



- (51) **International Patent Classification:**
H01L 51/42 (2006.01) **H01L 51/00** (2006.01)
H01L 51/44 (2006.01)
- (21) **International Application Number:**
PCT/GB2012/051263
- (22) **International Filing Date:**
6 June 2012 (06.06.2012)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
1109389.5 6 June 2011 (06.06.2011) GB
- (71) **Applicant (for all designated States except US):** **INSIDE2OUTSIDE LIMITED** [GB/GB]; 4th Floor Brook Point, 1412 High Road, London N20 9BH (GB).
- (72) **Inventors; and**
- (75) **Inventors/Applicants (for US only):** **CARPENTER, Robert** [GB/GB]; c/o Inside2Outside Limited, 4th Floor Brook Point, 1412 High Road, London N20 9BH (GB). **FLEMING, Patrick** [GB/GB]; c/o Opus 21 Limited, 21 Berkshire Road, Henley-on-Thames, Oxfordshire RG9 1ND (GB). **STOEVA, Zlatka** [GB/GB]; c/o DZP Technologies Limited, 22 Signet Court, Cambridge, Cambridgeshire CB5 8LA (GB). **TONCHEV, Dan** [CA/GB]; c/o

DZP Technologies Limited, 22 Signet Court, Cambridge, Cambridgeshire CB5 8LA (GB).

- (74) **Agents:** **BROWN, George** et al.; Urquhart-Dykes & Lord LLP, Tower North Central, Merrion Way, Leeds, Yorkshire LS2 8PA (GB).

- (81) **Designated States (unless otherwise indicated, for every kind of national protection available):** AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) **Designated States (unless otherwise indicated, for every kind of regional protection available):** ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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- (54) **Title:** TENSILE SOLAR CELL, METHOD OF MANUFACTURING, APPARATUS AND SYSTEM

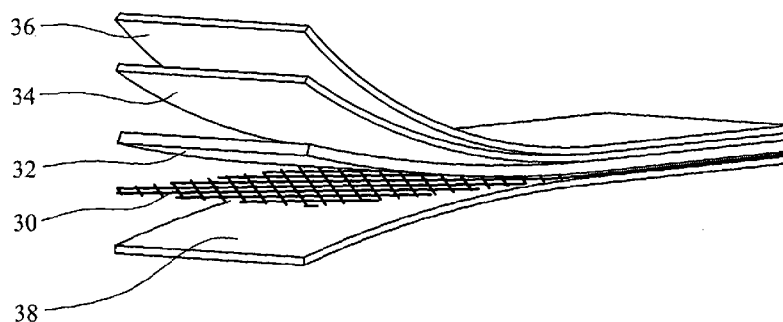


FIG. 5

(57) **Abstract:** A solar cell which remains operative when subject to an applied tensile load is described. The solar cell comprises: a tensile layer; a first photovoltaic structure; and first and second electrodes, each connected to a different surface of the first photovoltaic structure. The tensile layer enables a tensile load to be carried and the photovoltaic structure can maintain its properties when subject to strain. The photovoltaic cell preferably comprises a bulk heterojunction. A method of manufacturing a bulk heterojunction for use in a photovoltaic structure is also described. The method comprises depositing an electron transport layer on an electrode surface using solution deposition; and depositing a hole transport layer on the electron transport layer using solution deposition. It has been found that manufacture of the layers in this way allows spontaneous creation of a bulk heterojunction between the electron transport layer and the hole transport layer. An apparatus for improved cooling of a solar cell in use, thereby improving its efficiency is also described. The apparatus comprises: a supporting structure; a flexible container comprising a first flexible sheet forming an upper surface and a second flexible sheet forming a lower surface, wherein the flexible container is attached to the supporting structure so that the second sheet is at least partially in tension; at least one flexible solar cell at least partially covering the upper surface of the flexible container; an inlet for supplying fluid into the container; and an outlet for removing fluid from the container.





Published:

- *without international search report and to be republished
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TENSILE SOLAR CELL, METHOD OF MANUFACTURING, APPARATUS AND SYSTEM

The present application relates to solar cells incorporating a tensile layer and methods of
5 manufacturing that can be applied to such solar cells. The present invention also relates to an apparatus and system which can provide cooling for a solar cell.

It is known to incorporate solar cells into the roof surfaces of buildings to generate electricity from incident sunlight. However, conventional solar cells are inflexible and
10 planar. Conventionally, solar cells are therefore applied to roofs in an array which does not cover the whole surface of the roof. Typically, the cells are aligned on the surface of the roof which is south facing, or alternatively, are simply arranged flat on top of a flat roof. These arrangements are inefficient at collecting incident particularly in the morning and evening when the sun is low in the sky.

15 It would be desirable to provide a solar cell which could be formed into a more versatile three-dimensional structure than existing solar cells.

Solar cells fabricated on a flexible membrane have been proposed. For example, GB-A-
20 2424121 discusses a solar cell using an electrode formed from cotton fabric coated with conductive polymer. The cell comprises a cotton cloth coated with polyethylene (PE), a Poly(3,4-ethylenedioxythiophene) (PEDOT) film formed on the PE coated cloth, a light-absorbing polymer film on the PEDOT film and an aluminium layer formed by
25 evaporation on the polymer film. The electrodes of the cell are provided by the PEDOT film on the cloth and the aluminium layer. This can produce a fabric solar cell that may be incorporated in, amongst other items, clothing, bags, umbrellas, furnishings, tents, flags or sails.

Flexible solar cells as described in GB-A-2424121 are not suitable for use in tensile
30 membranes. A tensile membrane can support a load applied across the plane of the membrane. As a result of the applied tensile load, the membrane will be placed under strain and deform along the plane of the membrane. Transferring the strain to the solar cell

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on the flexible membrane can be detrimental to the functional properties of the cell, especially its conductive properties. This detrimental effect is observed because solar cells are typically comprised of polycrystalline materials where grain size and spacing between the grains determine of level of electrical conductivity. For example, it is known from

5 (Chen et al, 2011, Semicond. Sci. Tech 26, 034005; Jedaa et al, 2009, Appl Phys Lett, 95, 103309) that tensile strain applied on electronic devices such as flexible transistors causes an increase in the inter-grain spacing and increased energy barrier for charge hopping which leads to deterioration and eventual failure of the transistors deposited on flexible substrates. Similar effect was observed in poly-silicon photovoltaics (Watanabe et al.,

10 2007, Materials Science Forum, 558-559, 843) where unidirectional and rotational solidification from the melt was employed to control the grain boundary microstructure and to produce desirable bulk electrical properties in polysilicon photovoltaics.

The prior art cited above demonstrates the serious challenges which are encountered in the design and manufacture of electrical and electronic devices on tensile substrates. The

15 structure disclosed in GB-A-2424121 does not work as a solar cell if a tensile load is applied to the cotton cloth because of the strain transfer to the solar cell.

A tensile structure incorporating solar cells is discussed in WO-A-2010/011649 (FTL Solar). It mentions a tensile structure in which a membrane is attached to vertical support

20 members, forming a roof. A plurality of flexible solar cells is integrated with the membrane. Various methods of integration are discussed but the preferred method is to affix a solar cell by adhesive or lamination. WO-A-2010/011649 does not recognise that conventional flexible solar cells will lose their functional properties when subject to an applied tensile load. While use of an adhesive to attach a solar cell to the membrane may

25 allow an attached solar cell to function when a tensile load is applied to the membrane, this is most likely because the adhesive is flexible and does not transfer the strain from the tensile load to the solar cell.

Various solutions have also been proposed to allow use of solar cells which are curved and

30 non-planar. EP-A-0874404, US-6288324 and US-6215060 by Canon discuss a solar cell and manufacture for curved roof surfaces. US-4419531 by Siemens relates to a solar cell suitable for curved surfaces where the solar module is embedded in synthetic resin. WO-

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A-2009/039666 discusses an array of interconnected solar cells which are arranged in such a way that the light collecting area can collect light over a wide range of angles.

5 It would be desirable to provide a solar cell which can still function when a tensile load and resulting strain are applied to the solar cell. Such a solar cell could be used in wide variety of applications and simplify the construction of three-dimensional structures incorporating solar cells.

10 The efficiency of photovoltaic solar cells is known to vary with temperature. In general, as the temperature of the solar cell increases, the efficiency decreases. The stronger the solar radiation incident on a solar cell, the higher the temperature it will be heated to. Therefore, when the incident solar radiation on the solar cell is strong, the temperature of the cell will be high and its efficiency will decrease.

15 It would be desirable to provide a mechanism for cooling a photovoltaic solar cell.

FR-A-2924864 discusses a photovoltaic solar module which has a surface exposed to solar radiation and another surface fixed on a support. A heat exchanger is placed on the surface fixed on a support and includes a channel that allows passage of a coolant such as air.

20 Such a construction can allow cooling of a photovoltaic solar cell. However, the construction is large, bulky and heavy.

It would be desirable to provide an improved apparatus which provides support for and allows cooling of a solar cell in use.

25

In an aspect of the invention, there is provided a solar cell which is formed on a tensile membrane and which comprises a photovoltaic structure comprising a bulk heterojunction. The tensile membrane allows a tensile load to be carried and the solar cell can maintain its properties when subject to strain, allowing a solar cell which can still function under

30 tensile load to be produced.

In an aspect of the invention, a structure of a solar cell which remains operative when subject to an applied tensile load is provided. The solar cell comprises: a tensile layer; a first photovoltaic structure; and first and second electrodes, each connected to a different surface of the first photovoltaic structure. Photovoltaic structure herein means any layered structure which exhibits photovoltaic effect when irradiated by light, when placed between two electrically conductive electrodes. In one preferred embodiment, the first photovoltaic structure comprises an electron transport layer, a hole transport layer and a bulk heterojunction between the electron transport layer and the hole transport layer.

10 This structure can be produced efficiently using deposition techniques. Suitable deposition techniques include known printing methods such as flexographic, gravure, screen, gravure, inkjet printing, in addition to other known deposition methods such as vacuum deposition, sputtering, chemical vapour deposition, etc. The structure can be fabricated using a single deposition method, for example flexographic printing; or a combination of deposition
15 methods where the photovoltaic structure and the electrode layers are fabricated using different deposition methods.

The photovoltaic structure is comprised of material which exhibits photo-voltaic effect and which can be deposited as a thin film layer. Examples of suitable materials include
20 amorphous silicon; chalcogenide compounds such as cadmium telluride and cadmium selenide; chalcopyrite materials such as copper indium selenide (CIS) and its alloys; organic polymer light-absorbing material such as a blend of poly(3-hexylthiophene) (P3HT) and phenyl-C61-butyric acid methyl ester (PCBM); organic molecule light-absorbing material such as a blend of copper phthalocyanine and phenyl-C61-butyric acid
25 methyl ester (PCBM). When blends of organic molecule or organic polymer are used, as in the latter two examples, the two materials can be applied in either planar or bulk heterojunction configuration. Bulk heterojunctions, where the two components mix and then form interpenetrating, phase-separated network with a nano-scale morphology, are most promising according to the prior art (B. Keppelen et al, Energy and Envir. Science, 2009,
30 2, 241-332; J. Peet et al, Acc. Chem Res, 2009, 42, 1700-1708). Such bulk heterojunctions enable optimised charge carrier diffusion to the electrodes of the cell which increases the light-conversion efficiency.

It has been found in the disclosed invention that a bulk heterojunction can arise spontaneously when adjacent layers for electron transport and hole transport are formed.

- 5 The electrode material can be any material which has sufficient electrical conductivity and which can be deposited as a conductive grid, film or pattern. Examples include aluminium, silver, gold and other conductive metals, conductive carbonaceous material, conductive polymers, conductive oxides or combination of these materials. Additionally, the top electrode has to be made out of transparent material which is conductive, for instance
- 10 silver or other metal mesh, transparent conductive oxide (e.g. indium tin oxide, zinc oxide), or transparent conductive polymer such as poly(3,4-ethylenedioxythiophene) (PEDOT), or a combination of these materials.

In one embodiment, the electron transport layer may comprise carbon flakes. The carbon

15 flakes are preferably less than 5 μm in size, more preferably between 0.5 μm and 5 μm in size. Using carbon flakes reduces cost and allows the electron transport layer to be produced by solution deposition or printing using inks that comprise the carbon flakes. In another embodiment, the electron transport layer comprises a fullerene, carbon fibres or carbon nanotubes. The hole transport layer may comprise copper phthalocyanine or zinc

20 phthalocyanine. Again, this can be produced by solution deposition or printing using inks that comprise copper phthalocyanine or zinc phthalocyanine.

In another embodiment, the electron transport layer comprises Zinc Oxide. The hole transport layer then preferably comprises zinc phthalocyanine.

25

In other embodiments, the hole transport layer may comprise hole conjugated polymer.

In still other embodiments, at least one of the electron transport layer or the hole transport layer contains acrylic polymer of below 20% by weight.

30

In some embodiments, the electron transport layer and the hole transport layer are each less than 2 μm thick. This minimises the materials required to produce the photovoltaic

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structure. Layers of this thickness can be formed by solution deposition or printing processes.

In one embodiment, the solar cell further comprises:

- 5 a second photovoltaic structure; and
 - a third electrode connected to a surface of the second photovoltaic structure;
- wherein the second photovoltaic structure comprises an electron transport layer, a hole transport layer and a bulk heterojunction between the electron transport layer and the hole transport layer. In this embodiment, the presence of first and second photovoltaic
- 10 structures means that more of the incident light is converted into electrical power.

Preferably, the first photovoltaic structure is configured to generate an electric potential from a first range of wavelengths of incident light and the second photovoltaic structure is configured to generate an electric potential difference from a second range of wavelengths

15 of incident light, which is different from the first range of wavelengths. For instance, a photovoltaic structure comprising an amorphous Si light- absorber layer responds to wavelengths longer than 350nm whereas a photovoltaic structure comprising a CdS/CdTe layer absorbs strongly at wavelengths longer than 480nm. Other light-absorbing materials which generate electric potential at different incident light wavelength are presented later

20 in the text.

By configuring the first and second photovoltaic structures to be responsive to different wavelengths of light, the efficiency can be further improved. This is particularly advantageous if the construction of the tensile membrane is such that the solar cells are

25 transparent enough to allow transmission of light which is not absorbed by them.

In one embodiment, the first electrode may be shared between both the first and second photovoltaic structures, simplifying construction. Alternatively, a fourth electrode can be provided so that the third and fourth electrodes are connected to different surfaces of the

30 second photovoltaic structure.

In some embodiments, the tensile layer itself may be conductive and function as one of the electrodes. This can simplify construction.

In another embodiment, protection means for protecting the solar cell may be provided.

- 5 The protection means may be provided by a layer of protective material. Alternatively, the protection means can be incorporated into the tensile layer.

In another aspect of the invention, there is provided, a method of manufacturing a bulk heterojunction for use in a photovoltaic structure comprising:

- 10 depositing an electron transport layer on an electrode surface using solution deposition; and

depositing a hole transport layer on the electron transport layer using solution deposition.

- 15 It has been found that manufacture of the layers in this way allows spontaneous creation of a bulk heterojunction between the electron transport layer and the hole transport layer.

Preferably, the electron transport layer and the hole transport layer are deposited using printing techniques. This allows simple and cost-effective production.

20

Preferably, the hole transport layer is deposited using a printing technique which applies pressure. This assists the formation of the bulk heterojunction.

In another aspect, a solar cell is provided which comprises a bulk heterojunction

- 25 manufactured according to the method described above. Such a solar cell can be manufactured at low cost, for example using printing techniques.

In a further aspect, the present invention provides an apparatus with a supporting structure and a flexible container attached to the supporting structure. At least one solar cell is

- 30 provided on the flexible container, and the supporting structure holds the flexible container in tension. An inlet and an outlet allow for fluid flow through the flexible container. This

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allows a lightweight construction which can be used on its own or affixed to other structures, such as buildings.

According to a yet further aspect of the present invention, there is provided an apparatus
5 comprising:

a supporting structure;

a flexible container comprising a first flexible sheet forming an upper surface and a second flexible sheet forming a lower surface, wherein the flexible container is attached to the supporting structure so that the second sheet is at least partially in tension;

10 at least one flexible solar cell at least partially covering the upper surface of the flexible container;

an inlet for supplying fluid into the container; and

an outlet for removing fluid from the container.

15 The reference to a “sheet” is used to refer to an element with a typical thickness of 1mm, although other embodiments may have other thicknesses, for example a thickness less than 1mm or a thickness of greater than 1 mm, providing that the thickness is small in relation to the length and width of the sheet. The first and second sheet may be formed from natural or synthetic material. The first and second sheets may be formed from a single
20 material, provided as a continuous membrane or by weaving threads. In other embodiments, these sheets may be composites with a layered construction of different materials. The first and second sheets are preferably impermeable to fluid to prevent its loss from the container. Suitable material include, but are not limited to PVC, EVDF or any other polymer suitable for forming a tensile fabric or to act as a substrate for a solar
25 cell. The sheets may be reinforced by polyester, aramid or carbon fibre, or by natural fibres.

In some embodiments both the first and the second sheet may be in tension.

30 The inlet and the outlet may be provided as any suitable point on the container but are preferably provided at opposite ends.

This aspect of the invention provides a lightweight, inexpensive apparatus that can be used to generate electricity directly by the solar cell. The inlet and the outlet allow fluid to be circulated within the container, provided cooling for the solar cell in use, improving its efficiency. The flexible solar cell is attached to the upper surface of the first flexible sheet
5 and therefore is not necessarily required to carry a tensile load, which is carried by the second flexible sheet. The first flexible sheet may be lightly in tension, with this tension being transmitted to the lower sheet through fluid present inside the container.

The circulation of fluid may be unassisted, for example, using convection currents.
10 Alternatively, the circulation of fluid may be assisted, for example by using a pump or compressor.

The second sheet is at least partially in tension. This provides strength to the flexible container and ensures that it holds a particular shape.
15

In one embodiment, the supporting structure comprises a frame defining at least one opening. The first and the second sheet are attached to the frame so that they extend over an opening. This provides a lightweight supporting structure with flexibility in the overall appearance, design and shape of the resulting apparatus.
20

The supporting structure may comprise a channel for attachment to an edge portion of the first sheet and the second sheet. This allows easy connection of the flexible container to the supporting structure, by inserting its edges into the channel.

25 In one embodiment, the first sheet and the second sheet are attached to the channel by wrapping them around an elongated member which is received in the channel. This provides a secure connection. The elongated member can be of any suitable shape, for example it may be a rod or cylindrical shape. Some embodiments may use beading as the elongated member. In this construction, the wrapping of the first and second sheets around
30 the elongate member also serves to attach the two sheets to each other and define the container. In some embodiments, the first and second sheets may also be bonded together, as well as using the mechanical connection with the channel.

In other embodiments, the first and the second sheet are attached to the channel using an adaptor comprising:

- a receptacle for at least a part of the edge of the first sheet and at least part of the
- 5 edge of the second sheet; and
- a connecting member which is received in the channel.

The receptacle may have various different forms. For example, it may define a generally rectangular cross-section for receiving the sheets of the container one on top of the other.

- 10 Alternatively, it may have a triangular cross-section with the first sheet bonded to one side of the triangle cross-section and the second sheet bonded to the other side.

- In one embodiment, the first and second sheet are integrally formed. In other words, in this embodiment the first and second sheet together form a generally tubular structure that
- 15 defines a continuous space inside along its length. The structure is optionally bonded or mechanically closed by its attachment to the supporting structure at its open ends.

- The apparatus may further comprise a plurality of elements within the container attached to either or both of the first sheet and the second sheet and arranged to define channels to
- 20 direct fluid flow within the cavity between the inlet and the outlet. This construction is particularly advantageous when the internal space of the container is held at a pressure which is less than atmospheric. In these circumstances, the action of the atmosphere on the outer surfaces of the container may press those surfaces together, so that at some points the first sheet is directly in contact with the second sheet. This reduces cooling efficiency. By
 - 25 providing the elements the first and second sheets are prevented from directly touching each other and flow of fluid throughout the container can be promoted.

- Preferably, the plurality of elements are arranged to define a single path or a pattern of paths from the inlet to the outlet. The single path preferably covers substantially all the
- 30 area beneath the at least one flexible solar cell. This enables the fluid to be guided to ensure that the area of the solar cell is cooled efficiently.

The apparatus described above may be used in a system further comprising means for supplying fluid to the inlet. The means for supplying fluid to the inlet may be a pump or compressor. For example, the fluid may be supplied to maintain the pressure within the container at a greater pressure than external atmospheric pressure, inflating the flexible
5 container.

The apparatus described above may also be used in a system comprising means for removing fluid from the outlet. These means may be a pump and can be used to create a pressure less than atmospheric pressure within the container.

10

The apparatus may further comprise a heat exchanger connected to the outlet. This can allow efficient removal of heat from the outlet fluid. The heat from the heat exchanger may be used in many ways, including providing hot water, for example for domestic hot water supplies, building heating or electricity generation, such as using a Stirling engine.

15

In another aspect, the present invention provides a tensile membrane that can form the basis of a three dimensional structure, wherein substantially all of the surface area of the three dimensional structure comprises a solar cell. This allows improved gathering of incident light and greater electricity generation for a given surface.

20

According to a another aspect of the invention, there is provided a tensile membrane comprising a plurality of solar cell portions, wherein the plurality of solar cell portions do not cover the entire area of the tensile membrane; and the plurality of solar cell portions have a shape configured such that, when cut from the tensile membrane, they can be joined
25 to others of the plurality of solar cell portions to form a 3-dimensional shape which comprises a solar cell portion over substantially all the surface area of the 3-dimensional shape.

A solar cell portion is used to refer to an area covered by a solar cells or cells. Depending
30 on configuration it may be a single solar cells or comprise a plurality of interconnected solar cells.

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A single tensile membrane is manufactured comprising a plurality of solar cell portions, so the solar cell portions can be manufactured easily on a production line, for example using known printing processes. Unlike prior solar cells, the solar cell portions are printed so that they do not cover the entire area of the tensile membrane, enabling them to be later cut
5 to shape and joined to others to form a three dimensional structure. Preferably, sufficient space is left that a tab can be formed around the solar cell portion for connection to other solar cell portions.

In one embodiment, at least some of the plurality of solar cell portions have a shape
10 including at least one curved edge. Including a curved edge in the shape means that when the membrane is joined to others, the curved edge will distort the membrane so that it is non-planar. This is unlike existing applications of solar cells and can enable greater amounts of incident light to be collected.

15 Preferably, each of the plurality of solar cell portions comprises a plurality of individual solar cells of substantially equal area. The plurality of individual solar cells are divided into at least two groups and each of the least two groups contains the same number of individual cells connected in series.

20 By making the solar cell portion from a plurality of individual solar cells and dividing those into groups of the same number of cells, the solar cell portion can comprise several sections which will output the same voltage. This allows flexibility in design of the solar cell portion because output voltage is not dependent on the total area, but on the area of each group of cells. The solar cell portion can be divided in any suitable way into
25 individual groups of cells.

Preferably, series connection of cells within groups is made by connecting a lower electrode of a first individual solar cell to an upper electrode of a second individual solar cell. This allows the connection to be formed easily.

30

The groups of cells are preferably connected in parallel, enabling the solar cell to give a consistent voltage output whatever its actual area, with an increase in area increasing the

number of groups connected in parallel and therefore increasing the power output without increasing the voltage.

In another aspect of the present invention, there is provided a tensile membrane comprising
5 a solar cell portion over substantially all its surface area and having a shape configured
such that it can be joined to other tensile membranes to form a 3-dimensional shape which
comprises a solar cell portion over substantially all the surface area of the 3-dimensional
shape. The tensile membrane of this aspect may be formed by cutting it from a tensile
membrane according to the above-described first aspect.

10

As with the above described aspect, in this aspect, the shape may have at least one curved
edge to give a non-planar configuration in use.

The solar cell portion preferably comprises a plurality of individual solar cells of
15 substantially equal area. The plurality of individual solar cells are divided into at least two
groups and each of the least two groups contains the same number of individual cells
connected in series. A series connection is preferably made by connecting a lower
electrode of a first individual solar cell to an upper electrode of a second individual solar
cell. The at least two groups may be connected in parallel.

20

According to another aspect of the invention, there is provided a three-dimensional
structure comprising a plurality of tensile membranes as described above and a supporting
structure for holding the plurality of tensile membranes. This allows construction of a cost
effective, lightweight surface covering. The tensile membranes together provide a solar
25 cell portion which covers substantially all the surface of the three dimensional structure.

The shape of the three-dimensional structure may comprise one or more peaked structures
to maximise gathering of incident light in the morning and evening when the sun is low in
the sky.

30

In one embodiment, at least some of the tensile membranes are non-planar, this can
increase the efficiency of light gathering.

In an aspect of the invention, a structure of a tensile membrane with an integrated solar cell is provided. The structure comprises a tensile membrane and a first photovoltaic structure. First and second electrodes are provided, each connected to a different surface of the first
5 photovoltaic structure. Protection means is provided for protecting the tensile membrane

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings, in which:

- 10 Figure 1 is a diagrammatic representation of a tensile membrane according to an embodiment of the invention with a plurality of solar cell portions thereon;
Figure 2 is a diagrammatic representation of a three-dimensional structure according to an embodiment of the present invention;
Figure 3 is a diagrammatic representation of a series connection between cells according to
15 an embodiment of the invention;
Figure 4 is a diagrammatic representation of a solar cell layout within a solar cell portions according to an embodiment of the invention;
Figures 5-10 are diagrammatic representations of layered structures of a tensile membrane according to various embodiments of the invention.
- 20 Figure 11 depicts a diagrammatic representation of an embodiment according to the invention;
Figure 11A depicts a close up of the connector configuration by which a flexible container is attached to a frame;
Figure 12 depicts a diagrammatic representation of an alternative embodiment of the
25 invention;
Figure 12A depicts a close up of the area marked A in Figure 12;
Figure 13 depicts a cross-section of a diagrammatic representation of one way of connecting a flexible container to a support frame;
Figure 14 depicts a diagrammatic representation of a further way of fixing a flexible
30 container to a support frame;
Figure 15 depicts a close up of an adaptor depicted in Figure 14;

Figure 16 depicts a diagrammatic representation of an alternative adaptor for use in the embodiment of Figure 14;

Figure 17 depicts a diagrammatic representation of one end of a flexible container according to another embodiment using a plurality of elements within the flexible
5 container;

Figure 18 depicts a conceptual diagram of a system for providing circulation of fluid within the apparatus described above at a pressure within the flexible container that is greater than atmospheric pressure; and

Figure 19 depicts a conceptual diagram of a system for supplying fluid through the flexible
10 container of the apparatus described above where the fluid in the container is at a pressure lower than atmospheric pressure.

Figure 1 depicts a base layer 2, which is a tensile membrane, preferably a woven base material. For example, it may be formed from a synthetic or natural polymer, or any
15 suitable tensile material.

Solar cell portions 4 are formed on the base layer 2, for example using known deposition techniques where layers are deposited in sequence to form a desired photovoltaic structure which is capable of displaying photo-voltaic effect. Suitable deposition techniques include
20 known printing methods such as flexographic, gravure, screen, gravure, inkjet printing, in addition to other known deposition methods such as vacuum deposition, sputtering and chemical vapour deposition.

The layered structure of the solar cell portions 4 will be described in detail later. Figure 2
25 illustrates how solar cell portions 4 do not cover the entire area of base layer 2. This allows the solar cell portions to be cut from the base layer 2 to assemble a three-dimensional structure. In prior art methods, the material would be directly incorporated into the three-dimensional structure, and, because it had solar cells formed over substantially its entire area, it could not easily be cut to different sizes or shapes.

30

The area around the solar cell portions 4 which will be cut is illustrated by line 6. The dashed line 8 inside the line 6 indicates a connection portion or tab where no solar cell is

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formed for attachment to other solar cell portions to form a 3D structure. The connection portions may be joined by any suitable method, for example welding.

As can be seen in Figure 1, the solar cell portions 4 have a generally triangular shape and include at least one curved edge. The curved edge allows the solar cell portion to take on a non-planar configuration when assembled into a three-dimensional structure.

Figure 1 illustrates four solar cell portions formed on base layer 2. However, it will be appreciated that any number of solar cell portions could be formed. Alternative shapes may also be used, depending on the desired final three-dimensional structure.

One example three dimensional structure is depicted in Figure 2. The three dimensional structure comprises a plurality of solar cell portions 4 connected to other solar cell portions 4, for example by welding and tensioned under a supporting structure 10. This holds the solar cell portions in tension and forms a lightweight, strong structure. In this embodiment the solar cell portions 4 form a generally pyramidal shape, with non-planar surfaces. This shape is more efficient at gathering incident light. The particular benefit is that the use of solar cell portions 4 means that substantially all the whole surface of the structure is covered with a solar cell portions, ensuring that the entire surface area of the roof is used to its maximum effect.

The solar cell portions 4 can be made up of a plurality of individual solar cells. Figure 3 illustrates how the individual solar cells can be connected in series. The photovoltaic structure 12 of a first cell has an upper conductor 14 and a lower conductor 16. Lower conductor 16 forms the upper conductor of a second photovoltaic structure 18 and a lower conductor 20 is provided for the second photovoltaic structure 18. Connecting conductors 14 and 20 produces a serial connection between the cells formed by photovoltaic structure 12 and 18. The serial connection depicted in Figure 3 can be achieved by depositing the conductors 14 and 20 in two steps.

The cells may have any shape which tessellates over the area of the solar cell portion. Figure 4 depicts one example where the solar cells have a diamond shape. For the

purposes of illustration, the solar cells in Figure 4 are shown with either no colour, or filled in black. These illustrate the different groups formed from a solar cell portion. Each group comprises the same number of solar cells, eleven in this example, and so will produce the same voltage. The individual groups are connected in parallel. Figure 4 depicts one
5 illustrative example of the way the cells may be arranged, other arrangements may be used depending on the particular circumstances of the application. Referring to Figure 4, one group of cells 22 (coloured in black) can be seen adjacent another group of cells 24 (not filled). Each individual cell, for example that indicated by reference numeral 26 is shown in outline.

10

The detailed structure of the solar cell portion 4 will now be described. This is formed from a layered structure. In one embodiment, illustrated in Figure 5, a tensile membrane is formed from a woven conducting material 30. The conducting material can be obtained by dip-coating or impregnation of the woven material with aluminium, gold, silver or other
15 conductive metal; conductive carbonaceous material such as graphene, carbon nanotubes, carbon fibres, carbon flakes, etc; conductive polymer such as poly(3-hexylthiophene) (P3HT) and its derivatives; or combination of these materials. Because the woven conducting material 30 is conductive, it forms a lower electrode of a solar cell. A photovoltaic structure 32 displaying photo-voltaic effect is formed on top of the woven
20 conducting material, for example by printing, or by other deposition and coating methods such as vapour deposition, sputtering, spray coating. A top transparent conductor 34 is formed on top of the photovoltaic structure 32, so that the woven conducting material 30 and the top conductor 34 form the two electrodes of a solar cell. The transparent conductor 34 comprises, for example, aluminium, gold, silver or other conductive metal mesh,
25 transparent conductive oxide (e.g. indium tin oxide, zinc oxide), or transparent conductive polymers such as poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS), commercially available polymers such as Orgacon supplied by Agfa, and Clevios supplied by Heraeus; or a combination of these materials. The top transparent electrode 34 can be fabricated by printing, coating or other known deposition methods.

30

A protection polymer-based coat 36 is formed on top of the top conductor 34 which protects the cell from moisture and oxygen from the environment which otherwise would

lead to degradation of the cell. Another protection and preparation coat 38 is formed under the conducting material 30, so that the final structure is protected.

Next the disclosed embodiment of the invention is described by a reference to examples of photovoltaic structures which are given as examples and do not limit the scope of protection.

Example 1

In this example, a photovoltaic structure 32 is deposited on the top of the lower electrode using flexographic printing. The lower electrode is made out of aluminium. The photovoltaic structure comprises a multilayer structure where a layer containing conductive carbon flakes is printed in contact with the lower electrode, followed by printing of copper phthalocyanine layer on top of the carbon flake layer. The carbon flake layer acts as an electron transport layer whereas the copper phthalocyanine layer acts as a hole transport layer.

The carbon layer is deposited using water-based acrylic ink comprising 5-30% (by weight) conductive carbon flakes of size 0.5 – 5 microns using dispersions commercially available from Emerald Performance Materials LLC. Carbon flakes of sufficient conductivity should be used, in order to ensure that the generated charges are transported and collected at the electrodes.

The copper phthalocyanine layer is printed using inks commercially available DZP Technologies Ltd. These inks are water-based acrylic inks curable at room temperature and suitable for printing on heat-sensitive substrates.

Each of the two printed layers is about 1.5 μm thick and air-dried at room temperature without other temperature or UV treatment. Following the two consecutive printing steps, a bulk hetero-junction of thickness 10-20 nm is spontaneously formed between the carbon flake and the copper phthalocyanine layers as a result of the interlayer diffusion between the two printed layers during printing and drying. The formation of the bulk hetero-

junction is further facilitated by the slight pressure applied by the flexographic roller. The obtained photovoltaic structure displays strong photovoltaic effect when exposed to incident light.

5 Example 2

This example is analogous to Example 1, except that fullerene C₆₀ is used to form the electron acceptor layer. Similarly to Example 1, the cells obtained in this way display strong photo-voltaic effect.

10

Example 3

This example is similar to Examples 1 and 2, however in this case zinc phthalocyanine is used as to print the hole transport layer, and ZnO is used to print the electron acceptor layer. The ZnO layer is deposited next to the lower electrode. Both materials are deposited by flexographic printing using water-based acrylic inks commercially available from DZP Technologies Ltd. The printed layers are of thickness 1.5µm and are cured at room temperature. The cells obtained in this way display photovoltaic effect, in addition to being transparent.

20 Those skilled in the art will be able to devise other examples which make use of the disclosed invention. For instance, hole-transport polymers can be used instead of phthalocyanine compounds. In addition to the widely used P3HT, other suitable hole-transport polymers include poly(2-methoxy-5-(3'-7'-dimethyloctyloxy)-1,4-phenylenevinylene) (MDMO-PVV), poly[[9-(1-octylnonyl)-9H-carbazole-2,7-diyl]-2,5-thiophenediyl-2,1,3-benzothiadiazole-4,7-diyl-2,5-thiophenediyl] (PCDTBT), poly(di-2-thienylthienopyrazine)s (PBEHTT), poly[9,9'-dioctyl-fluorene-co-bithiophene] (F8T2).

25

Instead of fullerene C₆₀, one can use fullerene derivatives such as phenyl-C₆₁-butyric acid methyl ester (PCBM), [6,6]-phenyl-C₇₁-butyric acid methyl ester (PC70BM).

30

Further, it is desirable to incorporate other charge transport layers which increase the conversion efficiency of the fabricated solar cells. These are usually layers comprising

-20-

electron-conducting metal oxides (ZnO , $\text{TiO}_{x(x \leq 2)}$) or layers comprising hole-conducting materials such as V_2O_5 , MoO_3 , indium tin oxide. In Example 3 above, ZnO is conveniently used to form both a charge transport layer located next to the lower electrode, and a bulk hetero-junction with the zinc phthalocyanine at the interface between the two printed
5 layers.

Another embodiment of the invention is depicted in Figure 6. The construction of this embodiment is the same as the first. However, in this embodiment the woven conducting material 30 also forms an electrode for a second photovoltaic structure 40 formed beneath
10 it. A third electrode 42 is formed beneath the second photovoltaic structure 40, so that the combination of the woven conducting material 30 and the third electrode 42 form a second photovoltaic structure. A protection and preparation coat 44 is formed on the third conductor 42. This embodiment is particularly useful when thin film constructions are used, for example using the $1.5 \mu\text{m}$ thick layers discussed above.

15 With this construction, the first photovoltaic structure is tuned to a particular wavelength range, and remaining wavelengths are transmitted through it to the second photovoltaic structure which absorbs a different wavelength range. Example 3 which is described above provides a photovoltaic structure composed of Zn phthalocyanine and ZnO which is
20 particularly well suited to this embodiment, as this layer exhibits good transparency.

Light sensitive organic polymers and organic molecules can be readily tuned to absorb light of different wavelength and can be used according to the disclosed invention. For instance, the low band-gap, hole-transport polymer poly[2,1,3-benzothiadiazole-4,7-
25 diyl[4,4-bis(2-ethylhexyl)-4H-cyclopenta[2,1-b:3,4-b']dithiophene-2,6-diyl]] (PCPDTBT) absorbs intensively in the range 600 – 850 nm, while the high band-gap, hole-transport polymer P3HT shows strong absorption in the range 400-650 nm. In another example, the organic molecule chloroaluminum phthalocyanine (ClAlPc) absorbs in the range 600 – 850 nm, whereas copper phthalocyanine absorbs in the range 400 – 850 nm.

30 Another embodiment of the layered construction is depicted in Figure 7. In this embodiment the tensile membrane 46 is not conductive. A protection and preparation

layer 48 is formed on its upper surface and another protection and preparation layer 50 is formed on its lower surface. A solar cell comprising a first conductor 52, photovoltaic structure 54 and upper conductor 56 is formed on the protection and preparation coat 48. In this embodiment the woven fabric provides the tensile strength. The protective coating provides durability and also acts as preparation for the solar cell. The first conductor 52 comprises aluminium, gold, silver or other conductive metal; conductive carbonaceous material such as graphene, carbon nanotubes, carbon fibres, carbon flakes, etc; conductive polymer such as poly(3-hexylthiophene) (P3HT) and its derivatives; or combination of these materials. The said first conductor 52 consists of a coating, grid or pattern which can be obtained by printing or other known deposition method such as vacuum deposition, sputtering, spray coating. The photovoltaic structure 54 and the upper conductor 56 are fabricated as described above in relation to Figure 5.

Another embodiment of the layered structure is depicted in Figure 8. This embodiment is the same as that depicted in Figure 7, except that a second solar cell is formed underneath the woven fabric by third electrode 58, photovoltaic structure 60 and fourth electrode 62. As discussed above in relation to Figure 6, in this construction the first and second photovoltaic structures 54, 60 may be responsive to different wavelengths of light, allowing greater efficiency. The four electrodes and the two photovoltaic structures are fabricated as described in relation to the previous figures and embodiments.

Another embodiment of the layered tensile membrane of the present invention is depicted in Figure 9. In this embodiment the woven layer 64 incorporates protection within it. A solar cell is formed on top of the woven protective layer 64 by first electrode 66, photovoltaic structure 68 and second electrode 70.

The embodiment of Figure 10 is the same as the embodiment of Figure 9 but incorporates a second solar cell formed by third electrode 72, photovoltaic structure 74 and fourth electrode 76. Again, this embodiment is advantageous in using all the incident light.

Figure 11 depicts a diagrammatic representation of an apparatus according to an embodiment of the present invention. The apparatus comprises a flexible container 100

with an upper surface comprising at least one flexible photovoltaic cell (in Figure 11 these are shown as rectangular elements). The flexible container 100 is attached to a support frame 102. The support frame 102 defines a generally rectangular opening across which the flexible container 100 is provided.

5

The flexible container is attached to the frame by the use of channels 104 which can be seen in Figure 11A. The channel has an opening which is narrowed by lips 106 so that to insert the edge of the flexible container into the channel the lips 106 must be resiliently deformed. This provides a secure fitting of the edge of flexible container 100 into the

10 channel 104.

Figure 12 depicts a diagrammatic perspective view of the apparatus of Figure A. This allows the construction of the flexible container as comprising a first upper flexible sheet 108 and a second lower flexible sheet 110 to be seen more clearly. The second flexible

15 sheet 110 is attached to the support frame 102 so that it is in tension. This provides rigidity and strength to the flexible container 100. The first flexible sheet 108 generally has an area slightly larger than the second flexible sheet 110 so that it is not held in tension, or is held at a reduced tension, over the support frame and the difference in areas define an internal space of the flexible container 100.

20

Figure 12A depicts a close up of the connection of the flexible container 100 to the support frame 102 in Figure 12. Here it can be seen that the channel 112 is partially tubular, with sides extending over an angle more than 180° about the axis of the tube. This provides a lip so that a similar secure fit as in the embodiment of Figure 11A can be achieved.

25

In the embodiment of Figure 12, the first sheet 108 and the second sheet 110 may be separate elements. In that case, the first and second sheet may be bonded together at their edges to form the container. For example, any suitable adhesive may be used, alternatively, depending on the materials of the first and second sheet other methods of

30 bonding, such as thermal bonding may also be possible. It is preferred to using bonding with an adhesive of silicone rubber to improve the ability to retain fluid inside the container.

Figure 13 depicts an example of a mechanical connector which could be used with the channel of Figure 11A in more detail. Here it can be seen how the first sheet 108 and second sheet 110 are sandwiched together around a central rod 114 within channel 104.

5

Figure 14 depicts an alternative embodiment of the connection between the flexible container and the support frame. In this embodiment, elongated adaptors 116 are used to connect the flexible container to the channel. A close up of the cross-section of adaptor 116 is depicted in Figure 15. The first sheet 108 and second sheet 110 are sandwiched in a receptacle 118 which has a generally rectangular cross-section, so that the first sheet 108 and second sheet 110 are forced into contact with each other at their edges. The receptacle 118 may define a space which is slightly less than the combined thickness of the first sheet 108 and second sheet 110. In that case, the first sheet 108 and second sheet 110 may be connected by a mechanical connection. Alternatively, the first sheet 108 and second sheet 110 may be bonded in place within the adaptor.

10

15

Figure 16 depicts an alternative adaptor for use with the arrangements depicted in Figure 14. This adaptor is particularly suited when the first sheet and second sheet are integrally formed to produce a generally tubular container 120. The adaptor 122 comprises a receptacle 124 with a triangular cross-section into which the flexible container 120 is bonded, defining an edge of the container for attachment to the support frame. The receptacle 124 also serves to define the boundary between the upper surface and the lower surface of the first container.

20

25

Figure 17 depicts an alternative embodiment of the apparatus of the invention. This embodiment is intended for use with fluid at a lower pressure than atmospheric pressure. Figure 17 depicts the first sheet 126 partially peeled away to allow the inner structure to be seen. This is purely for ease of understanding, in use, the first sheet 126 is securely attached to second sheet 128. It can be seen that a plurality of longitudinal elements 130 are provided within the container. These elements serve two purposes. Firstly, they prevent the first sheet 126 from touching the second sheet 128 when the container is compressed while held at a pressure lower than atmospheric. They also define a path for

30

fluid through the container from an inlet 132 to an outlet (not illustrated). It can be seen that the longitudinal elements 130 define a snaking path by which the fluid must move left and right over the area of the container.

- 5 The solar cell in any of the above described embodiments may be any suitable flexible solar cell attached to the first sheet of the flexible container. Preferably, the flexible solar cell has a construction as described above.

10 In the conceptual diagrams of the apparatus discussed above, the precise location of the inlet and outlet is not shown. However, it will be appreciated that the inlet and outlet are generally on opposite sides to allow fluid to flow through the container and provide cooling in use. The apparatus may be used with natural fluid flow to provide cooling due to naturally occurring convection currents resulting from the heating of the fluid by incident sunlight onto the flexible container. For example, the fluid will be heated when
15 sunlight is incident on the solar cells. Heat transfer to the fluid within the container is achieved without requiring a heat exchanger due to the relatively thin dimension of the first flexible sheet.

In some embodiments it is preferred to provide fluid into the flexible container at a
20 pressure which is either above or below atmospheric pressure to assist its flow. Figure 18 depicts a conceptual diagram of a system incorporating an apparatus of the invention. In this embodiment, pressurised gas is pumped from the inlet to the outlet, inflating the flexible container. The inflation helps to add structural strength to the flexible container. The pressurised gas within the container will transfer any stress from the first sheet down
25 to the second sheet. The second sheet is held under tension to resist this stress.

The pressurised gas is circulated by a pump 134. Gas passes from this pump through an optional pressure regulator 136 to the inlet 138. An optional pressure release valve 140 is provided to prevent over inflation of the flexible container. The pressurised gas within the
30 container is heated by incident sunlight on the first sheet. This heat is carried away by the circulation of the gas which leaves the container via outlet 142. This heated gas may be

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used either directly (illustrated by arrow 144) or passed through a heat exchanger 146 to extract its heat before the gas is recirculated.

To provide fail safes, an optional auxiliary pump 148 and gas receiver 150 are also
5 provided. The gas receiver maintains a reservoir of gas to keep the flexible container inflated in the event that both pump 134 and auxiliary pump 148 fail or are switched off.

Figure 19 depicts a conceptual diagram of a second embodiment of the invention, in which fluid is contained within the flexible container at a pressure less than atmospheric pressure.
10 Preferably, one end of the container is raised so that the outlet is at a greater height than the inlet. This embodiment uses the construction of container depicted in Figure 17. In this embodiment, the separation between the first sheet and the second sheet is minimised due to the action of atmospheric pressure on the flexible container. Liquid is provided at an inlet 152. The angling of the flexible container 100 ensures that any gas which is produced
15 within the flexible container collects at the outlet 154 where it can be removed along with any liquid. The circuit may operate by natural convection currents, relying on heating of the liquid and may also comprise a pump 156 to extract liquid from the outlet 154 and maintain a negative pressure within the flexible container with respect to atmospheric pressure. A phase separator 158 is provided to separate any gas present at the outlet. A
20 reservoir of the liquid is maintained in header tank 160. The liquid then circulates to a heat exchanger 162. A pressure regulator 164 is also provided.

Thus, these embodiments provide an apparatus which allows cooling of a photovoltaic cell with a lightweight and cost-effective construction. In some embodiments, the heat
25 extracted by the cooling may be used directly, for example to provide heating or hot water, or through a heat exchanger to extract further energy from incident solar radiation.

CLAIMS

1. A solar cell which remains operative when subject to an applied tensile load, the solar cell comprising:
 - 5 a tensile layer;
 - a first photovoltaic structure; and
 - first and second electrodes, each connected to a different surface of the first photovoltaic structure.
- 10 2. A solar cell according to claim 1, wherein the first photovoltaic structure comprises an electron transport layer, a hole transport layer and a bulk heterojunction between the electron transport layer and the hole transport layer.
3. A solar cell according to claim 2, wherein the electron transport layer comprises
 - 15 carbon flakes.
4. A solar cell according to claim 3, wherein the carbon flakes are less than 5 μm in size.
- 20 5. A solar cell according to claim 1, wherein the electron transport layer comprises a fullerene, carbon fibres, carbon nanotubes.
6. A solar cell according to claim 3, 4 or 5, wherein the hole transport layer comprises copper phthalocyanine or zinc phthalocyanine.
 - 25
7. A solar cell according to claim 2, wherein the electron transport layer comprises Zinc Oxide.
8. A solar cell according to claim 7, wherein the hole transport layer comprises zinc
 - 30 phthalocyanine.

9. A solar cell according to any one of claims 2 to 8, wherein the hole transport layer comprises hole transport conjugated polymer.

10. A solar cell according to any one of claims 2 to 9, wherein at least one of the
5 electron transport layer or the hole transport layer contains acrylic polymer of below 20% by weight.

11. A solar cell according to any one of claims 2 to 10, wherein the electron transport layer and the hole transport layer are each less than 2 μm thick.

10

12. A solar cell according to any one of the preceding claims, further comprising:
a second photovoltaic structure; and
a third electrode connected to a surface of the second photovoltaic structure;
wherein the second photovoltaic structure comprises an electron transport layer, a
15 hole transport layer and a bulk heterojunction between the electron transport layer and the hole transport layer.

13. A solar cell according to claim 12, wherein the first photovoltaic structure is configured to generate an electric potential difference from a first range of wavelengths of
20 incident light and the second photovoltaic structure is configured to generate an electric potential difference from a second range of wavelengths of incident light, which is different from the first range of wavelengths.

14. A solar cell according to claim 12 or 13, wherein the first electrode is also
25 connected to a surface of the second photovoltaic structure, such that the first and third electrodes are connected to different surfaces of the second photovoltaic structure.

15. A solar cell according to claim 12 or 13, further comprising a fourth electrode connected to a surface of the second photovoltaic structure, such that the third and fourth
30 electrodes are connected to different surfaces of the second photovoltaic structure.

16. A solar cell according to any one of the preceding claims, wherein the tensile layer is conductive and functions as one of the first, second, third or fourth electrode.

17. A solar cell according to any one of the preceding claims, further comprising
5 protection means for protecting the solar cell.

18. A solar cell according to claim 17, wherein the protection means is a layer of protective material.

10 19. A solar cell according to claim 17 or 18, wherein the protection means is incorporated into the tensile layer.

20. A method of manufacturing a bulk heterojunction for use in a photovoltaic structure comprising:

15 depositing an electron transport layer on an electrode surface using solution deposition; and

depositing a hole transport layer on the electron transport layer using solution deposition.

20 21. A method according to claim 20, wherein the electron transport layer and the hole transport layer are deposited using printing techniques.

22. A method according to claim 20 or 21 wherein the hole transport layer is deposited using a printing technique which applies pressure.

25

23. A solar cell comprising a bulk heterojunction manufactured according to the method of any one of claims 20 to 22.

24. An apparatus comprising:

30 a supporting structure;

-29-

a flexible container comprising a first flexible sheet forming an upper surface and a second flexible sheet forming a lower surface, wherein the flexible container is attached to the supporting structure so that the second sheet is at least partially in tension;

at least one flexible solar cell at least partially covering the upper surface of the
5 flexible container;

an inlet for supplying fluid into the container; and

an outlet for removing fluid from the container.

25 An apparatus according to claim 24, wherein the supporting structure comprises
10 an frame defining at least one opening and wherein the first sheet and the second sheet are attached to the frame so that they extend over an opening.

26. An apparatus according to claim 24 or 25, wherein the supporting structure
comprises a channel for attachment to an edge portion of the first sheet and the second
15 sheet.

27. An apparatus according to claim 26, wherein the first sheet and the second sheet
are attached to the channel by wrapping them around an elongated member which is
received in the channel.

20

28. An apparatus according to claim 26, wherein the first sheet and the second sheet
are attached to the channel using an adaptor comprising:

a receptacle for at least a part of the edge of the first sheet and at least part of the
edge of the second sheet; and

25 a connecting member which is received in the channel.

29. An apparatus according to any one of claims 24 to 28, wherein the first and
second sheet are integrally formed.

30 30. An apparatus according to any one of claims 24 to 29, further comprising a
plurality of elements within the container attached to either or both of the first sheet and

-30-

the second sheet and arranged to define channels to direct fluid flow within the cavity between the inlet and the outlet.

31. An apparatus according to claim 30, wherein the plurality of elements are
5 arranged to define a single path or a pattern of paths from the inlet to the outlet which covers substantially all the area beneath the at least one flexible solar cell.

32. A system comprising:
an apparatus according to any one of claims 24 to 31; and
10 means for supplying fluid to the inlet.

33. A system comprising:
an apparatus according to any one of claims 24 to 31; and
means for removing fluid from the outlet.
15

34. A system according to claim 32 or 33, further comprising a heat exchanger connected to the outlet.

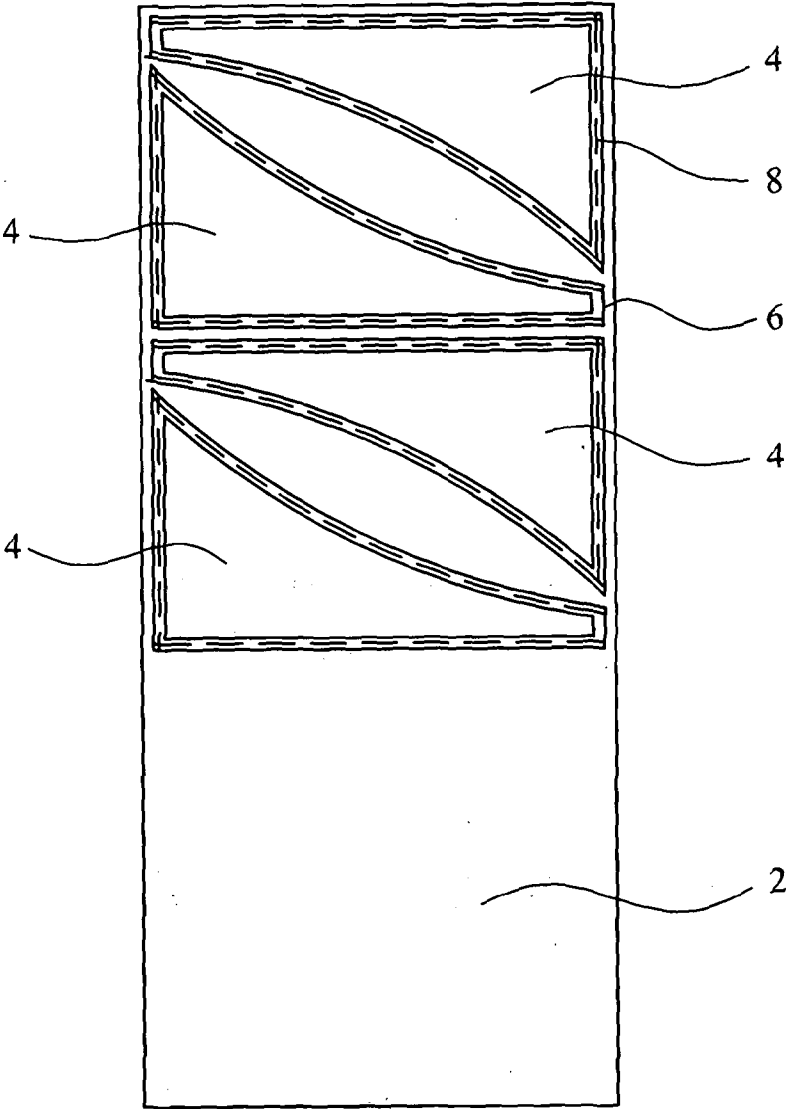


FIG. 1

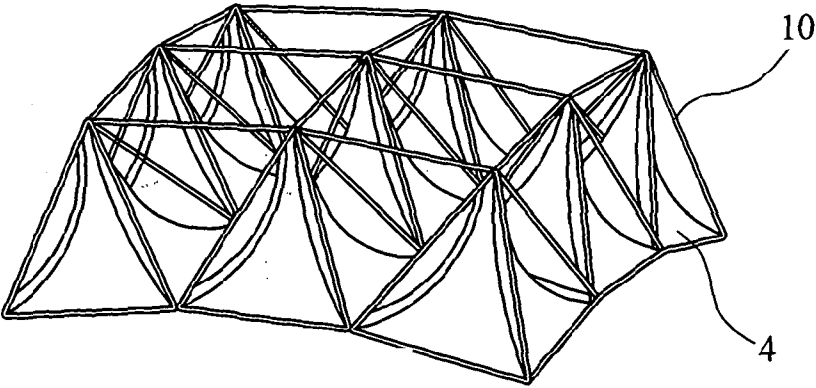


FIG. 2

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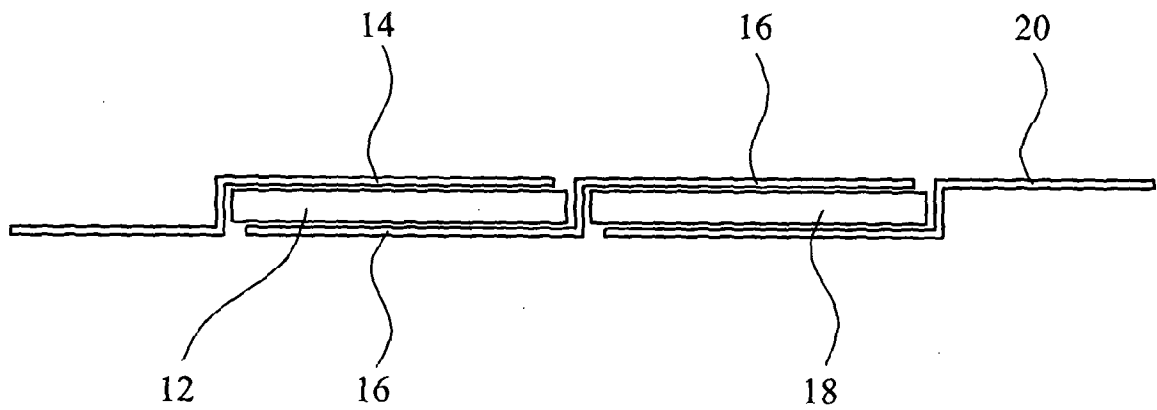
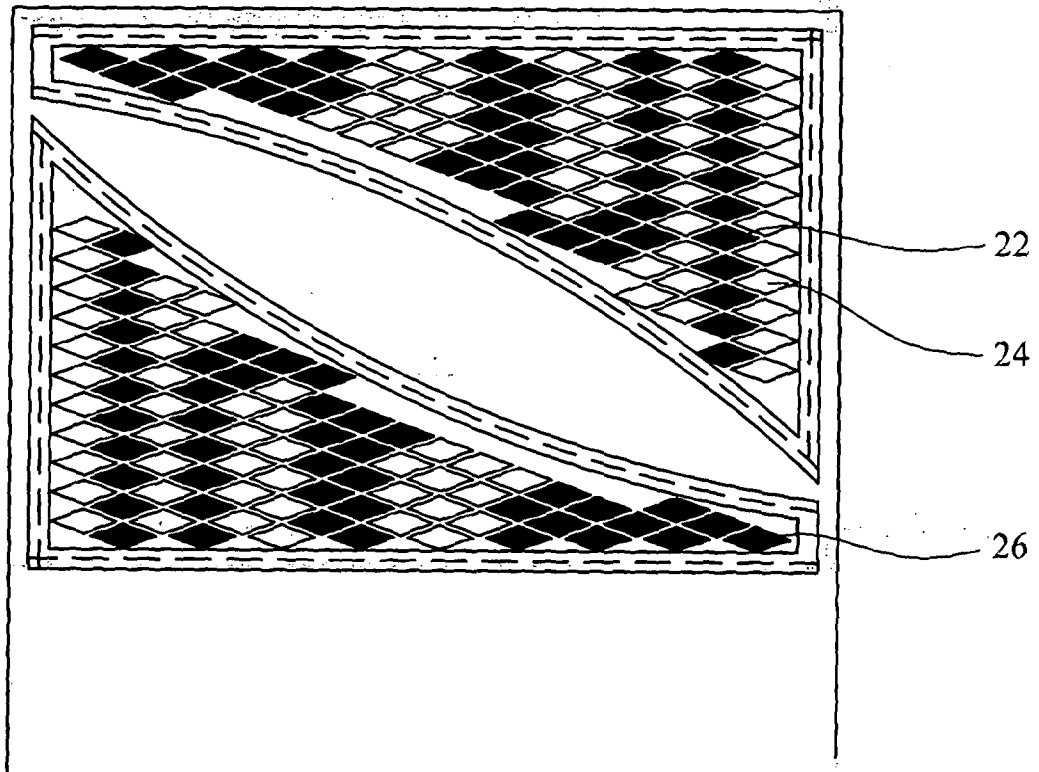


FIG. 3



-3/14-

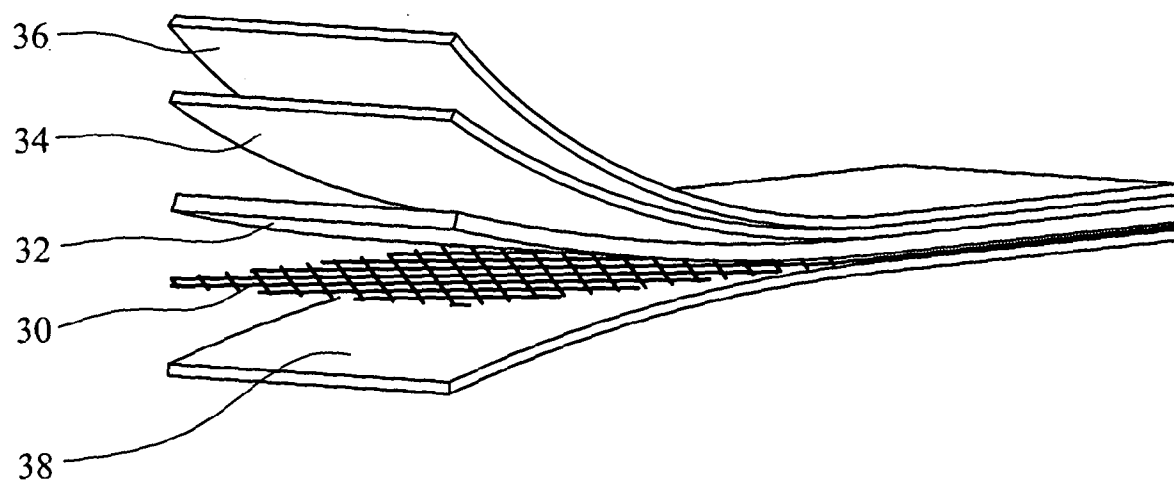


FIG. 5

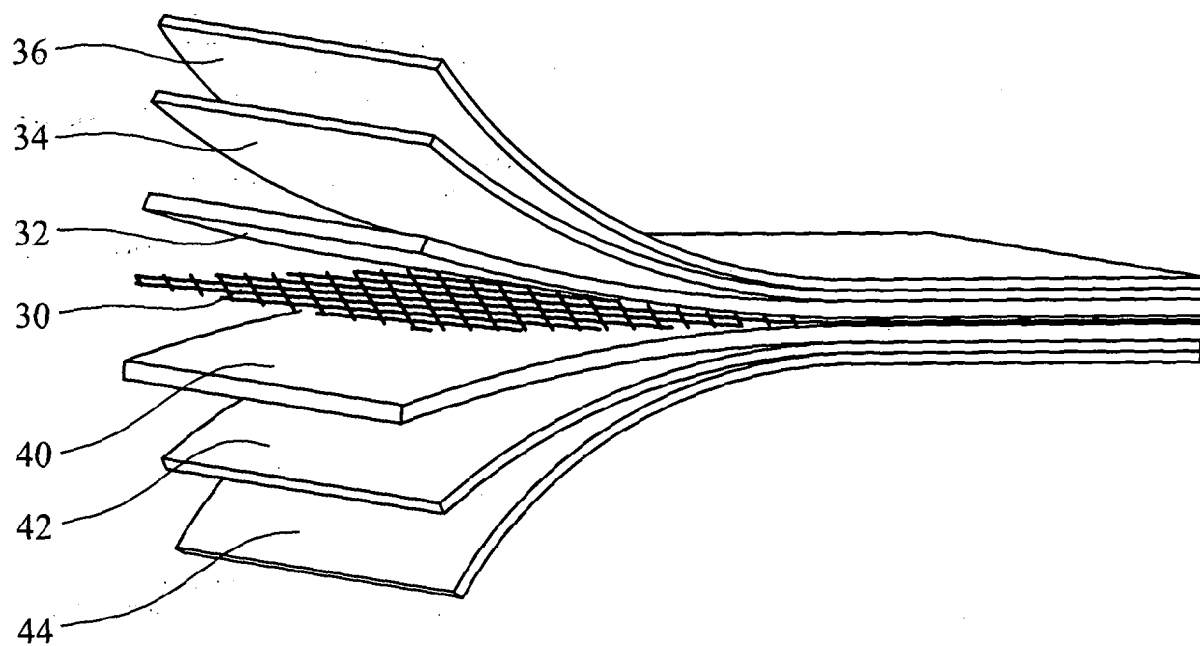


FIG. 6

-4/14-

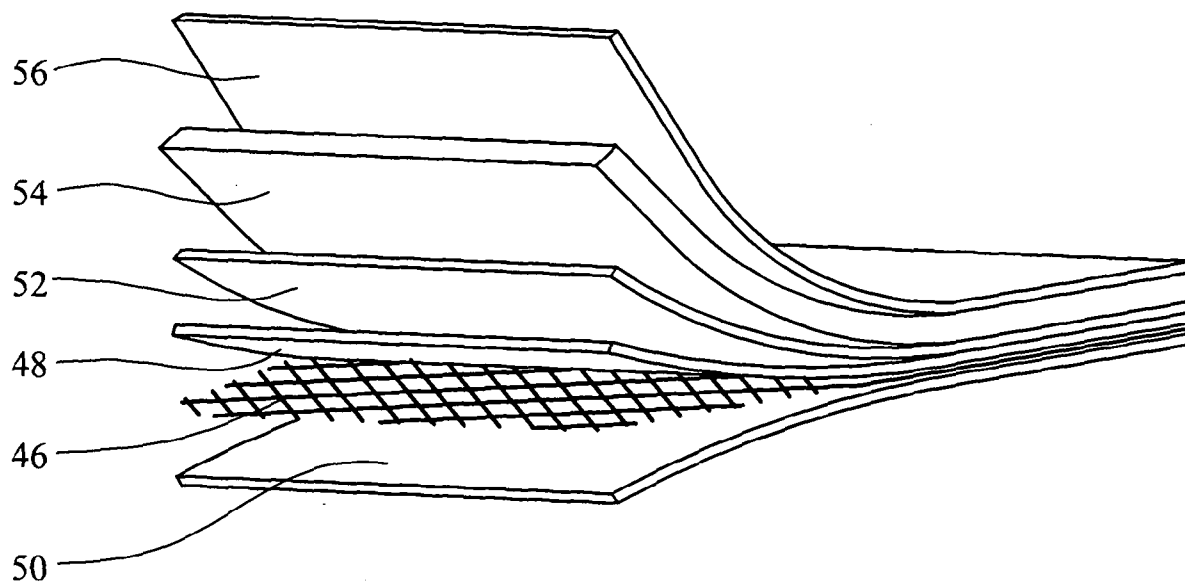


FIG. 7

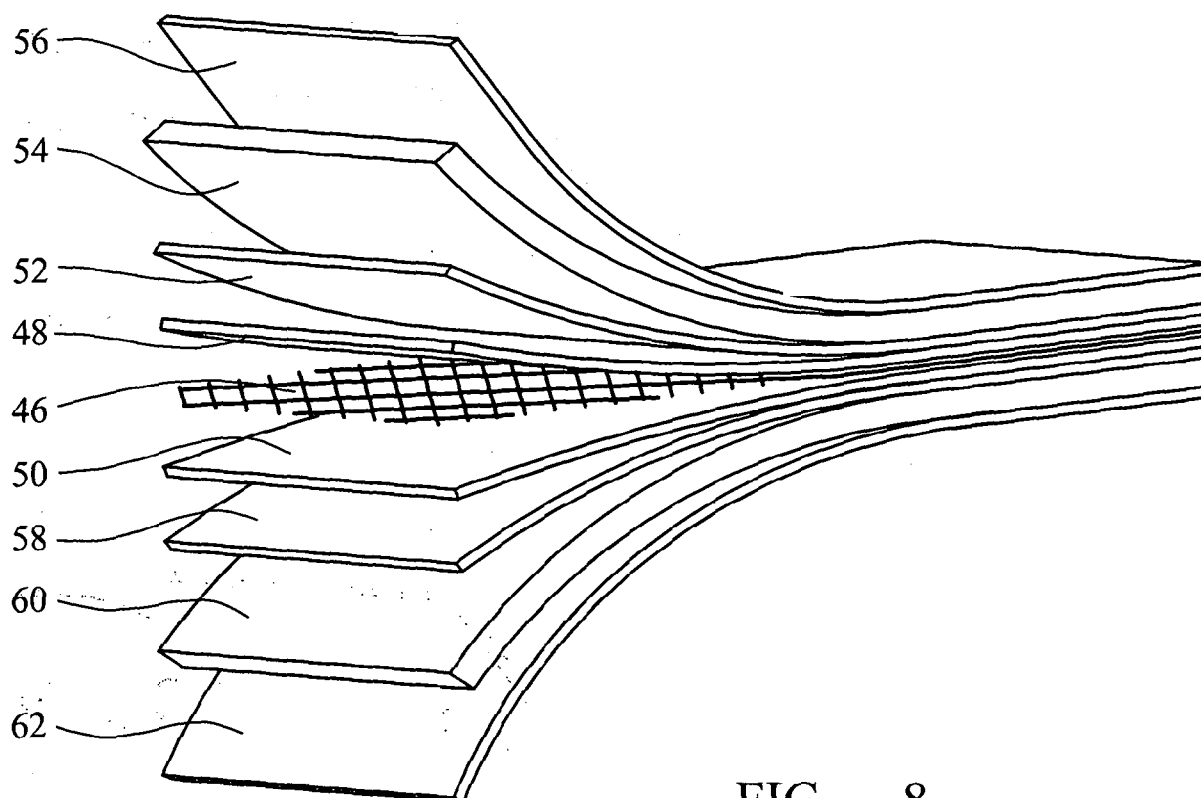


FIG. 8

-5/14-

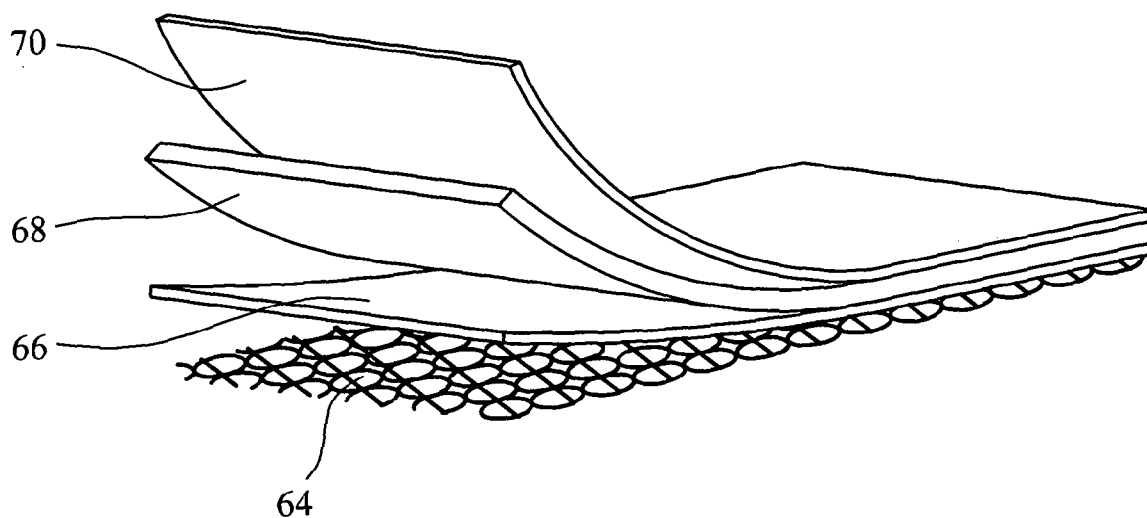


FIG. 9

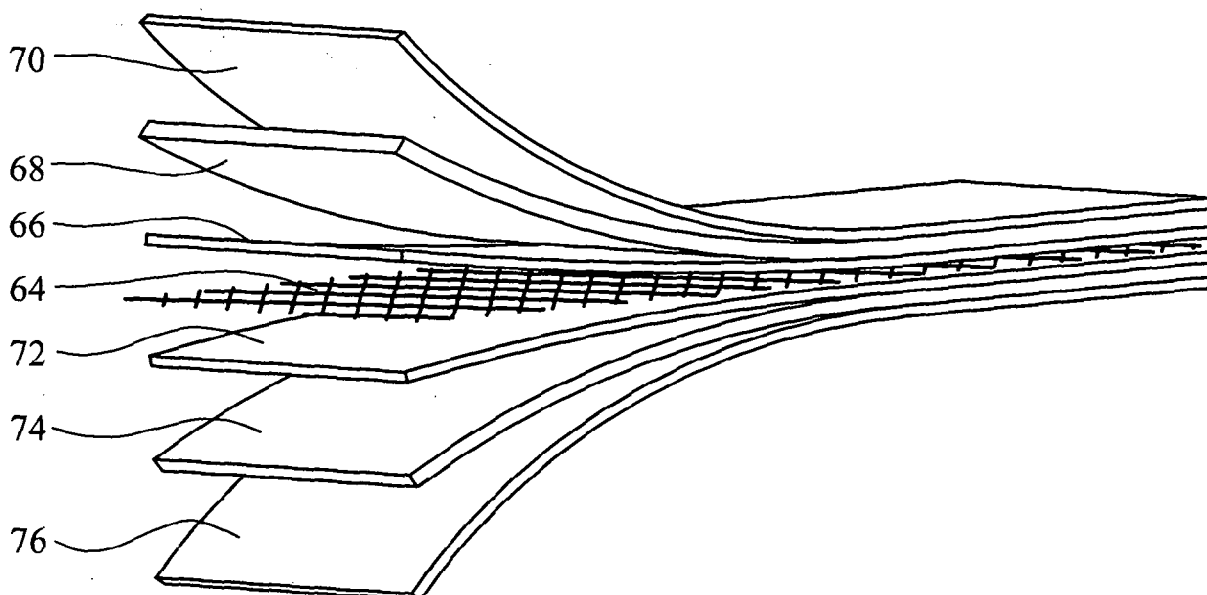


FIG. 10

-6/14-

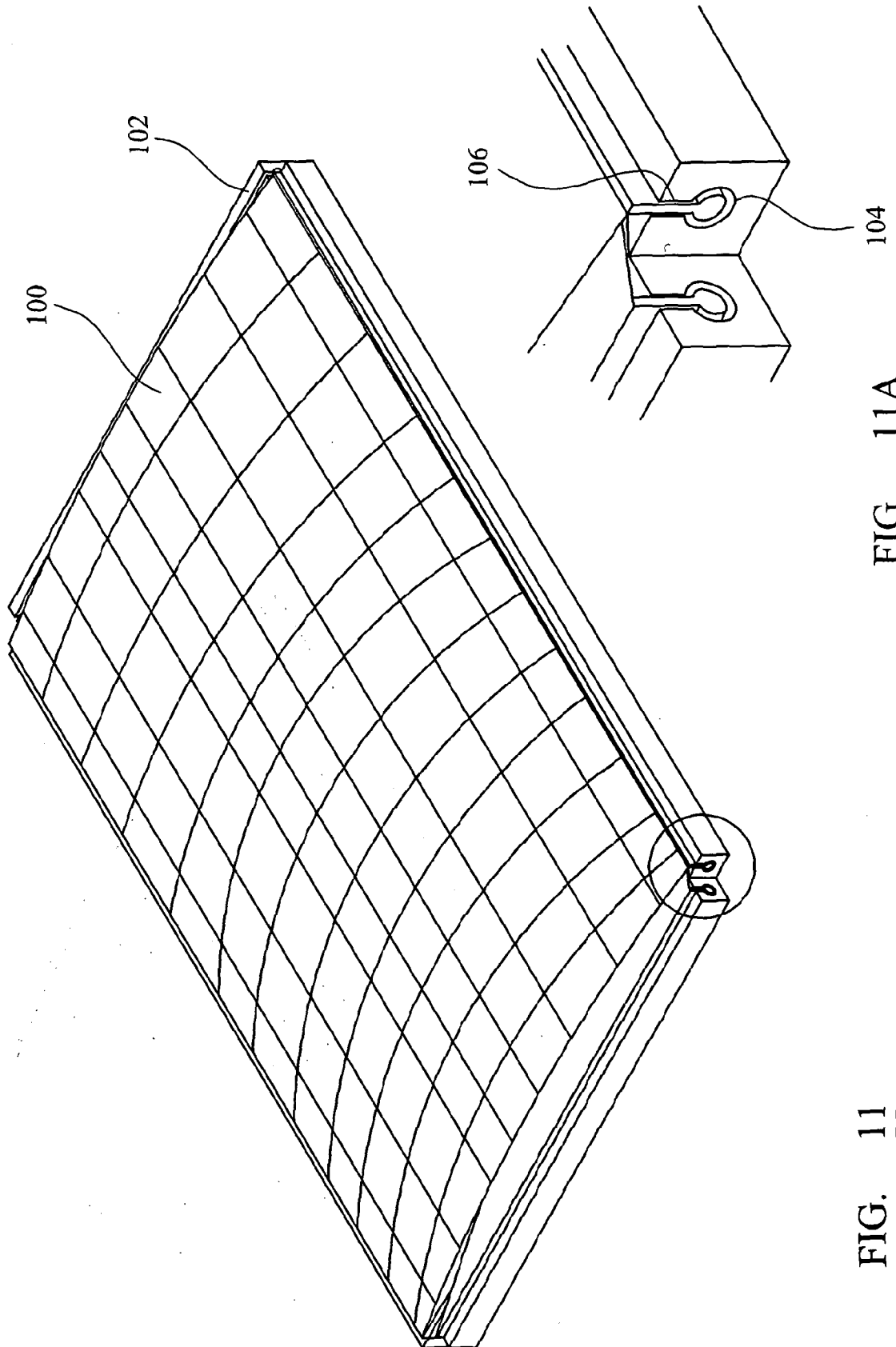


FIG. 11

FIG. 11A

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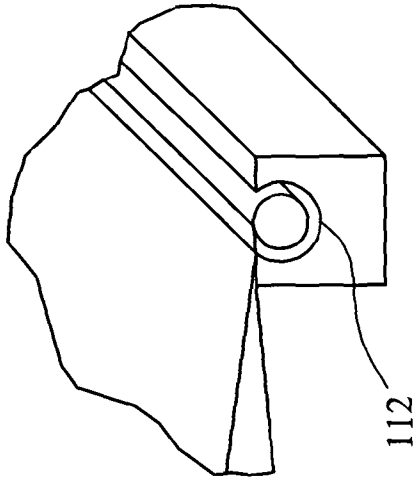
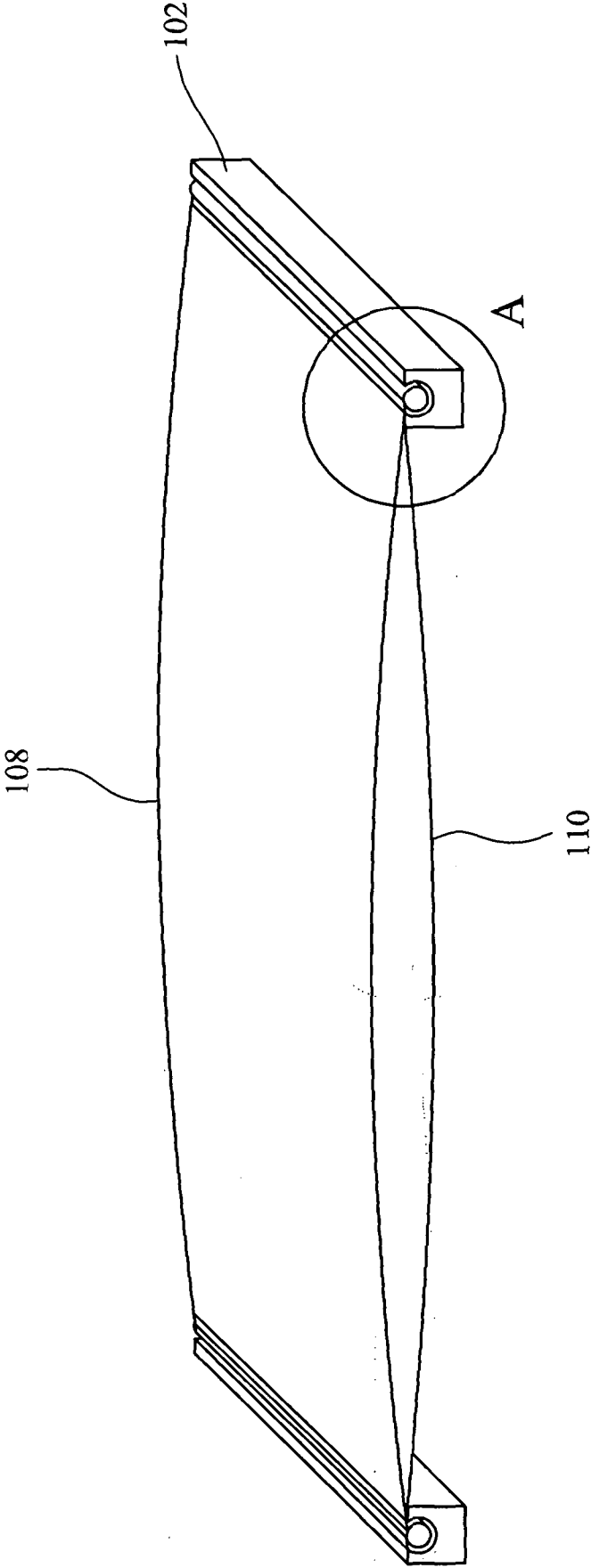


FIG. 12

FIG. 12A

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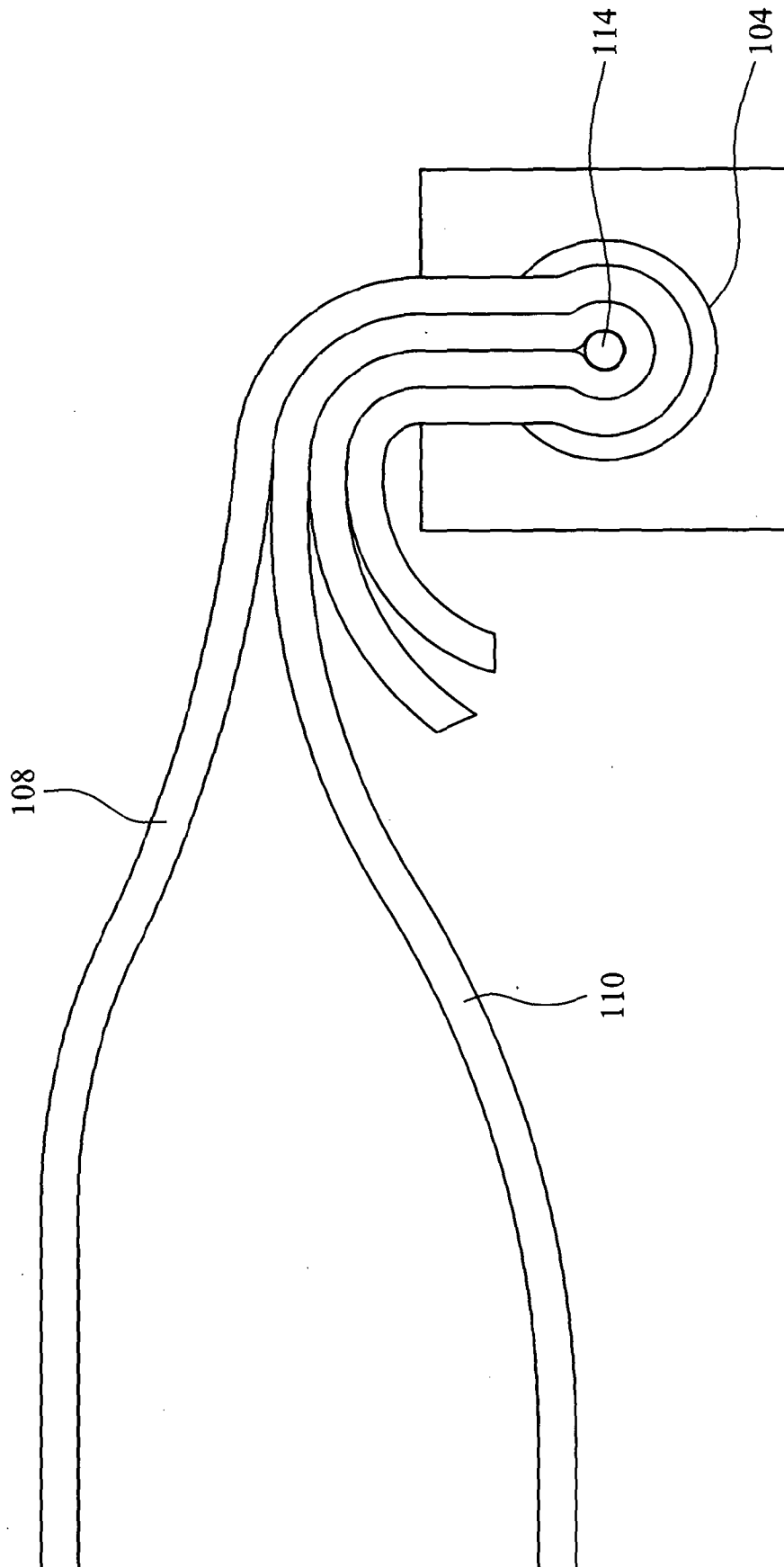


FIG. 13

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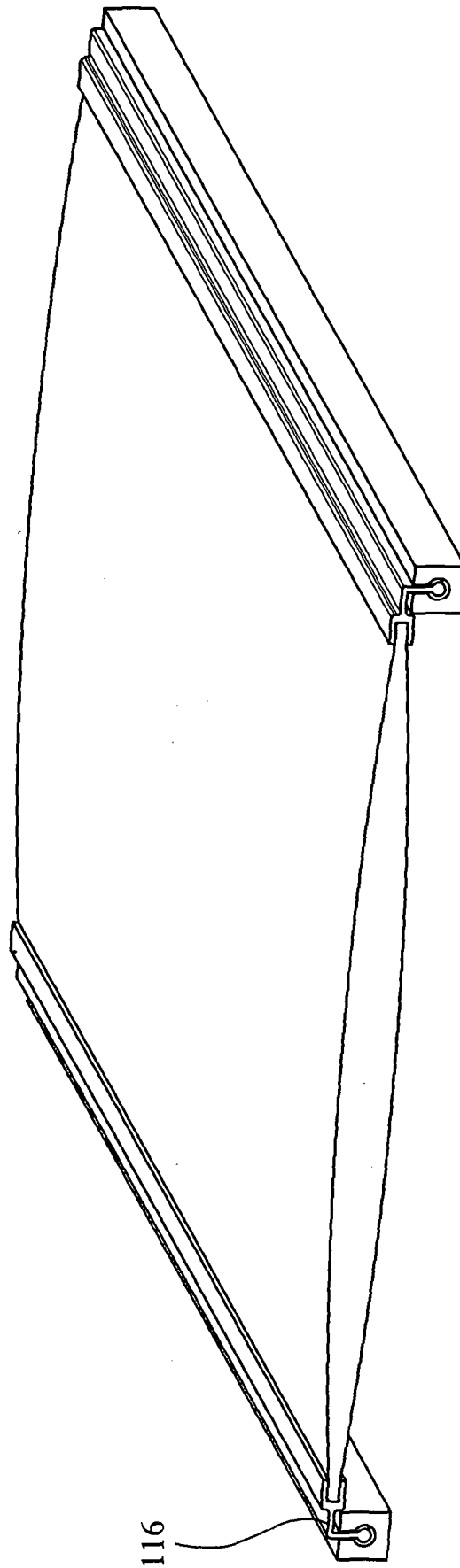


FIG. 14

-10/14-

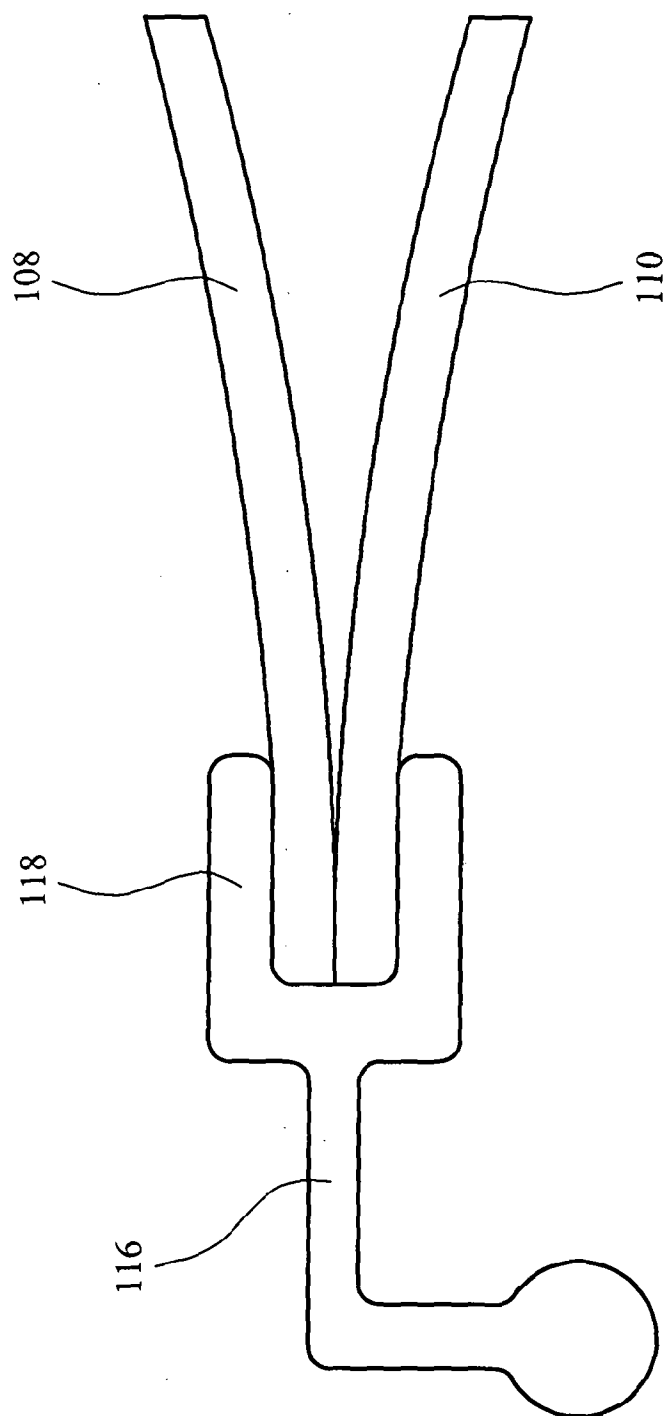


FIG. 15

-11/14-

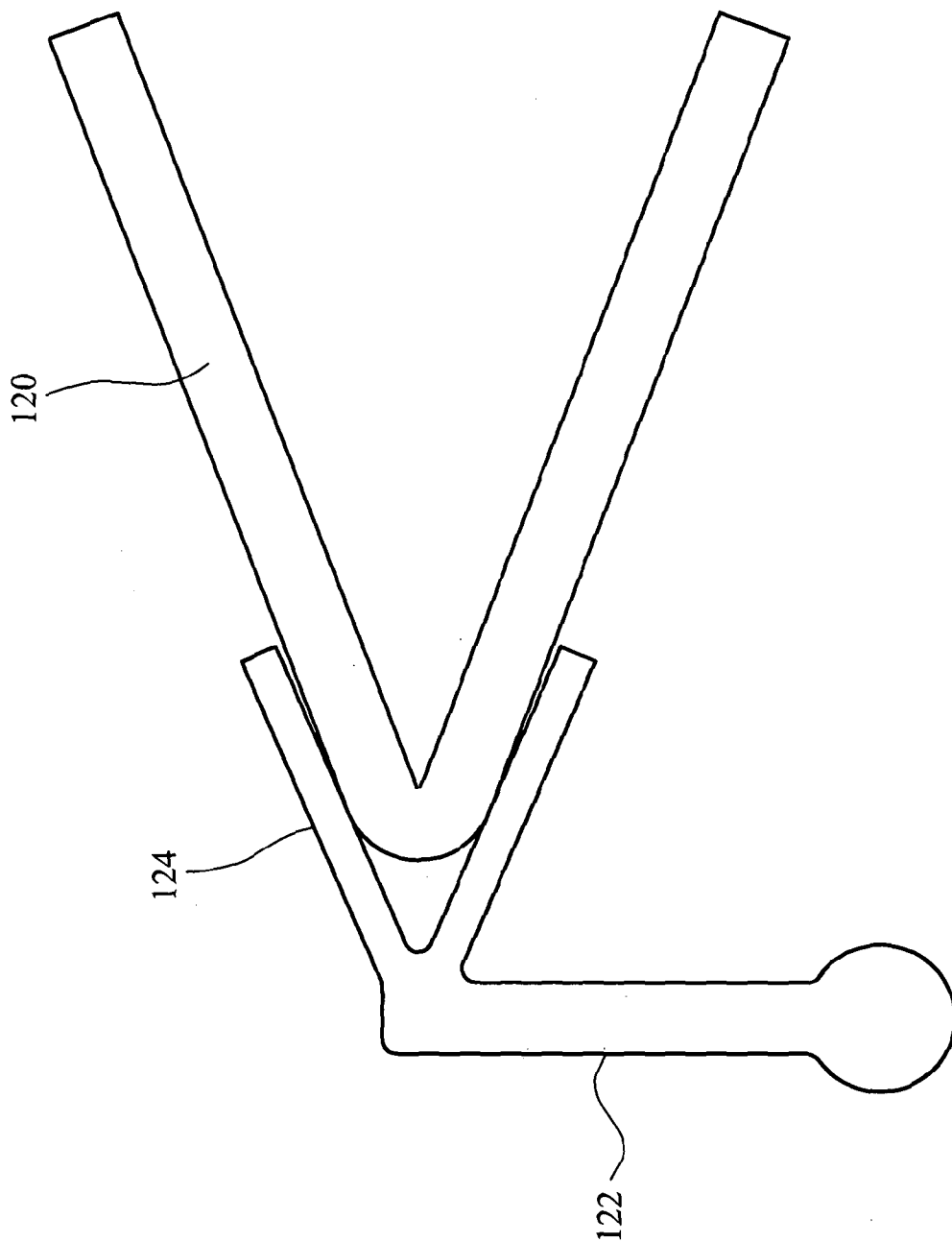


FIG. 16

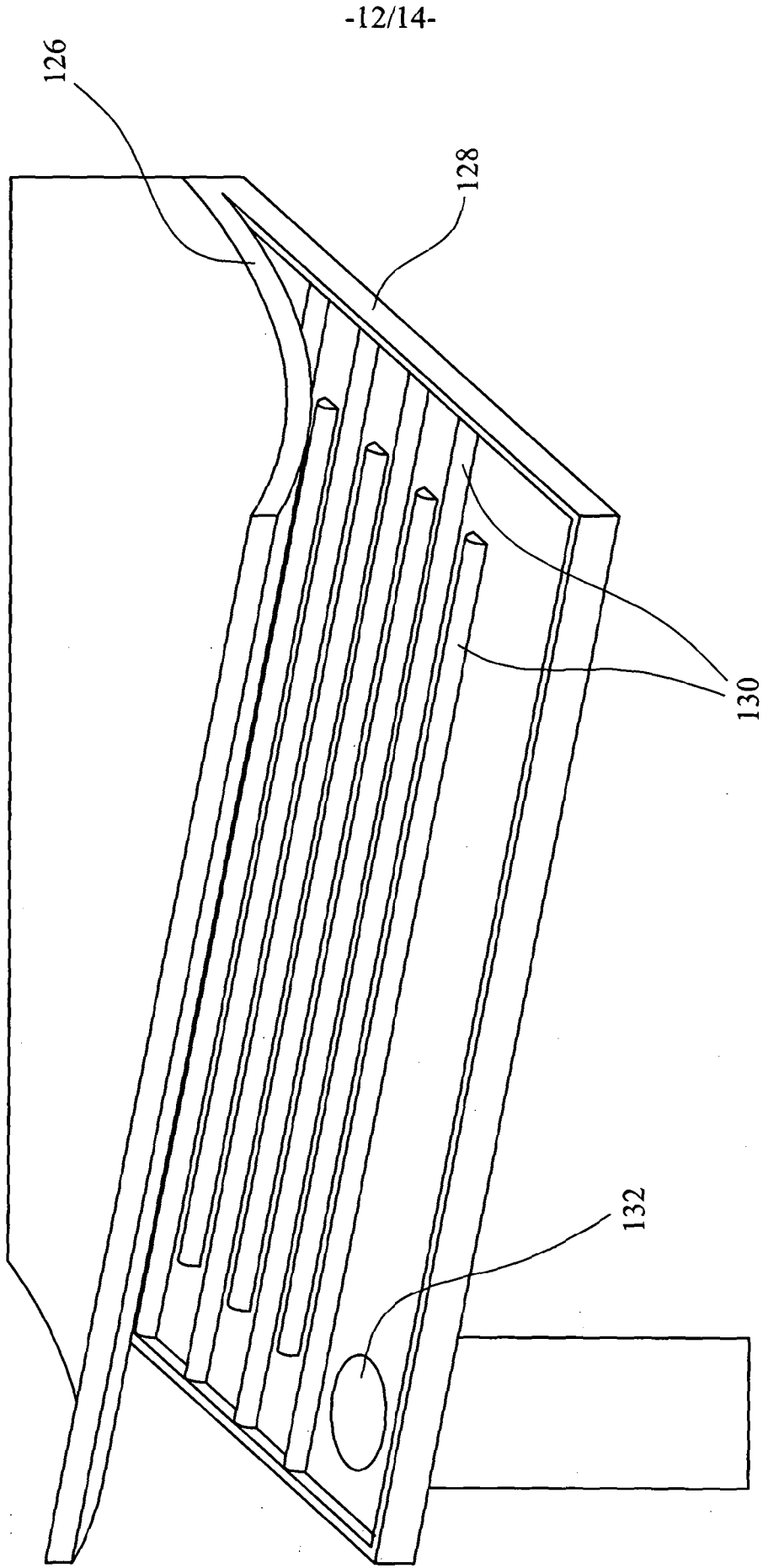


FIG. 17

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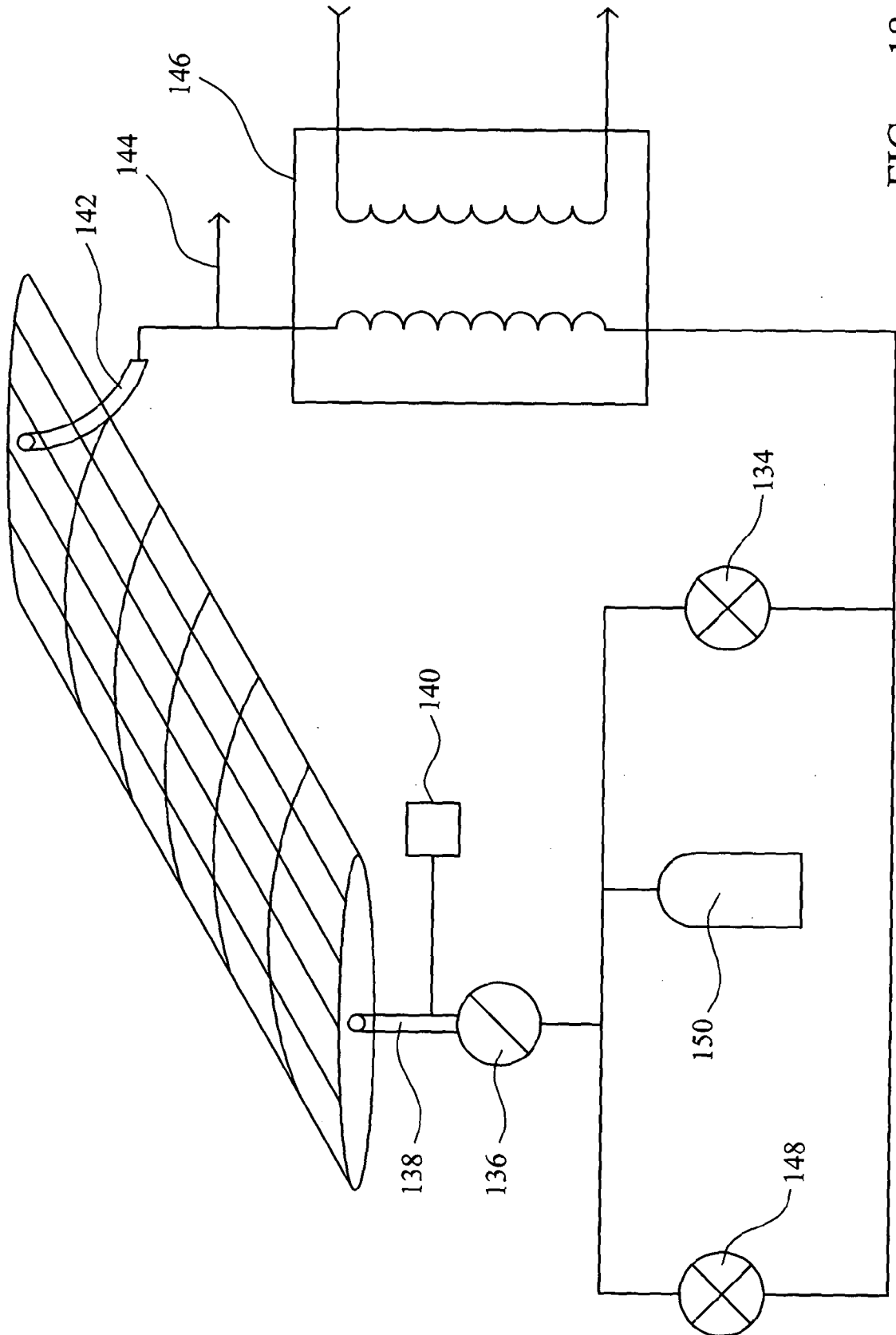


FIG. 18

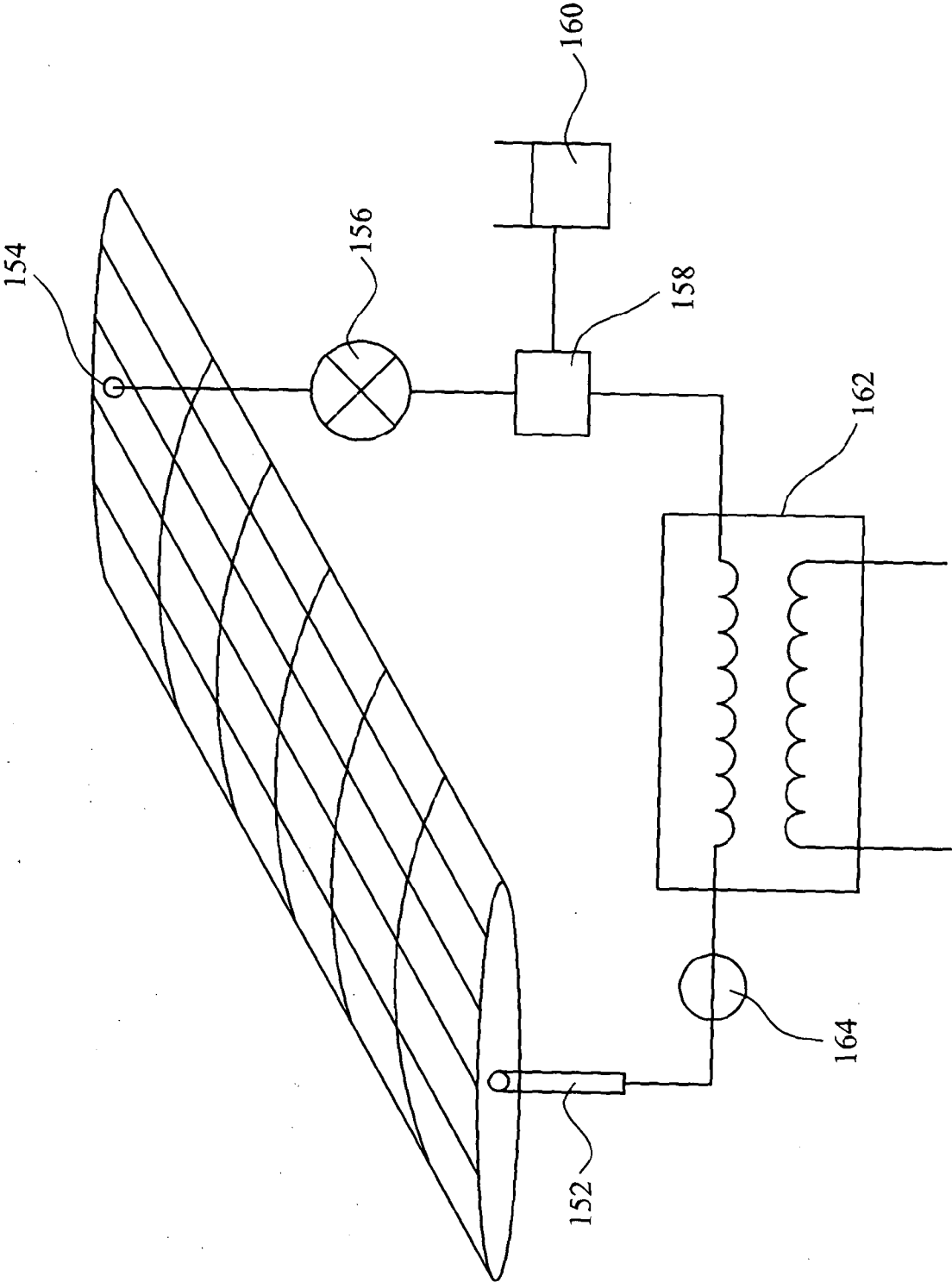


FIG. 19