

Transmittance of selected nanostructured solar glasses designated via relative change in electrical parameters of silicon solar cells

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Abstract. Photovoltaics is one of the most promising technologies for electricity production. In the future, photovoltaics could be an effective and safe source of energy. In this work were present the results of the analysis of a special solar glasses transmissivity coefficient used as protective cover of photovoltaic cell. Antireflective glass due to its unique physical properties eliminate reflections and significantly increasing light transmission. The study of the relative change in the electrical parameters of photovoltaic cells ,with and without coats, as open-circuit current I_{SC} and the maximum power point MPP are presented in this paper. Research were undertaken with using the solar simulator QuickSun130CA, Class AAA+, under Standard Test Conditions.

1 Introduction

Thanks to the use of nanotechnology and the introduction of morphological changes of the glass surface used in the manufacture of solar glasses, D.A. Glass Company, were achieved extremely high performance light transmittance of samples of solar glasses measured at STC. We able to design transmittance of these solar glasses with use of the solar cell simulator QS130CA, Endeas Oy, Finland.

manufactured at D.A. Glass, which the company set and published on its website. The specific distinguishing feature of the market glasses solar company D.A. Glass is to improve permeability in the range 700 – 900 nm .

A special product of the company are NSTM AR glasses. Samples are performed via chemical and nanostructured etching provided to inbuilding into surface structure of solar glasses the micro inclusions similar to short spaghetti. The visible increasing of transmittance DAGlass103 type of glass is registered for the angle of incident ray over 75° (see Fig. 1).

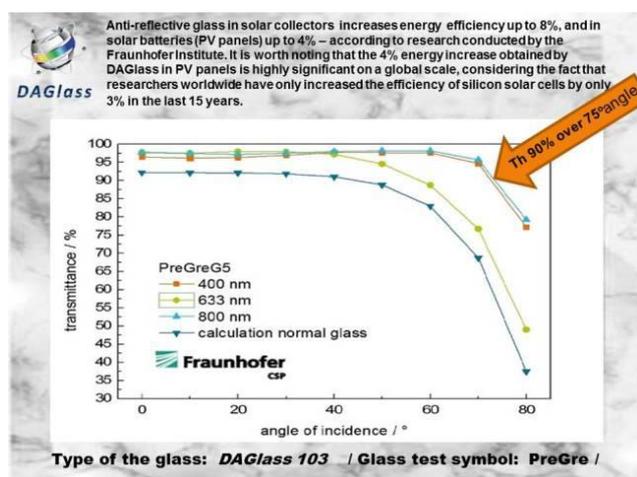


Fig. 1. Increase of transmittance of DAGlass103 type of glass measured for the angle of incident ray over 75° [1].

D.A. Glass Company products were tested. T_d ratio is 99.3%. The aim performed tests was provided to check the transmissivity of solar glasses samples

2 Samples and methods

There were tested six samples of solar glasses, D.A. Glass Company. All measurements were performed on QS130CA solar simulator at Renewable Energy Sources Laboratory of Centre for Innovation and Transfer of Natural Sciences and Engineering Knowledge of University of Rzeszow.

Before calculation we must describe the impact of glass area in the degradation of I_{SC} and P_{MM} (Fig. 2), the selected parameters of solar cell, when we applied to a cell a solar glass sample. There were measured a group of six different samples. The way how the measurements were performed is presented on Fig. 2. Using an optical profilometer ContourGT, Bruker (Fig. 3) there were examined the structure of anti-reflective coatings.

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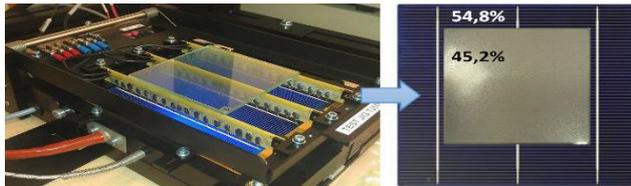


Fig. 2. Solar glass sample placed on referency solar cell. The signal is recorded in 45,2% from the cell masked by glass, and in 54,8% from the non masked cell.

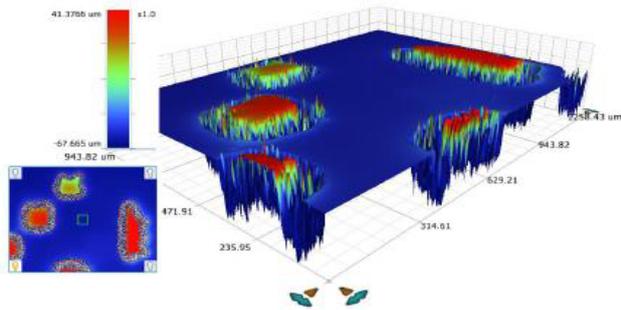


Fig. 3. Results of profile measurements with help of ContourGT, an example for sample No4.

The mean difference between the peak asperities, and the smooth surface of the glass were measured. To measure the density of surface roughness for all samples has been used a *Pro HR* Dino-Lite microscope. The measured and calculated parameters of all investigated probes are listed in Table 1. Sample No6 is lack of nanostructured inclusion.

Table 1. Parameters of solar glasses, specially S_i/S – the real surface of solar cell from which the $I=f(U)$ signal was measured.

Sample No	Sample image, Profile	Profile high [um] of antireflecti on coat via X-axis and Y-axis	Sample image	Area, S [cm ²]	S/S	Depth, d [mm]
Referency Sample	c-Si solar cell		c-Si solar cell	243,36	45,20	
1		X: 27,2304 Y: 26,4061		110,01	44,89	3,82
2		X: 29,1359 Y: 29,7996		109,24	44,89	3,82
3		X: 30,8609 Y: 33,5099		108,38	44,53	3,82
4		X: 15,4092 Y: 14,7752		108,99	44,78	3,84
5		X: 29,6276 Y: 31,3585		107,06	44,00	3,81
6				101,09	41,54	3,82

There were measured typical optical parameters of solar glasses like transmittivity T and absorption A .

Transmittivity T :

$$T_I = \frac{I_{scR}}{I_{sc(ref)}} \cdot 100\%, \quad T_P = \frac{P_{MPR}}{P_{MP(ref)}} \cdot 100\% \quad (1)$$

Real value of open current, I_{scR} :

$$I_{scR} = \left(I_{sc(1,2,3,...)} * \frac{S_{(1,2,3,...)}}{S_{(ref)}} \right) + \left(I_{sc(ref)} * \left[1 - \frac{S_{(1,2,3,...)}}{S_{(ref)}} \right] \right) \quad (2)$$

Real value of maximum power, P_{MPR} :

$$P_{MPR} = \left(P_{MP(1,2,3,...)} * \frac{S_{(1,2,3,...)}}{S_{(ref)}} \right) + \left(P_{MP(ref)} * \left[1 - \frac{S_{(1,2,3,...)}}{S_{(ref)}} \right] \right) \quad (3)$$

And transmittancy T described throught both current (fotmula (2)) and power (formula (3)) parameters, as a final result :

$$T = T \pm |T_I - T_P|_{\max} \quad (4)$$

The absorption coefficient of solar glasses is done classically:

$$I_{scR} = I_{sc(ref)} e^{-Ad} \quad (5)$$

where d – depth of solar glass,
 A – absorption coefficient of solar glass.

$$\frac{I_{scR}}{I_{sc(ref)}} = e^{-Ad}, \quad (6)$$

and optical density E is given by:

$$\log \frac{I_{sc(ref)}}{I_{scR}} = E, \quad (7)$$

$$E = Ad \cdot \log \cdot e = 0,4343 \cdot Ad \quad (8)$$

$$A = \frac{E}{0,4343 \cdot d} \quad (9)$$

and

$$R + A + T = 1. \quad (10)$$

Our investigations were focused on describing transmittancy T , and reflectivity coefficient R was only calculated withot any measurements. Our goal was to measure transmittancy T .

The silicon cell operates much worse overlaid by a solar glass. Such a impediment placed on the road incident on cell radiation significantly reduces its performance. Electrical parameters of such setup (Fig. 2) were measured with help of solar simulator QS130CA.

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QuickSun® 130CA
Cell Solar Simulator



QuickSun 130CA is a versatile manually operated single flash simulator for testing both ordinary and high capacitance crystalline silicon solar cells. The system is easily customized also up to 32 x 42 cm mini modules manufactured e.g. from any thin film material.

This novel simulator exceeds the ordinary Class A criterions of IEC904-9 ed. 2 with clear margin providing enhanced IV graph measurement accuracy and reliability for PV industry.

Spectrum: Class A+ Irradiance non-uniformity: Class A+ STI and LTI: Class A+

Fig. 4. QuickSun 130CA solar simulator, Endeads Oy, Finland [2].

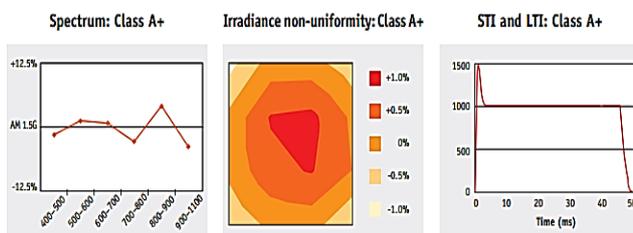


Fig. 5. QuickSun 130CA solar simulator, Endeads Oy, Finland class AAA+ [2].

- Flash pulse is triggered, irradiance measured with monitor cell.
- When target irradiance level is reached, I-V measurement initiated. Typically at 1200 W/m².
- Module is swept from short circuit to open circuit during the following approx. 2 ms. Voltage, current and irradiance signals are recorded simultaneously.

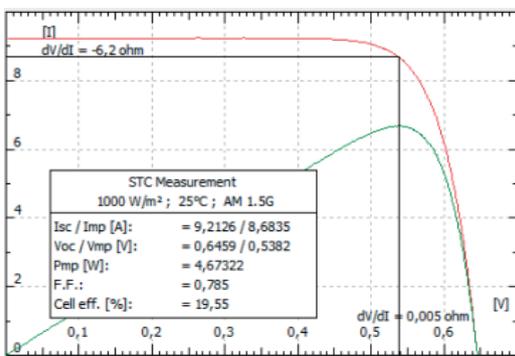
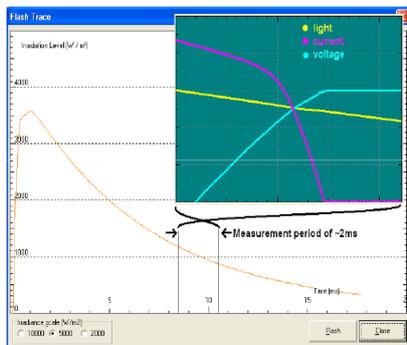


Fig. 6. QuickSun130CA Software. The idea of measurements in brief [2].

3 Results and discussion

There were measured both sides of investigated samples: smooth and nanostructured. Every test was repeated twice, and average value represents a final result of measurements performed on QS130CA solar simulator [3].

In Fig. 7 are presented selected results of tests for sample No 1. There were three curves, each indicates voltage-ampere characteristics: black – reference cell signal, red – signal taken from cell and glass from nanostructured side, and green - signal taken from cell and glass from smooth side.

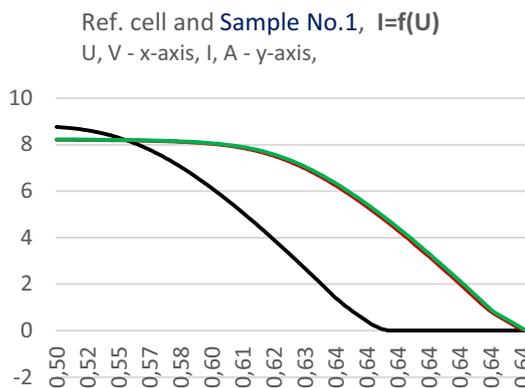


Fig. 7. Results of tests done with help of QS130CA for sample No 1 with certificate of measurements.

STC: 1000W/m ² ; 25°C; AM 1.5G Sample No. 1			
Parameter	Ref. cell	nanostruct.	smooth
Isc [A]	8,945	8,254	8,253
Voc [V]	0,643	0,642	0,642
Pmp [W]	4,55	4,19	4,20
F.F. [%]	79,063	79,173	79,16
Cell eff. [%]	18,7	17,233	17,237

In Tables 2-6 are presented results of measurements and calculations.

Table 2. Electrical parameters of tested solar cell with coating the investigated samples of solar glasses taken from nanostructured side and from smooth side.

Sample, No ; analysed side	I _{sc} [A]	V _{oc} [V]	P _{mp} [W]	FF [%]
ref. cell	8,945	0,643	4,55	79,06
1: nanostruct.	8,254	0,642	4,19	79,17
smooth	8,253	0,642	4,20	79,16
2: nanostruct.	8,238	0,642	4,187	79,15
smooth	8,262	0,642	4,20	79,13
3: nanostruct.	8,263	0,642	4,20	79,14
smooth	8,266	0,642	4,20	79,10
4: nanostruct.	8,276	0,642	4,20	79,18
smooth	8,277	0,642	4,21	79,16
5: nanostruct.	8,275	0,642	4,21	79,24
smooth	8,274	0,642	4,21	79,21
6: smooth/smooth	8,476	0,642	4,21	79,10

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Table 3. Relative displacement voltage in the current – voltage curves ΔU_{oc} . Electrical parameters of tested solar cell with coating the investigated samples of solar glasses taken from nanostructured side and from smooth side.

Sample	I [A]	U _{oc_nanostr.} [V]	U _{oc_smooth} [V]	ΔU_{oc}
No. 1	0,5	0,63899	0,63933	-0,00034
	2	0,62997	0,63071	-0,00101
	4	0,61468	0,61593	-0,00125
No. 2	0,5	0,63909	0,63806	0,00103
	2	0,62940	0,62800	0,0014
	4	0,61480	0,61327	0,00153
No. 3	0,5	0,63905	0,63870	0,00035
	2	0,63010	0,62941	0,00069
	4	0,61484	0,61410	0,00074
No. 4	0,5	0,63947	0,63798	0,00149
	2	0,63011	0,62837	0,00174
	4	0,61534	0,61309	0,00225
No. 5	0,5	0,63914	0,63914	0
	2	0,62914	0,62954	-0,00040
	4	0,61548	0,61464	0,00084

Table 4. Transmittivity of investigated solar glasses samples for measurements taken from smooth side of sample.

Sample, No ; smooth side	$T_I = \frac{I_{SCR(1,2,3)}}{I_{SCR(ref)}} [\%]$	$T_P = \frac{P_{MPR(1,2,3)}}{P_{MPR(ref)}} [\%]$
ref. cell:	100,00	100,00
1:	96,50 ± 0,02	96,52 ± 0,02
2:	96,57 ± 0,03	96,55 ± 0,03
3:	96,62 ± 0,05	96,57 ± 0,05
4:	96,66 ± 0,01	96,65 ± 0,01
5:	96,70 ± 0,01	96,69 ± 0,01
6:	97,82 ± 0,93	96,90 ± 0,93

Table 5. Transmittivity of investigated solar glasses samples for measurements taken from nanostructured side of sample.

nanost. side	$\frac{g}{S_{sample}}, [\%]$	$T_I = \frac{I_{SCR(1,2,3)}}{I_{SCR(ref)}} [\%]$	$T_P = \frac{P_{MPR(1,2,3)}}{P_{MPR(ref)}} [\%]$
ref. cell	-	100,00	100,00
1:	39	96,51 ± 0,09	96,42 ± 0,09
2:	73	96,45 ± 0,04	96,42 ± 0,04
3:	63	96,60 ± 0,03	96,57 ± 0,03
4:	28	96,65 ± 0,10	96,56 ± 0,10
5:	62	96,70 ± 0,02	96,69 ± 0,02
6:	0	97,82 ± 0,93	96,90 ± 0,93

Table 6. Absorption coefficient and calculated from formula (10) reflectivity coefficient R.

Sample No ; analysed side	A _{SCR} [%]	A _{MPR} [%]	R _{SCR} [%]	R _{MPR} [%]
ref. cell	0	0	0	0
1: nanostruct.	0,93	0,95	2,56	2,63
	0,93	0,93	2,57	2,55
2: nanostruct.	0,95	0,95	2,60	2,63
	0,91	0,92	2,52	2,53
3: nanostruct.	0,90	0,91	2,50	2,52
	0,90	0,91	2,48	2,52
4: nanostruct.	0,89	0,91	2,46	2,53
	0,89	0,89	2,45	2,46
5: nanostruct.	0,88	0,88	2,42	2,43
	0,88	0,88	2,42	2,43
6: smooth/smooth	0,58	0,83	1,60	2,27

Positive offset values indicate that higher light transmittance shows a rough surface solar glass (with a reflective coating), sometimes we observed greater transmissivity of the smooth side of the sample (Table 3 and Table 4). From certificate of sample done on QS130CA the differences in U_{oc} between nanostructured and smooth side of glasses ΔU_{oc} is not visible (Table 2), but if we describe such differences for different currents, we can see visible changes (Table 3). The biggest difference in voltage values estimated for the sample No. 4, the smallest - for the sample No. 5 (Table 3). All samples (except on the sample No.1) have a higher transmissivity for the roughened side of the glass (Table 5). Sample No.1 is the only one that has a superior transmission properties of the smooth surface of the sample than the nanostructured surface.

We can noticed that the lower the density of the surface nanostructured roughness (and absorption coefficient, Table 6), the higher the relative transmissivity of the glass (Table 5). The lower the height of the roughness (Table 1) the higher relative transmissivity of glass (Table 5). The smaller the surface density and the smaller the roughness height the greater the measured voltage differences between smooth and rough surface of the glass. For all samples except sample 1, the anti-reflection layer exhibits a significantly better transmissivity (Table 5). Contribution of reflection and absorption coefficient is 3.6% (Table 6), but the manufacturer's data shows that it is 0.7%. The values of reflectance and transmittance should be treated as estimates, because they were measured without any integrating sphere.

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4 Conclusions

The relative changes in electrical solar cell parameters (short-circuit current, maximum power), it sets the relative transmissivity of solar glasses, are able to provide a test of quality of solar glasses.

From the information provided by D.A. Glass: the solar transmittance of glass is the best at range 60°-80° of angles of incidence of solar radiation. With help of QS130CA measurement were done with perpendicular angle of irradiation, and sample No. 6 for that reason (both smooth sides) is the best for such tests. It should be emphasized the role and importance of experimentally determined relative displacement voltage in the current – voltage curves. Transmissivity coefficient measured via presented way was achieved 96,7% for nanostructured side of sample No.5. Our method shows that the best transmittancy has sample No.6 (without absorption coat), for perpendicular incidence of light to the test element.

References

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2. www.endeas.fi/download/QuickSun130CA.pdf
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