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SILICON SOLAR CELL PROCESS DEVELOPMENT, FABRICATION AND ANALYSIS

Fourth Quarterly Report for July 1–September 30, 1979

By
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SILICON SOLAR CELL PROCESS
DEVELOPMENT, FABRICATION AND ANALYSIS

FOURTH QUARTERLY REPORT

FOR PERIOD COVERING

1 JULY 1979 to 30 SEPTEMBER 1979

BY

H.I. YOO, P.A. ILES AND F.F. HO

JPL CONTRACT NO. 955089

OPTICAL COATING LABORATORY, INC.
PHOTOELECTRONICS DIVISION
15251 EAST DON JULIAN ROAD
CITY OF INDUSTRY, CA 91746

"The JPL Low-Cost Silicon Solar Array Project is sponsored by the U. S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE."

ABSTRACT

Evaluation was performed for three sheet silicon forms:

- (a) Continuous Czochralski Growth (Varian)
- (b) EFG Multi-Ribbon (Resistance-heated)
- (c) Dendritic Web Silicon

AMO efficiencies (average) obtained were as follows: (efficiencies of control cells made from Czochralski silicon, processed alongside are in parentheses)

- (a) Continuous Czochralski Cells 10.7% (10.9%)
- (b) EFG Cells
 - (i) Standard Process 6.5% (~12%)
 - (ii) High Efficiency Process ~8.0% (>12%)
- (c) Dendritic Web
 - (i) Standard Process 10.1% (11.2%)

In addition to the illuminated performance, the usual backup measurements were made of diffusion length, spectral response, dark diode characteristics, and fine light spot scanning.

Early attempts to include BSF processes to low resistivity silicon led to excessive cell shunting; work proceeds to identify the reasons.

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INTRODUCTION

This program investigates, develops and utilizes technologies appropriate and necessary for improving the efficiency of solar cells made from various unconventional silicon sheet materials. During this reporting period, work has progressed in fabrication and characterization of solar cells from continuous Czochralski ingots (Varian), EFG (RH) ribbons (Mobil-Tyco), and dendritic webs (Westinghouse). Solar cells were fabricated using a standard process typical of those used currently in the silicon solar cell industry. Also back surface field (BSF) processing and other process modifications were included to give preliminary indications of the possible improved performance.

The parameters measured included open circuit voltage, short circuit current, curve fill factor, and conversion efficiency (all taken under AMO illumination). Additional measurements at AM1 have been included, for direct evaluation and to collect information on the AM1/AMO conversion factors for the various sheet materials. Also measurement for typical cells included spectral response, dark I-V characteristics, minority carrier diffusion length, and photoresponse by fine light spot scanning. The results were compared to the properties of cells made from conventional single crystalline Czochralski silicon with an emphasis on statistical evaluation.

Increased emphasis was given toward modifying the process to yield increased performance. The process modifications were selected based on analysis of the probable defects limiting the output from cells made by the standard process. Difficulties were experienced with the BSF process used with low resistivity silicon and further tests continue to find the causes.

II. TECHNICAL DISCUSSION

1.0 CONTINUOUS CZOCHRALSKI GROWTH (VARIAN) SOLAR CELLS

1.1 Solar Cell Fabrication

Three sections of a continuous CZ growth Varian ingot (cut from top, middle and bottom) were delivered to ASEC and were sliced into wafer form. Resistivity of the wafers was about 3.5 ohm-cm with p-type conductivity. Minority carrier diffusion length of the bulk wafers was in the range between 130-170 μm using SPV measurements. These wafers were sliced into 2x2 cm blanks and solar cells were fabricated using either standard or BSF processes. [Refer to Appendix III of Annual Report (1) for the process details.] Control blanks were prepared from conventional CZ wafers, with resistivity range and minority carrier diffusion lengths about 1-2 ohm-cm and 140 μm respectively. Reference (2) provides technical details of the continuous CZ growth from Varian.

1.2 Performance and Characterization

• Illumination Characteristics

Thirty-six (36) solar cells (2x2 cm) were prepared from the Varian blanks using the standard process. Solar cell parameters under illumination are given in Appendix III. The majority of the standard cells showed consistent performance, indicating an average AMO efficiency of about 10.7% at 25°C test block temperature. A summary of the parameters of the standard cells is given in Table 1, the cells showing severe shunting (nine cells) and high series resistance (three cells) are not included in this table. Control solar cells showed an average efficiency of 10.9%, indicating slightly

better performance than those made from the Varian material. There seems to be no difference in cell performance between the cells from the top, middle and bottom sections of the ingot. Lower V_{OC} of the Varian solar cells (about 20 mV lower than that of the controls) is mainly due to the slightly lower doping level of the Varian wafers; 3-4 ohm-cm for the Varian versus 1-2 ohm-cm for the controls. All BSF solar cells showed shunting problems, for both the Varian and control cell, and efforts to identify the causes of this problem are discussed in Section 4.0.

- Dark I-V Characteristics

Dark I-V plots (forward) were obtained using a semi-automatic plotter and sample cells were selected from these data to measure their forward and reverse dark I-V characteristic using point-by-point measurements. The plots of these measurements are given in Figure 1. Calculated "A" factors from the simple diode equation were about 1.7 for both Varian cells and a control cell. The saturation current density (J_0) obtained from the plots was about 3×10^{-8} A/cm² for the Varian cells and 2×10^{-8} A/cm² for the control cells. Based on the current at low bias voltages, the control cell showed lower shunt resistance than a Varian cell, but this shunt resistance indicated by the control cell (about 200 ohms for a 2x2 cm) did not appear to reduce either V_{OC} or CFF.

- Spectral Response

Absolute spectral response (A/W) was measured using a filter wheel set up [refer to Appendix V of reference (1) for the details of measurements]. Response versus wavelength for standard process cells from a typical control and Varian wafers are given in Figure 2. Varian cells showed

responses very close to those of the control cell. A Varian cell (Cell No. B10-2) showed slightly higher overall response.

- Photoresponse by Small Light Spot Scanning

Localized photoresponse of the solar cells was obtained by light spot scanning [refer to Appendix V of reference (1) for the details of measurements]. A typical result of the scanning is given in Figure 3. The Varian cell showed response close to that of the control cell.

FIGURE 1

Dark I-V Characteristics of Standard
Solar Cells From Varian Continuous CZ Wafers

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CITY OF INDUSTRY, CA 91746
TELEPHONE (213) 968-6581

ABSOLUTE SPECTRAL
RESPONSE

SAMPLE IDENTIFICATION

x: Control Cell No

o: Cell No. B10-2

Δ: Cell No. E7

DATE:

FIGURE 2

Spectral Response of Standard Solar Cells
From Varian Continuous CZ Wafers

FIGURE 3

Small Light Spot Scanning of a Standard
Solar Cell From Varian Continuous CZ Wafers

TABLE 1

Summary of Parameters of Standard
Solar Cells Fabricated From Varian Continuous CZ Wafers

PARAMETER		TOP	MIDDLE	BOTTOM	CONTROL
V_{OC} , mV	Average	573	575	574	592
	Standard Deviation	1.2	3	1.7	2
	Range	571-574	570-580	572-576	590-594
J_{SC} , mA/cm ²	Average	34.3	34	34.0	34.7
	Standard Deviation	0.2	0.4	0.3	0.3
	Range	34-34.8	33.5-34.8	33.5-34.3	34.5-35
CFF, %	Average	74	74	74	72
	Standard Deviation	2	2	1	2
	Range	71-76	71-77	73-76	70-74
η , %	Average	10.7	10.7	10.7	10.9
	Standard Deviation	0.3	0.4	0.2	0.4
	Range	10.3-11.1	10.1-11.3	10.4-10.9	10.5-11.3

NOTES:

1. Varian Ingot Identification Run 191, Ingot No. 3
2. Measured Under AMO Condition at 25°C.
3. Cells (2x2 cm) With SiO AR Coating.
4. Number of Samples:

Varian: Top: 9 Cells
 Middle: 10 Cells
 Bottom: 5 Cells
 Control: 3 Cells

2.0 EFG (RH) MULTI-RIBBON SOLAR CELLS

2.1 Solar Cell Fabrication

The EFG ribbons delivered were of the RH furnace type grown with multiple dies (five dies). Measured resistivity of the ribbons was about 1 ohm-cm with p-type conductivity; micrometer thickness measurements ranged from 14-19 mils. SPV measurement using an illuminated beam size around 3 mm diameter indicated the D.L. of the bulk starting EFG blanks averaged 47 μm , with a range 20-100 μm . D.L. of the diffused EFG wafers showed an average of about 30 μm , slightly lower values than those measured on the starting EFG ribbons. Reference (3) provides technical details of the EFG process.

Ribbon blanks (2x2 cm) were formed and the standard process solar cells (1st run) were fabricated. However, problems with front contact peeling-off, mostly for the control cells, prevented these cells from providing reliable data. Thus a second standard process run (No. 5) was made to yield reliable solar cells.

Attempts to fabricate high efficiency solar cells (Run No. 3 and No. 4) were made by the formation of a shallow junction, fine front contact grid lines and the application of MLAR coating. The diffusion included 10 minutes of oxidation and 10 minutes of diffusion followed by a slow pull from the diffusion furnace (cooled to room temperature within 5-10 minutes). This diffusion cycle provided a sheet resistance of about 40 ohm/square for the EFG ribbons. Fine grid line patterns for the front contact were

applied by photolithographic techniques and the active area of the finished solar cell was about 90-92%. Finally a MLAR coating was applied to achieve high current gain, (above 45% gain over bare silicon surface).

A third standard process run (No. 2) was carried out on the EFG blanks with modified pre-surface treatment before the cell fabrication. The surface treatment involved the formation of phosphorus diffused oxides for gettering and subsequent removal of the oxides and thin surface layer (about 2 μm) from the EFG ribbons. The oxide layer was formed by phosphorus diffusion at 875°C. No subsequent heat treatment was done.

Work is still in progress, to apply other process modification to optimize the EFG cell performance.

2.2 Performance and Characterization

• Illumination Characteristics

Solar cell parameters, such as I_{SC} , V_{OC} , CFI and η were measured under AM0 and AM1 solar simulators. Descriptions of the simulators and calibration methods used are discussed in Appendix IV of reference (1) for the AM0 conditions and Appendix II of this report for the AM1 conditions. The measurement of test block temperature was 25°C, which is expected to result in an exposed surface cell temperature of about 28°C. However, problems of accurate cell temperature measurement were experienced for EFG cells since it was difficult to make good thermal or electrical contact to the test block because of surface unevenness. To solve the electrical contacting problem, a conducting rubber* was placed between the cell and test block. However,

*The conducting rubber was supplied by courtesy of Dr. C.T. Ho, of Mobil-Tyco. The rubber is available from Chomerics, MA

this rubber pad gave temperature control problems due to its relatively poor thermal conductivity compared with a metal. Thus the temperature of the cooling test block was adjusted in such a way that the V_{OC} of a flat control cell was about the same with the conducting pad as measured for a 25°C block temperature with no pad. This might not be the best way to eliminate thermal and electrical contacting problems, but is thought to minimize measurement errors because of uneven surfaces.

Important parameters of individual solar cells from Run No. 1 to Run No. 5 are given in Appendix IV. The first standard run was intended to show the performance variation of ribbon cells as a function of dies and growth sequences. The front contact peeling-off, particularly for the control cells, prevented these cells from providing reliable data. However, there seemed to be no specific correlation between cell performance, and growth sequence and different die location. The second standard process run (No. 5) was repeated and a statistical evaluation was obtained from the run. Table 2 summarizes the important solar cell parameters from the standard process, showing an average AMO efficiency of about 6.1%. An average AM1 efficiency of these cells was about 6.7%.

Significant improvement in efficiency was achieved by the surface treatment run (Run No. 2) [refer to Section 2.1 for details of the process]. Not many cells were fabricated using this process but these cells did show an average AMO efficiency of about 7.2%, a significant improvement over the standard process cells without any surface treatment.

Summaries of solar cell parameters from the high efficiency processes are given in Table 3 for Run No. 3 and Table 4 for Run No. 4. An average efficiency of the cells from Run No. 3 and Run No. 4 was about 7.6% and 8%, respectively. A maximum AMO efficiency of 9% was achieved from the process which corresponded to an AMI efficiency of 10%. A consistent conversion could not be obtained between AMO and AMI readings possibly due to the problems of proper temperature control and contacting in Run No. 3.

A summary of an AMO to AMI conversion, for given specific measurement conditions, was made using AMO and AMI data from Run No. 4 and Run No. 5, and the results of the short circuit current density and the efficiency are given in Table 5. The table suggests that J_{SC} under AMO conditions is about 20% higher than those under AMI conditions for both EFG and control cells. Consistent results were observed from the cells with and without anti-reflective coating. Efficiency conversion ratios, AMI/AMO, ranged from 1.11-1.13. It is worthwhile to emphasize that this conversion ratio is only valid under the specific illumination spectrum and intensity calibration methods used.

- Dark I-V Characteristics

Measurements were carried out by the point-by-point and consequent the forward and reverse characteristics are plotted in Figure 4. The "A" factor in the simple diode equation was 1.9 for an EFG cell and 1.6 for a control cell. Saturation current density (J_0)(in the diode equation) of the EFG cell and the control cell was about 4×10^{-7} A/cm² and 6×10^{-9} A/cm², respectively.

- Spectral Response

Absolute spectral response (A/W) of the EFG cells was measured using the filter wheel set up described in Appendix V-A of reference (1). Plots of the response are given in Figure 5 and Figure 6; the former for the standard cells (Run No. 5) and the latter for the standard cells with surface treatment (Run No. 2). In both cases, the EFG cells gave lower response than single crystalline control cells at long wavelength ($\lambda > 0.6 \mu\text{m}$), mostly due to the smaller minority carrier diffusion length. The EFG cells from Run No. 2, in Figure 6, indicate a slight improvement of response over the cells from Run No. 5 (see Figure 5 and Figure 6 for comparison). No definite explanation can be given at present, but work is in progress to identify the causes for the slight increase.

- Minority Carrier Diffusion Length

Minority carrier diffusion length (L) was obtained using the surface photovoltage (SPV) method for the bulk EFG ribbons and the short circuit current (I_{SC}) method for the finished solar cells. The SPV method indicated an average L of about $45 \mu\text{m}$ for the EFG blanks. The size of the illuminated monochromatic beam was about three (3) mm in diameter and generally L variation of 20-100 μm was measured from spot-to-spot. D.L. by the I_{SC} method (for the finished cells) showed slightly lower L values; an average of 32 μm with range between 18-50 μm .

- Photoresponse by Small Light Spot Scanning

Localized photoresponses of solar cells (standard process) were obtained by small light spot scanning, using a set up described in Appendix V-C

of reference (1). A typical result is given in Figure 7. The light scanning direction was perpendicular to ribbon growth, i.e. across the ribbon width. A significant number of electrically active defect sites is identified from the figure.

FIGURE 4:

Dark I-V Characteristics of a EFG (RH) Multi-Ribbon Solar Cell at R.T.
 ($\approx 4 \text{ cm}^2$ in area, standard cell)

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ABSOLUTE SPECTRAL
RESPONSE

SAMPLE IDENTIFICATION

x: Control Cell #1

o: EFG 5-1092-7-1

Δ : EFG 5-1092-7-5

DATE:

FIGURE 5

Spectral Response of EFG (RH) Multi-Ribbon Solar Cells
(Standard Process)

16.

2204

FIGURE 6

Spectral Response of a EFG (RH) Multi-Ribbon Solar Cell
(Standard Process with Surface Treatment, Run #2)

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ABSOLUTE SPECTRAL
RESPONSE

SAMPLE IDENTIFICATION

x: Control Cell #1

o: EFG 5-1094-142-2

DATE:

FIGURE 7

Small Light Spot Scanning of a EFG (RH) Multi-Ribbon Solar Cell
(Standard Process, Run #5)

TABLE 2
SUMMARY OF PARAMETERS OF SOLAR CELLS FABRICATED FROM
EFG (RH) MULTI-RIBBONS; STANDARD PROCESS

		EFG		CONTROL	
		AM0	AM1	AM0	AM1
$V_{OC}(mV)$	Average	507	500	591	583
	Standard Deviation	6	5	2	2
	Range	502-519	497-510	588-592	580-584
$J_{SC}(mA/cm^2)$	Average	22.3	18.5	33.1	27.9
	Standard Deviation	.6	.5	.5	.4
	Range	21.8-23	18-19	32.3-33.5	27.3-28.3
CFF(%)	Average	72.5	72.5	77.1	77.2
	Standard Deviation	1	1.1	1.2	1.8
	Range	71.1-73.9	71-74	75.2-78.2	74-78
$\eta(\%)$	Average	6.1	6.7	11.1	12.5
	Standard Deviation	.3	.3	.3	.4
	Range	5.8-6.5	6.5-7.2	10.6-11.4	11.8-12.7

NOTES:

- Cells (2x2 cm) with SiO AR coating, measured at 25°C test block temperature.
- Sample cells from Run No. 5. Sample size: EFG - 6 cells
Control - 5 cells

TABLE 3

SUMMARY OF PARAMETERS OF SOLAR CELLS FABRICATED FROM
EFG (RH) MULTI-RIBBONS; HIGH EFFICIENCY PROCESS

		EFG		CONTROL	
		AM0	AM1	AM0	AM1
$V_{OC}(mV)$	Average	525	525	588	585
	Standard Deviation	11	14	5	5
	Range	506-538	495-539	581-592	579-590
$J_{SC}(mA/cm^2)$	Average	28	23.5	36.5	30.6
	Standard Deviation	1.6	1.4	.6	.4
	Range	25.4-31	21.3-26	36-37.2	30.1-31.1
CFF(%)	Average	69.4	64.9	74	71
	Standard Deviation	3.6	6.9	3.7	4.5
	Range	63-75	53-78	70-78	67-77
$\eta(\%)$	Average	7.6	8	11.7	12.6
	Standard Deviation	.6	1	.7	1
	Range	6.6-8.4	6.5-9.9	11-12.6	11.9-14.1

NOTES:

1. Cells ($\sim 2 \times 2$ cm) with MLAR coating and shallow junction (from Run No. 3), measured at 25°C test block temperature.
2. Sample size: EFG - 10 cells
Controls - 4 cells
3. Problems of temperature control and contacting were experienced during AM1 measurements.

TABLE 4

SUMMARY OF PARAMETERS OF SOLAR CELLS FABRICATED FROM
EFG (RH) MULTI-RIBBONS; HIGH EFFICIENCY PROCESS

		AM0	AM1
$V_{OC}(mV)$	Average	538	533
	Standard Deviation	17	15
	Range	506-552	504-544
$J_{SC}(mA/cm^2)$	Average	26.8	22.2
	Standard Deviation	2	1.8
	Range	23.2-28.7	19-23.8
CFF(%)	Average	75	75
	Standard Deviation	3	3
	Range	71-78	71-78
$\eta(\%)$	Average	8	8.9
	Standard Deviation	1	1.1
	Range	6.1-9	6.9-10

NOTES:

1. Cells (irregular size, maximum cell size $\sim 9\text{ cm}^2$) with MLAR coating and shallow junction (from Run No. 4), measured at 25°C test block temperature.
2. Sample size: 6 EFG cells

TABLE 5

An AMO-AM1 Conversion of Short Circuit Current Density (J_{SC}) and Efficiency (η) of EFG Ribbon Solar Cells

	J_{SC} , AMO/AM1		η , AM1/AMO	
	AR	No AR	AR	No AR
EFG	1.20	1.20	1.11	1.11
Control	1.19	1.19	1.13	----

NOTE:

1. Data obtained from Run #4 and Run #5.
2. See Appendix IV of Reference (1) for an AMO simulator and Appendix II of this report for AM1 simulator and intensity calibration.

3.0 DENDRITIC WEB SOLAR CELLS

3.1 Solar Cell Fabrication

Blank shaping (2x2 cm) and removal of the surface deposit (SiO) were carried out using the same method described in Section E of reference (1). Four point probe measurements indicated a resistivity of about 7-10 ohm-cm with p-type conductivity. The SPV measurement of minority carrier diffusion length (L) showed a variation of L from web to web. An average L value was about 65 μm with a range of 40 to 120 μm . Reference (4) provides technical details of Westinghouse's dendritic web process.

Two batches of solar cells, Run No. 1 and Run No. 2, were fabricated using a standard process described in Appendix III of reference (1). An incorrect diffusion process for the first run (Run No. 1) led to removal of the surface layer and repeat of the diffusion process. Thus, the second run for the standard process (Run No. 2) was carried out to provide reliable data on standard web solar cells. BSF and other process modifications are in progress.

3.2 Performance and Characterization

- Characteristics and Illumination

The important parameters of the standard web solar cells processed are given in Appendix V, in which both AM0 and AM1 parameters are provided for the cells from Run No. 2. Run No. 1 did not show any significant difference in cell performance compared with Run No. 2. However, performance variation from web to web was noticed mainly due to the variation of sheet quality,

specifically in regard to minority carrier diffusion length. Table 6 summarizes the cell parameters from a standard process (Run No. 2). Both AMO and AMI parameters are given in the table, indicating an average efficiency of web cells about 10.1% for AMO and 11.5% for AMI. The average AMO and AMI efficiency of the control cells was 11.2% and 12.5%, respectively, which is approximately 1% higher efficiency than those of the web cells.

- Dark I-V Characteristics

Dark I-V characteristics (forward and reverse) were obtained from selected samples at room temperature. The plots were made from the point-by-point measurements and a typical result is given in Figure 8. "A" factors of both the web cells and the control cell were about 1.6 and the saturation current densities (J_0) were 9×10^{-9} A/cm² for the web cell and 5×10^{-9} A/cm² for the control cell. The web cells showed consistently low leakage characteristics, which was observed from the current level at low bias voltages ($V_B < 0.3$ volts).

- Spectral Response

Absolute spectral response was obtained using a filter wheel set-up described in Appendix V-A of reference (1). The wavelength dependence of the response of the standard web solar cells is given in Figure 9. The web cells showed response close to that of a control cell, with slightly lower long wavelength response than the control cells.

- Minority Carrier Diffusion Length

Minority carrier diffusion length (L) was measured using the SPV method for the bulk webs and the short circuit current (I_{SC}) method for the solar

cells [refer to Appendix V-B of reference (1) for details]. Both methods showed an average L of about 65 μm .

- Photoresponse by Small Light Spot Scanning

Localized photoresponse of the sheet cells was obtained by light scanning [refer to Appendix V-C of reference (1) for details]. A typical scanning result from a standard web cell is given in Figure 10. The web cells showed close response to that of the control and no significant number of active defect sites was observed.

FIGURE 8

Dark I-V Characteristics of a Dendritic Web Solar Cell at R.T.
 ($\approx 4 \text{ cm}^2$ in area, standard process)

x: A Control Cell No. 4

o: A Web Cell No. 17-1152-4

--: Forward Characteristics

--: Reverse Characteristics

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ABSOLUTE SPECTRAL
RESPONSE

SAMPLE IDENTIFICATION

x : Control #4

o : Web 17-1152-4

Δ : Web 17-1155-1

DATE:

FIGURE 9

Spectral Response of Solar Cells From Dendritic Webs
(Standard Process)

.6

.4

.3

.2

.1

FIGURE 10

Small Light Spot Scanning of a Dendritic Web Solar Cell
(Standard Process)

SUMMARY OF PARAMETERS OF SOLAR CELLS FABRICATED FROM DENDRITIC WEB; STANDARD PROCESS

NOTES.

- 2204

4.0 BACK SURFACE FIELD (BSF) PROCESS DEVELOPMENT

The BSF process is a well-known and widely used technique to improve solar cell performance, especially for higher resistivity starting silicon sheets. This process can provide advantages in cell performance but in practice can also give possible yield problems, mainly due to shunting, especially for lower resistivity silicon. Thus, experiments were initiated to investigate methods for obtaining reliable BSF formation techniques for low resistivity ($\sim 1-3$ ohm-cm) silicon. At present, most of the effort was directed to exploring the shunting mechanism related to the BSF process.

The BSF process was carried out by screen printing Al paste followed by an alloy step at $\sim 800^\circ\text{C}$. The BSF process was applied on single crystalline 3" wafers divided into three batches; (1) 10 ohm-cm CA, (2) 2 ohm-cm CZ, and (3) 2 ohm-cm FZ. Each group consisted of ten 3" wafers and each wafer provided six identical 2x2 cm cells. To minimize the effects of other parameters the cells (2x2 cm) were not AR coated. Table 7 summarizes the cell parameters related to the shunting characteristics. The table suggests that 10 ohm-cm CZ and 2 ohm-cm FZ single crystal does not have any significant shunting problems, while 2 ohm-cm CZ material have severe shunting problems.

No definite explanation for these results has been reached yet, but the results do suggest that shunting problems were caused by the interaction of the BSF process with some properties of the starting silicon blanks, such as non-uniform doping profile, crystallographic defects, oxygen and carbon complexes, etc. This effort is being continued to seek an explanation.

TABLE 7

Range of Parameters of Solar Cells From a BSF Process

CELL TYPE	V_{OC} (mV)	I_{SC} (mA)	CFF (%)
10 ohm-cm (CZ)	575-585	108-112	76-78
2 ohm-cm (CZ)	565-590	101-102	46-78
2 ohm-cm (FZ)	578-585	105-107	78-79

Note:

1. Cells (2x2 cm) without AR coating under AMO condition.
2. BSF Process: Al paste plus alloy.

III. CONCLUSIONS AND RECOMMENDATIONS

Although there were some minor process difficulties, the general conclusions confirmed earlier work are;

The performance of all three sheet materials processed in the standard sequence was consistent, showing continued good correlation between the measured physical parameters (resistivity, diffusion length) and the device performance (illuminated I-V, dark I-V, spectral response, fine light scanning). The addition of the AMI measurements will help in the overall comparison with the LSA project. The continuous Czochralski material showed good consistency in cells made from the top, center and the bottom of the ingot supplied.

During this period, additional effort was directed towards improved performance using process modifications suggested by the analysis of the standard processed cells. (Of course, obvious modifications such as shallow diffusion, fine grid line patterns and improved AR coatings gave expected improvements.), Thus for EFG ribbon, additional surface etching gave slightly increased output. The use of BSF methods for both continuous Czochralski and dendritic webs appeared promising. However, preliminary tests showed serious shunting when applying a well-proven BSF process to the control slices. Therefore additional tests on the causes of this increased shunting were performed, to try and identify whether the BSF process and the detailed silicon properties were interacting adversely.

IV. WORK PLAN STATUS

The following areas of work are planned during the next period.

EFG (RH) Multi-Ribbon

- Process optimization by gettering and surface treatment such as etching and texturizing.
- Large area cell fabrication

Dendritic Web

- Fabrication of cells using BSF process
- Other process modification to improve η
- Large area cell fabrication

BSF Process Development

- Work will continue to identify mechanism leading to shunting problems

Metal Shadow Mask Design

- Tool design for 1" x 1" metal shadow mask

The following additional silicon sheets are planned to process for evaluation.

- Cast silicon by HEM
- Coated silicon by SOC

V.

REFERENCES

1. H.I. Yoo, et.a., "Silicon Solar Cell Process Development, Fabrication and Analysis", JPL Contract No. 955089, Annual Report, June 1979.
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3. F.V. Wald, et.al., "Large Area Silicon Sheet by EFG", JPL Contract No. 954355, Technical Reports, to LSA Project, Mobil-Tyco.
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APPENDIX I

Time Schedule

APPLIED SOLAR ENERGY CORPORATION

formerly Optical Coating Laboratory Photoelectronics Division

15251 E. Don Julian Road P.O. Box 1212

City of Industry, California 91746

(213) 968-6581 Twx 910-584-4890

TIME SCHEDULE (PHASE II)

TASK		MONTH												
		JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL
A-2	PROCESS SHEET SAMPLES													
	(A) STANDARD CELLS	=====	=====	=====	==	==	==	==	==	==	==	==	==	==
	(B) ANALYSIS	=====	=====	=====	==	==	==	==	==	==	==	==	==	==
	(C) BACK UP MEASUREMENTS	=====	=====	=====	==	==	==	==	==	==	==	==	==	==
	(D) TEST ALTERNATE PROCESS		=====	=====	==	==	==	==	==	==	==	==	==	==
	(E) BSF PROCESS DEVELOPMENT	=====	=====	=====	==	==	==	==	==	==				
REPORTS														
	(A) MONTHLY		▲	▲		Δ	Δ		Δ	Δ		Δ	Δ	
	(B) QUARTERLY				▲			Δ			Δ			
	(C) FINAL													Δ

APPENDIX II

AM1 Simulator and Calibration

The following are the conditions used for AMI simulation.

(a) Light Source

Spectrolab Model XT-10 was used as a light source for AMI conditions. Features of the AMI simulator consist of a 35-element lenticular optics assembly to provide spatial and temporal uniformity (intensity uniformity of $\pm 3\%$ within beam size of 8 inches) and a xenon lamp with air mass one filters. Refer to technical brochure of XT-10 for details.

(b) Light Intensity Calibration

Light intensity was calibrated by using a terrestrial secondary standard (TSS-014) from JPL. The standard cell was calibrated in accordance with the method described in NASA/ERDA Workshop "Document "Interim Solar Cell Testing Procedures for Terrestrial Applications".

NOTE: Two major area of possible errors are involved in this AMI simulation conditions; they are (1) difference in spectrum between the simulator and real AMI conditions, and (2) difference in spectral response between solar cells (to be measured) and a standard cell used to calibrate light intensity. Work continues to resolve these problems.

APPENDIX III

Electrical Data Sheets For Solar
Cells From Continuous CZ Growth (Varian)

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from Varian cz process, STD process
SiO AR coating, ~90% Active area, Parenthesis values after edge trim

TEST CONDITION: AMO
TEMPERATURE: 25°C

DATE:

NO.	V _{OC}	I _{SC}	I _{SCB}	I _{SCR}	I _{Max}	V _{Max}	P _{Max}	CFF	η	AREA
	mV	mA	mA	mA	mA	mV	mW	%	%	cm ²
B0-1	573	138	53	86	125	450	56.25	71	10.4	4
B2-2	571	137	54	84	107	380	40.66	52	7.5	"
	(568)	(135)	(54)	(81)	(108)	(365)	(39.42)	(51)	(7.4)	(3.95)
B10-1	570	139	54	85	120	392	47.04	59	8.7	4
	(567)	(137)	(54)	(82)	(114)	(395)	(45.03)	(58)	(8.4)	(3.95)
B10-2	574	139	53	86	128	455	58.24	73	10.8	4
B18-1	573	136	51	85	127	460	58.42	75	10.8	"
B18-2	574	137	52	85	126	455	57.33	73	10.6	"
B26-1	571	137	54	83	125	455	56.87	73	10.5	"
B26-2	572	137	52	85	125	445	55.63	71	10.3	"
B34-1	563	97	52	77		shunted badly				"
	(561)	(101)	(54)	(76)		(shunted badly)				(3.95)
B34-2	573	138	54	84	125	415	51.88	66	9.6	4
	(571)	(135)	(54)	(81)	(118)	430	(50.74)	(66)	(9.5)	(3.95)
B42-1	574	136	53	83	127	465	59.05	76	10.9	4
B42-2	573	138	54	84	128	470	60.16	76	11.1	"
B50-1	571	137	53	83	126	465	58.69	75	10.9	"

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from Varian cz process, STD process
 TEST CONDITION: SiO AR coating, 90% Active area, Parenthesis numbers after edge trim
 TEMPERATURE: AMO
 25°C

DATE: _____

NO.	V _{OC} mV	I _{SC} mA	I _{SCB} mA	I _{SCR} mA	I _{Max} mA	V _{Max} mV	P _{Max} mW	CFF %	η %	AREA cm ²
C 2	580	136	53	83	126	455	57.33	73	10.6	4
C 3	565	115	53	82		SHUNTED	badly			4
	(560)	(115)	(54)	(80)	1	(SHUNTED	badly)			(3.95)
C 10	568	105	52	79		SHUNTED	badly)			4
	(563)	(114)	(52)	(80)		(SHUNTED	badly)			(3.95)
C 11	574	134	52	81	119	458	54.50	71	10.1	4
C 18	576	135	51	84	1217	470	59.69	77	11.1	"
C 19	594	135	52	83	1217	450	57.15	74	10.6	"
C 26-1	575	137	53	84	128	455	58.24	74	10.8	"
C 26-2	577	138	54	85	130	455	59.15	74	11.0	"
C 34-1	567	93	52	72		SHUNTED	badly			"
	(561)	(101)	53	76		(SHUNTED	badly)			(3.95)
C 34-2	578	139	54	85	131	465	60.92	76	11.3	4
C 42-1	573	134	53	80	122	430	52.46	69	9.7	"
C 42-2	570	137	53	83	128	460	58.88	76	10.9	"
C 48	572	134	53	81	123	450	55.35	72	10.3	"
C 50	573	136	53	83	124	460	57.04	73	10.6	"

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from Varian cz process, STD process
 SiO AR coating, $\approx$ 90% Active area, Parenthesis values after edge trim
 TEST CONDITION: AMO
 TEMPERATURE: 25°C DATE: _____

NO.	V _{OC}	I _{SC}	I _{SCB}	I _{SCR}	I _{Max}	V _{Max}	P _{Max}	CFF	η	AREA
	mV	mA	mA	mA	mA	mV	mW	%	%	cm ²
E 2	576	137	52	85	126	455	57.33	73	10.6	4
E 7	572	134	52	83	122	459	55.99	73	10.4	"
E 12	574	136	53	83	126	465	58.59	75	10.9	"
E 17	571	135	52	83	118	400	47.20	61	8.7	"
	(568)	(133)	(53)	(81)	(110)	(415)	(45.65)	(60)	(8.6)	(3.95)
E 22	567	134	54	82		shunted badly				4
	(562)	(131)	(54)	(79)	(91)	(360)	(32.76)	(45)	(6.1)	(3.95)
E 217	565	107	54	79		shunted badly				4
	(560)	(124)	(54)	(78)		(shunted badly)				(3.95)
E 32	576	135	52	83	128	460	58.88	76	10.9	4
E 42	574	137	52	85	127	465	59.15	75	10.9	"
E 47	560	115	53	79		shunted badly				"
	(556)	(113)	(53)	(76)		(" ")				(3.95)
				Control Cells						
1	593	138	55	84	124	480	59.52	73	11.0	4
2	594	140	54	86	126	485	61.11	74	11.3	"
3	590	138	53	85	118	480	56.64	70	10.5	"
	(588)	(135)	(54)	(82)	(118)	(470)	(55.46)	(70)	(10.4)	(3.95)

APPENDIX IV

Electrical Data Sheets for Solar Cells From EFG (RH) Multi-Ribbon

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: EFG (Milti-Ribbon, RH) Solar Cells (2 x 2 cm) 1st Run (STD process)

With SiO AR coating

TEST CONDITION: AMO

TEMPERATURE: 25°C Test Block

DATE: _____

NO.	V _{OC} mV	I _{SC} mA	I _{SCB} mA	I _{SCR} mA	I _{Max} mA	V _{Max} mV	P _{Max} mW	CFF %	η %	AREA cm ²
5-1096 5-1	498	92	42	48	62	366	22.69	50	4.2	4
5-1096 79-1	450	88	41	45	63	322	20.29	51	3.8	"
5-1096 79-2	525	92	42	48	81	415	33.62	70	6.2	"
5-1096 79-3	521	92	44	47	83	423	35.11	73	6.5	"
5-1096 79-4	514	87	41	44	67	416	27.87	62	5.2	"
5-1096 157-1	533	100	44	55	90	426	38.34	72	7.1	"
5-1095 12-1	515	92	42	48	79	429	33.89	72	6.3	"
5-1095 12-2	500	87	42	42	65	405	26.33	61	4.9	"
5-1095 12-3	527	99	44	53	85	410	34.85	67	6.5	"
5-1093 22-1	485	75	37	35	56	392	21.95	60	4.1	"
5-1092 6-1	506	88	41	47	81	409	33.13	74	6.1	"
Control Cells										
1	584	126	53	79	70	396	27.72	38	5.1	"
2	591	126	49	78	85	425	36.13	49	6.7	"
3	592	130	50	81	118	436	51.21	67	9.5	"

Note: Low CFF is partly due to poor contact adhesion.

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from EFG (RH) Multi-Ribbon, 2nd Run

With SiO₂ AR coating, Parenthesis numbers before AR coating (STD process)

TEST CONDITION: AMO

TEMPERATURE: 25°C Test Block

DATE:

[illegible]

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from EFG (Multi-Ribbon) High efficeincy cells
after MLAR coating Run #3

TEST CONDITION: AMO

TEMPERATURE: 25°C Block

DATE: 9/26/79

NO.	V _{OC} mV	I _{SC} mA	I _{SCB} mA	I _{SCR} mA	I _{Max} mA	V _{Max} mV	P _{Max} mW	CFF %	η %	AREA cm ²
5-1095-10-1	534	78	37	40	68	437	29.7	71.3	8.4	2.62
5-1095-10-3	537	109	52	56	97	427	41.4	70.8	8.2	3.75
5-1095-10-4	533	124	57	66	97	427	41.4	62.7	7.7	4
5-1095-10-7	529	112	55	56	96	420	40.3	68.1	7.5	4
5-1095-10-8	538	109	50	59	90	426	38.3	65.4	7.1	4
5-1093-64-1	526	111	53	57	100	432	43.2	74.0	8.2	3.88
5-1093-64-2	506	68	35	33	58	410	23.8	69.1	6.6	2.68
5-1093-64-3	517	107	53	54	97	425	41.2	74.5	7.6	4
5-1093-64-4	515	109	54	54	92	415	38.2	68.0	7.1	4
5-1093-64-7	515	108	54	54	93	420	39.1	70.2	7.2	4
				Control	Cells					
1	592	144	60	84	124	492	61.0	71.6	11.4	3.95
2	587	142	60	82	128	495	63.1	76.0	11.9	"
3	581	143	60	83	130	450	58.5	70.4	11.0	"
4	592	147	62	86	136	496	67.5	77.5	12.6	"

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from EFG (RH) Multi-Ribbon, Run #3 High efficiency with MLAR coating

TEST CONDITION: AM1

TEMPERATURE: 25°C Test Block

DATE: _____

NO.	V_{OC}	I_{SC}	I_{SCB}	I_{SCR}	I_{Max}	V_{Max}	P_{Max}	CFF	η	AREA
	mV	mA	mA	mA	mA	mV	mW	%	%	cm ²
5-1095 10-1	539	65			53	417	32.1	63.1	5.5	4
5-1095 10-3	537	91			80	415	33.2	67.9	8.3	"
5-1095 10-4	537	104			79	415	32.8	58.7	8.2	"
5-1095 10-7	529	94			79	412	32.6	65.5	8.1	"
5-1095 10-8	536	92			71	365	25.9	52.6	6.5	"
5-1093 64-1	526	93			82	468	38.4	78.5	6.5	"
5-1093 64-2	495	57			44	408	18.0	63.6	4.5	"
5-1093 64-3	519	90			81	411	33.3	71.3	8.3	"
5-1093 64-4	515	91			73	407	29.7	63.4	7.43	"
5-1093 64-7	514	90			73	410	29.9	64.7	7.5	"
				Control	Cells					
1	588	121			103	463	47.7	67.0	11.9	4
2	584	119			104	470	48.8	70.3	12.2	"
3	579	120			104	452	47.0	67.7	11.8	"
4	590	123			112	498	55.8	76.9	13.9	"

Control Cells	
---------------	--

A4-5

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells from EFG (RH) Multi-Ribbon, Run #4 (High efficiency)

With MLAR coating

TEST CONDITION: WTC
AMO

TEMPERATURE: 25°C Test Block

DATE:

[illegible]

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells from EFG (RH) Multi-Ribbon, Run #4 (High efficiency)

After MLAR coating

TEST CONDITION: 250C Test Block

TEMPERATURE:

DATE:

[illegible]

A4-7

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from EFG (RH) Multi-Ribbon, Run #5 (STD process)

After SiO AR coating, Parenthesis for before AR coating

TEST CONDITION: AMO

TEMPERATURE: 25°C Test Block

DATE:

NO.	V _{OC} mV	I _{SC} mA	I _{SCB} mA	I _{SCR} mA	I _{Max} mA	V _{Max} mV	P _{Max} mW	CFF %	n %	AREA cm ²
5-1092 67-2	519	92	43	48	84	420	35.3	73.9	6.5	4
	(497)	(168)	(32)	(35)	(62)	(400)	(24.6)	(73.0)	(4.6)	"
5-1092 67-3	508	91	42	48	81	415	33.6	72.7	6.2	"
	(489)	(167)	(31)	(35)	(59)	(400)	(23.4)	(71.4)	(4.3)	"
5-1092 7-1	506	90	42	48	79	415	32.8	72.0	6.1	"
	(483)	(168)	(32)	(36)	(57)	(396)	(22.0)	(67.1)	(4.1)	"
5-1092 7-2	502	87	41	46	78	410	32.0	73.2	5.9	"
	(480)	(166)	(32)	(34)	(57)	(390)	(22.0)	(69.5)	(4.1)	"
5-1092 7-4	505	87	41	48	78	410	32.0	71.1	5.9	"
	(483)	(167)	(32)	(35)	(58)	(400)	(23.0)	(71.0)	(4.3)	"
5-1092 7-5	504	87	41	45	77	410	31.6	72.0	5.8	"
	(475)	(165)	(31)	(34)	(53)	(375)	(19.9)	(64.4)	(3.7)	"
Control Cells										
C-1	591	132	52	80	124	492	61.0	78.2	11.3	4
C-2	591	133	53	81	124	490	60.8	77.3	11.2	"
C-3	588	129	50	80	118	485	57.2	75.2	10.6	"
C-4	592	134	52	83	126	490	61.7	77.8	11.4	"
C-5	592	133	52	81	122	498	60.7	77.2	11.2	"

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from EFG (RH) Multi-Ribbon, Run #5 (STD process)

After SiO AR Coating, Parenthesis numbers for before AR coating.

TEST CONDITION: AM1

TEMPERATURE: 25°C Test Block

DATE: _____

NO.	V _{OC} mV	I _{SC} mA	I _{SCB} mA	I _{SCR} mA	I _{Max} mA	V _{Max} mV	P _{Max} mW	CFF %	η %	AREA cm ²
50-1092 67-2	510 (498)	76 (56)			70 (51)	410 (400)	28.7 (20.4)	74.0 (73.0)	7.2 (5.1)	4 "
50-1092 67-3	499 (490)	76 (55)			69 (49)	400 (390)	27.4 (18.9)	72.0 (70.2)	6.9 (4.7)	" "
50-1092 7-1	500 (483)	75 (56)			64 (47)	415 (380)	26.6 (17.9)	71.0 (66.0)	6.6 (4.7)	" "
50-1092 7-2	497 (481)	72 (54)			63 (48)	415 (380)	25.9 (18.1)	72.0 (69.5)	6.5 (4.5)	" "
50-1092 7-4	498 (482)	74 (56)			64 (49)	415 (390)	26.4 (18.9)	73.0 (70.0)	6.6 (4.7)	" "
50-1092 7-5	497 (476)	72 (53)			63 (44)	415 (350)	25.9 (15.4)	73.0 (61.0)	6.5 (3.9)	" "
Control Cells										
C-1	583	111			105	480	50.4	78.0	12.6	4
C-2	583	112			106	480	50.9	78.0	12.7	"
C-3	580	109			99	475	47.0	74.0	11.8	"
C-4	584	113			105	480	50.4	78.0	12.6	"
C-5	583	113			105	480	50.4	78.0	12.6	"

APPENDIX V

Electrical Data Sheets for Solar Cells From Dendritic Web

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from Dendrite Web, Run #1 (STD process)

After SiO AR coating

TEST CONDITION: AMO

TEMPERATURE: 25°C Test Block

DATE: _____

NO.	V _{OC}	I _{SC}	I _{SCB}	I _{SCR}	I _{Max}	V _{Max}	P _{Max}	CFF	η	AREA
	mV	mA	mA	mA	mA	mV	mW	%	%	cm ²
17-1105-1	547	131	50	80	118	440	51.9	72.5	9.6	4
17-1114-1	547	126	50	76	118	440	51.9	75.3	9.6	4
17-1114-2	549	129	49	80	118	440	51.9	73.3	9.6	4
17-1114-3	548	128	52	76	119	450	53.5	76.3	9.9	4
17-1152-1	554	134	52	82	123	453	55.7	75.1	10.3	4
17-1152-2	555	134	51	83	123	455	56.0	75.3	10.3	4
17-1152-3	549	133	52	81	117	450	52.7	76.1	9.7	4
17-1155-1	550	131	52	80	121	442	53.5	74.2	9.9	4
17-1097-1	555	134	52	82	123	452	56.5	76.0	10.4	4
17-1097-2	555	134	53	83	125	455	56.9	76.5	10.5	4
17-1097-3	554	136	54	82	123	452	55.6	73.8	10.3	4
				Control Cells						
C-1	594	133	52	81	123	500	61.5	77.8	11.4	4
C-2	586	133	53	80	118	485	57.2	73.4	10.6	4
C-3	576	134	54	80	117	395	46.3	59.9	8.5	4
C-4	576	133	52	81	108	465	50.2	65.6	9.3	4

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from Dendrite Web, Run #2 (STD process)

After SiO AR coating, Parenthesis numbers for before AR coating

TEST CONDITION:

AM0

TEMPERATURE:

25°C Test Block

DATE:

NO.	V _{OC} mV	I _{SC} mA	I _{SCB} mA	I _{SCR} mA	I _{Max} mA	V _{Max} mV	P _{Max} mW	CFF %	η %	AREA cm ²
17-1152-1	552	134	52	81	124	449	55.7	75.3	10.3	4
	(539)	(98)	(38)	(60)	(91)	(440)	(39.8)	(75.4)	(7.4)	"
17-1152-2	555	135	52	83	127	455	57.8	77.1	10.7	"
	(541)	(99)	(39)	(60)	(94)	(440)	(41.1)	(77.0)	(7.6)	"
17-1152-3	555	134	50	84	124	449	55.7	74.9	10.3	"
	(541)	(99)	(39)	(60)	(92)	(440)	(40.5)	(75.6)	(7.5)	"
17-1152-4	556	135	51	85	124	449	55.7	74.2	10.3	"
	(541)	(99)	(40)	(60)	(93)	(440)	(40.9)	(76.4)	(7.6)	"
17-1152-5	555	132	50	83	124	449	55.7	76.0	10.3	"
	(541)	(98)	(38)	(60)	(92)	(440)	(40.3)	(76.0)	(7.4)	"
17-1105-1	551	130	51	79	120	458	55.0	76.8	10.2	"
	(537)	(95)	(38)	(57)	(89)	(440)	(39.2)	(77.0)	(7.2)	"
17-1105-2	549	130	51	79	120	458	55.0	77.0	10.2	"
	(535)	(95)	(38)	(57)	(89)	(440)	(39.2)	(77.0)	(7.2)	"
17-1155-1	546	131	53	78	119	440	52.4	73.2	9.7	"
	(532)	(95)	(39)	(57)	(87)	(430)	(37.4)	(74.0)	(6.9)	"
17-1155-2	549	132	52	80	121	448	54.2	75.0	10.0	"
	(535)	(96)	(39)	(57)	(89)	(430)	(38.3)	(75.6)	(7.1)	"

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from Dendrite Web, Run #2 (STD process)

After SiO AR coating, Parenthesis numbers for before AR coating

TEST CONDITION: AMO

TEMPERATURE: 25°C Test Block

DATE: _____

NO.	V _{OC}	I _{SC}	I _{SCB}	I _{SCR}	I _{Max}	V _{Max}	P _{Max}	CFF	η	AREA
	mV	mA	mA	mA	mA	mV	mW	%	%	cm ²
17-1155-3	548	129	50	79	117	455	53.2	75.3	9.8	4
	(533)	(95)	(38)	(57)	(89)	(430)	(38.1)	(75.2)	(7.0)	4
17-1097-1	555	136	52	83	124	455	56.4	74.8	10.4	4
	(540)	(99)	(39)	(60)	(91)	(440)	(40.0)	(75.0)	(7.5)	4
17-1097-2	556	135	52	83	124	455	56.4	75.2	10.4	4
	(541)	(99)	(39)	(60)	(92)	(440)	(40.3)	(75.6)	(7.5)	4
17-1097-3	554	121	45	76	114	455	51.9	77.4	9.6	4
17-1114-1	550	128	49	79	119	450	53.5	76.1	9.9	4
	(535)	(95)	(38)	(56)	(90)	(430)	(38.5)	(75.8)	(7.1)	4
17-1110-1	541	125	48	71	114	440	50.1	74.2	9.3	4
	(525)	(92)	(37)	(55)	(84)	(430)	(36.1)	(74.7)	(6.7)	4
17-1110-2	545	128	50	77	119	450	53.6	76.8	9.9	4
	(529)	(94)	(38)	(56)	(88)	(430)	(37.8)	(76.0)	(7.0)	4

A5-4

2204

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Control Cells (2 x 2 cm) for Dendrite Web, Run #2 (STD process)

After SiO₂ AR Coating

TEST CONDITION: AMO

TEMPERATURE: 25°C Test Block

DATE:

[illegible]

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Solar Cells (2 x 2 cm) from Dendrite Web, Run #2 (STD process)

With SiO AR coating

TEST CONDITION: AM1

TEMPERATURE: 25°C Test Block

DATE:

NO.	V _{OC}	I _{SC}	I _{SCB}	I _{SCR}	I _{Max}	V _{Max}	P _{Max}	CFF	η	AREA
	mV	mA	mA	mA	mA	mV	mW	%	%	cm ²
17-1105-1	544	110			102	448	45.7	76.	11.4	4
" - 2	543	110			102	448	45.7	76.	11.4	"
17-1110-1	533	105			96	436	41.9	75	10.5	"
" - 2	536	108			100	448	44.8	77	11.2	"
17-1114-1	542	108			100	448	44.8	77	11.2	"
17-1152-1	545	112			102	453	46.2	76	11.6	"
" - 2	547	114			105	460	48.3	78	12.1	"
" - 3	547	112			104	454	47.2	77	11.8	"
" - 4	548	115			104	455	47.3	75	11.8	"
" - 5	547	112			103	456	47.0	77	11.7	"
17-1155-1	538	111			100	441	44.1	74	11.0	"
" - 2	541	111			103	444	45.7	76	11.4	"
" - 3	539	109			100	448	44.8	76	11.2	"
17-1197-1	547	114			104	454	47.2	76	11.8	"
" - 2	547	113			104	458	47.6	77	11.9	"

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: Control Cells (2 x 2 cm) Dentrite Web, Run #2 (STD process)

With SiO₂ AR coating

TEST CONDITION: AM1

TEMPERATURE: 25°C Test Block

DATE:

[illegible]

A5-7

2204

APPENDIX VI

Abbreviations

ABBREVIATIONS

V_{OC} :	Open Circuit Voltage
I_{SC} :	Short Circuit Current
J_{SC} :	Short Circuit Current Density
I_{SCR} :	Short Circuit Current (Red Response) at Wavelength Above $0.6 \mu m$
I_{SCB} :	Short Circuit Current (Blue Response) at Wavelength Below $0.6 \mu m$
CFF:	Curve Fill Factor
η :	Solar Cell Conversion Efficiency
L:	Minority Carrier Diffusion Length (D.L.)
I_{MAX} :	Current at Maximum Power Point
V_{MAX} :	Voltage at Maximum Power Point
P_{MAX} :	Maximum Power Point
BSF:	Back Surface Field
V_B :	Bias Voltage
I_0 :	Diode Saturation Current
HEM:	Heat Exchanger Method
EFG:	Edge Defined Film-Fed Growth
SOC:	Silicon on Ceramic
RTR:	Ribbon-to-Ribbon
SPV:	Surface Photovoltage
MLAR:	Multi-Layer Anti-Reflective
R_s :	Series Resistance