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Measuring the light recovery factor of backsheets in photovoltaic modules

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ABSTRACT

We measure the short circuit current improvement of various commercial backsheets for passivated emitter and rear solar cells (PERC) in photovoltaic (PV) modules. We quantify this improvement by a light recovery factor k defined as the share of the light reflected by the backsheet around the cell in a PV module laminate, which is converted into electrical current by the solar cells in the module relative to a reference rear surface. The presented measurement method allows measuring the light recovery factor as function of the incident light beam angle, which are important for the calculation of the yield analysis in the field. Simulations of the recovery factor with the optical ray tracing program DIADALOS are performed in order to support the interpretation of the results. For measuring the absolute light recovery probability of a backsheet one should use a reference backsheet with an absorbance of close to 100% to avoid systematic reflection errors especially for high incident light beam angles $> 50^\circ$. The ranking of various recovery factors are compared to the ranking measured by reflectance measurements defined in standard IEC 62788-2 Ed.1 for backsheets. The standard shows a substantial deviation between the ranking of recovery factor and the reflectance which can be corrected by using an adapted definition for the reflectance measurement method.

1. Introduction

The area between the solar cells in a PV module contributes to the power generation of the module by light scattering. It is important to know how much light from the backsheet can be scattered on the solar cells to generate power. With the rising efficiency of the solar cells the power contribution from the backsheet is also rising. The performance of industrial-type screen-printed 156-mm-sized PERC solar cells significantly increased during the past years. Efficiencies of up to 22,6% have been published in reviewed paper [1] and up to 23.6% have been published on manufactures internet pages [2]. An increase in module power often comes along with a larger sized module area in order to benefit from additional light scattering from the cell gap region onto the cells by multiple reflections within the module. However, this results in an increase in consumption of materials during module fabrication and in increased installation costs since both scale with the module area [3]. To obtain high module efficiencies the whole PV module area must use as much light as possible for energy conversion.

There are many methods to measure the light recovery of passive module areas. Passive areas are module parts which do not generate electric power but may influence the power generation of the active parts (unshaded solar cell area) by internal light reflection. Some methods use light beam induced current (LBIC) [4,5] or local external quantum efficiency [6] measurements to determine the position dependent recovery of cell metallization, cell interconnect ribbon or wire as well as various backsheets. These methods are applied by scanning over the non-active module area and measuring the resulting current in one electrically contacted cell. The resulting current weighted by the current of a fully active area gives spatial (LBIC) or wave length dependent information on the light recovery of the inactive module area. Another method uses the reciprocity theorem of the (electro-) luminescence to measure optical recovery of inactive module parts [7]. With this method it is possible to access the light recovery from a passive module part by luminescence imaging for wavelength equivalent to the semiconductor bandgap by weighting the luminescence signal of an active area to an passive module area. Finally, it is possible to measure the light recovery by a flasher [7,8]. Headrich et al. separate the recovery factor of the backsheet from influences of other components of the module by masking the inactive area around one active cell by at least two mask dimensions. The coupling gain is calculate by the difference between the short circuit measured with a mask size of the full cell area and the mask size corresponding to the full cell area plus the surrounding cell gap. This difference is normalized to short circuit current of full cell area. The measured light recovery for backsheets can

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be used to calculate and assess the module power as shown by Haedrich [7]. All these techniques need to have a finalized PV module for each tested backsheet. Additional to the material and time consumption, this comes along with material variations and different cell performances leading to an increase in measurement uncertainty of the recovery factor. In order to overcome this limitation we present a simple method to measure the light recovery factor. Typically PV modules are laminated with Ethylene-vinyl acetate (EVA) to laminate the cells to the glass front cover. Therefore, we use one and the same glass/EVA/cell/EVA laminate to which various backsheets are attached successively by liquid paraffin. Variations in the module performance due to the different backsheets are determined by measuring the short circuit current. The calculation of the recovery factor in this work is similar to the method by Haedrich et al. However, with the new method the recovery factor is normalized to short circuit measurement of a reference backsheet acting as a light trap. We use this method to measure the angle dependence of the recovery factor of the backsheet of the module. To validate the applicability of the new method, we directly laminate the backsheet to the test module without liquid paraffin and re-measured the recovery factor again. Furthermore, the measured recovery factors of the new method are compared to reflection measurements of backsheet. Simulations of the measurement with the raytracing program Diadalos [3] are performed to evaluate the underling effects occurring during angle dependent measurement.

2. Method to measure the recovery factor of backsheets

2.1. Experimental test modules

We manufacture a semi-finished test module without backsheet; details of the module lay-up are given in Table 2. In the test modules a 156 mm × 156 mm-sized three busbar multi crystalline PERC cell is located in the centre surrounded by 8 cell parts as shown in Fig. 1. The purpose of these electrically unconnected cell parts is to simulate the optical environment of a middle cell in the centre strings of a standard sized module. The rear metallization of a monofacial crystalline Si solar cells does not cover the complete cell rear side. There is a distance between rear metallization and wafer edge of 1 mm for the used cells. A black aperture is laminated onto the front, rear and the edges of the test module to avoid light coupling into the module from the glass area that extends over the centre cell and the 8 cell parts or the glass edges. Fig. 1 shows a photograph of such a test module with aperture and 4 mm cell gap. Such laminates are made for cell gaps of 2 mm, 4 mm and 6 mm. We measure the cell thickness and the distance between cell edge and rear side metallization. The mean of the height and width of the active cell measured through the cell middle is l_{cell}. We measure the four distances between each edge of the active middle solar cell and the closed parallel edge of the neighbour solar cell. l_{BS} is the mean of this four distances measured through the middle of the active solar cell. The cell gap d is defined as $d = l_{BS} - l_{cell}$. The distance measurements of l_{cell} and l_{BS} are shown in the right part of Fig. 4. All distances are measured by a Vernier calliper with an uncertainty of 0.1 mm.

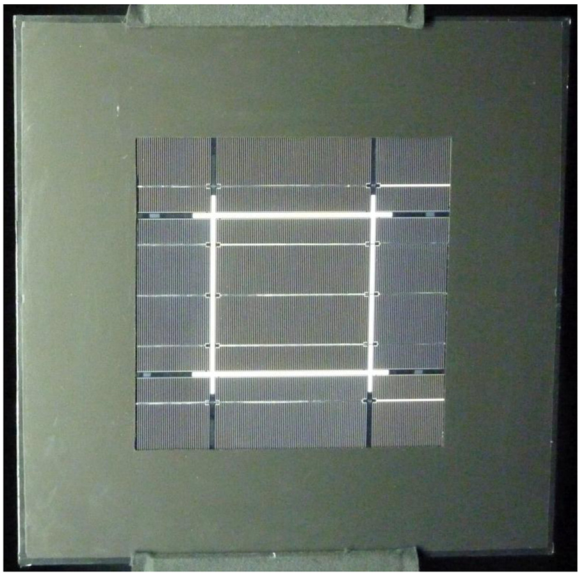

Fig. 1. Test module (SA4) with 4 mm cell gap with aperture and partly covered backsheet around the cell. For storage the rear side is protected by a static foil.

Various backsheets are successively attached to the test module by a thin (20 µm − 50 µm) film of liquid paraffin. We use Paraffinum perliquidum from Caesar & Loretz GmbH, Germany. The liquid paraffin film is prepared without bubbles between the laminates and the backsheet. Fig. 2 shows a schematic cross sectional view of the test module prepared with a paraffin and a backsheet. Before applying the backsheet to a test module or any optical measurement, the backsheet materials are pre-treated by a standard lamination process to catch optical changes due to the lamination procedure. Possible rough adhesive layers on the backsheet become mirror like flat after the procedure.

The reflection of a green laser pointer on all white backsheets show a more or less Lambertian like intensity distribution on a white piece of paper.

To compare the effect of the optical coupling between EVA, liquid paraffin and the backsheet we use one extra test module SB4 with 4 mm cell gap. We measured the light recovery probabilities with one and the same test module first with a paraffin coupled backsheet and later on with the same backsheet laminated to its rear. We determine the error of the method by comparing these two measurements. Table 1 shows all samples prepared for this paper and Table 2 provides a list of the used backsheets. We want to introduce a new measurement method and the used backsheets only serve as examples for the technique.

Compared to other methods we need to prepare semi-finished test modules ones. Afterwards we can reuse the modules for various backsheet characterizations. This reduces the effort by factor n when testing n backsheets in total. Once this test modules are build and characterized, one can quickly measure multiple new backsheets just with one additional I_{sc} measurement. Compared to the mask method published by Haedrich [5] this method accounts also for the optical coupling of neighbour cells in the laminate [4]. Furthermore it is also applicable to angle dependent measurements, because there is no shading from the mask at angles unequal 0°.

2.2. Experimental measurements

The *IV* parameters of the test modules are measured by an AAA flasher system from h.a.l.m. The used measurement range has an uncertainty of the reproducibility of 0.01 A for the short circuit current. To reduce the uncertainty of the reproducibility we do three repeated measurements for each shot. A measurement with backsheet as well as a measurement without backsheet and a light trap behind the test module allows the calibration of the realist optical cell environment of recovery factor of the cell gap with nearly zero light recovery. A source of uncertainty is stray light from the flash or other light sources reaching the rear of the module. This is also important while measuring semi-transparent backsheets where additional light from the rear distorts the measurement. The rear EVA foil is prepared optically flat to avoid stray light form the EVA/air interface during the light trap (LT) reference measurement.

To assess the impact of the moving sun on the internal reflections of the inactive backsheet material, the test modules are rotated along the vertical middle axis of the module. We measure the angle dependence of the electric current gain of the samples from −80° to 80° in steps of 10° according to the indoor method described in standard IEC 61853–2 [6]. For the angle adjustment the mechanical rotation stage has