

A cover member for a photovoltaic device

Technical Field

The present invention relates to an improved cover member for a photovoltaic device.

5 Background

Photovoltaic (PV) devices are generally installed at rooftops but it would be advantageous to use PV devices on outer walls of buildings to maximise the use of solar light.

While having PV devices on outer walls of buildings would be advantageous, this is not
10 commonly being done. One of the reasons for this is because installing traditional PV devices on the outer wall would interfere with the aesthetics of the building. It is therefore required for a PV device to have excellent aesthetic properties which is able to blend in with or enhance the overall look of the building.

Most commonly available coloured PV devices are monochromatic. Introducing colour
15 to the front cover glass of a PV device results in loss in PV efficiency as ink and frit pigments absorb and reflect particular wavelengths to achieve the desired colour.

A standard PV device typically comprises solar cells interconnected in series and/or parallel. When designing a multi-coloured PV device, simply combining different colours would lead to non-uniform light transmittance to the interconnected solar cells.
20 As a result, uneven distribution of solar irradiation would cause: (1) power losses due to current mismatch; and formation of hot-spots during operation of the PV device, which could lead to long-term and non-irreversible destruction to the PV device. Hot-spots are also one of the main reasons to cause fires in PV device systems.

There is therefore a need for a PV device with an improved front cover which may be
25 coloured and yet be suitably, reliably and safely used while minimising loss on the PV device's power efficiency.

Summary of the invention

The present invention seeks to address these problems, and/or to provide an improved cover member for a PV device.

According to a first aspect, the present invention provides a cover member for a photovoltaic (PV) device, the cover member comprising at least two coloured and/or patterned areas, wherein each of the at least two coloured and/or patterned areas provides uniform light transmittance such that in use, each solar cell comprised in the PV device has the same electrical efficiency.

The electrical efficiency may be measured by the short-circuit current.

The light transmittance may be determined by print opacity and ink density of each of the at least two coloured and/or patterned areas.

According to a particular aspect, each of the at least two coloured and/or patterned areas may comprise the same or different colours. In particular, each of the at least two coloured and/or patterned areas may comprise at least two colours. According to another particular aspect, each of the at least two coloured and/or patterned areas may comprise the same or different pattern.

The at least two coloured and/or patterned area may be formed by any suitable method. For example, the at least two coloured and/or patterned area may be formed by, but not limited to: screen printing, digital printing, frit printing, structural colouration such as interference coating, sputter coating, scattering, or a combination thereof.

The cover member may be formed of any suitable material. For example, the cover member may be made of, but not limited to: glass, thermoplastic polymer, poly(methyl methacrylate), polycarbonate, or a combination thereof.

The cover member may be provided on or adjacent a surface of a solar cell comprised in a PV device. The solar cell may be any suitable solar cell. For example, the solar cell may comprise: perovskite solar cell, cadmium telluride (CdTe), copper indium selenide (CIS), copper indium gallium selenide (CIGS) solar cell, copper indium gallium sulphur selenide (CIGSSe) solar cell, silicon solar cell, organic photovoltaics, or a combination thereof.

According to a further aspect, the PV device comprising the cover member according to the first aspect may be comprised in a building-integrated photovoltaic (BIPV) module.

Brief Description of the Drawings

In order that the invention may be fully understood and readily put into practical effect there shall now be described by way of non-limitative example only exemplary embodiments, the description being with reference to the accompanying illustrative drawings. In the drawings:

Figure 1A shows a change in short-circuit current as a function of print opacity at 100% ink density; Figure 1B shows a change in short-circuit current as a function of ink density at 100% print opacity;

Figure 2A, 2B and 2C show cover members according to three separate embodiments; and

Figure 3 shows the I-V curves of various PV devices.

Detailed Description

As explained above, there is a need for an improved photovoltaic (PV) device which may be comprised in building-integrated photovoltaic (BIPV) modules.

In general terms, the invention relates to a cover member for a PV device for use in a BIPV module that may enable the BIPV module to match or enhance the aesthetic of buildings.

According to a first aspect, the present invention provides a cover member for a photovoltaic (PV) device, the cover member comprising at least two coloured and/or patterned areas, wherein each of the at least two coloured and/or patterned areas provides uniform light transmittance such that in use, each solar cell comprised in the PV device has the same electrical efficiency.

When each solar cell comprised in the PV device has the same electrical efficiency, current mismatch losses and hot-spot formation is minimised, thereby improving the overall efficiency, reliability and safety of the PV device. Minimising hot-spot formation also minimises the risk of the PV device catching fire.

According to a particular aspect, the electrical efficiency of each solar cell comprised in the PV device may be measured by the short-circuit current. The short-circuit current (I_{sc}) may be defined as the current through a solar cell when the voltage across the

solar cell is zero (i.e., when the solar cell is short circuited). For example, if there is current mismatch in a PV device, severe power reductions may be experienced if a poor solar cell comprised in the PV device produces less current than the maximum power current of the good solar cells comprised in the PV device. Further, if the combination of solar cells is operated at short circuit or low voltages, the high-power dissipation in the poor solar cells experiencing a lower I_{SC} as compared to the other solar cells within the PV device can cause irreversible damage to the PV device.

For the purposes of the present invention, "uniform light transmittance" may be defined as each pre-determined area having similar or the same light transmittance. For example, the light transmittance may be determined by print parameters such as, but not not limited to, print opacity and ink density of each of the at least two coloured and/or patterned areas, and/or geometrical area of patterns comprised in each of the at least two coloured and/or patterned areas when there is a pattern present.

Print opacity may be defined as the translucency of each of the at least two coloured and/or patterned areas. For example, by adjusting the print opacity, a lighter or darker shade of colour may be obtained.

Ink density may be defined as the amount of ink output per printed dot, ink thickness or ink volume. For example, the higher the ink density, the more intense the colour.

Accordingly, each of the at least two coloured and/or patterned areas may provide uniform light transmittance by selection of suitable combination of print opacity and ink density, such that when the cover member is in use on a PV device, the solar cells comprised in the PV device may generate the same amount of current based on the light absorbed by the solar cell through the cover member.

Each of the at least two coloured and/or patterned areas may comprise at least two colours. The at least two colours may be any suitable colour. For example, the colours may be selected from the Natural Colour System (NCS). In particular, the colours may be at least one of the six primary NCS colours, which are, but not limited to, blue, green, red, white, black and yellow.

According to a particular aspect, each of the at least two coloured and/or patterned areas may comprise the same or different colours. When each of the at least two

coloured and/or patterned areas comprises different colours, the print opacity and the ink density of each colour may be appropriately determined so that each of the at least two coloured and/or patterned areas has the same amount of light transmittance. In particular, the print opacity and the ink density of each colour may be appropriately
5 determined so that each of the at least two coloured and/or patterned areas has the same shading, thereby resulting in each of the solar cells comprised in the PV device onto which the cover member is used to have the same short-circuit current.

According to a particular aspect, each of the at least two coloured and/or patterned areas may comprise the same or different pattern. When each of the at least two
10 coloured and/or patterned areas comprises the same pattern, the cover member may comprise repeated patterns. When each of the at least two coloured and/or patterned areas comprises different patterns, the cover member may comprise a non-repeated pattern. The advantage of the cover member having repeated patterns may be that there will be homogeneous light transmittance across the cover member, thereby
15 minimising current mismatch between each of the solar cells comprised within the PV device on which the cover member is applied since each of the solar cells may generate the same amount of current. If each of the at least two coloured and/or patterned areas comprises different patterns, resulting in the cover member having non-repeated patterns, the patterned areas may be adjusted to ensure that each of the
20 at least two coloured and/or patterned areas comprises the same geometrical area. In particular, each of the at least two coloured and/or patterned areas may be adjusted such that each of the at least two coloured and/or patterned areas provides uniform light transmittance.

The at least two coloured and/or patterned areas may be formed by any suitable
25 method. For example, the at least two coloured and/or patterned area may be formed by, but not limited to: screen printing, digital printing, frit printing, structural colouration such as interference coating, sputter coating, scattering, or a combination thereof. The at least two coloured and/or patterned area may comprise a spectrally selective reflective material. According to a particular aspect, the at least two coloured and/or
30 patterned areas may be formed by digital printing.

The cover member may be formed of any suitable material. For example, the cover member may be made of, but not limited to: glass, thermoplastic polymer, poly(methyl

methacrylate), polycarbonate, or a combination thereof. In particular, the cover member may be formed of glass.

The cover member may be provided on or adjacent a surface of at least one solar cell comprised in a PV device. The solar cell may be any suitable solar cell. For example, the solar cell may comprise, but not limited to: perovskite solar cell, cadmium telluride (CdTe), copper indium selenide (CIS), copper indium gallium selenide (CIGS) solar cell, copper indium gallium sulphur selenide (CIGSSe) solar cell, silicon solar cell, organic photovoltaics, or a combination thereof. The PV device may be any suitable PV device. According to a particular aspect, the PV device comprising the cover member may be further comprised in a building-integrated photovoltaic (BIPV) module.

According to a second aspect, there is provided a PV device comprising a cover member according to the first aspect. The PV device may be any suitable PV device. The PV device may further comprise a plurality of solar cells. The solar cell may be any suitable solar cell. For example, the solar cell may comprise, but not limited to: perovskite solar cell, cadmium telluride (CdTe), copper indium selenide (CIS), copper indium gallium selenide (CIGS) solar cell, copper indium gallium sulphur selenide (CIGSSe) solar cell, silicon solar cell, organic photovoltaics, or a combination thereof.

In particular, the PV device of the second aspect may be comprised in a building-integrated photovoltaic (BIPV) module.

There is also provided a method for producing a cover member described above, the method comprising:

- selecting a colour and/or a pattern for forming at least two coloured and/or patterned areas on the cover member;
- determining print opacity and ink density for the colour based on the pattern selected such that each of the at least two coloured and/or patterned areas comprises uniform light transmittance; and
- printing the cover member with the selected colour and/or a pattern with the determined print opacity, ink density and pattern geometrical area.

The selecting may comprise selecting two or more colours and/or a pattern for forming the at least two coloured and/or patterned areas. The colour and/or pattern may be as described above.

The printing may be by any suitable method. For example, the printing may be by, but
5 not limited to: screen printing, digital printing, frit printing, structural colouration such as interference coating, sputter coating, scattering, or a combination thereof. According to a particular aspect, the printing may be by digital printing.

The cover member may be formed of any suitable material. For example, the cover member may be formed of, but not limited to: glass, thermoplastic polymer, poly(methyl
10 methacrylate), polycarbonate, or a combination thereof. In particular, the cover member may be formed of glass.

The advantage of the present invention is that by selecting appropriate colours and printing parameters such as print opacity and ink density, the cover member comprising the different colour areas would have uniform light transmittance. Further,
15 by ensuring that the cover member has the same pattern geometrical area with the patterns across the various coloured and/or patterned areas comprised on the cover member, the solar cells within the PV device onto which the cover member is applied would have uniform light transmittance. Accordingly, the solar cells would be subjected to uniform shading, thereby eliminating current mismatch between solar cells
20 comprised in the PV device onto which the cover member may be applied, as well as minimise hot-spot risks.

Accordingly, the cover member enables PV devices to be integrated into buildings such that the PV devices provide electricity while at the same time being aesthetically pleasing.

25 Having now generally described the invention, the same will be more readily understood through reference to the following embodiment which is provided by way of illustration, and is not intended to be limiting.

Example

Coloured PV devices were formed by modifying the front cover member made of glass with digital printing technology. In particular, the PV module short-circuit current for six NCS primary colours were determined, with varying print opacity and ink density.

Figures 1A and 1B illustrate the results. From the results, it could be concluded that besides colours, two parameters of the design and printing processes also affected the shading and electrical efficiency: i) print opacity of the raw image in imaging software being used, such as Adobe Photoshop, and ii) the ink density (ink thickness/ink volume) of the printing process.

The information from Figures 1A and 1B was then used to prepare two cover members with multi-colour and repeated pattern designs, as shown in Figures 2A and 2B respectively, and one cover member with multi-colour and a non-repeated pattern design, as shown in Figure 2C.

In particular, for the two-colours design pattern in Figure 2A, the print opacity and ink density for the blue colour were 100% and 300%, respectively; while for white colour, the print opacity and ink density were 100% and 100%, respectively.

For the three-colours design pattern shown in Figure 2B, the print opacity and ink density for the green colour were 100% and 200%, respectively; for red colour, the print opacity and ink density were 100% and 100%, respectively; and for yellow colour, the print opacity and ink density were 100% and 200%, respectively.

For the two-colour design pattern shown in Figure 2C, the print opacity and ink density for the blue colour were 100% and 300%, respectively while for white colour, the print opacity and ink density were 100% and 100%, respectively.

To test the choice of print opacity and ink density, PV devices comprising the cover members with the colour and designs shown in Figure 2A and 2B were fabricated. The PV device with the cover member comprising the design shown in Figure 2A was termed "Blue-white peranakan PV" and the PV device with the cover member comprising the design shown in Figure 2B was termed "Tri-colour peranakan PV". A further PV device was fabricated in which the cover member comprised a multi-coloured and patterned design (not shown) in which little attention was paid to non-

uniform shading and hot-spot reliability concern. This PV device was termed "Singapore-landscape PV".

The PV devices were characterized for their electrical performance under Standard Test Conditions (STC). Figure 3 shows the I-V curves of the PV devices including that of a reference standard PV device which comprised the same solar cell and back cover as the PV devices having the cover members of Figure 2A and 2B. However, the reference standard PV device had a transparent cover member. From Figure 3, it can be seen that there was no mismatch power loss observed for the peranakan PV devices, implying a uniform light transmittance to all solar cells. On contrary, a step curve is observed for the Singapore-landscape PV device: it suffers from cell-to-cell current mismatch, which leads to mismatch power loss.

To validate whether the PV devices were free of hot-spots, an outdoor hotspot endurance test was performed and the localized temperature of the solar cells in the PV devices were measured with an IR image of the rear side of the PV device under exposure. It was found that two solar cells in the Singapore-landscape PV device exhibited temperatures exceeding 100°C. This suggests potential of localised heating and hot-spot development for them. In contrast, despite also having colour and pattern printings on the front glass, the peranakan PV devices showed fairly homogeneous temperature distribution, thereby not forming hot-spots.

Whilst the foregoing description has described exemplary embodiments, it will be understood by those skilled in the technology concerned that many variations may be made without departing from the present invention.

Claims

1. A cover member for a photovoltaic (PV) device, the cover member comprising at least two coloured and/or patterned areas, wherein each of the at least two coloured and/or patterned areas provides uniform transmittance such that in use, each solar cell
5 comprised in the PV device has the same electrical efficiency.
2. The cover member according to claim 1, wherein each of the at least two coloured and/or patterned areas comprises at least two colours.
- 10 3. The cover member according to claim 1 or 2, wherein the light transmittance is determined by print opacity and ink density of each of the at least two coloured and/or patterned areas.
4. The cover member according to any preceding claim, wherein each of the at
15 least two coloured and/or patterned areas comprises the same or different colours.
5. The cover member according to any preceding claim, wherein each of the at least two coloured and/or patterned areas comprises the same or different pattern.
- 20 6. The cover member according to any preceding claim, wherein the electrical efficiency is measured by the short-circuit current.
7. The cover member according to any preceding claim, wherein the at least two coloured and/or patterned area is formed by: screen printing, digital printing, frit
25 printing, interference coating, sputter coating, scattering, spectrally selective reflective material, or a combination thereof.
8. The cover member according to any preceding claim, wherein the cover member is made of: glass, thermoplastic polymer, poly(methyl methacrylate),
30 polycarbonate, or a combination thereof.
9. The cover member according to any preceding claim, wherein the cover member is provided on or adjacent a surface of a solar cell comprised in a PV device.

10. The cover member according to claim 9, wherein the solar cell comprises: perovskite solar cell, cadmium telluride (CdTe), copper indium selenide (CIS), copper indium gallium selenide (CIGS) solar cell, copper indium gallium sulphur selenide (CIGSSe) solar cell, silicon solar cell, organic photovoltaic, or a combination thereof.

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11. The cover member according to claim 9 or 10, wherein the PV device is comprised in a building-integrated photovoltaic (BIPV) module.