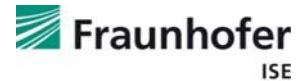


Report on inter-comparison between OAI and Fraunhofer ISE CalLab PV Cells

Object of inter-comparison

To compare IV-measurement under OAI sun-simulator to measurements done at Fraunhofer ISE CalLab PV Cells for 6" 3 busbar silicon solar cells. The set of cells was organized by OAI.



Scope of the inter-comparison

A set of 5 waferbased solar cells (6", 3BB, continuous BB, full metall on back side) are measured:

- 1) ISE tests the short term stability
- 2) Calibration at ISE (SR+IV)
- 3) Measurement at OAI (cells and result are sent to ISE)
- 4) ISE re-measures IV-curves of the cells
- 5) ISE compares the results (generates report)

Description of the calibrated object

The device under test is a silicon solar cell. The front contact is realised by the contact grid without cell interconnectors. The back contact is formed by the whole backside area of the cell. The used area is the "total area" /7/.

Measurement procedure

The calibration of the test sample was performed at Standard Testing Conditions (STC) in accordance with /1/ under irradiation with a steady-state class A solar simulator according to /6/. The irradiance is controlled with a monitor cell during the measurement in order to correct fluctuations. The divergence of the peripheral beams is $< 8^\circ$. The solar cell is kept at constant temperature on a vacuum chuck.

Traceability of the reference solar cell :

Identity-Nr. :	Certificate-Nr. :	Traceability :
023-2010	47048-PTB-13	PTB

The spectral mismatch - caused by the deviation of the simulator spectrum from the standard spectrum AM1.5G /3/ in combination with the different spectral response of reference cell and device under test (DUT) - is calculated according to /4/ and corrected. For the spectral mismatch correction the spectral distribution of the solar simulator is measured with a spectroradiometer, the spectral response of the DUT is measured with a filter monochromator according to /5/. The traceability of the measurement of the spectral distribution to SI-Units is achieved using a standard lamp for the calibration of the spectroradiometer.

Identity-Nr.:	Certificate-Nr.:	Traceability:
BN-9101-451	40002-14-PTB	PTB

Measurement conditions

Standardtestbedingungen (STC) / Standard Testing Conditions (STC) :

Total irradiance: 1000 W/m²
Temperature of the DUT: 25 °C
Spectral irradiance distribution: AM1.5G Ed.2 (2008) /3/

Measurement Uncertainty:

Open-circuit voltage : 0.34%
Short-circuit current
(Ed.2-2008): 1.90%
Fill factor : 0.65%
Efficiency : 2.00%
maximum
power : 2.00%

The expanded measurement uncertainty resulting from the standard measurement uncertainty multiplied with a factor $k=2$ is specified. The calculation was carried out according to the "Guide to the expression of Uncertainty in Measurement". The value corresponds to a Gaussian distribution denoting the deviations of the measurement value within a probability of 95%.

Description of measurement procedure at OAI

OAI IV Tester was used with cell No. 5 as reference for irradiance calibration: I_{SC} provided by ISE CalLab PV Cells was set as calibration factor. Measurement at OAI at 11/1/2014.

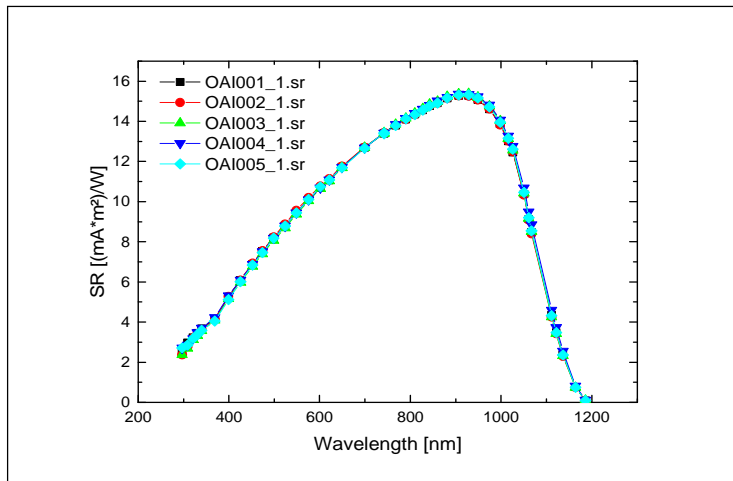
1) Short Term Stability Test

	after illumination	after dark storage	after illumination	after dark storage
	ΔU_{oc}	ΔU_{oc}	ΔI_{sc}	ΔI_{sc}
OAI001	0.01%	0.04%	0.26%	-0.10%
OAI002	0.14%	0.08%	0.47%	0.03%
OAI003	0.13%	0.12%	0.43%	-0.05%
OAI004	0.00%	0.09%	0.43%	-0.13%
OAI005	0.01%	0.02%	0.33%	-0.02%



2) Calibration at ISE

Ext. ID	Int. ID	MM	Area [cm ²]	I_{sc} [mA]	J_{sc} [mA/cm ²]	V_{oc} [mV]	I_{mpp} [mA]	J_{mpp} [mA/cm ²]	V_{mpp} [mV]	FF [%]	P_{mpp} [mW]	eta [%]	Ref. Cell ID
1	OAI001	1.0035	243.89	8670.7	35.55	631.4	8178.9	33.54	531.2	79.36	4344.9	17.82	023-2010
2	OAI002	1.0039	244.11	8704.8	35.66	628.7	8191.9	33.56	528.4	79.10	4328.6	17.73	023-2010
3	OAI003	1.0039	243.89	8663.6	35.52	630.7	8155.7	33.44	530.5	79.18	4326.5	17.74	023-2010
4	OAI004	1.0025	243.91	8710.1	35.71	631.3	8204.7	33.64	530.2	79.12	4350.5	17.84	023-2010
5	OAI005	1.0037	243.95	8680.3	35.58	628.1	8179.2	33.53	530.0	79.51	4335.0	17.77	023-2010



3) Measurement at OAI

Ext. ID		Area [cm ²]	I_{sc} [mA]	J_{sc} [mA/cm ²]	V_{oc} [mV]	I_{mpp} [mA]	J_{mpp} [mA/cm ²]	V_{mpp} [mV]	FF [%]	P_{mpp} [mW]	eta [%]	Ref. Cell ID
1		240.25	8723.6	36.31	630.43	8338.2	34.71	518.17	78.57	4320.7	17.98	5
2		240.25	8692.9	36.18	628.73	8281.7	34.47	517.17	78.37	4283.2	17.83	5
3		240.25	8669.3	36.08	628.77	8248.2	34.33	516.27	78.12	4258.3	17.72	5
4		240.25	8731.9	36.35	631.30	8332.8	34.68	517.83	78.28	4314.8	17.96	5
5	used as reference at OAI	240.25	8683.4	36.14	627.47	8292.2	34.52	516.47	78.63	4282.8	17.83	5

Comparison ISE/OAI

Ext. ID		Δ Area [%]	ΔI_{sc} [%]	ΔJ_{sc} [%]	ΔV_{oc} [%]	ΔI_{mpp} [%]	ΔJ_{mpp} [%]	ΔV_{mpp} [%]	ΔFF [%]	ΔP_{mpp} [%]
1		-1.50	0.61	2.12	-0.16	1.93	3.42	-2.49	-1.00	-0.56
2		-1.59	-0.14	1.46	0.01	1.09	2.68	-2.15	-0.93	-1.06
3		-1.50	0.07	1.58	-0.31	1.13	2.63	-2.72	-1.35	-1.59
4		-1.51	0.25	1.76	0.01	1.55	3.06	-2.37	-1.07	-0.82
5	used as reference at OAI	-1.53	0.04	1.57	-0.11	1.37	2.90	-2.59	-1.12	-1.21

The deviation for the comparison is calculated as: (OAI-ISE)/(OAI+ISE)*2.



4) Re-measurement at ISE: Comparison with initial measurement

Ext. ID	Int. ID			ΔI_{sc} [%]	ΔJ_{sc} [%]	ΔV_{oc} [%]	ΔI_{mpp} [%]	ΔJ_{mpp} [%]	ΔV_{mpp} [%]	ΔFF [%]	ΔP_{mpp} [%]
1	OAI001			-0.08	-0.08	0.13	0.05	0.05	0.13	0.12	0.18
2	OAI002			0.02	0.02	0.05	-0.03	-0.03	0.04	-0.05	0.01
3	OAI003			-0.24	-0.24	0.10	-0.17	-0.17	0.19	0.16	0.02
4	OAI004			-0.10	-0.10	0.06	-0.10	-0.10	0.01	-0.05	-0.09
5	OAI005			0.08	0.08	0.14	0.14	0.14	0.12	0.04	0.27

Literature

/1/ IEC 60904-1-Ed.2:2006, *Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics*

/2/ IEC 60904-3-Ed.1:1989, *Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

/3/ IEC 60904-3-Ed.2:2008, *Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

/4/ IEC 60904-7-Ed.3:2008, *Photovoltaic devices - Part 7: Computation of the spectral mismatch error introduced in the testing of a photovoltaic device*

/5/ IEC 60904-8-Ed.2:1998, *Photovoltaic devices - Part 8: Measurement of the spectral response of a photovoltaic (PV) device*

/6/ IEC 60904-9-Ed.2:2010, *Photovoltaic devices - Part 9: Solar simulator performance requirements*

/7/ M.A. Green, K. Emery, Y. Hishikawa, W. Warta, and E. D. Dunlop, *Solar cell efficiency tables (version 39)*. Progress in Photovoltaics: Research and Applications, 2012. 20: p. 12-20.

Datum Leiter des Kalibrierlaboratoriums
Date Head of the calibration laboratory

Bearbeiter
Person in charge

27.11.2014 Wilhelm Warta

Jochen Hohl-Ebinger