

PP-0157 PCT

TITLE

METHOD FOR FABRICATING A PHOTOVOLTAIC MODULE USING A FIXTURE HAVING PRESSURE
GENERATING MEMBERS OR AN EXTERNAL FORCE TRANSMITTING SEAL OR SEALING INSERT

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CLAIM OF PRIORITY

This application claims priority from each of the
following United States Provisional Applications, each of
10 which is hereby incorporated by reference:

Method For Fabricating A Photovoltaic Module Using
A Fixture, Application S.N. 61/423,332, filed December
15, 2010 (PP0104);

Method For Fabricating A Photovoltaic Module Using
15 A Fixture Having An Internal Force Generating Member,
Application S.N. 61/548,764, filed October 19, 2011
(PP0157);

Method For Fabricating A Photovoltaic Module Using
A Fixture Having An External Force Generating Member,
20 Application S.N. 61/548,766, filed October 19, 2011
(PP0158);

Method For Fabricating A Photovoltaic Module Using
A Fixture Having A Deflectable External Force
Transmitting Seal, Application S.N. 61/548,769, filed
25 October 19, 2011 (PP0159);

Method For Fabricating A Photovoltaic Module Using
A Fixture Having An Externally Accessible Edge-Sealing
Insert, Application S.N. 61/548,773, filed October 19,
2011 (PP0160);

30 Method For Sealing Electrical Leads Passing
Through An Access Aperture Using A Sealing Plug and
Module Produced Thereby, Application S.N. 61/568,317,
filed December 8, 2011 (PP0224);

Photovoltaic Module Having A Sealed Access
Aperture with Electrical Leads Extending Therethrough,
Application S.N. 61/568,322, filed December 8, 2011
(PP0225);

5 Method For Sealing Electrical Leads Using A
Collapsible Stem, Application S.N. 61/568,327, filed
December 8, 2011 (PP0226);

Photovoltaic Module Having Electrical Leads
Extending Through A Collapsed Stem, Application S.N.
10 61/568,333, filed December 8, 2011 (PP0227);

Method For Fabricating A Photovoltaic Module Using
Localized Heating, Application S.N. 61/568,339, filed
December 8, 2011 (PP0228); and

Photovoltaic Module Having Encapsulant With Areas
15 Of Increased Heating Capability, Application S.N.
61/568,340, filed December 8, 2011 (PP0229).

BACKGROUND OF THE INVENTION

Field of the Invention This invention relates to
20 various methods for fabricating a photovoltaic module and
for the module produced thereby.

CROSS-REFERENCE TO RELATED APPLICATIONS

Subject matter disclosed herein is disclosed in the
25 following copending applications, all filed
contemporaneously herewith and all assigned to the assignee
of the present invention:

Method For Fabricating A Photovoltaic Module Using
A Fixture And Using Localized Heating To Heat Areas Of
30 Increased Heating Capability and Module Produced
Thereby, Application S.N._____, filed_____,
(PP0228) (a cognate of PP0104, PP0228 and PP0229);

Method For Sealing Electrical Leads Passing
Through An Access Aperture Using A Sealing Plug and
35 Module Produced Thereby, Application S.N._____,

filed_____ (PP0224) (a cognate of PP0224 and PP0225);
and

Method For Sealing Electrical Leads Extending
Through A Collapsed Stem and Module Produced Thereby,
Application S.N._____, filed_____ (PP0226) (a
cognate of PP0226 and PP0227).

Description of the Art The potential of solar energy
as a clean, renewable energy source is well documented.

However, a substantial impediment to more widespread use of
solar energy, especially in residential applications, is the
significant cost of photovoltaic module fabrication.

As used herein the term "photovoltaic module" or
"module" refers to a generally planar photovoltaic
generating device that includes a laminated structure
typically enclosed within a support frame. The laminated
structure, or "laminate", is itself generally indicated by
the reference character L. The laminate L includes an array
of photovoltaic cells operative to convert incident
radiation into electricity.

The first step in the fabrication of a photovoltaic
module is to pre-assemble, or "lay-up", the various
components which are included within the finished module.
Figures 1A and 1B are stylized exploded cross section views
illustrating the various layers comprised within a typical
laminate.

In general, the laminate L comprises at least a transparent layer T, a support layer S, and a photovoltaic layer V. Both the transparent layer T and the support layer S have respective interior surfaces T_I , S_I and respective opposed exterior surfaces T_E , S_E thereon. The interior surfaces T_I , S_I cooperate to define an interior volume within the laminate. The interior volume is generally indicated by the reference character M. In some configurations the support layer S has an exhaust aperture A formed therein, for a purpose to be discussed.

The transparent layer T may be glass, polycarbonate, acrylic, a polyvinyl fluoride film such as that sold by E. I. du Pont de Nemours and Company, Wilmington, DE, under the trademark Tedlar® or any other transparent medium which permits solar radiation to pass thereby to illuminate the cells in the active photovoltaic layer V. The glass usually has a thickness that is less than ten millimeters (10 mm) and typically in the range from about one-half to about six millimeters (0.5 to about 6 mm).

The support layer S may be implemented using glass, aluminum, steel, polyester, the polyvinyl fluoride film mentioned above, or other suitable material.

As shown in Figure 1A the laminate L may be formed such that the edges of the layers forming the same are all laterally coextensive. Alternatively, the various interior layers of the laminate may be arranged such that a depletion zone D is defined about the periphery of the laminate. This arrangement is depicted in Figure 1B. It is noted that the transparent and support layers need not extend equal distances beyond the photovoltaic layer.

The photovoltaic layer V may be formed from a plurality of discrete solar cells. Alternatively, the photovoltaic layer V may be realized using a thin film fabrication technology in which the cells are integrated directly on one of the layers of the laminate (e.g., transparent layer T).

The cells in the photovoltaic layer V are interconnected in any desired electrical pattern by internal interconnectors. The internal interconnectors usually take the form of busbars and/or conductor ribbons. Such busbars and/or conductor ribbons are metallic members (e.g., copper, covered with a solder coating) that are generally rectangular in cross section, with a width dimension typically on the order of one to six millimeters (1 to 6 mm) and a thickness dimension typically on the order of 0.1 mm to 0.4 mm. The internal interconnectors of the laminate are shown as generally rectangular members denoted by the reference character B. The members are diagrammatically illustrated only in the Figures 1 and 12 and are omitted from the other Figures of the drawings for clarity of illustration.

The electrical output produced by the photovoltaic layer is conducted to the exterior of the module via electrical leads. These electrical leads may be implemented in a variety of common forms, including busbars or ribbons. The electrical leads are depicted diagrammatically in the Figures as curled wires and are denoted by reference character W. The leads W may extend side-wise from the laminate, i.e., from opposed lateral edges or from the same lateral edge of the photovoltaic layer V, or, perhaps more commonly, they may be conveyed through the aperture A formed in the support layer S.

Often individual modules are interconnected to form an array of energy generating devices. After the module is completed the electrical leads W emanating from the exhaust aperture of the module are connected into a molded plastic junction box typically is mounted on the backside of the photovoltaic module. The junction box is made weather-tight using a pottant compound, often a two-part silicone mixture. Typically a diode is also included as part of the electrical network within the junction box to prevent backflow of

current into the module that may occur if the module is shaded or otherwise obstructed.

Since a module contains components that are sensitive to moisture it is necessary to encapsulate and to seal these active components and generated electricity from the effects of moisture and oxygen ingress and deterioration. To this end an encapsulant, generally indicated by the reference character E, is disposed at various positions within the laminate L. As will be discussed more fully herein, the choice of the encapsulant material E has a significant bearing on the performance and longevity of the module.

The encapsulant E includes, at a minimum, one or more interlayer(s) I (usually in sheet form) that are disposed between the photovoltaic layer V and either the transparent layer T or the support layer S, or both. The interlayer I also overlays and surrounds any internal interconnectors B and the electrical leads W. The encapsulant E may also include edge inserts G (in suitable physical form) that are disposed to fill depletion regions D that may be defined in the laminate.

As generally noted, moisture ingress, oxygen ingress, ultraviolet degradation or other environmental factors reduce power output and/or module lifetime. Accordingly, after the laminate is laid-up it is subjected to an encapsulation process that seals the laminate to yield an encapsulated module. The process of encapsulation generally follows the basic steps of air removal, application of heat and pressure, followed by cooling/depressurization (the latter performed when pressurization is utilized). There are many variations and specific methodologies that have been developed for accomplishing this encapsulation process.

A vacuum laminator has conventionally been used in the preparation of photovoltaic modules. This technique generally consists of a heated platen surface upon which the laminate assembly is placed. The laminator has a large

chamber in which the assembly is placed. The chamber is sealed and heat is transferred into the assembly, largely through conduction. Heat is used to soften the encapsulant, allow for flow to occur and for bonding of the encapsulant with the materials within the photovoltaic module. This type of equipment can be expensive, especially for large surface area modules, as the encompassing chamber is large and must be designed and constructed to withstand the pressure differential between ambient atmospheric pressure being constantly present on the outside of the chamber/platen and the inside of the chamber which during evacuation/deairing is at low absolute pressure (often less than one (1) millibar absolute). This process is in widespread use and affords a lengthy cycle time and lacks manufacturing process robustness.

Yet another type of process is vacuum bagging. Vacuum bagging is a process where air removal is accomplished by surrounding the entire laminate preassembly with a membrane film creating a substantially air-tight enclosure and then withdrawing air through an access port or tube inserted through the bag. These bags are generally either of the disposable type (e.g. nylon or polyester films) and are designed to be used through one process cycle of lamination and then discarded. Alternatively, the bag may be of a reusable type made of a relatively thick, more durable material (e.g. silicone), on the order of three to five millimeters (3 to 5 mm). Such a bag can be used for many processing cycles until the material either deteriorates from repeated exposure to heat or becomes physically damaged. Vacuum bagging is generally a manual process which requires significant time per unit assembly.

One significant problem with thicker bagging material is the extra compression force that it exerts around the periphery of the module as the bagging extends outward beyond the module edge. This is due to the inability of the

bagging material to closely conform to the laminate/module shape. This extra force can create edge-pinching, causing additional flow of encapsulant out from the edge and edge stress. This condition is known to accelerate the future deterioration of modules as this stress can ultimately lead to delamination or bubble formation between the encapsulant and the layers and/or within the encapsulant. These types of defects will generally shorten the lifetime and performance of the photovoltaic module since a shortened path for moisture and oxygen ingress to the module would then exist.

On the other hand, bagging material that is relatively thin (~0.01 to 0.2 millimeters) can conform readily around the periphery to minimize edge compression and edge pinching. Thin films of any type will allow for the passage of infrared radiation therethrough and to be available for irradiation of the laminate below or within. For example, polyvinyl fluoride film such as that sold by E. I. du Pont de Nemours and Company sold under the trademark Tedlar[®] has been found to provide sufficient infrared transparency. Any other transparent medium which permits incident radiation during processing to pass in a significant manner to illuminate the cells in the active photovoltaic layer V may be used.

Yet another type of process of air removal is vacuum ringing. In this process air removal is accomplished by surrounding the entire laminate preassembly with a flexible vacuum ring (e.g., U.S. Patents 2,948,645 and 3,074,466). Most commonly, these rings are fabricated of silicone rubber and are made to engage with the specific geometry of the laminate preassembly. The channel of the vacuum ring includes a recessed portion which is maintained in a spaced-apart relationship with the entire peripheral edge of the preassembly, to define a vacuum passage, whereas the ring

extends onto the marginal edges of the outer preassembly surfaces and forms an air-tight seal.

Vacuum rings are currently used in the glass lamination industry for air removal and are often utilized within autoclaves, where super-atmospheric pressure and temperature completes the lamination process. In some instances, it is desirable to maintain the vacuum ring in place when the glass assembly is within the autoclave, and to apply a vacuum to the ring during at least part of the time the assembly is heated and pressurized. The specific design and processing cycle should be optimized so as to prevent the significant reduction of the thickness of the interlayers around the marginal edges of the assembly, thereby creating undesirable optical distortion and/or stress in those areas.

SUMMARY OF THE INVENTION

The present invention is directed to methods for fabricating a photovoltaic module and to the module produced thereby.

The photovoltaic module includes a laminate comprising a transparent layer, a support layer, and a photovoltaic layer. The transparent and support layers each have an exterior surface and an interior surface, with the interior surfaces of the layers defining an interior volume therebetween. The photovoltaic layer is disposed in the interior volume. An encapsulant material is disposed at least between the photovoltaic layer and either the interior surface of the transparent layer or the interior surface of the support layer, or both. The encapsulant material has a predetermined sealing temperature above which the encapsulant is able to flow into adhesive contact with the photovoltaic layer and the transparent layer and/or the protective layer. The encapsulant material also exhibits a predetermined energy absorptivity response. The encapsulant

may be polyvinyl butyral ("PVB"), ethylene vinyl acetate ("EVA"), or an unfilled or filled ionomeric material.

The method of the present invention includes, in any operative order, the steps of: sealing the interior volume
5 of the laminate in an air-tight manner; and, using a heating source, heating the encapsulant material within the laminate. Before the encapsulant is raised to its sealing temperature air is withdrawn from between the layers of the laminate so that atmospheric pressure compresses the layers
10 of the laminate, whereby the encapsulant adhesively contacts against the photovoltaic layer and an adjacent interior surface of the transparent layer and/or the protective layer thereby to form a sealed laminated structure.

Preferably the laminate is sealed in an air-tight
15 manner using a fixture that engages the laminate completely about its periphery while leaving the major portion of the exterior surfaces of the laminate exposed. The fixture comprises a pair of complementary rigid frames. The rigidity of the frames prevents edge-pinching of the
20 laminate. The seal between the frames of the fixture may be formed in any of a variety of ways. Use of such a fixture permits extraction of air from the laminate (either through an exhaust aperture in the support layer or from the periphery of the laminate) while simultaneously allowing
25 open access of the laminate to heating sources and to atmospheric pressure. Thus, the use of a vacuum bag or autoclave as required by the prior art and the impediments to efficiency attendant with their use are eliminated, such that advantages in efficiency and throughput may be
30 achieved.

The heating source has an energy output characteristic that is tuned to the energy absorptivity response of the encapsulant material so that the encapsulant is preferentially heated. In the preferred instance the
35 heating source is a source of infrared radiation having a

peak wavelength in the range from about one (1) to about ten (10) micrometers, whereby at least thirty percent (30%), more preferably at least fifty percent (50%) and most preferably at least sixty-five percent (65%) of the
5 available energy output from the infrared radiation source is directly absorbed by the encapsulant.

Locally enhanced heating effects can be imparted to predetermined targeted zones of the laminate by
10 strategically selecting the locations at which one or more of the heating sources is/are positioned. In addition or in the alternative source intensities and/or emitting wavelengths of the sources may be varied.

Another approach is to modify the absorptivity response
15 of the encapsulant material in those predetermined areas of the laminate in a way such that incoming energy is converted to heat at different rates, thus creating different temperature profiles. For example, the encapsulant material may contain one or more additives that cause the encapsulant
20 to respond to radiation. The additive can take the form of any pigment or filler, such as carbon black or glass fiber. Other alternatives are also disclosed herein.

Other aspects of the invention relate to the sealing of
25 the leads W that bring the electrical energy generated by the photovoltaic layer outward from the module for utilization against moisture or oxygen ingress.

Wires emanating from the laminate through an exhaust aperture are sealed using a plug that is inserted into the
30 aperture. The plug, when raised to its sealing temperature adhesively bonds to the leads. Leads emanating from lateral sides of the laminate are sealed using a stem that collapses in the presence of a pressure differential upon heating to a softening temperature.

The plug or stem, as the case may be, also adhesively bonds to the encapsulate. It is preferred that the plug or stem be made from the same material or a material compatible with the encapsulate so that a more intimate melding and fusing with the encapsulate can occur.

Each of these aspects of the present invention is believed advantageous in that they extend the encapsulation of the leads beyond the basic geometry of the module.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood from the following detailed description taken in connection with the accompanying Figures, which form a part of this application and in which:

Figures 1A and 1B are stylized diagrammatic exploded views of alternative forms of a photovoltaic laminate constructed in accordance with the prior art;

Figures 2A through 2C are stylized diagrammatic exploded views during the encapsulation of a photovoltaic laminate as shown in Figure 1A using a fixture and heating arrangement in accordance with the process of the present invention;

Figures 3A through 3C are stylized diagrammatic exploded views during the encapsulation of a photovoltaic laminate as shown in Figure 1B using the fixture and heating arrangement in accordance with the process of the present invention, while Figure 3D illustrates the encapsulated module with an edge insert material in the depletion region;

Figures 4A and 4B are stylized diagrammatic exploded views during the encapsulation of a photovoltaic laminate as shown in Figure 1B using a modified form of the fixture in accordance with the process of the present invention, while Figure 4C illustrates the encapsulated module with an edge insert material in the depletion region;

Figures 5A and 5B are stylized diagrammatic exploded views during the encapsulation of a photovoltaic laminate as shown in Figure 1B using another modified form of the fixture in accordance with the process of the present invention, while Figure 5C illustrates the encapsulated module with an edge insert material in the depletion region;

Figures 6A and 6B are stylized diagrammatic exploded views during the encapsulation of a photovoltaic laminate as shown in Figure 1B using still another modified form of the fixture in accordance with the process of the present invention, while Figure 6C illustrates the encapsulated module with an edge insert material in the depletion region;

Figures 7A and 7B are stylized diagrammatic exploded views during the encapsulation of a photovoltaic laminate as shown in Figure 1B using yet another modified form of the fixture in accordance with the process of the present invention, while Figure 7C illustrates the encapsulated module with an edge insert material in the depletion region;

Figure 8 is a graphical representation of blackbody emissive power and absorptance of EVA, PVB and unfilled ionomer encapsulant materials and glass both plotted against wavelength output from an infrared heating source;

Figure 9 is a graphical representation similar to Figure 8 of blackbody emissive power and absorptance unfilled and filled ionomer encapsulant materials plotted against wavelength output from an infrared heating source;

Figures 10A and 10B are stylized diagrammatic views illustrating a first embodiment of an aspect of the invention whereby electrical leads emanating through an exhaust aperture in the support layer of a module are sealed against moisture and oxygen ingress;

Figure 10C is a stylized diagrammatic view illustrating a second embodiment of the invention for sealing the electrical leads emanating from the module through the exhaust aperture;

Figures 11A and 11B are stylized diagrammatic views illustrating a first embodiment of yet another aspect of the invention whereby electrical leads emanating laterally from the laminate are sealed against moisture and oxygen ingress;

5 Figure 11C is a stylized diagrammatic view illustrating a second embodiment of the aspect of the invention for sealing laterally emanating electrical leads as modified for use within a fixture; and

10 Figures 12A through 19B are diagrammatic views used in connection with the Examples disclosed herein.

DETAILED DESCRIPTION OF THE INVENTION

Throughout the following detailed description similar reference numerals refer to similar elements in all figures of the drawings. It should be understood that various details of the structure and operation of the present invention as shown in various Figures have been stylized in form, with some portions enlarged or exaggerated, all for convenience of illustration and ease of understanding.

20 THE PHOTOVOLTAIC LAMINATE After the laminate L is pre-assembled as shown in Figure 1A or 1B it is moved to a predetermined operational location where it is encapsulated. The term "predetermined operational location" is intended to encompass one or more work stations or positions at which operations on the laminate are performed. The operational location could be a location along an assembly line past which the laminate is movable.

30 ENCAPSULANT MATERIALS As noted earlier, to protect against the effects of moisture and oxygen ingress the laminate L includes an encapsulant E disposed at various positions within the laminate L.

As used herein, the terms "encapsulant", "encapsulant material" or the like are to be construed to include all

material(s) that serve(s) to encapsulate and to seal against moisture and oxygen ingress into the interior volume M of the laminate.

Whether used as an interlayer I (usually in sheet form) or as an edge insert G for a depletion region D (in any suitable physical form, as will be discussed) it has been found advantageous in accordance with the invention that the material used for the encapsulate E exhibits an energy absorptivity response that optimizes the effective heating rate of the material(s) being heated.

By "energy absorptivity response" it is meant the ability of a material under irradiation to receive incoming energy and convert it to heat energy.

Each material used as an encapsulant (whether for an interlayer or an edge insert) has a predetermined sealing temperature at which the encapsulant is able to flow into adhesive contact against the photovoltaic layer and an adjacent interior surface of the transparent layer and/or the support layer, or both. This arrangement is believed to best seal the module against moisture and oxygen intrusion and maximize mechanical robustness and overall durability.

It should be understood that a "sealing temperature" for a given material in a given application is not a fixed value but a situation-dependent property. Sealing temperature is a function of the particular geometry and internal topography that the encapsulant must accommodate in a particular application. Generally speaking, sealing temperatures for an encapsulant lie within the range from about eighty to one hundred twenty degrees Centigrade (80 °C to 120 °C).

The encapsulant material should possess low outgassing potential. Outgassing potential may be determined by headspace gas chromatography (e.g., ASTM F1884-04) and/or tested after processing by reheating the laminate to an elevated temperature (e.g. 120 °C) to simulate the end use

application and longevity and performance of the module for latent defects (e.g., bubble formation). Low moisture within the encapsulant materials will also help to prevent and/or minimize outgassing. Upper concentration limits for these various outgassing substances (volatiles) would advantageously be set for the resultant laminates to be largely free of bubble-like defects. This is particularly important since the high pressure that would be present in traditional autoclave processing is not present to suppress bubble formation.

Encapsulant Interlayers Materials suitable for use as encapsulant interlayers in the present inventions may be any of a variety of polymeric materials, such as ethylene vinyl acetate ("EVA"), polyvinyl butyral ("PVB"), unfilled and filled ionomers and the like. Most preferably, the encapsulant material possesses thermoplastic properties such that application of heat can allow for plastic flow to occur whereby sealing/encapsulation of the laminate may be facilitated. A preferred polymeric material is one that provides a high degree of clarity to maximize the solar radiation reaching the photovoltaic active region, durability for longevity of the photovoltaic module and its electrical generation properties, ability to bond to the materials in the module, sufficiently low moisture ingress properties, and the ability to process readily using proper combinations of vacuum, heat, and pressure.

In particular, ionomeric materials, which generally exhibit these advantageous properties, can be used as encapsulant interlayers in the present inventions. Ionomers are polymers produced by partially or fully replacing the hydrogen atoms of the acid moieties of precursor (also known as "parent") acid copolymers with ionic moieties. This is generally accomplished by neutralizing the parent acid copolymers, for example copolymers comprising copolymerized units of α -olefins and α,β -ethylenically unsaturated

carboxylic acids. Neutralization of the carboxylic acid groups present in such parent or precursor copolymers is generally effected by reaction of the copolymer with a base, e.g. sodium hydroxide or magnesium hydroxide, whereby the hydrogen atoms of the carboxylic acids are replaced by the cations of the base. The ionomers thus formed are ionic, fully or partially neutralized compositions that comprise carboxylate groups having cations derived from reaction of the carboxylic acid with the base. Ionomers are well known in the art and include polymers wherein the cations of the carboxylate groups of the ionomer are metal cations, including alkali metal cations, alkaline earth cations and transition metal cations. Commercially available ionomers include those having sodium, magnesium, potassium, zinc and lithium cations.

The use of ionomer compositions in laminated safety glass as interlayers is known in the art. It is known to utilize a rigid fixture to effect the lamination of safety glass. Representative of this technique is U.S. Patent 6,737,151 (Smith), assigned to the assignee of the present invention.

In recent years, certain ionomer compositions have also been developed as solar cell encapsulant materials. See, e.g., U.S. Patent Publication No. US2008-0023063 (AD7398). This publication discloses an ionomeric material that comprises a finite amount of polymerized residues of an α -olefin and from about eighteen to about twenty-five weight percent (18 to about 25 wt%) of polymerized residues of an α,β -ethylenically unsaturated carboxylic acid based on the total weight of the composition, said ionomeric material is about 20% to about 40% neutralized with one or more metallic ions based on the total carboxylic acid content, and said ionomeric material has a melt flow rate of less than about 10g/10min g/10min (ASTM method D1238 at 190°C). It is also known to use as an encapsulant for photovoltaic purposes an

ionomeric material that has a melt flow rate of about 25 g/10min (ASTM method D1238 at 190°C).

Representative of such materials especially useful as an encapsulant interlayer in the present inventions are the ionomer-based encapsulants available from E. I. Du Pont de Nemours and Company) as DuPont™ PV5300 and PV5400.

U.S. Patent 5,476,553 discloses the use, among others, of sodium ionomers such as Surlyn® 1601 resin as an encapsulant material. U.S. Patent 6,114,046 discloses a multi-layer metallocene polyolefin/ionomer laminate structure that can be used as an encapsulant.

As used herein, ionomers are neutralized derivatives of a precursor α -olefin carboxylic acid copolymer, wherein about 10% to about 60% of the total content of the carboxylic acid groups present in the precursor α -olefin carboxylic acid copolymer have been neutralized with metal ions, and wherein the precursor α -olefin carboxylic acid copolymer comprises (i) copolymerized units of an α -olefin having two to ten carbons and (ii) about eighteen to about thirty weight-percent (about 18 to about 30 wt%), based on the total weight of the α -olefin carboxylic acid copolymer, of copolymerized units of an α,β -ethylenically unsaturated carboxylic acid having three to eight carbons.

Suitable α -olefin comonomers may include, but are not limited to, ethylene, propylene, 1-butene, 1-pentene, 1-hexene, 1-heptene, 3-methyl-1-butene, 4-methyl-1-pentene, and the like and mixtures of two or more thereof. Preferably, the α -olefin is ethylene.

Suitable α,β -ethylenically unsaturated carboxylic acid comonomers may include, but are not limited to, acrylic acids, methacrylic acids, itaconic acids, maleic acids, maleic anhydrides, fumaric acids, monomethyl maleic acids, and mixtures of two or more thereof. Preferably, the α,β -ethylenically unsaturated carboxylic acid is selected from

acrylic acids, methacrylic acids, and mixtures of two or more thereof.

The precursor acid copolymers may further comprise copolymerized units of other comonomer(s), such as

5 unsaturated carboxylic acids having two to ten, or preferably three to eight carbons, or derivatives thereof. Suitable acid derivatives include acid anhydrides, amides, and esters. Esters are preferred. Specific examples of preferred esters of unsaturated carboxylic acids include,

10 but are not limited to, methyl acrylates, methyl methacrylates, ethyl acrylates, ethyl methacrylates, propyl acrylates, propyl methacrylates, isopropyl acrylates, isopropyl methacrylates, butyl acrylates, butyl methacrylates, isobutyl acrylates, isobutyl methacrylates,

15 tert-butyl acrylates, tert-butyl methacrylates, octyl acrylates, octyl methacrylates, undecyl acrylates, undecyl methacrylates, octadecyl acrylates, octadecyl methacrylates, dodecyl acrylates, dodecyl methacrylates, 2-ethylhexyl acrylates, 2-ethylhexyl methacrylates, isobornyl acrylates,

20 isobornyl methacrylates, lauryl acrylates, lauryl methacrylates, 2-hydroxyethyl acrylates, 2-hydroxyethyl methacrylates, glycidyl acrylates, glycidyl methacrylates, poly(ethylene glycol)acrylates, poly(ethylene glycol)methacrylates, poly(ethylene glycol) methyl ether

25 acrylates, poly(ethylene glycol) methyl ether methacrylates, poly(ethylene glycol) behenyl ether acrylates, poly(ethylene glycol) behenyl ether methacrylates, poly(ethylene glycol) 4-nonylphenyl ether acrylates, poly(ethylene glycol) 4-nonylphenyl ether methacrylates, poly(ethylene glycol)

30 phenyl ether acrylates, poly(ethylene glycol) phenyl ether methacrylates, dimethyl maleates, diethyl maleates, dibutyl maleates, dimethyl fumarates, diethyl fumarates, dibutyl fumarates, dimethyl fumarates, vinyl acetates, vinyl propionates, and mixtures of two or more thereof. Examples

35 of preferable suitable comonomers include, but are not

limited to, methyl acrylates, methyl methacrylates, butyl acrylates, butyl methacrylates, glycidyl methacrylates, vinyl acetates, and mixtures of two or more thereof.

The precursor acid copolymers may be polymerized.

5 Preferably, the precursor acid copolymers are polymerized under process conditions such that short chain and long chain branching is maximized.

The precursor acid copolymer may have a melt flow rate (MFR) of about five hundred (500) g/10 min or less,
10 preferably about two hundred (200) g/10 min or less, more preferably about sixty (60) g/10 min or less, as determined in accordance with ASTM method D1238 at 190°C and 2.16 kg. The corresponding partially neutralized ionomer preferably has a MFR of about one hundred (100) g/10 min or less, more
15 preferably about sixty (60) g/10 min or less, and most preferably about forty (40) g/10 min or less. The ionomer may also preferably have a flexural modulus greater than about 10,000 psi (68.9 MPa), more preferably greater than about 12,500 psi (86.2 MPa), and most preferably greater
20 than about 15,000 psi (103 MPa), as determined in accordance with ASTM method D638.

The ionomers of the present invention may also contain one or more additives, including, but not limited to, processing aids, flow enhancing additives, lubricants,
25 pigments, dyes, flame retardants, impact modifiers, nucleating agents, anti-blocking agents such as silica, thermal stabilizers, infrared ("IR") absorbers, ultraviolet ("UV") absorbers, ultraviolet stabilizers, dispersants, surfactants, chelating agents, coupling agents,
30 reinforcement additives, such as glass fiber, fillers and the like.

Encapsulant Edge Inserts Materials suitable for use as encapsulant edge insert G include poly(isobutylene), poly(urethane), poly(sulfides) and silicone. Preferred
35 materials are made using ionomeric materials, either

unfilled or filled. Fillers including but not limited to pigments such as carbon black and/or glass fibers may be added to enhance the energy absorptivity response of the material for faster heating. Glass fibers and the like may be added to the encapsulant edge insert for improving creep resistance. Other additives such as EVOH, mica, dessicants (e.g. zeolites) are known in the industry to provide reduced moisture ingress may advantageously be compounded into the ionomeric resin for improved moisture ingress properties.

Silanes or other additives can additionally be added for enhancing adhesion to the transparent layer and/or support layer. Improved creep resistance can be achieved by using an additive which crosslinks upon heating. Various peroxides are well-known in the industry for providing this polymer modification feature. Alternatively, creep-resistance can be facilitated by adding a higher melting point polymer resin to the ionomeric resin. For example, one compounded resin was made by taking clear ionomer encapsulant and compounding in two percent (2%) carbon black, twenty percent (20%) Nucrel[®] HS0411 ethylene meth(acrylic) acid (available from E. I. Du Pont de Nemours and Company) and twenty percent (20%) polypropylene (Atofina 3480Z). This compounded resin was found to have a broader melting point range and higher sealing temperature. By increasing the energy absorptivity response of these materials a higher incident portion of infrared radiation is absorbed, so that the temperature of the material in this region is raised above its sealing temperature and that of the encapsulant material in close proximity to the region receiving the higher incident portion of infrared radiation. This will occur primarily through conduction of heat energy to those regions.

THE LAMINATING FIXTURE In the preferred instance the laminate L is formed into a finished module using an air-

tight fixture 20 and a heating source 40 that is operative in a coordinated manner in accordance with the present invention. However, as will be developed, it should also be understood that various aspects of the invention may be performed in which the internal volume of the laminate is sealed without the use of the fixture 20.

The fixture 20 used in the present invention may take any of a variety of forms, representative ones of which are illustrated in Figures 2 through 7. However, in all of its various forms the fixture 20 includes a top frame member 22T and a bottom frame member 22B, with the primary difference among the various forms being the manner in which the air-tight sealed integrity of the fixture 20 is maintained when a laminate L is received therein and is being operated thereupon. The frames 22T, 22B are preferably made of machined aluminum but can be made of any material that is substantially rigid in a plane parallel to the plane of the transparent layer and support layers of the laminate L. The term "substantially rigid" is used herein to mean the fixture will not deflect to an extent that it unduly pinches the peripheral edges of a laminate being fabricated therein.

Regardless of the form of the fixture each of the top and bottom frames 22T, 22B carries a peripheral seal 23T, 23B, respectively. The seals 23T, 23B seat in air-tight abutment against selected surfaces of the laminate L such that the laminate is completely engaged about its periphery by the fixture when the laminate is received within the fixture. In practice, the seals 23T, 23B may seat against the peripheral margins of the upper and lower exterior surfaces T_E , S_E of the respective transparent layer T and the support layer S of the laminate L. Alternatively, the seals 23T, 23B may be disposed on the frames in such positions that they engage the peripheral lateral edges (as opposed to the planar surfaces) of the layers of the laminate. In either case, when received within the fixture

20 the major portion (i.e., almost the full area) of the exterior surfaces T_E , S_E of the laminate L are exposed to ambient atmosphere. When the fixture is completely engaged against the periphery of the laminate (as described) and the
5 air-tight sealed integrity established between frames of the fixture, air may be withdrawn from the laminate L so that atmospheric pressure acts to compresses the layers of the laminate L, as will be more fully explained herein.

In the arrangements of the fixture 20 shown in Figures
10 2A and 2B, Figures 3A and 3B, and Figures 4A and 4B, each frame member 22T, 22B has a circumferential lip 24T, 24B formed thereon. A gasket 25 is mounted on one of the lips, e.g., the lip 24T. In these arrangements the gasket 25 is the member that serves to maintain the sealed integrity of
15 the interior of the fixture when the frames 22T, 22B are joined together.

A vacuum port 26 is formed in one of the frames (e.g., the frame 22T). The port communicates with the interior annular volume 27 that surrounds the laminate L when the
20 frames 22T, 22B are conjoined.

The fixture 20 shown in Figure 4A includes a force generating member 28 disposed in the annular interior volume 27 defined within the closed fixture. The force generating member 30 may implemented by any suitable pneumatic,
25 electrical, mechanical or electro/mechanical actuator. In the arrangement illustrated the force generating member 28 takes the form of an expandable bladder. The bladder may be conveniently attached to one of the frames, e.g., the frame 22B, if desired. The bladder 28 has an inflation nipple 28N
30 that extends in any convenient manner to the exterior of the fixture 20, as through an access port 22P provided in the lower frame 22B. Alternatively, the force generating member may take the form of a constricting belt arrangement.

As shown in Figure 4A an edge insert G may be disposed
35 within the fixture 20 inwardly of the force generating

member 28. The edge insert G serves to form a peripheral seal between the layers of the laminate to further limit the ingress of moisture into the finished module. As mentioned earlier herein the edge insert G is formed of a material
5 having a predetermined sealing temperature above which the material is able to flow into adhesive contact with a layer of the laminate to which it is adjacent.

In Figure 4A, since the air-tight seal between the frames 22T, 22B is effected by the gasket 25, the edge
10 insert G need not provide the primary seal between these members and hence it may take any of a variety of physical forms. Among the various physical forms available, the encapsulant for the edge insert G may implemented as a flexible strip-like member or profile that keeps its shape
15 at room temperature, a bead of a flexible deformable material (akin to a mass of spackle compound), a bead of a viscous liquid (e.g., of toothpaste-like consistency) or a mass of particles (e.g., grains or pellets).

In the fixture 20 shown in Figure 5A and 6A the
20 peripheral margins of the frames 22T, 22B are spaced from each other, i.e., the circumferential lip regions 24T, 24B shown in Figures 2A and 3A are not provided. In this instance the air-tight circumferential seal between the frames (when the fixture is closed) is provided by a force
25 generating member or a force transmitting member that extends between the confronting surfaces of the frames. This member may, if desired, be connected to one of the frames (e.g., the frame 22B).

In Figure 5A the force generating member is implemented
30 using an inflatable bladder 28 similar to that shown in Figure 4A. The bladder may be made of a suitable expandable material such as neoprene or silicone rubber. The interior contoured surface 28I of bladder 28 is presented to the interior volume defined by the conjoined frames, while the
35 exterior contoured surface 28E of the bladder 28 is directly

accessible from the exterior of the fixture. The bladder 28 forms a sealing interface with the frames, as suggested at reference character 28S.

In Figure 6A an air-tight circumferential seal between the frames is provided by an external force transmitting member in the form of a deflectable diaphragm seal 32. The interior surface 32I of the diaphragm 32 faces toward the interior volume defined by the conjoined frames, while the exterior surface 32E of the diaphragm 32 is directly presented to the exterior of the fixture. The diaphragm 32 has upper and lower circumferential rims 32T, 32B that abut against in sealed engagement against the edge surfaces of frames 22T, 22B, respectively. The diaphragm may be fabricated from the same material as the inflatable bladder.

The arrangements shown in Figures 5 and 6 further include an edge insert G surrounding the periphery of the laminate. Similar to the situation extant in Figure 4, since the air-tight seal between frames is provided by the bladder 28 or the deflectable diaphragm 32, as the case may be, the edge insert G may take any of the physical form as discussed in connection with that Figure.

However, in the arrangement of the fixture shown in Figure 7A the air-tight seal between the frame members is provided by an externally accessible edge insert G. In this instance the edge insert G must be dimensionally stable at room temperatures and exhibit a geometric shape to allow it to engage in contacting relationship with the top and bottom internal surfaces of the frame members and/or the peripheral edge of the transparent layer and support layer. The shape of the edge insert G is selected such that mating surfaces with the frame and/or peripheral edges of the transparent layer and support layer will form a sealed relationship once assembled (assembly could be performed at room temperature or could be preheated) or during the primary process heating step. This step would precede the laminate reaching its

sealing point, such that air removal from the internal volume of the laminate can be achieved. An air withdrawal nipple(s) 33 is disposed at predetermined circumferential location(s) about the edge insert G. The nipple(s) 33 extend(s) through the edge insert G so that air may be removed from the laminate.

THE HEATING SOURCE The heating source 40 serves to heat the material of the laminate to promote the development of a bond with the layers and components therein and to further soften of the encapsulant to achieve flow around busbars, leads, cells, and required conformation to surfaces within the laminate. In cases where a cross-linking of the encapsulant is desired the heating source can drive those reactions. If an edge insert G is also included within the fixture the source 40 also provides the heat energy to cause the same to soften and to flow into desired locations on the laminate, as will be discussed. Several forms of heating sources are available, including convection, conduction, infrared, radio frequency, induction, or microwave.

The heating source 40 has an energy output characteristic tuned to the energy absorptivity response of the encapsulant material. Energy output characteristic relates to the spectral distribution of emitted energy from the heating source. By "tuning" it is meant the matching of the emitted energy from the source to the energy absorptivity response of the encapsulant material to maximize the efficiency and/or rate of conversion to heat energy of the encapsulant being irradiated.

In the context of this application infrared heating is preferred. Various infrared element technologies are available, each with different spectral emission characteristics and power densities, as will be discussed in connection with Figures 8 and 9. Heated element ceramic heaters generally operate in the five hundred to one

thousand degrees Kelvin range (500 °K to 1000 °K) emitting infrared radiation in the two to ten micrometer (micron) (2 to 10 micrometer) range. Quartz tube emitters generally operate around twenty-five hundred degrees Kelvin (2500 °K) and emit peak radiation in the short-infrared range around one to two micrometer (1 to 2 micrometer). Infrared lamps with tungsten-halogen filaments generally operate in a range from about twenty-six hundred to twenty-nine hundred Kelvin (2600 °K to 2900 °K) and emit peak radiation in the short-infrared range around one micrometer (1 micrometer). The benefit of these shorter wavelength emitters is their power densities are much higher (e.g. $\sim 40\text{W}/\text{cm}^2$) than the mid- and long-wavelength infrared emitters. Additionally, their response time (time to heat-up and reach full emitter output) is short (seconds). Generally, the useful range for heating is 0.3 micrometers to one hundred (100) micrometers, preferably 0.4 micrometers to twenty (20) micrometers, and most preferably 0.4 micrometers to ten (10) micrometers. It should be recognized that a portion of this emission is in the visible range.

Regardless of the form taken by the fixture 20 (or whether a fixture is used) preferably the heating source 40 is implemented using one or more infrared lamps 40L (and any associated equipment, e.g., reflectors and the like) that are supported in any convenient positions with respect to the fixture 20 (see Figures 2A and 3A). The lamps 40L are positioned to irradiate one or both of the exposed surfaces of the laminate. If desired the sources 40 may be positioned at various predetermined distances "d" (e.g., Figures 2B, 3B) from various predetermined regions of the laminate, as will be discussed. The lamps 40L are omitted from Figures 4 through 7, 10B, 10C, 11B and 11C for clarity of illustration.

METHODS OF THE PRESENT INVENTION As described earlier the laminate L may be such that the various interior layers of the same are either edge-wise coextensive with the top layer T and support layer S (Figure 1A) or recessed from those edges by a depletion zone D (Figure 1B).

After the laminate L is pre-assembled the first step in accordance with the method of the present invention is to seal the interior volume of the laminate from communication with the atmosphere. In the practice of some of the aspects of this invention (e.g., as described in Figures 10 and 11) it suffices to seal the periphery of the laminate using a band of sealing material such as a tape. A vacuum ring may also be utilized to seal the laminate completely about its periphery in an air-tight manner such that a major portion of the exterior surface of one or both the transparent and a support layers of the laminate is/are exposed to atmospheric pressure.

Preferably, however, the laminate is sealed by engaging the laminate completely about its periphery with a selected form of air-tight fixture. As earlier discussed, regardless of the form of fixture used, when mounted within the fixture the seals 23T, 23B on the respective frames 22T, 22B seat against the peripheral margins of the upper and lower exterior surfaces T_E , S_E or the edge surfaces of the respective transparent layer T and the support layer S of the laminate L.

Figure 2A illustrates a laminate L having edge-wise coextensive layers received within a fixture 20 of the type having circumferential lips, while Figure 3A shows a laminate L having a depletion zone D as received within the same form of fixture.

Figure 4A shows a laminate L having a depletion zone D as received within a fixture of the type that includes an internal force generating member (the bladder 28). In using the arrangement of Figure 4A, prior to the closing of the

frames 22T, 22B, the edge insert G is inserted into the fixture in surrounding relationship to the laminate. The insert G extends completely about the periphery of the laminate. The force generating bladder 28 is then disposed
5 in surrounding relationship to the insert G.

In Figures 5A and 6A a laminate L with a depletion zone D is received within a fixture having an external force generating bladder. In these cases, as is the case with the arrangement of Figure 4A, the edge insert G is positioned
10 between the interior surface of the force generating member and the periphery of the laminate.

In Figure 7A, after the laminate L is disposed in a frame member, the edge insert G is positioned in closely surrounding relationship. The other frame member is then
15 mounted on the first frame.

It should be appreciated that although Figures 4A through 7A illustrate a given fixture used in conjunction with a laminate L having a depletion region D, a laminate having edge-wise coextensive layers (Figure 1A) may be used
20 with equal effect.

Regardless of the form of fixture used, once the laminate L is engaged within a fixture, the next step in the process is heating the encapsulant material E within the laminate using the lamps 40L. As will be more fully
25 developed herein the energy output from the lamps 40L is tuned to the particular encapsulant material within the laminate so that energy is more efficiently channeled into heating of the encapsulant material.

While the encapsulant material is being heated, but
30 before it is raised to its sealing temperature, air is withdrawn from the volume lying between the interior surfaces T_I , S_I of the transparent layer T and the support layer S of layers of the laminate L.

Air is removed from between the layers of the laminate
35 via the vacuum port 26. Alternatively, if the support layer

S has an exhaust aperture A provided therein, air can be removed therethrough. In this event a vacuum shoe 42 may be positioned about the aperture A. If air removal is through the exhaust aperture the vacuum port 26 of the fixture need
5 not be utilized. Air is removed until the pressure within the laminate is in the range from about zero to about fifty (50) millibar absolute.

As air is evacuated from between the layers of the laminate L atmospheric pressure acts on the exposed exterior
10 surfaces T_E , S_E to compress the layers of the laminate and the encapsulant material. Simultaneously, as the temperature of the encapsulant material is raised past its sealing temperature, it adhesively contacts against the photovoltaic layer and an adjacent interior surface(s) of
15 the transparent layer and/or the protective layer, thereby to form a sealed composite structure. Further increase in temperature causes the encapsulant to flow to surround busbars, leads, cells, and to conform to surfaces within the laminate.

If the fixture shown in Figures 2A and 3A is being used, the finished, sealed, module (Figures 2C, 3C) is removed from the fixture 20. As suggested in Figure 3D, as a separate step, the depletion zone D of the finished module may then be filled with encapsulant material for the edge
25 insert G.

Use of any of the fixtures as shown in Figures 4A through 7A is believed to be of even further advantage in that the peripheral edges of the module are also sealed simultaneously with the formation of the module.

Using the arrangement of Figure 4A, before the encapsulant (including the interlayer and the edge insert) reach their sealing temperatures and as the air is being withdrawn air from between the layers of the laminate so that atmospheric pressure compresses the layers of the
35 laminate, the force generating bladder 28 is actuated to

bring the same into contact with the exterior surface of the insert 29. Thus, as the temperature of the materials of the encapsulant are raised past their sealing temperatures, the force generating bladder 28 acts against the edge insert G to force the interior surface thereof into adhesive contact at least against the edge of the photovoltaic layer and at least the edges of the transparent and protective layers, thereby to form a sealed laminated structure. If the laminate has a depletion region D the force produced by the bladder 28 forces the edge insert G thereinto, whereby the insert also adhesively contacts against the interior surfaces of the transparent and protective layers. Similar action obtains if the arrangement of Figure 5A is used.

If the fixture of Figure 6A is utilized, as air is withdrawn from the fixture atmospheric pressure acts against the deflectable diaphragm 32 to force the insert material 29 into contact with the laminate, as described.

Using a fixture as shown in Figure 7A, atmospheric pressure acts directly against the mass of insert material G to force the same into contact with the available surfaces of the laminate.

Selective absorption and heating can be accomplished by the proper selection of the materials of construction, including encapsulant and glass. There are two approaches that may be used in choosing the materials of construction, including a calculation method and a direct heating rate measurement method.

The calculation method allows an estimation of heating efficiency to be made by either using blackbody radiation emission as described by Planck's Law or by using the actual emission spectra of the emission source. Integration of the spectral output coupled with the absorption spectra of each respective layer/material of the substrate and/or entire assembly provides a reasonable approach for predicting

heating rates on a relative basis. Choice of emitter type and peak temperature with optimization of materials of construction can be made in this manner.

5 A second method useful in determining the preferred materials of construction is the direct measurement of their heating rate under irradiation from the infrared emitter. Several approaches exist, but one is to obtain or produce uniform plaques of the material of interest having a uniform thickness. A thermocouple is taped to the underneath side
10 of the plaque to be tested and the sample placed onto a heat-resistant surface. It is best to avoid materials with high thermal conductivity such as metals. The infrared source is placed at a distance consistent with manufacturer recommendations or how it might be positioned in the actual
15 equipment. The infrared source is activated and the time for the plaque to heat to a given temperature (e.g. sealing temperature) is recorded or if a recording thermometer is used, the heating rate data is captured. This information can be compared between various infrared sources and
20 operating conditions against various materials and arrangements.

As infrared element temperature goes up the peak emission wavelength decreases and the total energy output increases. Therefore, selection of encapsulant materials
25 with an energy absorptivity response that enables them to absorb more energy at shorter wavelengths than glass will enable faster processing times and cycle rates. This is shown in Figures 8 and 9. In these Figures blackbody emissions of eight hundred degrees Kelvin (800 °K) and 2635
30 °K are shown, with peak emission wavelengths of 4.5 micrometers and 1.1 micrometers, respectively.

Figure 8 shows the blackbody emissive power as well as the absorption of encapsulants including unfilled ionomer, PVB and EVA. The absorption of glass is also shown. It can
35 be seen that employing sources having wavelength emissions

of 4.5 micrometers or less allows the encapsulant materials to directly absorb the energy, while the glass will absorb much less. As used herein the term "directly absorb" means that radiation is absorbed by the encapsulant material and converted to heat within the material. If radiation enters one of the layers of the laminate (e.g., the glass layer) the radiation is converted to heat within the glass and the encapsulant is heated by conduction.

Figure 9 shows the blackbody emissive power as well as the absorption of encapsulants that are unfilled ionomer, ionomer filled with glass fiber and ionomer filled with carbon black. The addition of glass fiber and carbon black to the ionomer increases the absorption of the emitted energy.

When the calculation method as described above is applied to the spectral output in Figures 8 and 9, it can be seen that at least thirty percent (30%) of the available energy from the infrared radiation source is directly absorbed by the EVA, PVB and unfilled ionomer encapsulants. As shown in Figure 12, this percentage increases to at least fifty percent (50%) for ionomer filled with twenty percent weight by weight (20% w/w) glass fiber, and to at least sixty-five percent (65%) for ionomer filled with two percent weight by weight (2% w/w) carbon black.

ENHANCED LOCALIZED HEATING In accordance with another aspect of this invention enhanced heating effects can be imparted to predetermined targeted zones of the laminate. Such enhanced heating effects are useful, for example, to heat the edge insert material G in the depletion region D, to heat the interlayer encapsulant material I in regions having internal interconnectors B and/or leads W, and/or in any areas where additional encapsulant flow is desirable.

In particular, the geometric shape and thickness of the internal interconnectors B and electrical leads W create

special regions where increased encapsulant flow must occur to accommodate the volume of these members. Preferentially, the encapsulant should flow so as to form a seal around these shapes and achieve a seal for the overall

5 laminate/module assembly. In addition, sufficient flow of encapsulant away from the immediate area surrounding these shapes redistributes the encapsulant and regains the overall flatness of the transparent layer and support layers. This reduces the residual stress-level in the completed module so
10 that longevity/durability is improved. Otherwise, these heightened regions of stress can result in locations where delaminations, bubbles or other defects occur during exposure to environmental stresses such as high humidity and thermal extremes.

15 The ability to target specific areas of the laminate is difficult to achieve in conventional heating approaches with convective air or heated platens.

One approach, already discussed, to achieve zonal heating effects is to strategically position the heating
20 sources and/or focus the energy distribution produced thereby in such a way as to create more energy flux to the laminate where the higher induced temperature will facilitate enhanced thermoplastic flow. This can either reduce the overall energy needed if the entire pre-assembly
25 had to reach this temperature or can greatly reduce the time necessary for sufficient flow to occur. This expedient can be accomplished by varying the distance "d" (e.g., Figure 2B) at which one or more of the sources 40 is/are positioned and/or the source intensities and/or the operating
30 wavelengths at which the sources emit.

Another approach is to modify the absorptivity characteristic of the encapsulant material that is located in those predetermined areas of the laminate in a way such that incoming energy is converted to heat at different rates
35 thus creating different temperature profiles.

For example, the encapsulant material may contain one or more additives that cause the encapsulant to respond to radiation. The additive can take the form of any pigment or filler. Carbon black is preferred.

5 In practical use, this filled area would be positioned in areas where higher absorption of infrared radiation would create higher temperatures or faster heating rates. This would be useful to target areas surrounding internal interconnectors, leads, cells and/or and other regions
10 (e.g., the depletion region) exhibiting physical geometries where enhanced flow would be beneficial. These expedients are illustrated diagrammatically in Figures 12A, 12B and 17A, 17B.

As yet another alternative a removable energy absorbing
15 mask may be placed on one or both of the transparent or support layers while the laminate is being heated. This further increases the absorption of infrared radiation in that local region as compared with the surrounding non-masked region. The mask could be placed on the exterior
20 surface of the glass on the infrared source side of the laminate (Figures 14A, 14B), or exterior surface of the support layer (Figures 16A, 16B). The mask can be conveniently implemented using a physical member, as a sheet or panel, or by painting or inking the surface.

25 In some instances it is the practice in the art to secure the interconnectors B within the volume M of the module using a (double-sided) mounting tape. By introducing an infrared absorbing additive into the mounting tape increased localized heating in the areas having the mounting
30 tape can be achieved.

SEALING OF LEADS EMANATING FROM MODULE A significant
challenge presented in the art is the need to seal the leads
W that bring the electrical energy generated by the
35 photovoltaic layer outward from the module for utilization.

Figures 10A through 10C and Figures 11A through 11C illustrate additional aspects of the invention that address this challenge. As will be developed these aspects of the present invention are believed advantageous in that they
5 extend the encapsulation of the leads beyond the geometry of the module.

Leads Emanating From Exhaust Aperture Figures 10A through 10C illustrate alternate versions of an aspect of the invention in which the electrical leads W that emanate
10 from the module through the exhaust aperture A in the support layer S are sealed against moisture and oxygen ingress. It is noted that Figures 10A through 10C illustrate situations in which the internal volume M of the laminate L is sealed without the use of the fixture 20. In
15 the cases illustrated in Figures 10A through 10C the interior volume M of the laminate is sealed using a band 46 of sealing material (e.g., tape) disposed circumferentially about the periphery of the laminate L. It should be understood, however, that the arrangements for sealing the
20 leads W described in Figures 10A through 10C may be utilized in situations wherein the laminate is fabricated within any of the fixtures 20 described herein

In the specific embodiment shown in Figures 10A and 10B each lead W is electrically connected to a cylindrical
25 metallic socket 48 which thereby becomes a portion of the lead W. The exhaust aperture A in the support layer S is sealed using a sealing plug 50 that is inserted into the aperture A, as suggested by the arrow 52. The plug 50, whose exterior configuration corresponds to the shape of the
30 aperture A, has at least one, but preferably a pair, of openings 50B extending therethrough. The socket 48 of each lead W is inserted through a respective opening 50B in the sealing plug 50.

The plug 50 is formed of a material having a
35 predetermined sealing temperature above which the material

of the plug is able to flow into adhesive contact with the electrical lead passing therethrough. Most preferably the plug 50 should be formed of a material that is the same as or compatible with the encapsulant material, to insure more complete and intimate melding or fusing of the plug to the encapsulant, as will be described.

With the interior volume of the laminate L isolated in an air-tight manner from the atmosphere (by the peripheral band 46) the sealing plug 50 and the encapsulant material(s) within the laminate are heated by the heating source 40.

Before the sealing plug 50 and the encapsulant material(s) are raised to their respective sealing temperatures, air is withdrawn from the interior volume M of the laminate L so that atmospheric pressure compresses the layers of the laminate. As the temperature of the encapsulant is raised past its sealing temperature, the encapsulant adhesively contacts against the photovoltaic layer, the adjacent interior surface of the protective layer, and the portions of the leads W therein.

Further, as the temperature of the sealing plug 50 is raised past its sealing temperature, the plug 50 adhesively contacts against the socket portion 48 of the electrical leads W as well as the encapsulant material within the laminate. If the plug 50 is fabricated from the same or compatible material as used for the encapsulant the plug 50 more intimately melds together and fuses with the encapsulant. Thus, a sealed laminated structure is formed in which the leads W (including sockets 48) are completely sealed from a point within the laminate L to the outer ends of the sockets.

Air may be withdrawn from within the laminate using the vacuum shoe 42 (also shown, for example, in Figures 2B, 3B). The shoe 42 has an internal evacuation channel 42C therethrough. The mouth of the channel 42C is surrounded by an O-ring seal 42S. The shoe 42 advantageously may be

provided with a pair of positioning posts 42P which assist in locating the shoe 42 against the support layer S and maintaining the relative position of the sockets with respect to the laminate. As suggested by the arrows 53 the shoe 42 is brought into sealed engagement against the support layer S in a position surrounding the aperture A such that the shoe 42 is in a sealed relationship with the support layer S and the channel 42C in the vacuum shoe is in fluid communication with the aperture A. The evacuation channel 42C is connected to a vacuum and, before the encapsulant and the material of the plug 50 reach their sealing temperatures, air is withdrawn from the laminate L through the aperture and the openings in the plug, as suggested by the arrow 54.

After the sealed laminated structure is formed the shoe 42 is removed. As a result of the practice of the invention the finished module has a typical multi-prong female receptacle formed thereon whereby electrical connection with the leads W may be using a compatible male plug. The compatible male plug typically includes cylindrical metal pins (not shown, but analogous in structure to the posts 42P). The pins of such a male plug are typically about one-quarter inch (6 mm) long, with a diameter of about four millimeters (4 mm). It is appreciated that the female-male receptacle-plug arrangement as described may be implemented in variety of ways.

In the alternative embodiment in accordance with this aspect of the invention shown in Figure 10C it is also possible to gain further manufacturing efficiency by integrating the mounting of a junction box 56 to the laminate during fabrication. In this alternative both of the leads W extend through a respective opening 50B in the plug 50 to leave relatively short lead tails 50T that project beyond the outer surface of the plug 50. Thus, in this alternative, the sockets 42S are omitted.

The junction box 56 contains appropriate electrical conductors 56C and circuitry 56D to terminate the leads W. The box 56 is filled with a suitable filler material 56F. The filler 56F has a predetermined sealing temperature associated therewith. Preferably the same material as is used to form the plug 50 may be used for the filler material 56F within the box 56.

The box 56 has an evacuation port 56P formed in a wall thereof. A hollow evacuation stem 60 is connected, as with a grommet, in fluid communication to the evacuation port. This portion of the box is diagrammatically exaggerated in Figure 10C for illustrative clarity. The conductors 56C exit the box 56 through the evacuation port 56P and the stem 60.

The stem 60 serves as the pathway for air removal from within the laminate during the air evacuation from the laminate, as will be developed. The stem 60 is formed of a heat softenable material, again preferably the same material as used for the plug 50 and the filler material 58.

After each conductor 56C from the junction box 56 is electrically connected to the tails 56T of a respective one of the electrical leads W passing through the sealing plug 50 the box 56 is mounted against the support layer S. An O-ring or adhesive seal 56S seals the box against the support layer S during processing so that the interior of the box 56 is in fluid communication with the aperture A. It should be appreciated that alternative electrical connections may be effected between the leads W and the conductors 56C in the junction box 56.

During the heating step, as both the plug 50 and the filler material 58 are both heated but before each reaches its respective sealing temperature, a vacuum source is connected to the evacuation stem 60 and air is withdrawn from the laminate L through the aperture A and the box 56. When the temperature of the sealing plug 50 is raised past

its sealing temperature the plug 50 adhesively contacts against the electrical leads extending therethrough. In addition, as the temperature of the filler material 56C is raised past its sealing temperature, the filler material 56C adhesively contacts the plug 50 thereby to seal the connection between the lead tails 56T and the conductors 56C. Moreover, if the plug 50 is fabricated from the same or compatible material as used for the filler, the plug 50 and the filler 56C more intimately meld and fuse together. In either event a sealed laminated structure is formed in which the leads W, lead tails 56T, and conductors 56C are completely sealed from a point within the laminate L to the evacuation port 56P of the junction box 56. The box 56 is itself permanently secured to the support layer S by the filler material 56F.

During the heating step the evacuation stem 60 is also heated to its softening temperature. As air is withdrawn from the laminate the stem softens and responds to the pressure differential between the atmosphere and the interior of the stem by collapsing into a sealed relationship with the electrical conductors.

Laterally Emanating Leads Figures 11A through 11C illustrate arrangements whereby the leads emanating from the sides of the laminate L may be sealed against moisture and oxygen ingress. In these arrangements a collapsible stem similar to that shown in Figure 10C is used to advantage.

Figures 11A and 11B again illustrate a situation in which the internal volume M of the laminate L is sealed using a peripheral band 46, without the use of the fixture 20. Figure 11C illustrates this aspect of the invention using any of the fixtures 20 described herein.

In Figures 11A and 11B a stem 60 is provided for a single lead W emanating from different regions of the laminate L, in order to illustrate modifications of the invention. If convenient (and if the leads W are suitably

electrically isolated) both of the electrical leads W from the laminate may occupy a single stem. The stem(s) could extend for any desired distance.

At least a portion 60C of each stem 60 is collapsible
5 in response to a pressure differential once the stem has reached a predetermined softening temperature. The stem 60 may be made from a material that is able to adhesively seal with the encapsulant. Preferably, the stem 60 should be formed of a material that is the same as or compatible with
10 the encapsulant material, to insure more complete and intimate melding or fusing of the stem 60 to the encapsulant.

As shown in Figure 11A the stem 60 is positioned with respect to the laminate such that the first, inner, end 60I
15 of the stem 60 is proximal and in fluid communication with the interior volume of the laminate L. A convenient expedient for positioning the stem would be to puncture the stem through a short length of tape 62 and then to affix that length of tape to the edges of the transparent and
20 support layers of the laminate. At least one (or both of the leads if the leads are jacketed with insulation) is(are) threaded through the stem 60. If the encapsulant includes an edge insert G the insert material assists in holding the stem in position. Thereafter, the remaining portion of the
25 periphery of the laminate is itself sealed using a band 46.

The outer end 60E of one or both stem(s) 60 is(are) connected to an evacuation line 62. If only one stem 60 is connected to the evacuation line (e.g., the stem shown on the right hand side of Figure 11A) the outer end 60E of the
30 other stem 60 is covered by a cap 63.

Using the heating source, the encapsulant within the laminate L and the collapsible region 60C of the stem 60 are heated toward their respective sealing and softening temperatures. Before the encapsulant is raised to its
35 sealing temperature, air from the interior volume of the

laminate through the stem 60, so that, as the temperature of the collapsible region is raised past its softening temperature it is able to respond to exposure to a pressure differential to collapse into sealed contact against the electrical lead therein, as illustrated diagrammatically at locations 64 in Figure 11B. One suitable expedient for creating a pressure differential is to expose the stem, after evacuation, to atmospheric pressure.

In the same way as explained earlier, as the temperature of the encapsulant is raised past its sealing temperature the encapsulant is able to adhesively contact against the photovoltaic layer and an adjacent interior surface of the transparent layer and/or the protective layer (as described earlier).

In addition, the encapsulant adhesively contacts with the inner end region of the stem, thereby to form a sealed laminated structure in which at least a portion of the electrical lead is enclosed in sealed relationship by the encapsulant and the material of the collapsible region of the stem. If an edge insert is used the stem adhesively contacts with the encapsulant material used for the edge insert. If an edge insert is omitted the stem adhesively contacts with the encapsulant material forming the interlayer. If the stem is made from a material that is the same or compatible with the encapsulant the stem 60 is more intimately melded and fused with the encapsulant. This melded relationship is suggested at reference 65 character in the drawings.

In a more preferred implementation the stem 60 includes a rigid portion 60R that is spaced axially from the collapsible portion 60C. The rigid portion 60R may be conveniently implemented using a sleeve 60S that is inserted into the stem. The free end W_E of the lead W is inserted into the stem 60 to the extent that the free end W_E is contained within and surrounded by the rigid portion 60R of

the stem. The rigid portion of the stem shields the collapsible region of the stem from collapsing onto the free end W_E of the lead. The rigid portion 60R of the stem is later cut (as along cut lines 66, Figure 11B) to expose the end W_E of the electrical lead.

Alternatively, as shown in the left-hand portion of Figure 11A, the free end W_E of each electrical lead W may be covered with a suitable release jacket 67 that prevents the collapsible portion 60C of the stem 60 from sealing to the free end W_E of the electrical lead. The stem is cut (as along cut lines 68) to access the free end W_E of the lead. The release jacket 67 is opened to expose the free end of the lead.

A fixture 20 may be used to insure the air-tight sealed integrity of the laminate L. In this instance the laminate with stem 60 attached as shown in Figure 10A (with the evacuation tube omitted) is disposed on the interior of the fixture. Air is withdrawn from the laminate through the vent opening 26 in the fixture 20, as described earlier. In this case, since no pressure differential exists between the interior and exterior of the stem while the laminate is within the fixture, the stem does not collapse until the frames of the fixture are separated and the stem is exposed to atmospheric pressure.

Figure 11C illustrates an alternative whereby the stem may be held in position against the fixture within the fixture. In this case the stem has a flanged base 60F that is sized to abut against the side edges of the transparent and support layers T, S, respectively, of the laminate. A biasing spring 68 is positioned within the fixture. One end 68I of the spring bottoms against the flange 60F while the other end 60E of the spring abuts the interior surface of a frame of the fixture. Any suitable alternative biasing element may be utilized.

Examples

The following Examples were performed using the following encapsulants. The encapsulants were sheets with a thickness of approximately 0.38mm (15 mils). The glass was 3mm standard clear annealed glass (30 cm squares) and was washed with deionized water and dried thoroughly before use.

The following Examples were fabricated in one of five different primary configurations. These configurations are shown in the configuration of Figures 12A through 19B, specifically Examples shown relative to Figures 12A through 15B and Figures 17A, 17B. The first configuration (Figures 12A, 12B) utilized a uniform layer of unfilled encapsulant over the entire photovoltaic laminate surface area. This configuration was used for Examples CE40, CE41, 42-45 and 49. The second configuration (Figures 13A, 13B) utilized a clear ionomer encapsulant sheet over a major portion of the surface area of the photovoltaic laminate, but a region of filled ionomer (2% w/w carbon black) was also present as a strip (4 cm width) through the centerline of the laminate.

The Examples employing configuration of Figures 13A, 13B were the following: 46-48. In these examples, the infrared lamp was positioned at fifteen centimeters (15 cm), seven centimeters (7 cm), and three centimeters (3 cm), from the laminate surface and energy absorbed by the laminate assembly. Example (50) utilized configuration of Figures 14A, 14B where a solid black ink marking (six centimeters square)

Similarly, in Example 51, an adhesive electrical isolation tape containing carbon black was used between the glass and the busbar. This was also found to increase the absorption of infrared radiation in that local region. All Examples of Table 1 used the clear ionomer encapsulant available from by E. I. du Pont de Nemours and Company, Wilmington, DE as DuPont™ PV5400. Examples 46-48 used ionomer encapsulant which had a 2% w/w carbon black extruder

compounded layer. Little to no effect on electrical conductivity due to this loading of carbon black but heat-up time was shortened dramatically. Example 52 was prepared by using clear ionomer encapsulant within the active

5 photovoltaic/solar cell portion of the module (light receiving area - active area) and around the perimeter (outer 3 cm) of the module, strip of a higher melting, more infrared radiation absorbing resin was used. This was prepared by taking clear ionomer encapsulant and compounding

10 in two percent (2%) carbon black, twenty percent (20%) Nucrel[®] HS0411 (available from E. I. Du Pont de Nemours and Company) and twenty percent (20%) polypropylene (Atofina 3480Z). This compounded resin was found to a broad melting point range and higher sealing temperature. By absorbing a

15 higher incident portion of infrared radiation, the temperature of this perimeter region was raised above its sealing temperature and that of the surrounding encapsulant material. A creep test was performed on this module configuration and was found to be creep-resistant to a

20 temperature of 128 °C versus the standard module (Figures 12A, 12B) using DuPont[™] PV5400 ionomer encapsulant only at 93 °C. This test is run by placing the laminate in a vertical position, full support of the back light of glass (e.g. substrate) and allowing the front glass light to be

25 free-standing (unsupported other than by the encapsulant and perimeter filled region of encapsulant). The laminate is heated in a convection oven for a period of sixteen hours and movement of the front glass is measured. Movement less than one millimeter (1 mm) is considered to be "creep-

30 resistant".

Table 1: Heating Times and 'Zonal' Heating

Example #	Heating Source	PV Module Assembly Configuration *	Time to reach 120 °C Zone 1 (Zone 2) #

	Distance "d"		Min:sec
CE40	Convective (Forced-air oven @ 130 °C)	Figures 12A, 12B	16:15
CE41	Platen heating (@ 130 °C)	Figures 12A, 12B	7:25
42	Platen heating (@ 160 °C)	Figures 12A, 12B	5:33
43	IR Lamp (1.1 um peak emission) 15 cm	Figures 12A, 12B	2:30
44	IR Lamp (1.1 um peak emission) 7 cm	Figures 12A, 12B	2:01
45	IR Lamp (1.1 um peak emission) 3 cm	Figures 12A, 12B	1:46
46	IR Lamp (1.1 um peak emission) 15 cm distance	Figures 12A, 12B	2:30 (1:06)
47	IR Lamp (1.1 um peak emission) 7 cm distance	Figures 12A, 12B	2:01 (0:58)
48	IR Lamp (1.1 um peak emission) 3 cm distance	Figures 12A, 12B	1:46 (0:44)
49	Ceramic IR Heater (4 um peak emission) 7 cm distance	Figures 12A, 12B	3:47
50	IR Lamp (1.1 um peak emission) 15 cm distance	Figures 14A, 14B	2:30 (1:36)
51	IR Lamp (1.1 um peak emission) 15 cm distance	Figures 15A, 15B	2:30 (1:10)
52	IR Lamp (1.1 um peak emission) 15 cm distance	Figures 17A, 17B	2:30 Zone 1 @ 120C Zone 2 reached 154C

The photovoltaic module laminate assembly requires significant time (16:15 min:sec) for the internal temperature to reach 120 °C via a conventional convective heating approach with a forced-air oven set at 130 °C (CE40). Conductive heat as supplied in Example CE41 (platen setpoint @ 130 °C) provides a reduced heating period which can be further reduced by increasing the platen temperature to 160 °C (Example 42). Good process control (e.g. minimizing unplanned temperature variations and process cycle timing) is critical when operating a non-equilibrium heating process (i.e., disparate differences between the heating source temperature and the desired laminate assembly temperature).

Examples 43 through 45 show a significant further reduction in heating time which is advantageous over conventional heating means. By decreasing the distance of the infrared lamp to the surface of the laminate assembly, heating time is progressively shortened. Examples 46 through 52 follow from the laminate assemble configurations illustrated by Figures 12A 12B; Figures 13A, 13B; Figures 14A, 14B; Figures 15A, 15B and Figures 17A, 17B being exemplified. In each of these Figures a second zone was introduced to possess an energy absorptivity characteristic that would have an optimized effective heating rate under infrared irradiation. The time for the interlayer encapsulant to reach 120 °C, and parenthetically, the time for the optimized heating rate zone were both measured and listed in the table. The optimized heating zones all had increased heating rates and hence shortened heating times as compared with the interlayer encapsulant regions. Example 49 used a longer wavelength infrared emission (peak emission of 4um) with an effective heating rate that was slower than the infrared source (peak emission wavelength of 1.1 um) used in Example 46. The solid black inking marked on the

surface facing the infrared lamp allowed for the heating time to be reduced from 2:30 (min:sec) to 1:36 (min:sec) as measured within the interlayer encapsulant.

5

-o-0-o-

As may be appreciated from the foregoing the process of the present invention, making use of a heating source whose
10 energy output characteristic is tuned to the energy absorptivity response of the encapsulant material is believed to offer several significant advantages over the art. By tuning the energy output characteristic of the heat
15 source to the energy absorptivity response of the encapsulant radiation is directly absorbed by the encapsulant, which is believed to result in more efficient direct heating of the encapsulant.

The use of a fixture to support the laminate is also believed to provide significant advantages over the art.
20 Use of a fixture avoids the need for expensive autoclave equipment. The fixture affords open access to heat sources from both top and bottom surfaces of the laminate. The fixture is rigid in a plane parallel to the transparent and support layers, thus significantly avoiding the edge
25 compression and edge pinching problems of the prior art.

The fixture encompasses a relatively low volume, thus allowing quick extraction of air remaining within the pre-assembly (rather than requiring pumping of a large chamber). Since substantially the entire exterior surface area of the
30 laminate is exposed, the fixture affords the ability to observe the laminate during processing for adjusting cycle time, minimizing cycle time and even targeting zonal heat for problematic areas noted (e.g., voids, defects).

A process using the fixture and heat source as
35 described herein may be readily automated and is adaptable

to assembly line operation or to a system that has discrete stations or operating positions, thus reducing manufacturing step, cost and improving cycle time.

5 In accordance with other aspects of the invention, sealing around electrical leads connections improves performance against wet current leakage/durability, reduction of manufacturing steps/cost/junction box.

10 Targeted heating of localized zones for either edge sealing and/or additional heating can be provided in busbar and lead regions and the like where additional encapsulant flow is desirable.

15 Those skilled in the art, having the benefit of the teachings of the present invention as hereinabove set forth may effect numerous modifications thereto. Such modifications are to be construed as lying within the contemplation of the present invention as defined by the appended claims.

20

WHAT IS CLAIMED IS:

PP-0157 PCT

1. A method for fabricating a photovoltaic module comprising, in any operative order, the steps of:

5 (a) forming a laminate comprising:

a transparent layer and a support layer,
each of the transparent layer and the support
layers having an exterior surface, an interior
surface and an edge surface;

10 a photovoltaic layer disposed between the
interior surfaces of the transparent layer and
the support layer; and

an encapsulant material disposed between
the photovoltaic layer and either the interior
15 surface of the transparent layer or the
interior surface of the support layer, or both,

the encapsulant material having a
predetermined sealing temperature above which
the encapsulant is able to flow into adhesive
20 contact with the photovoltaic layer and the
transparent layer and/or the protective layer;

the laminate having a periphery
therearound;

(b) engaging the laminate completely about its
25 periphery with an air-tight fixture,

the fixture having an insert therein, the
insert extending completely about the
periphery of the laminate, the insert having
an interior and an exterior surface thereon,
30 the insert being formed of a material having a
predetermined sealing temperature above which
the insert is able to flow into adhesive
contact with an adjacent layer;

the fixture further having a force
35 generating member therein, the force

generating member being disposed adjacent to
the exterior surface of the insert,

(c) using a heating source, heating the encapsulant
and the insert; and

(d) before the encapsulant and the insert are
raised to their sealing temperatures,

i) withdrawing air from between the
layers of the laminate so that atmospheric
pressure compresses the layers of the
laminate, and

ii) actuating the force generating member
to bring the same into contact with the
exterior surface of the insert,

whereby, as the temperature of the encapsulant and
the insert are raised past their sealing temperatures,

the encapsulant adhesively contacts
against the photovoltaic layer and the
adjacent interior surface of the transparent
layer and/or the protective layer, and

the force generating acts against the
insert to force the interior surface of the
insert into adhesive contact at least against
the edge of the photovoltaic layer and at
least the edges of the transparent and
protective layers,

thereby to form a sealed composite structure.

PP-0158

2. A method for fabricating a photovoltaic module
comprising, in any operative order, the steps of:

(a) forming a laminate comprising:

a transparent layer and a support layer,
each of the transparent layer and the support
layers having an exterior surface, an interior
surface and an edge surface;

a photovoltaic layer disposed between the interior surfaces of the transparent layer and the support layer; and

an encapsulant material disposed between the photovoltaic layer and either the interior surface of the transparent layer or the interior surface of the support layer, or both,

the encapsulant material having a predetermined sealing temperature above which the encapsulant is able to flow into adhesive contact with the photovoltaic layer and the transparent layer and/or the protective layer;

the laminate having a periphery therearound;

(b) engaging the laminate completely about its periphery with a fixture,

the fixture having an insert therein, the insert extending completely about the periphery of the laminate, the insert having an interior and an exterior surface thereon, the insert being formed of a material having a predetermined sealing temperature above which the insert is able to flow into adhesive contact with an adjacent layer;

the fixture further having an expandable bladder disposed adjacent to the exterior surface of the insert,

the expandable bladder being disposed in an air-tight relationship with the fixture to seal the fixture from the atmosphere;

(c) using a heating source, heating the encapsulant and the insert;

(d) before the encapsulant and the insert are raised to their sealing temperatures, withdrawing air from between the layers of the laminate, whereby,

atmospheric pressure acts against the exterior surfaces of the transparent and the protective layers to compress the encapsulant against the layers of the laminate; and

5 (e) while the air is being withdrawn from the laminate and before the encapsulant and the insert are raised to their sealing temperatures,

inflating the expandable bladder to bring the same into contact with the exterior surface
10 of the insert and force the insert into contact with the laminate,

such that, as the temperature of the encapsulant and the insert are each raised past their respective sealing temperatures,

15 the encapsulant adhesively contacts against the surfaces of adjacent layers of the laminate and,

the insert adhesively contacts against the edge of the photovoltaic layer and at least the edge surfaces of the transparent and protective layers,

20 thereby to form a sealed composite structure

3. A method for fabricating a photovoltaic module comprising, in any operative order, the steps of:

(a) forming a laminate comprising:

25 a transparent layer and a support layer, each of the transparent layer and the support layers having an exterior surface, an interior surface and an edge surface;

a photovoltaic layer disposed between the
30 interior surfaces of the transparent layer and the support layer; and

an encapsulant material disposed between the photovoltaic layer and either the interior surface of the transparent layer or the
35 interior surface of the support layer, or both,

the encapsulant material having a predetermined sealing temperature above which the encapsulant is able to flow into adhesive contact with the photovoltaic layer and the transparent layer and/or the protective layer;
the laminate having a periphery therearound;

(b) engaging the laminate completely about its periphery with a fixture,

the fixture having an insert therein, the insert extending completely about the periphery of the laminate, the insert having an interior and an exterior surface thereon, the insert being formed of a material having a predetermined sealing temperature above which the insert is able to flow into adhesive contact with an adjacent layer;

the fixture further having a deflectable diaphragm disposed adjacent to the exterior surface of the insert, the deflectable diaphragm itself having an exterior surface communicating with the atmosphere,

the deflectable diaphragm being disposed in an air-tight relationship with the fixture to seal the fixture from the atmosphere;

(c) using a heating source, heating the encapsulant and the insert; and

(d) before the encapsulant and the insert are raised to their sealing temperatures, withdrawing air from between the layers of the laminate, whereby,

(i) atmospheric pressure acts against the exterior surfaces of the transparent and the protective layers to compress the encapsulant against the layers of the laminate; and

(e) while the air is being withdrawn from the laminate, atmospheric pressure acts against the exterior surface of the deflectable diaphragm to bring the same into contact with the exterior surface of the insert and to force the insert into the depletion region,

such that, as the temperature of the encapsulant and the insert are each raised past their respective sealing temperatures,

the encapsulant adhesively contacts against the surfaces of adjacent layers of the laminate and,

the insert adhesively contacts against the edge of the photovoltaic layer and at least the edge surfaces of the transparent and protective layers,

thereby to form a sealed composite structure.

4. A method for fabricating a photovoltaic module comprising, in any operative order, the steps of:

(a) forming a laminate comprising:

the fixture having an insert therein, the insert extending completely about the periphery of the laminate, the insert having an interior and an exterior surface thereon, the insert being formed of a material having a predetermined sealing temperature above which the insert is able to flow into adhesive contact with an adjacent layer;

the fixture further having an expandable bladder disposed adjacent to the exterior surface of the insert,

the expandable bladder being disposed in an air-tight relationship with the fixture to seal the fixture from the atmosphere;

(b) engaging the laminate completely about its periphery with a fixture,

the fixture having an insert therein, the insert extending completely about the periphery of the laminate, the insert having an interior and an exterior surface thereon, the insert being disposed in sealed engagement with the fixture with the exterior surface of the insert being in fluid communication with the atmosphere, the insert being formed of a material having a predetermined sealing temperature above which the insert is able to flow into adhesive contact with an adjacent layer;

(c) using a heating source, heating the encapsulant and the insert within the laminate; and

(d) before the encapsulant and the insert are raised to their sealing temperatures, withdrawing air from between the layers of the laminate, whereby,

(i) atmospheric pressure acts against the exterior surfaces of the transparent and the protective layers to compress the encapsulant against the layers of the laminate; and

(ii) atmospheric pressure acts against the exterior surface of the insert to cause the insert to contact the laminate,

such that, as the temperature of the encapsulant and the insert are each raised past their respective sealing temperatures,

the encapsulant adhesively contacts against the surfaces of adjacent layers of the laminate and,

the insert adhesively contacts against the edge of the photovoltaic layer and at least the edge surfaces of the transparent and protective layers,

thereby to form a sealed composite structure.

5. The method of any of claims 1 to 4 wherein the support layer of the laminate has an exhaust aperture therein, and wherein,

in step d), air is withdrawn from the laminate through the exhaust aperture in the support layer.

5 6. The method of claim 5 wherein air is withdrawn through the exhaust aperture until a pressure within the laminate between the transparent layer and the support layer lies in the range from about 0 to 50 millibar absolute.

10 7. The method of any of claims 1 to 4 wherein the fixture has a vacuum port therein, and wherein, in step (d), air is withdrawn from the laminate through the vacuum port in the fixture.

15 8. The method of claim 7 wherein air is withdrawn through the vacuum port until a pressure within the laminate between the transparent layer and the support layer lies in the range from about 0 to 50 millibar absolute.

20 9. The method of any of claims 1 to 4 wherein in step b), the fixture engages the exterior surface of the transparent layer or the exterior surface of the support layer or the exterior surface of both the support and
25 transparent layers.

10. The method of any of claims 1 to 4 wherein, in step b), the fixture engages the edge surface of
30 the transparent layer or the edge surface of the support layer or the edge surface of both the support and transparent layers.

11. The method of any of claims 1 to 4 wherein the
35 fixture is substantially rigid in planes parallel to the

exterior surfaces of the transparent and support layers, such that, during step c)

the rigidity of the fixture prevents pinching of the layers of the laminate in the vicinity of their edges.

5

12. The method of any of claims 1 to 4 wherein the heating source is a source of radiation having a wavelength in the range 0.3 to 100 micrometers.

10

13. The method of claim 12 wherein the heating source is a source of radiation having a wavelength in the range 0.4 to 20 micrometers

15

14. The method of any of claims 1 to 4 wherein the heating source is a source of radiation having a wavelength in the range 0.4 to 10 micrometers

20

15. The method of any of claims 1 to 4 wherein the transparent layer of the laminate is made from glass having a thickness of about three millimeters (3) mm, wherein the encapsulant is a PVB, EVA or an ionomeric material, and

25

wherein the heating source is a source of infrared radiation having a peak wavelength in the range from about one (1) to about ten (10) micrometers, whereby at least thirty percent (30%) of the available energy from the infrared radiation source is directly absorbed by the encapsulant.

30

16. The method of any of claims 1 to 4 wherein the transparent layer of the laminate is made from glass having a thickness of about three (3) mm, wherein the encapsulant is an ionomeric material filled by 20% weight filled by weight glass filler and

wherein the heating source is a source of radiation having a peak wavelength in the range from about one (1) to about ten (10) micrometers,

5 wherein at least fifty percent (50%) of the available energy from the infrared radiation source is directly absorbed by the encapsulant.

17. The method of any of claims 1 to 4 wherein the transparent layer of the laminate is made from glass
10 having a thickness of about three (3) mm,

wherein the encapsulant is an ionomeric material filled with 2% weight by weight carbon black and

wherein the heating source is a source of radiation having a peak wavelength in the range from about one (1)
15 to about ten (10) micrometers,

wherein at least sixty-five percent (65%) of the available energy from the infrared radiation source is directly absorbed by the encapsulant.

20 18. The method of any of claims 1 to 4 wherein the photovoltaic layer is disposed between the interior surfaces of the transparent layer and the protective layers with the edge of the photovoltaic layer lying a predetermined distance inwardly from the
25 edges of the transparent layer and the protective layer, thereby to define a depletion region extending peripherally about the laminate; and wherein,

in step (d), the force generating member acts against the insert to force the interior surface of the
30 insert into the depletion region and into contact against the interior surfaces of the transparent and protective layers.

19. The method of claim 1 wherein the force generating member comprises an expandable bladder, and wherein,

5 in step d), the force generating member is actuated by inflating the expandable bladder to bring the same into contact with the exterior surface of the insert and force the insert into adhesive contact at least against the edge of the photovoltaic layer and at least the edges of the transparent and protective layers.

10

1/19

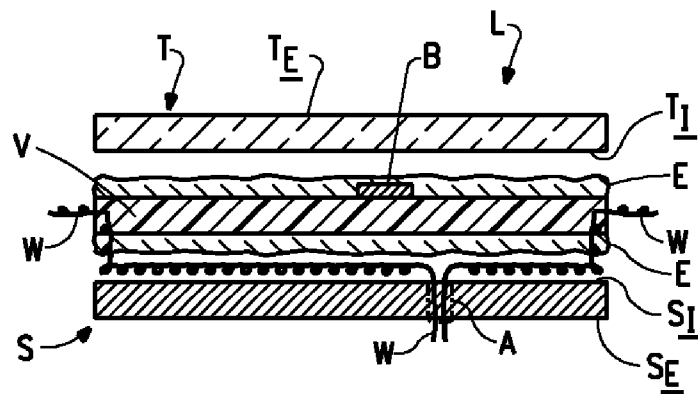


FIG. 1A
(Prior Art)

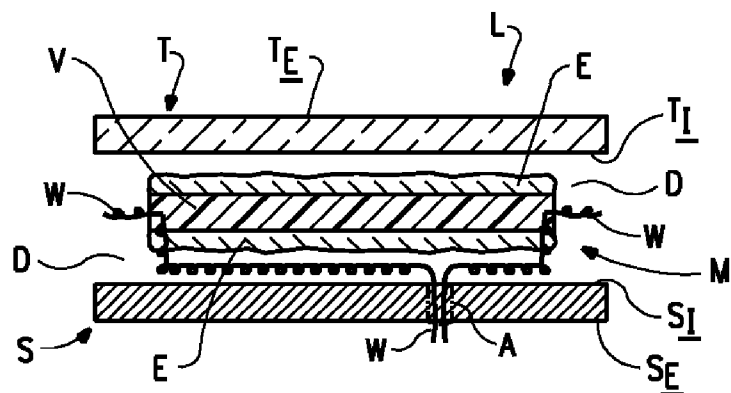


FIG. 1B
(Prior Art)

2/19

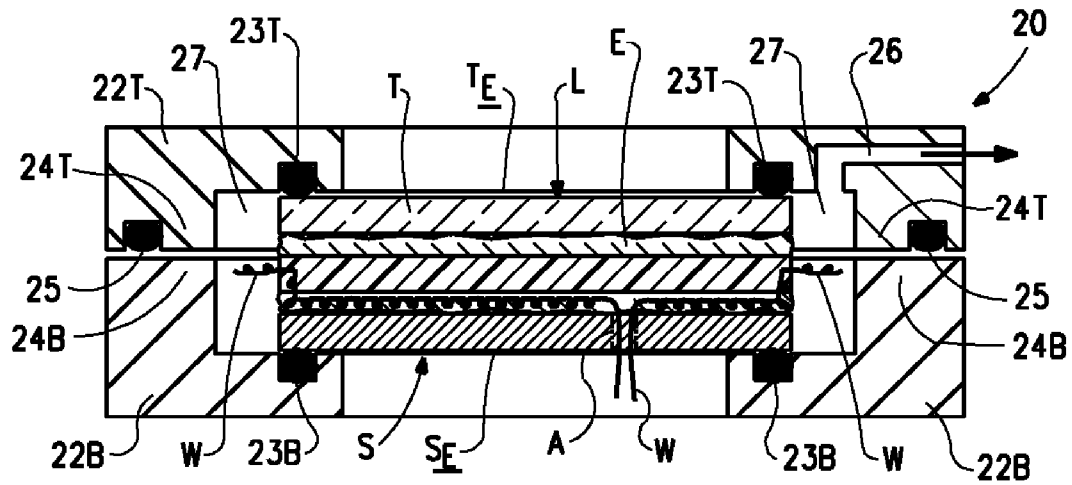


FIG. 2A

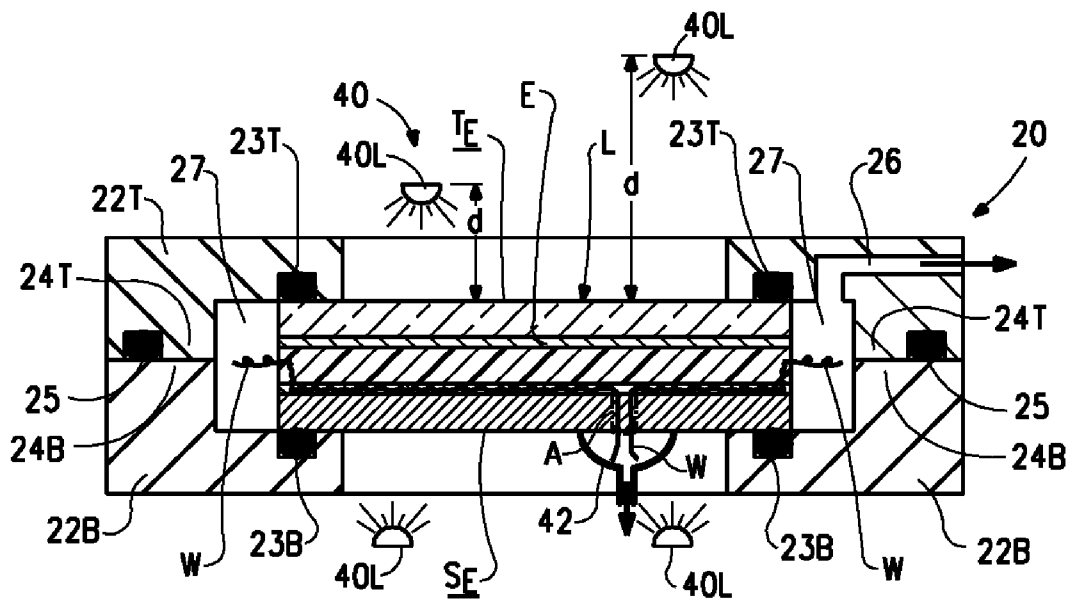


FIG. 2B

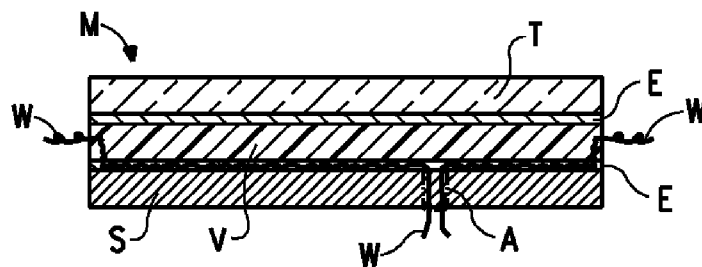


FIG. 2C

3/19

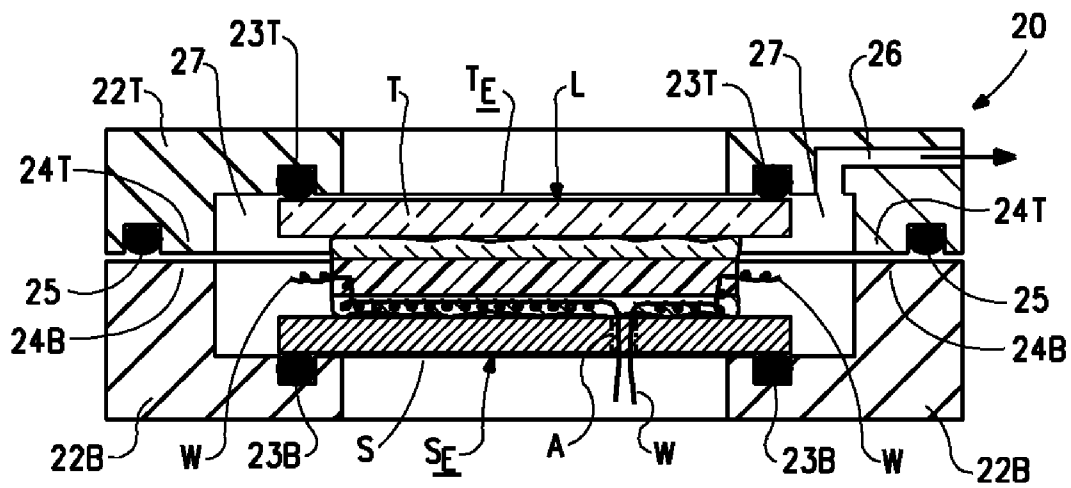


FIG. 3A

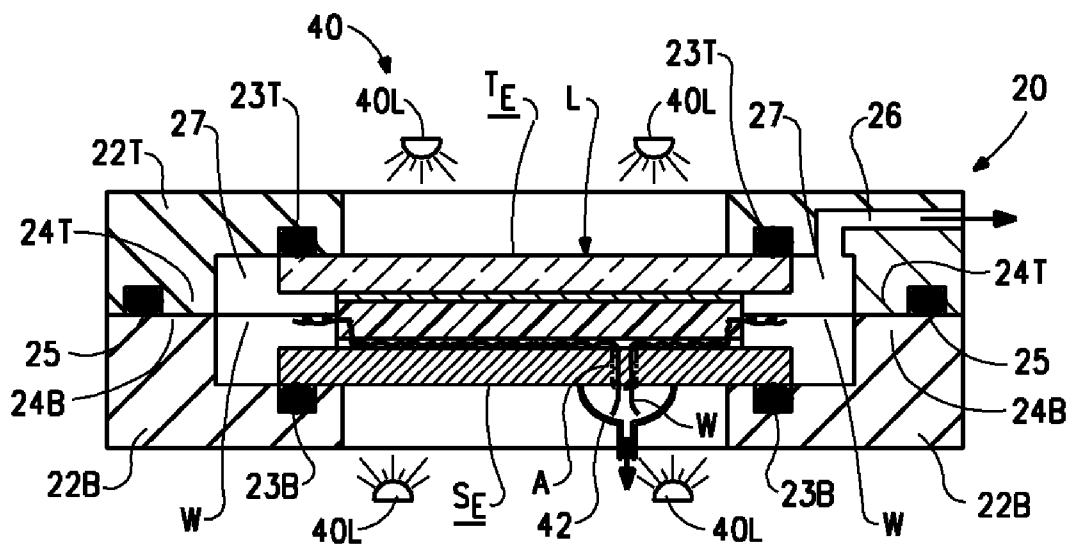


FIG. 3B

4/19

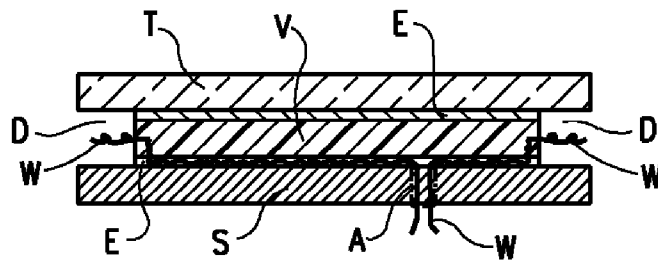


FIG. 3C

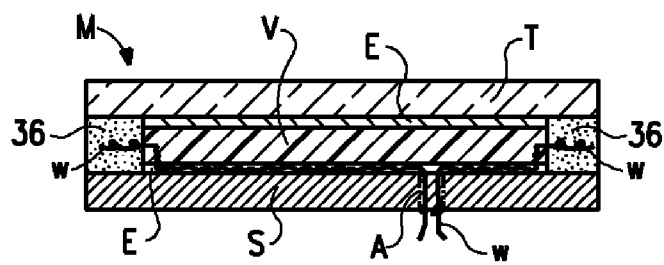


FIG. 3D

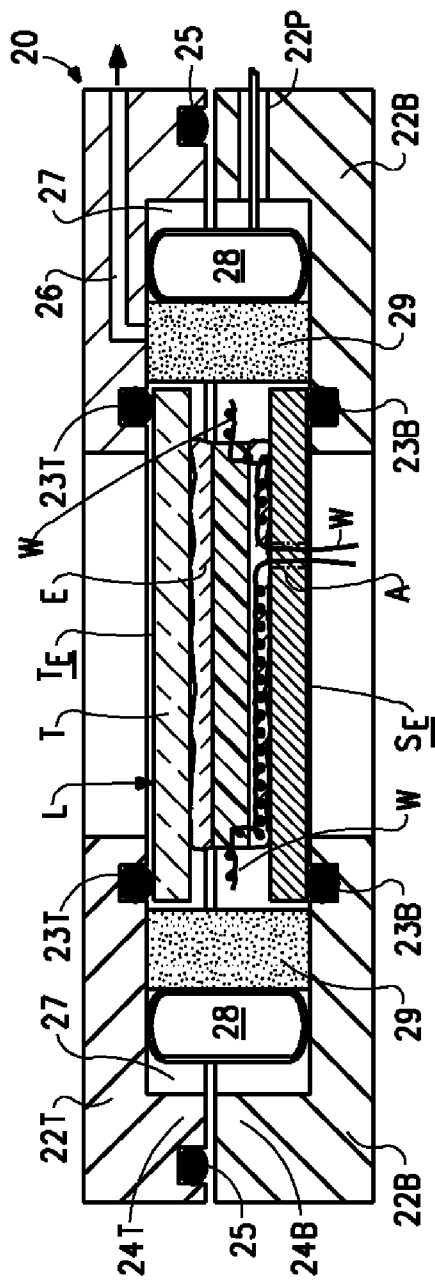


FIG. 4A

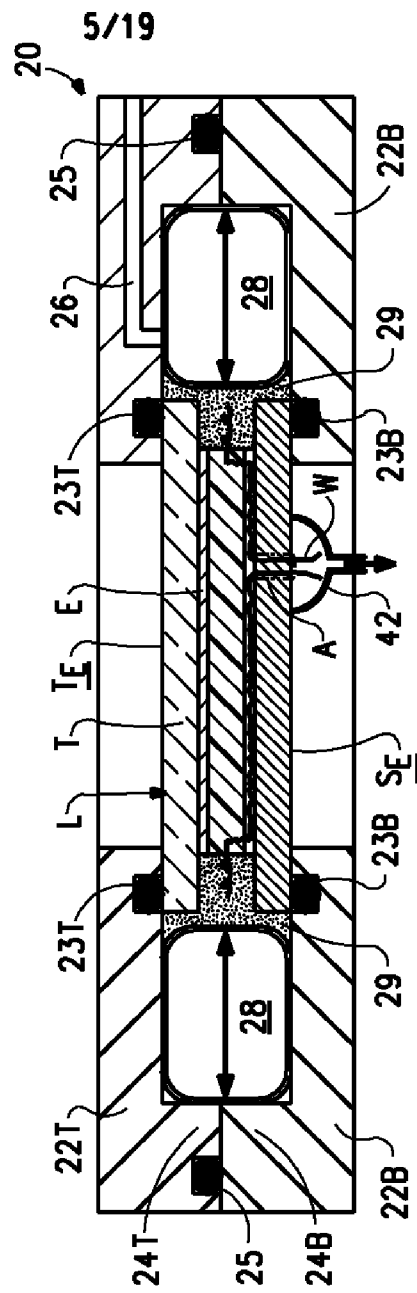


FIG. 4B

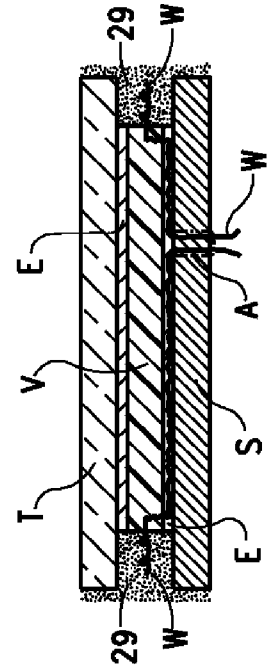


FIG. 4C

6/19

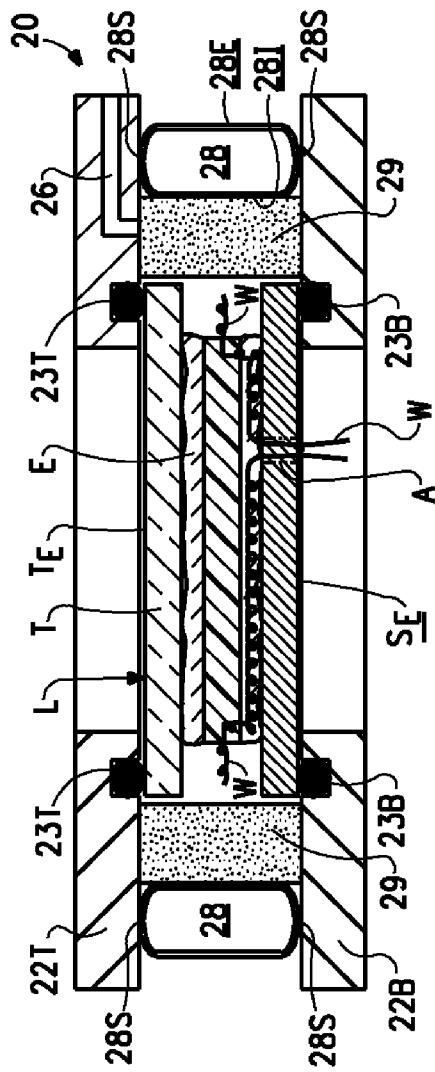


FIG. 5A

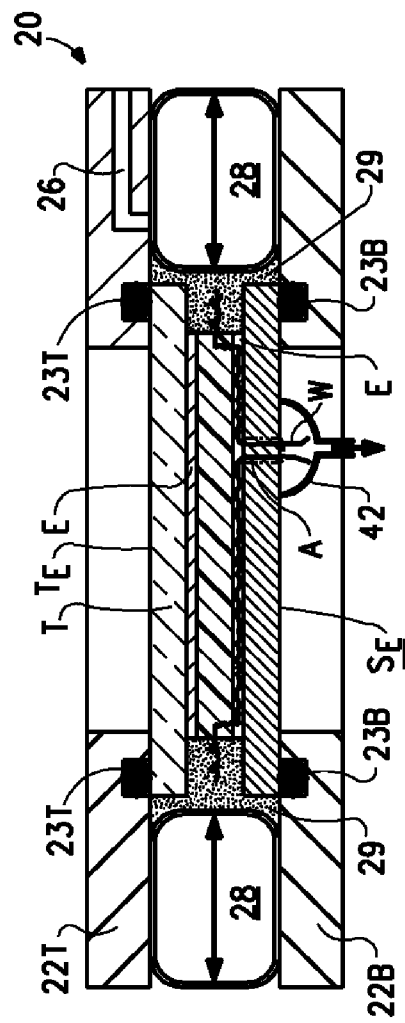


FIG. 5B

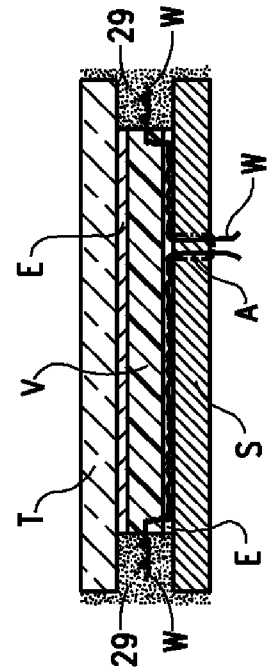


FIG. 5C

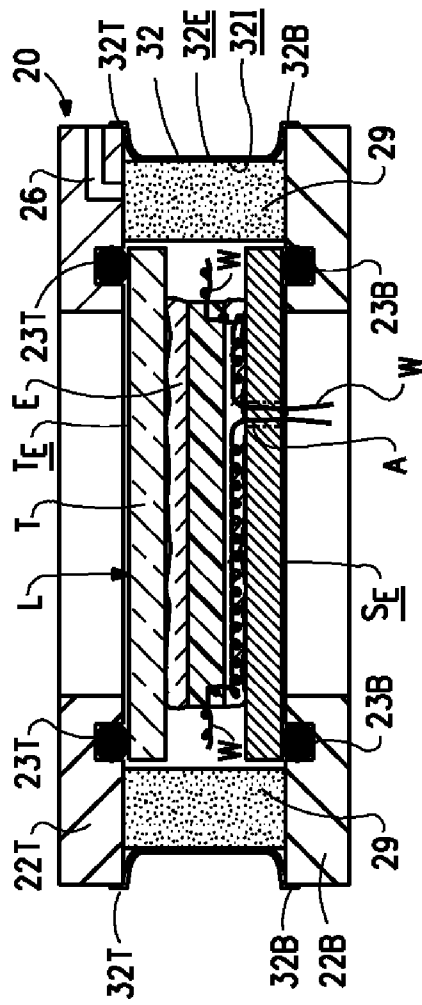


FIG. 6A

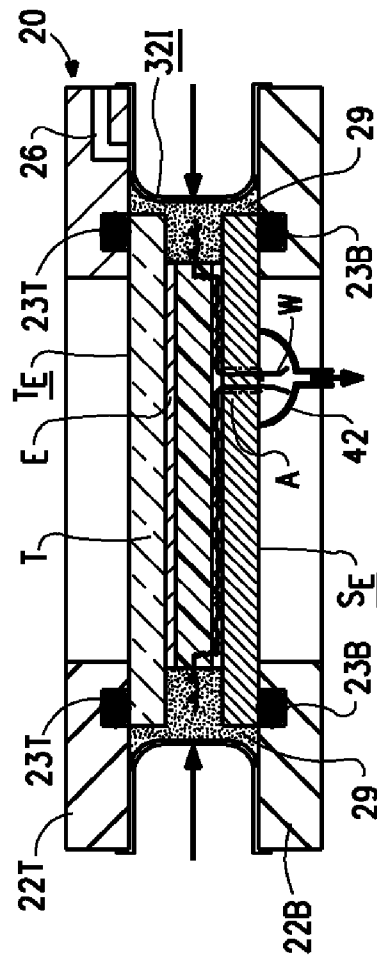


FIG. 6B

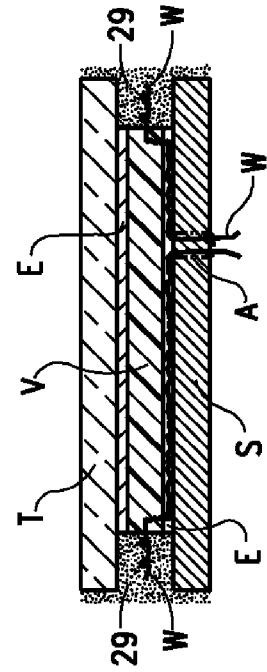


FIG. 6C

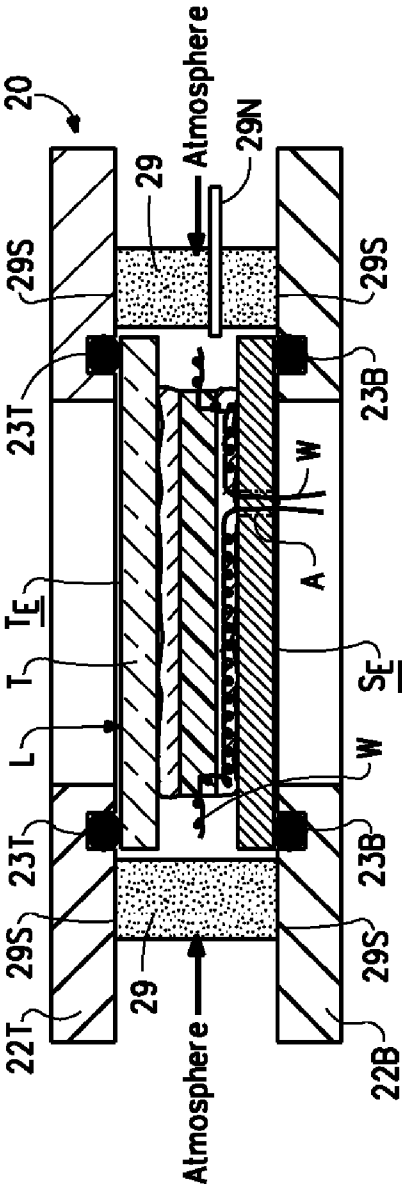


FIG. 7A

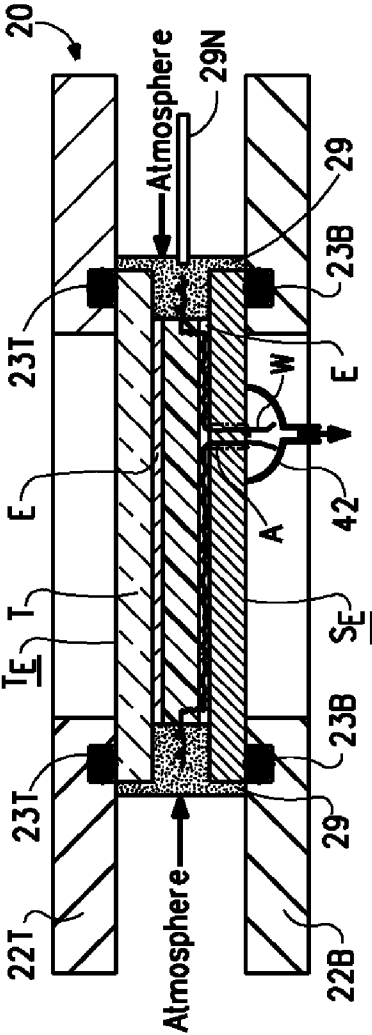


FIG. 7B

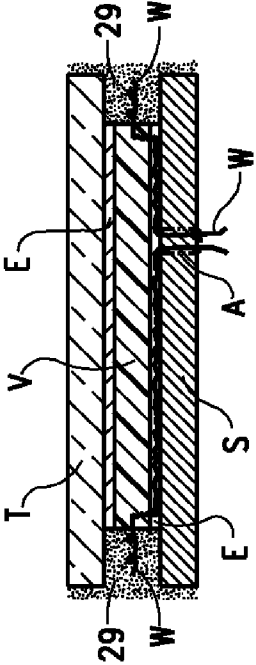


FIG. 7C

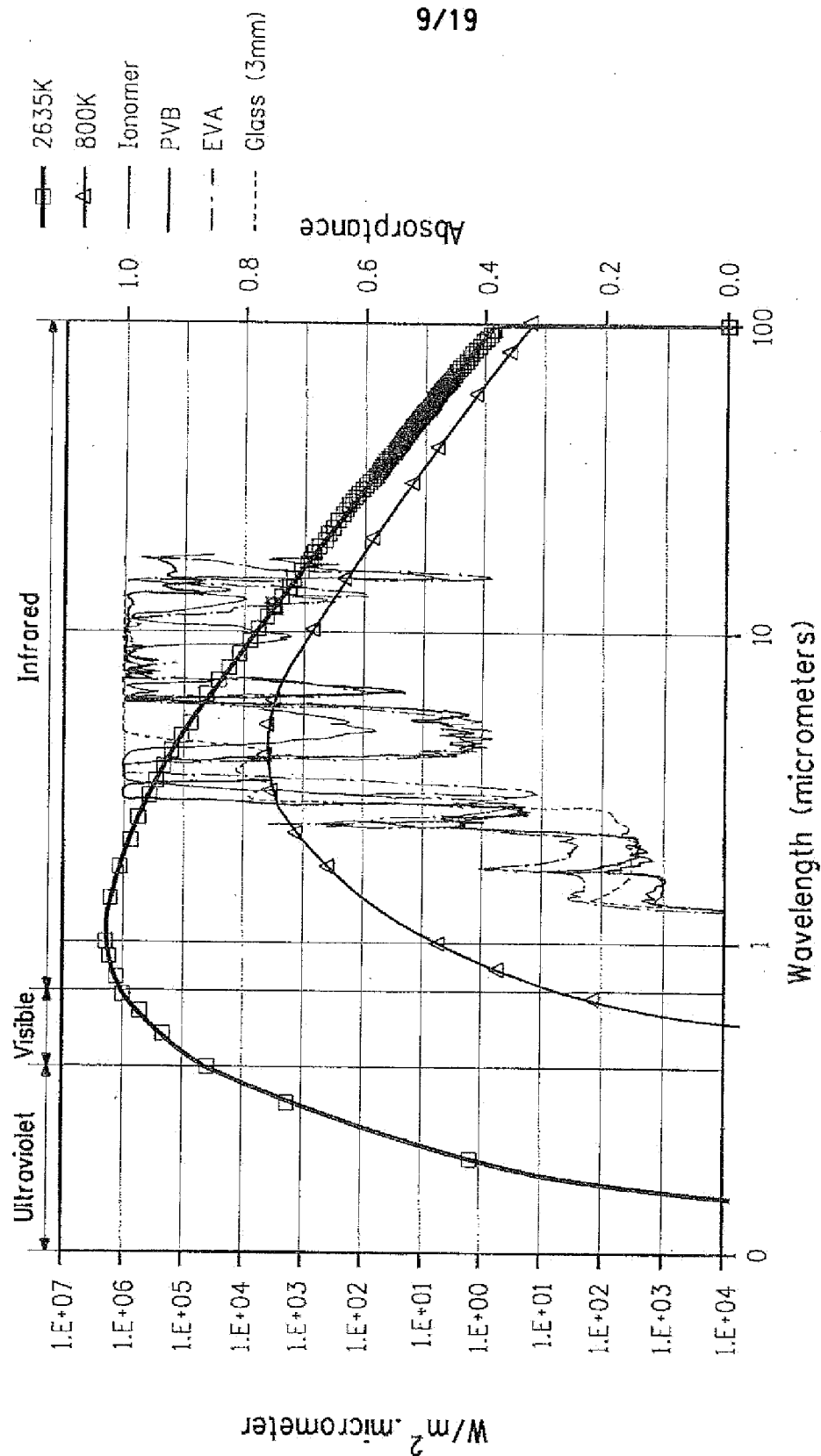


FIG. 8

10/19

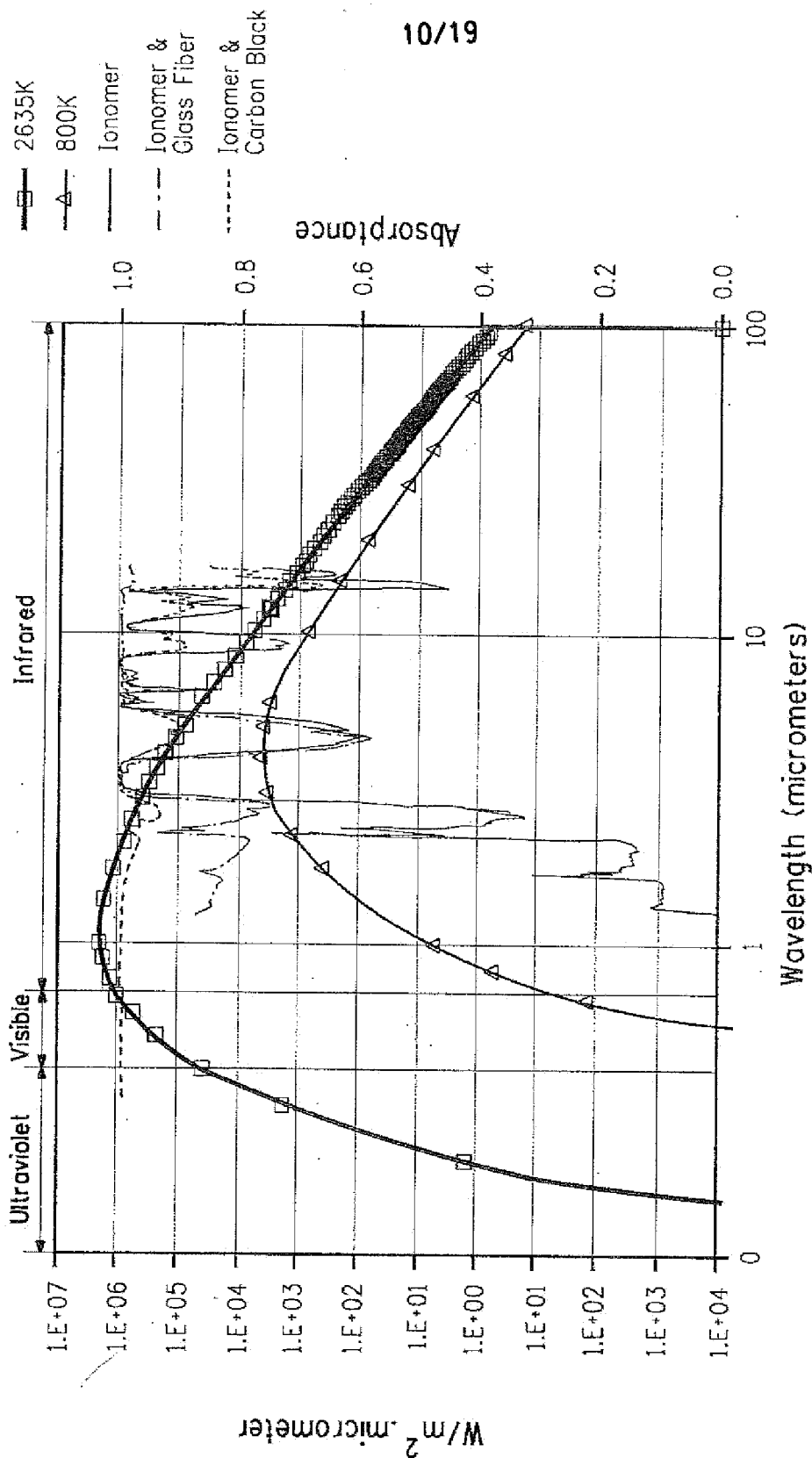


FIG. 9

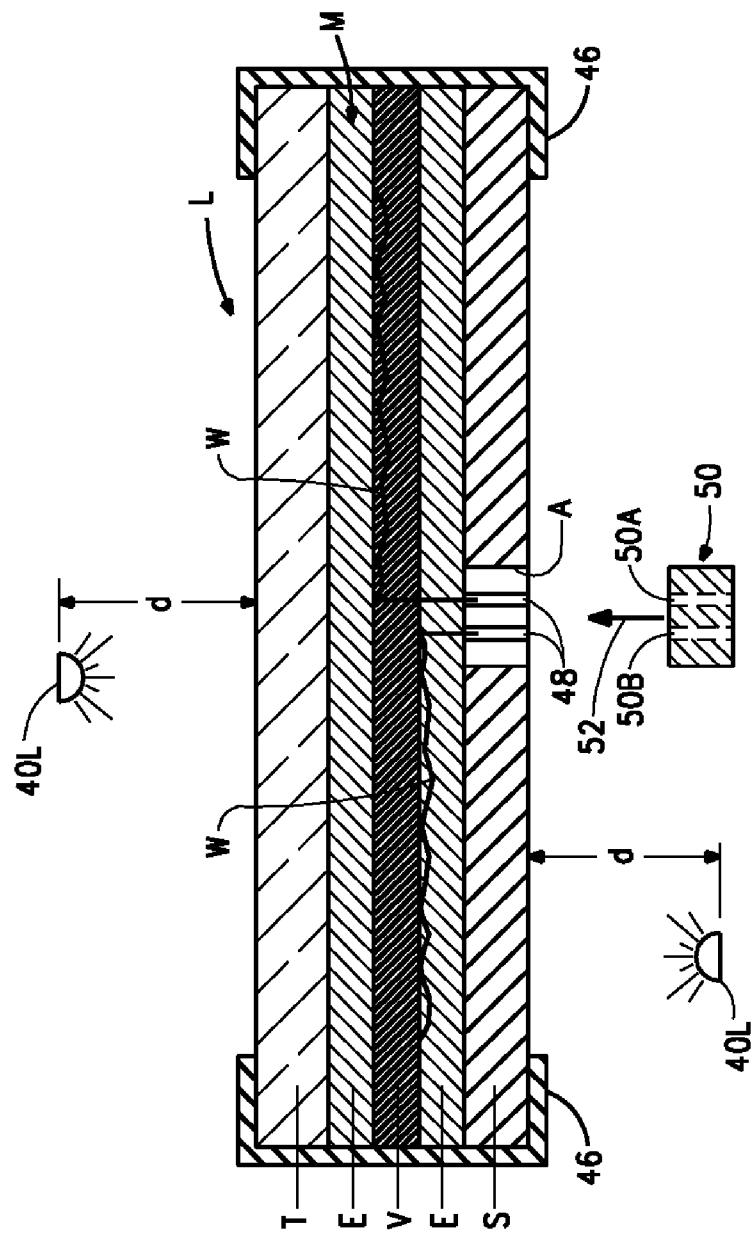


FIG. 10A

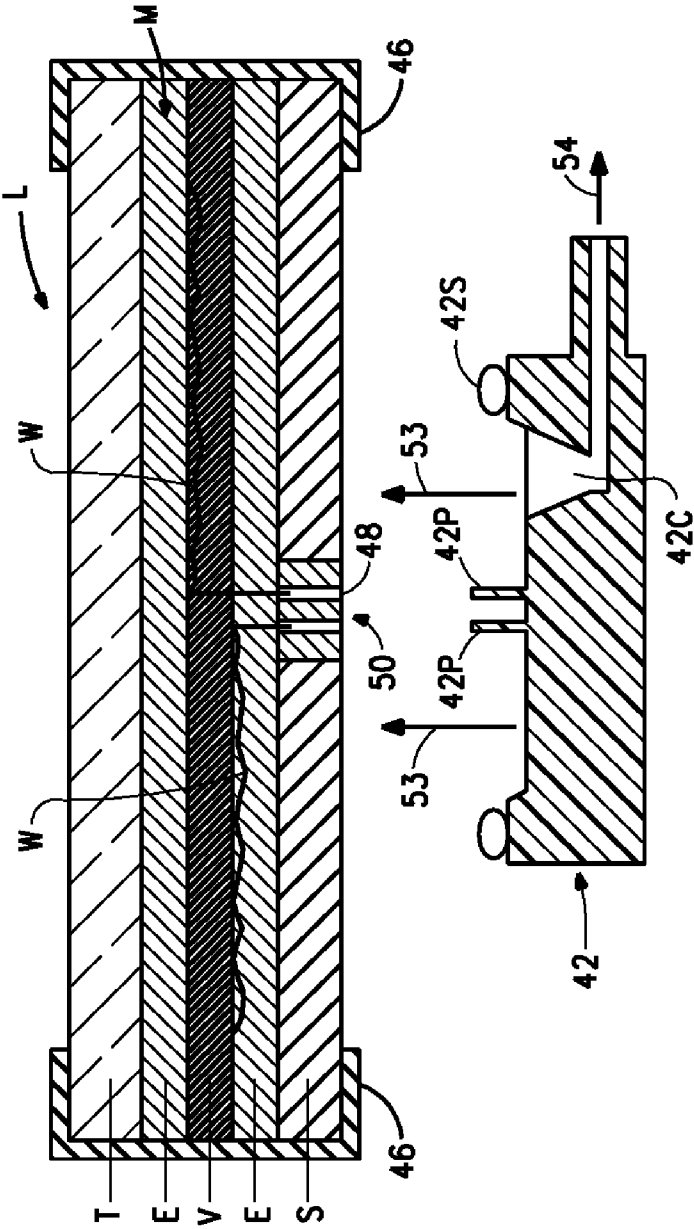


FIG. 10B

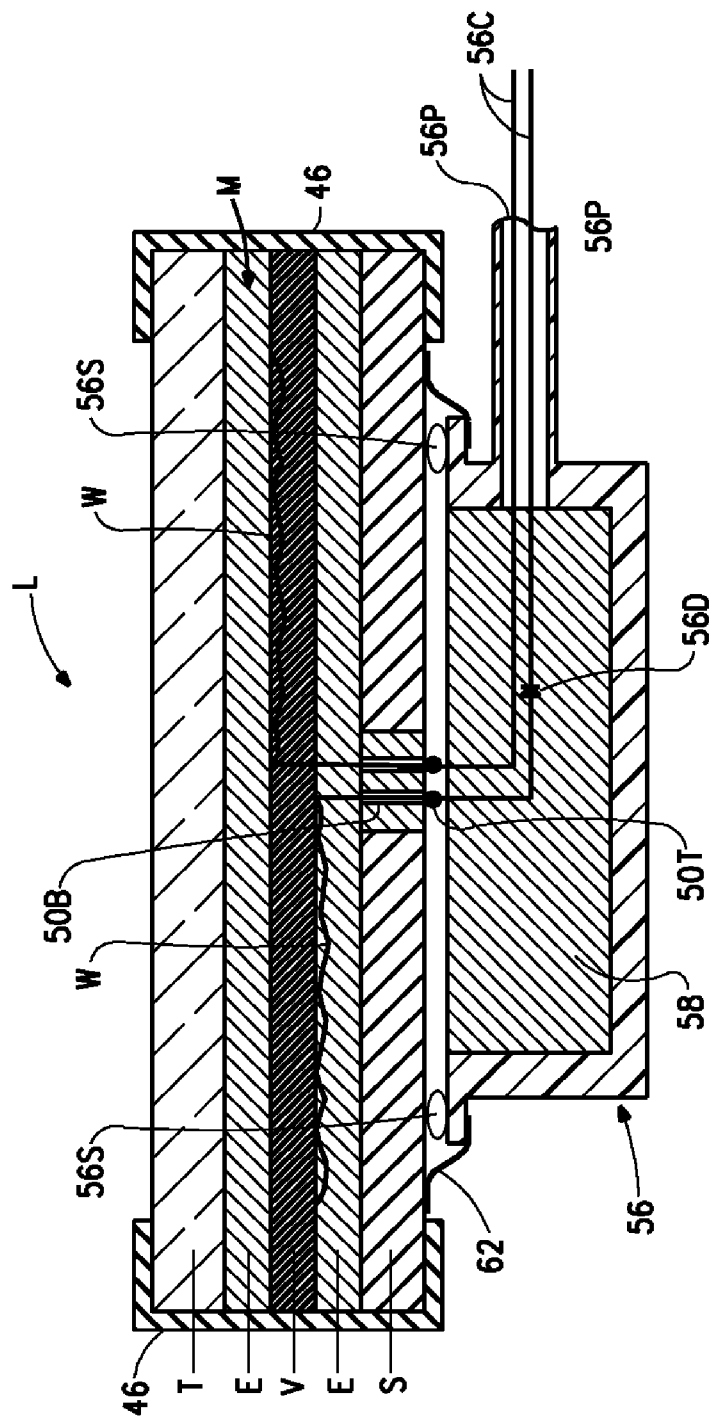


FIG. 10C

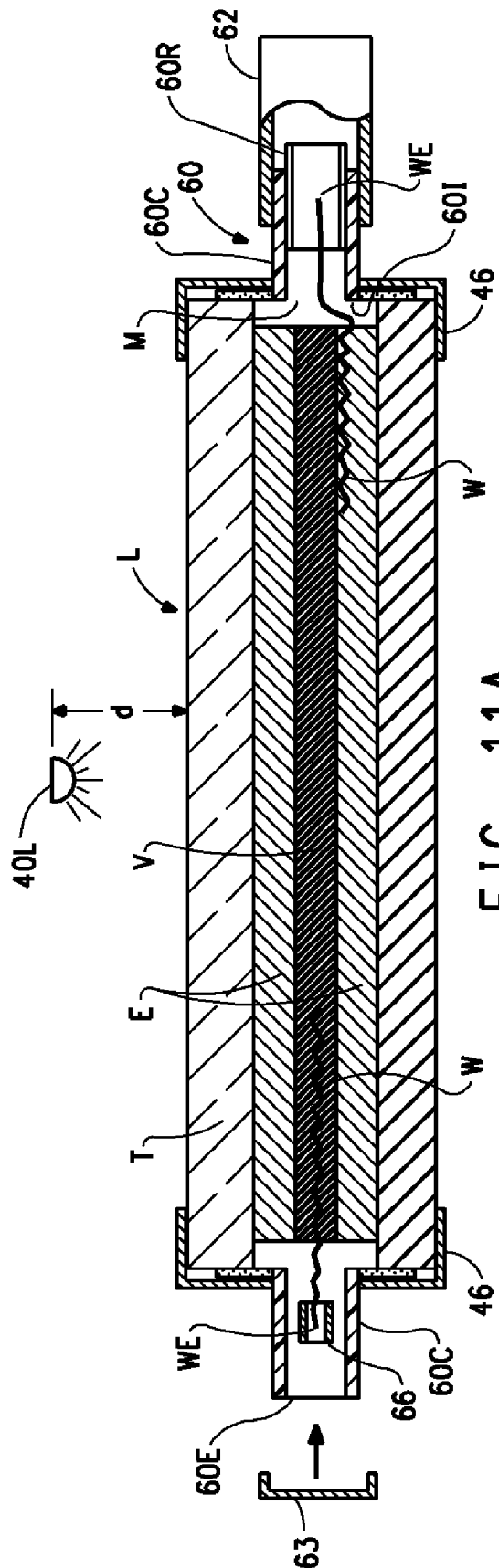


FIG. 11A

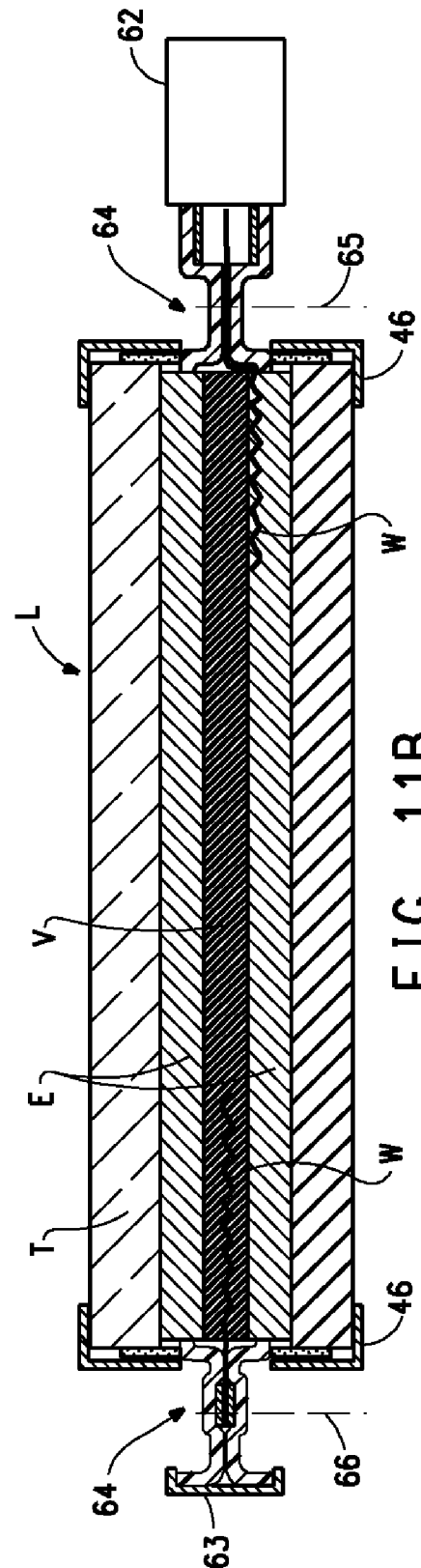


FIG. 11B

15/19

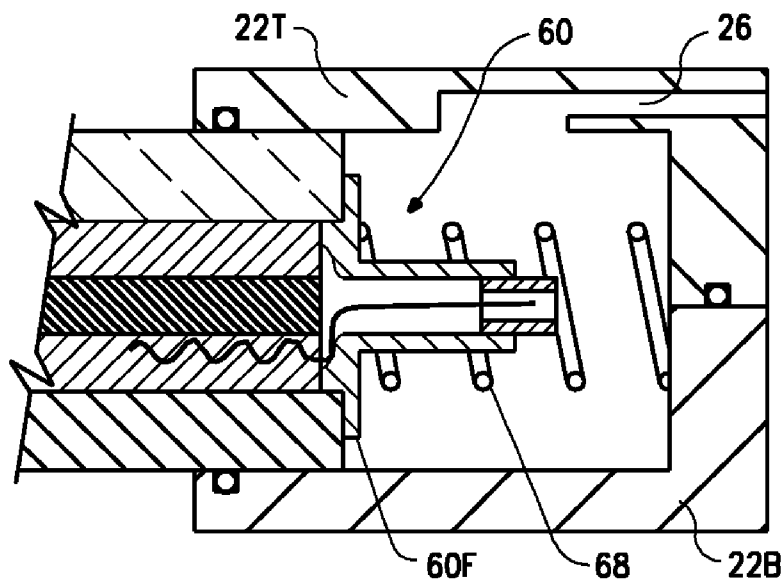


FIG. 11C



FIG. 12A

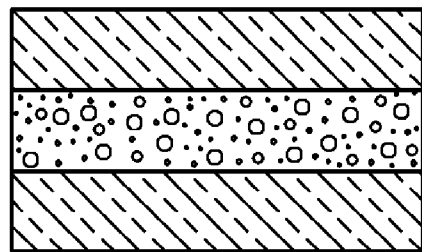


FIG. 12B

16/19

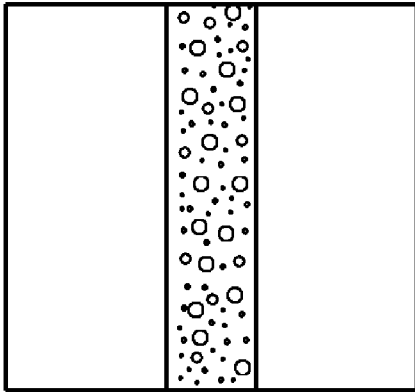


FIG. 13A

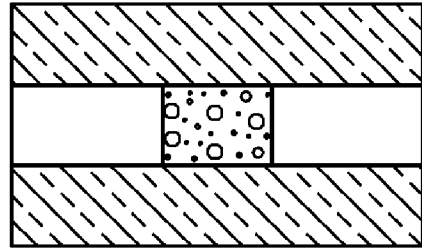


FIG. 13B

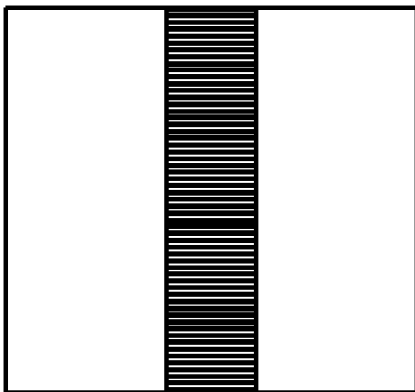


FIG. 14A

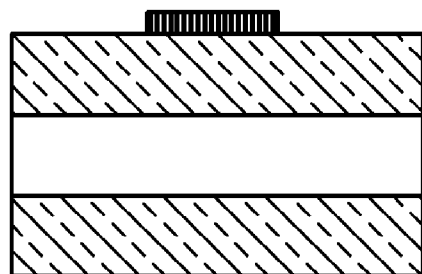


FIG. 14B

17/19

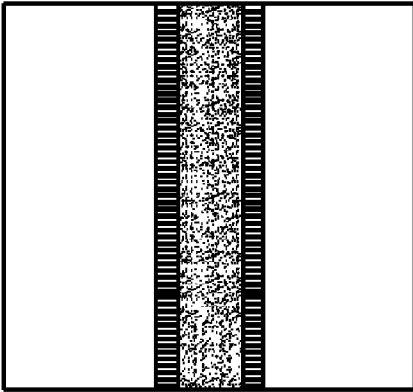


FIG. 15A

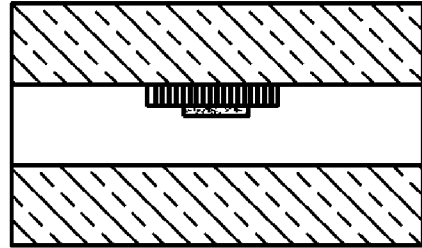


FIG. 15B

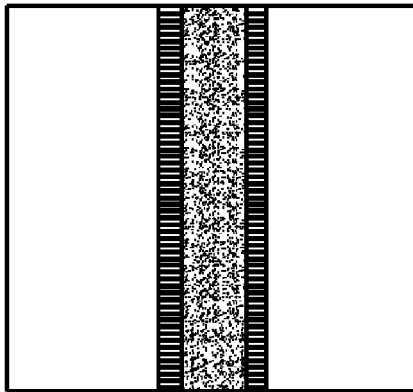


FIG. 16A

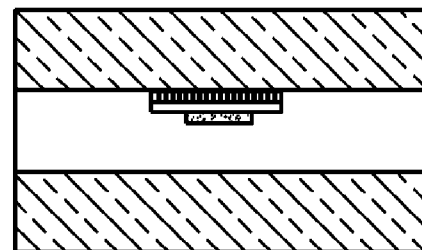


FIG. 16B

18/19

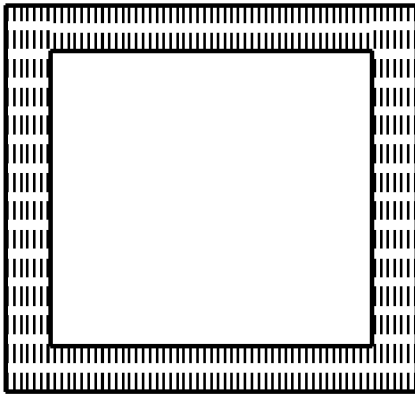


FIG. 17A

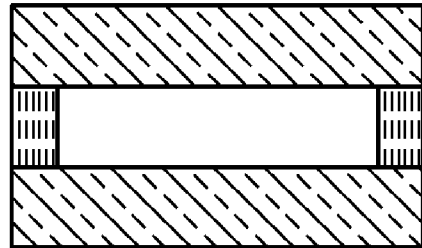


FIG. 17B

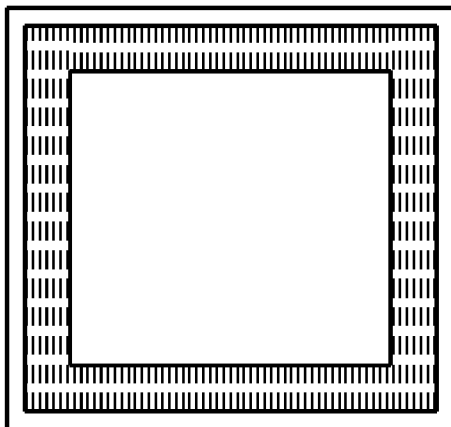


FIG. 18A

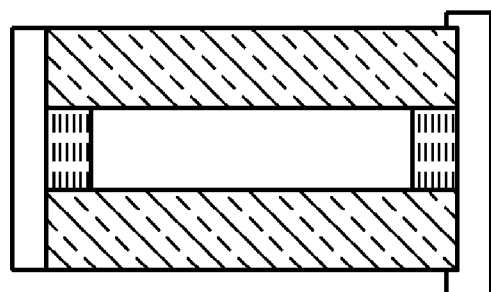


FIG. 18B

19/19

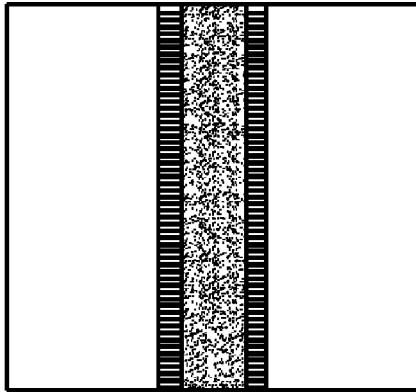


FIG. 19A

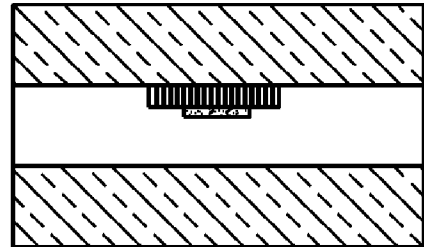


FIG. 19B

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/064937

A. CLASSIFICATION OF SUBJECT MATTER
 INV. H01L31/048 B32B17/10 B32B37/10
 ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B32B H01L B30B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 733 382 A (HANOKA JACK I [US]) 31 March 1998 (1998-03-31) column 5, line 18 - column 6, line 49 column 8, line 35 - column 10, line 51; figures 6,7	1,3,5,6, 17,18
A	----- US 2010/101647 A1 (CADWALLADER ROBERT J [US] ET AL) 29 April 2010 (2010-04-29) paragraph [0009] - paragraph [0022] paragraph [0038] - paragraph [0053] paragraph [0067] - paragraph [0069]; claims	1-4, 12-15,17
A	----- US 2010/224235 A1 (TAKAGI NAOTO [JP] ET AL) 9 September 2010 (2010-09-09) paragraph [0065] - paragraph [0071] paragraph [0088] claims; figures	1-4,7-11
	----- -/-	



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

10 May 2012

Date of mailing of the international search report

22/05/2012

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/064937

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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