



Proprietary Calibration Certificate

Object: thin film solar cell

Manufacturer: Solibro

Serial number: 130618-3A

Internal serial number: SBR003

Calibration mark: 1003196SBR0813

Customer: Solibro Reserach AB
Vallvägen 5
756 51 Uppsala
Sweden

Datafile: 00379_SBR003_27.09.2013_18-41_IV-Kennlinie.txt

Number of pages: 6

Date of calibration: 27.09.2013

Date of receipt: 12.08.2013

Head of calibration lab: Freiburg i.B., 11.10.2013 Examiner:

Wilhelm Warta

Astrid Semeraro

1. Description of the calibrated object

The device under test is a CIGS thin film solar cell on glass substrate. The contacts are realised by contact pads. The temporal stability of the solar cell performance was not controlled.

2. 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:
028-2010	47179-PTB-10	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 grating monochromator according to /5/ (cf. Calibration Mark: xxx).

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	40006-11-PTB	PTB

The entire inspection equipment used is subject to a controlled quality management system according to ISO 9001:2008.

3. Measurement conditions

Standard Testing Conditions (STC):

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

The measurement of the IV-curve is performed with a 4-quadrant power amplifier and a set of Burster calibration resistors.

4. Measurement result

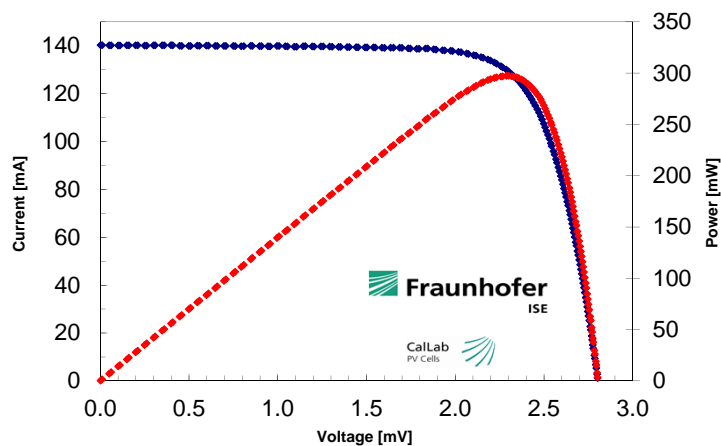
Mismatch factor : = 1.0007
 (for spectral correction)
 Area (da)¹: = (15.892 ± 0.049) cm²

IV-curve parameter under standard testing conditions (STC):

V_{OC} = (2.804 ± 0.014) V
 I_{SC} (Ed.2 - 2008)/3/ = (140.2 ± 3.5) mA
 I_{MPP} = 129.6 mA
 V_{MPP} = 2.293 V
 P_{MPP} = (297.2 ± 8.9) mW
 FF = (75.60 ± 0.76) %
 η = (18.70 ± 0.56) %

For comparison purposes:

Calculated value according to previous standard spectrum:
 I_{SC} (Ed.1 - 1989)/2/ = (139.4 ± 3.5) mA



¹: (t) = total area, (ap) = aperture area, (da) = designated illumination area

The expanded measurement uncertainty resulting of 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". It corresponds to a Gaussian distribution referring to the deviations of the measurement value within a probability of 95%.

Voltage [V]	Current [mA]	Power [mW]
-0.198	140.35	-27.8
-0.190	140.35	-26.7
-0.150	140.26	-21.0
-0.139	140.25	-19.5
-0.098	140.13	-13.7
-0.091	140.12	-12.8
-0.049	140.17	-6.9
-0.039	140.21	-5.5
0.001	140.28	0.2
0.010	140.27	1.4
0.050	140.20	7.0
0.061	140.21	8.5
0.101	140.15	14.1
0.110	140.14	15.4
0.149	140.18	20.9
0.161	140.18	22.5
0.199	140.19	27.9
0.210	140.18	29.5
0.249	140.10	34.9
0.261	140.08	36.6
0.300	140.19	42.0
0.309	140.21	43.3
0.349	140.22	48.9
0.360	140.22	50.5
0.398	140.24	55.9
0.408	140.23	57.2
0.447	140.01	62.6
0.459	139.96	64.2
0.498	139.95	69.8
0.508	139.96	71.2
0.546	140.05	76.5
0.558	140.03	78.2
0.597	140.07	83.6
0.609	140.09	85.3
0.647	139.93	90.5
0.659	139.90	92.1
0.697	139.92	97.5
0.708	139.92	99.0
0.749	139.94	104.8
0.760	139.89	106.3
0.794	139.80	111.0
0.809	139.84	113.1
0.847	139.98	118.6
0.857	139.96	119.9
0.897	139.84	125.4
0.908	139.87	127.0
0.944	139.80	132.0
0.957	139.76	133.7
0.996	139.92	139.3
1.007	139.93	140.9
1.042	139.81	145.7
1.055	139.76	147.5
1.093	139.61	152.6
1.106	139.62	154.4
1.144	139.83	159.9
1.155	139.83	161.5
1.193	139.70	166.7
1.205	139.69	168.3
1.243	139.71	173.6
1.256	139.73	175.5
1.292	139.66	180.4
1.307	139.58	182.4
1.342	139.51	187.3
1.353	139.52	188.8
1.391	139.48	194.1
1.403	139.44	195.7
1.441	139.40	200.9
1.452	139.38	202.4
1.491	139.33	207.8
1.504	139.34	209.5
1.539	139.30	214.4
1.549	139.28	215.8
1.587	139.18	220.9
1.601	139.13	222.8
1.636	139.18	227.7
1.652	139.22	229.9

Voltage [mV]	Current [mA]	Power [mW]
1.687	139.18	234.8
1.700	139.13	236.5
1.735	138.92	241.0
1.746	138.85	242.5
1.783	138.73	247.3
1.796	138.74	249.2
1.832	138.84	254.4
1.845	138.83	256.2
1.879	138.52	260.2
1.892	138.38	261.8
1.928	138.15	266.3
1.941	138.09	268.0
1.974	137.91	272.2
1.985	137.79	273.5
2.018	137.48	277.5
2.033	137.34	279.2
2.064	136.81	282.4
2.074	136.59	283.3
2.104	136.05	286.3
2.117	135.82	287.6
2.146	135.26	290.2
2.158	134.98	291.2
2.184	134.26	293.3
2.198	133.82	294.2
2.220	133.02	295.3
2.233	132.52	295.9
2.257	131.47	296.7
2.267	130.95	296.9
2.288	130.00	297.4
2.300	129.30	297.4
2.318	128.03	296.8
2.329	127.27	296.5
2.347	126.07	295.9
2.359	125.15	295.2
2.374	123.81	293.9
2.384	122.78	292.8
2.398	121.42	291.1
2.409	120.23	289.6
2.421	118.86	287.7
2.431	117.68	286.0
2.442	116.20	283.8
2.451	114.96	281.8
2.462	113.50	279.4
2.472	112.10	277.1
2.482	110.57	274.4
2.490	109.16	271.8
2.499	107.41	268.4
2.506	105.96	265.6
2.514	104.39	262.4
2.523	102.73	259.1
2.531	101.16	256.0
2.539	99.29	252.1
2.544	98.10	249.5
2.553	95.96	245.0
2.560	94.55	242.0
2.568	92.58	237.7
2.573	91.20	234.6
2.581	89.20	230.2
2.588	87.47	226.4
2.595	85.60	222.1
2.601	83.99	218.4
2.607	82.13	214.1
2.613	80.38	210.0
2.619	78.56	205.7
2.625	76.86	201.7
2.631	74.88	197.0
2.636	73.25	193.1
2.643	71.10	187.9
2.648	69.47	184.0
2.654	67.52	179.2
2.659	65.66	174.6
2.664	63.77	169.9
2.668	62.01	165.4
2.673	60.07	160.6
2.679	57.93	155.2
2.683	56.48	151.5

Voltage [V]	Current [mA]	Power [mW]
2.689	54.17	145.7
2.693	52.52	141.4
2.698	50.52	136.3
2.704	48.51	131.2
2.709	46.61	126.2
2.713	44.71	121.3
2.717	42.74	116.1
2.721	40.81	111.1
2.725	38.93	106.1
2.730	36.90	100.7
2.735	34.81	95.2
2.739	33.03	90.5
2.743	30.95	84.9
2.747	28.98	79.6
2.751	27.10	74.6
2.755	25.20	69.4
2.761	22.73	62.8
2.764	21.32	58.9
2.769	18.77	52.0
2.772	17.16	47.6
2.775	15.00	41.6
2.778	13.55	37.6
2.785	10.64	29.6
2.787	9.36	26.1
2.792	6.78	18.9
2.795	5.34	14.9
2.799	2.75	7.7
2.802	1.20	3.4
2.806	-1.16	-3.2
2.809	-2.79	-7.8
2.814	-5.45	-15.3
2.816	-6.63	-18.7
2.822	-9.64	-27.2
2.824	-10.74	-30.3
2.829	-13.66	-38.7

5. 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: 2007, Photovoltaic devices - Part 9: Solar simulator performance requirements

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