

-1-

Seal For A Fuel Cell Stack

FIELD OF THE INVENTION

5

The present invention relates to a seal assembly for separating gases in a fuel cell stack. It is particularly applicable to providing gas-tight seals between the faces of components in a stack of planar solid-oxide fuel cells.

10 BACKGROUND OF THE INVENTION

Solid oxide fuel cell stacks operate at elevated temperature using both fuel gases and oxidising gases. A single stack is formed by stacking a plurality of fuel cell components together with interconnecting manifolds to allow respective fuel and oxidizing gases to
15 flow between components of each cell. The cell components include alternately arranged fuel cell plates and gas separator plates, with seals provided therebetween to separate the gases flowing through the stack. Additional structures are also required to guide the flow of the gases over the fuel cells and to regulate the spacing between adjacent plates of each cell.

20

Difficulties have been encountered in producing a reliable and robust seal between facing surfaces of the cell plates and the gas separator plates because of the difficult environment in which the seal needs to operate.

25 Solid oxide fuel cell stacks operate at typically 700 to 1100°C, preferably 700 to 850 or 900°C and it has been proposed to form the seals from molten or semi molten glass positioned at contact points between facing surfaces of the fuel cell and gas separator plates. An axial compressive force needs to be applied to the stack in order to hold the plates together but such a compressive force also has the effect of tending to squeeze any
30 sealing material from between the mating surfaces. This is exacerbated in the case of a vertically standing stack where the plates at the bottom of the stack may have, in addition

- 2 -

to the axial compressive force induced throughout the stack, the additional weight of the plates above them also tending to squeeze the sealing material from between the mating faces.

5 It has been proposed to produce such a seal by mixing a glass powder with a binder before positioning the resultant sealing material between the facing surfaces, where sealing is required. The sealing material may be applied to the appropriate surface(s) by way of a screen printing process. In order to complete formation of the seal, the material needs to be exposed to oxygen during warm up of the stack, in order to burn out the binder and
10 develop the final seal. In many situations it is difficult to deliver an adequate oxygen supply to all areas of the seal in order to provide a satisfactory burn out process within a reasonable time. An incomplete burn out process may result in a porous and possibly non-functional seal. The burn out also produces emissions which are costly to collect and treat in a commercial mass production operation.

15 In order to reduce the likelihood of such a seal being squeezed out from between the mating surfaces of the fuel cell plates, it has been proposed to incorporate higher melting point sand particles into the glass sealing material in order to provide a spacer between the mating surfaces, but extended durability tests on fuel cell stacks indicate that this means of
20 spacing is unreliable for long term operation. The sand also compromises the density of the glass seal.

An aim of the present invention is to provide a seal which addresses these difficulties.

25 SUMMARY OF THE INVENTION

According to the invention, there is provided a fuel cell stack comprising alternating solid oxide fuel cell plates and gas separator plates stacked face to face with one or more seal assemblies provided between opposed generally planar surfaces of each adjacent pair of
30 said fuel cell and gas separator plates, each of said seal assemblies comprising a pair of rigid ribs projecting from one of said surfaces with a valley defined therebetween, and a

- 3 -

third rigid rib projecting from the other of said surfaces and nested between said pair of ribs, wherein each rib has side walls and tapers away from the respective plate, said side walls of the rib forming opposed contact surfaces that cooperate to define the maximum insertion of the third rib into the valley with said third rib having a profile that leaves a
5 void between the valley and the third rib at said maximum insertion, and wherein each of said seal assemblies further comprises a glass sealant along the valley in said void that contacts the surface of the valley and the third rib.

With the defined seal assembly, a load bearing interlocking arrangement of ribs is provided
10 that physically supports the fuel cell and gas separator plates whilst ensuring that the glass sealant is not load bearing. Additionally, the ribs are designed such that they cause the seal assemblies to be self-aligning upon interlocking of the fuel cell and gas separator plates. To facilitate this, each rib tapers away from the respective plate towards a distal surface of the rib and the side walls of the ribs form the opposed contact surfaces, whereby the void is
15 formed between the distal surface of the third rib and the surface of the valley. Preferably, each rib has two inclined side walls.

In this arrangement, the distal surface of at least one of the pair of ribs may also contact the opposed plate at the maximum insertion of the third rib into the valley, in order to spread
20 the load bearing.

Preferably, the fuel cell stack is a columnar stack and said one of said surfaces is upwardly facing so that the valley between the pair of ribs is upwardly open but for the third rib and the glass sealant can be readily disposed in the valley during assembly of the stack.
25 Conveniently, the glass sealant is introduced to the valley as a powder that is heated to melt the glass after assembly.

The glass sealant is advantageously fully molten but viscous at a temperature in the operating temperature range of the stack of about 700 to about 1100°C, and most
30 preferably the glass sealant is fully molten but viscous at any temperature in the preferred operating range of 700 to 900°C. One possible composition range for the glass sealant is

- 4 -

0-2 wt% Li_2O , 0-18 wt% Na_2O , 2-25 wt% K_2O , 0-4 wt% MgO , 0-15 wt% CaO , 0-10 wt% SrO , 0-30 wt% BaO , 0-25 wt% B_2O_3 , 0-10 wt% Al_2O_3 , 30-75 wt% SiO_2 and 0-10 wt% ZrO_2 . More preferably, the glass sealant has a composition range of 0-0.7 wt% Li_2O , 0-1.2 wt% Na_2O , 5-15 wt% K_2O , 0-2 wt% MgO , 2-12 wt% CaO , 0-2 wt% SrO , 2-10 wt% BaO ,
5 2-10 wt% B_2O_3 , 2-7 wt% Al_2O_3 , 50-70 wt% SiO_2 and 0-2 wt% ZrO_2 .

The ribs should have a sufficient height to provide the desired spacing for the respective gas flow between the adjacent plates. For example, the ribs may have a height in the range of 250 to 1000 μm .

10

The portions of the fuel cell and gas separator plates incorporating the seal assemblies may be formed of metallic or ceramic material. In the case of metallic material, the ribs and valley of each seal assembly could be etched on respective sides of the plates. Alternatively, in either case, the ribs could be formed by depositing on the plate an
15 appropriate rib material or precursor material that would adhere to the plate. Thus, in the case of ceramic plates, the ribs may be formed by screen printing a slurry of the rib material in a binder onto the respective surfaces, and drying and firing the resultant structure. The ribs are conveniently formed of the same ceramic material as the respective

plates, for example zirconia. In the case of the gas separator plates, the zirconia may contain up to 20 wt% alumina. Preferably the ribs on the fuel cell plates are formed on the electrolyte and the electrolyte is yttria-stabilised zirconia.

- 5 The fuel cell stack may be internally and/or externally manifolded for the incoming and exhaust gases, and the shape and location of the seal assemblies must be adjusted accordingly.

In the described embodiment the fuel cell stack is internally manifolded for the incoming
10 fuel gas and exhaust fuel gas, and each aperture through the fuel cell and gas separator plates for said incoming fuel gas and exhaust fuel gas is surrounded by a respective one of the seal assemblies on a cathode-side of each pair of adjacent fuel cell and gas separator plates. Advantageously, there are two exhaust fuel gas manifolds, and the seal assemblies around the apertures therefor each have an arm extending away from the respective
15 aperture towards but spaced from the incoming fuel gas manifold and alongside the cathode to guide oxygen-containing gas over the cathode.

Also in the described embodiment the fuel cell stack is externally manifolded for incoming and exhaust oxygen-containing gas, and a single one of said seal assemblies extends in a
20 closed loop on an anode side of each pair of adjacent fuel cell and gas separator plates outwardly of said apertures through the plates. The closed loop is conveniently shaped to direct the incoming fuel gas over the anode. In a preferred embodiment, the incoming and exhaust oxygen-containing gas manifolds are defined by the periphery of the plates, the seal assemblies and a housing in which the stack is disposed. The manifolds between the
25 periphery of the plates and the housing may be separated from each other by seals.

BRIEF DESCRIPTION OF THE DRAWINGS

One embodiment of a fuel cell stack in accordance with the invention will now be
30 described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a plan view of the fuel cell stack;

Figure 2 is an exploded schematic perspective view looking downwards and illustrating the general orientation of cell plates and gas separator plates within the stack shown in Figure 1;

Figure 3 is a schematic perspective view looking upwards at the cell plates and gas separator plates in the same exploded positions shown in Figure 2;

Figure 4 is a perspective view of the top side of one of the cell plates as shown in Figure 2;

Figure 5 is a cut-away perspective view of the top side of one of the gas separator plates shown in Figure 2;

Figure 6 is a cut-away underside view of the separator plate shown in Figure 5; and

Figure 7 is a diagrammatic cross-sectional view through a portion of a gas seal assembly between the plates shown in Figures 1 and 2.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Referring to Figures 1, 2 and 3 a solid oxide fuel cell stack assembly 2 comprises a stack 3 of alternating fuel cell components, in the form of cell plates 10 and gas separator plates 30 held within a tubular housing 4. All of the cell plates 10 are identical and all of the separator plates 30 are identical. Typically there might be 20 to 500 of each of these plates in the stack 3. Fuel gas and air are supplied at one axial end of the stack assembly and exhaust gases are collected at the other end in a co-current manifolding system. Either end is suitable for the supply and exhaust functions, but the manifold system may alternatively be counter-current. In the described co-current embodiment, the fuel and air supplies are both at the bottom and the exhausts are at the top, but in many circumstances it is preferred for the fuel to be supplied from the bottom and the air to be supplied from the top in a counter-current arrangement. Alternatively, all of the gas supplies and exhausts may be at the same end.

Referring to Figures 1 to 6, each cell plate 10 has a substantially central, square anode layer on an upper face of the electrolyte-based cell plate and a substantially central, square cathode layer on a lower face of the cell plate to form a substantially square fuel cell 12.

5 The cell plates 10 and separator plates 30 have the same outer shape, which could be described as generally trilobular, or part way between a circle and a triangle. The shape could alternatively be described as generally circular with three rounded lobes extending therefrom. Two of the lobes 74 and 76 are the same size and the third lobe 72 extends about 50% further than the others circumferentially around the periphery of the plate. At
10 each lobe 72, 74 and 76 a kidney shaped aperture (numbered 14, 16 and 18 in the cell plate and 15, 17 and 19 in the separator plate respectively) extends through the plate. The larger lobes 72 carry the larger apertures 14 and 15. A system of rib or ridge-shaped seals on the faces of the plates directs the gas flows within the stack. These seals are described hereinafter in more detail.

15

Fuel distribution and exhaust collection manifolds 5 and 6, respectively, (Figure 1) defined by the three aligned series of apertures 14 and 15, 16 and 17, and 18 and 19 in the fuel cell and gas separator plates and formed by interlocking the seal components of the plates 10 and 30, conduct the fuel inlet and exhaust streams past the air side of the plates to the
20 anode side. Air supply and collection manifolds 7 and 8 respectively are created by three volumes formed between the periphery of the stack 3 and the inside wall of the housing 4. Manifold 7 is formed essentially between the lobes 74 and 76 of the plates, and the two exhaust manifolds 8 are formed essentially between the lobes 72 and 74 and the lobes 72 and 76, respectively, of the plates. Air inlet manifold 7 has an angular extent that is about
25 50% larger than the each of the two exhaust manifolds 8, and is opposite the fuel inlet or distribution manifold 5. Respective elongate, sliding fibrous seals 9 extend along the stack adjacent the lobes 72, 74 and 76, between the stack 3 and the inside wall of the housing 4 to separate the air supply manifold 7 from the two air collection manifolds 8. The fibrous seals may permit a degree of leakage between the manifolds 7 and 8, but this is not likely
30 to be detrimental to the operation of the stack.

The housing 4 is constructed of a suitable heat resistant steel sheet material, which may be lined with a suitable insulating material, and is slid into position over the stack 3 after the plates 10 and 30 have been assembled together.

- 5 In operation of the stack, fuel gas flows up through the larger aperture 14 defining an inlet port in each cell plate 10 and (at arrow A) across the face of the fuel cell anode, then divides its flow (arrows B and C) to exit up through exhaust port apertures 17 and 19, respectively, in the adjacent gas separator plate 30. On the opposite face of the cell plate 10 air, which has passed up the side of the stack 3 through the inlet manifold 7 between the
- 10 stack and the housing, flows in (arrow D) from the periphery of the stack 3 and across the face of the fuel cell cathode, in counter-current to the fuel gas flow across the fuel cell anode, before dividing its flow to exit (arrows E and F) from the periphery of the stack 3 and then continuing up through the exhaust manifolds 8 to the top of the stack.
- 15 Referring to Figure 4, the generally planar cell plate 10 used in the stack 3 is shown in greater detail. The square fuel cell 12 on the plate (the anode is visible) has an electrolyte supported structure with the electrolyte material extending out to form the main body of the plate 10. The electrolyte is preferably a yttria stabilised zirconia and suitable 3Y, 8Y and 10Y materials are known to those in the art. The anode is preferably a nickel-zirconia
- 20 cermet and the cathode is preferably a conductive Perovskite such as lanthanum strontium manganate. The underside of the cell plate 10 and the cathode are visible in Figure 3.

A pair of parallel ribs 20 and 21 project from the planar surface 24 of the cell plate 10 forming a valley or groove 22 therebetween. The surface 24 is the upper, anode surface of

25 the cell plate when the stack is oriented for use. The ribs are formed of zirconia and may be integrally formed with the main body of the plate or may be formed separately, for example from a screen printed slurry, and be fired into integral relationship with the main body. Each rib 20 and 21 forms a continuous path or closed loop outwardly of the apertures 14, 16 and 18 through the cell plate and around the perimeter of the region which

30 the fuel gas is permitted to contact. In particular, the closed loop defined by the ribs 20

and 21 is waisted alongside the anode to direct fuel gas from the inlet aperture 14 over the anode.

In all the Figures, the thickness of the plates 10 and 30 and the height of the ribs are shown greatly exaggerated to assist the explanation of the components. In this embodiment, the fuel cell 12 is 2500mm^2 , the cell plate is $150\mu\text{m}$ thick and the ribs are approximately $500\mu\text{m}$ high, 1mm wide and approximately 2mm apart.

On the lower, cathode-side 54 of each fuel cell plate 10, as shown in Figure 3, a respective single rib 34 (that corresponds to the ribs 20 and 21 in term of size and how it is formed) extends around each of the apertures 14, 16 and 18 through the plate. Each of the ribs 34 around the apertures 16 and 18 has an arm 35 that extends inwardly and towards the aperture 14 (but short thereof) alongside the cathode layer of the fuel cell 12 to assist guidance of incoming air over the cathode. One of the ribs 34 is also shown in Figure 7 and the use of the rib seals is described with reference to that Figure.

Figures 5 and 6 show the planar gas separator plate 30 in greater detail. In Figure 5, the surface 33 is the upper, cathode-contacting surface of the separator plate 30 when the stack is oriented for use. Respective pairs of parallel ribs 36 and 37 project from the planar surface 33 of the separator plate 30 forming valleys or grooves 38 therebetween. The pairs of parallel ribs 36 and 37 correspond to the ribs 20 and 21 in terms of size, spacing and how they are formed, but extend around the apertures 15, 17 and 19 through the plate 30 to cooperate with the ribs 34 on the cathode-side of the adjacent fuel cell plate 10. The respective ribs 36 associated with the apertures 17 and 19 each have a double-walled arm 39 that is closed at its distal end to cooperate with and receive the arm 35 of the corresponding rib 34.

On the lower, anode-contacting side 32 of each gas separator plate 30, a single rib 42 is shown in Figure 6 and partly in Figure 5. The rib 42 corresponds to the ribs 20 and 21 in terms of size and how it is formed, and forms a continuous path outwardly of the apertures 15, 17 and 19 through the plate 30 and around the perimeter of the region that the fuel gas

is permitted to contact. The outline of the rib 42 corresponds to the groove 22 between the ribs 20 and 21 on the anode surface of the adjacent fuel cell plate 10 and cooperates with those ribs in forming a seal.

- 5 As explained hereinafter, with reference to Figure 7, glass sealant 40 is used in both of valleys 22 and 38 to form a seal between the ribs.

Each separator plate 30 is conveniently manufactured from a zirconia to substantially match the coefficient of thermal expansion of the main body of the cell plates 10. This
10 greatly minimises thermal stresses in the assembly during start-up, operation and shut-down. The zirconia may be yttria-stabilised, but could be, for example, an alumina-added zirconia with up to 20 wt% alumina.

The zirconia is not electrically conductive, and the separator plate 30 has an array of
15 perforations 50 extending perpendicularly through its full thickness that are filled with an electrically conductive plug material. These perforations may be formed by laser cutting and occupy a region in the plate 30 which is directly opposite the region occupied by the fuel cell 12 in plate 10. The plug material may be metallic silver (commercially pure) which is plated into the perforations by standard plating or printing techniques.
20 Alternatively the perforations may be filled with a silver alloy or a silver composite, such as a composite of silver or silver alloy in glass. Suitable alloying elements include gold, palladium and platinum. Alternatively, the silver may be mixed with stainless steel, for example as powder prior to sintering in the perforations.

25 The perforations have an average cross-sectional dimension of about 300 μm , and the plug material seals the perforations to present a total cross-sectional area of plug material in the range of 0.2 to 5mm² per 1000mm² of surface area opposed to the respective electrode, measured on one side only of the plate 30. The electrically conductive silver based plug which fills each perforation is preferably plated with a protective Ni coating on the anode
30 side and an Ag-Sn coating on the cathode side. The coatings advantageously extend over the entire electrode contacting areas of the plate. The nickel coating may have an

- undercoating of Ag to assist the Ni to bond to the separator body and to enhance the compliance of the coating, and the Ag-Sn coating may have a SnO_2 surface layer. Such coatings, for example by screen printing of powder materials in a binder and subsequent firing, may act to fill the perforations 50 from the outside so as to ensure that electrically
- 5 conductive paths are provided via the perforations from one of the outer surfaces to the other outer surface of the gas separator plate. By way of example only, the nickel coating, the Ag coating (if present) and the Ag-Sn coating may have thicknesses in the range of 60-100 μm , 20-200 μm and 100-150 μm , respectively.
- 10 An array of parallel ridges 48 is positioned parallel to the air flow stream in the cathode contacting area on the side 33 of each plate 30. These ridges 48 are each aligned over a corresponding row of perforations 50 and over any Ag-Sn coating. To assist explanation, about half of the ridges 48 have been removed in Figures 2 and 5. The ridges 48 perform two major functions. First they provide a conductive path between the plug material in
- 15 perforations 50 or Ag-Sn coating and the fuel cell 12. Second they provide physical support to brace the thin and fragile cell plate as well as means for distributing gas flows in the narrow spaces between the cell plates and the separator plates. The ridges 48 thus need to be both electrically conductive and structurally stable. The ridges 48 are approximately 500 μm high and could be made from a conductive perovskite, such as the LSM material
- 20 of the cathode, optionally with a metallic silver coating about 50 μm thick over the ridges.
- On the underside of plate 30 (ie. surface 32 shown in Figure 6), the rows of plugged perforations 50 and any Ni coating and/or Ag undercoating are covered by an array of parallel ridges 62 that are positioned parallel to the fuel gas flow stream. Again, about half
- 25 the ridges 62 are cut away in Figure 6 to assist visualisation of the structure. The ridges 62 perform as a current collector whereby current is conducted between the plug material in the perforations 50 or any coating and the anode. They also provide physical support for the cell plate and additionally provide means for directing and distributing gas flows in the narrow spaces between the cell plates and separator plates. The ridges are approximately
- 30 500 μm high and could be formed from the same material as the anode, optionally with an overlay (approx 50 μm thick) of nickel.

- 12 -

Referring to Figure 7, a pool of glass sealant 40 is located between the ribs 36 and 37 and is pressed into by rib 34. Each rib has a tapered profile with oppositely inclined flanks and a distal surface. A similar arrangement applies between the ribs 20 and 21 and rib 42, but will not be described separately. During manufacture, the glass is introduced as a powder and the stack assembled before the stack is heated to melt the glass in order to form the required seal. Thus, no binder is required. In operation of the stack the glass sealant 40 is fully molten but highly viscous and is retained in the groove 38 by one of the following three options not all shown in Figure 7. The glass advantageously has a composition range of 0-0.7 wt% Li_2O , 0-1.2 wt% Na_2O , 5-15 wt% K_2O , 0-2 wt% MgO , 2-12 wt% CaO , 0-2 wt% SrO , 2-10 wt% BaO , 2-10 wt% B_2O_3 , 2-7 wt% Al_2O_3 , 50-70 wt% SiO_2 and 0-2 wt% ZrO_2 .

In this embodiment, when the third rib 34 is inserted to its maximum extent into the groove 38, each inclined flank 52 of the third rib 34 would engage a corresponding inclined flank 58 of a respective one of the pair of ribs 36 and 37 defining the groove 38, leaving distal surfaces 60 and 61 of the ribs 36 and 37, respectively, clear of basal surfaces 54 of the plate 10 and distal surface 51 of the rib 34 clear of floor 56 of the groove 38. In this case the sealant 40 would fill the volume between the distal surface 51 and the floor 56. If desired, the relative proportions of the ribs may be such that at the maximum insertion of the third rib 34 the basal surfaces 54 of the plate 10 contact the distal surfaces 60 and 61 of the ribs 36 and 37, respectively, at the same time as the flanks 52 and 58 engage as described.

25

The described embodiment provides a stack configuration which is simple to construct and has substantial flexibility in control of the gas flows to, from and over the fuel cell electrodes. It uses a relatively small number of components and the sliding interfaces provided by the fibrous seals produce much lower stresses during thermal cycling.

30

Whilst the above description includes the preferred embodiments of the invention, it is to be understood that many variations, alterations, modifications and/or additions may be introduced into the constructions and arrangements of parts previously described without

- 13 -

departing from the essential features or the spirit or ambit of the invention as defined by the following claims.

For example, the preferred embodiment has separator plates made from zirconia.

5 Alternatively they may be made from a lanthanum chromite to facilitate electrical conductivity therethrough, or from a self-aluminising stainless steel.

Other aspects of the fuel cell stack described herein are disclosed and claimed in copending International patent applications filed concurrently herewith entitled Solid
10 Oxide Fuel Cell Stack Configuration and A Fuel Cell Gas Separator Plate, respectively claiming priority from Australian provisional patent applications PR6344 and PR6365 filed 13 July 2001, and the contents of both of said copending International patent applications and of their US national phase equivalents are incorporated herein by reference.

15

It will be also understood that where the word "comprise", and variations such as "comprises" and "comprising", are used in this specification, unless the context requires otherwise such use is intended to imply the inclusion of a stated feature or features but is not to be taken as excluding the presence of other feature or features.

20

The reference to any prior art in this specification is not, and should not be taken as, an acknowledgment or any form of suggestion that such prior art forms part of the common general knowledge.

CLAIMS

1. A fuel cell stack comprising alternating solid oxide fuel cell plates and gas separator plates stacked face to face with one or more seal assemblies provided between
5 opposed generally planar surfaces of each adjacent pair of said fuel cell and gas separator plates, each of said seal assemblies comprising a pair of rigid ribs projecting from one of said surfaces with a valley defined therebetween, and a third rigid rib projecting from the other of said surfaces and nested between said pair of ribs, wherein each rib has side walls and tapers away from the respective plate, said side walls of the rib forming opposed
10 contact surfaces that cooperate to define the maximum insertion of the third rib into the valley with said third rib having a profile that leaves a void between the valley and the third rib at said maximum insertion, and wherein each of said seal assemblies further comprises a glass sealant along the valley in said void that contacts the surface of the valley and the third rib.
15
2. A fuel cell stack according to claim 1 wherein each rib has two inclined side walls.
3. A fuel cell stack according to claim 1 or claim 2 wherein at least one of the pair of ribs has a distal surface that also contacts the opposed plate at said maximum insertion.
20
4. A fuel cell stack according to any one of claims 1 to 3 which is a columnar stack and said one of said surfaces is upwardly facing.
5. A fuel cell stack according to any one of claims 1 to 4 wherein the glass sealant has
25 a composition range of 0-2 wt% Li_2O , 0-18 wt% Na_2O , 2-25 wt% K_2O , 0-4 wt% MgO , 0-15 wt% CaO , 0-10 wt% SrO , 0-30 wt% BaO , 0-25 wt% B_2O_3 , 0-10 wt% Al_2O_3 , 30-75 wt% SiO_2 and 0-10 wt% ZrO_2 .
6. A fuel cell stack according to claim 5 wherein the glass sealant has a composition
30 range of 0-0.7 wt% Li_2O , 0-1.2 wt% Na_2O , 5-15 wt% K_2O , 0-2 wt% MgO , 2-12 wt% CaO , 0-2 wt% SrO , 2-10 wt% BaO , 2-10 wt% B_2O_3 , 2-7 wt% Al_2O_3 , 50-70 wt% SiO_2 and 0-2

wt% ZrO_2 .

7. A fuel cell stack according to any one of claims 1 to 6 wherein the glass sealant is fully molten but viscous at a temperature in the operating temperature range of the stack of
5 about 700 to about 1100°C.

8. A fuel cell stack according to claim 7 wherein the glass sealant is fully molten but viscous at any temperature in the range 700 to 900°C.

10 9. A fuel cell stack according to any one of claims 1 to 8 wherein all of the plates are ceramic and the ribs are formed by screen printing a slurry of the rib material in a binder onto the respective surfaces, and drying and firing the resultant structure.

10. A fuel cell stack according to any one of claims 1 to 9 wherein all of the plates are
15 ceramic and the ribs formed are respectively of the same material.

11. A fuel cell stack according to claim 10 wherein the gas separator plates are formed of zirconia containing up to 20 wt% alumina.

20 12. A fuel cell stack according to claim 10 or claim 11 wherein the ribs on the fuel cell plates are formed on the electrolyte and the electrolyte is yttria-stabilised zirconia.

13. A fuel cell stack according to any one of claims 1 to 12 wherein the fuel cell stack is internally manifolded for the incoming fuel gas and exhaust fuel gas and each aperture
25 through the fuel cell and gas separator plates for said incoming fuel gas and exhaust fuel gas is surrounded by a respective one of the seal assemblies on a cathode-side of each pair of adjacent fuel cell and gas separator plates.

14. A fuel cell stack according to claim 13 wherein there are two exhaust fuel gas
30 manifolds and the seal assemblies around the apertures therefor each have an arm extending away from the respective aperture towards but spaced from the incoming fuel

- 16 -

gas manifold and alongside the cathode to guide oxygen-containing gas over the cathode.

15. A fuel cell stack according to claim 13 or claim 14 wherein the fuel cell stack is externally manifolded for incoming and exhaust oxygen-containing gas and a single one of
5 said seal assemblies extends in a closed loop on an anode side of each pair of adjacent fuel cell and gas separator plates outwardly of said apertures through the plates.

16. A fuel cell stack according to claim 15 wherein the closed loop is shaped to direct the incoming fuel gas over the anode.

10

17. A fuel cell stack according to claim 15 or claim 16 wherein the incoming and exhaust oxygen-containing gas manifolds are defined by the periphery of the plates, the seal assemblies and a housing in which the stack is disposed.