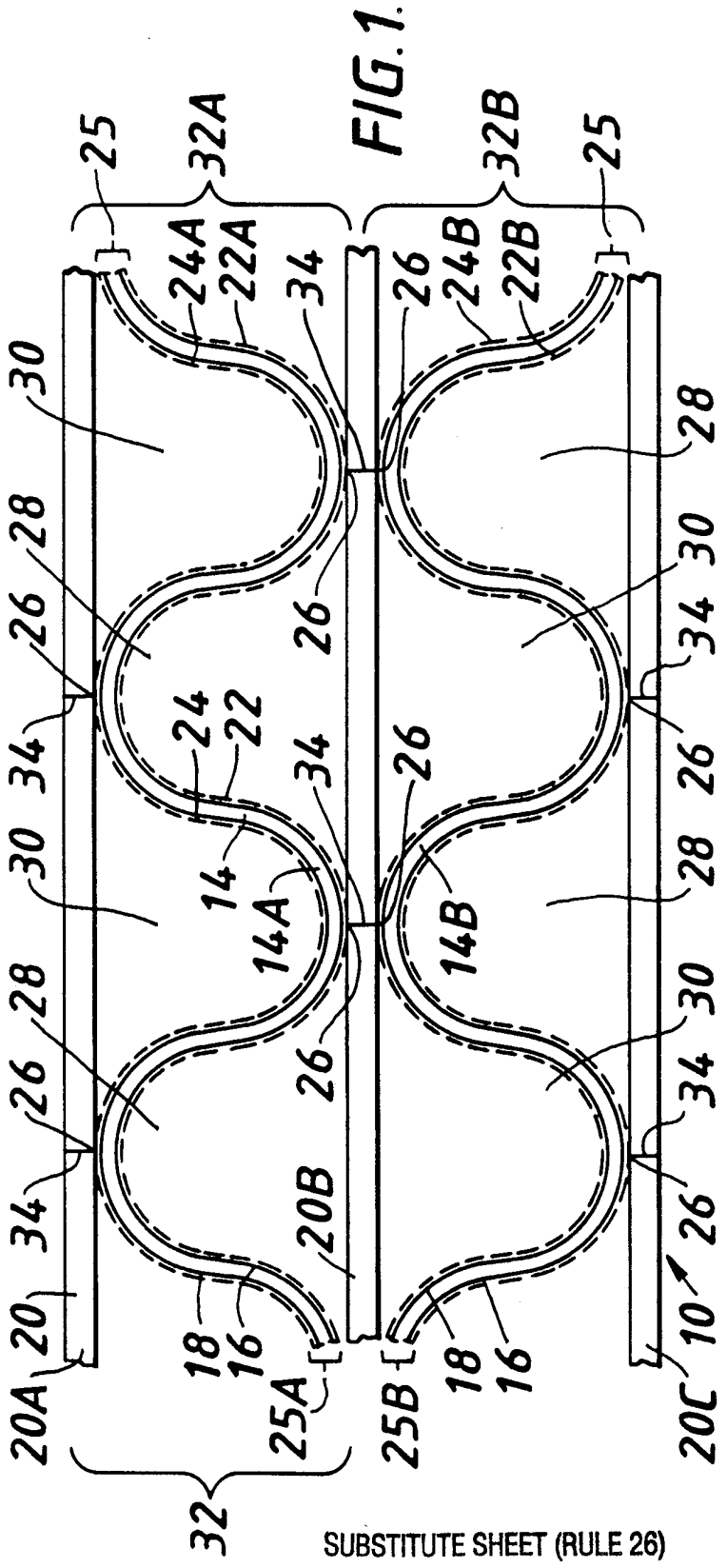
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FIG.1.

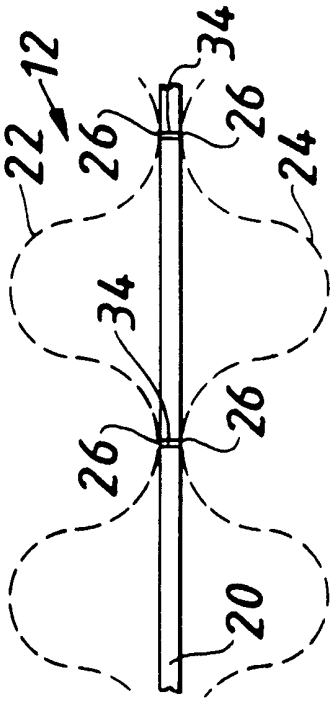
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FIG.2.

FIG. 3.

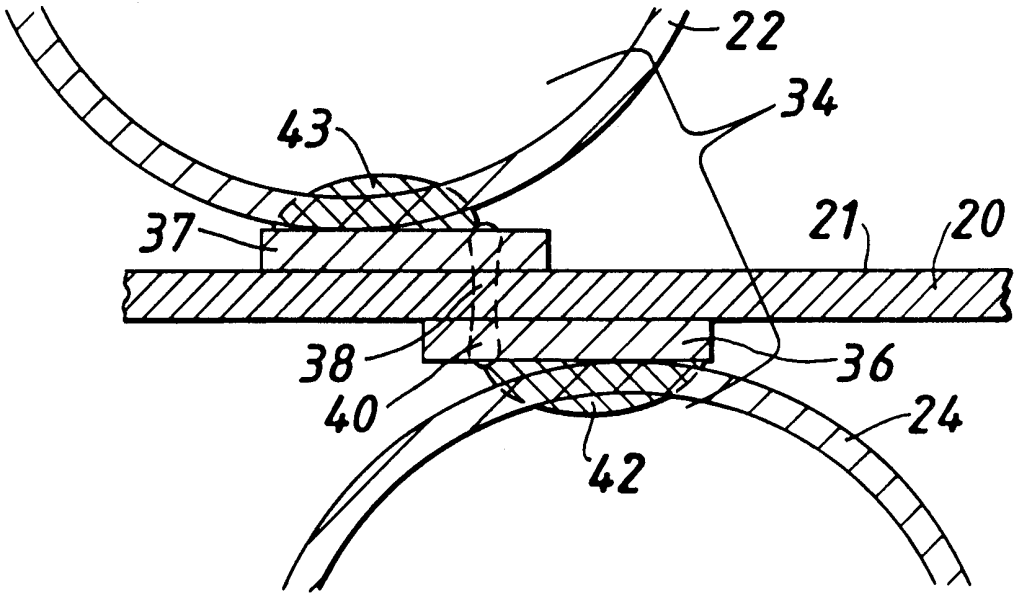


FIG. 4.

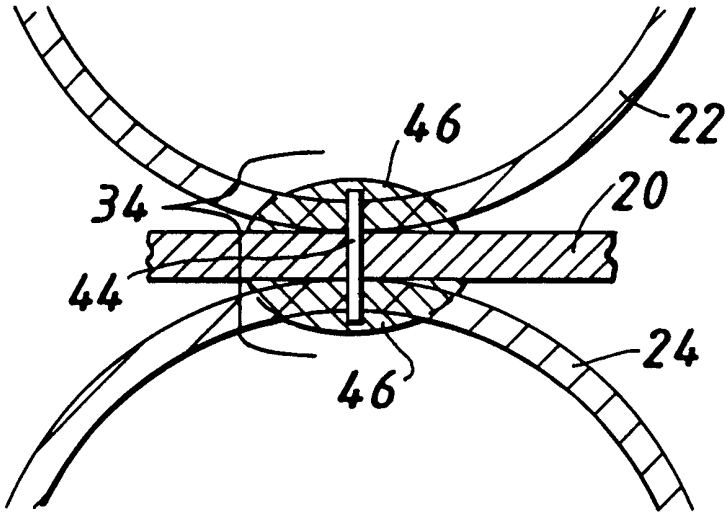


FIG. 5.

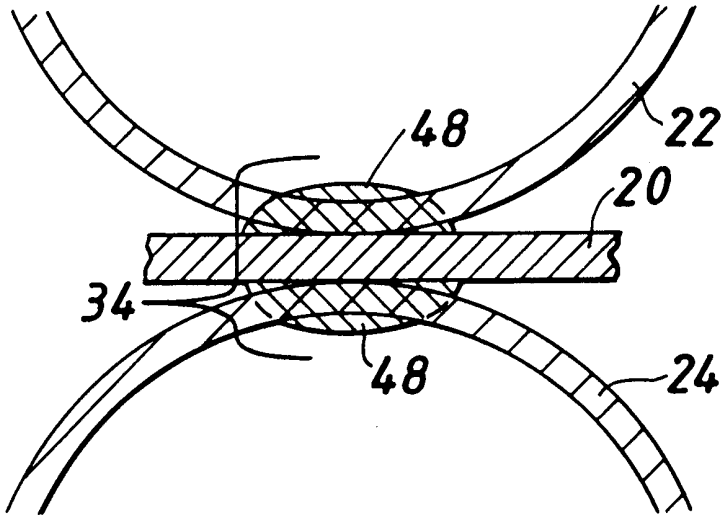
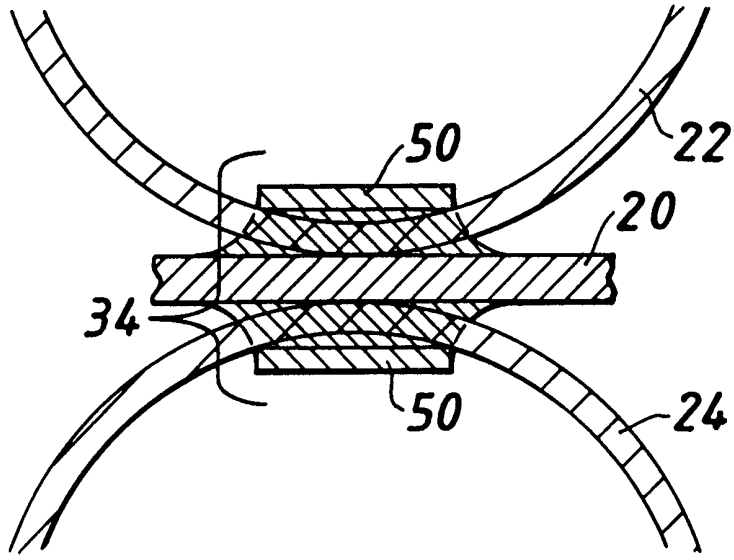


FIG. 6.



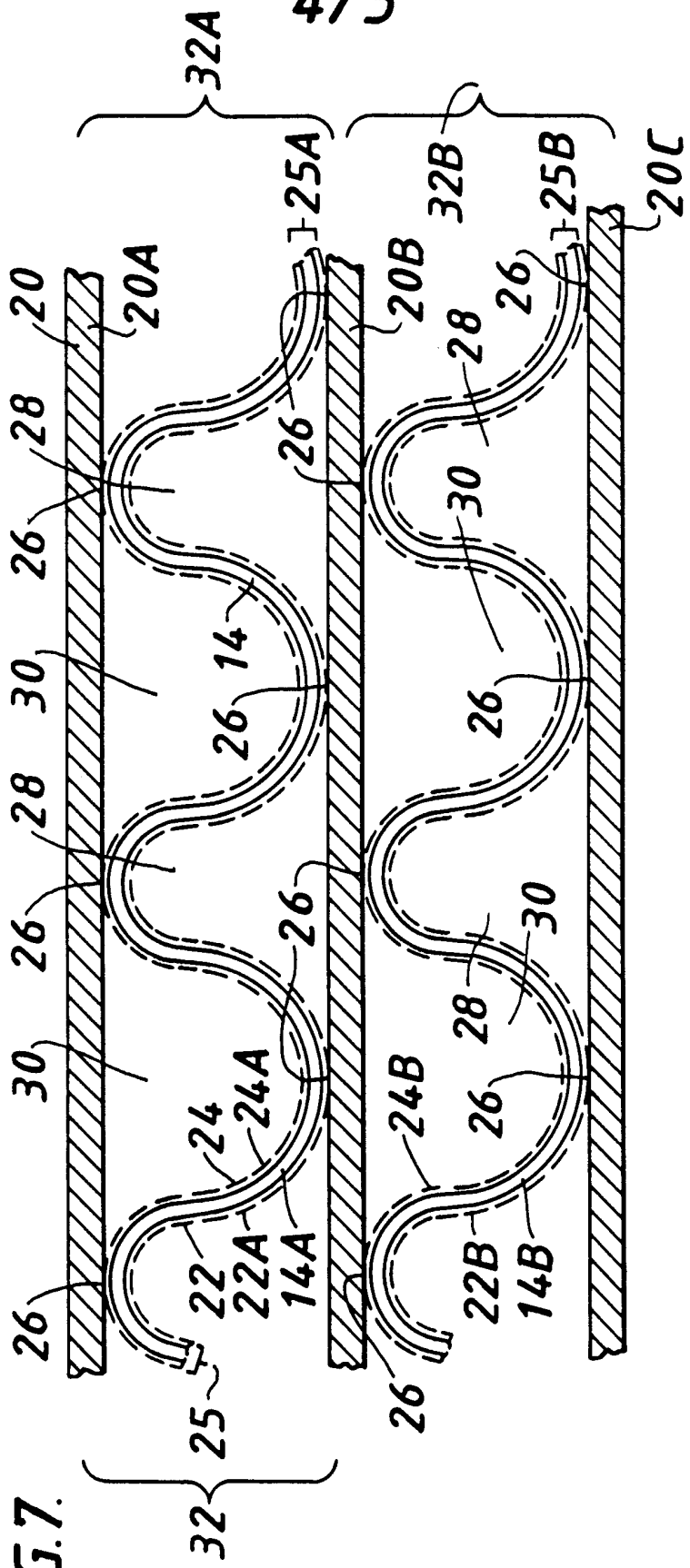

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FIG.7.

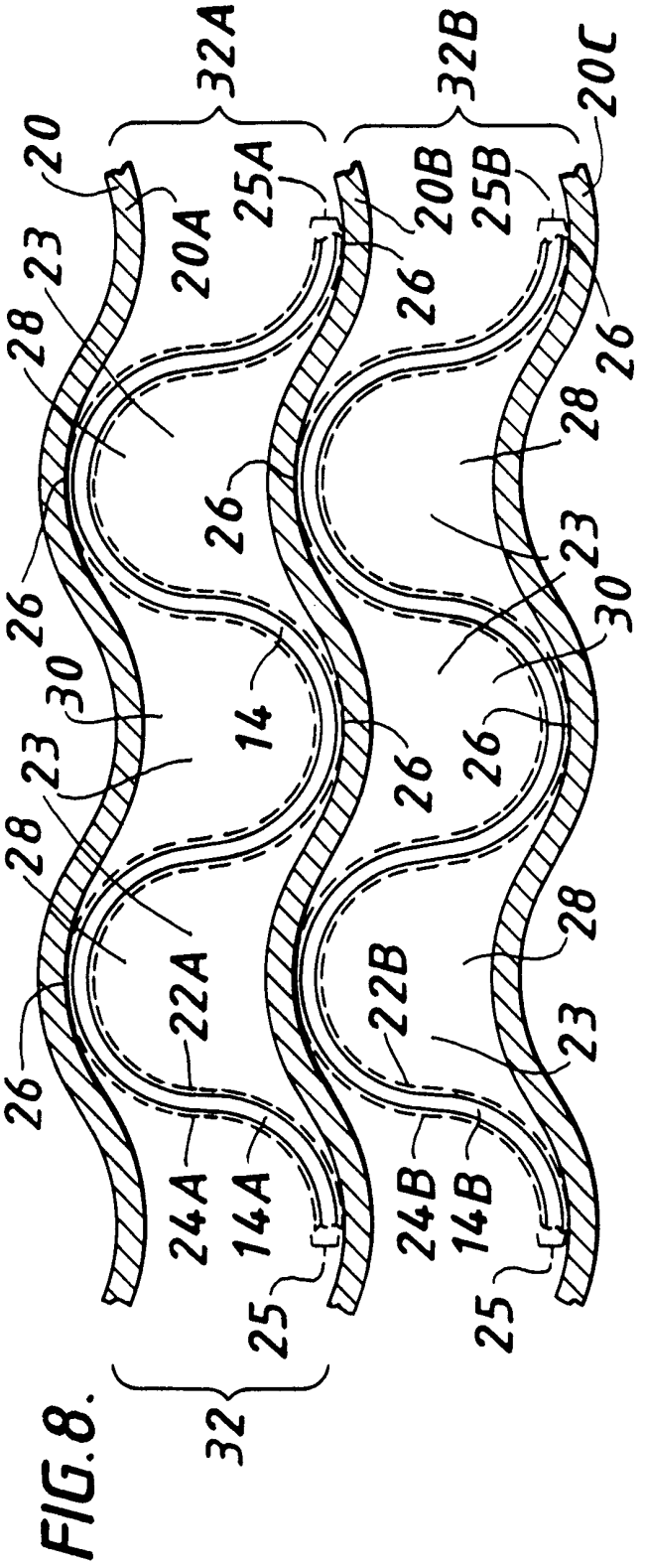
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FIG.8.