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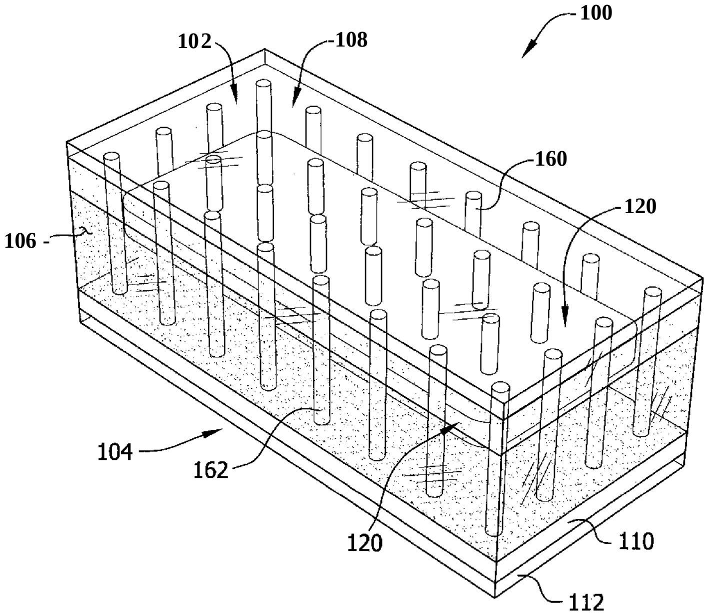
(54) **Title:** SOLAR MODULE HEAT TRANSFER SYSTEM

FIG. 1



(57) **Abstract:** A solar module having improved heat transfer properties is disclosed. The module has an upper surface and a lower surface and includes a photovoltaic cell having a front side and a back side. A back side encapsulant is disposed adjacent the back side of the cell and extends adjacent the lower surface of the module. A front side encapsulant is disposed adjacent the front side of the cell and extends adjacent the upper surface of the module. Regions of particles are disposed in the front side encapsulant. The particles have a heat transfer coefficient greater than a heat transfer coefficient of the front side encapsulant and facilitate the anisotropic transfer of heat through the module.

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SOLAR MODULE HEAT TRANSFER SYSTEM

FIELD

[0001] This disclosure relates generally to solar modules used to convert solar energy into electricity and, more specifically, to systems for improving heat transfer in solar modules.

BACKGROUND

[0002] Solar modules conventionally include a photovoltaic cell that is laminated between an upper layer (e.g., made of glass or a similar transparent material) and a bottom layer that is generally water resistant. Two layers of encapsulant are positioned between these outer layers, and the cells are positioned within the encapsulant.

[0003] One factor that affects the efficiency of the solar module is the temperature of the photovoltaic cell within the solar module. Typically, the efficiency of a solar module decreases by .5% for each degree Celsius that the temperature of the photovoltaic cell exceeds the normal operating cell temperature (NOCT).

[0004] Numerous attempts have been made to reduce the temperature of the photovoltaic cells within solar modules. These prior attempts to reduce the temperature of the photovoltaic cell within the solar module have been costly, inefficient and/or ineffective. Thus there exists a need for an improved system for reducing the temperature of photovoltaic cells within solar modules.

[0005] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

SUMMARY

[0006] One aspect is a solar module comprising a photovoltaic cell having a front side and a back side. The photovoltaic cell is configured for converting light into electricity. A back side encapsulant is disposed adjacent the back side of the cell. Thermally conductive particles are interspersed in the back side encapsulant and the particles have a heat transfer coefficient greater than a heat transfer coefficient of the back side encapsulant. A front side encapsulant is disposed adjacent the front side of the cell. A discrete region of thermally conductive particles is disposed in the front side encapsulant. The heat transfer coefficient of the particles is greater than a heat transfer coefficient of the front side encapsulant. The discrete region of particles facilitates anisotropic heat transfer from an upper surface of the module to the backside encapsulant.

[0007] Another aspect is a solar module having an upper surface and a lower surface. The module comprises a photovoltaic cell having a front side and a back side and the cell is configured for converting light into electricity. A back side encapsulant is disposed adjacent the back side of the cell and extends adjacent the lower surface of the module. A front side encapsulant is disposed adjacent the front side of the cell and extends adjacent the upper surface of the module. Regions of particles are disposed in the front side encapsulant and the particles have a heat transfer coefficient greater than a heat transfer coefficient of the front side encapsulant.

[0008] Still another aspect is a solar module having an upper surface and a lower surface. The module comprises a photovoltaic cell having a front side and a back side and the photovoltaic cell configured for converting light into electricity. An optically opaque back side encapsulant is disposed adjacent the back side of the cell. An optically transparent front side encapsulant is disposed adjacent the front side of the cell. A back sheet defines the lower surface of the solar module.

[0009] Various refinements exist of the features noted in relation to the above-mentioned aspects of the present disclosure. Further features may also be incorporated in the above-mentioned aspects of the present disclosure as well. These refinements and additional features may exist individually or in any combination. For instance, various features discussed below in relation to any of the illustrated embodiments of the present disclosure may be incorporated into any of the above-described aspects of the present disclosure, alone or in any combination.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Figure 1 is a perspective view of a solar module;

[0011] Figure 2 is a top plan view of the solar module of Figure 1;

[0012] Figure 3 is a cross-sectional of the solar module of Figure 2 taken along the 3-3 line; and

[0013] Figure 4 is a cross-sectional view of another solar module.

[0014] Corresponding reference characters indicate corresponding parts throughout the drawings.

DETAILED DESCRIPTION

[0015] Referring to the drawings, an exemplary solar module system is shown in Figure 1 and indicated generally at 100. It should be understood that the relative dimensions of the various components described in greater below and shown in the drawings are exaggerated for clarity. As compared to prior systems, the system described herein is generally operable to increase the amount and/or rate of heat transferred from an upper surface of a solar module to a lower surface of the solar module. This increase in heat transfer increases the efficiency of the solar module, resulting in the generation of greater amounts of electricity compared to prior modules operating under the same or similar conditions.

[0016] As described in greater detail below, discrete regions of thermally conductive particles disposed in a front side encapsulant facilitate the anisotropic transfer of heat through the module. This anisotropic heat transfer increases the rate of heat transferred through the module, thus reducing the operating temperature of the photovoltaic cell.

[0017] The system 100 has an upper surface 102, a lower surface 104 and vertical sides 106. A glass panel 108 forms the upper surface 102 in the example embodiment. A coating is disposed on the outermost surface of the glass which has a high emissivity (e.g., greater than about 0.95) in the infrared wave lengths above 1100 nm and a low emissivity (e.g., less than about 0.1) in the wave lengths below 1100 nm. The coating thus reflects more light that is in the infrared wave lengths than in wave lengths greater than the infrared range. That is, the coating reflects light in the infrared wave lengths and transmits light in wave lengths lower than the infrared range. This reflection of infrared light reduces the amount of heat transferred to the module by solar energy. This coating may be a metallic film in some embodiments. The coating may also be a multi-layered coating that enhances reflection of infrared photons while allowing photons having lower wave lengths to pass therethrough.

[0018] The vertical sides 106 may be made of silicone or other suitable material that is water-resistant. Such materials generally adhere well to the outer surfaces of the system 100 to provide a weather-tight seal.

[0019] A thermally conductive back sheet 110 (broadly, a "structure") forms the lower surface 104 in the example embodiment. The back sheet 110 is made of a metallic material in the example embodiment. A similar coating 112 as that disposed on the glass panel 108 may also be disposed on the back sheet 110. The back sheet 110 can be attached to a heat sink (not shown) with a thermally conductive adhesive. In some embodiments, the back sheet 110 has an infrared emissivity such that a heat sink is not needed. In these embodiments, the back sheet 110 effectively functions as a heat sink when its emissivity is greater than about 0.95.

[0020] A photovoltaic cell 120 (referred to herein interchangeably as "the cell") is disposed between the upper surface 102 and lower surface 104. The photovoltaic cell 120 is operable to convert the energy of light (e.g., solar energy) into electricity via the photovoltaic effect. While a single photovoltaic cell 120 is shown in the Figures, other embodiments may use multiple photovoltaic cells in a single solar module 100. The photovoltaic cell 120 has a front side 122 configured for receiving solar energy and is positioned in use to face a source of light (e.g., the sun). The photovoltaic cell 120 has a back side 124 opposite the front side. As shown in the Figures, the front side 122 of the photovoltaic cell 120 is disposed nearest the upper surface 102 of the module 100 while the back side 124 of the cell 120 is disposed nearest the lower surface 104 of the module.

[0021] A front side encapsulant 130 is disposed adjacent the front side 122 of the cell and the upper surface 102 of the module 100. In the example embodiment, the front side encapsulant 130 is made of a substantially transparent material such that it does not impede the transmission of solar energy to the front side of the cell. Examples of such materials include silicone and/or ethylene-vinyl acetate.

[0022] A back side encapsulant 140 is disposed adjacent the back side 124 of the cell 120 and the lower surface 104 of the module 100. The back side encapsulant 140 and front side encapsulant 130 are in contact with each other along a region 150 that is generally coincident with the front side 122 of the cell 120 in the example embodiment. The location of this region 150 may differ in other embodiments. For example, the region 150 may be coincident with the back side 124 of the cell 120 or with a portion of the cell between its back side and front side 122. This region 150 may not necessarily be a defined plane, as the encapsulants 130, 140 melt and flow during manufacture of the system 100 and thus the region 150 is an interface zone between the encapsulants.

[0023] In the example embodiment, the back side encapsulant 140 is made of an optically opaque material. Examples of such materials include silicone, polyurethane, or ethylene-vinyl acetate. Additives may be added to these materials to make them optically opaque if they are not already. These materials have a heat transfer coefficient that is greater than that of the materials used to form the front side encapsulant 130. Accordingly, the back side encapsulant 140 is thermally conductive and facilitates the transfer of heat from the region 150 adjacent the front side encapsulant 130 and the back side 124 of the cell 120 to a position adjacent the lower surface 104 of the module 100.

[0024] Discrete regions 160 of thermally conductive particles are disposed in the front side encapsulant 130. The number and relative size and shape of the regions 160 shown in the Figures are merely illustrative and may be altered without departing from the scope of the embodiments. These discrete regions 160 of particles facilitate anisotropic heat transfer from the upper surface 102 of the module 100 to the back side encapsulant 140. These regions 160 extend in a direction generally perpendicular (i.e., normal) to the photovoltaic cell 120 from a position near the front side 122 of the cell to a position near the upper surface 102 of the module 100. The regions 160 thus facilitate the transfer of heat in a single direction through the module 100 in anisotropic manner.

[0025] The heat transfer coefficient of these particles is greater than that of the front side encapsulant 130. In the example embodiment, the heat transfer coefficient of the particles is about 100 times or greater than that of the front side encapsulant 130. The particles are made of any suitable material in the example embodiment. Examples of such materials include nickel, copper, other metals, or other thermally conductive materials.

[0026] The regions 160 are sized and spaced so as to not impede, or to substantially permit, the transmission of solar energy to the front side of the cell. In the example embodiment, the regions 160 are circular-shaped although in other embodiments they may be shaped differently (e.g., oblong, oval, rectangular, etc.).

[0027] The particles contained in the discrete regions 160 in the example embodiment are oblong-shaped such that their length is greater than their width. This shape of the particles increases the number of particles which are in contact with each other in the regions 160. This physical contact between particles increases the ability of the regions 160 to conductively transfer heat between the particles, and thus ability of the regions to transfer heat.

[0028] Moreover, these particles are insulated from contact with the front side 122 of the photovoltaic cell 120. In the example embodiment, they are insulated by a gap between the regions 160 and the cell 120 that is filled by the front side encapsulant 130. In other embodiments, different apparatus or methods may be used to insulate the particles in the regions 160 from the front side 122 of the photovoltaic cell 120.

[0029] In the example embodiment, similarly sized and shaped discrete regions 162 of thermally conductive particles are also formed in the back side encapsulant 140. The particles in these regions 162 are suitably made of the same materials as those of the regions 160 in the front side encapsulant 130. These regions 162 in the back side encapsulant 140 transfer heat from the back side 124 of the photovoltaic cell 120 to the lower surface 104 of the solar module 100.

[0030] Moreover, the particles in the regions 162 in the back side encapsulant 140 are insulated from contact with the back side 124 of the photovoltaic cell 120. In the example embodiment, they are insulated by a gap between the regions 162 and the cell 120 that is filled by the back side encapsulant 140. In other embodiments, different systems can be used to insulate the particles in the regions 162 from the back side 124 of the photovoltaic cell 120.

[0031] In some embodiments, some of the regions 160 of thermally conductive particles may extend uninterrupted from adjacent the front surface 102 of the module 100 to adjacent the lower surface 104 of the module 100. These particular regions 160 are spaced outward from the cell 120 towards the sides 106 of the module 100.

[0032] As shown in the embodiment of Figure 4, thermally conductive particles 164 may be interspersed in the back side encapsulant 140. These particles 164 have a heat transfer coefficient greater than that of the back side encapsulant 140. In the example embodiment, the particles 164 are of the same type as those used in the discrete regions 160 in the front side encapsulant 130. The particles 164 may also be insulated from contact with the cell 120 by a gap filled with back side encapsulant 140 or by any other suitable insulation system. In embodiments where regions 160 are spaced outward from the cell 120, some of the particles in the regions 160 are in contact with some of the particles 164 interspersed in the back side encapsulant 140.

[0033] Embodiments of the present disclosure, such as system 100, increase the efficiency of the solar module by reducing the temperature of the photovoltaic cell 120. As described above, the coating disposed on the glass panel 108 reduces the amount of infrared light absorbed by the module 100. This reduction in absorption of infrared light reduces the amount of heat transferred to the module 100 from solar energy. The discrete regions 160, 162 of thermally conductive particles and particles 164 facilitate the anisotropic heat transfer from the upper surface 102 of the module 100 through the encapsulants 130, 140 to the lower surface 104. Moreover, the thermally conductive backsheet 110 facilitates the flow of heat away from the back side encapsulant 140.

[0034] The systems 100 described herein thus increase the rate and/or amount of heat transferred from the upper surface 102 of the solar module 100 to the lower surface 104 of the module. By increasing the amount and/or rate of heat transferred, the temperature of the photovoltaic cell 120 is increased by the solar energy to a lesser degree than in prior systems subject to similar conditions. The temperature of the photovoltaic cell 120 is thereby reduced compared to prior systems operating under similar conditions. This reduction in temperature of the photovoltaic cell 120 increases the efficiency of the cell, which in turn increases the amount of electricity generated by the cell.

[0035] These systems 100 also have advantages over other methods of reducing the temperature of the solar modules and their photovoltaic cells 120. For example, the systems 100 are "passive" in that they do not require the expenditure of any additional energy to cool the photovoltaic cells. For example, "active" cooling systems using forced air or a cooling fluid to reduce the temperature of solar modules have generally not been used because of their increased initial capital costs and recurring operating costs. Moreover, such "active" systems require continued maintenance and upkeep that is time-consuming and costly.

[0036] When introducing elements of the present disclosure or the embodiments thereof, the articles "a", "an", "the" and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," "containing" and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. The use of terms indicating a particular orientation (e.g., "top", "bottom", "side", etc.) is for convenience of description and does not require any particular orientation of the item described.

[0037] As various changes could be made in the above constructions and methods without departing from the scope of the disclosure, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

WHAT IS CLAIMED IS:

1. A solar module comprising:

a photovoltaic cell having a front side and a back side, the photovoltaic cell configured for converting light into electricity;

a back side encapsulant disposed adjacent the back side of the cell;

thermally conductive particles interspersed in the back side encapsulant, the particles having a heat transfer coefficient greater than a heat transfer coefficient of the back side encapsulant;

a front side encapsulant disposed adjacent the front side of the cell; and

a discrete region of thermally conductive particles disposed in the front side encapsulant, the heat transfer coefficient of the particles being greater than a heat transfer coefficient of the front side encapsulant, wherein the discrete region of particles facilitates anisotropic heat transfer from an upper surface of the module to the backside encapsulant.

2. The solar module of claim 1 wherein the particles interspersed in the back side encapsulant and wherein the particles disposed in the front side encapsulant are made of the same material.

3. The solar module of claim 2 wherein the particles are metallic and oblong.

4. The solar module of claim 1 wherein the particles disposed in the front side encapsulant are insulated from contact with the photovoltaic cell.

5. The solar module of Claim 4 wherein the particles are insulated from contact with the photovoltaic cell by the front side encapsulant.

6. The solar module of claim 1 further comprising a plurality of regions of thermally conductive particles disposed in the front side encapsulant.

7. The solar module of claim 6 wherein the regions extend in a direction generally perpendicular to the photovoltaic cell from a position near a front of the photovoltaic cell.

8. The solar module of claim 1 wherein at least some of the particles of the region in the front side encapsulant are in contact with at least some of the particles interspersed in the back side encapsulant.

9. The solar module of claim 8 further comprising a structure positioned adjacent a lower surface of the solar module, and wherein the particles of the region in the front side encapsulant and the particles in the back side encapsulant transfer heat from an upper surface of the solar module through the encapsulants to the structure.

10. The solar module of claim 9 wherein the structure is a metallic back sheet.

11. A solar module having an upper surface and a lower surface, the module comprising:

a photovoltaic cell having a front side and a back side, the photovoltaic cell configured for converting light into electricity;

a back side encapsulant disposed adjacent the back side of the cell and extending adjacent the lower surface of the module;

a front side encapsulant disposed adjacent the front side of the cell and extending adjacent the upper surface of the module; and

regions of particles disposed in the front side encapsulant, the particles having a heat transfer coefficient greater than a heat transfer coefficient of the front side encapsulant.

12. The solar module of claim 11 wherein the regions extend perpendicular to the front side of the encapsulant to facilitate anisotropic heat transfer.

13. The solar module of claim 11 wherein the regions extend in a direction generally perpendicular to the photovoltaic cell from a position near a front of the photovoltaic cell.

14. The solar module of claim 13 wherein the regions extend from the position near the front of the photovoltaic cell to a position near the upper surface of the solar module and wherein the regions facilitate the anisotropic transfer of heat from the upper surface through the front side encapsulant.

15. The solar module of claim 11 wherein the regions are separated from each other by at least the front side encapsulant.

16. The solar module of claim 11 wherein the regions are insulated from contact with the photovoltaic cell by the front side encapsulant.

17. The solar module of claim 11 wherein at least some of the regions are disposed in both the front side encapsulant and back side encapsulant.

18. The solar module of claim 11 wherein the back side encapsulant is optically opaque and thermally conductive.

19. The solar module of claim 18 further comprising a structure positioned adjacent the lower surface of the solar module, and wherein the regions in the front side encapsulant and the back side encapsulant transfer heat from the upper surface of the solar module through the encapsulants to the structure.

20. The solar module of claim 19 wherein the structure is at least one of a back sheet and a heat sink.

21. The solar module of claim 11 further comprising a coating disposed adjacent the upper surface of the module, the coating having relatively high emissivity in wavelengths above

about 1100 nanometers and relatively low emissivity in wavelengths below about 1100 nanometers.

22. A solar module having an upper surface and a lower surface, the module comprising:

a photovoltaic cell having a front side and a back side, the photovoltaic cell configured for converting light into electricity;

a back side encapsulant disposed adjacent the back side of the cell, the back side encapsulant being optically opaque;

a front side encapsulant disposed adjacent the front side of the cell, the front side encapsulant being optically transparent; and

a back sheet defining the lower surface of the solar module.

23. The solar module of claim 22 wherein the back side encapsulant has a heat transfer coefficient greater than the front side encapsulant and wherein the back side encapsulant is thermally conductive.

24. The solar module of claim 22 wherein the back sheet is metallic.

25. The solar module of claim 22 further comprising a coating disposed adjacent the upper surface of the module, the coating having relatively high emissivity in wavelengths above about 1100 nanometers and relatively low emissivity in wavelengths below about 1100 nanometers.

26. The solar module of claim 22 wherein the coating comprises layers.

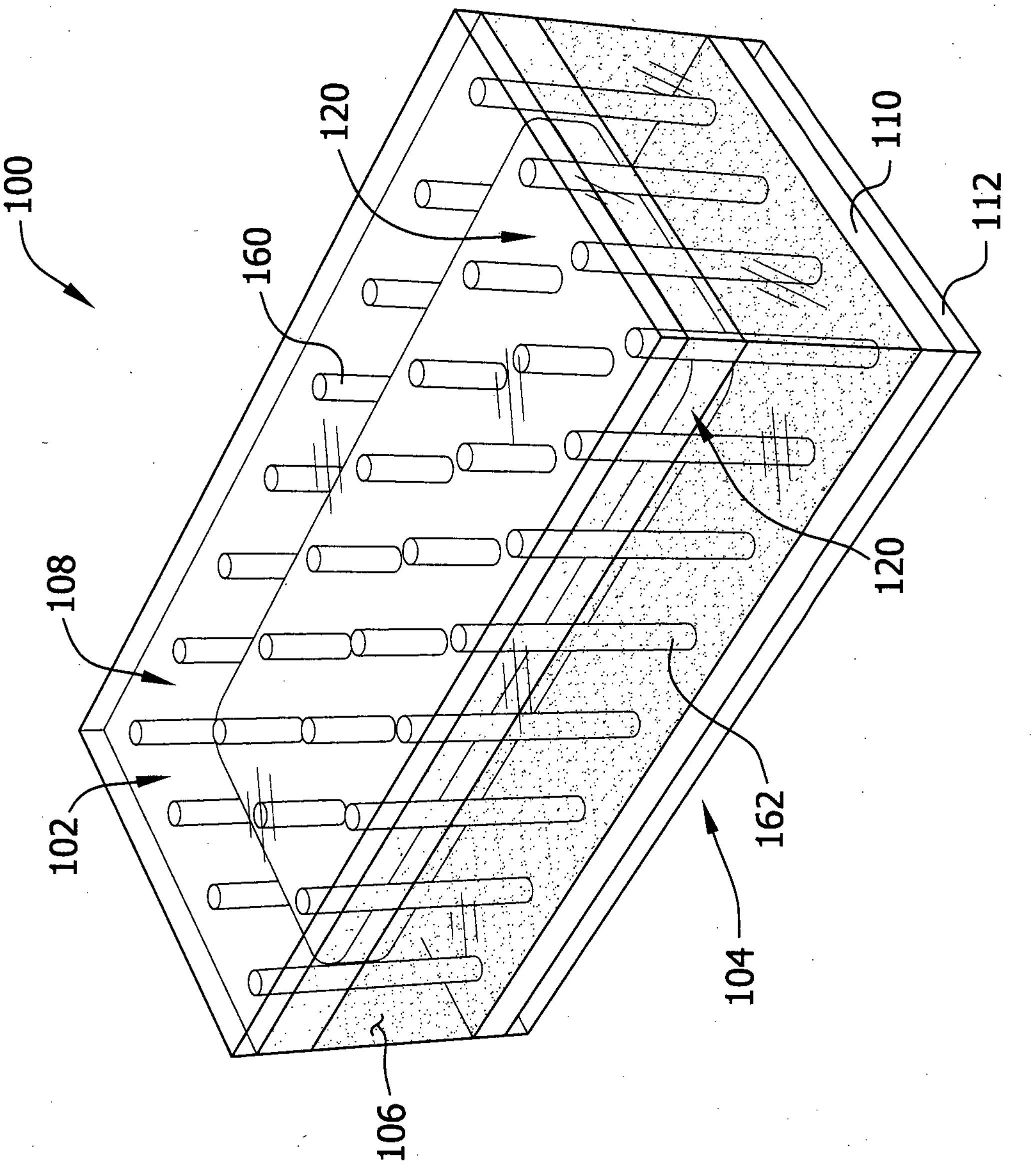

FIG. 1

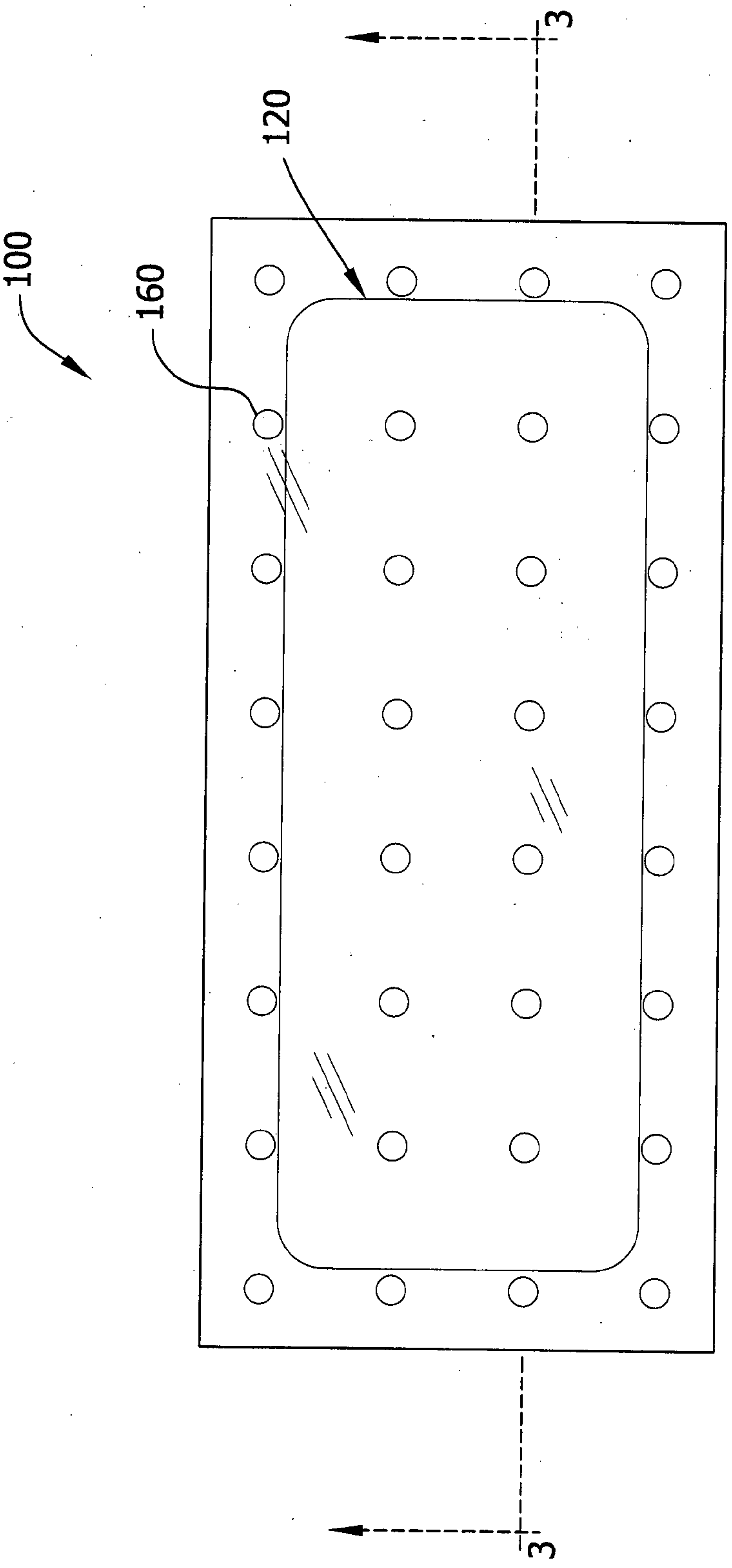

FIG. 2

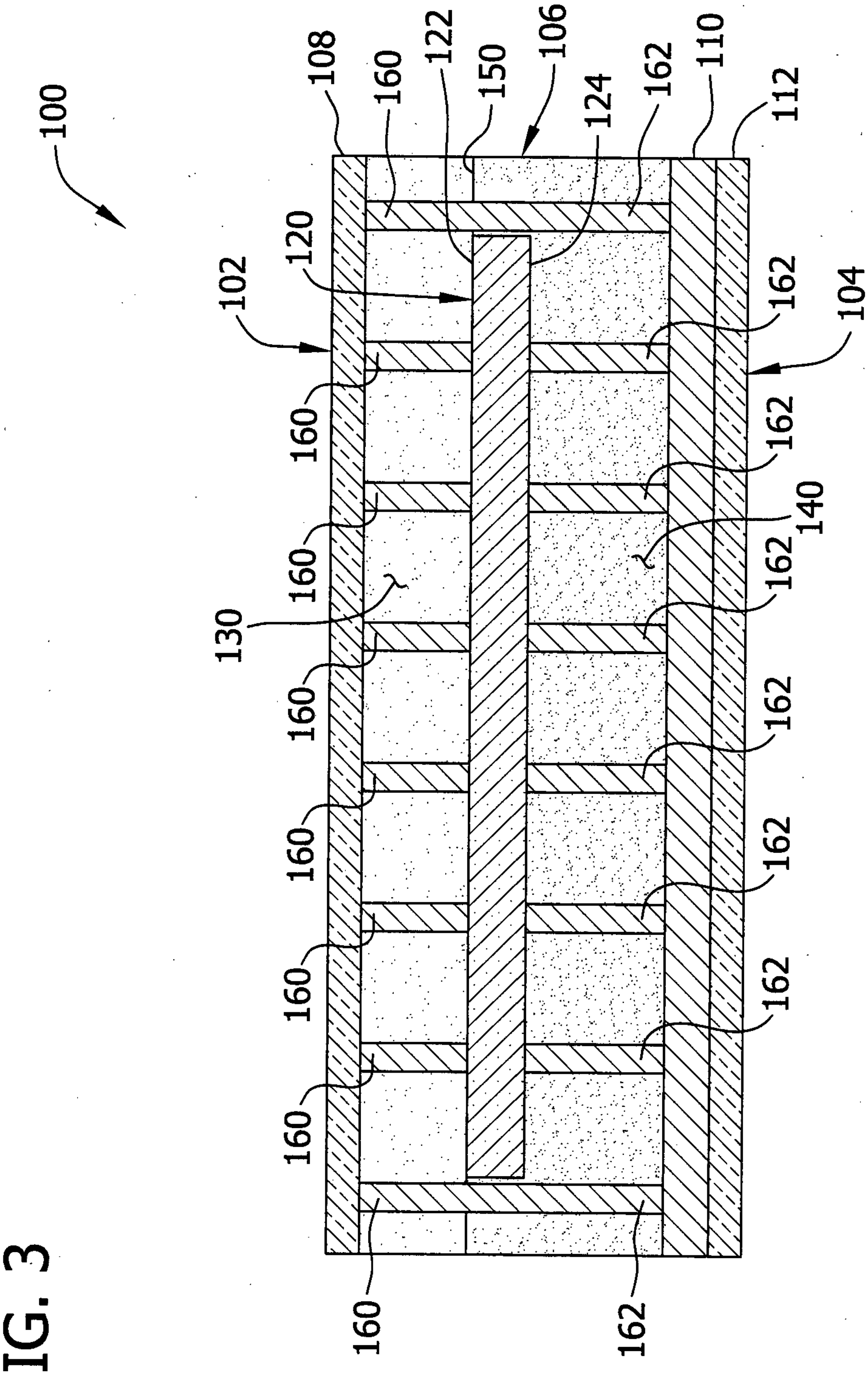
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FIG. 3

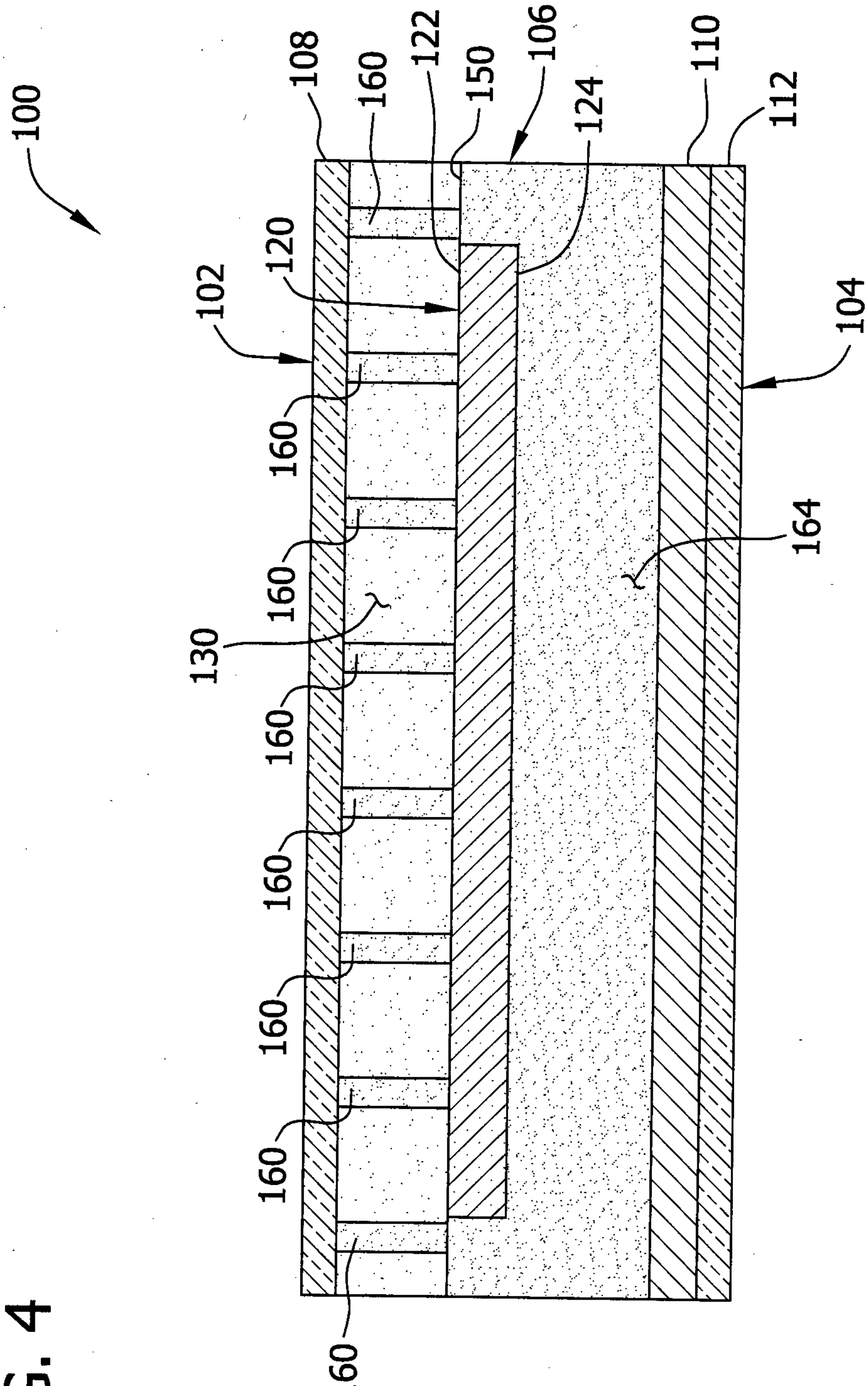
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FIG. 4