YIELD AND SPECTRAL EFFECTS OF A-SI MODULES

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ABSTRACT: Aim of this study was to investigate the relevant factors that influence electrical energy yield of photovoltaic modules based on thin film technologies, in particular amorphous silicon (a-Si). Models of different manufacturers have been compared in theory and in the outdoor laboratory of TU-Berlin and PI-Berlin.

Amorphous silicon modules show higher energy yields for diffuse light irradiation. This was as well calculated – using the spectral match of the diffuse irradiance (as given in the spectra of CIE 85) and the spectral response for single junction a-Si modules – as confirmed via outdoor field measurements.

Highly diffuse skies and high sun elevation angles (AMs) result in the highest increase of short circuit current (and electrical yield) for amorphous based modules relative crystalline silicon (c-Si) modules. For moderate diffuse skies c-Si performs better. Although spectral effects have been successfully separated from other performance factors with the result that their influence can be quite significant for some conditions (e.g., >30% gain in I_{SC} at a-Si for a 90% overcast sky at spectral matching), their overall contribution to the annual energy yield is relatively small: 1.3 % for a tandem µ-morph, and 3.2% for single junction amorphous (a-Si) modules. Therefore, spectral effects alter performance in about the same range as thermal and weak light performance factors.

Particular problems for yield evaluation of a-Si modules occur due to degradation of power output. In the outdoor lab the effect of the annealing/degradation process on electrical performance has been investigated: Seasonal degradation and recovery of the a-Si modules resulted in a fluctuation of ±6% of the short-circuit current I_{sc} and of energy yield. Accordingly, the effects of seasonal degradation (resp. recovery) are by a factor of two higher than the spectral effects observed. Future efforts are targeted on the modeling of degradation and recovery of tandem cells.

Keywords: Energy Rating, Performance, Spectral Response, Degradation.

1 INTRODUCTION

Spectral effects are usually thought to be a key factor for the performance and yield evaluation thin film modules, but it is difficult to separate them from other effects regarding annual energy yields for a given location [1],[2]. Aim of this study is to quantify the differences in the energy yield due to the spectral effect (matching of the actual solar spectrum with the spectral response of different PV technologies, see Fig. 1) between amorphous silicon thin film technologies (a-Si) and crystalline silicon (c-Si) as a stabile reference.

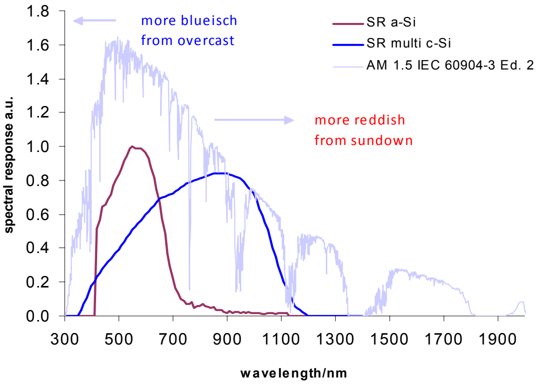

Figure 1: Spectral responses (SR) of different PV technologies and the standard spectrum according to IEC 60904-3 for STC measurements. Actual sun spectra at overcast skies differ from the IEC spectrum and are shifted to shorter wavelengths. Most thin film modules have an enhanced spectral response in the blue part and therefore benefit from the blue shift at overcast skies.

2 APPROACH

2.1 Site for Measurements

Outdoor data were taken at a fixed installation on PI-Berlin's and TU-Berlin's outdoor lab in Berlin-Charlottenburg. The distribution of irradiance levels together with the share of direct and diffuse irradiance at the site is shown in Fig. 2.

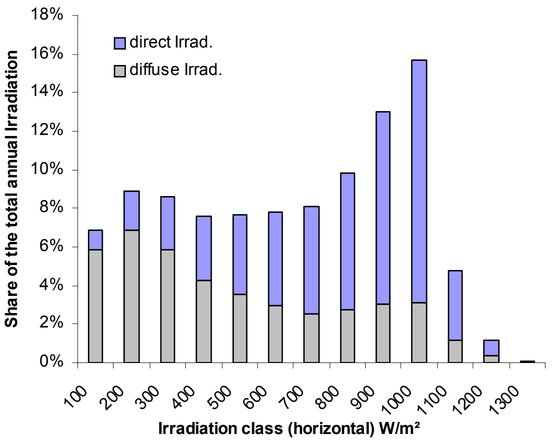

Figure 2: The share of direct and diffuse irradiation in Berlin 2009 distribution of irradiance levels (measured by PI-Berlin).

Angle-of-incidence effects were considered as small and were circumvent by a direct comparison of the short circuit currents of both modules types [3].

For a set of full-size modules the irradiation (in the plane of the modules and horizontally) was recorded every minute together with the actual *I-V*-characteristics of the modules, the wind speed at the test site, ambient and module temperatures.

The modules were installed in September 2008 and received initial light soaking under outdoor conditions until stabilization before the logging period.

3.2 Spectral Matching

To evaluate the theoretical spectral effect a matching of the spectral response with the solar spectrum for different sky conditions has been carried out.

Fig. 3. shows the calculation of difference in short-circuit current *delta* I_{SC} by multiplying the spectral response (SR) of the module with the actual solar spectrum at each wavelength and integrating it, for each diffuse/direct ratio ("overcastness"), as derived from CIE 85:1989 Ed. 1, Tables 7 and 8. [4].

$$I_{SC} = \int SR(\lambda) \cdot Solar\ spectrum(\lambda)\ d\lambda$$

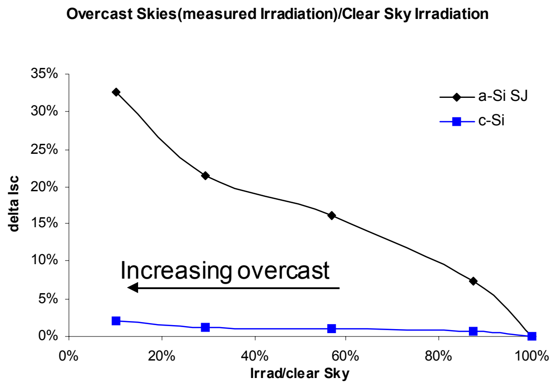

Figure 3: Comparison of performance (change in I_{SC} at different overcast conditions using spectral matching) for amorphous and crystalline silicon PV modules.

Strong effects (>30% gain) for a-Si can be observed for increasing overcast conditions.

3 RELATIVE PERFORMANCE MEASUREMENTS

To find out the differences in performance of the different PV technologies, the relation of short-circuit currents was used as an indicator. Beside a single junction a-Si module (a-Si SJ), also two tandem cell modules - consisting of a microcrystalline silicon base layer with an amorphous silicon layer above (µm-Si) have been investigated. As a reference a multi-crystalline silicon (c-Si) module was used. The results, in the form of relative short-circuit currents I_{SC}, have been plotted as a function of the sun's elevation angle, resp. the Air Mass, and the diffuse share of the irradiance in the plane of the modules, as shown in Figs. 4 a-c.

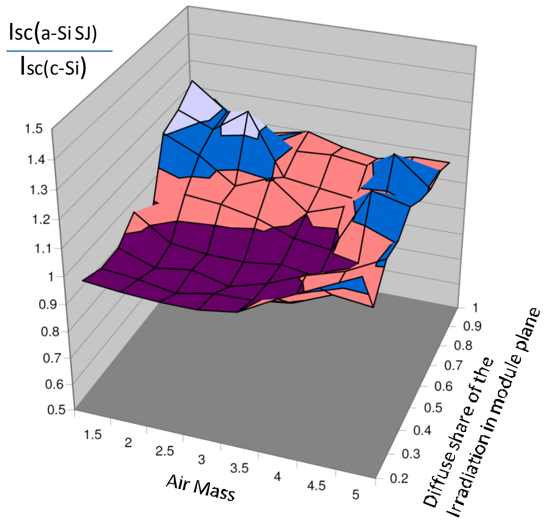

Figure 4a: Relative performance of an a-Si single junction module vs. the multi c-Si reference module.

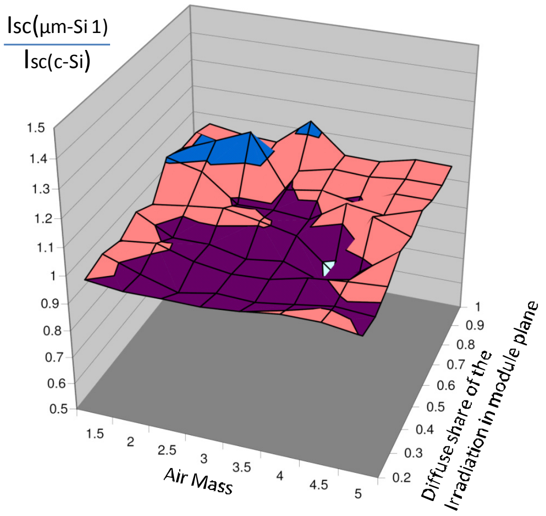

Figure 4b: Relative performance of an a-Si/µ-Si tandem junction module (product 1) vs. the multi c-Si reference.

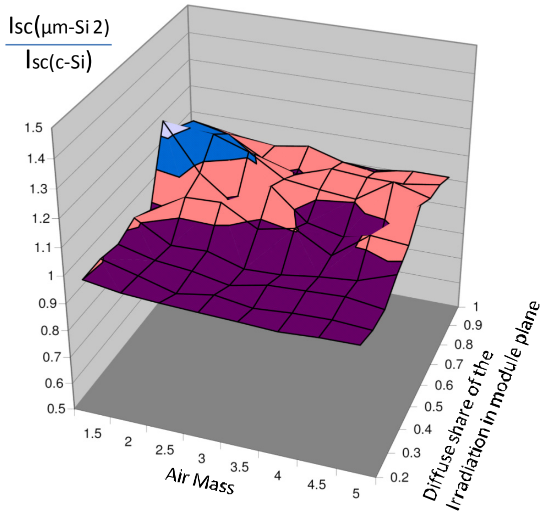

Figure 4c: Relative performance of a-Si/µ-Si tandem junction (product 2) vs. the multi c-Si reference.

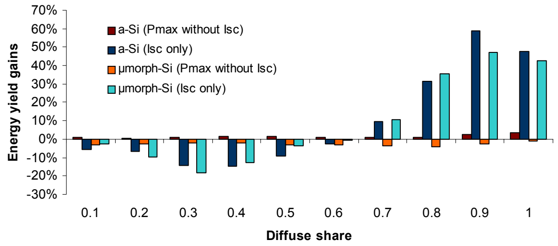

Figure 5: Gain in relative yield for amorphous cell technologies for different diffuse shares of the irradiance (separated in the spectral effects via I_{SC} and the weak light and temperature effects via P_{max} – without the effect of I_{SC} change).

The spectral shift (more "bluish") for overcast sky result in higher I_{sc} for diffuse light. While temperature differences and the weak light effect have an impact principally on voltage and form factor only, they can be separated from the spectral effects. Considering that, Fig. 5 shows that temperature and weak light show a minor effect on $P_{max.}$

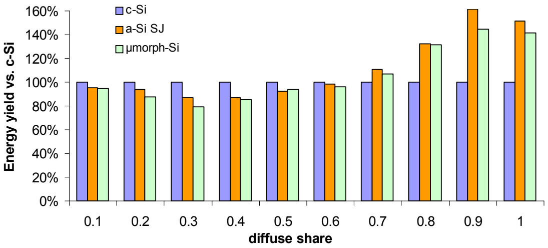

Figure 6: Relative energy yield as a function of diffuse share, measured from February to June 2009 in Berlin

Fig. 6 compares the relative energy yields of different PV technologies, using the same reference module (c-Si) and the same micromorph module (Product 2) as in Fig. 4a and 4c). It is clearly visible that the amorphous modules dominate for irradiations with high diffuse shares.

4 DEGRADATION

To investigate the degradation by irradiance and its regeneration by elevated temperatures I_{SC} has been monitored during the test period. Fig. 7 shows the effect of seasonal degradation, which results in a fluctuation of ±6% in $I_{SC.}$

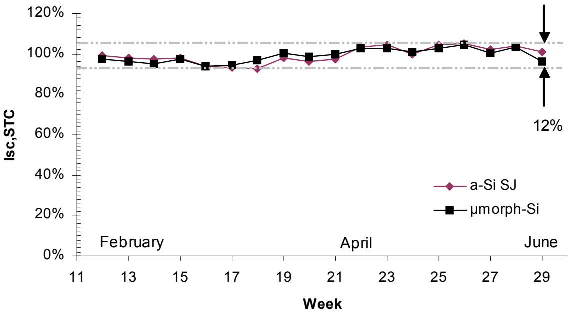

Figure 7: The seasonal degradation and recovery of the a-Si layers. I_{SC} was taken from averaged outdoor data at 0.20 ± 0.05 diffuse share and at AM 1.5 ± 0.5 after correction to STC.

5 ENERGY YIELD

Table I shows the overall effect on the energy yield taking into account the actual distribution of irradiance levels and diffuse-direct shares measured at the test-site in Berlin during 2009 (as shown ind Fig.2)

Table I: The annual energy yield estimated from a half-year period in Berlin

Feb 2009 – June 2009	**energy yield increase from summed Pmax**	energy yield increase through spectral mismatch	other effects (weak light, temperature
a-Si vs. c-Si	**4.5%**	3.2%	1.3%
µm-Si vs. c-Si	**-1.1%**	1.3%	-2.4%

The strong spectral effects indicated in Fig. 6 are diluted in for the total energy yield due to the little contribution of irradiation with high diffuse shares (as shown in Fig. 2) and from the reduction of I_{SC} at moderate diffuse shares from 0.2 to 0.5, which have an much higher contribution.

6 CONCLUSION

Amorphous silicon modules show higher energy yields for diffuse light irradiation. This was as well calculated – using the spectral match of the diffuse irradiance (as given in the spectra of CIE 85) and the spectral response for single junction a-Si modules – as confirmed via outdoor field measurements.

Highly diffuse skies and high sun elevation angles (AMs) result in the highest increase of short circuit current (and electrical yield) for amorphous based modules relative crystalline silicon (c-Si) modules. For moderate diffuse skies c-Si performs better. Although spectral effects have been successfully separated from other performance factors with the result that their influence can be quite significant for some conditions (e.g., a >30% gain in I_{SC} at a-Si for a 90% overcast sky), their overall contribution to the annual energy yield is relatively small: 1.3 % for a tandem µ-morph, and 3.2% for single junction amorphous (a-Si) modules. Therefore, spectral effects alter performance in about the same range as thermal and weak light performance factors.

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Accordingly, the effects of seasonal degradation (resp. recovery) are by a factor of two higher than the spectral effects observed. Future efforts are targeted on the modeling of degradation and recovery of tandem cells. The aim is to clarify, which combination of bottom and top cell results in an optimum for initial and degraded STC power as well as in an optimized spectral match for real sky spectra under field conditions.

7 REFERENCES

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[4] CIE 85-1989, Solar Spectrum Irradiance ISBN 3 900 734 22 4, Table 7 & 8.