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HIGH EFFICIENCY, LONG LIFE TERRESTRIAL SOLAR PANEL

FIRST QUARTERLY REPORT

For Period Covering

1 September 1977 Through 30 November 1977

By

T. Chao, S. Khemthong
K. Ling and S. Clah

JPL CONTRACT NO. 954831

OPTICAL COATING LABORATORY, INC.
Photoelectronics Division
15251 East Don Julian Road
City of Industry, CA 91746



This work was performed for the Jet Propulsion Laboratory California Institute of Technology, under NASA Contract NAS7-100 for the U.S. Department of Energy, Division of Solar Energy.

The JPL Low-Cost Silicon Solar Array Project is funded by DOE and forms part of the DOE Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays.

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ABSTRACT

The design of a high efficiency, long life terrestrial module has been completed. It utilizes 256 rectangular, high efficiency solar cells to achieve high packing density and electrical output. Tooling for the fabrication of solar cells is in house and evaluation of the cell performance has begun. Based on the power output analysis, the goal of a 13% efficiency module is achievable.

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1.0 INTRODUCTION

The objective of this program is to design, fabricate, and deliver six (6) high efficiency, long life terrestrial solar panels utilizing high efficiency solar cells and increased packing density. The overall dimensions of the solar panels will be approximately 46 inches by 23 inches. Each panel will 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.

2.0 TECHNICAL DISCUSSION

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

2.1 Module Design

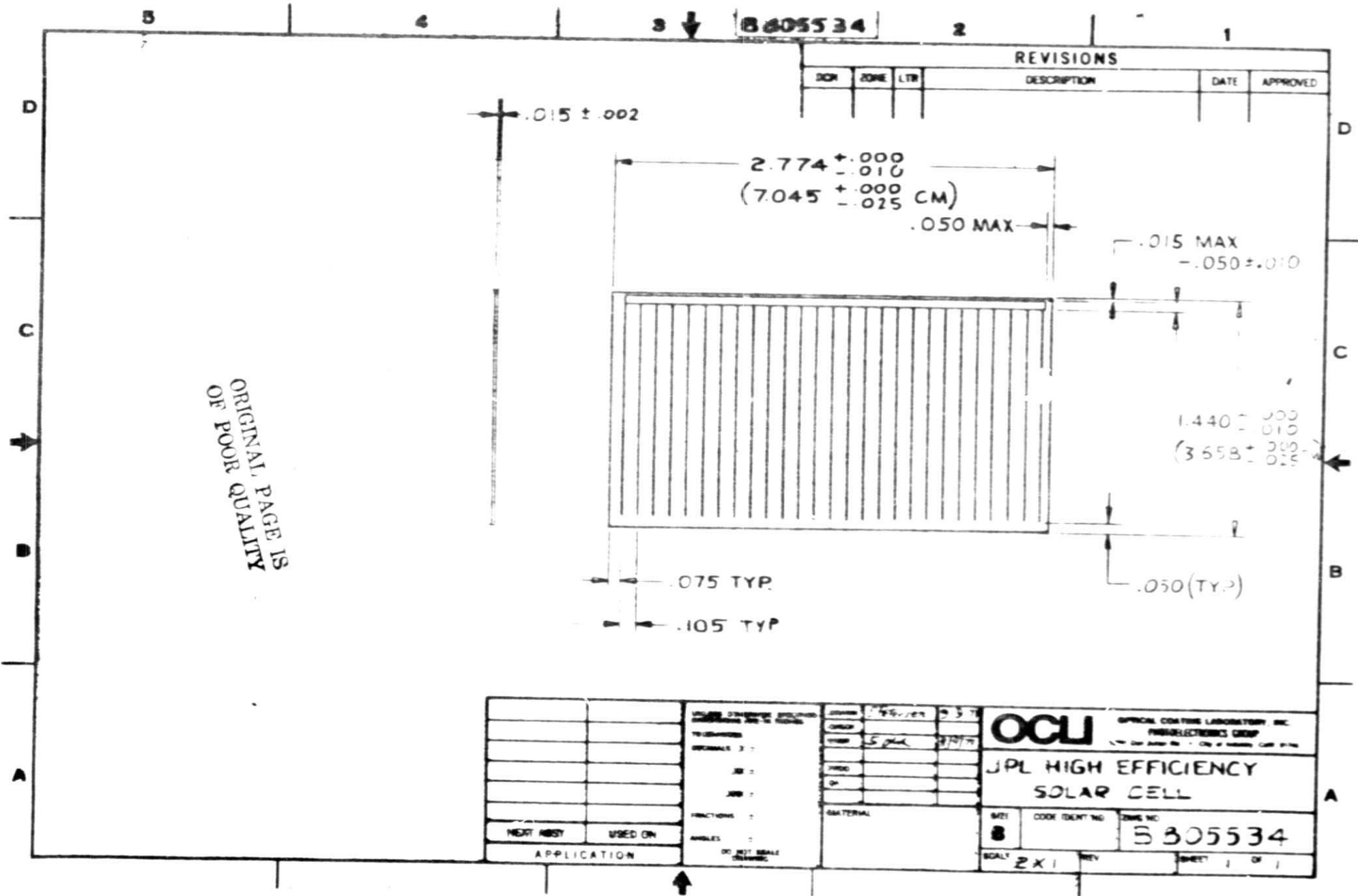
The detailed panel design has been completed, as shown in Figure 1. The module consists of a piece of 46" x 23" Sunadex water white glass, aluminum frame, solar cells, RTV-615 for encapsulation, monoacrylic or polysulfide for edge sealing, Mylar film for moisture barrier, and the necessary terminals. Each module will have 256 rectangular solar cells, 8 strings in parallel with each string having 32 cells in series. A flexible, over-lapping design will be utilized to connect the cells in series to eliminate the spacings between cells and the electrically inactive N-contact. The solar cell assembly will be encapsulated to the Sunadex glass window with GE RTV-615. A thin film will be used for moisture barrier. The edges of the module will be sealed with polysulfide or monoacrylic. Aluminum frame and electrical terminals will be attached to the assembly to complete the panel.

Component drawings, sub-assembly drawings, tooling drawings and assembly procedures have been prepared.

2.1.1 Solar Cell

The size of the solar cells will be nominally 7.045cm by 3.658cm by 0.038cm in thickness, as shown in Figure 2. The cell will have the N-contact

FIGURE 2



5

4

3

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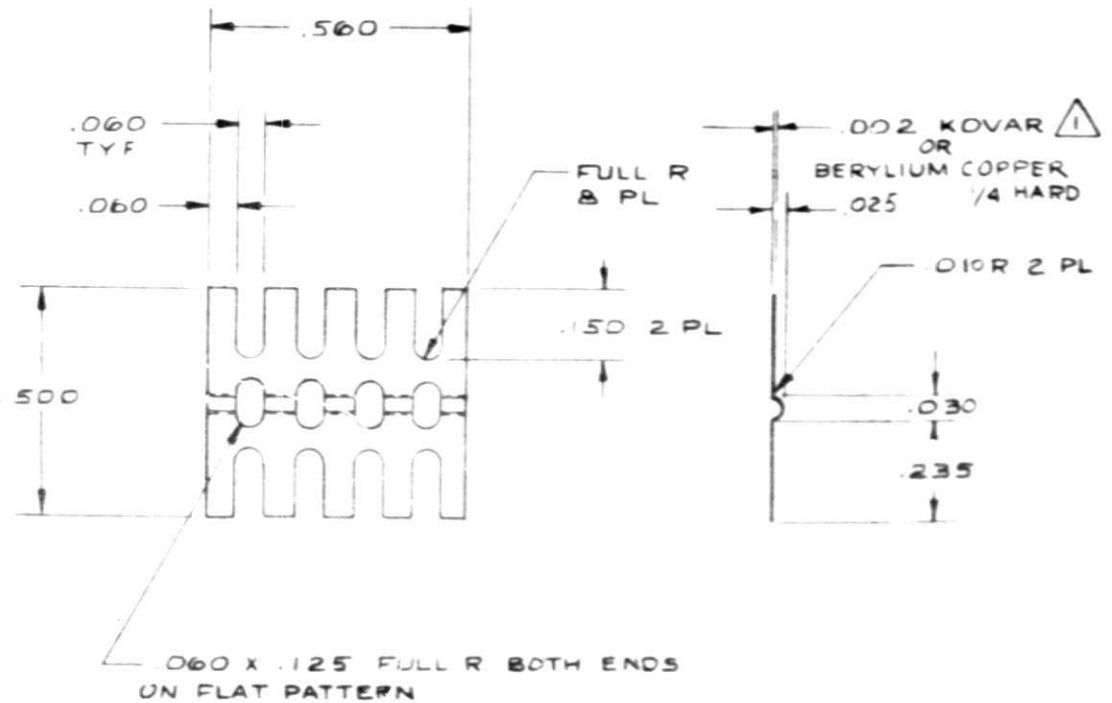
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REVISIONS

DCN	ZONE	LTR	DESCRIPTION	DATE	APPROVED
7676		AGE	#7/28/77	7-17-77	26 DC

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⚠ BASE MATERIAL THICKNESS .002

- 2. FLAT STOCK .560 x COIL
- 3. FINISH FOR KOVAR
COPPER PLATE PER MIL-C-14550 .0005
SOLDER PLATE .0002
SILVER PLATE .0002
AFTER FABRICATION
- 4. FINISH FOR BERYLIUM COPPER
SOLDER PLATE .0005

		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
		TOLERANCES
		DECIMALS X -
		XX -
		XXX - .005
		FRACTIONS -
		ANGLES -
		DO NOT SCALE DRAWING
NEXT ASSY	USED ON	
APPLICATION		

DRAWN <i>[Signature]</i>	9-9-77	OCLI OPTICAL COATING LABORATORY INC. PHOTOELECTRONICS GROUP 1001 San Antonio Rd. • Oak Ridge, Tenn. 37830
CHECK <i>[Signature]</i>	8-29-77	
ENG'D		JPL HIGH EFFICIENCY SOLAR CELL INTERCONNECT
PROD		
QA <i>[Signature]</i>	8-11-77	SIZE B
MATERIAL ⚠		CODE IDENT NO
		DWG NO B 805535
		SCALE 4 X 1
		REV N/C
		SHEET 1 OF 1

0.153cm in width, along the 7cm edge and 27 gridlines equally spaced. An alloyed aluminum P+ layer will be applied to the back side of the cell and an OCLI proprietary multilayer antireflective coating will be evaporated onto the active surface of the cell. The titanium-palladium-silver contact system was chosen for the humidity resistance property and its demonstrated reliability in the space programs.

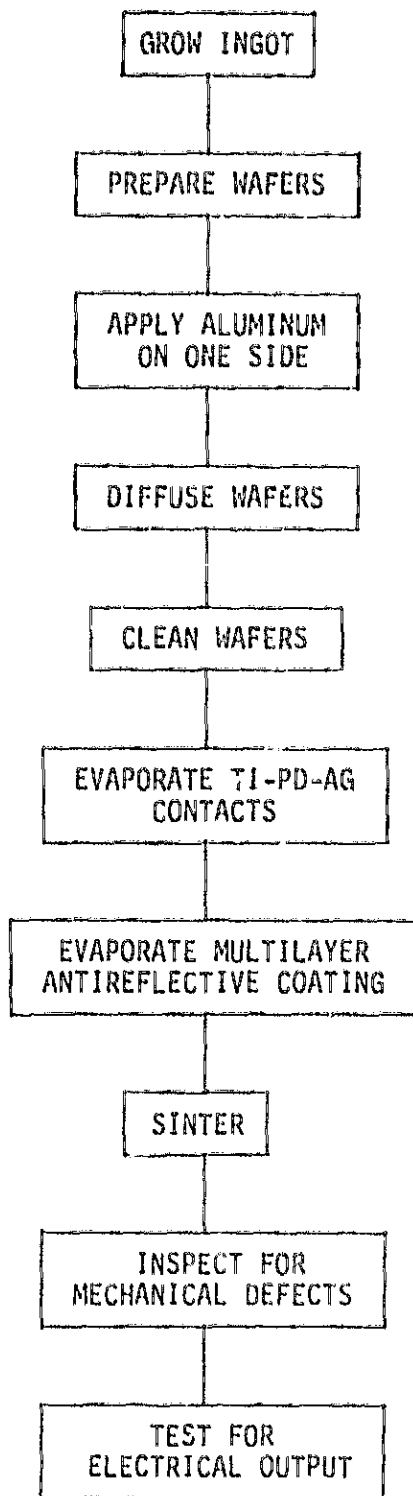
The manufacturing sequence of the solar cell is shown in Figure 3. The processing procedures, used for space cells for many years, are well in hand.

Toolings for fabrication of the cells have been received from vendors and the evaluation of the cell performance has begun.

2.1.1.1 Multilayer Antireflective 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 rejection 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

FIGURE 3
CELL FLOW CHART



a result, the multilayer AR coating was developed. OCLI considers both the materials and the technique of application of the MLAR coating as proprietary.

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 multilayer AR coating provides a low reflectance over a wide band of wavelength, resulting in a high electrical gain after encapsulation or glassing.

2.1.2 Glass Window

The tempered water white Sunadex glass has been selected for the front window material. The glass will be 3/16" in thickness with one surface having a lightly-diffused pattern. An experiment had been 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 antireflective coating and heat

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OCCL - 13

OCCL OPTICAL COATING
LABORATORY, INC.
2789 G-Hen Avenue
Santa Rosa, California
Telephone (707) 545-6440

SPECTRAL PERFORMANCE

DATA IDENTIFICATION

OCCL No. 13

Run No.

Spec. No.

SAMPLE IDENTIFICATION

Sample Type
OCLI MLAR COATING
ON SILICON CELL

Part Number

TEST OPERATING PARAMETERS

DK-2

Wavelength

Aperture

Pressure

Humidity

Humidity 0-50

Percent Transmission

Percent Reflection

TEST CONDITIONS

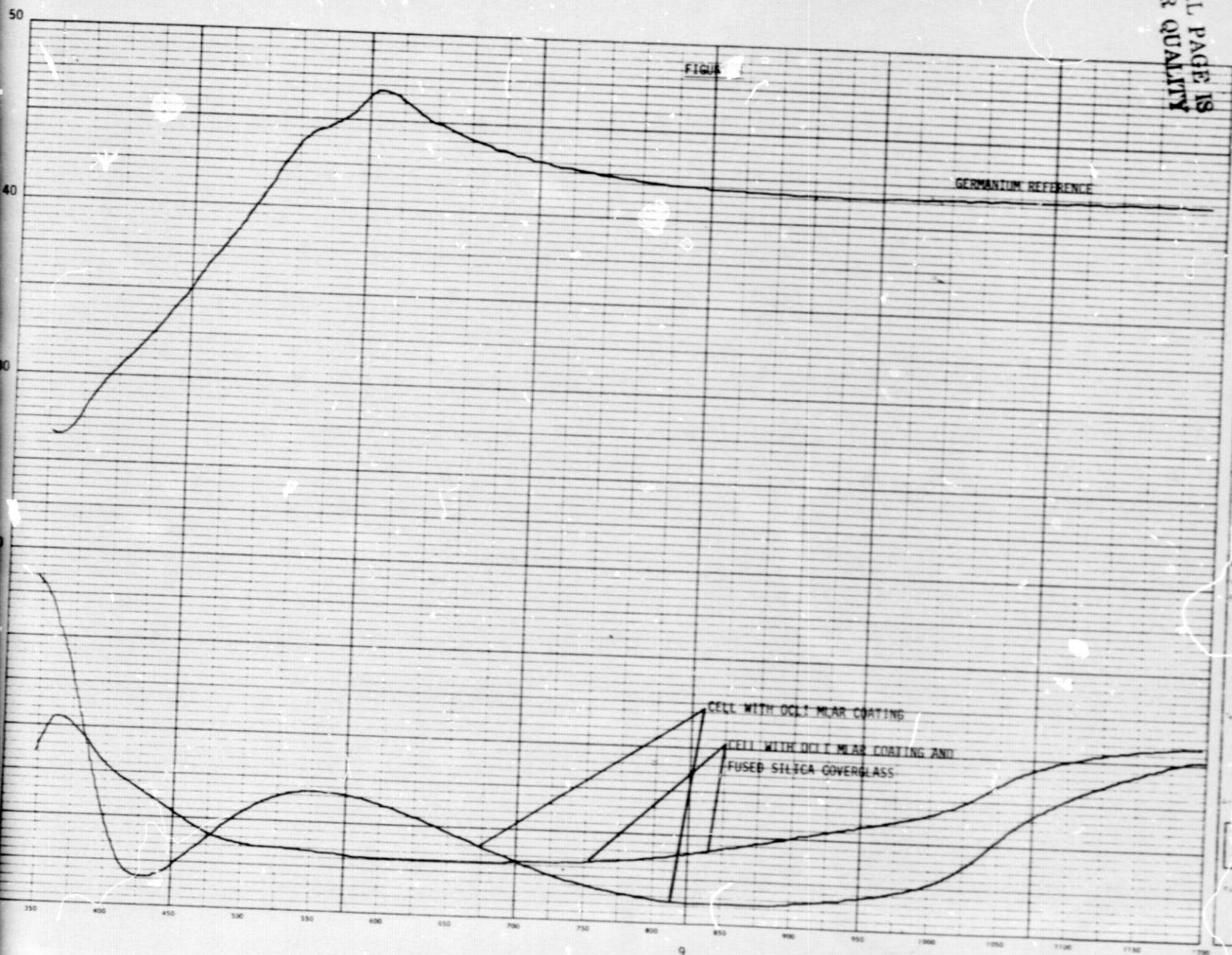
Temp. ROOM Atmos. 70°

Run No. SK Date 12-15-77

GEARS 96 FRONT
48 BACK
EXPANSION 1X

PAGE 1 of 1

WAVELENGTH, MILLIMICRONS



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 antireflective coating were applied to the opposite side of the glass. Four (4) 2x2cm 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/cm^2 . All cells had multilayer antireflective coating. The cells were then bonded to the glass on the side with the heat rejection coating with RTV-602. 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 antireflective coating on the Sunadex glass is very small. The small improvement in output could not justify the cost of applying the coating.

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

The heat rejection coating on the coverglass does not appear to be effective. As expected, the coating reduced the transmission of the glass slightly, resulting in a lesser gain in electrical output after bonding of the glass.

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 similar to texturing. If there is no difference in electrical output, the module would be easier to clean with the smooth side facing the sun. It was found that the short circuit current was increased from 100.3mA to 108.6mA (8.3% gain) after bonding. Unless the problem of removing the bubbles in the adhesive during the curing cycle was encountered, the solar cell assembly will be bonded to the side of the glass with the diffused pattern.

2.1.3 Interconnect

Two mil thick silver-tin plated Kovar interconnect with stress relief loop, as shown in Figure 5, had been designed for the module. The choice of Kovar is to match the coefficient expansion of silicon. The stress relief loop will allow movement between cells during temperature changes.

2.1.4 Encapsulation and Assembly

The cell assembly will be bonded to a piece of Sunadex glass with RTV-615. A sheet of 5 mil thick Mylar will be bonded to the back of the cell assembly as moisture barrier.

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

The sealed assembly is held down mechanically with hold-down angles. A .06" thick closed cell neoprene gasket is bonded to the hold down flange of the angle. The encapsulation assembly is not bonded to the aluminum chassis to permit linear thermo-expansion between the glass window and the aluminum chassis.

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 assembled module. To decide on the choice 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 assembly

technique is the same as proposed for the module for this program. The construction of the closed chassis is more rugged. However, the concern was the temperature difference between the two designs. The temperature of the two panels were measured in sunlight in the OCLI parking lot. It was found that the panel with the closed chassis was only 0.9°C hotter. Due to the rugged construction, the closed chassis will be used for this program.

2.1.6 Terminals

The electrical leads from the solar array are connected to environment-resistant panel mounted receptacles. The receptacles are the screw type connector, Amp 48-13R10-20SN. The wiring connection is protected with an enclosure fastened to the chassis. The enclosure is sealed with a .03 inch thick polyethylene gasket against moisture.

2.2 Power Output Analysis

$$\begin{aligned}\text{Total Panel Area} &= 46'' \times 254 \text{ cm/in} \times 23'' \times 2.54 \text{ cm/in} \\ &= 6824.1 \text{ sq.cm.}\end{aligned}$$

$$\begin{aligned}\text{Cell Active Area} &= 7.045 \text{ cm} \times (3.658 - .153)\text{cm} \\ &= 24.693 \text{ sq.cm.}\end{aligned}$$

$$\begin{aligned}\text{Total} \\ \text{Cell Active Area} &= 256 \times 24.693 \\ &= 6321.4 \text{ sq. cm}\end{aligned}$$

For panel assembly it is estimated that there will be 7% glassing gain and 2% wiring loss, resulting in a net gain of 5%.

CASE I - For 80 Watt Panel

$$\begin{aligned}\text{Power Output Per Cell} &= \frac{80}{256 \times 1.05} \\ &= 0.298 \text{ Watts}\end{aligned}$$

$$\begin{aligned}\text{Cell Efficiency} &= \frac{0.298}{24.693 \text{ cm}^2 \times 0.1 \text{ W/cm}^2} \times 100 \\ &= 12.1\%\end{aligned}$$

CASE II - For 13% Efficiency Panel

$$\begin{aligned}\text{Panel Power Output} &= 6824.1 \text{ cm}^2 \times 0.1 \text{ W/cm}^2 \times 13\% \\ &= 88.7 \text{ Watts}\end{aligned}$$

$$\begin{aligned}\text{Power Output Per Cell} &= \frac{88.7}{256 \times 1.05} \\ &= 0.330 \text{ Watts}\end{aligned}$$

$$\begin{aligned}\text{Cell Efficiency} &= \frac{0.330}{24.693 \text{ cm}^2 \times 0.1 \text{ W/cm}^2} \times 100 \\ &= 13.4\%\end{aligned}$$

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

OCLI has produced large area terrestrial cells with the conversion efficiency greater than 13.4% at AM1 and 28°C. Consequently, the program goal of fabricating solar modules with overall efficiency of 13% appears to be achievable.

3.0 CONCLUSIONS

The design of the solar cell and the solar module have been completed. Drawings for all components, sub-assemblies, assembly, and tooling have been prepared. Tooling for contact evaporation and antireflective coating are in house. Evaluation of cell performance has begun. Based on the power output analysis, the objective of the program of producing modules with an overall conversion efficiency of 13% at AM1 and 28°C is achievable.

4.0 RECOMMENDATIONS

No recommendations can be made during this reporting period.

5.0 NEW TECHNOLOGY

There is no new technology developed during this period.

6.0 PROGRAM PLAN

6.1 The program is essentially on schedule. Work planned for the next reporting period is as follows:

6.1.1 Conduct design review.

6.1.2 Upon completion of design review, initiate procurement for components and assembly tooling.

6.1.3 Complete cell evaluation and begin manufacture of cells.

6.1.4 Begin construction of modules.

6.2 A Milestone Chart is provided on the next page.

MI:LESTONE CHART

DESCRIPTION	MONTH						
	SEP	OCT	NOV	DEC	JAN	FEB	MAR
1. DESIGN OF PRELIMINARY SOLAR MODULE	█						
2. DESIGN OF HIGH EFFICIENCY SOLAR CELL							
A. DESIGN AND ACQUISITION OF CONTACT EVAPORATION TOOLING	█	█	█	█			
B. DESIGN AND ACQUISITION OF AR COATING TOOLING	█	█	█	█			
C. DESIGN AND ACQUISITION OF INTERCONNECTS		█	█	█			
D. DESIGN AND ACQUISITION OF SHINGLING TOOLING		█	█	█			
E. DESIGN AND ACQUISITION OF MODULE LAY-DOWN TOOLING		█	█	█			
3. THERMAL DESIGN							
A. DESIGN, PREPARATION, AND TEST OF HEAT REJECTION COATING		█	█	█			
B. DESIGN, PREPARATION, AND TEST OF AR COATING		█	█	█			
4. FABRICATION OF SOLAR CELLS				█	█		
5. PREPARATION OF DESIGN DATA PACKAGE				█	█		
A. PREPARATION OF DETAILED MODULE ASSEMBLY DRAWING				█	█		
B. PREPARATION OF ASSEMBLY PROCEDURE				█	█		
6. DESIGN REVIEW							
7. FABRICATION AND DELIVERY OF SIX (6) MODULES							

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MILESTONE CHART (CONTINUED)

DESCRIPTION	MONTH						
	SEP	OCT	NOV	DEC	JAN	FEB	MAR
8. PARTICIPATION IN MEETINGS							
A. PROJECT INTEGRATION MEETINGS				▲			
B. WORKSHOPS							
9. REPORTS							
A. MONTHLY REPORTS		▲	▲		▲	▲	
B. QUARTERLY REPORT				▲			
C. FINAL REPORT							▲
D. COST DOCUMENTATION AND PROJECTIONS							▲
- END -							