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HIGH EFFICIENCY, LONG LIFE TERRESTRIAL SOLAR PANEL

Final Report, September 1, 1977—March 31, 1978

By
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H. Yoo

Work Performed Under Contract No. NAS-7-100-954831

Optical Coating Laboratory, Incorporated
Photoelectronics Division
City of Industry, California

MASTER

U.S. Department of Energy

Solar Energy

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FINAL REPORT

FOR PERIOD COVERING
1 SEPTEMBER 1977 THROUGH 31 MARCH 1978

BY

S. KHEMTHONG, K. LING, S. OLAH AND H. YOO

JPL CONTRACT NO. 954831

MASTER

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."

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ABSTRACT

Six high efficiency, long life terrestrial modules were designed, fabricated and delivered to JPL. The module utilized 256 large area, rectangular, high efficiency solar cells. A flexible, overlapping design to connect cells in series was used to maximize the packing density. The efficiency of the six modules delivered, based on the overall dimensions at 100 mW/cm² and 28°C is tabulated in Table 2, and the contract goal of 13% array efficiency was achieved.

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The objective of this program was to design, fabricate, and deliver six (6) high efficiency, long life terrestrial solar modules utilizing high efficiency solar cells and increased packing density. The overall dimensions of the solar modules were approximately 46 inches by 23 inches. Each module was to produce a minimum of 80 watts of peak power at AM1 and 28°C, with the design goal of achieving an overall operating efficiency of 13% or greater, corresponding to 88.7 watts or more per module.

2.0

TECHNICAL DISCUSSION

The basic concept of the high efficiency, long life module is to utilize high efficiency solar cells and increased packing density. The design of the module and its important components will be discussed in the following paragraphs.

2.1

Module Design

The detailed module design is shown in Figure 1. The module consists of a piece of 46" x 23" Sunadex water white glass, an aluminum frame, solar cells, RTV-602 for encapsulation, monoacrylic for edge sealing, Mylar film for moisture barrier, and the necessary terminals. Each module had 256 rectangular solar cells, 8 strings in parallel with each string having 32 cells in series. A flexible, over-lapping design was utilized to connect the cells in series to eliminate the spacings between cells and the electrically inactive N-contact. The solar cell assembly was encapsulated to the Sunadex glass window with GE RTV-602 adhesive. A thin film of Mylar was used as moisture barrier. The edges of the module were sealed with monoacrylic. The aluminum frame and electrical terminals were attached to the assembly to complete the module.

2.1.1

Solar Cell

The size of the solar cells was nominally 7.045 cm by 3.658 cm by 0.038 cm in thickness, as shown in Figure 2. The cells had the N-contact, 0.153 cm in width, along the 7 cm edge and 35 gridlines equally spaced. An alloyed aluminum P+ layer was

FIGURE 1

FIGURE 2

applied to the backside of the cell and an OCLI patented multi-layer anti-reflection coating was evaporated onto the active surface of the cell. The titanium-palladium-silver contact system was chosen for its humidity resistance property and its demonstrated reliability in the space programs.

The manufacturing sequence of the solar cell is shown in Figure 3. The processing procedures, used for space cells for many years, are well established.

2.1.1.1 Multi-layer Anti-reflective Coating

The MLAR coating was developed by OCLI in 1975 for space solar cells. A computer analysis was performed using coverglass-adhesive-solar cell as a stack. The following components were used for the analysis: 12 mil thick fused silica coverglass with AR coating and 0.35 micron cut-on absorptive coating, Dow Corning DC93-500 adhesive, and shallow junction silicon solar cell. Both the transmission and the index of refraction of each component were taken into consideration. As a result, the multilayer AR coating used here was developed.

The reflectance measurements on a bare MLAR coated cell and a glassed cell are shown in Figure 4, respectively. The measurements were performed on a Beckman DK-2A Ratio Recording Spectro-Photometer. As it can be seen from the graphs, the multi-layer AR coating provides a low reflectance over a wide band of wavelength, resulting in a high electrical gain after encapsulation or glassing, the broad band low reflectance was also advantageous when used on cells for use at AM1.

FIGURE 3

CELL FLOW CHART

FIGURE 4

OCL1 - 13

OCL1 OPTICAL COATING
LABORATORY, INC.
2789 Giffen Avenue
Santa Rosa, California
Telephone (707) 545-6440

SPECTRAL PERFORMANCE

DATA IDENTIFICATION

OCL1 W-0

Run No

Serial No

SAMPLE IDENTIFICATION

Filter Type

Material OCL1 MLAR COATING
ON SILICON CELL

Configuration

INST OPERATING PARAMETERS

DK-2

Resolution

Scan Speed

Response

Aperture

Expansion 0-50

Percent Transmission

X Percent Reflection

TEST CONDITIONS

Temp ROOM Angle 10°

Analyst SK Date 12-15-77

GEARS 96 FRONT
48 BACK
λ EXPANSION 1X

PAGE 1 of 1

WAVELENGTH - MILLIMICRONS

2.1.2

Glass Window

The untempered water white Sunadex glass was selected for the front window material. The glass was 1/8" in thickness with one surface having a lightly-diffused pattern. An experiment was performed to determine the transmission characteristics of the Sunadex glass. A 3" hexagonal terrestrial solar cell with MLAR and two flexible leads attached was measured for its electrical output before and after the cell was bonded to the Sunadex glass with RTV-602. The data showed an increase of 7% in output after bonding.

2.1.2.1

AR Coating and Heat Rejection Coating

An experiment was performed to determine the effectiveness of anti-reflective coating and heat rejection coating on the water white Sunadex glass. The coatings were evaporated on the glass at OCLI's Santa Rosa facility in the following manner:

	AR COATING
HEAT REJECTION COATING	HEAT REJECTION COATING + AR COATING

The heat rejection coating and the anti-reflective coating were applied to the opposite side of the glass. Four (4) 2x2 cm solar cells with leads attached to the contacts and a copper-constantan thermocouple soldered to the N-contact had their IV characteristics

and operating temperature measured under the tungsten simulator at 80 mW/cm². All cells had multi-layer anti-reflective coating. The cells were then bonded to the glass with RTV-602 on the side with the heat rejection coating. The IV characteristics and the temperatures of the cells were measured again. The results are tabulated in Table 1.

It can be concluded that the electrical enhancement due to the anti-reflective coating on the Sunadex glass is very small. The small improvement in output could hardly justify the cost of applying the coating.

The application of the available heat rejection coating was also not effective. It was realized that the coating had not been optimized for this particular application. To design a suitable coating to reduce the module temperature, a computer analysis needs to be programmed followed by experiments and measurements to verify the design. It was decided that the magnitude of the program was beyond the scope and the funding level of the contract.

2.1.2.2 Bonding Cell to Reversed Side of Glass

A second experiment was performed to determine the effect on bonding the cell to the glass on the side having the diffused pattern. If no difference in electrical output can be observed, the module would be easier to clean with the smooth side facing the sun. It was found that the short circuit current increased from 100.3 mA to 108.6 mA (8% gain) after bonding. It was decided

TABLE 1

EFFECTS OF HEAT REJECTION AND ANTIREFLECTION COATING

	BEFORE BONDING		AFTER BONDING		CHANGES	
	I_{sc} (mA)	T (°C)	I_{sc} (mA)	T (°C)	I_{sc}	T (°C)
NO COATING	100	31.2	107	32.2	+7%	+1
WITH AR COATING	100	28.9	108	32.4	+8%	+3.5
WITH HEAT REJECTION COATING	101	30.9	103	34.2	+2%	+3.3
WITH HEAT REJECTION AND AR COATING	96	28.7	100	32	+4%	+3.3

That the solar cell assembly would be bonded to the side of the glass with the diffused pattern.

2.1.2.3 Experiment to Determine the Effect of a Reflecting Surface in Back of Solar Cells

OCLI had learned that if the back of the cell assembly had a white reflecting surface, such as RTV-77, and the cell assembly was mounted to the diffused side of the Sunadex glass, the electrical performance of the module would have a substantial enhancement due to the reflected light from the white surface.

The following experiments were performed to ascertain the electrical gain, if any, from the white surface and other reflecting surface such as Alzac aluminum.

2.1.2.3.1 A thirty-nine (39) 3" cell assembly was built and the IV curves were measured under the following conditions:

- (a) Bare cell assembly.
- (b) After the cell assembly was bonded to Sunadex glass with RTV-602.
- (c) After the Mylar sheet was bonded to the backside of the assembly with RTV-77 (a white reflecting compound).

The cross-section of the assembly is shown in Figure 5 and the IV curves are shown in Figure 6-8.

The bare cell assembly has an output of 17.85 watts. The output was increased to 19.4 watts (8.7% improvement) after bonding to the Sunadex glass and to 20.7 watts (6.7% improvement) after attachment of the Mylar sheet with RTV-77. The overall

gain from the bare assembly to the final panel was 16%.

The advantage of using a white reflecting surface to enhance the electrical output of a solar panel is impressive and inexpensive. However, the advantage is alleviated if the packing density of the panel is improved such as was the case for the panel design under this contract.

2.1.2.3.2 A thirty-nine (39) 3" series connected cell assembly was built and five IV curves were measured under the following conditions:

- (a) Bare cell assembly.
- (b) After the cell assembly was bonded to the Sunadex glass.
- (c) After the standard aluminum chassis was mounted to the back of the cell assembly.
- (d) After a sheet of "Alzac" reflector aluminum was placed behind the cell assembly, to replace the standard aluminum chassis.
- (e) After a mirror was placed behind the cell assembly instead of the Alzac aluminum sheet.

The measurements showed that an improvement in electrical output by 7% was realized after the cell assembly was bonded to the Sunadex glass between (a) and (b), as expected. However, no electrical improvement was observed after (c), (d), and (e).

It can be concluded that a diffusing reflecting surface such as RTV-77, white paint, etc., in conjunction with the Sunadex glass is necessary to realize the electrical gain. Surfaces such as Alzac aluminum, mirror, etc., that reflect light normally cannot achieve the electrical enhancement.

APPLICATION				REVISIONS			
NEXT ASSY	USED ON	LTR	DCN	DESCRIPTION	DATE	APPROVED

FIGURE 5:

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES: DECIMALS .X $\pm$.XX $\pm$.XXX $\pm$ FRACTIONS $\pm$ ANGLES $\pm$ DO NOT SCALE DRAWING	DRAWN	T. TAPP	2-6-78	OCL OPTICAL COATING LABORATORY, INC. PHOTOELECTRONICS GROUP 16351 Den Julian Rd. • City of Industry, Calif. 91746
	CHECK			
	ENGR			
	PROD			
	QA			
MATERIAL				CROSS SECTION OF RTV 77 ENCAPSULATION
				SIZE A CODE IDENT NO. DWG NO.
				SCALE REV N/C SHEET 1 OF 1

FIGURE 6
39 3" CELLS
CONNECTED IN SERIES
100 mW/cm², 28°C

1-25-78

FIGURE 7
AFTER THE CELL ASSEMBLY WAS
BONDED TO THE DIMPLED SIDE OF THE
SUNADEx GLASS WITH RTV-602.

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BELLAIRE, TEXAS
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OMNIGRAPHIC®

CURRENT IN AMPERES

4

2

1.0

0.8

0.6

0.4

0.2

0

5

10

15

20

25

30

VOLTAGE IN VOLTS

16

FIGURE 8
AFTER A SHEET OF MYLAR WAS
BONDED TO THE BACKSIDE OF
THE CELL ASSEMBLY WITH RTV-77.

20.7 WATTS

1-27-78

2.1.3. Interconnects

Two mil thick silver-tin plated Kovar interconnect with stress relief loop, as shown in Figure 9, were designed for the module. The choice of Kovar is to match the coefficient expansion of silicon. The stress relief loop allowed movement between cells during temperature changes. For the anticipated range of operating temperature of -40 to +90°C, copper interconnects would be also satisfactory with the additional advantage of having higher conductivity.

2.1.4 Encapsulation and Assembly

The cell assembly was bonded to a piece of Sunadex glass with RTV-602. A sheet of 5 mil thick Mylar was bonded to the back of the cell assembly as moisture barrier.

The encapsulated cell assembly was placed on the aluminum chassis and sealed with monoacrylic sealant around the edges. Other work performed under JPL-DOE contract indicated that monoacrylic and polysulfide are equally effective as a moisture sealant. Monoacrylic was chosen over polysulfide as it is a single component sealant, thus minimizing handling.

The sealed assembly was held down mechanically with hold-down angles. A .06" thick neoprene gasket was bonded to the inside flange of a hold-down angle. The encapsulation assembly was not bonded to the aluminum chassis, to permit linear thermal expansion between the glass window and the aluminum chassis.

FIGURE 9

2.1.5 Structural Support

A chassis type anodized aluminum construction was designed. This configuration provides full structural support protection to the back of the encapsulation and easy installation of the assembled module. To choose between an open chassis with the Mylar sheet exposed to the ambient, and a closed chassis, (a solid sheet of aluminum adjacent to the Mylar sheet) two panels were built, each having 39 3-inch terrestrial solar cells. The construction of the closed chassis appeared to be more rugged, thus it was chosen for this program.

2.1.6 Terminals

The electrical leads from the solar array were connected to two environment-resistant panel mounted terminals connected in parallel for redundancy. The receptacles were the screw type connector, No. 206430-1 manufactured by Amp Special Industries. The wiring connection was protected with an enclosure fastened to the chassis. The enclosure is sealed with a .03 inch thick polyethylene gasket against moisture.

2.1.7 Packing Density

The packing density can be determined as follows:

$$\begin{aligned}\text{Total Panel Area} &= 46" \times 2.54 \text{ cm/in} \times 23" \times 2.54 \text{ cm/in} \\ &= 6824.1 \text{ sq. cm}\end{aligned}$$

$$\begin{aligned}\text{Cell Active Area} &= 7.045 \text{ cm} \times (3.658 - .153) \text{ cm} \\ &= 24.639 \text{ sq. cm}\end{aligned}$$

$$\begin{aligned}\text{Total Cell Active Area} &= 256 \text{ cells} \times 24.639 \text{ cm}^2/\text{cell} \\ &= 6321.4 \text{ sq. cm}\end{aligned}$$

$$\text{Packing Density} = \frac{6321.4 \text{ cm}^2}{6824.1 \text{ cm}^2} = 92.6\%$$

The 92.6% packing density is considerably higher than the 70% value, typical of 3" round cell modules.

2.2 Fabrication of Six High Efficiency Modules

2.2.1 Solar Cells

After the processing procedure was finalized, the production of cells was transferred to the Manufacturing Department. A total of 3,674 cells was fabricated. The mechanical yield was extremely high. The only rejects were eight broken cells. All cells were measured under a tungsten simulator at 100 mW/cm² and 28°C and sorted into current groups of 25 mA increments at 480 mV. The electrical distribution of the cells is shown in Figure 10.

2.2.2 Cell Strings

Two interconnects were soldered to the N-contact of each cell. Eight cells from the same electrical grouping were soldered into a series string. Each series string was measured under the OCLI large area solar simulator which consists of a ring of 28 tungsten

FIGURE 10

ELECTRICAL DISTRIBUTION OF
LARGE RECTANGULAR SOLAR CELLS

TOTAL NO. OF CELLS TESTED
AT 100 mW/cm² & 28°C - 3,674

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DIVISION OF BUSHNELL & LOMAX
TEXAS
CHART NO. FC-10 PRINTED IN U.S.A.

OMNIGRAPHIC®

KSL 5/2/78

iodine lamps. The uniformity of the illumination is within 5% of a 30" by 30" area. The 8-cell strings were matched electrically into pairs, with approximately the same current output at 7.75 volts. Eight pairs of cell strings with total the current output (at 15.5 volts) of 5.68 amperes were selected to be assembled into a module.

2.2.3 Fabrication of Six Modules

Prior to fabrication of six deliverable modules, one prototype module was built for the purpose of correlating electrical output between OCLI and JPL, because the 23" x 46" module is beyond the uniform illumination area of the OCLI simulator. The solar cell assembly was measured before and after encapsulation. The same module was measured at OCLI and JPL. The IV curves of both measurements are shown in Figures 11 and 12. The OCLI measurement was lower by 2.4% due to the limited uniform illuminated area of the simulator. The measurements allowed OCLI to determine power output of the module correlatable to JPL measurement.

Examination of the test data revealed that the earlier anticipated 7% gain due to the Sunadex glass did not materialize. To confirm this finding, each 8-cell string for the next module was carefully measured and the 256-cell assembly before and after encapsulation was measured again. The currents at 15.5 volts were 5.35 and 5.40 amperes, respectively, essentially no glassing gain. As the loss of the anticipated glassing gain would impact the cell selection of the module assembly, an additional experiment

FIGURE 11

PROTOTYPE MODULE
(JPL MODULE NO. 1)

MEASURED UNDER OCLI
LARGE AREA SIMULATOR
100 mW/cm²

3/22/78

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PHOTOVOLTAIC MFG & TEST PROJECT GROUP

was performed on small assemblies. It was found that to realize the glassing gain, there must be spaces between cells for diffused or reflected light to enter the cells.

Based on the above results, the efficiency of the cells selected for the module assembly was shifted slightly upward. The final electrical performance of the six modules measured at JPL is shown in Table 2 and IV curves are shown in Figure 13-18.

TABLE 2

ELECTRICAL PERFORMANCE
(At 100 mW/cm² and 28°C)

MODULE NO.	I _{SC} (A)	V _{OC} (V)	P (W)	EFF. (%)
1	6.083	19.089	87.73	12.6
2	6.241	19.038	88.99	13.0
3	6.360	19.065	88.99	13.0
4	6.124	19.065	89.96	13.2
5	6.321	18.945	89.80	13.2
6	6.261	18.945	89.23	13.1

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10A

CURRENT (MILLIAMPS x)

FIGURE 13
MODULE NO. 1

Y3C-1252
AMB-23°C

I-V CHARACTERISTIC CURVE
BY cm DATE 5/2/78
☐ CELL ☐ SUBMODULE ☒ PANEL
SERIAL No. 001 TYPE M
TEST RCK 154 UNIT
TEST TEMP ☒ 28°C ☐ °C
INTENSITY 1.0 MW/CM² ☐ SUNLIGHT
SIMULATOR: ☐ X25L ☐ X25 MK 2
☐ TUNGSTEN OTHER LiAlP5S
Isc 608.3 MA Imp 552.0 MA
Voc 190.89 MV Vmp 157.50 MV
L mv MA Pmax MW

P_{max} 87.73

27

VOLTAGE (VOLTS x) 35V

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10A

CURRENT (MILLIAMPS x)

FIGURE 14
MODULE NO. 2

Y30-125 I-V CHARACTERISTIC CURVE
AMB-23° BY Am DATE 5/2/78
☐ CELL ☐ SUBMODULE ☒ PANEL
SERIAL No. 002 TYPE M
TEST RECK 154 INIT
TEST TEMP ☒ 28°C ☐ °C
INTENSITY 100 MW/CM² ☐ SUNLIGHT
SIMULATOR: ☐ X25L ☐ X25 MK 2
☐ TUNGSTEN OTHER LAPSIS
Isc 6.241 MA Imp 576.50 MA
Voc 17.238 MV Vmp 15.750 MV
I mv MA Pmax MW

P_m 88.99

28

VOLTAGE (VOLTS x) 35V

0.7

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CONTROL

10A

CURRENT (MILLIAMPS x)

FIGURE 16
MODULE NO. 4

Y30-125Z
AMB-24°C

I-V CHARACTERISTIC CURVE
BY cm DATE 5/2/78
☐ CELL ☐ SUBMODULE ☒ PANEL
SERIAL No. 004 TYPE M
TEST RCK 154 INIT
TEST TEMP ☒ 28°C ☐ °C
INTENSITY 100 MW/CM² ☐ SUNLIGHT
SIMULATOR: ☐ X25L ☐ X25 MK 2
☐ TUNGSTEN OTHER LAP 5.3
I_{sc} 6.124 MA Imp 5730 MA
V_{oc} 1906.5 MV V_{mp} 15700 MV
I_m mv MA P_{max} MW

P_m 89.96

30

VOLTAGE (VOLTS x) 35V

0.7

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10A

CURRENT (MILLIAMPS x)

FIGURE 17
MODULE NO. 5

Y30-1252
AMB 23°C

I-V CHARACTERISTIC CURVE
BY Cm DATE 5/2/78
☐ CELL ☐ SUBMODULE ☒ PANEL
SERIAL No. 005 TYPE M
TEST RCK 154 1.1.1.1
TEST TEMP ☒ 28°C ☐ °C
INTENSITY 1.00 MW/CM² ☐ SUNLIGHT
SIMULATOR: ☐ X25L ☐ X25 MK 2
☐ TUNGSTEN OTHER LA PSS
Isc 6.321 MA Imp 5.720 MA
Voc 18.945 MV Vmp 15.700 MV
 mv MA Pmax MW

P_m = 89.80

31

VOLTAGE (VOLTS x)

0.7
35✓

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Input cost data was prepared in accordance with JPL Solar Array Manufacturing Industry Costing Standards (SAMICS) to evaluate manufacturing processes, and manufacturing cost parameters were displayed in a manner as shown in the standard process description format (Format A in SAMICS). This report covers the entire process, starting from crystal growth to final solar array module assembly. The entire sequence was divided into three functioning companies; wafer company, cell company and module company. Process sequences of each company was described using Format B of SAMICS and important cost parameters of each process step of the company is provided in Format A. These data were fed into process work sheet and company work sheet and cost factors from SAMICS were incorporated to obtain the final cost at each process step and sequence. All the cost information given here was based on the price year 1977.

Cost analysis of the wafer company is given in Table 3, in which the cost at each process step and the cost related to equipment, space, direct labor, materials and utilities for each process step are detailed for clarity. Purchased product expense (Poly Si) was also added to get final wafer cost. The same procedures were applied for the cell and module companies and the results are given in Table 4 and Table 5, respectively. Table 6 shows a cost summary at three process levels (wafer company, cell company and module company) and a new cost account catalog is given in Table 7.

Electrical outputs of the solar panel were above 89 watts, which is corresponding to 13% panel efficiency, at the cost per panel of \$1,900, indicating \$21.35/Wpk.

TABLE 3
COST ANALYSIS (SAMICS) OF WAFER COMPANY

PROCESS	EQPT	SQFT	DLAB	MATS	UTIL	PURCHASED PRODUCT	TOTAL
X-G	0.0754	0.0199	0.1374	0.2808	0.0125		0.5260
B-S	0.0026	0.0007	0.0285	0.0003	0.0001		0.0322
SLC	0.0274	0.0108	0.0560	0.0265	0.0006		0.1213
CHEM-P	0.0013	0.0021	0.0550	0.1251	-----		0.1835
PURCHASED PRODUCT							0.8319
TOTAL	0.1067	0.0335	0.2769	0.4327	0.0132	0.8319	1.6949

NOTE

1. \$/Wafer in 1977 Price.
2. Cost Factors From SAMICS Were Consideres.
3. Purchased Product: Poly Si \$60/Kg.

TABLE 4
COST ANALYSIS (SAMICS) OF CELL COMPANY

PROCESS	EQPT	SQFT	DLAB	MATS	UTIL	PURCHASED PRODUCT	TOTAL
DIFF-MAS	0.0023	0.0009	0.0469	0.0023	0.0003		0.0527
DIFF	0.0017	0.0007	0.0234	0.0036	0.0002		0.0296
AN-W	0.0051	0.0020	0.0174	0.0305	0.0015		0.0565
DGR	0.0034	0.0054	0.1384	0.0114	-----		0.1585
AL-EVA	0.0504	0.0133	0.2289	0.0502	0.0007		0.3435
AL-AL	0.0033	0.0018	0.0453	0.0028	0.0010		0.0542
C-A-A	0.0018	0.0029	0.0376	0.0111	-----		0.0534
MET-CON	0.2595	0.0593	1.5308	1.0435	0.0016		2.8947
MLAR	0.1037	0.0205	0.2651	0.0143	0.0005		0.4041
SINT	0.0032	0.0017	0.0436	0.0159	0.0038		0.0682
ELE-TEST	0.0082	0.0038	0.0557	-----	0.0064		0.0741
PURCHASED PRODUCT							1.9365
TOTAL	0.4426	0.1123	2.4331	1.1856	0.0160	1.9365	6.1261

NOTE

1. \$/Cell in 1977 Price.
2. Cost Factors in SAMICS Were Considered.
3. Purchased Product: Chemically Polished Wafers.

TABLE 5

COST ANALYSIS (SAMICS) OF MODULE COMPANY

PROCESS	EQPT	SQFT	DLAB	MATS	UTIL	PURCHASED PRODUCT	TOTAL
MOD-ASS	----	8	146	176	----		330
PURCHASED PRODUCT							1,570
TOTAL	----	8	146	176	----	1,570	1,900

NOTE

1. \$/Module in 1977 Price.
2. Cost Factors in SAMICS Were Considered.
3. Purchased Product: Solar Cell

TABLE 6

COST SUMMARY (SAMICS) OF HIGH EFFICIENCY MODULE

	WAFER CO.		CELL CO.		MOD. CO.	
	\$/WAFER	%	\$/CELL	%	\$/MOD	%
EQUIPMENT	0.107	6.3	0.443	7.2	-----	0
SPACE	0.034	2	0.112	1.8	8	0.4
LABOR	0.277	16.3	2.433	39.8	146	7.7
MATERIALS	0.433	25.5	1.185	19.3	1,176	9.3
UTILITIES	0.013	0.8	0.016	0.3	-----	0
PURCHASED PRODUCT	0.832	49.1	1.937	31.6	1,570	82.6
TOTAL	1.696	100	6.126	100	1,900	100

NOTE

1. Price Year: 1977
2. Cost Factors in SAMICS Were Considered.

TABLE 7

A NEW COST ACCOUNT CATALOG

CATALOG NO.	ITEM DESCRIPTION	UNIT	PRICE
G2010D	QUARTZ CRUCIBLE	EA.	\$ 70.00
G2020D	ARGON GAS	CU.FT.	\$.0235
G2030D	O.D. BLADE	EA.	\$100.00
G2040D	8" I.D. BLADE	EA.	\$150.00
G2050D	PLANAR ETCH ACID	GAL.	\$ 4.82
G3010D	ALUMINUM EVAPORATION SOURCE	GM.	\$.40
G3020D	SILVER EVAPORATION SOURCE	GM.	\$.395
G3030D	TITANIUM EVAPORATION SOURCE	GM.	\$.362
G3040D	PALLADIUM EVAPORATION SOURCE	GM.	\$ 1.805
G3050D	FRONT METAL MASK	EA.	\$ 23.50
G4010D	HARDWARE CHASSIS	EA.	\$102.00
G4020D	INTERCONNECT	EA.	\$.0083
G4030D	DIFFUSED SUNADEX GLASS	SQ.FT.	\$.93
G4040D	RTV-602	LBS.	\$ 11.00

CONCLUSIONS

The design goal of achieving 13% module was accomplished. Six high efficiency modules were designed, fabricated, tested, and delivered. The cost of the module was relatively high due to the large number of cells required. The efficiencies of the six modules were between 12.9% and 13.2%, as shown in Table 2 and Figures 13-18. However, it should be partially offset by reduction in cost in support structure, real estate, maintenance etc., as well as by consideration of the manufacturing procedures if these were directed towards larger number of such arrays.

The module methods used were easily adapted to the cells, showing that high efficiency cells can maintain their higher electrical output with a variety of possible lower cost module designs, and will be cost-effective for larger scale use if their manufacturing cost can be reduced. The suggested programs (Section 4.0) include programs to investigate this potential.

5.0

RECOMMENDATIONS

OCLI recommends the following areas of development work:

- 5.1 Program to develop high efficiency solar cells with lower manufacturing costs to effect cost reduction in dollars per watt.
- 5.2 Program to investigate heat rejection coating on module window. The program should include computer analysis, experimental samples, electrical and temperature measurements of the module, etc.
- 5.3 Program to develop low cost interconnecting schemes to minimize labor. This may involve designing new cell contact configurations.
- 5.4 Program to study cost trade-off between the high packing density module and a high efficiency module with round cells, Sunadex glass, and white reflecting surface. The results are to be verified by building and comparing actual modules.

6.0

NEW TECHNOLOGY

There is no new technology developed during the performance of this contract.