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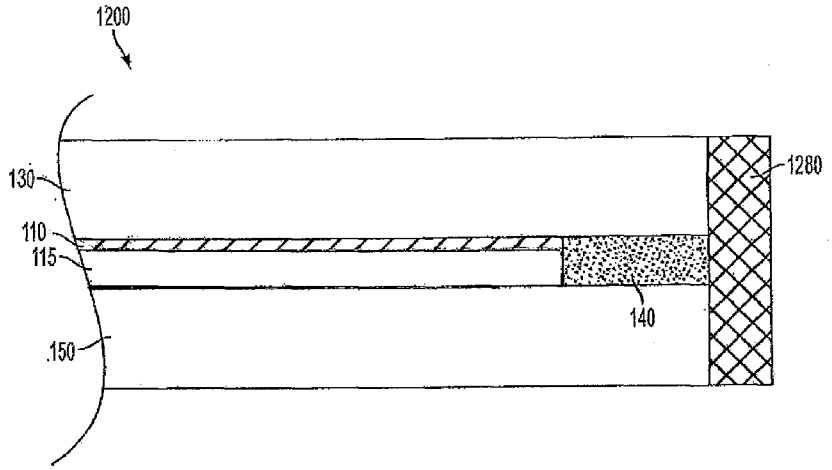
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(54) Title: SOLAR MODULES AND METHODS OF FORMING THE SAME



(57) Abstract: Methods of forming an edge coating for a glass panel-based electronic device comprising forming a fluoropolymer material coating adjacent to an edge of the glass panel-based electronic device, such as a solar module or flat panel display. An edge-coated electronic device, such as a solar module is also described. The solar module includes a solar module with a front support, a back support, and an active layer between the front support and the back support, where edges of the front support and back support form a solar module edge, and an edge coating adjacent to the solar module edge, where the edge coating includes a fluoropolymer.

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SOLAR MODULES AND METHODS OF FORMING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority of United States Provisional Patent Application Serial No. 61/722,538 filed on November 5, 2012 hereby incorporated herein by reference in its entirety.

FIELD OF INVENTION

[0002] The invention relates to the field of photovoltaic (PV) power generation systems, and more particularly to a solar module having a fluoropolymer edge coating and a manufacturing method thereof.

BACKGROUND OF THE INVENTION

[0003] A solar module, also known as a solar panel or photovoltaic module, is a device that converts sunlight energy into electricity by a process called the photovoltaic effect. A solar module includes a plurality of cells, which are typically formed between front and back supports of the solar module. In thin-film modules, the photovoltaic cells can include sequential layers of various materials formed between a front support and a back support. The layers can include, for example, a barrier layer, a transparent conducting oxide (TCO) layer, a buffer layer, and an active material layer, all of which can be deposited on top of either the front or back support, depending on the solar cell configuration. The active material layer is formed of one or more layers of semiconductor material such as amorphous silicon (a-Si), copper indium gallium diselenide (CIGS), cadmium telluride (CdTe), cadmium sulfide (CdS), a photosensitive dye, or any other suitable light absorbing material.

[0004] Solar modules are typically designed to endure extreme environmental conditions, which may include heat, humidity, UV light, chemical exposures (i.e., acid rain, cleaning

solvents, saline conditions in coastal regions), etc., for the duration of their useful life, which can be more than 30 years. In addition to resisting environmental condition considerations, the module must also be electrically insulated so that leakage current around the sides of the device at high voltages can be minimal throughout the useful life.

[0005] Additional considerations must also be taken into account. A surface tracking path within a solar module is any path along a surface of an insulative material, such as either the front or back supports or an insulating edge seal thereof, along which an electrical current from the active material may travel to reach a point on an outer surface of the module. In order to reduce this risk of electrical shock, a minimum distance for a surface tracking path between the active material and the outer surface of the module needs to be maintained. The distance between the surface tracking path and the outer surface is known as the tracking distance. The edges of a solar module may be sealed in order to maintain a suitable tracking distance (in addition to providing insulation, preventing moisture ingress into the module, and assisting in bonding the front glass to the back glass); this sealing may be accomplished for example, with a variety of materials ranging from a butyl-type elastomer applied along the edges of the solar module in either frame-less or framed configurations (metal or polymeric). The effectiveness of the sealing strategy helps to determine the minimum tracking distance required. Active area utilization (active area/total module area), durability, electrical insulation, and cost are typical considerations to conventional approaches for sealing module edges while maintaining the necessary minimum surface tracking path length.

[0006] Among other attributes, the electrical output from a solar module depends on the surface area available for active light collection. Accordingly, there is an ever increasing demand for higher efficiency in solar modules. Accordingly, a solar module with improved energy output, sealing effectiveness, high active area utilization (active area/total module area), durability, and electrical insulation is desirable.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a partial cross-sectional view of a solar module to which disclosed embodiments may be applied.

[0008] FIG. 2 is a partial cross-sectional view of an example embodiment of a solar module.

[0009] FIG. 3 is a partial cross-sectional view of another example embodiment of a solar module.

[0010] FIG. 4 is a partial cross-sectional view of another example embodiment of a solar module.

[0011] FIG. 5 is a partial cross-sectional view of another example embodiment of a solar module.

[0012] FIG. 6 is a partial cross-sectional view of another example embodiment of a solar module.

[0013] FIG. 7 is a partial cross-sectional view of another example embodiment of a solar module.

[0014] FIG. 8 is a partial cross-sectional view of another example embodiment of a solar module.

[0015] FIG. 9 is a partial cross-sectional view of another example embodiment of a solar module.

[0016] FIG. 10 is a partial cross-sectional view of another example embodiment of a solar module.

[0017] FIG. 11 is a top view of another example embodiment of a solar module.

[0018] FIG. 12 is a partial cross-sectional view of another example embodiment of a solar module.

[0019] FIG. 13 is a partial cross-sectional view of another example embodiment of a solar module.

[0020] FIG. 14 is a partial cross-sectional view of another example embodiment of a solar module.

DETAILED DESCRIPTION OF THE INVENTION

[0021] In the following detailed description, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific embodiments that may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to make and use them, and it is to be understood that structural, logical, or procedural changes may be made to the specific embodiments disclosed without departing from the spirit and scope of the invention.

[0022] As previously discussed, exposure of the photovoltaic cells, conductors, and other components contained between the substrate and back cover can lead to a safety risk to individuals handling the solar modules (such as electrical shock) and can result in damage to the solar modules. One solution has been to include an edge coating around the edge portions of a solar module which coats the edges of the substrate and back cover as well, as a portion of a face of the substrate and a portion of a face of the back cover, as disclosed, for example, in U.S. Patent Application Serial No. 12/636,689 ("the '689 application"), also assigned to First Solar, Inc., and which is incorporated by reference herein in its entirety.

[0023] An additional and/or alternative option for edge coating of solar modules to that disclosed in the '689 application is disclosed in the instant application. The instant application discloses a module and method of forming the same that provides electrical insulation and abrasion and moisture resistance by incorporating a fluoropolymer material coating at the edges of the module. The fluoropolymer material may also include a reinforcing material to provide improved cut and abrasion resistance, and/or the fluoropolymer material may be formed in alternating layers with a ceramic material in order to provide improved moisture resistance. By coating the exposed edge of a solar module with a fluoropolymer-based material, it is possible to achieve not only a high level of electrical insulation (typically 3000 to 7000 DCV/mil), but also increased abrasion resistance and protection against water ingress/moisture transport. Possible choices for the application process include, but are not limited to, roll/transfer application, spraying, needle dispense (flow coating), vacuum coating, and dip coating. Specific embodiments are discussed in more detail in the following.

[0024] Fluoropolymer paints have been used, for example, within the building material industry, to coat structures that need to last and are difficult to re-coat (i.e. skyscrapers, bridges, etc.). A 20 to 30 year (or longer) lifespan has been achieved using these paints with minimal polymeric degradation of the fluoropolymer paint, as evidenced by superior gloss/color retention, negligible chalking, and the absence of blistering/delamination. Fluoropolymers are also hydrophobic and may be considered for use as a moisture barrier, as evidenced by the absence of rust on the metallic substrate in some architectural applications. Also, fluoropolymers Tefzel® (ethylene-tetrafluoroethylene ETFE) and Kynar® (polyvinylidene fluoride PVDF) film have been successfully used as a superstrate for some solar module applications, providing cut/abrasion resistance, good optical properties, and a high bond strength to the underlying encapsulant.

[0025] Since the fluoropolymer edge coating of the disclosed embodiments is light-transmissive, it may cover at least a portion of the active area of the module with minimal effect on the module's efficiency. This allows the active material to extend further toward the edge of the

module. This in turn will allow the active area of the module to be optimized, while maintaining a tracking distance capable of providing safe use throughout the useful life of the module. For example, it is possible to achieve a 5% active area increase for a conventional 600 mm by 1200 mm solar module by applying the fluoropolymer edge coating, as proposed by the invention. The increase in active area utilization that is enabled by a fluoropolymer based edge coating can be proportional to the length and width dimensions of the solar module. Additionally, with the improvement in barrier properties that a fluoropolymer edge coating of the disclosed embodiments provides, it may also be possible to reduce (or eliminate) the previously used internal edge sealant materials (such as those disclosed in the '689 application), resulting in a further possibility for increasing the effective active area. These possibilities of increased active area may provide cost savings by improving the area-specific power density of the solar module (in addition to decreasing the amount of conventional edge sealant material required). Further savings may be realized on a system-level because fewer modules would be required to meet the customer's power targets, thereby saving clips, rails, wires, etc. and physical space.

[0026] An example of a solar module 100 to which the fluoropolymer edge coating of the disclosed embodiments may be applied is depicted in FIG. 1. It should be noted that solar module 100 is not intended to be considered a limitation on the types of solar modules to which the disclosed embodiments may be applied, but rather a convenient representation for the following description. For example, solar module 100 may be representative of any type of photovoltaic device, including thin-film photovoltaic devices, such as copper, indium, gallium (di)selenide devices (CIGS), cadmium telluride (CdTe) based devices, silicon-based (e.g. crystalline or amorphous silicon), Cadmium Sulfide (CdS), photosensitive dyes, or any other photovoltaic devices and is not limited to any particular embodiment.

[0027] Solar module 100 includes a front support 130 and a back support 150 with an active photosensitive material 110, along with other material layers, located between front support 130 and back support 150. Front support 130 has a front facial surface 123 and front support edge

portion 124. Back support 150 has a back facial surface 126 and a back support edge portion 125. For simplicity, front support 130 and back support 150 are illustrated in the figures as having squared off corners; however, as necessary, the edge may alternatively have a finite radius. The width and length of front support 130 is substantially the same as the width and length of back support 150. A solar module edge 90 is comprised of front support edge portion 124 and/or back support edge portion 125. Front support refers to the side of the module upon which sunlight is incident. As discussed herein, photovoltaic modules (which may be referred to as photovoltaic devices or or cells) can include multiple layers (or coatings) created on a substrate (or superstrate). For example, a photovoltaic device can include a barrier layer, a transparent conductive oxide layer, a buffer layer, and a semiconductor layer formed in a stack on a substrate. Each layer may in turn include more than one layer or film. For example, a semiconductor window layer and a semiconductor absorber layer together can be considered a semiconductor layer. Additionally, each layer can cover all or a portion of the device and/or all or a portion of a layer or a substrate underlying the layer. For example, a "layer" can include any amount of any material that contacts all or a portion of a surface.

[0028] Front support 130 and back support 150 may be formed from any suitable insulative and transparent/translucent material including, but not limited to,to glass (e.g. soda-lime glass) and a polyimide. The active material 110 can include any suitable material, for example, copper, indium, gallium (di)selenide devices (CIGS), cadmium telluride (CdTe) based devices, silicon-based (e.g. crystalline or amorphous silicon), Cadmium Sulfide (CdS), photosensitive dyes, or any other photovoltaic devices. The active material 110 may include a semiconductor absorber layer, which is generally referred to as any single or multiple layer capable of generating a photocurrent; or may be part of an active photovoltaic cell and can be adjacent to other layers included in solar module 100. As noted, the solar module 100 is described as an example, but other configurations may be used. The solar module 100 may further include additional features (not shown in Fig. 1) such as a transparent conducting layer and a semiconductor window layer (e.g., of cadmium sulfide) formed between the front support 130 and the semiconductor active material 110;

a barrier layer between the front support 130 and the transparent conducting layer; a buffer layer between the transparent conducting layer and the semiconductor window layer; a contact layer between the active material 110 and the back support 150; and/or any suitable electrical connections, including any suitable electrical conductors between the active material 110 and the back support 150.

[0029] A plurality of photovoltaic cells formed on either a single continuous substrate (or superstrate) or multiple sections thereof can be connected by suitable electrical conductors and covered with a back support such as a back cover glass to form a solar module. Multiple solar modules can be electrically connected in any suitable configuration to form a solar module array which can be used to generate electrical power from all the constituent solar modules.

[0030] The edge coating including a fluoropolymer material of the disclosed embodiments can be implemented in a variety of different ways. Figs. 2-14 disclose several variations of an edge coating, in accordance with disclosed embodiments, each of which will be disclosed in more detail below. In each of the embodiments, the edge coating is referred to as comprising a fluoropolymer material. The details of the fluoropolymer material comprising the edge coating are described in more detail below.

[0031] As seen in Fig. 2, which illustrates a first embodiment, a solar module 200 includes an edge coating, implemented in this embodiment as an edge sealant 280. The solar module 200 includes the front support 130, the back support 150, and the active material 110 therebetween, with the front support 130 and the back support 150 forming the solar module edge 90, as described with respect to Fig. 1. In this embodiment, the edge sealant 280 includes a fluoropolymer sealant located in the space between the front support 130 and the back support 150 and between the active material 110 and the solar module edge 90. As shown in Fig. 2, the edge sealant 280 has a width equal to the distance between the active material 110 and the solar module edge 90. In this embodiment, the width of the edge sealant 280 is equal to the tracking distance 220, which is the minimum distance along which an electrical charge from the active material 110 would have to

travel to reach a person or component contacting either the front support 130 or the back support 150. The tracking distance 220 may be greater than 1 mm; greater than 4 mm; greater than 9 mm; about 10 mm; or greater than 10 mm. The tracking distance 220 may also be between about 1mm and about 4mm, between about 4mm and about 9mm, and between about 4mm and about 10mm.

[0032] Fig. 3 depicts another embodiment of a solar module 300 including a fluoropolymer edge coating 380. The solar module 300 includes the front support 130, the back support 150, and the active material 110 therebetween, with the front support 130 and the back support 150 forming the solar module edge 90, as described with respect to Fig. 1. An auxiliary conventional edge sealant 140, such as a butyl-type elastomer previously noted, is provided adjacent to the active material 110 and extends to the solar module edge 90. The fluoropolymer edge coating 380 is formed adjacent thesolar module edge 90. In this embodiment, the fluoropolymer edge coating 380 contacts the front support edge portion 124 (Fig. 1) of front support 130, edge sealant 140, and the back support edge portion 125 (Fig. 1) of back support 150. An exterior profile 385 of the fluoropolymer edge coating 380 is substantially straight and substantially parallel to the solar module edge 90. The thickness of the fluoropolymer edge coating 380 depends on the insulating properties of the particular fluoropolymer material used, and may vary between a thin film (<5 micron) to approximately 3 mm. Further, similarly to the corners of the front support 130 and the back support 150, the fluoropolymer edge coating (e.g., 380, Fig. 3) may be illustrated throughout as having squared off corners, but the edge coating may also alternatively include an edge with a finite radius.

[0033] In the embodiment of Fig. 3, the fluoropolymer edge coating 380 extends the tracking distance 320a, 320b of the solar module 300, as compared to the tracking distance 220 seen in the embodiment of Fig. 2. The solar module 200 has a tracking distance 220 equal to the distance between the active material 110 and the solar module edge 90. The fluoropolymer edge coating 380 shown in Fig. 3 is coextensive with the front and the back tracking distances 320a, 320b. The front tracking distance 320a equals the length of the path from active material 110 along the front support

130 to the edge of front support 130, and along the front support edge portion 124 to the periphery of the edge coating 380 adjacent to the front support 130. The back tracking distance 320b equals the length of the path from the active material 110 along back support 150 to the edge of back support 150, and along the back support edge portion 125 to the periphery of the edge coating 380 adjacent to the back support 150. The particular length of the tracking distance depends on the materials used, the location of the active material 110 and the periphery of fluoropolymer edge coating 380.

[0034] Fig. 4 shows another embodiment of a solar module 400 including a fluoropolymer edge coating 480 having a T-shaped cross section. As can be seen in Fig. 4, the edge coating 480 contacts both the edge portions of the front support 130 and the back support 150, as well as the interior faces of the inner surfaces of the front support 130 and the back support 150 and the active material 110. In this embodiment, an interior profile of the fluoropolymer edge coating 480 includes a protrusion into the interior of the solar module 400. The exterior profile 485 of the fluoropolymer edge coating 480 is substantially straight and substantially parallel to the solar module edge 90. The tracking distance 420 equals the length of the path from the active material 110 along the front support 130 to the edge of the front support 130, and along the front support edge portion 124 to the periphery of the edge coating 480 adjacent to the front support 130.

[0035] Fig. 5 shows yet another embodiment of a solar module 500 including an edge coating 580. The exterior profile 585 of the fluoropolymer edge coating 580 is curved as compared to the solar module edge 90. In this embodiment, the conventional edge sealant 140 (similar to that described with respect to Fig. 3) is included. Alternatively, the edge sealant 140 may be omitted and the fluoropolymer edge coating 580 may include an interior profile that protrudes into the interior of the solar module 500, as described above with respect to the solar module 400 and the edge coating 480 shown in Fig. 4.

[0036] Fig. 6 shows another embodiment of a solar module 600. In this embodiment, a fluoropolymer edge coating 680 wraps around the front and the back of the solar module 600,

contacting the solar module 600 both at the front support edge portion 124 and the back support edge portion 125, as well as on the front facial surface 123 and the back facial surface 126. As an example, the fluoropolymer edge coating 680 may extend a distance of approximately 1 cm onto the front facial surface 123 and the back facial surface 126 of the solar module 100. This embodiment provides an increased tracking distance 620 as compared to, e.g., the embodiment of Fig. 3. The exact distance that the fluoropolymer edge coating 680 should extend along the facial surfaces can be determined by one of skill in the art by determining a sufficient electrical tracking distance based on the UL 840 standards and the particular materials being used.

[0037] Having an edge coating cover part of a surface of the substrate (or superstrate) is that the edge coating may block light from the reaching part of the active area under the coating. The disclosed embodiments minimize this unusable peripheral portion of the solar module, by coating the solar module edge with a light-transmissive fluoropolymer edge coating. The light-transmissive fluoropolymer edge coating allows for an adequate tracking distance while allowing light transmitted from the light-transmissive surface to be converted by the solar module to electricity. This is one way in which solar modules with an increased active area 110 may be provided.

[0038] With the improvement in barrier properties that the fluoropolymer edge coating of the disclosed embodiments provide, it may also be possible to reduce (or eliminate completely) conventional edge sealant material 140 located between the active area 110 and the module edge 90, and allow the active area 110 to be extended closer to the solar panel edge. This is another way in which solar modules with an increased active area 110 can be provided.

[0039] Two embodiments in which the edge coating overlaps the active are disclosed in Figs. 7 and 8. In Fig. 7, solar module 700 includes fluoropolymer edge coating 780 and shortened/reduced internal edge sealant 140 between active material 110 and fluoropolymer edge coating 780 (as compared to that, e.g., in the embodiment of Fig. 6). Fig. 8 shows another embodiment, where the conventional edge sealant is absent from solar module 800. Adequate tracking distances 720, 820 are maintained in each of these embodiments due to the portions of the

fluoropolymer edge coating 780, 880 that contact the front facial surface 123 and back facial surface 126 of the respective solar modules 700, 800. Further, in the embodiment of Fig. 8, fluoropolymer edge coating 880 is sufficiently thick and provides adequate insulation, thereby removing the need fora conventional edge sealant. As previously indicated, adequate tracking distances 720, 820 can be determined by one of skill in the art by determining a sufficient electrical tracking distance based on the UL 840 standards and the particular materials being used.

[0040] With respect to each of the embodiments described previously, a surface primer may be further included between the surface of the front support and back support and the fluoropolymer edge coating. An example of such an embodiment is illustrated in Fig. 9. As can be seen in Fig. 9, surface primer 981 is provided between the surface of the front and back supports 130, 150 and the fluoropolymer edge coating 980. Surface primer 981 may include any suitable layer that is able to yield a high adherend surface/coating bond strength. In some applications, the primer may serve multiple functions, including acting as a moisture barrier. Surface primer 981 may also be light-transmissive. It should be understood that the surface primer 981 described with respect to Fig. 9 may also be implemented in any of the embodiments described herein.

[0041] With respect to each of the embodiments described previously, the appropriate thickness of the fluoropolymer coating will depend primarily on the required dielectric strength and moisture barrier properties. As previously noted, the thickness of fluoropolymer edge coating depends on the particular material, and may vary, for example, between a trace layer (e.g., <5 micron) to approximately 3 mm.

[0042] With most application techniques, a wet film of approximately 4 mil (0.004") to 6 mil (0.006") is considered to be a thick application. Since most solvent-based fluoropolymer coatings have between approximately 30 and 70% solids, the dry film thickness will be roughly half of the wet film thickness. Therefore, if a thickness of greater than approximately 4 mil (0.004") is desired for the fluoropolymer material, at least two layers of fluoropolymer edge coating 1080, 1081 may be necessary in order to build up the total desired thickness on the solar module 1000, as shown

in Fig. 10. Depending on the product-level engineering requirements, these layers can either be the same or different. In some situations, it may be advantageous to have a base coat with improved tensile properties and adhesion and a highly weatherable, scratch/cut resistant top coat. It should be understood that the multiple coating layers 1080, 1081 described with respect to Fig. 10 may be implemented in any of the embodiments described herein.

[0043] With respect to each of the embodiments described previously, the fluoropolymer edge coating may frame the entire solar module, along the entire solar module edge. This can be seen in the top view depiction of solar module 1100 seen in Fig. 11, where the fluoropolymer edge coating 1180 surrounds the entire solar module 1100. It should be understood that the fluoropolymer edge coating 1180 shown in Fig. 11 may be implemented in accordance with any of the embodiments described herein.

[0044] With respect to each of the embodiments described previously, the solar module 1200 may further include a conventional encapsulant 115 between back support 150 and active layer 110, as seen in Fig. 12, to provide further protection of the solar module components. Encapsulant 115 may be formed of any suitable material, including, for example acrylonitrile butadiene styrene (ABS), acrylic (PMMA), celluloid, cellulose acetate, cycloolefin copolymer (COC), ethylene-vinyl acetate (EVA), ethylene vinyl alcohol (EVOH), fluoroplastics (PTFE), ionomers, Kydex®, liquid crystal polymer (LCP), polyacetal (POM), polyacrylates, polyacrylonitrile (PAN), polyamide (PA), polyamide-imide (PAI), polyaryletherketone (PAEK), polybutadiene (PBD), polybutylene (PB), polybutylene terephthalate (PBT), polycaprolactone (PCL), polychlorotrifluoroethylene (PCTFE), polyethylene terephthalate (PET), polycyclohexylene dimethylene terephthalate (PCT), polycarbonate (PC), polyhydroxyalkanoates (PHAs), polyketone (PK), polyester, polyethylene (PE), polyetheretherketone (PEEK), polyetherketoneketone (PEKK), polyetherimide (PEI), polyethersulfone (PES), polyethylenechlorinates (PEC), polyimide (PI), polyactic acid (PLA), polymethylpentene (PMP), polyphenylene oxide (PPO), polyphenylene sulfide (PPS), polyphthalamide (PPA), polypropylene (PP), polystyrene (PS), polysulfone (PSU), polytrimethylene

terephthalate (PTT), polyurethane (PU), polyvinyl acetate (PVA), polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), styrene-acrylonitrile (SAN), butyl rubber, or any combination thereof.

[0045] As previously noted, front support 130 and back support 150 may be formed of a glass substrate. In embodiments including encapsulant 115, the glass/encapsulant/coating boundary has the potential to be a high-stress location, since the coefficient of thermal expansion (CTE) for fluoropolymer edge coating 1280 can be greater than glass, but is likely less than conventional encapsulants 115. To mitigate this effect, an edge sealant 140 may be provided between the glass/encapsulant 115 and the edge coating 1280. This edge sealant 140 should be selected such that it is compatible with both the encapsulant 115 and the fluoropolymer material of fluoropolymer edge coating 1280 to act as a tie-layer between the encapsulant 115 and the fluoropolymer edge coating 1280, thus reducing potential stress in the module 1200. It should be understood that encapsulant 115 shown in Fig. 12 may be implemented in accordance with any of the embodiments described herein.

[0046] In each of the disclosed embodiments, the fluoropolymer edge coating is referred to as a fluoropolymer material, for clarity of the discussion. The details of the fluoropolymer material that may be used with any of the disclosed embodiments is now described in more detail.

[0047] The base fluoropolymer resin may include, but is not limited to, one or more of polyvinylidene fluoride (PVDF), ethylene tetrafluoroethylene (ETFE), fluorinated ethylene propylene (FEP), polyvinyl fluoride (PVF), polytetrafluoroethylene (PTFE), ethylene chlorotrifluoroethylene (ECTFE), polychloro-trifluoroethylene (PCTFE), polyimide (PI), polyetherimide (PEI), polyetherketone (PEK), polyamide-imide (PAI), polyphenylene sulfide (PPS), and polysulfone (PSU). A grafted fluoropolymer resin with a modified base chain featuring polar functionality can also be used.

[0048] The fluoropolymer material may further include one or more reactive moieties of vinyl acetate, vinyl ether, urethane, methyl methacrylate, and maleic anhydride built into the base chain during the synthetic process; one or more crosslinking agents of isocyanate (high or low NCO%) (e.g., blocked or unblocked aliphalic polyisocyanate), organic peroxide, tertiary amine, organometallic compound, and aziridine; one or more coupling agents for improved adhesion strength (e.g. silane or titanate); one or more UV stabilizers, radical scavengers, catalyst, non-reactive diluents, deaerator/anti-foam, and colorants. Colorants can be added to the formulation when the application has certain cosmetic requirements (e.g., white, black, gray, etc.); however a balance should be struck between module efficiency and the aesthetic requirements. Without colorant, most fluorocarbon-based coatings are highly transparent with a light transmittance of 90% or more in the visible range and a refractive index compatible with the front support material (e.g., glass) and most conventional interlayer materials. Alternatively, the coating may consist of a high temperature thermoplastic material or a system that is UV-curable.

[0049] The fluoropolymer material forming the fluoropolymer edge coating of the disclosed embodiments may be light transmissive. For example, the fluoropolymer material may be transmissive to visible light with a wavelength between about 400 and 780 nm; infrared radiation (IR) with a wavelength between about 0.7 and 300 micrometers; and/or ultraviolet (UV) light with a wavelength between about 10 and 400 nm. The fluoropolymer edge coating may be configured to transmit light or radiation with any suitable wavelength range. The fluoropolymer edge coating may be configured to have a certain coefficient of absorption and/or a certain light transmission. For example, the fluoropolymer edge coating of the disclosed embodiments may have light transmission greater than 70%, greater than 80%, greater than 90%, or greater than 95%, for example, in the range from 70% to 100%. In certain embodiments, the fluoropolymer edge coating transmits the wavelength of light optimized to be absorbed by the active material.

[0050] The fluoropolymer edge coating of the disclosed embodiments may transmit more light in any or all of the above wavelength ranges than a coating including less light-

transmissive materials. For example, the fluoropolymer edge coating can transmit more light in the visible range than an edge coating including, for example, material that is opaque, such as an opaque plastic or polymer, or other materials that can reflect, absorb, or scatter radiation in the desired wavelength. In addition, texture can be applied to the surface of the fluoropolymer edge coating in order to maximize total internal reflection (TIR), which can further increase module efficiency.

[0051] The fluoropolymer edge coating may be secured to the peripheral portions of front support 130 and back support 150 in any suitable manner. For example, adhesion to the front support 130 and back support 150 can be promoted by the inclusion of a coupling agent in the formulation such as a suitable modified organosilane or organic titanate. In addition, depending on the module configuration, surface preparation may be necessary in order to define a proper bondable surface. Surface preparation may include solvent washing, mechanical abrasion, high voltage discharge (corona or plasma treatment), or the utilization of a primer.

[0052] The fluoropolymer edge coating of each of the disclosed embodiments may also include reinforcing material. This reinforcing material will provide improved cut resistance and resistance against other mechanical forces (such as scratches, punctures, or other types of impact) to the edge coating. The reinforcing material may be added to the bulk coating and/or separately to the adherend surface before or during coating application. Bulk reinforcing materials may include glass microspheres, chopped fiberglass strands, or other suitable materials. Reinforcing materials that can be separately introduced may include either a non-oriented fibrous material, woven fiberglass fabric, or long, unidirectional fibrous strands. The non-oriented fibrous material may include nonwoven glass fiber veils, nonwoven polyester fiber veils, or other suitable materials. The non-oriented fibrous material may also involve the use of a binder that is designed to be compatible with the surrounding fluoropolymer material in which it is included. This binder may allow the reinforcing material to be heat-sealable for improved processability. The reinforcing material may have a refractive index that causes it to be difficult to visually detect within the fluoropolymer material once curing is complete. This is particularly important in embodiments where the coating and

reinforcing system is to extend over the active area, such as those embodiments described in Figs. 6-10. In addition, fibrous materials may also function as a wicking aid, helping to draw the coating into the standing edge of the module construction.

[0053] In one aspect, the reinforcing material may be mixed in with the fluoropolymer coating before application to the solar module; in this instance, the structure of the solar module may be the same as any of the previously described embodiments. In an embodiment including multiple layers of the fluoropolymer coating, such as that described with respect to Fig. 10, the reinforcing material may be included in one of the fluoropolymer layers (e.g., in a layer closest to the substrate, suspended in the middle of the coating, or toward the outer surface), a plurality of the fluoropolymer layers, or all of the fluoropolymer layers. In another aspect, shown in Fig. 13, the reinforcing material 1382 of solar module 1300 may be included as a separate layer than the fluoropolymer coating 1380, proximal to the substrate (e.g., front cover 130 and back cover 150), immediately before application of the fluoropolymer coating 1380. This reinforcing material 1382 may be formed, for example, by wrapping the edge directly with the material (e.g., fixturing) or by using a binder system (such as, e.g., an acrylic) to heat tack the reinforcing material 1382 to the module 1300. It should be understood that the fluoropolymer edge coating including the reinforcing material may be implemented with any of the embodiments described herein.

[0054] The fluoropolymer edge coating of each of the described embodiments may also be configured as multiple, alternating layers of the fluoropolymer material and a low-permeability ceramic coating. An example embodiment is shown in Fig. 14. Module 1400 includes alternating layers of ceramic material 1483 and fluoropolymer material 1480. For simplicity only four alternating layers are illustrated, however, it should be recognized that any appropriate number of alternating layers may be used to achieve the desired effect. For example, the module may include only one layer of each of the ceramic material 1483 and fluoropolymer material 1480 or may include several layers of each. In this configuration, improved resistance to moisture transport is provided.

Using multiple, alternating layers significantly decreases the probability of micro defects, thereby improving moisture resistance and prolonging the longevity and robustness of the system.

[0055] The ceramic layers 1483 may comprise any transparent oxides or nitrides with good barrier properties, such as silicon oxides and/or silicon nitrides. For example, the ceramic layers 1483 may comprise a polyester plus silicon oxide, calcium oxide and/or aluminum oxide. In modules of this embodiment, the substrate (e.g., front cover 130 and back cover 150) should have a low coefficient of thermal expansion (CTE) in order to minimize crack formation in the ceramic layers 1483. With this embodiment, a moisture vapor transmission rate (MVTR) of between 10^{-5} and 10^{-6} g/m^2/day at room temperature is achievable. The ceramic layers 148 of the moisture resistance embodiment may be deposited via plasma enhanced chemical vapor deposition (PECVD). With respect to the ceramic layers 1483, "low-permeability" means moisture transport through the layer is minimized. It should be understood that the fluoropolymer edge coating including the ceramic layers may be implemented with any of the embodiments described herein.

[0056] The fluoropolymer edge coating of each of the described embodiments may also be configured to be loaded with a desiccant in order to provide additional moisture protection.

[0057] The fluoropolymer edge coating of each of the described embodiments may also be configured to be applied to any glass panel-based electronics, other than solar modules, where an edge coating may be desired, such as for example, a flat panel display used, for example, for a computer monitor or television.

[0058] The edge coating of the disclosed embodiments may be formed by injection molding the edge coating adjacent to the solar module edge; by brushing an edge coating material adjacent to the solar module edge to form the edge coating; by spraying an edge coating material adjacent to the solar module edge to form the edge coating; by needle dispensing/flow coating; by vacuum coating; or by molding the edge coating. The manufacturing method may also include applying an additional material, e.g., a moisture resistant material, a separate reinforcing material, a

primer, and/or an adhesive tie-layer, as discussed above with respect to the various embodiments, before forming the edge coating adjacent to the solar module edge. Each of these methods of manufacturing can be used with any of the disclosed embodiments, as appropriate.

[0059] Forming the edge coating adjacent to a solar module edge can include contacting the edge coating to a front support edge portion of the front support; contacting the edge coating to a front support peripheral portion of a front support facial surface of the front support; contacting the edge coating to a back support edge portion of the back support; and/or contacting the edge coating to a back support peripheral portion of a back support facial surface of the back support.

[0060] While embodiments have been described in detail, it should be readily understood that the invention is not limited to the disclosed embodiments. Rather the embodiments can be modified to incorporate any number of variations, alterations, substitutions, or equivalent arrangements not heretofore described without departing from the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. A solar photovoltaic module comprising:

a front support;

a back support;

an active layer between the front support and the back support, edges of the front support and back support forming a solar module edge; and

an fluoropolymer edge coating adjacent to the solar module edge.

2. The solar module of claim 1, wherein the edge coating comprises a grafted fluoropolymer resin with a modified base chain featuring polar functionality.

3. The solar module of claim 1, wherein the edge coating comprises one or more UV stabilizer, radical scavenger, catalyst, non-reactive diluent, deaerator/anti-foam, or colorant.

4. The solar module of claim 1, wherein the edge coating is transparent.

5. The solar module of claim 1, wherein the edge coating has a light transmittance of 70 - 100% in the visible range and a refractive index compatible with a material comprising the front support.

6. The solar module of claim 1, wherein the edge coating contacts a front support edge portion of the front support.

7. The solar module of claim 1, wherein the edge coating contacts the active material.

8. The solar module of claim 1, further comprising an auxiliary edge seal between the active material and the edge coating.

9. The solar module of claim 1, wherein an exterior profile of the edge coating has one of a rounded shape and a T-shaped cross section.

10. The solar module of claim 1, wherein the edge coating comprises at least two layers of fluoropolymer material.

11. The solar module of claim 1, further comprising at least one additional layer between the solar module edge and the edge coating.

12. The solar module of claim 11, wherein the at least one additional layer comprises one or more of non-woven glass fiber veils, non-woven polyester fiber veils, and a ceramic material.

13. The solar module of claim 12, wherein the solar module further comprises a plurality of alternating layers of the ceramic material and the fluoropolymer.

14. A solar photovoltaic module comprising:

a front support;

a back support;

an active layer between the front support and the back support, edges of the front support and back support forming a solar module edge; and

an fluoropolymer edge coating adjacent to the solar module edge contacting the front support, the back support, and the active layer.

15. A method of forming an edge coating for a glass panel-based electronic device comprising forming a fluoropolymer material adjacent to an edge of the glass panel-based electronic device.

16. The method of claim15, wherein forming the fluoropolymer material comprises brushing the fluoropolymer material adjacent to the edge of the glass panel-based electronic device to form the edge coating.

17. The method of claim15, wherein forming the fluoropolymer material comprises spraying the fluoropolymer material adjacent to the edge of the glass panel-based electronic device to form the edge coating.

18. The method of claim 15, wherein forming the fluoropolymer material comprises a combination of a needle/flow coat dispensing method, a vacuum coating based method, molding the edge coating, and applying an additional material before forming the edge coating adjacent to the solar module edge.

19. The method of claim15, wherein the glass panel-based electronic device is a solar module.

20. The method of claim 19, wherein the solar module comprises a front support, a back support, and an active layer between the front support and the back support, wherein the front support and back support form the edge of the solar module, and the method further comprises forming the edge coating adjacent to the solar module edge by contacting the edge coating to a front support edge portion of the front support and to a back support edge portion of the back support.

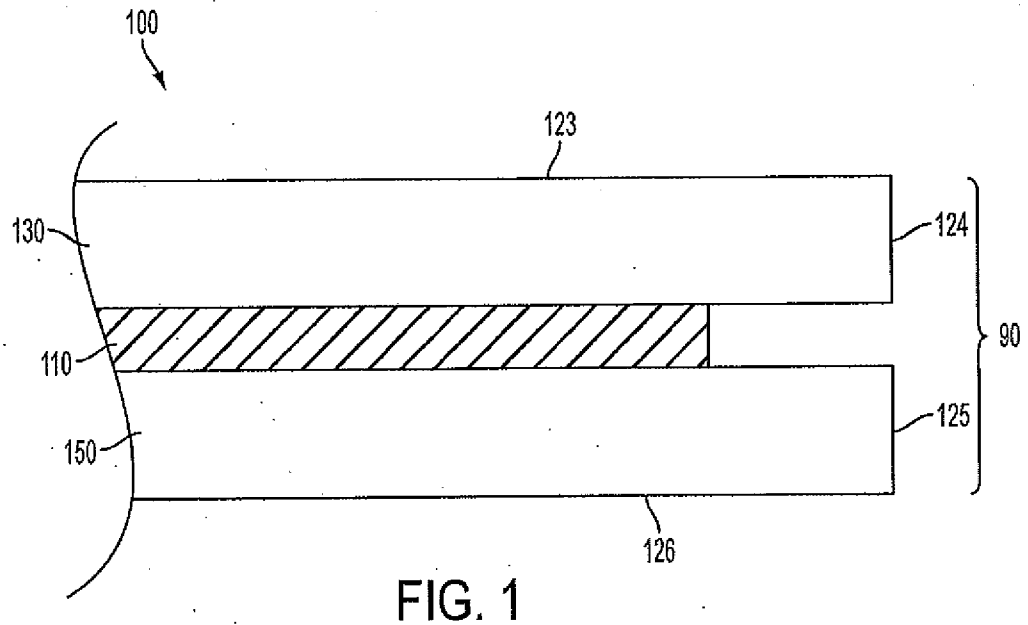


FIG. 1

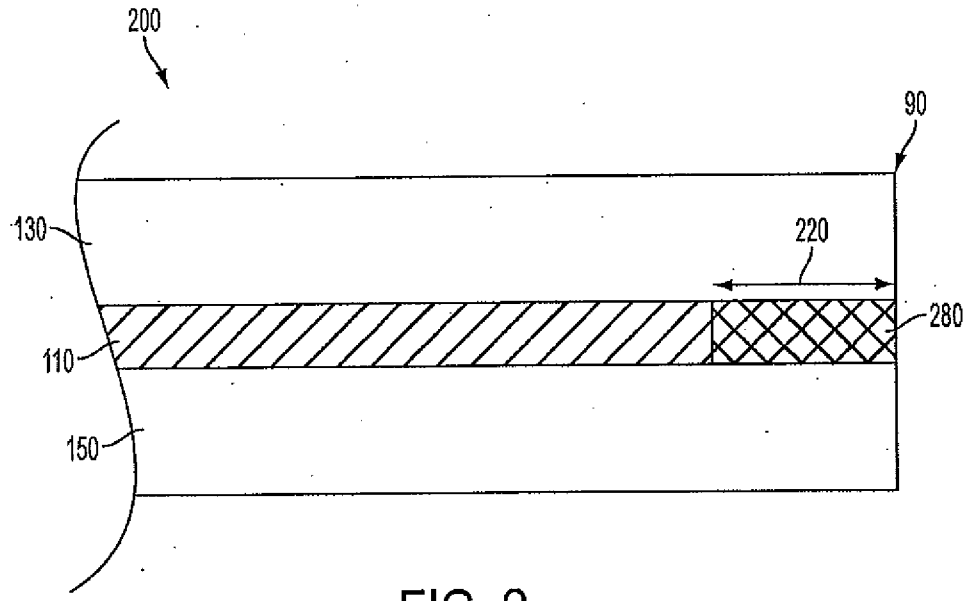


FIG. 2

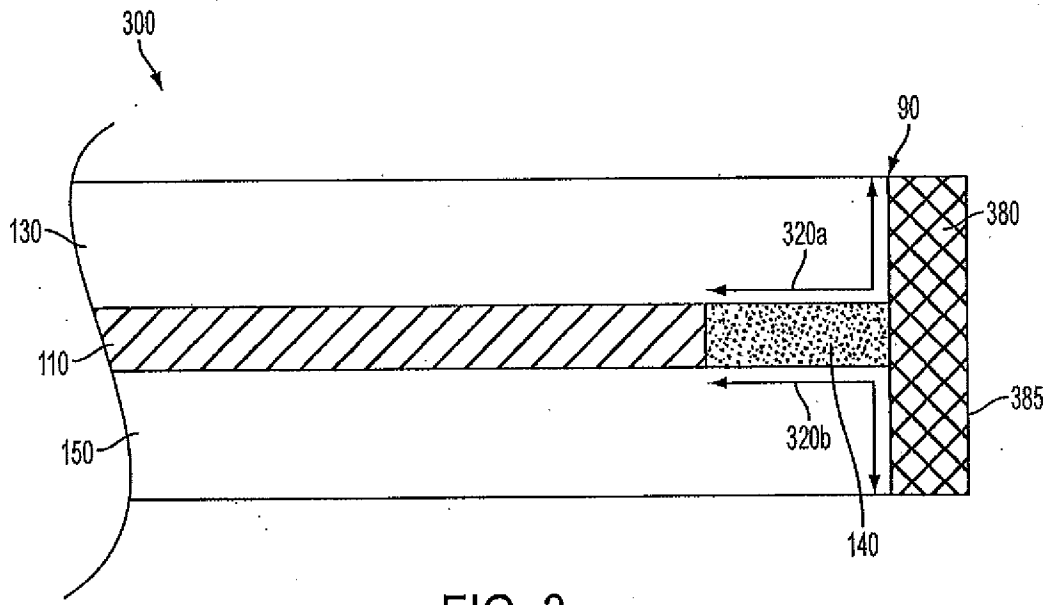

300
90
130
320a
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320b
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FIG. 3

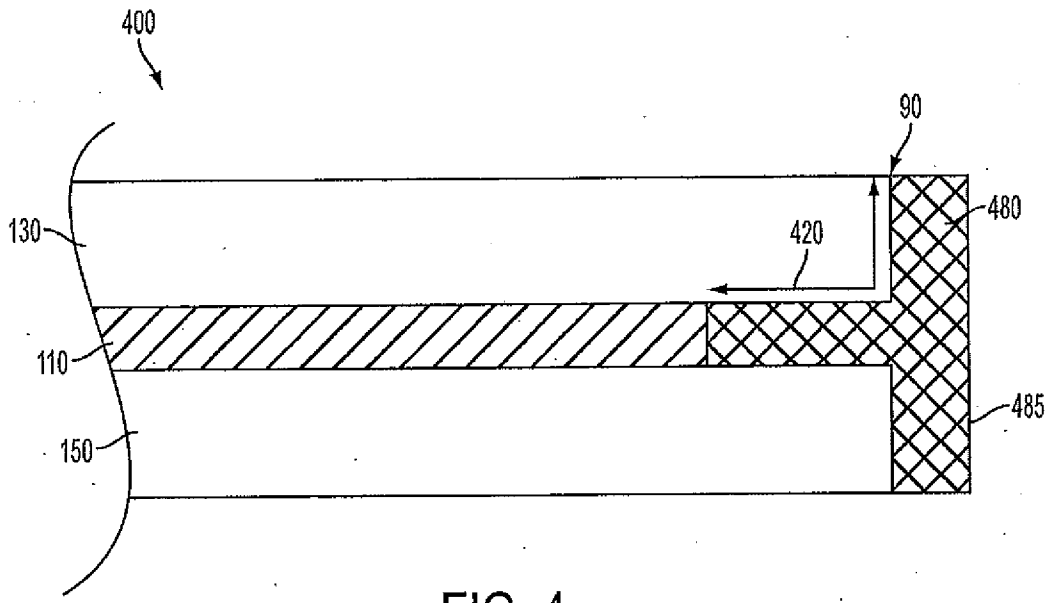

400
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FIG. 4

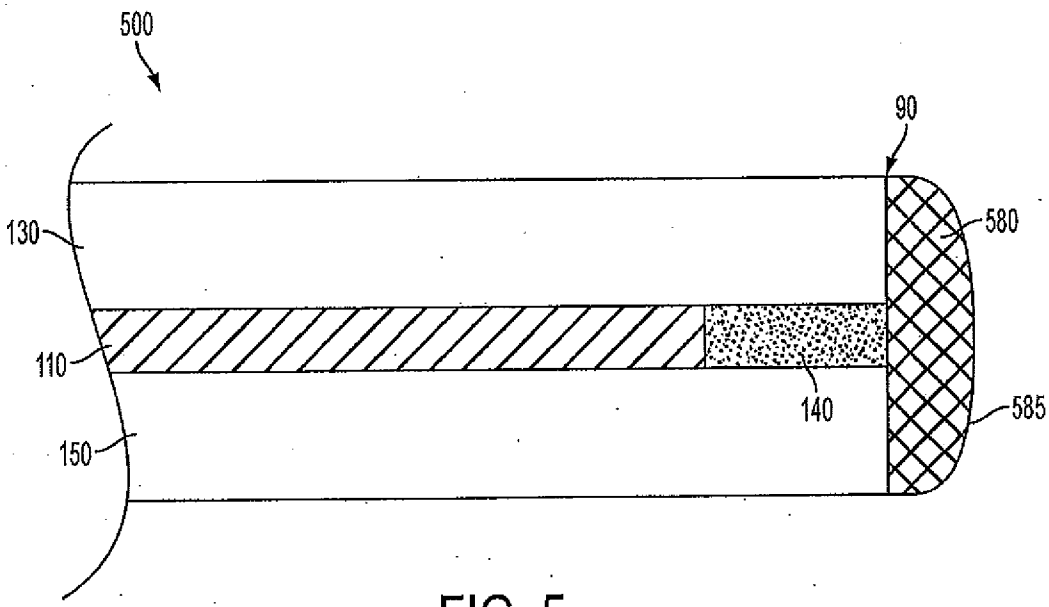


FIG. 5

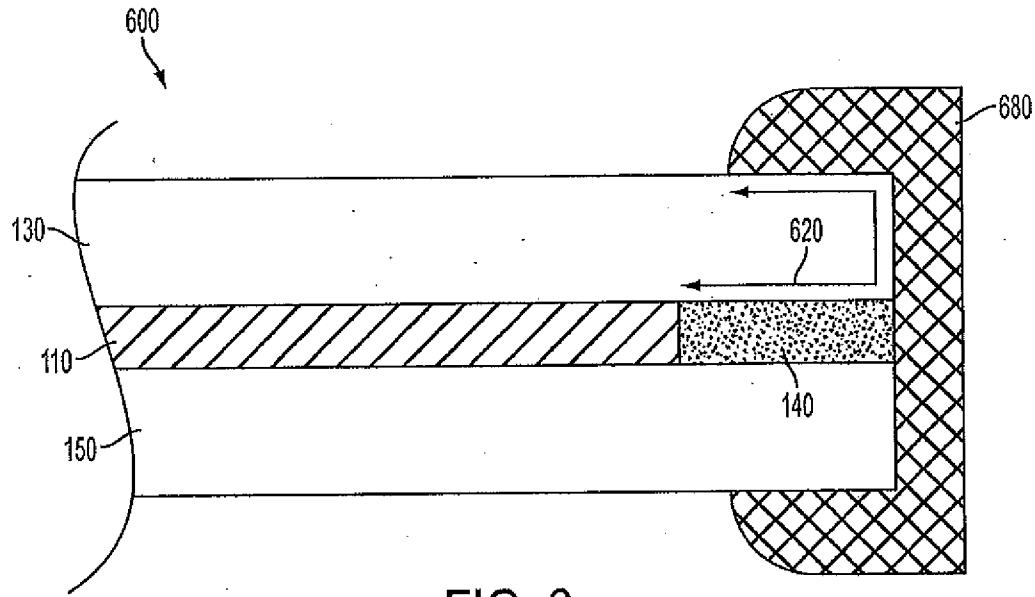


FIG. 6

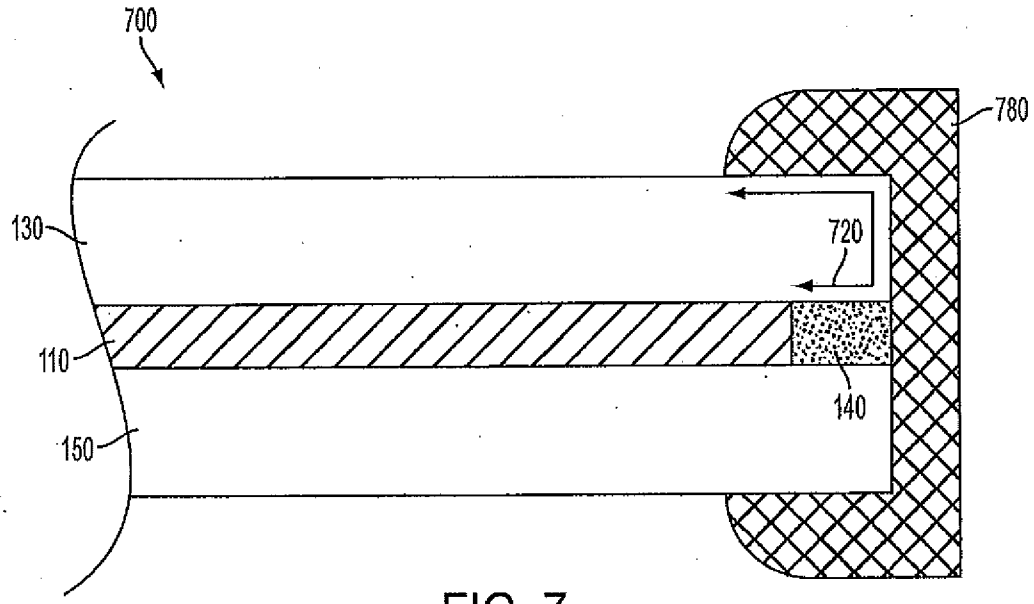


FIG. 7

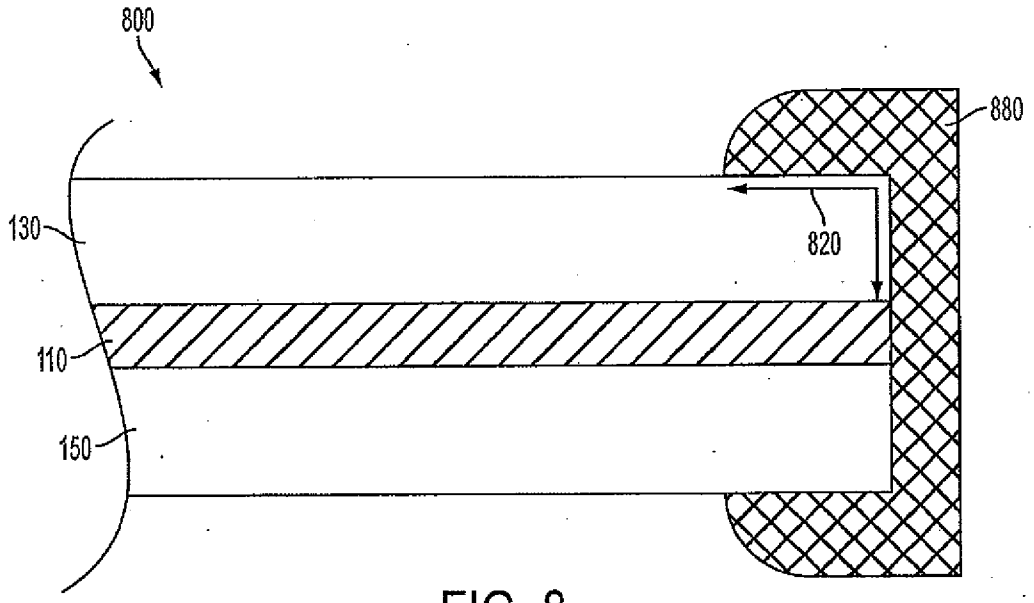


FIG. 8

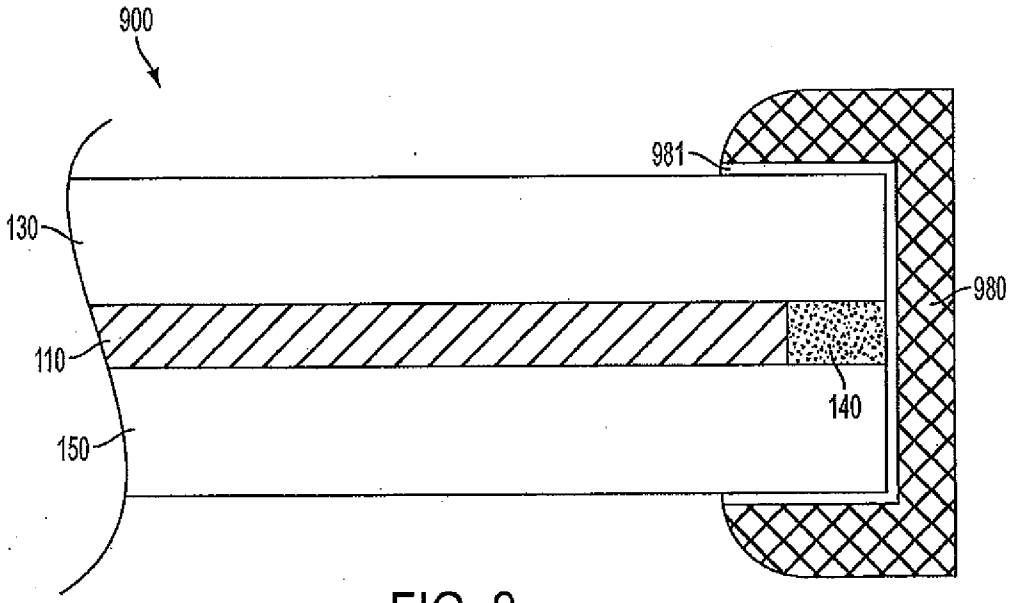


FIG. 9

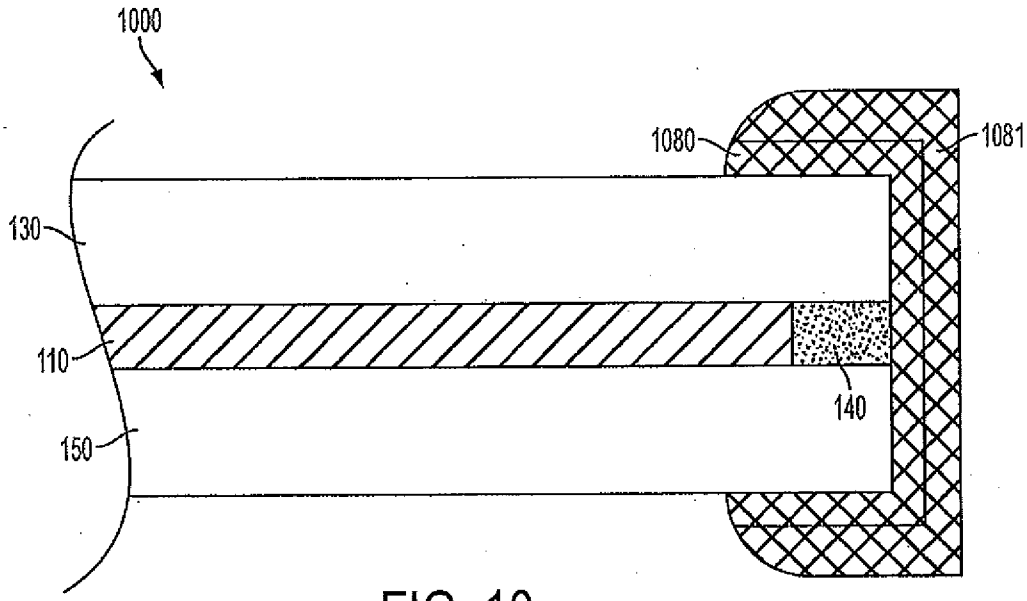


FIG. 10

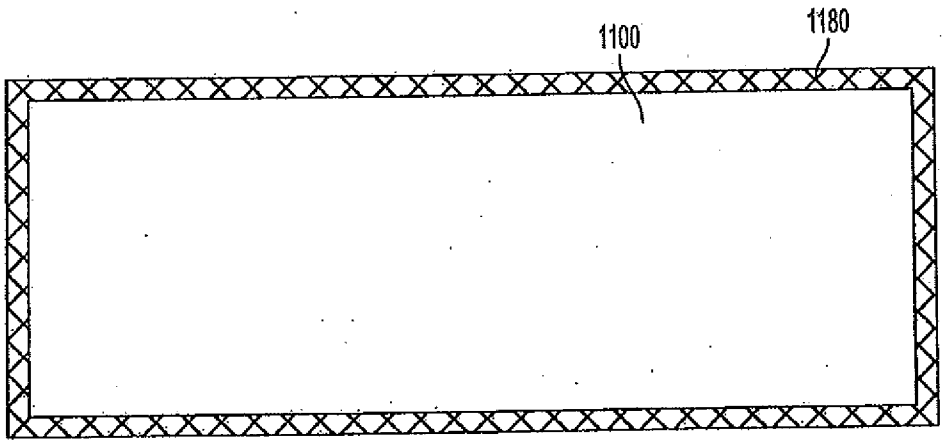


FIG. 11

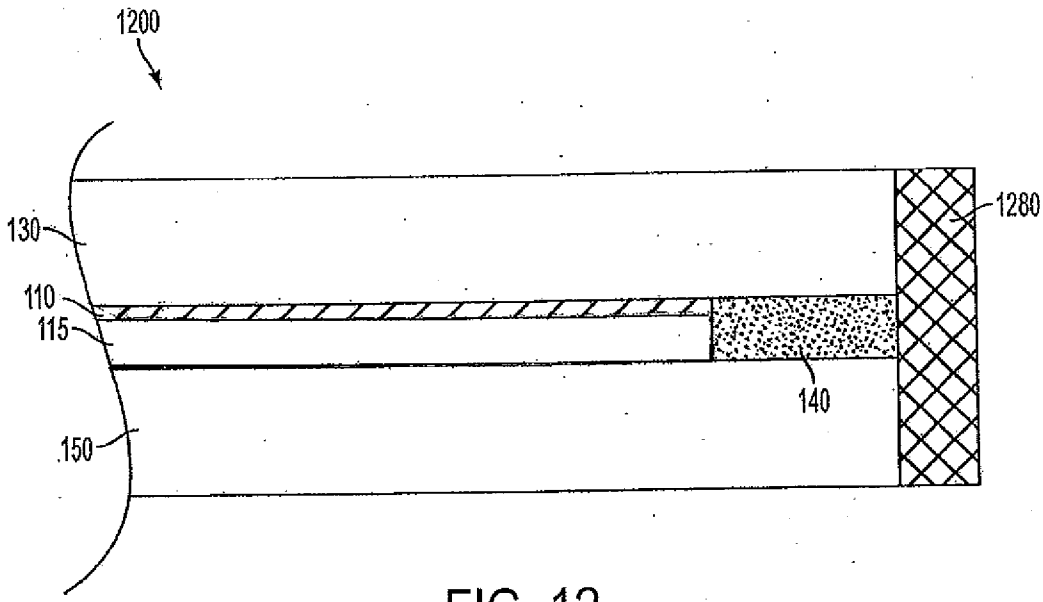


FIG. 12

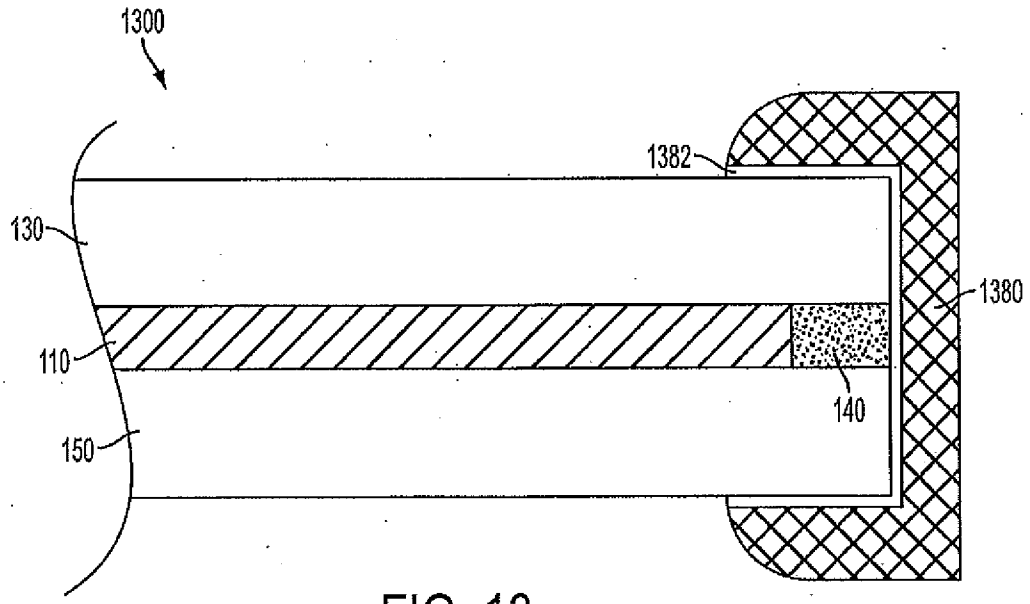

1300
1382
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FIG. 13

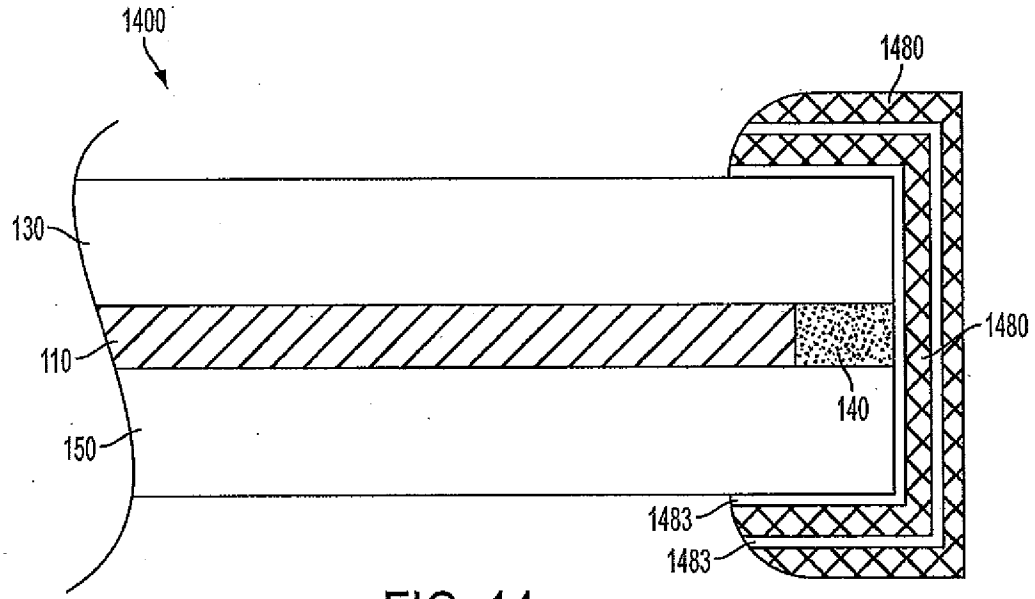

1400
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1483
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FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/068392

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H01L 31/042 (2014.01)
USPC - 136/244
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)
IPC(8) - H01L 31/042, 31/00; H02N 6/00 (2014.01)
USPC - 136/244, 246, 251, 256, 259; 428/421, 422

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - H01L 31/042, 31/05, 31/0522 (2013.01)

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,578,526 A (NAKANO et al) 25 March 1986 (25.03.1986) entire document	1, 7, 14-15, 19
Y		2-6, 8-13, 16-18, 20
Y	US 2011/0129676 A1 (BRAVET et al) 02 June 2011 (02.06.2011) entire document	2, 10
Y	US 2010/0206377 A1 (SAHLIN et al) 19 August 2010 (19.08.2010) entire document	3, 17
Y	US 2012/0055550 A1 (BULLER et al) 08 March 2012 (08.03.2012) entire document	4-6,8,9,11-13,20
Y	US 5,059,254 A (YABA et al) 22 October 1991 (22.10.1991) entire document	12-13
Y	US 2010/0319751 A1 (DAY et al) 23 December 2010 (23.12.2010) entire document	16
Y	US 2010/0326501 A1 (ZHAO et al) 30 December 2010 (30.12.2010) entire document	18
A	US 2012/0006400 A1 (TAI et al) 12 January 2012 (12.01.2012) entire document	1-20
A	US 2010/0193029 A1 (MURPHY et al) 05 August 2010 (05.08.2010) entire document	1-20
A	US 2012/004835 A1 (GONZALEZ) 01 March 2012 (01.03.2012) entire document	1-20

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 March 2014	28 MAR 2014

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)