(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
**24 October 2019 (24.10.2019)**

WIPO | PCT

(10) **International Publication Number**
**WO 2019/201415 A1**

(51) **International Patent Classification:**
*H01L 31/048* (2014.01) *H01L 31/054* (2014.01)

(21) **International Application Number:**
PCT/EP2018/059636

(22) **International Filing Date:**
16 April 2018 (16.04.2018)

(25) **Filing Language:** English

(26) **Publication Language:** English

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

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

**Published:**
— *with international search report (Art. 21(3))*

(54) **Title:** PHOTOVOLTAIC MODULES AND METHODS OF MANUFACTURE THEREOF

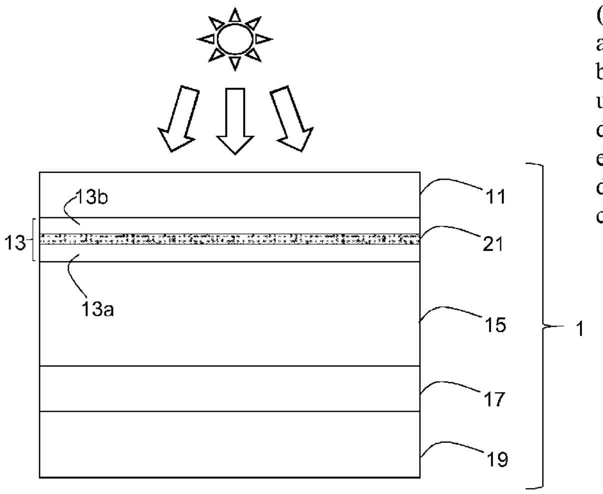


Figure 1

(57) **Abstract:** Photovoltaic module (1) comprising: - a front sheet (11) arranged on a light incident side of said photovoltaic module (1); - a back sheet (19) arranged on an opposite side of said photovoltaic module (1) to said front sheet (11); - a photovoltaic conversion device (15) disposed between said front sheet (11) and said back sheet (19); - a front encapsulation layer (13) disposed between said photovoltaic conversion device (15) and said front sheet (11); characterized in that said front encapsulation layer (13) comprises a fibre mesh (21) embedded therein.

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Description

# PHOTOVOLTAIC MODULES AND METHODS OF MANUFACTURE THEREOF

## Technical Field

[0001] The present invention relates to the technical field of photovoltaic devices. More particularly, it relates to photovoltaic devices comprising a fibre mesh, as well as to methods of manufacture thereof.

## State of the art

[0002] The natural colour of photovoltaic (PV) devices, also referred to as solar cells or solar panels, tends to be near black, often with a purple or indigo tint, with a clearly-defined pattern of the individual cells being visible. When such PV devices are mounted on buildings they can be unsightly, and it is often unacceptable to use them directly as building cladding for this reason.

[0003] In order to overcome this problem, coloured PV devices have been proposed, which enable their integration into the structure of a building, notably as exterior cladding.

[0004] Document US 9,281,186 discloses a film placed on the front sheet of the PV device to modify the appearance of the module. However, this film requires a specific profile which requires alignment with the geometry of the individual PV cells making up the module, and relies on a complex design involving facets in the front sheet and embedded elements in the inactive part of the module.

[0005] US 2014/326292 discloses a PV device comprising a graphic film placed inside the module. This film is printed with a colour or texture, and requires a selective reflector layer to limit the impact of the film on the efficiency of the module.

[0006] US 9,276,141 and US 8,513,517 disclose decorative film overlays placed on or within a PV module.

[0007] However, all of these prior art solutions are either complex, or require extra continuous layers to be applied to modules. Essentially, for each additional layer added to a module, the risk of delamination of the module increases since there are more interfaces between layers which can separate. Furthermore, special manufacturing techniques or equipment may be required.

[0008] The aim of the present invention is thus to at least partially overcome the above-mentioned drawbacks of the prior art.

## Disclosure of the invention

[0009] More specifically, the invention relates to a photovoltaic module comprising:

[0010] - a front sheet arranged on a light incident side of said photovoltaic module, made of e.g. glass, transparent ceramic, polymer or other suitable transparent material;

[0011] - a back sheet arranged on an opposite side of said photovoltaic module to the front sheet, the back sheet being made of e.g. glass, metal, polymer, ceramic or other material;

[0012] - a photovoltaic conversion device disposed between said front sheet and said back sheet, the PV conversion device being of any convenient type;

[0013] - a front encapsulation layer disposed between said photovoltaic conversion device and said front sheet, this layer comprising a thermoplastic or cross-linkable polymer such as EVA, polyolefin or similar. A back encapsulant between the PV conversion device and the back sheet can also be provided, if required.

[0014] According to the invention, said front encapsulation layer comprises a fibre mesh embedded therein, at any desired distance between the adjacent layers.

[0015] By providing a fibre mesh as mentioned above, the visual appearance of the module can be made suitable for integration in buildings, and so on, without requiring special manufacturing processes or expensive layers, in a manner which is compatible with conventional processing techniques, particularly lamination.

[0016] Advantageously, said fibre mesh comprises individual fibres with a diameter between 10 μm and 1 mm, said individual fibres being arranged in a regular or irregular pattern, and being woven or unwoven. The fibre mesh may for instance have a density of between 5 g/m2 and 250 g/m2, preferably between 10 g/m2 and 150 g/m2.

[0017] These ranges provide a good visual effect and do not typically cause a significant reduction in the external quantum efficiency or the current produced by the underlying photovoltaic device, notably in the case in which the mesh is made of glass fibre or other colourless fibres.

[0018] Advantageously, the fibre mesh may comprise a colour, image or pattern printed thereupon. Alternatively, the fibre mesh itself may create a visible pattern or texture. This enables further modification of the visual appearance of the PV module. Furthermore, at least a portion of said front encapsulation layer is situated between said fibre mesh and said photovoltaic conversion device and can be coloured. This provides a good background colour for an image or other printing provided on the mesh, further improving the appearance of the module.

[0019] Advantageously, the module can further comprise an internal front sheet situated adjacent to said front encapsulation layer, and an internal front encapsulation layer situated between said internal front sheet and said photovoltaic conversion device. Such a construction can be easily fabricated by applying the front sheet and front encapsulant to a pre-existing, pre-fabricated PV device, and thereby provide the advantages of the invention to pre-existing, commercially-available PV modules.

[0020] The invention also relates to a method of manufacturing a photovoltaic module comprising the steps of:

[0021] - providing a lamination device such as a vacuum bag or other lamination device;

[0022] - disposing in the lamination device a layer stack comprising:

[0023] - a front sheet intended to be arranged on a light incident side of said photovoltaic module, the front sheet being made of e.g. glass, transparent ceramic, polymer, or other suitable transparent material;

[0024] - a back sheet intended to be arranged on an opposite side of said photovoltaic module to the front sheet, the back sheet being made of e.g. glass, metal, polymer, ceramic or other material;

[0025] - a photovoltaic conversion device of any convenient type disposed between said front sheet and said back sheet;

[0026] - at least one front encapsulation layer disposed between said photovoltaic conversion device and said front sheet. A back encapsulant between the PV conversion device and the back sheet can also be provided, if required;

[0027] - a fibre mesh immediately adjacent to said at least one front encapsulation layer; if two or more layers of front encapsulant are provided, the mesh may be situated between them;

[0028] - applying heat and pressure to said layer stack so as to assemble it into said photovoltaic module by means of fusing and/or cross-linking the encapsulant layer(s).

[0029] The layer stack can be assembled with either the front sheet or back sheet downwards.

[0030] As a result, the front encapsulant layer will fuse and flow into the mesh, resulting in a PV device incorporating a fibre mesh in its front encapsulant. This renders the visual appearance of the module suitable for integration in buildings and so on, without requiring special manufacturing processes or expensive layers since it uses conventional lamination techniques.

[0031] In another variant, the invention relates to a method of manufacturing a photovoltaic module comprising the steps of:

[0032] - providing a lamination device as described above;

[0033] - disposing in said lamination device a layer stack comprising:

[0034] - a prefabricated photovoltaic module of any convenient type;

[0035] - at least one front encapsulation layer disposed on a light incident side of said prefabricated photovoltaic module, i.e. on the side thereof intended to be illuminated when in use;

[0036] - a fibre mesh immediately adjacent to said at least one front encapsulation layer; and

[0037] - front sheet arranged on a light incident side of said at least one front encapsulation layer. A back encapsulant between the PV conversion device and the back sheet can also be provided, if required;

[0038] - applying heat and pressure to said layer stack so as to assemble it into said photovoltaic module.

[0039] The layer stack can be assembled with either the front sheet or prefabricated PV device downwards.

[0040] As a result, the advantageous mesh-containing front encapsulant of the invention can be retrofitted to a pre-existing commercial PV module, thereby providing it with the advantages mentioned above.

[0041] Advantageously, the fibre mesh can be disposed between two layers of front encapsulation material, such that the mesh ends up part way through the thickness of the front encapsulant, which flows into it from each side. The possibility of dry spots of mesh which have not been wetted by fused encapsulant material is hence reduced, which maximises the strength of the arrangement.

[0042] Alternatively, the fibre mesh can be disposed adjacent to a single layer of front encapsulation material, either said fibre mesh or said layer of front encapsulation material being directly or indirectly in contact with said front sheet.

[0043] Advantageously, said fibre mesh may comprise individual fibres with a diameter between 10 µm and 1 mm, said individual fibres being arranged in a regular or irregular pattern, and being woven or unwoven. The fibre mesh may also have a density of between 5 g/m2 and 250 g/m2, preferably between 10 g/m2 and 150 g/m2.

[0044] These ranges provide a good visual effect, and do not typically cause a significant reduction in the external quantum efficiency or the current produced by the underlying photovoltaic device, notably in the case in which the mesh is made of glass fibre or other colourless fibres.

[0045] Advantageously, said fibre mesh comprises a colour, image or pattern printed thereupon. Alternatively, the mesh itself may create patterns or textures. This enables further modification of the visual appearance of the PV module. Furthermore, at least a portion of said front encapsulation layer is situated between said fibre mesh and said photovoltaic conversion device and can be coloured, for instance white. This provides a good background colour for an image or other printing provided on the mesh, further improving the appearance of the module.

## Brief description of the drawings

[0046] Further details of the invention will appear more clearly upon reading the description below, in connection with the following figures which illustrate:

- Figure 1: a schematic cross-sectional view of a photovoltaic module according to the invention;
- Figures 2a and 2b: schematic representations of various meshes which can be used with the PV module according to the invention;
- Figures 3a and 3b: schematic cross-sectional views of variations on the photovoltaic module of figure 1;
- Figure 4: a schematic cross-sectional view of a further photovoltaic module according to the invention;
- Figures 5 and 6: charts of experimental results obtained with PV modules according to the invention;
- Figure 7: a schematic view of light scattering in a photovoltaic module according to figure 1;
- Figure 8: a further chart of experimental results obtained with various PV modules according to the invention;
- Figure 9: schematic representation of the manufacture of a photovoltaic module according to the invention by means of a lamination device; and
- Figure 10: a schematic representation of a building structure provided with a photovoltaic module according to the invention.

## Embodiments of the invention

[0047] It should be noted in the following that, unless explicitly stated that a particular layer is disposed directly on the adjacent layer, it is possible that one or more intermediate layers can also be present between the layers mentioned. As a result, “on” should be construed by default as meaning “directly or indirectly on”. Furthermore, patterning of certain layers, connectors and so on are not represented since they are well-known to the skilled person.

[0048] Figure 1 illustrates a first embodiment of a photovoltaic (PV) module 1 according to the invention.

[0049] This module 1 comprises a front sheet 11, on the light incident side of the module 1, intended to be illuminated in use (as indicated in the figures by means of a sun symbol), and a back sheet 19, on the opposite side of the module 1 to the front sheet 11. The front sheet may be glass, transparent ceramic, polymer or any other convenient substantially transparent material, and the back sheet may be metal, glass, ceramic, polymer or any other convenient material. The front sheet 11 may be structured, and may be provided with coatings.

[0050] Situated between the front and back sheets is a photovoltaic conversion device 15 comprising one or more PV cells comprising NIP, PIN, NP or PN semiconductor junctions, patterned and interconnected as is generally known. The PV cells may be based on thin-film silicon, crystalline silicon, germanium, perovskite, dye-sensitised cells, or any other type of PV technology adapted to generate electrical power from light impinging on the light-incident side of the PV module 1.

[0051] The PV conversion device 15 is encapsulated on its front side by a front encapsulant 13, which seals it to the front sheet 11, and on its back side by a rear encapsulant 17. This latter seals the PV conversion device 15 to the back sheet 19, although it may indeed itself form the rear sheet. The encapsulants can be standard substances such as polyolefin, EVA (ethylene-vinyl acetate), polyvinyl butyral, thermoplastic polyurethane elastomer, ionomer, silicone or similar.

[0052] It should be noted that other intermediate layers may be provided between the illustrated layers, and that the layers do not have to be flat and can describe curves or more complex surfaces.

[0053] According to the invention, a fibre mesh 21 is incorporated into the front encapsulant 13. This mesh 21 is typically provided as a mat of fibres aligned in different directions, interweaved or simply laid upon each other, in a regular or irregular pattern. Figure 2a illustrates in schematic plan view variations of regular fibre meshes 21 at varying densities, and figure 2b illustrates quasi-random fibre meshes in which the angles and positions of the individual fibres are irregular.

[0054] The fibres can be made of metal, polymer, glass or similar, and can have diameters from 10μm to 1mm. Fibres from about 10μm to 100μm are typically invisible to the naked eye, whereas those from about 100μm to 1mm are visible, and give the PV device 1 a visible texture or pattern. The fibres may be continuous lengths from one side of the module 1 to the other, or may be shorter, particularly in the case of an irregular arrangement of fibres, and the thickness of the fibre mat may vary from twice the fibre diameter to 3mm.

[0055] The fibres can also be dyed or be printed upon, for instance by inkjet printing, sublimation, lithography or similar to create patterns or to provide images thereupon that will be visible. This printing can be carried out before placing the mesh 21 in a lamination device, or can even be carried out in-situ, when the mesh has been positioned in a lamination device but before lamination has been carried out.

[0056] In the case of printed fibres, the portion 13a of the front encapsulant 13 below the mesh 21, i.e. on the side facing away from the light-incident side of the PV device 1, can be white or coloured so as to provide a good background for visibility of the printing provided on the fibres.

[0057] Typically, the front encapsulant 13 has a thickness of between 100 μm and 3mm or more, typically between 100 μm and 2000 μm. In the embodiment of figure 1, the PV module 1 is produced in the conventional manner, by stacking the various layers in a lamination device in the correct order, and subsequently applying heat and pressure so as to fuse and/or cross-link the encapsulant and bind the various layers together.

[0058] In order to integrate the fibre mesh 21 into the front encapsulant, several variations are possible.

[0059] In the embodiment of figure 1, the fibre mesh 21 is laid into the layer stack between two sheets of encapsulant material 13a, 13b, with the layer stack oriented either with the front sheet 11 or the back sheet 19 down in a lamination device (not illustrated in figure 1). Heat and pressure sufficient to cause the encapsulant to soften and flow are then applied as normal, and the two sheets of encapsulant material 13a, 13b fuse together and flow around the fibres of the fibre mesh 21, thereby integrating the mesh 21 with the resulting front encapsulant layer 13. As normal, this process causes the front and rear encapsulants 13, 17 to adhere to their respective adjacent layers, as normal. This process is compatible with all types of lamination, including hot-press and vacuum lamination, as well as roll-to-roll processes for flexible photovoltaic devices.

[0060] In figure 1, the two sheets of encapsulant material 13a, 13b are of the same thickness, however they can have different thicknesses so as to position the mesh 21 at any location desired in the thickness of the front encapsulant 13. The lower sheet 13a may optionally be white or coloured in order to provide an appropriate background colour to the fibres and to any printing thereupon.

[0061] Figure 3a illustrates another embodiment in which the fibre mesh 21 is disposed immediately adjacent to the PV device. To manufacture this arrangement, it is possible to use a single layer of front encapsulant 13, however better adhesion to the PV conversion device 15 is achieved by using a very thin film of encapsulant (e.g. with a thickness up to half the thickness of the fibre mesh 21) which almost entirely flows into the fibre mesh 21 to ensure that there are no points of contact between mesh 21 and PV conversion device 15 which are not covered by encapsulant material.

[0062] Figure 3b illustrates a yet further embodiment in which the fibre mesh 21 is disposed immediately adjacent to the front sheet 11. The same comments as in respect of figure 3a apply equally here, mutatis mutandis, regarding use of a single layer of encapsulant or one thick and one thin layer thereof.

[0063] Figure 4 illustrates a yet further construction of a PV module 1 according to the invention. In this construction, the front encapsulant layer 13 and the front sheet 11 are laminated in a lamination device under conditions of heat and pressure onto a pre-existing prefabricated PV module 27, which hence already comprises its own front sheet which becomes inner front sheet 25 and its own front encapsulation which becomes internal front encapsulation 23. The remaining layers 15, 17 and 19 are as before and need not be described again. The variations to front encapsulant layer 13 as described in relation to figures 3a and 3b are equally applicable in this embodiment.

[0064] This arrangement allows the visual advantages of the invention to be applied to any commercially-available PV module 27, by laminating the front encapsulant 13 and front sheet 11 layers onto the existing module 27.

[0065] In order to assess whether the presence of the fibre mesh 21 negatively influences the structural integrity of the module 1, a conventional 90° peeling test was carried out using random glass fibre as mesh 21 and EVA as encapsulant, so as to measure the adhesion between the mesh and the encapsulant. As a reference, the same peeling test was carried out between the same encapsulant material and a glass plate. The results obtained are as follows:

| | Ref | 10 g/m$^2$ mesh | 21 g/m$^2$ mesh | 50 g/m$^2$ mesh | 72 g/m$^2$ mesh | PET film |
|---|---|---|---|---|---|---|
| Adhesion (N/cm) | >200 | >200 | >200 | >200 | 145 | <15 |

(Table 1)

[0066] As can clearly be seen, for a mesh density of 50 g/m$^2$ or less, the adhesion remains above 200 N/cm, above which the adhesion reduces due to incomplete impregnation of the denser mesh by the encapsulant material at higher mesh densities. However, in any case the adhesion at 72 g/m$^2$ density is still high, and is significantly above that of a continuous PET film construction.

[0067] Next, the performance losses due to the fibre mesh 21 were measured, again using random, uncoloured glass fibre as before for the fibre mesh 21.

[0068] Samples of PV modules according to the invention were fabricated, and the external quantum efficiency (EQE) of the resulting PV module was measured. The results are reproduced in figure 5, for mesh densities of 20 $g/m^2$, 50 $g/m^2$, 72 $g/m^2$ and 91 $g/m^2$. As can clearly be seen, the effect of the presence of the mesh is rather minimal, with losses of no more than 1% compared to a reference with the same thickness of front encapsulant but with no fibre content.

[0069] Figure 6 illustrates a graph of the current loss for the same series of tests. The loss in all of the tests is limited to 1% at most, and it is noted that the apparent gain of current for 20 $g/m^2$ and 50 $g/m^2$ is within the measurement error, but could indeed represent a genuine – albeit trivial - gain due to improved scattering of light due to the fibre mesh.

[0070] Indeed, the relatively trivial reduction of EQE and current due to the presence of the fibre mesh is an unexpected and surprising effect. At the fibre densities tested, only a relatively very small amount of light impinging on the fibres is reflected or scattered back towards the light-source side. The majority of the incident light either passes between the fibres, or is refracted, reflected or scattered therefrom at an angle that nevertheless causes it to pass through the photovoltaically active layers 15, as indicated by figure 7. Furthermore, since the fibres in this example are colourless, a certain amount of light will pass straight through them. In this figure, the fibre mesh 21 has been represented schematically by a number of circles representing the cross-section of a number of fibres, and certain light pathways have been illustrated to indicate various ways in which light can either be reflected from, or can enter the PV module 1.

[0071] It appears from the results that, at least up to around 50$g/m^2$ fibre density for the colourless glass fibres tested, that the scattering of a certain amount of light, which leads to longer light pathways through the photovoltaically-active layers of the PV device 15, compensates at least partially for the losses associated with scattering and reflection of light back towards the light-incident side of the module 1.

[0072] Figure 8 illustrates the results of a spectral analysis of two different PV modules 1 according to the invention, in which the fibre mesh 21 is made of polymer fibres of the same diameter and density, but coated with different coatings. Coating 1 is substantially of aluminium colour (grey, white), and coating 2 is brown, reflecting light in the 400-600nm wavelength range which hence does not enter into the photovoltaically-active layers of the PV device 15 contained within the PV module 1.

[0073] It should be noted, however, that the coloured coating 2 does not affect the EQE in the infrared range, since it is substantially transparent to these wavelengths. As a result, the efficiency of PV devices sensitive to infrared wavelengths is unaffected by this coating.

[0074] Finally, figure 9 illustrates generically and schematically a method of manufacture of a PV module 1 according to the invention. A lamination device 29 is provided, in which is placed a layer stack 31 comprising the various layers as discussed above, disposed in the desired order. The layer stack may, depending on the embodiment as discussed above, comprise individual layers, or may comprise a pre-fabricated PV module to which the front encapsulant, mesh and front sheet will be applied to convert it into a PV module 1 according to the invention. The lamination device applies heat and pressure to the layer stack 31 sufficient to fuse the various encapsulant layers and thereby to assemble the layer stack 31 into the PV device 1 of the invention.

[0075] Finally, figure 10 illustrates a photovoltaic module 1 according to the invention mounted on the roof of a building 35. Alternatively, the PV module 1 can be mounted to an exterior wall, or integrated into the structure of the wall and/or roof, e.g. as cladding. In general terms, the PV module 1 can be mounted on or in the structure of the building 35.

[0076] Although the invention has been described in terms of specific embodiments, variations thereto are possible without departing from the scope of the invention as defined in the appended claims.

## Claims

1. Photovoltaic module (1) comprising:
   - a front sheet (11) arranged on a light incident side of said photovoltaic module (1);
   - a back sheet (19) arranged on an opposite side of said photovoltaic module (1) to said front sheet (11);
   - a photovoltaic conversion device (15) disposed between said front sheet (11) and said back sheet (19);
   - a front encapsulation layer (13) disposed between said photovoltaic conversion device (15) and said front sheet (11);

   characterized in that said front encapsulation layer (13) comprises a fibre mesh (21) embedded therein.

2. Photovoltaic module (1) according to claim 1, wherein said fibre mesh (21) comprises individual fibres with a diameter between 10 µm and 1 mm, said individual fibres being arranged in a regular or irregular pattern, and being woven or unwoven.

3. Photovoltaic module (1) according to any preceding claim, wherein said fibre mesh (21) has a density of between 5 $g/m^2$ and 100 $g/m^2$, preferably between 10 $g/m^2$ and 75 $g/m^2$.

4. Photovoltaic module (1) according to any preceding claim, wherein said fibre mesh (21) comprises a colour, image or pattern printed thereupon.

5. Photovoltaic module (1) according to any preceding claim, wherein at least a portion (13a) of said front encapsulation layer (13) is situated between said fibre mesh (21) and said photovoltaic conversion device (15) and is coloured.

6. Photovoltaic module (1) according to any preceding claim, further comprising an internal front sheet (25) situated adjacent to said front encapsulation layer (13),

and an internal front encapsulation layer (23) situated between said internal front sheet (25) and said photovoltaic conversion device (15).

7. Method of manufacturing a photovoltaic module (1) comprising the steps of:
- providing a lamination device (29);
- disposing in said lamination device (29) a layer stack (31) comprising:
  - a front sheet (11) intended to be arranged on a light incident side of said photovoltaic module (1);
  - a back sheet (19) intended to be arranged on an opposite side of said photovoltaic module (1) to said front sheet (11);
  - a photovoltaic conversion device (15) disposed between said front sheet (13) and said back sheet (19);
  - at least one front encapsulation layer (13) disposed between said photovoltaic conversion device (15) and said front sheet (11);
  - a fibre mesh (21) immediately adjacent to said at least one front encapsulation layer (11);
- applying heat and pressure to said layer stack (31) so as to assemble it into said photovoltaic module (1).

8. Method of manufacturing a photovoltaic module (1) comprising the steps of:
- providing a lamination device (29);
- disposing in said lamination device (29) a layer stack comprising:
  - a prefabricated photovoltaic module (27);
  - at least one front encapsulation layer (13) disposed on a light incident side of said prefabricated photovoltaic module (27);
  - a fibre mesh (21) immediately adjacent to said at least one front encapsulation layer (13; 13a, 13b); and
  - front sheet (11) arranged on a light incident side of said at least one front encapsulation layer (13; 13b);
- applying heat and pressure to said layer stack (31) so as to assemble it into said photovoltaic module (1).

9. Method according to one of claims 7-8, wherein said fibre mesh (21) is disposed in the lamination device (29) between two layers (13a, 13b) of front encapsulation material.

10. Method according to one of claims 7-8, wherein said fibre mesh (21) is disposed in the lamination device (29) adjacent to a single layer (13) of front encapsulation material, said fibre mesh (21) or said front encapsulation material (13) being in contact with said front sheet (11).

11. Method according to one of claims 7-10, wherein said fibre mesh (21) comprises individual fibres with a diameter between 10 μm and 1 mm, said individual fibres being arranged in a regular or irregular pattern, and being woven or unwoven.

12. Method according to one of claims 7-11, wherein said fibre mesh (21) has a density of between 5 $g/m^2$ and 250 $g/m^2$, preferably between 10 $g/m^2$ and 150 $g/m^2$.

13. Method according to one of claims 7-12, wherein said fibre mesh (21) comprises a colour, image or pattern printed thereupon.

14. Method according to claim 9 or claim 13 as dependent upon claim 9, wherein one of said two layers (13a) of front encapsulation material is situated between said fibre mesh (21) and said photovoltaic conversion device (13), said layer of front encapsulation material (13a) being coloured.

15. Building (35) comprising at least one photovoltaic module (1) according to one of claims 1-6.

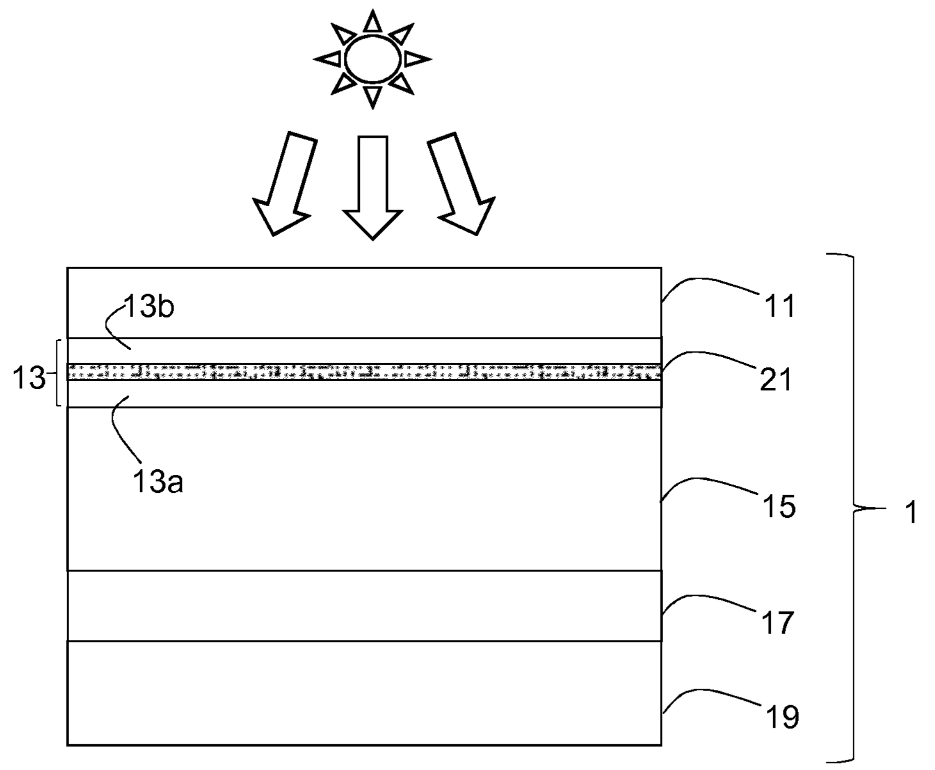


Figure 1

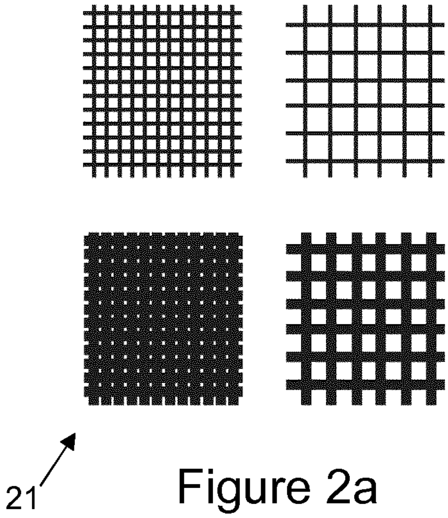


Figure 2a

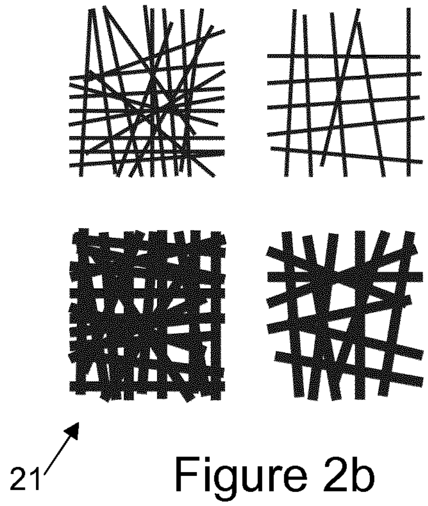


Figure 2b

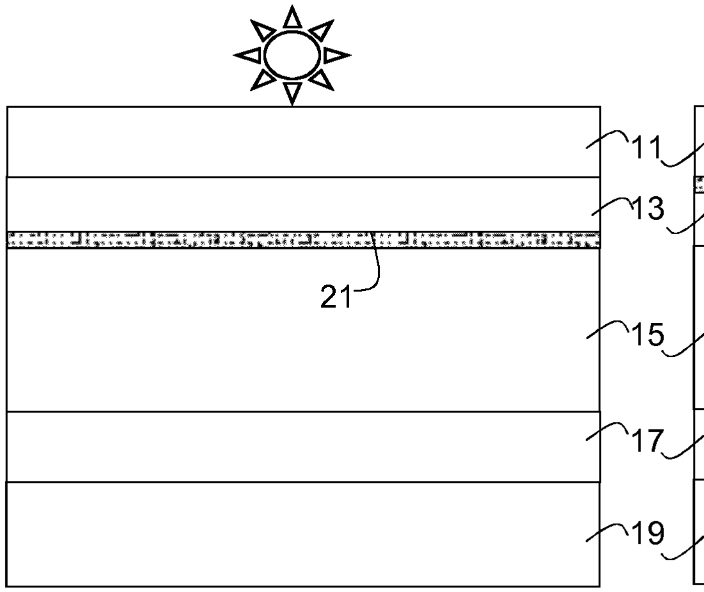


Figure 3a

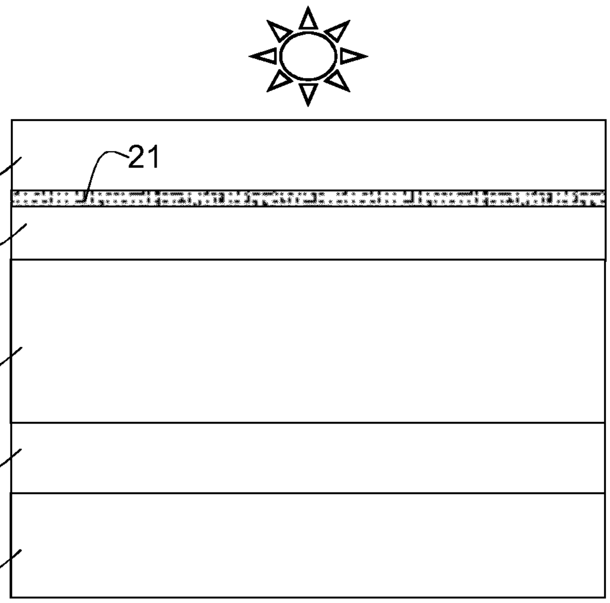


Figure 3b

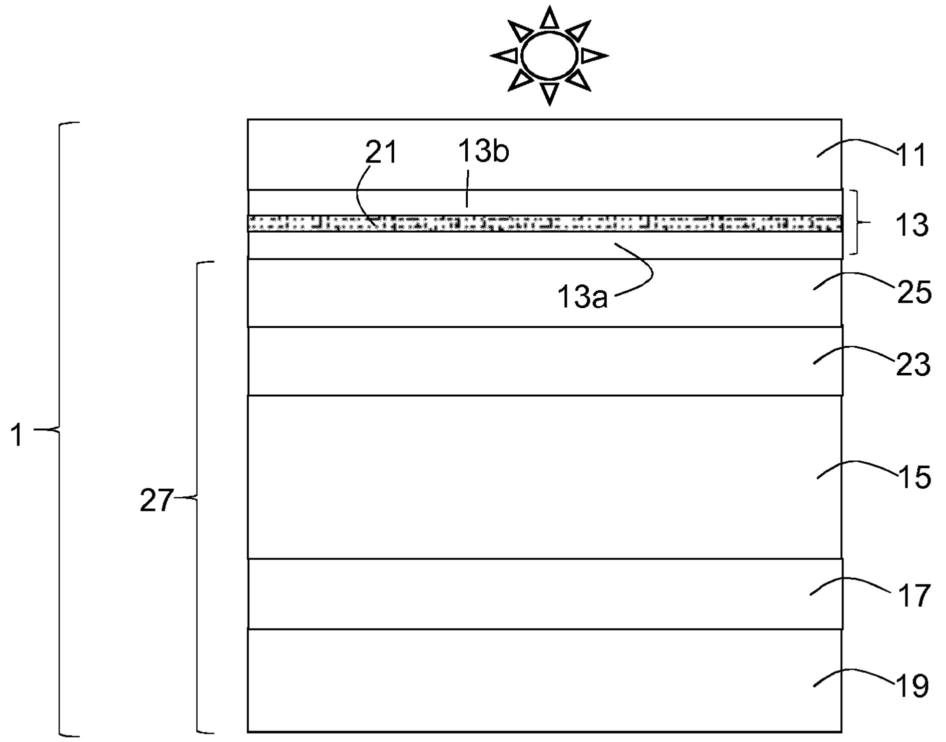


Figure 4

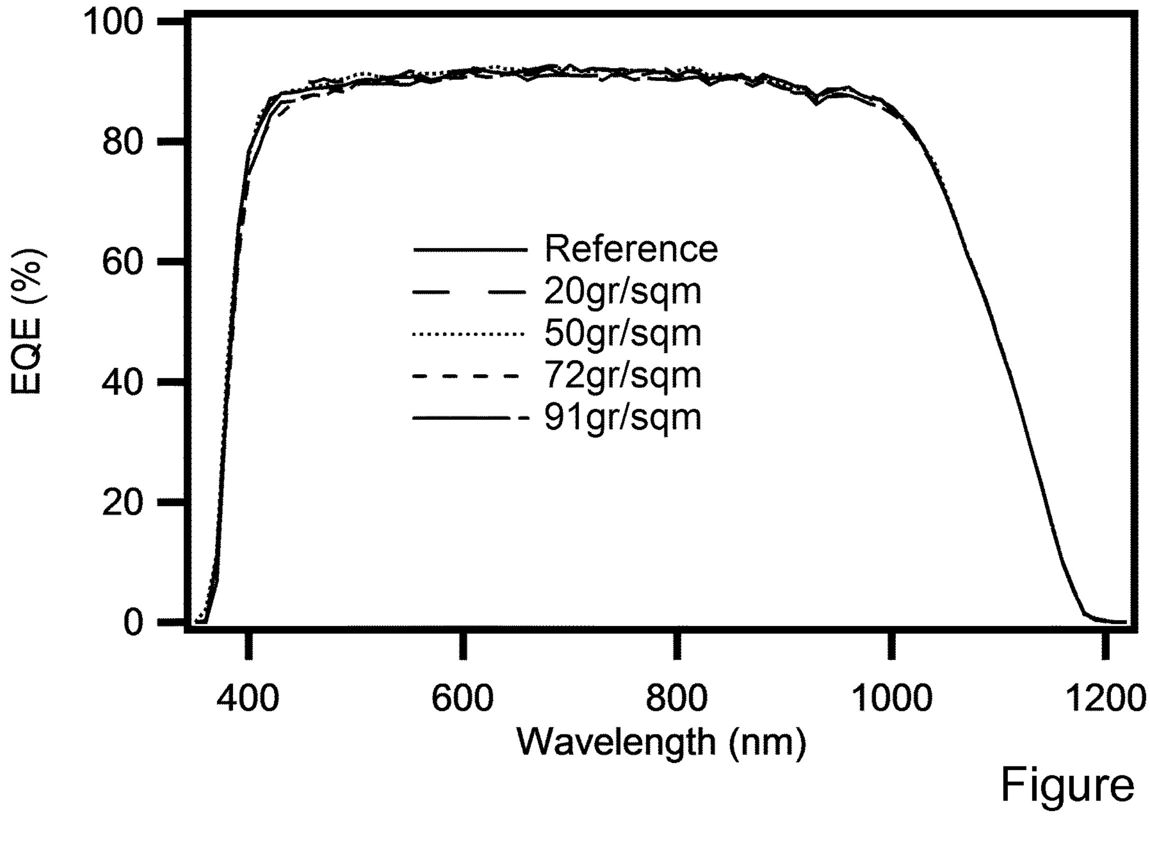


Figure 5

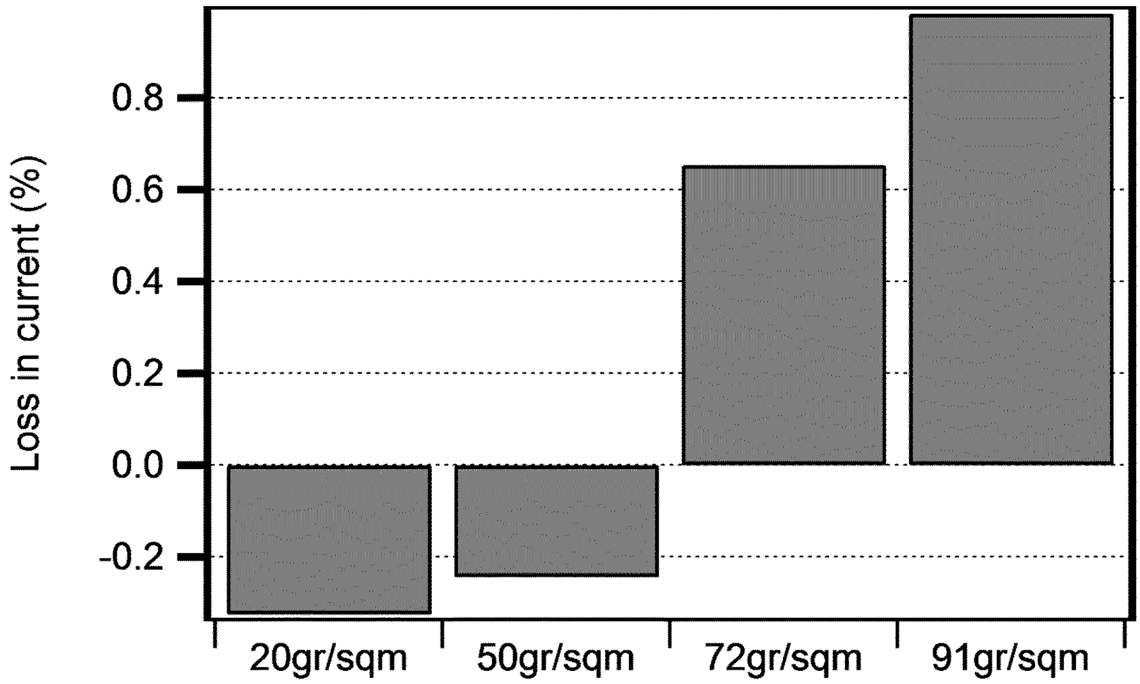


Figure 6

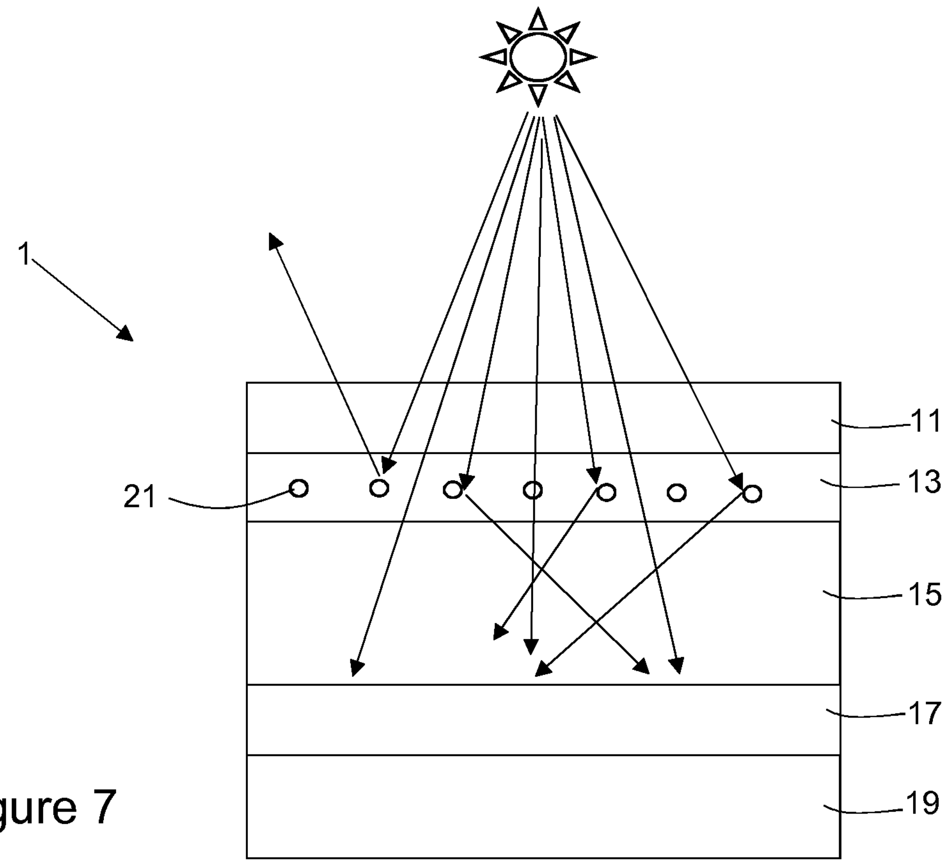


Figure 7

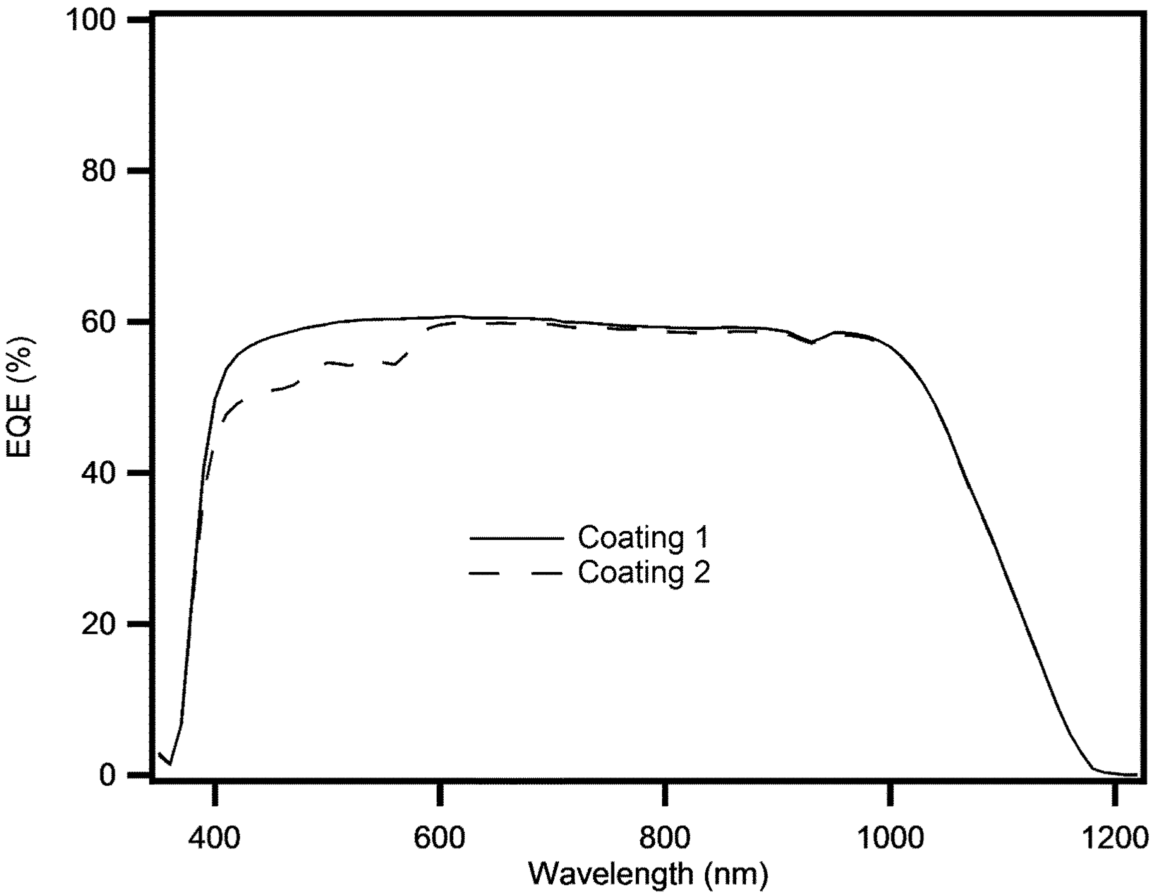
100
80
60
40
20
0
EQE (%)
400
600
800
1000
1200
Wavelength (nm)
Coating 1
Coating 2

Figure 8

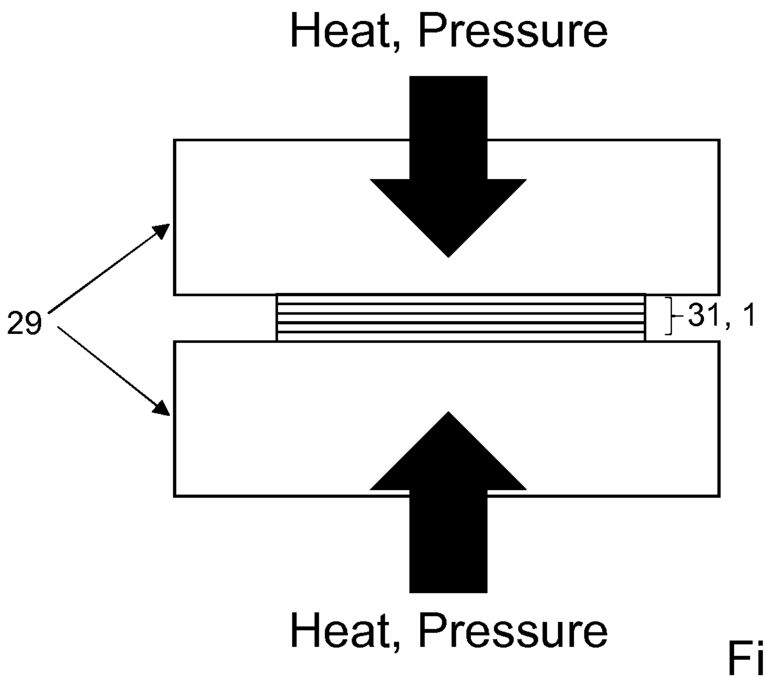


Figure 9

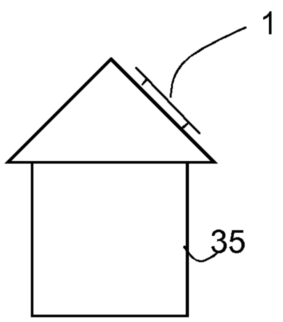


Figure 10

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/059636

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. H01L31/048 H01L31/054
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)
H01L

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, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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"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 |
|---|---|
| 26 June 2018 | 05/07/2018 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Chao, Oscar |

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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| Y | page 10, lines 1-5 | 5,14 |
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**Information on patent family members**

International application No
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| Patent document cited in search report | | Publication date | Patent family member(s) | | | Publication date |
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