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Effect of diffusion of light on thin-film photovoltaic laminates

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ABSTRACT

A large fraction of the daylight incident on building-integrated photovoltaic (BIPV) laminates is diffuse irradiance. In this study, fabrics of various weaves were used to simulate combinations of direct and diffuse irradiance on façade-mounted PV. The scattering of light achieved with the fabrics at varying angles of incidence was measured with a goniophotometer. The transmittance distribution was used to quantify the percentage of diffusion created by the fabrics. A photovoltaic (PV) laminate was shaded with the fabrics to simulate diffuse irradiance and the short circuit current of the module was measured. The experimental results indicate fabrics of different porosity can be used to simulate various combinations of direct and diffuse irradiance. However, these fabrics can affect the module output. Preliminary results show that the proximity of the fabric to the thin-film PV laminate during the test skews the measured electrical parameters.

1. Introduction

Thin-film photovoltaic (PV) modules are integrated into the façade to balance electrical power generation and daylighting requirements [1,2]. Installing transparent thin-film PV laminates instead of glass in the façade offsets the initial cost as an extra layer of glass may not be required [3]. This factor can be an incentive for builders to use thin-film PV in various architectural designs. For a significant percentage of these vertically façade-mounted modules, the incident irradiance is diffuse. It is important to characterise these modules under simulated conditions of diffuse irradiance in the laboratory and understand the effect of this diffuse irradiance on the thin-film solar cells.

The origin of the diffuse light that is reaching the solar cells is either (a) scattering structures in the module top sheet or (b) diffuse irradiance incident on the modules. Diffuse irradiance is defined as the portion of the sunlight that does not arrive at the surface of interest in a straight line from the sun [4]. Diffuse illumination is the result of scattering by clouds and suspended particles in air. Previous reports in literature have tried to understand the effect of oblique incidence on thin-film modules by simulation [5] and monitoring of PV systems [6]. Paretta et al. [7] have conducted transmittance measurements in diffuse light for glass top sheets used in modules. Diffusing materials were also used previously to characterise modules indoors in an earlier study [8] and the angle dependence was investigated separately as well. Concentrators have been used to focus this diffuse irradiance for BIPV at different angles [9] to improve module output. PV modules should be characterised under combinations of diffuse and direct light at different angles of incidence to predict their performance under variable sky conditions.

In this study, we have explored the use of fabrics to simulate incidence of diffuse light on thin-film PV laminates in the laboratory. Fabrics were chosen for this test because they are a cheap resource and are available in a variety of weaves and transparencies. The diffusion created by the fabric can be used to test the PV laminate output. The transmittance distributions of two different fabrics were measured with a goniophotometer at different angles of incidence to understand the scattering of light and the combination of direct-diffuse transmission achieved by the fabrics. A layer of each fabric was placed in front of the PV laminate; the transmission and the short circuit current (I_{sc}) were measured at 0° and 70° incidence. This test was repeated with two configurations – the fabric at a distance of 0 cm from the module and the fabric at a distance of 10 cm from the module – to determine whether the diffusion effect achieved was equivalent. The focus of this investigation was to determine whether the effect of the fabrics could change with the experimental setup and subsequently affect the electrical characterisation of the module. The results obtained from goniophotometry are complemented with electrical data of the PV laminate to present the effect of such diffusing materials at different angles.

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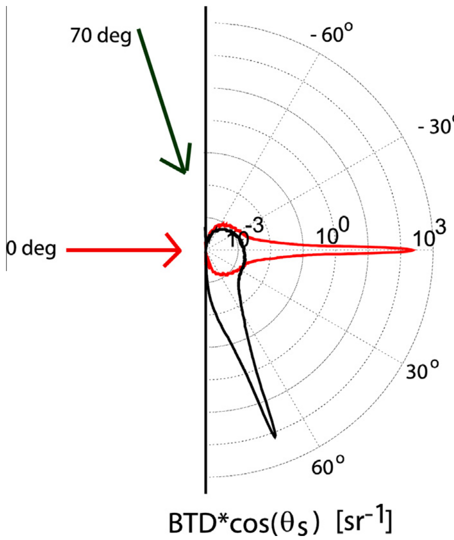

Fig. 1. Transmitted scatter of the PV laminate for light incident at 0° and 70°. BTDF gives the transmittance per unit solid angle along Θ_s. The sharp transmission peak is similar to clear glass.

2. Experimental methods

The measurements were done as two separate sets: angle-dependent transmission tests with goniophotometer and angle-dependent electrical characterisation with an I–V tracer. One a-Si module with a rated power of 42 W at standard testing conditions and a visible transmittance of 10% was selected for the tests. Several white fabrics of different transparencies and weaves were collected for transmittance measurements.

(i) *Goniophotometer tests:* The goniophotometer is an instrument that measures angle resolved reflectance and transmittance in the whole hemisphere [10]. Scattering of patterned samples can be quantified at any chosen angle of incidence. For the measurements, a halogen lamp was used with a silicon detector revolving around the sample. The data points were later used to generate the bidirectional transmittance distribution function (BTDF), which is the ratio of the amount of light transmitted along a given solid angle (direction) to the amount of light incident on the sample. The BTDF data show the diffusion created by the fabric when the light is transmitted. The cosine corrected BTDF was used to quantify transmitted scatter along a given scattering angle Θ_s for a specific incident angle Θ_i.
The transmittance of several fabrics was measured at 0° incidence with the goniophotometer. Two of those fabrics with a transmittance of 30% and 60% were selected for the study denoted "fabric30" and "fabric60" respectively. These two fabrics were chosen due to the magnitudes of transmittance forming a ratio. Any proportional changes in electrical properties would be easily noted. The PV laminate was measured individually with the goniophotometer. The BTDF was quantified at different angles of incidence from 0° to 70° at ten-degree intervals. The goniophotometer was also used to measure the transmittance distribution of the PV laminate together with the fabrics.

(ii) I_{sc} *test:* The second set of tests was done with the PV laminate fully illuminated by a solar simulator lamp at 0° and 70°. These two conditions were chosen to represent near-normal incidence and large angle of incidence. The incident irradiance was monitored and the short circuit current I_{sc} of the module was measured for both angles of incidence. The I_{sc} was also measured with the module covered by two different fabrics. This measurement was used to correlate the effect of diffuse light at large angles to the electrical output. Since absorption is almost constant for PV modules, effect of large incidence angles is often assigned to the reflectance loss of the top layer of glass. A better understanding of the mechanisms are provided when the scattering properties

Table 1
Transmittance properties of two fabrics used in this study. Fabric60 has a higher fraction of direct transmittance at 0° and 70°. These values are obtained by integrating the data from BTDF measurements shown in Fig. 2.

Fabric name	*T* at 0° (%)	Ratio of direct: diffuse *T* at 0°	*T* at 70° (%)	Ratio of direct: diffuse *T* at 70°
Fabric60	60	1:9	35	1:8
Fabric30	30	1:29	20	1:19

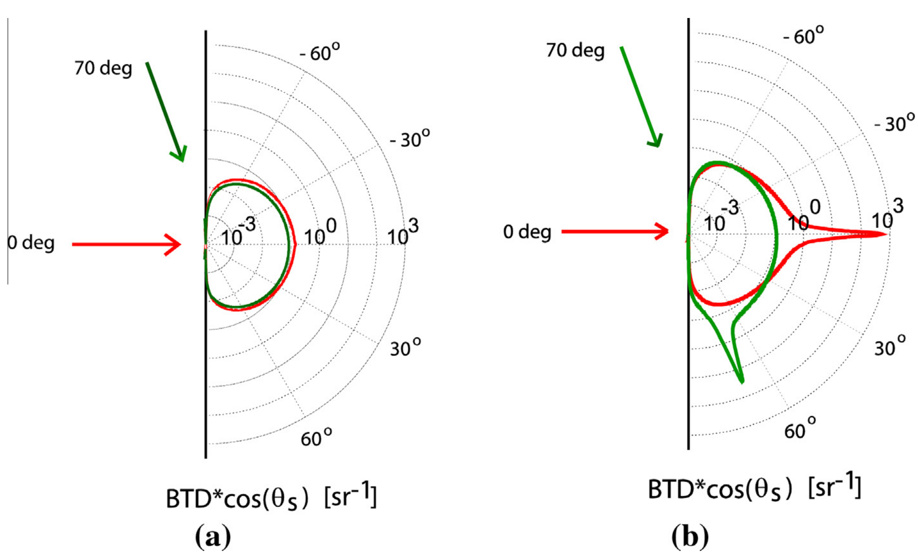

Fig. 2. Transmitted scatter of (a) fabric30 at 0° and 70° incidence and (b) fabric60 for 0° and 70° of incidence. Fabric30 shows no peak and has diffuse transmission at both angles of incidence. Fabric60 has a large lobe with a sharp peak, combining diffuse and direct transmission.