Luminescent scattering or reflecting layer for enhanced photovoltaic device performance

Citation for published version (APA):
Debije, M. G., & Dekkers, W. (2012). Luminescent scattering or reflecting layer for enhanced photovoltaic device performance. (Patent No. *WO2012023094A2*).

Document status and date:
Published: 23/02/2012

Please check the document version of this publication:

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Download date: 08. Feb. 2024

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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 February 2012 (23.02.2012)

PCT

(10) International Publication Number
WO 2012/023094 A2

(51) International Patent Classification:
H01L 31/05 (2006.01)

(21) International Application Number:
PCT/IB2011/053595

(22) International Filing Date:
12 August 2011 (12.08.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10172928.3 16 August 2010 (16.08.2010) EP

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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, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, 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, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) Title: LUMINESCENT SCATTERING OR REFLECTING LAYER FOR ENHANCED PHOTOVOLTAIC DEVICE PERFORMANCE

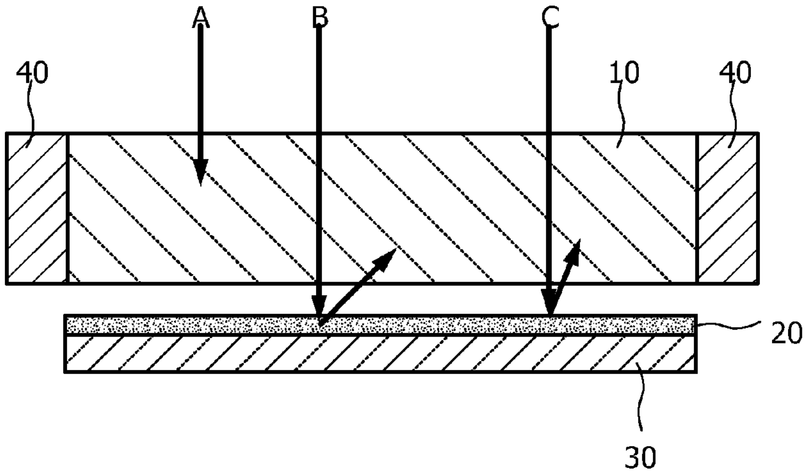

FIG. 1

(57) Abstract: The present invention relates to a photovoltaic device, such as for example a solar concentrator, which uses a scattering or reflecting layer on the rear side of its waveguide. The scattering or reflecting layer also incorporates luminescent or phosphorescent material for absorption and emission. The additional functionality of absorption and emission in the scattering or reflecting layer allows for a more dynamic use of incoming light.

LUMINESCENT SCATTERING OR REFLECTING LAYER FOR ENHANCED PHOTOVOLTAIC DEVICE PERFORMANCE

FIELD OF THE INVENTION

The present invention relates to a photovoltaic device for converting radiation (e.g. solar light) into electricity.

BACKGROUND OF THE INVENTION

Photovoltaics (PVs) enable conversion of solar light into electricity without detrimentally affecting the environment. Unfortunately, solar cells require high-cost semiconductors, which makes them expensive. Concentrator systems help to minimize the coverage needed by the solar cells, but normal concentrators only work for a narrow angular range of incident solar radiation. Moreover, concentrators need tracking devices and are poorly suited to capturing diffuse radiation. Luminescent solar concentrators (LSCs) avoid these disadvantages.

Conventional LSCs consist of a flat plate which acts as a waveguide, which is usually made from plastic, and is either filled with fluorescent dyes, phosphors and/or quantum dots, or coated with luminophores in a thin layer (< 100 microns) on the top or bottom of the waveguide. To one or more edges of the waveguide are attached photovoltaic cells for conversion of the emitted light to electricity. A mirror or white scattering layer is often placed at the bottom face of the waveguide, either attached or separated by an air gap. Further details can be gathered from W. G. Van Sark et al., “Luminescent solar concentrators: a review of recent results”, Opt. Express 16, pp. 21773–21792, 2008.

For situations where maximal light collection from the edge of the LSC is desired, the amount of light absorbed by the dye molecules should be maximized. However, large concentrations of dye material in the waveguide or in a thin layer on top of the clear waveguide are often undesirable due to limited solubility of the dye or, owing to the non-unity quantum yield of the dyes and limited Stokes shifts, the reabsorption of emitted light by subsequent dye molecules, where this reabsorption may result in loss of light as heat or through subsequent emissions being directed outside the waveguiding mode of the waveguide.

To enhance absorption while avoiding high dye concentrations, it has become common to use either a reflecting layer (a mirror) or a scattering layer at the rear of the waveguide. These rear layers may either be directly attached to the waveguide via intermediate layers, or left with an air gap between the rear layer and the waveguide. These layers will intercept incident light that was not absorbed in the first passage through the waveguide, returning it through the thickness of the dye layer, thereby increasing the probability of absorption. For example, by using a perfect rear layer in a system with an initial absorption of 50%, one could expect an increase in the absorption to 75% without having to use additional dye.

The use of the mirror can be problematic as even the best silver mirrors absorb >5% of incoming light, and so scattering layers have been preferred. The scattering layers tend to be based on white paints (mostly containing titanium oxides) so that they scatter back a wide range of wavelengths indiscriminately.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a photovoltaic device with increased absorption rate.

This object is achieved by a photovoltaic device as claimed in claim 1 and by a manufacturing method as claimed in claim 12.

Accordingly, the rear scattering or reflecting layer is enhanced through incorporation of a luminescent or phosphorescent material. This provides the advantage of being able to shift unabsorbed light to a wavelength better used by the main waveguide dye, enhancing absorption, and to assist in the scattering of light outside the absorption band of the dye by converting it to wavelength closer to those best utilized by the photovoltaic cell, all the while maintaining normal scattering function.

According to a first aspect, the scattering or reflecting layer may be adapted to absorb incoming radiation energy at a wavelength shorter than an absorption peak of the waveguide dye and to emit this radiation energy at a wavelength closer to the absorption peak. Thereby, overall absorption of the device can be enhanced.

According to a second aspect which can be combined with the above first aspect, the scattering or reflecting layer may be adapted to absorb radiation energy at a wavelength longer than a dye absorption band of the waveguide and to emit the radiation energy at a wavelength closer to a responsivity band of the at least one photovoltaic cell. Again, overall absorption of the device can be enhanced.

According to a third aspect which can be combined with any one of the above first and second aspects, the scattering or reflecting layer may be employed in a thin film photovoltaic element, so as to shift the absorbed light spectra to wavelengths better absorbed by the photovoltaic element.

According to a fourth aspect which can be combined with any one of the above first and third aspects, the scattering or reflecting layer may be directly attached to the waveguide, attached via intermediate layers, or separated from the waveguide by an air gap. Various options for arranging the scattering or reflecting layer are thus provided.

According to a fifth aspect which can be combined with any one of the above first and fourth aspects, the luminescent or phosphorescent material may comprise inorganic phosphor.

According to a sixth aspect which can be combined with any one of the above first and fifth aspects, the luminescent or phosphorescent material may comprise quantum dots or quantum rods with a capability of scattering unabsorbed light passing through said waveguide.

According to a seventh aspect which can be combined with any one of the above first and sixth aspects, the scattering or reflecting layer may comprise a non-luminescent layer mixed with organic or inorganic luminophores.

According to an eighth aspect which can be combined with any one of the above first and seventh aspects, the scattering or reflecting layer may comprises organic luminophores in a binding agent used to hold scattering particles together. In an exemplary implementation, the organic luminophores in the binding layer may be provided in conjunction with inorganic phosphor.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following drawings:

Fig. 1 shows a schematic cross-sectional layer model of the functionality of a PV device according to an embodiment;

Fig. 2 shows emission spectra obtained by a scattering layer with and without luminescent material at a low plate absorbance; and

Fig. 3 shows emission spectra obtained by a scattering layer with and without luminescent material at a high plate absorbance.

DETAILED DESCRIPTION OF EMBODIMENTS

In the following embodiments, enhancement of a PV device performance by a luminescent scattering layer is described based on a luminescent solar concentrator (LCS) as an exemplary photovoltaic device.

A luminescent scattering layer is provided at the rear side or bottom side of a waveguide so as to receive incident light having passed through the waveguide without being absorbed. The luminescent scattering layer can be obtained by modifying a conventional or standard rear scattering layer (sometimes also called “scatterer”) through incorporation of a luminescent material within the scattering matrix. The scattering layer with the luminescent material can have several functions when arranged in this manner. It can absorb incoming sunlight or other radiation energy at a wavelength shorter than the absorption peak or main absorption band of a waveguide dye included in the waveguide material and emit this radiation energy at a wavelength closer to the absorption peak, thereby enhancing overall absorption of the system. Additionally, the scattering layer can be tuned or adapted to absorb light or other radiation energy at a wavelength outside (longer than) the dye absorption band and emit radiation energy at a wavelength closer to the responsivity band of a silicon cell or photovoltaic cell of the LCS, which may be around 1100 nm, for example.

Used in this way, the material(s) contained in the scattering layer could be, for example, phosphor(s) that have an absorption cross section normally considered too low for proper use in the waveguide, or with quantum efficiencies lower than normally necessary for use in the waveguides, for if the light is not absorbed by the phosphor it still is returned through the waveguide, where it could be absorbed, or it could be scattered by the layer, as normal for the scattering layer, and reach the photovoltaic cell at the waveguide edge in this manner.

Fig. 1 shows a schematic layer model of the LCS with the proposed luminescent scattering functionality according to the embodiment. Three exemplary cases with different wavelengths of incident light are shown in Fig. 1.

In a first case, incident light A at a wavelength around the absorption maximum of the luminophore used in the LSC waveguide 10 is absorbed and re-emitted at a longer wavelength within the waveguide 10. A fraction of the light is trapped by total internal reflection (TIR) within the polymeric plate of the waveguide 10 and directed towards the edges of the waveguide where the light may be collected by a photovoltaic cell 40 attached to both edges of the waveguide 10.

In a second case, incident light C longer than the absorption range of the luminophore passes through the waveguide 10 and is scattered by a scattering layer 20 which forms a backing plate.

In a third case, incident light B shorter in wavelength than around the peak of the luminophore used in the waveguide 10 passes through the waveguide and is absorbed by the scattering layer which emits the light energy at a wavelength that is around the maximal absorption band of the luminophore in the waveguide 10.

As shown in Fig. 1, the luminescent scattering layer 20 may be separated from the waveguide 10 by a lower index material or an air gap. Furthermore, the scattering layer may be arranged on a support substrate 30.

The LCS or other photovoltaic device can thus be manufactured by attaching at least one photovoltaic cell 40 to the edge of a waveguide 10 and placing a scattering or reflecting layer 20 at or near a rear side of the waveguide 10 so as to receive incident radiation having passed through the waveguide 10. Additionally, the luminescent material or a phosphorescent material is incorporated into the scattering layer 20 or a reflection layer for absorption and also emission purposes.

In a specific implementation of the scattering layer 20, a YAG:Ce phosphor may be used in an organic binder to obtain an increase in integrated edge emission of 2-12% for 5x5 cm waveguides, depending on the absorbance of the waveguide 10, with the effects more pronounced with waveguides utilizing less dye.

In the following, results of applying a phosphor scattering layer 20 are explained with reference to Figs. 2 and 3.

Fig. 2 shows emission spectra of a polycarbonate waveguide plate containing Red305 dye of absorbance 0.2 exposed to light from a solar simulator on a white (solid line) and phosphor-containing (dashed line) scattering layer 20. Due to the low absorbance of the waveguide, the enhanced absorbance achieved by the use of the luminescent scattering layer 20 can be seen at the dashed spectrum line.

Fig. 3 shows emission spectra of polycarbonate plate containing Red305 dye of absorbance 1.0 exposed to light from a solar simulator on a white (solid line) and phosphor-containing (dashed line) scattering layer 20. Here, the emission does not change very much, as nearly all incident light is already absorbed in the waveguide.

To enhance performance, the absorption region of the phosphor may be modified. As an alternative or additional option, the rear scattering layer could be employed in thin film photovoltaic elements, in place of the regular rear layer. In this case, the emitted light from the phosphor can be used to shift the absorbed light spectra more to wavelengths better absorbed/utilized by the photovoltaic (silicon) cell (e.g., closer to 1100 nm).

Thus, the conventional passive rear reflecting/scattering layer is suggested to be replaced by a reflecting/scattering layer with luminescent or phosphorescent material that adds the functionality of absorption and emission for more dynamic use of the incoming light, extending the materials usable in the LSC or other photovoltaic device and thereby enhancing the functionality of the device. Several variations or modifications of the embodiment can be implemented. At least one of inorganic phosphors, quantum dots and quantum rods can be used as the luminescent material, each with the capability of also scattering unabsorbed light. An alternative embodiment could be to use a non-luminescent scattering or reflection layer such as titanium, tin, etc. oxides mixed with organic or inorganic luminophores, or to include organic luminophores in the binding agent used to hold the scattering particles together, or to use this organic luminophore in binding agent in conjunction with inorganic phosphors.

Thus, the proposed luminescent scattering or reflection layer can be used in concentrators, photovoltaic cells or other photovoltaic devices. It differs from conventional rear layers in its functionality of absorption and emission along with scattering or reflection. The width of the scattering layer may be in the order of 30-50 micrometers, for example.

In summary, a photovoltaic device, such as for example a solar concentrator, has been described, which uses a scattering layer on the rear side of its waveguide 10. The scattering layer also incorporates luminescent or phosphorescent material for absorption and emission. The additional functionality of absorption and emission in the scattering layer 20 allows for a more dynamic use of incoming light.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor, sensing unit or other unit may fulfil the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

Any reference signs in the claims should not be construed as limiting the scope thereof.

The present invention relates to a photovoltaic device, such as for example a solar concentrator, which uses a scattering or reflecting layer on the rear side of its waveguide. The scattering or reflecting layer also incorporates luminescent or phosphorescent material for absorption and emission. The additional functionality of absorption and emission in the scattering or reflecting layer allows for a more dynamic use of incoming light.

CLAIMS:

1. A photovoltaic device comprising:

- a waveguide (10),

- at least one photovoltaic cell (40) attached to at least one edge of said waveguide and adapted to convert radiation guided in said waveguide to electricity; and

- a scattering or reflecting layer (20) placed at rear side of said waveguide so as to receive incident radiation having passed through said waveguide;

- wherein said scattering or reflecting layer (20) comprises a luminescent or phosphorescent material for absorption and emission.

2. The device according to claim 1, wherein said scattering or reflecting layer (20) is adapted to absorb incoming radiation energy at a wavelength shorter than an absorption peak of said waveguide dye and to emit this radiation energy at a wavelength closer to said absorption peak.

3. The device according to claim 1, said scattering or reflecting layer (20) is adapted to absorb radiation energy at a wavelength longer than a dye absorption band of said waveguide (10) and to emit said radiation energy at a wavelength closer to a responsivity band of at least one photovoltaic cell (40).

4. The device according to claim 1, wherein said scattering or reflecting layer (20) is employed in a thin film photovoltaic element.

5. The device according to claim 1, wherein said scattering or reflecting layer (20) is directly attached to said waveguide (10), attached via intermediate layers, or separated from said waveguide (10) by an air gap.

6. The device according to claim 1, wherein said luminescent or phosphorescent material comprises inorganic phosphor.

7. The device according to claim 1, wherein said luminescent or phosphorescent material comprises quantum dots or quantum rods with a capability of scattering unabsorbed light passing through said waveguide (10).

8. The device according to claim 1, wherein said scattering or reflecting layer (20) comprises a non-luminescent layer mixed with organic or inorganic luminophores.

9. The device according to claim 1, wherein said scattering or reflecting layer (20) comprises organic luminophores in a binding agent used to hold scattering particles together.

10. The device according to claim 9, wherein said organic luminophores in said binding layer are provided in conjunction with inorganic phosphor.

11. The device according to claim 1, wherein the scattering or reflecting layer (20) has a thickness between 1μm and 1000μm, preferably between 10μm and 500μm.

12. A method of manufacturing a photovoltaic device, said method comprising:

- attaching at least one photovoltaic cell (40) to at least one edge of a waveguide (10);
- placing a scattering or reflecting layer (20) at a rear side of said waveguide (10) so as to receive incident radiation having passed through said waveguide; and
- incorporating into said scattering or reflecting layer (20) a luminescent or phosphorescent material for absorption and emission.

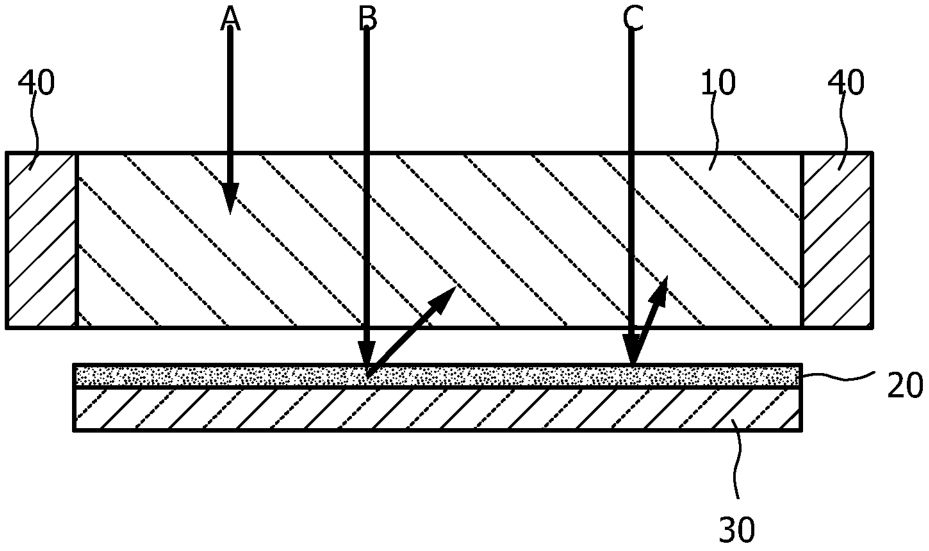

FIG. 1

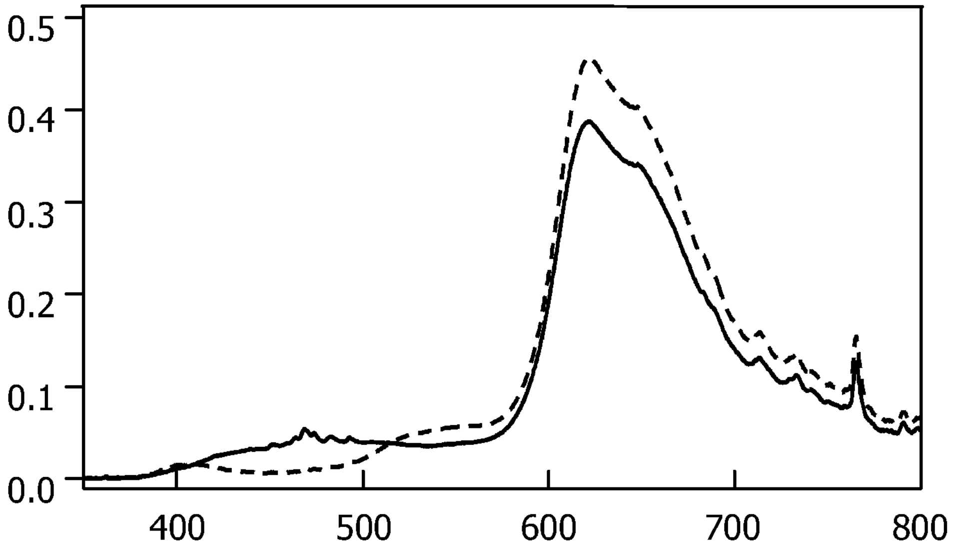

FIG. 2

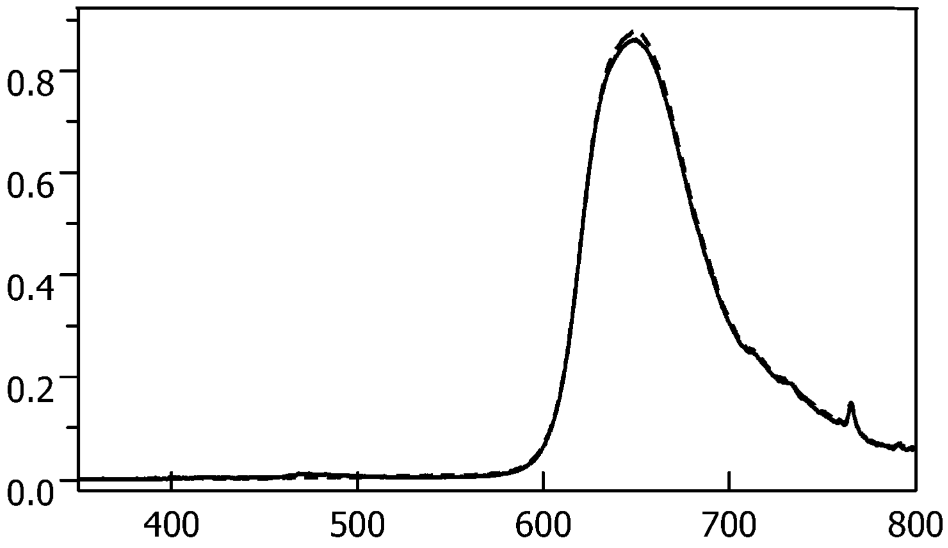

FIG. 3