CONTRACTOR REPORT

SAND82-7146
Unlimited Release
UC-63c

Concentrator Receiver Encapsulant Evaluation

Applied Solar Energy Corporation
15251 E. Don Julian Road
City of Industry, CA 91746

Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-76DP00789

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Sandia Contract No. 68-9412

Abstract

During this contract, receivers and encapsulated cell strings were fabricated utilizing four (4) different encapsulating materials in accordance with BDM-PRDA 35 Receiver Design as defined in Sandia National Laboratories, Document No. 68-9412. Three five-cell laminated segments, two one-foot receiver assembly and one five-foot receiver assembly were fabricated using each of the four encapsulating materials. The segments and assemblies were delivered to Sandia National Laboratories, Albuquerque, New Mexico for testing and evaluation. A manufacturing cost comparison was made per five feet receiver using each of the four encapsulant materials and assuming/1MW/year production quantity.

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1.0 INTRODUCTION

The objective of this work was to evaluate various encapsulants for the BDM-PRDA 35 PV receivers, using four different encapsulating materials. ASEC is to build three each five cell string laminates, two each one-foot receiver assembly segments, one each five-foot receiver assembly and deliver the items to Sandia National Laboratories to test and evaluate the encapsulating material. Furthermore, ASEC is to make an economic analysis of the cost per five feet receiver assembly for mass production using each of the four encapsulant. A secondary objective was to evaluate the method of application of the material.

2.0 TECHNICAL DISCUSSION

The PRDA 35 BDM receivers used polyvinyl butyral (PVB) as the encapsulant to bond the cell string to the Pyrex glass superstrate. When PVB is exposed to elevated temperature (120°C) in the presence of oxygen, the PVB will turn brown in color and/or bubble. Neither condition is desirable for concentrator applications. This program is to assess the suitability of other materials as the encapsulant. The following materials were to be evaluated:

a) Dow Corning Sylgard 184.

b) General Electric RTV 615

c) McGhan NuSil R-2602

d) 3M Film NPE-1677

2.1 Program Outline

The program consists of four (4) tasks.

2.1.1 Task 1

Under Task 1, ASEC fabricated three (3) each five-cell string laminates with each of the four materials listed above. The details of the laminates are shown in ASEC Drawing D-202982. 10-inch long pigtails were attached to the laminates for electrical connection.

2.1.2 Task 2

Under Task 2, ASEC fabricated two (2) each, one-foot sections of the PRDA 35 BDM receivers using each of the four materials listed above as the encapsulant. The detailed receiver assembly is shown in ASEC Drawing D-202986. The extrusion is cut to one foot length and one (1) five (5) cell laminate is attached to each side of the extrusion.

2.1.3 Task 3

Under Task 3, ASEC fabricated one each five-foot receiver section using each of the four materials listed above as the encapsulant. The receiver assembly is shown in ASEC Drawing D-202986.

2.1.4 Task 4

Under Task 4, ASEC performed an economic analysis on a five foot receiver section using each of the four materials as the encapsulant.

2.2 Cell String And Module Segment Design

The cell stack assembly consists of Corning #7740 Pyrex glass superstrate, encapsulant and concentrator solar cell. The encapsulated cell string assembly is bonded to an anodized aluminum extrusion with Emerson-Cuming #4952 white thermally conductive RTV. 1.8 mil thick Kapton tape applied to the extrusion is used as the dielectric insulator. The specification and application of the encapsulation materials will be discussed in the following paragraphs.

2.2.1 Dow Corning Sylgard 184

Sylgard 184 is a high strength, room temperature curing silicone elastomer, supplied as a two componant pourable system. It is a clear formulation with over 90% light transmission in a thin section and its index of refraction matches that of the glass. The room temperature curing time is high. It can be cured in elevated temperatures to shorten curing time. It has relatively low vicosity (800 CPS) which will be even lower under elevated temperature. The degassing time of the mixture is moderate, 5-10 minutes per 150 milligram in 30 inches of mercury vacuum. Because of the low viscosity, dammed fixturing is required to retain the Sylgard 184 in place. Also it requires the fixtures to be level. When a cell string is placed on top of the adhesive, small bubbles will appear between the cells and the glass. The bubbles are removed by applying pressure starting from one end of the cell string to the opposite end. The most time-consuming operation is to clean the encapsulated cell string assembly. Although the parts can be handled after one (1) hour of elevated temperature curing, complete curing will occur between 7-10 days at room temperature. Alcohol, MEK, Acetone, etc. cleansers must not be used for cleaning purposes because the uncured elastomer will absorb some quantities of solvent which will prevent complete curing of the adhesive.

2.2.2 General Electric RTV-615

It is a two component silicone elastomer formulated for room temperature curing. The basic viscosity is 5000 CPS. The light transmission and index of refraction are the same as those of Sylgard 184. RTV-615 has a very long (25-30 Min.) degassing time. Its application and fixturing are the same as those of Sylgard 184. The viscosity drops to 200-300PCS during temperature curing for a short period of time which may create voids or bubbles. The same technique used with Sylgard 184 to remove bubbles may be used with RTV-615 and cleaning of parts is similar to that of Sylgard 184.

2.2.3 McGhan Nu-Sil R-2602

It is the direct descendant of the discontinued GE-RTV-602. The two component elastomer is formulated for room temperature curing or for moderate temperature curing with a different catalyst. The viscosity is 1200 CPS which immediately starts to increase after mixing and degassing. The degassing time is about 5 minutes. Application of R-2602 is the easiest among the three elastomers used in the program. However, the curing time to handle the part is very long 10-12 days to complete curing. Although the fixturing is not as critical as in the two previously described materials, it requires damming and leveling of the fixture. The cleaning of the encapsulated parts is the same as that of the Sylgard 184 or RTV-615.

2.2.4 3M Film NPE-1677

This is a proprietory formulation, heat-pressure sensitive, 15 mil thick film supplied on a polymeric carrier. The film is tacky to the touch and it is highly adhesive. The film is applied to the clean surface of the coverglass, the polymeric carrier is easily removable and then the cell string is placed over the film on the pre-determined area. No holding fixture or taping is required because of the high adhesion characteristic of the film. The parts now can be batch processed in temperature and pressure controlled equipment in a vacuum bag. Processing temperature is $150^{\circ}C$ @ 100 PSI and 29 inches of mercury pressure in the vacuum bag. There is no after process cleaning required since the film does not melt or flow.

3.0 COST ANALYSIS

The cost of materials and the man hours required for manufacturing will be discussed in this paragraph. The analysis based on 1 MW per year production. Table No.1 shows the module parameters and the estimated module performance. From this figure, it is concluded that about 6.5 thousand modules are required to produce 1MW of power. Assumption was made that state-of-the-art manufacturing technology would be used.

This cost analysis does not deal with equipment, tooling, etc. installation, G & A, or profit G & A, and structure of any manufacturing facility. It shows the cost of material which makes up the module and the estimated man hours required to complete a module. A labor rate of $6.00/Hr. and an overhead rate of 250% were assumed for the calculation.

Table No.2 shows the cost of the common materials used in each of the four modules and shows the common labor hour requirement that is present in each module. Table 3 shows the concentrator cell cost. Tables 4,5,6, and 7 show the estimated cost of the modules with the four different encapsulation. Table 8 presents the module cost and the dollar per watt cost of the module.

4.0 CONCLUSION

RTV Silicone elastomers have been used for encapsulating solar cells especially in space panel fabrication. They have good weatherability, good thermal stability, and high resistance against UV radiation. All these characteristics are desirable for concentrator application. However, only very limited data is available yet of its long time endurance under concentrated sunlight. The difficulty in application, cleaning, etc., make the elastomers more difficult to automate and less cost effective. A new application or processing technology has to be developed.

The economic analysis indicates the cell cost dominates the module cost which is relatively insensitive to the type of encapsulant chosen.

TABLE 1

MODULE ESTIMATED DATA

Module Parameters

44 Solar Cells, 22 On Each Side of the "V" Substrate:

Cell Size:	1.8 x 6.46cm Active Area
Connection:	22 in Series, Each Side
Diode:	(4) Four By-Pass Diode on Each Side, Internally Connected
Concentration Ratio:	27.75 Suns
Overall Length:	58 Inches

Estimated Performance

Efficiency:	13.5% @ 55^{o}C Cell Temperature
Insolation:	800 w/m^2 = .08 w/cm^2
Module Output:	1.8 x 6.46 x .8 x .135 x 27.75 x 44 = 153.3W
1 mW =	Approximately 6.5 K Receiver

TABLE 2
COST OF COMMON MATERIALS AND COMMON LABOR HOUR REQUIREMENT

COST OF MATERIAL PER MODULE

Material Description	Unit Cost	Requirement	TOTAL
Al Extrusion, Substrate	$1.00/lb.	3.75 lb.	$ 3.75
Pyrex Substrate	6.50 Ea.	8 Pcs.	52.00
Cu.Ribbon, Solder Clad	19.95/lb.	.32 lb.	6.40
End & Wire Cover, Die-Cast	.22 Ea.	4 Pcs.	.88
Diode, By-Pass	2.25 Ea.	8 Pcs.	10.25
Retainer Clips	.45 Ea.	36 Pcs.	16.20
Bonding, #4952 W RTV	13.50/lb.	.33 lb.	4.50
Insulating Tape, Misc.			6.50
Miscellaneous			1.75
		TOTAL	$102.23

COMMON LABOR HR. REQUIREMENT PER MODULE

Substrate Machineing & Finishing		.42 Hr.
Soldering & Cleaning		.75 Hr.
Testing		.25 Hr.
Taping		.66 Hr.
Cell Assembly Lay Down		.30 Hr.
Dielectric & Functional Test		.10 Hr.
Final Assembly & Cleaning		2.20 Hrs.
Final Test (1 Sun)		.10 Hr.
	TOTAL HOURS	4.78 Hr.

TABLE 3
SOLAR CELL COST

The following costs and rates are assumed.

High Purity Polysilicon	$65/Kilogram
Labor Rate	$ 6/Hour
Manufacturing Overhead	250%
Metallization	$0.80/Cell

COST/CELL

Silicon		$1.00
Metallization		.80
0.2 Hr/Cell		1.20
Overhead		3.00
		$6.00
At 80% Yield	COST/CELL =	$7.50

TABLE 4
ESTIMATED COST OF MODULE

RTV-615 ENCAPSULANT

Basic Material Cost			$102.23
Cost of RTV - 615	$21.3/lb. @ .65 lb./Module		13.84
Lay-Up Tape			1.64
Primer			.45
		TOTAL MATERIAL:	$118.16

SOLAR CELL

Basic Labor Hour		4.78 Hr.
Lay-Up Prep.		.26 Hr.
Encapsulation (Elevated Temperature)		.40 Hr.
Cleaning		.30 Hr.
	TOTAL HOURS:	$5.74 Hr.

TABLE 5
ESTIMATED COST OF MODULE

RTV-2602 ENCAPSULANT

Basic Material Cost			$102.23
RTV-2602	$50.00/lb. @ .65 lb./Module		32.50
Lay-Up Tape			1.64
Primer			.45
		TOTAL MATERIAL:	$136.82

SOLAR CELL

Basic Labor Hour		4.78 Hr.
Lay-Up Prep		.26 Hr.
Encapsulation (Room Temperature		.56 Hr.
Cleaning		.30 Hr.
	TOTAL HOURS:	5.90 Hr.

TABLE 6
ESTIMATED COST OF MODULE

SYLGARD 184 ENCAPSULANT

Basic Material Cost			$102.23
Sylgard 184	$20.2/lb. @ .65 lb./Module		13.13
Lay-Up Tape			1.64
Primer			.45
		TOTAL MATERIAL:	$117.45

SOLAR CELL

Basic Labor Hr.		4.78 Hr.
Lay-Up Prep		.26 Hr.
Encapsulation (Elev.Temp)		.40 Hr.
Cleaning		.30 Hr.
	TOTAL HOURS:	5.74 Hrs.

TABLE 7
ESTIMATED COST OF MODULE

3-M #NPE-1677 ENCAPSULANT

Basic Material Cost			$102.23
NPE-1677 Film	$6.5/Yrd.^2$ @ $.1 $Yrd.^2$		.65
		TOTAL MATERIAL:	$102.88

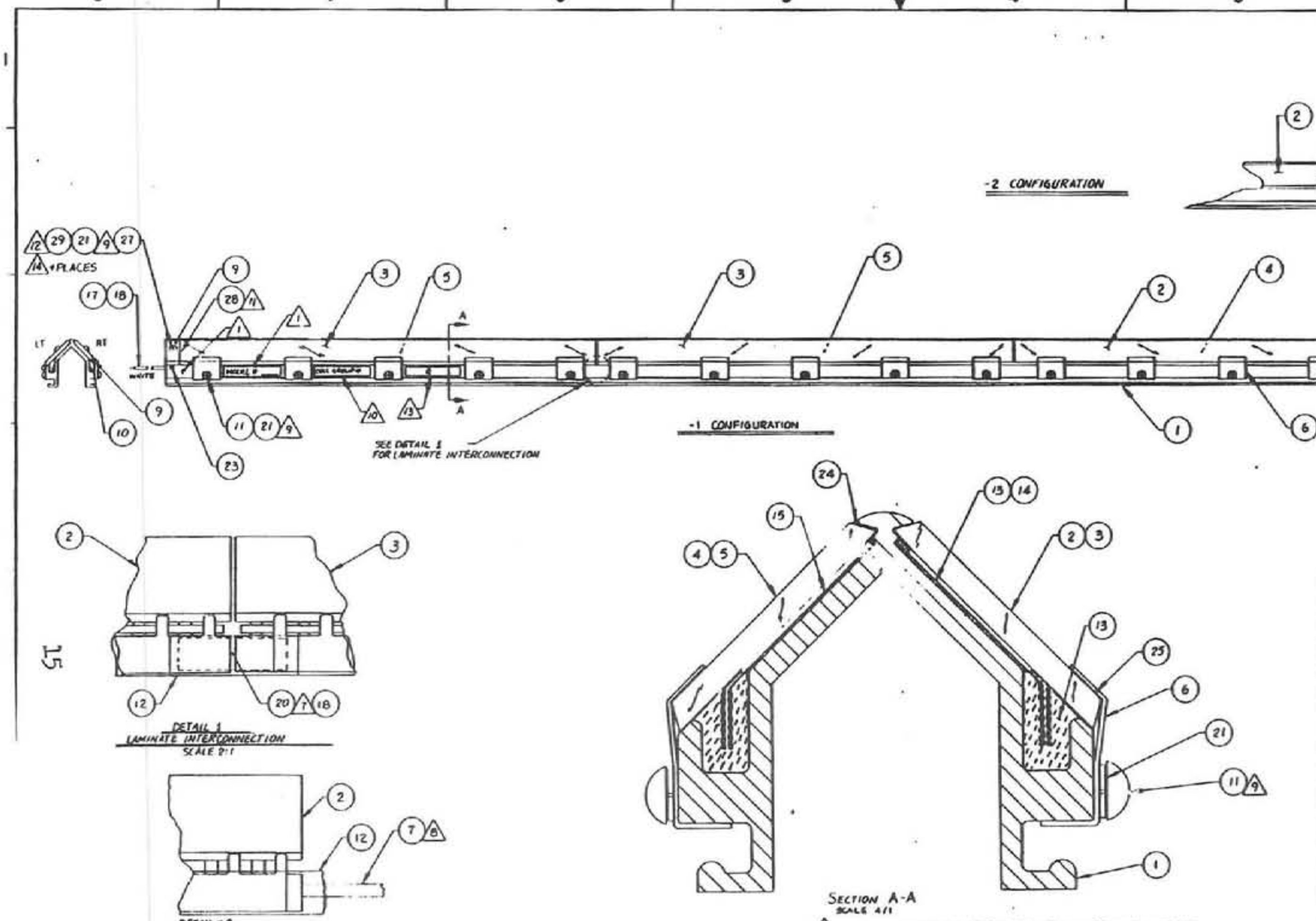
SOLAR CELL

Basic Labor Hr.		4.78 Hr.
Lay-Up		.05 Hr.
Encapsulation (Batch Process)		.01 Hr.
	TOTAL HOURS:	4.84 Hrs.

TABLE 8
MODULE COST

	RTV-615	RTV-2602	SYLGARD-184	NPE-1677
Module Material Cost	$108.16	$136.82	$ 117.45	$102.88
Labor Cost *	120.54	123.90	120.54	101.64
Cost of 44 Cells	330.00	330.00	330.00	330.00
	$558.70	$590.72	$ 567.99	$534.52
At 95% Yield, Cost/Module	$588.11	$621.81	$ 597.88	$562.65
COST/WATT	$ 3.84	$ 4.06	$ 3.90	$ 3.67

*Assume $6/Hr. and 250% Overhead



14. AFTER POLYSULFIDE CURES REMOVE ITEM 27, 21 & FILL SCREW HOLE WITH FRESH POLYSULFIDE & CLEAN.
13. MARK RIGHT SIDE "R" SIDE SHOWN, LEFT SIDE "L" FARSIDE.
12. PUT A THIN LAYER OF POLYSULFIDE ON RECEIVER SURFACE. ASSEMBLE END CLOSURE TOP IN PLACE. WIPE OFF EXCESS POLYSULFIDE.
11. PLACE ITEM 28 BETWEEN LAMINATE END & ENCLOSURE TOP. REMOVE ANY TEFLON TAPE FROM LAMINATE END BEFORE PLACING ITEM 28.
10. SCRIBE CELL ELECTRICAL GROUP NO. INTO RECEIVER USING 1/4" LETTERS. LOCATE APPROX AS SHOWN, BOTH SIDES. USE ONLY ONE CELL GROUP PER MODULE ASSEMBLY.
9. TORQUE SCREWS TO 20-OZ.
8. PEEL BACK TAPE, SPREAD INTERCONNECT (NEGATIVE OR POSITIVE AS SHOWN) PLACE FLATTENED END OF WIRE AND SOLDER IN PLACE AS SHOWN, INSULATE WITH TAPE (ITEM 12).
7. PEEL BACK TAPE. SPREAD INTERCONNECTS FOR SERIES CONNECTION. PLACE ITEM 20 AND SOLDER IN PLACE. INSULATE WITH TAPE (ITEM 12)
6. FOR -2 CONFIGURATION LEAVE END SECTION BLANK. ASSEMBLE AS SHOWN
5. MODEL -2 = 34 CELL MODULE MODEL 1 = 44 CELL MODULE
4. SEE BILL OF MATERIALS A202790
3. SEE ASSEMBLY LOT TRAVELER SC [illegible] ASSEMBLY STEPS AND INSTRUCTIONS
2. SEE LSPS 60-3065 & 60-3066-A DOCUMENT SUMMARY FOR THE 44 CELL & 34 CELL MODULES.
1. SCRIBE MODEL NUMBER, POSITIVE (+), NEGATIVE (-) INTO EXTRUSION, 1/4" LETTERS, BOTH SIDES

NOTES:

34 CELL MOD -2 REQ'D	44 CELL MOD -1 REQ'D	PART NUMBER	DESCRIPTION	ITEM
AR	AR	A203115	POLYSULFIDE	29
2	2	A20322	STRIP (STICK TAPE #144 1.312 X .125 X .06 THK	28
4	4	—	MACHINE SCREW, ROUND HD, PHILIPS SS #6-32 X 5/16	27
AR	AR	A203046	PERMACEL TAPE (TEFLON .010 THK) 3/4 WIDE	25
AR	AR	A203002	TEFLON TAPE (.0035 THK) 3/4 WIDE	24
4	4	—	SCREW SET, SS #6-32 UNC X 5/16	23
1	—	D202867-2	LONG EXTRUSION DETAIL, BDM-2	22
32	40	—	WASHER, LOCK, SS #6	21
4	6	A202993-4	COPPER RIBBON .005 X .20 X 1.00	20
AR	AR	A203077	COBAR 425 NF FLUX	19
AR	AR	A202944	SOLDER SN62	18
2	2	A202941-8	WIRE MARKER (+)	17
2	2	A202941-9	WIRE MARKER (-)	16
96"	116"	A202942	POLYIMIDE TAPE 3M #92 1 1/2 WIDE	15
AR	AR	A202938-2	RTV PRIMER SS 4004 (PINK)	14
AR	AR	A202996	RTV 4954 / CAT 50 (WHITE)	13
AR	AR	A202942-2	POLYIMIDE TAPE, 3M #92 (3/4-2)	12
28	36	—	MACHINE SCREW, ROUND HD, PHILIPS, SS #6-32 X 3/8	11
4	4	B202984	END CLOSURE, PLUG, BDM-2	10
4	4	B202983	END CLOSURE, TOP, BDM-2	9
2	2	A202910-2	TERMINATION WIRE, BDM-2 (WHITE)	8
2	2	A202910-1	TERMINATION WIRE, BDM-2 (BLACK)	7
28	36	B202894	LAMINATE RETAINING CLIP, BDM-2	6
2	2	D202982-2	LAMINATE ASSEMBLY (6 CELL) LEFT	5
1	2	D202982-1	LAMINATE ASSEMBLY (5 CELL) LEFT	4
2	2	D202981-2	LAMINATE ASSEMBLY (6 CELL) RIGHT	3
1	2	D202981-1	LAMINATE ASSEMBLY (5 CELL) RIGHT	2
—	1	D202867-1	LONG EXTRUSION DETAIL, BDM-2	1

NEXT ASSY	USED ON
—	60-3066
—	60-3065

APPLICATION

Applied Solar Energy Corporation

34 & 44 CELL MODULE ASS'Y, BDM-2

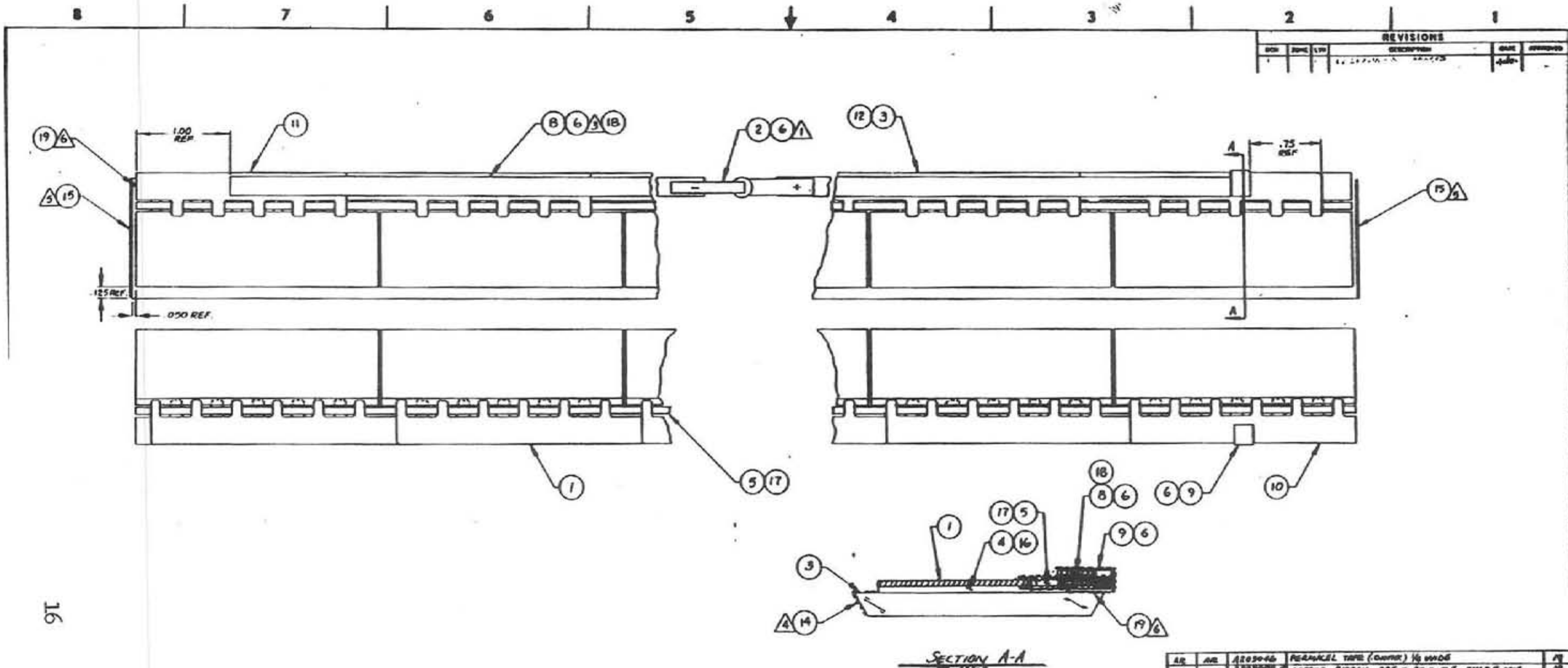
LSPS #'S: 60-3065 44 CELL; 60-3066 34 CELL

SIZE D DWG NO D202986

SCALE 1/2 REV G SHEET 1 OF 1

D202986

15



6 CELL ASSY -2	5 CELL ASSY -1	PART NUMBER	DESCRIPTION	ITEM
AR	AR	A203046	PERMACEL TAPE (.00?THK) 1/4 WIDE	19
1	—	A202993-2	COPPER RIBBON .005 x .20 x 12.5 SN60 R ANNE	18
1	—	A202994-2	EPOXY BOARD 15.36 LG x .040 THK x .490 ±.010 WIDE	17
1	—	A202995	PVB SR8 .015 x .800 x 15.36	16
2	2	A203000	PERMACEL TAPE (.010 THK) 1/2 WIDE x 1.312 TEFLON	15
AR	AR	A203002	TEFLON TAPE (.0055 THK) 1/4 WIDE	14
AR	AR	A203077	COBAR 425HF FLUX	13
1	—	D202810-1	COVER GLASS, BOM-2	12
1	1	D203005-2	INTERCONNECT, HALVES, BOM-2	11
1	1	D203005-1	INTERCONNECT, HALVES, BOM-2	10
1	1	A202993-3	COPPER RIBBON .005 x .20 x .40 SN60 R ANNE	9
—	1	A202993-1	COPPER RIBBON .005 x .20 x 10.0 SN60 R ANNE	8
AR	AR	A202944	SOLDER SN62	7
AR	AR	A202942-4	POLYIMIDE TAPE 3M #92 1/16 WIDE	6
—	1	A202994-1	EPOXY BOARD, 12.81 LG x .040 THK x .490 ±.010 WIDE (G10)	5
—	1	A202995	PVB SR11 .015 x .800 x 12.81	4
—	1	D202810-2	COVER GLASS, BOM-2	3
1	1	A202895	CONCENTRATOR DIODE ASS'Y	2
6	5	C202893	CELL-INTERCONNECT ASS'Y (RIGHT)	1

Applied Solar Energy Corporation

LAMINATE ASSEMBLY
(5 & 6 CELL) RIGHT

-1 = 5 CELL ASSY
-2 = 6 CELL ASSY

SIZE D | DWG NO D202981 | SCALE 2/1 | REV C | SHEET 1 OF 1

D202986 | NEXT ASSY | USED ON | APPLICATION

NOTES:
6. PLACE ITEM 19 ON GLASS BEFORE LAMINATION. TRIM FLUSH WITH ENDS OF GLASS.
5. PLACE ITEM 15 ON ENDS OF GLASS AFTER LAMINATION. TRIM FLUSH WITH GLASS.
4. PLACE TEFLON TAPE ON GLASS AND FOLD OVER APEX AS SHOWN AFTER LAMINATION.
3. CUT ITEM 8 IN HALF. SOLDER TO THE DIODE AND CELL INTERCONNECT ASS'Y AS SHOWN.
2. FRONT VIEW SHOWN WITHOUT GLASS.
1. DIODE TO BE SOLDERED IN PLACE AFTER LAMINATION IN AUTOCLAVE.

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