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CHARACTERIZATION OF ASEC BSR 2 OHM-CM SILICON SOLAR CELLS WITH DIELECTRIC WRAPAROUND CONTACTS AS A FUNCTION OF TEMPERATURE AND INTENSITY

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16. ABSTRACT

Twenty high performance BSR 2 ohm-cm silicon solar cells manufactured by ASEC have been evaluated at 1 AU conditions and at low temperatures and low intensities representative of deep space. These cells showed evidence of series resistance at 1 AU conditions and approximately 50% had reduced power outputs under deep space conditions. Average efficiency of these cells was 12.4% at 1 AU conditions of 1 SC/+25°C.

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TECHNICAL MEMORANDUM

CHARACTERIZATION OF ASEC BSR 2 OHM-CM SILICON SOLAR CELLS WITH DIELECTRIC WRAPAROUND CONTACTS AS A FUNCTION OF TEMPERATURE AND INTENSITY

I. INTRODUCTION

This is the fourth in a series of reports on the characterization of high performance cells under conditions of low temperatures and low intensities (LTLI). The data provided in these reports are aimed at identifying which of the currently available solar cells possess the best characteristics for deep space performance. Specifically, these data were produced to determine if the LTLI problems present in cells with conventional contacts were present in cells with wraparound contacts. This report contains data on 20 ASEC BSR 2 ohm-cm silicon cells with wraparound contacts taken at 2 temperatures and 2 intensities along a proposed deep space mission profile.

II. TEST PROGRAM

The cells as described in Table 1 were manufactured by Applied Solar Energy Corporation (ASEC) as high performance production run cells and were fabricated from crucible-grown p-type silicon, boron doped to a nominal resistivity of 2 ohm-cm. These cells which are 2 cm x 4 cm x 0.020 cm (8 mils) thick have dielectric wraparound contacts with 12 line grid patterns running the length of one side. Contact materials are Ti-Pd-Ag and the back surface reflector is formed from evaporated aluminum. A multilayer antireflectance coating was applied to the top of the cell.

Evaluation of the cells was made at three space environmental conditions: 1 SC/+25°C, 0.086 SC/+25°C and 0.086 SC/-100°C as described in Table 2. While this test profile was not as extensive as previous cell test profiles it is sufficient to define 1 AU cell performance capabilities and to determine the extensiveness of cell performance problems under LTLI conditions. Dark I-V data were generated at +25°C, 0°C and -50°C and is to be the subject of a separate report.

The cells were tested in three sets: Cells 1-5 comprised set 1, cells 6-12 set 2 and cells 13-20 set 3. A typical set is shown mounted in Figure 1. The cells were held in place to a copper plate by RTV 560. The copper plate was then heat sunk to a plate configured for cooling with liquid nitrogen and for heating with hot air. The copper plate and two cells were thermocoupled and temperatures monitored continually. Cell temperatures were maintained independent of the incident solar intensity to within $\pm 0.5^\circ C$ at $25^\circ C$ and $-100^\circ C$. The cells were installed in a vacuum system having a 30-cm diameter, 6 mm thick UV grade fused quartz window and tested at a pressure of 1×10^{-4} pascal or less.

The illumination source was a Spectrolab filtered X-75 solar simulator. This system provides a combined beam from three 2.5 kW xenon lamps covering an area of 230 cm^2. Beam intensity was measured at each cell position and was determined to have a uniformity of ± 2 percent. The spectral output was modified through the use of a filter system to approximate the solar spectrum. Illumination levels were maintained through the use of a set of neutral density filters and by varying the position of the test chamber. Cell illumination level was monitored by the use of a water-cooled calibrated cell in the test chamber that was maintained at $28^\circ C \pm 0.5^\circ C$. One solar constant utilized in the calibration was 135.3 mW/cm^2.

A Spectrolab electronic load model D-1550 provided the variable load for the cells. The cell I-V curves were plotted on an X-Y recorder. Digital voltmeters were used to read the open circuit voltages and short circuit currents. All instruments were calibrated prior to the initiation of these tests. The test setup with associated instrumentation is shown in Figure 2.

III. PRESENTATION OF TEST RESULTS

Current-voltage characteristics for each of the 20 cells were measured at the three environmental test conditions described above. These data, short circuit current (ISC), open circuit voltage (VOC), maximum power current (IMP), and maximum power voltage (VMP) are shown for each cell in Tables 3, 4 and 5 along with calculated maximum power (MP), fill factor (FF) and efficiency (EFF). Average values for these 20 cell data are shown along with their standard deviations. Effect of nonuniformity of beam illumination ($\pm 2\%$) is included in all cell current data as is the effect of temperature variation ($\pm .5^\circ C$) included in the voltage data. Table 6 contains temperature coefficients for VOC and MP determined between 0.086 SC/+$25^\circ C$ and 0.086 SC/ $-100^\circ C$.

IV. SUMMARY OF RESULTS

The 20 cells had closely matched current-voltage (I-V) characteristics at 1 AU conditions as is shown in Table 3. Some series resistance was evident in the

I-V curves and was determined using the method of Wolf and Rauschenbach to be approximately 0.2 ohm. Previous tests on 2 x 2 cm cells of the same nomenclature with conventional contacts had shown no appreciable series resistance.

Under LTLI conditions of 0.086 SC/-100°C a divergence of performance characteristics was observed in the 20 cells as noted in the current voltage parameters in Table 5. VMP values were as low as 491 mV. VOC suppression was also noted in four cells. Eleven cells showed evidence of reduced power output in the MP region (flat spot or broken knee effect) with six of these cells having severely broken knees. The flat spot or broken knee effect has been associated with the dissolution of silicon into the front contact metallization with the attendant formation of metal-silicide regions which extend through the cell junction. It is thought that this process occurs during the manufacturing of the cell and its effect is manifested only at LTLI conditions. The remaining nine cells showed no problems although four showed some rounding of the I-V curve in the MP region (soft knee). Temperature coefficients for VOC are given in Table 6 and averaged 2.2 mV/°C as expected. Also shown are coefficients for MP which vary depending upon the reduced VMP at low temperatures.

Performance problems at LTLI evident in the 2 x 4 cm wraparound contact cells are the same as those identified previously in the 2 x 2 cm cells with conventional contacts. The statistics of BSR cell performance at LTLI are also similar - approximately 50% are good. The appearance of appreciable series resistance at the high intensities was not seen in the previous testing of this type of cell with conventional contacts.

Solar cell data generated from these series of investigations are being provided to the solar cell manufacturers to aid in their cell design activities and to the solar array designers to assist in sizing the array.

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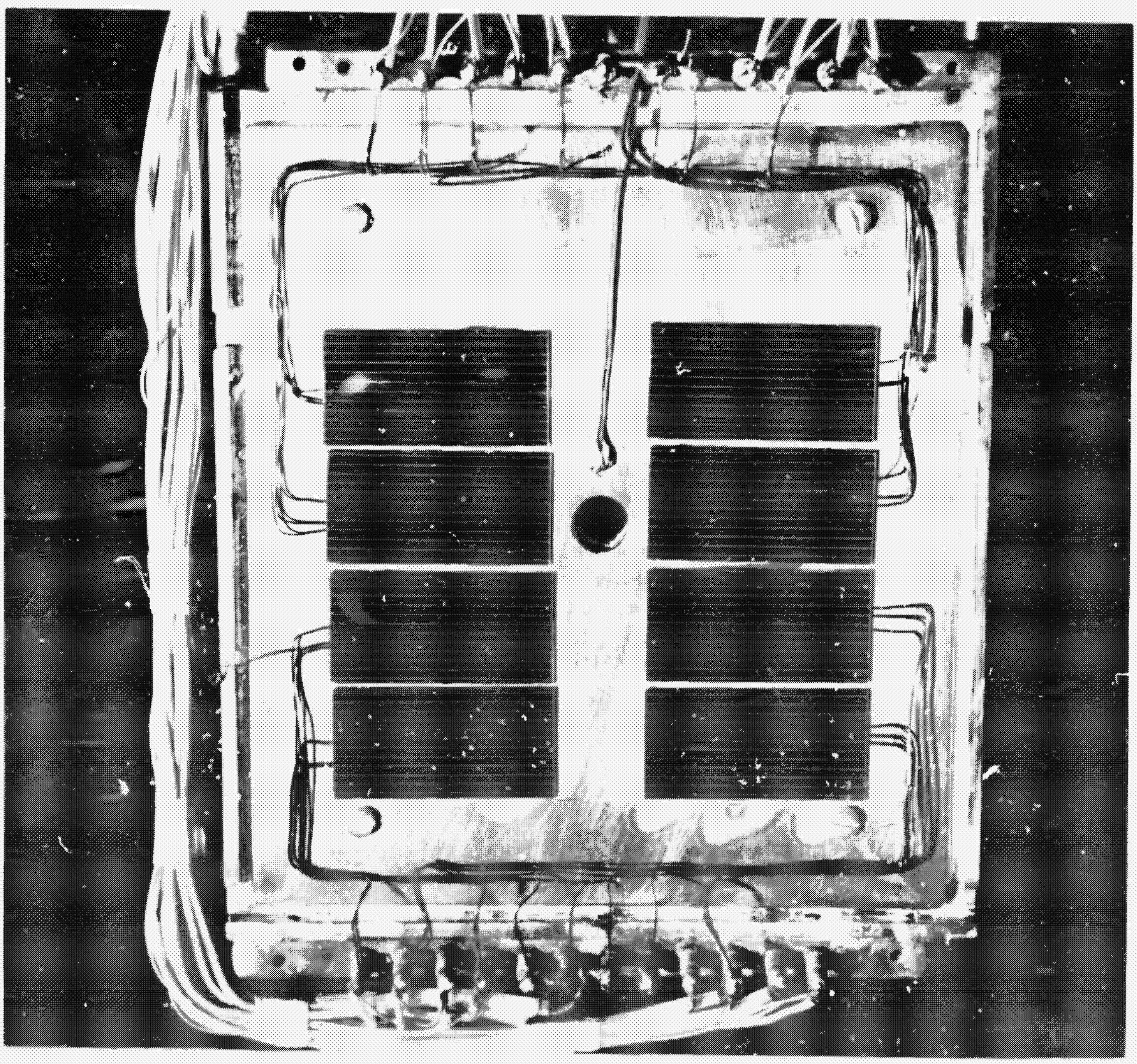

Figure 1. Solar Cell Test Plate

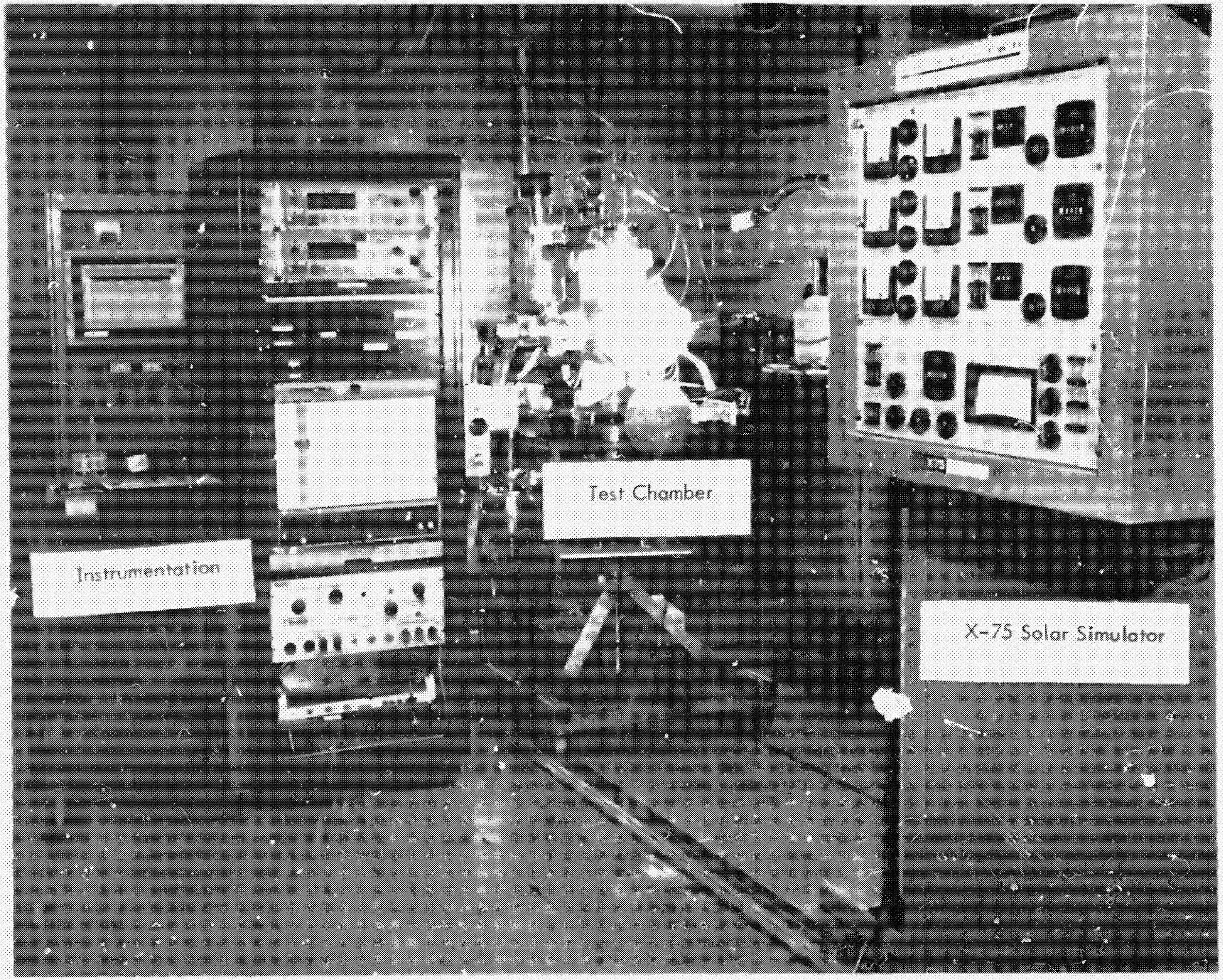

Figure 2. Solar Cell Characterization Equipment and Instrumentation

TABLE 1. TEST CELL DESCRIPTION

Number of Cells Tested	20
Type	N/P BSR with Dielectric Wraparound Contacts
Manufacturer	Applied Solar Energy Corporation
Silicon	Crucible-Grown P-Type, Boron-Doped
Size	2 cm x 4 cm x .020 cm (8 mils)
Nominal Base Resistivity	2 ohm-cm
Junction Depth	Shallow Diffused
Contacts	Ti-Pd-Ag, Dielectric Wraparound
BSR	Evaporated Aluminum
Grids	12 Lines
Cover Glass	Fused Silica
AR Coating	Multilayer

TABLE 2. TEST PROFILE

Illumination Level (SC)	Temperature (°C)
1.0	+25°C
0.086	+25°C, -100°C
Dark I-V	+25°C, 0°C, -50°C

TABLE 3

CURRENT-VOLTAGE DATA FOR BSR

2 OHM-CM WRAP-AROUND CONTACT

CELLS AT ILLUMINATION/TEMPERATURE OF 1 SC/+25°C

Parameter \ Cell No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	AVG.	STD. DEV.
ISC (mA)	304	302	310	305	305	320	308	309	313	304	307	313	305	30[illegible]	302	305	307	307	307	316	307.8	4.6
VOC (mV)	594	592	593	588	585	603	601	595	594	594	598	593	592	598	594	598	594	595	594	594	594.5	4.0
IMP (mA)	277	276	277	273	274	299	279	282	286	276	288	289	284	286	277	283	284	284	282	286	282.1	6.2
VMP (mV)	477	470	477	466	470	477	488	479	472	478	471	473	471	475	474	478	478	478	475	478	475.3	4.7
MP (mW)	132.0	129.8	132.0	127.3	129.0	142.6	135.9	135.4	134.9	132.2	135.5	136.9	133.8	136.0	131.1	135.2	135.6	135.6	134.1	[illegible]	[illegible]	[illegible]
FF	.73	.73	.72	.71	.72	.74	.73	.74	.73	.73	.74	.74	.74	.74	.73	.74	.74	.74	.74	.73	.73	.01
EFF (%)	12.2	12.0	12.2	11.8	11.9	13.2	12.6	12.5	12.5	12.2	12.5	12.6	12.4	12.6	12.1	12.5	12.5	12.4	12.5	12.7	12.4	.3

TABLE 4

CURRENT-VOLTAGE DATA FOR BSR

2 OHM-CM WRAP-AROUND CONTACT

CELLS AT ILLUMINATION/TEMPERATURE OF 0.086 SC/+25°C

Cell Parameter \ Cell No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	AVG.	STD. DEV.
ISC (mA)	25.9	25.5	26.5	26.1	26.4	26.3	25.1	26.1	26.9	25.4	26.6	26.3	25.1	25.0	25.3	25.[illegible]	26.4	25.8	26.8	26.7	25.7	1.4
VOC (mV)	521	522	514	515	519	532	531	528	529	525	530	527	523	522	523	529	528	528	522	525	524.7	5.0
IMP (mA)	23.4	22.0	20.4	19.2	22.5	23.3	21.5	23.1	24.4	21.9	24.5	23.2	22.2	20.8	21.9	22.2	22.5	23.2	22.4	23.6	22.4	1.3
VMP (mV)	432	451	428	423	424	451	450	451	446	444	446	451	444	425	438	444	444	438	444	437	440.6	9.5
MP (mW)	10.1	9.9	8.7	8.1	9.5	10.5	9.7	10.4	10.8	9.7	10.8	10.5	9.9	8.9	9.8	9.6	10.0	10.2	9.9	10.3	9.9	.7
FF	.75	.74	.64	.60	.69	.75	.73	.75	.76	.73	.77	.76	.75	.68	.73	.73	.72	.75	.71	.73	.72	.04
EFF (%)	10.8	10.6	9.3	8.7	10.2	11.3	10.4	11.2	11.6	10.4	11.6	11.3	10.6	9.6	10.3	10.5	10.7	11.0	10.6	11.1	10.6	.7

TABLE 5

CURRENT-VOLTAGE DATA FOR BSR
2 OHM-CM WRAP-AROUND CONTACT
CELLS AT ILLUMINATION/TEMPERATURE OF 0.086 SC/-100°C

Cell Parameter \ Cell No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	AVG.	STD. DEV.
ISC (mA)	24.5	24.2	25.1	24.9	25.1	24.8	23.6	24.7	25.5	23.9	25.5	24.9	23.9	23.6	24.1	23.9	25.2	24.4	25.4	25.2	24.6	.6
VOC (mV)	811	812	742	756	800	818	819	817	819	805	817	815	811	771	800	816	813	815	774	814	802	22.7
IMP (mA)	19.2	19.7	19.6	16.9	18.5	21.6	18.9	21.2	22.5	18.8	23.2	20.0	19.0	19.1	18.8	20.9	20.0	20.9	22.8	20.8	20.1	1.6
VMP (mV)	702	723	491	458	607	724	734	735	736	650	712	713	696	525	600	600	717	707	512	710	653	91.8
MP (mW)	13.5	14.2	9.6	7.7	11.2	15.6	13.9	15.6	16.6	12.2	16.5	14.2	13.3	10.0	11.3	12.6	14.0	14.8	11.7	14.8	13.2	2.4
FF	.68	.72	.52	.41	.56	.77	.72	.77	.79	.63	.79	.70	.69	.55	.59	.65	.68	.74	.60	.72	.66	.1
EFF (%)	14.5	15.3	10.3	8.3	12.0	16.8	14.9	16.8	17.8	13.1	17.7	15.3	14.3	10.7	12.1	13.5	15.0	15.9	12.6	15.9	14.1	2.6

TABLE 6

TEMPERATURE COEFFICIENTS FOR

VOC AND MP DETERMINED

AT 0.086 SC ILLUMINATION AND TEMPERATURES OF +25°C TO -100°C

Temp. Coefficient \ Cell No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	AVG.
T_{VOC} (mA/°C)	2.3	2.3	1.6	1.9	2.2	2.3	2.3	2.3	2.3	2.2	2.2	2.3	2.3	2.0	2.2	2.3	2.3	2.3	2.0	2.3	2.2
T_{MP} (mW/°C)	.027	.034	.007	-.003	.014	.041	.034	.042	.046	.020	.046	.030	.027	.009	.012	.024	.032	.037	.014	.036	.027

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GLOSSARY

AU	Astronomical Unit
BSR	Back Surface Reflector
I-V	Current-Voltage
IMP	Maximum Power Current
ISC	Short Circuit Current
LTLI	Low Temperature and Low Intensity
MP	Maximum Power
SC	Solar Constant
UV	Ultraviolet
VMP	Maximum Power Voltage
VOC	Open Circuit Voltage

APPROVAL

CHARACTERIZATION OF ASEC BSR 2 OHM-CM SILICON SOLAR CELLS WITH DIELECTRIC WRAPAROUND CONTACTS AS A FUNCTION OF TEMPERATURE AND INTENSITY

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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