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Angle of Incidence Characterization of Six Laminated Solar Cells for 2020 DTU Fotonik Inter-Laboratory Comparison Study

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ABSTRACT

Photovoltaic energy prediction models include functions or modifiers to account for sun angle reflection losses. These functions may be known interchangeably as Angle of Incidence (AOI) or Incident Angle Modifier (IAM). While standards exist, there is no universally accepted single best practice for developing these functions. They can be generated through characterization of representative modules or single cells, in natural sunlight or indoors using simulated light sources. Repeatability of measurements and the viability of cross-laboratory comparisons are critical to confidence in validation of both methods.

To investigate the differences between methods and labs, The Technical University of Denmark (DTU) initiated an international round-robin test comparison between several key test labs with AOI measurement capability. A total of six minimodules were provided in three different cell/interconnect/backsheet combinations. Sandia characterized these minimodules using methods developed over two decades specifically for the outdoor characterization of full-size photovoltaic modules. This report documents the characterization results, summarizes key observations and tabulates the processed data for comparison to results provided by other characterization labs.

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Acronyms and Definitions

Abbreviation	Definition
AOI	Angle of Incidence
DAS	Data Acquisition System
DMM	Digital Multimeter
DNI	Direct Normal Irradiance
E_{diff}	Diffuse Global Plane of Array Irradiance
GNI	Global Normal Irradiance
GPOA	Global Plane of Array Irradiance
I_{sc}	Short Circuit Current
IEC	International Electrotechnical Commission
IV	Current-Voltage
ISO	International Standards Organization
NI	National Instruments
NIP	Normal Incident Pyrheliometer
PSL	Primary Standards Laboratory
PSEL	Photovoltaic Systems Evaluation Laboratory
RETC	Renewable Energy Test Center
RTD	Resistance Temperature Detector
SAPM	Sandia Array Performance Model
Si	Crystalline Silicon
V_{oc}	Open Circuit Voltage
WRR	World Radiometric Reference

1. INTRODUCTION

Photovoltaic energy prediction models include functions or modifiers to account for sun angle reflection losses. These functions may be known interchangeably as Angle of Incidence (AOI) or Incident Angle Modifier (IAM). While standards exist, there is no universally accepted single best practice for developing these functions. They can be generated through characterization of representative modules or single cells, in natural sunlight or indoors using simulated light sources. Repeatability of measurements and the viability of cross-laboratory comparisons are critical to confidence in validation of both methods.

To investigate the differences between methods and labs, The Technical University of Denmark (DTU) initiated an international round-robin test comparison between a number of key test labs with AOI measurement capability. Test labs included DTU Fotonik, Fraunhofer ISE CalLab, CFV Solar Test Labs, the Renewable Energy Test Center (RETC), PV Evolution Labs (PVEL) and Sandia National Laboratories' Photovoltaic Testing Evaluation Laboratory (PSEL).

Three types of minimodules were produced; multicrystalline - two bus bar; multicrystalline - three bus bar and monocrystalline – two bus bar. Duplicates of each were produced for a total of six. Multicrystalline minimodules featured a white backsheet, while monocrystalline minimodules featured a black backsheet.

Sandia characterized these minimodules using methods developed over two decades specifically for the outdoor characterization of full-size photovoltaic modules. This report documents the characterization results, summarizes key observations and tabulates the processed data for comparison to results provided by other characterization labs. Testing was conducted between November 19, 2019 and January 13, 2020.

2. TEST DEVICES AND EXPERIMENTAL CONFIGURATION

Six single cell mini-modules were provided by DTU to Sandia in November 2019. Two utilized a multicrystalline cell with two bus bars, two utilized a multicrystalline cell with three bus bars and two used a monocrystalline cell with two bus bars and a black back sheet. Each was fabricated with two exposed tabbing ribbons for electrical interconnect. While the construction details mirrored those expected for full size modules, the mini-modules feature a greater ratio of visible back sheet to cell area than is typical. The test devices are shown below in Figure 2-1 and listed in Table 2-1.

Figure 2-1 Six Laminated Cells with Exposed Tabbing Ribbon (Top – Back, Bottom – Front)

Table 2-1 Test Devices

Cell Type	Bus Bars	Backsheet	DTU Fotonik	PSEL ID
Multicrystalline	2	white	FTNK-APV-0000026	4375
Multicrystalline	2	white	FTNK-APV-0000025	4379
Multicrystalline	3	white	FTNK-APV-0000028	4376
Multicrystalline	3	white	FTNK-APV-0000027	4378
Monocrystalline	2	black	FTNK-APV-0000008	4377
Monocrystalline	2	black	FTNK-APV-0000020	4380

Prior to conducting angle of incidence testing, all samples were flash tested on a Spire 4600 SLP class AAA, one-sun solar simulator. The cells were then mounted coplanar on an azimuth/elevation solar tracker. All six cells were mounted together as a group on the lower left-hand arm along with a reference device (Figure 2-2).

Figure 2-2. Six Laminated Cells Mounted on Sandia's Two-Axis Solar Tracker

3. INDOOR CHARACTERIZATION

3.1. Flash Testing

Each module was flash tested on a Class AAA [2] Spire 4600 SLP one-sun simulator at Standard Test Conditions (STC) of 1000 W/m^2, 25°C and incident spectrum matched to Air Mass 1.5. IV curves were recorded in the forward direction, short-circuit current to open circuit voltage. All flash testing was performed prior to any solar exposure. A summary of flash test results is listed in Table 3-1.

Table 3-1. STC Electrical Performance of Single Cell Minimodules

PSEL ID	T, °C	Isc	Voc	Imp	Vmp	Pmp	FF (%)	Ω @ Voc	Ω @ Isc
4375	24.9	8.276	0.58	7.369	0.398	2.93	60.7	0.0175	6.13
4379	25	7.966	0.58	6.788	0.387	2.63	57	0.0196	2.85
4376	24.9	9.509	0.62	8.577	0.426	3.65	61.8	0.0163	33.6
4378	25	9.287	0.62	8.447	0.427	3.60	62.5	0.0166	22.6
4377	25	8.918	0.63	7.973	0.414	3.30	58.8	0.0204	20.5
4380	25.3	9.019	0.63	8.140	0.442	3.60	62.9	0.0164	7.94

3.2. Electroluminescence

Electroluminescence imaging was performed in a custom dark chamber housing a Reltron EL camera. Images were recorded at voltage bias levels set such that current levels of 80% Isc was reached. Multicrystalline, 2 bus bar minimodules required significantly longer exposure times than the other two designs.

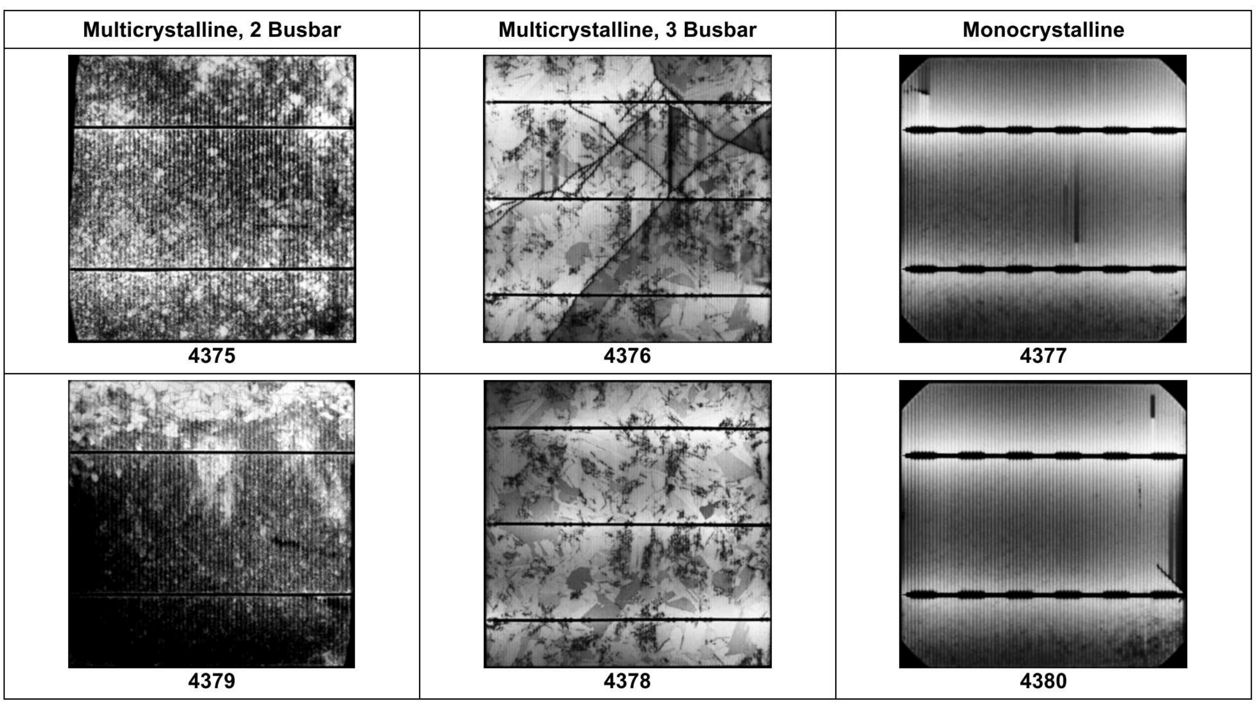

Figure 3-1. EL images for each minimodule at 80% measured Isc

4. TRACKER INSTRUMENTATION AND AOI TEST DETAILS

4.1. Cell Temperature Monitoring

Each cell was instrumented with a four wire Resistance Temperature Detector (RTD) (*Omega Engineering* SA1-RD-80, +/- .15 °C accuracy) adhered to the backsheet in the center of the cell with Kapton™ tape. The analog to digital (A/D) converters used to capture temperature signals (*ICPDAS* M7033) were not calibrated.

4.2. Data Acquisition System (DAS) Hardware

100-data point IV curves were recorded every two minutes when AOI tests were not being conducted. The modules were maintained in the maximum power state during these periods. Four wire measurements were made. During AOI testing, IV curves were swept continuously.

- Current and voltage signals were recorded on *National Instruments* (NI) PXIE-4081 digital multimeters (DMMs) with 7 ½ digit accuracy. The meters are calibrated at Sandia's International Standards Organization (ISO)-accredited *Primary Standards Laboratory* (PSL) annually.
- Voltage signals from each test device are switched into a single DMM channel with an NI PXIe-2527 Multiplexer. Current signals from each device are recorded on a different channel using the same DMM hardware.
- *Empro* Manganin™ shunts were used to capture current signals. These shunts were not calibrated but have been characterized numerous times.
- NI RMX-4120DC power supplies were used to back bias the cells.
- *Chroma Systems Solutions* 63640-80-80 electronic DC loads were used for IV curve tracing.

4.3. Irradiance Instrumentation

- Global plane of array irradiance (GPOA) and diffuse GPOA were both measured with *Kipp and Zonen* CMP11 pyranometers, mounted co-planar to the modules (clear sky uncertainty 2.0%). Use of this local diffuse measurement differs from procedures described in IEC 61835-2 [2], where diffuse irradiance is calculated from Direct Normal Irradiance (DNI) and Global Normal Irradiance (GNI).
- DNI was measured with a *Kipp and Zonen* CHP 1 normal incident pyrheliometer (NIP) mounted on a separate solar tracker that is part of the Photovoltaic Systems Evaluation Laboratory's (PSEL) weather station.
- All irradiance instruments were calibrated and traceable to the World Radiometric Reference (WRR).

4.4. Testing Procedure

AOI test and analysis procedures followed the Preferred Method described in [1]. The tracker was indexed in elevation only during the test and continued to track the Sun in azimuth. Indexing was from 0° to 85° in decreasing angular steps. The tracker was held at each angular offset while a minimum of five IV sweeps were measured. I_{sc} values used in the analysis were temperature corrected using *in-situ* derived temperature coefficients and averaged for each angular offset.

4.5. Test Conditions

Multiple AOI tests were run in November and December of 2019, but only results from three tests that were conducted over consecutive days in January 2020 are reported on because of measured cell temperature data loss due to communication issues. Each test was run such that the middle of the test (when the tracker was off-sun 45° in elevation) occurred at solar noon. Shown below in Table 4-1, ambient weather and irradiance conditions were stable throughout each test. Environmental variability is shown as 1-standard deviation for most measured quantities. Variations in measured irradiance values were on the order of the instrument calibration uncertainties. DNI/GNI ratios were almost as high as typically observed in Albuquerque (.92) indicating near optimal test conditions. Due to the time of year of the testing, absolute Air Mass was stable at 1.5 over all three tests. Variations between days were likewise relatively low.

Table 4-1. Weather Conditions for Three AOI Test Periods

Condition	1/11/2020	1/12/2020	1/13/2020
Ambient Temperature (°C)	1.7 ± 0.6	4.4 ± 0.3	9.2 ± 0.5
Wind Speed (m/s)	2.9 ± 1.0	2.3 ± 0.8	4.4 ± 1.2
Relative Humidity (%)	25	28	23
DNI W/m^2	1035 ± 1	1024 ± 3	1010 ± 1
GNI W/m^2	1133 ± 2	1124 ± 2	1122 ± 1
DNI/GNI	0.91	0.91	0.90
Air Mass	1.51 ± 0.01	1.51 ± 0.00	1.50 ± 0.01

5. ANGLE OF INCIDENCE TEST RESULTS

5.1. All Test Results

Four or five data points (measured Isc) per off-sun tracking angle were used for analysis. The average total number of data points per AOI test was 105. AOI test results shown below are grouped by PVID with three different test dates. AOI responses of each cell were satisfactory and repeatable. Modules with three bus bars displayed a slight tendency for response to rise above 1, possibly due to internal reflection off the increased bus bar area.

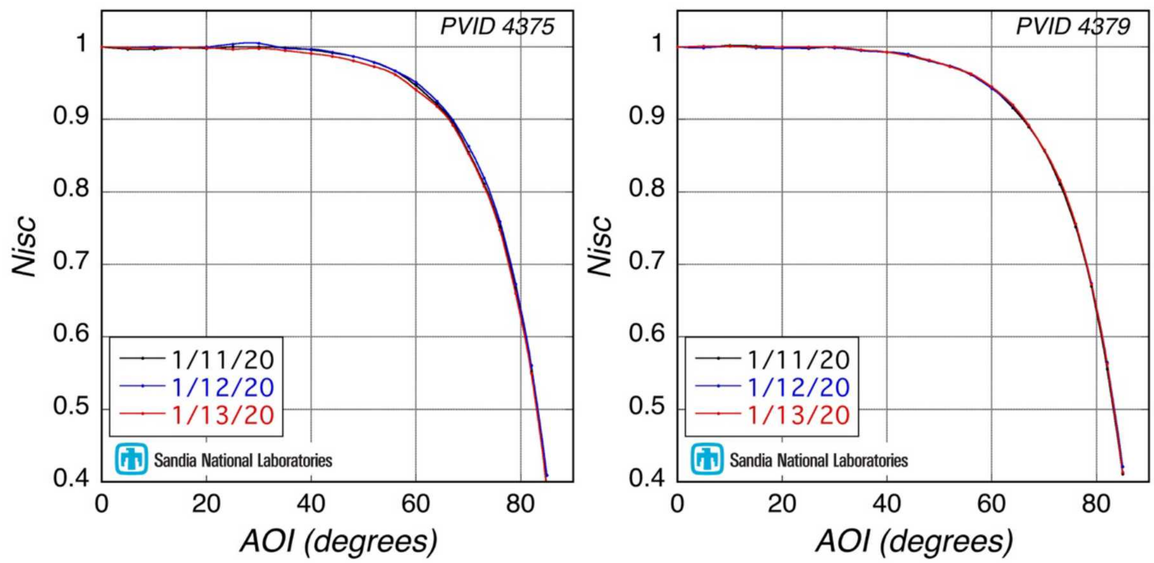

Figure 5-1. AOI Response of Multicrystalline, 2-Bus Bar Minimodules

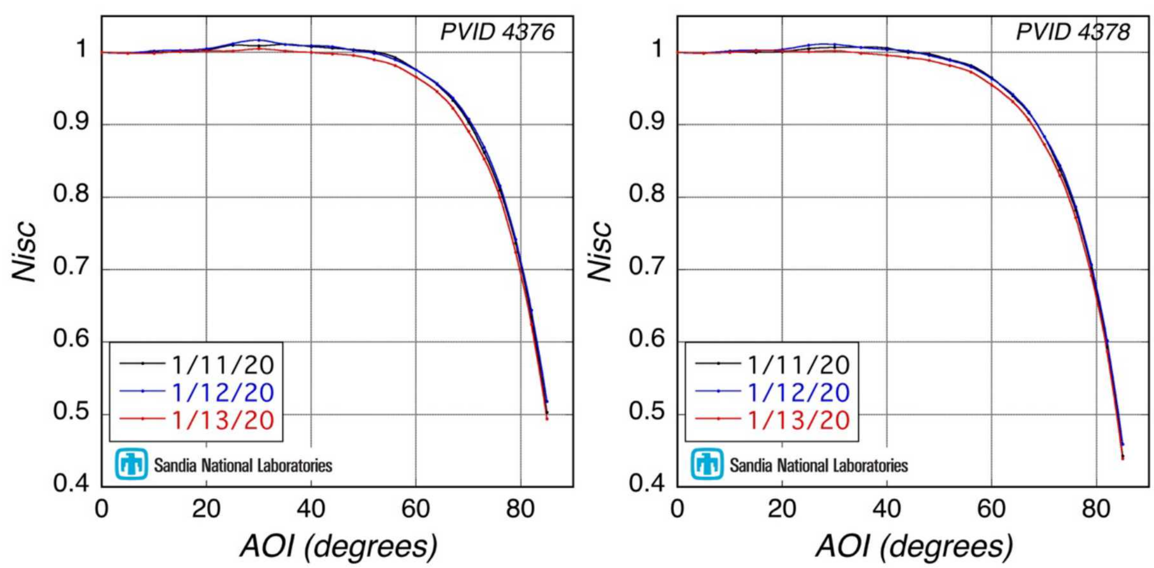

Figure 5-2. AOI Response of Multicrystalline, 3-Bus Bar Minimodules

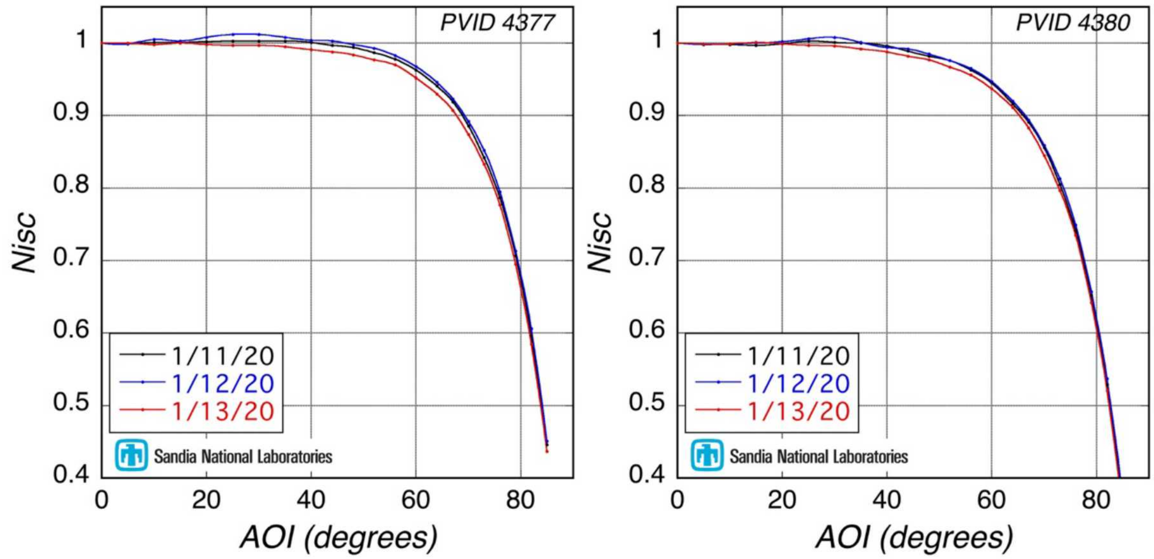

Figure 5-3. AOI Response of Monocrystalline, Black Backsheet Minimodules

5.2. Comparison between duplicate minimodules

Results from each day for each module were averaged. A comparison between minimodules of similar construction showed identical behavior for the multicrystalline, two bus bar design and a slight deviation at steep angles (> 40°) for the other two designs.

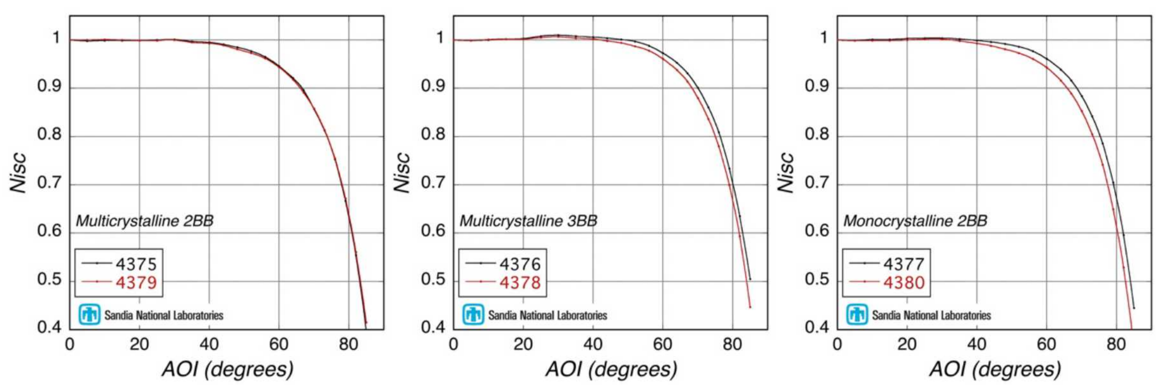

Figure 5-4. AOI Response of each cell/package type compared. Curves are an average of three days of testing.

5.3. Comparison between cell/package types

Finally, results from all testing for each module type were averaged to compare between cell/package types. Here, minimodules with two bus bars displayed nearly identical behavior while minimodules with three bus bar design displayed slightly enhanced response at all incident angles above ~20°.

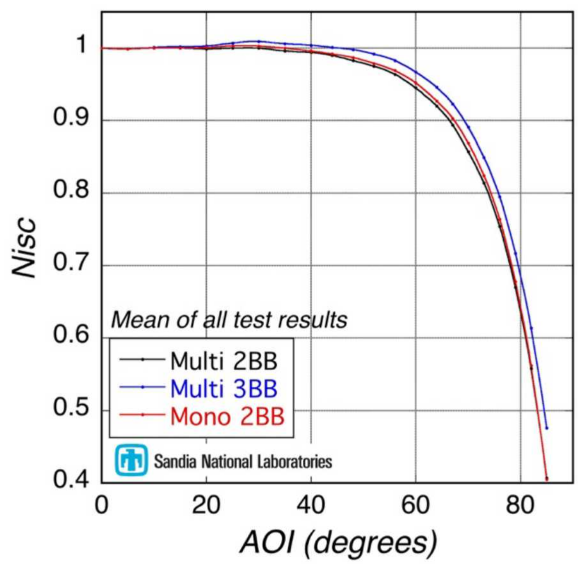

Figure 5-5. Comparison of AOI response between different cell/package combinations

REFERENCES

[1] Bruce H. King, Clifford W. Hansen, Dan Riley, Charles D. Robinson, Larry Pratt, "Procedure to Determine Coefficients for the Sandia Array Performance Model (SAPM)," SAND2016-5284, Sandia National Laboratories, Albuquerque, NM, 2016.

[2] IEC 61853-2:2016, "Photovoltaic (PV) module performance testing and energy rating – Part 2: Spectral responsivity, incident angle and module operating temperature measurements"

APPENDIX A. PROCESSED DATA TABLES

Processed test results are presented below. Each entry is an average of multiple measurements at each angle.

A.1. Multicrystalline, Two Bus Bar

Table A-1. PVID 4375, FTNK-APV-0000026

AOI	Test Date						Three Day Average
	1/11/2020		1/12/2020		1/13/2020		
	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}
0	1.000	0.000	1.000	0.000	1.000	0.001	1.000
5	0.997	0.001	0.999	0.001	0.999	0.001	0.998
10	0.997	0.001	1.000	0.001	0.999	0.001	0.999
15	0.999	0.001	0.999	0.001	0.999	0.001	0.999
20	0.998	0.001	1.000	0.001	0.999	0.000	0.999
25	1.000	0.001	1.004	0.001	0.997	0.000	1.000
30	1.000	0.001	1.005	0.000	0.998	0.000	1.001
35	0.999	0.001	0.998	0.004	0.995	0.001	0.997
40	0.996	0.001	0.997	0.001	0.991	0.001	0.995
44	0.992	0.003	0.993	0.001	0.987	0.001	0.991
48	0.987	0.001	0.987	0.002	0.981	0.001	0.985
52	0.979	0.001	0.979	0.001	0.973	0.001	0.977
56	0.967	0.001	0.967	0.001	0.962	0.001	0.965
60	0.947	0.001	0.951	0.002	0.941	0.001	0.946
64	0.921	0.002	0.925	0.001	0.918	0.001	0.921
67	0.896	0.002	0.899	0.001	0.892	0.002	0.896
70	0.855	0.008	0.863	0.002	0.853	0.001	0.857
73	0.811	0.001	0.819	0.003	0.808	0.002	0.813
76	0.752	0.003	0.759	0.002	0.748	0.002	0.753
79	0.668	0.003	0.673	0.001	0.660	0.002	0.667
82	0.552	0.003	0.561	0.002	0.550	0.004	0.554
85	0.395	0.001	0.409	0.003	0.392	0.007	0.399

Table A-2. PVID 4379, FTNK-APV-0000025

AOI	Test Date						Three Day Average
	1/11/2020		1/12/2020		1/13/2020		
	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}
0	1.000	0.001	1.000	0.001	1.000	0.001	1.000
5	0.999	0.001	0.999	0.001	1.001	0.001	1.000
10	1.002	0.002	1.001	0.001	1.001	0.001	1.001
15	1.001	0.002	0.999	0.001	1.000	0.001	1.000
20	1.000	0.001	0.998	0.001	1.000	0.001	0.999
25	0.998	0.001	0.999	0.001	1.000	0.001	0.999
30	1.000	0.000	0.999	0.001	1.000	0.001	1.000
35	0.995	0.001	0.995	0.000	0.996	0.001	0.995
40	0.993	0.001	0.993	0.001	0.993	0.001	0.993
44	0.988	0.001	0.990	0.002	0.988	0.001	0.989
48	0.981	0.001	0.981	0.001	0.982	0.001	0.981
52	0.973	0.001	0.974	0.000	0.973	0.002	0.973
56	0.962	0.001	0.962	0.001	0.963	0.001	0.962
60	0.944	0.003	0.943	0.003	0.945	0.001	0.944
64	0.916	0.001	0.919	0.001	0.920	0.002	0.918
67	0.890	0.002	0.892	0.002	0.892	0.002	0.891
70	0.857	0.001	0.858	0.002	0.858	0.001	0.858
73	0.811	0.004	0.816	0.004	0.816	0.001	0.814
76	0.752	0.002	0.756	0.002	0.756	0.001	0.755
79	0.670	0.003	0.674	0.001	0.673	0.003	0.672
82	0.556	0.012	0.565	0.002	0.563	0.001	0.561
85	0.411	0.005	0.421	0.009	0.413	0.005	0.415

A.2. Multicrystalline, Three Bus Bar

Table A-3. PVID 4376, FTNK-APV-0000028

AOI	Test Date						Three Day Average
	1/11/2020		1/12/2020		1/13/2020		
	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}
0	1.000	0.001	1.000	0.001	1.000	0.001	1.000
5	0.999	0.001	0.999	0.001	0.999	0.000	0.999
10	1.000	0.001	1.002	0.001	0.999	0.001	1.000
15	1.001	0.002	1.003	0.001	1.001	0.001	1.002
20	1.003	0.002	1.005	0.003	1.002	0.001	1.003
25	1.010	0.000	1.012	0.001	1.002	0.001	1.008
30	1.009	0.001	1.017	0.000	1.005	0.001	1.010
35	1.011	0.000	1.011	0.001	1.002	0.001	1.008
40	1.008	0.002	1.009	0.002	1.000	0.001	1.006
44	1.006	0.001	1.008	0.002	0.998	0.001	1.004
48	1.004	0.001	1.003	0.000	0.996	0.002	1.001
52	1.001	0.001	0.999	0.002	0.990	0.002	0.997
56	0.993	0.001	0.990	0.001	0.982	0.001	0.988
60	0.976	0.001	0.976	0.001	0.966	0.001	0.973
64	0.956	0.001	0.957	0.002	0.946	0.001	0.953
67	0.934	0.001	0.937	0.002	0.923	0.000	0.931
70	0.904	0.001	0.908	0.002	0.891	0.001	0.901
73	0.862	0.001	0.869	0.001	0.853	0.002	0.861
76	0.810	0.002	0.816	0.001	0.800	0.001	0.809
79	0.737	0.002	0.742	0.001	0.724	0.001	0.734
82	0.635	0.003	0.644	0.002	0.625	0.002	0.635
85	0.503	0.004	0.518	0.003	0.494	0.007	0.505

Table A-4. PVID 4378, FTNK-APV-0000027

AOI	Test Date						Three Day Average
	1/11/2020		1/12/2020		1/13/2020		
	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}
0	1.000	0.002	1.000	0.001	1.000	0.001	1.000
5	0.999	0.000	0.999	0.001	0.999	0.002	0.999
10	1.001	0.001	1.002	0.001	1.000	0.000	1.001
15	1.000	0.002	1.003	0.002	1.002	0.001	1.002
20	1.001	0.002	1.004	0.001	1.002	0.001	1.002
25	1.005	0.001	1.010	0.002	1.001	0.001	1.005
30	1.007	0.000	1.011	0.001	1.002	0.001	1.007
35	1.007	0.000	1.007	0.001	0.999	0.001	1.004
40	1.006	0.001	1.004	0.001	0.996	0.001	1.002
44	1.000	0.001	1.002	0.002	0.993	0.001	0.998
48	0.998	0.002	0.996	0.001	0.989	0.002	0.994
52	0.990	0.001	0.989	0.001	0.982	0.001	0.987
56	0.982	0.001	0.980	0.001	0.973	0.001	0.978
60	0.965	0.001	0.964	0.000	0.955	0.001	0.961
64	0.940	0.002	0.942	0.001	0.932	0.002	0.938
67	0.917	0.002	0.918	0.002	0.907	0.001	0.914
70	0.884	0.001	0.884	0.001	0.873	0.000	0.880
73	0.838	0.002	0.844	0.001	0.830	0.002	0.837
76	0.782	0.003	0.787	0.002	0.772	0.001	0.780
79	0.702	0.003	0.707	0.002	0.692	0.003	0.700
82	0.593	0.004	0.602	0.002	0.587	0.003	0.594
85	0.443	0.007	0.459	0.003	0.439	0.003	0.447

A.3. Monocrystalline, Two Bus Bar, Black Backsheet

Table A-5. PVID 4377, FTNK-APV-0000028

AOI	Test Date						Three Day Average
	1/11/2020		1/12/2020		1/13/2020		
	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}
0	1.000	0.000	1.000	0.003	1.000	0.001	1.000
5	0.999	0.001	0.999	0.002	1.000	0.001	0.999
10	1.001	0.002	1.005	0.001	0.998	0.001	1.001
15	1.001	0.002	1.003	0.001	1.000	0.001	1.001
20	1.002	0.003	1.008	0.002	0.998	0.001	1.003
25	1.003	0.001	1.012	0.002	0.997	0.001	1.004
30	1.003	0.001	1.012	0.001	0.997	0.001	1.004
35	1.003	0.001	1.008	0.001	0.995	0.001	1.002
40	1.001	0.001	1.004	0.001	0.991	0.000	0.999
44	0.997	0.001	1.003	0.001	0.988	0.001	0.996
48	0.994	0.001	0.998	0.000	0.984	0.001	0.992
52	0.987	0.001	0.993	0.002	0.977	0.001	0.986
56	0.978	0.001	0.983	0.001	0.970	0.001	0.977
60	0.963	0.002	0.968	0.001	0.952	0.001	0.961
64	0.941	0.002	0.946	0.002	0.930	0.001	0.939
67	0.919	0.001	0.923	0.002	0.907	0.001	0.916
70	0.886	0.002	0.892	0.002	0.874	0.002	0.884
73	0.842	0.001	0.852	0.001	0.833	0.002	0.842
76	0.787	0.002	0.795	0.002	0.777	0.001	0.786
79	0.707	0.004	0.713	0.002	0.695	0.002	0.705
82	0.596	0.002	0.606	0.003	0.585	0.002	0.596
85	0.446	0.005	0.451	0.027	0.437	0.007	0.445

Table A-6. PVID 4380, FTNK-APV-0000020

AOI	Test Date						Three Day Average
	1/11/2020		1/12/2020		1/13/2020		
	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}	Standard Deviation	Normalized I_{sc}
0	1.000	0.001	1.000	0.001	1.000	0.002	1.000
5	0.999	0.001	0.998	0.001	0.999	0.001	0.999
10	0.998	0.001	0.999	0.002	0.999	0.002	0.999
15	0.997	0.002	1.000	0.001	1.001	0.001	0.999
20	0.999	0.003	1.002	0.003	0.999	0.001	1.000
25	1.003	0.001	1.006	0.002	0.997	0.000	1.002
30	1.001	0.001	1.008	0.001	0.996	0.000	1.002
35	1.000	0.001	1.001	0.002	0.992	0.001	0.998
40	0.996	0.001	0.994	0.001	0.988	0.001	0.993
44	0.989	0.001	0.992	0.003	0.982	0.001	0.988
48	0.982	0.002	0.985	0.001	0.977	0.001	0.981
52	0.976	0.001	0.976	0.001	0.967	0.003	0.973
56	0.963	0.001	0.965	0.001	0.956	0.000	0.961
60	0.945	0.002	0.947	0.001	0.937	0.001	0.943
64	0.916	0.004	0.920	0.001	0.911	0.002	0.916
67	0.891	0.001	0.894	0.001	0.883	0.002	0.889
70	0.856	0.001	0.859	0.002	0.845	0.000	0.853
73	0.805	0.003	0.813	0.001	0.797	0.002	0.805
76	0.742	0.002	0.749	0.002	0.735	0.002	0.742
79	0.652	0.001	0.657	0.001	0.642	0.003	0.650
82	0.529	0.004	0.537	0.004	0.521	0.003	0.529
85	0.366	0.006	0.376	0.004	0.353	0.005	0.365

APPENDIX B. SERIAL NUMBER CROSS-REFERENCE

Table A-7. Serial Number Cross Reference

PSEL	DTU Fotonik	Fraunhofer	CFV	RETC	PVEL
4375	FTNK-APV-0000026	002TUD0418 TUD 007	19003-004	C-CA-1904-RET-045-D	PVEL-ENG-006-BoM 1
4376	FTNK-APV-0000028	002TUD0418 TUD 008	19003-006	C-CA-1904-RET-045-A	PVEL-ENG-006-BoM 1
4377	FTNK-APV-0000008	002TUD0418 TUD 003	19003-001	C-CA-1904-RET-045-E	PVEL-ENG-006-BoM 1
4378	FTNK-APV-0000027	002TUD0418 TUD 006	19003-005	C-CA-1904-RET-045-B	PVEL-ENG-006-BoM 1
4379	FTNK-APV-0000025	002TUD0418 TUD 005	19003-003	C-CA-1904-RET-045-C	PVEL-ENG-006-BoM 1
4380	FTNK-APV-0000020	002TUD0418 TUD 004	19003-002	C-CA-1904-RET-045-F	PVEL-ENG-006-BoM 1

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