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Power Sources Engineering Department

Automated Assembly of Gallium Arsenide and Fifty-Micron Thick Silicon Solar Cell Modules

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Final Test Report
December 1984

JPL Contract 956042,
"Development of Technologies for Welding Interconnects to Fifty-Micron Thick Silicon Solar Cells."

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AUTOMATED ASSEMBLY OF GALLIUM ARSENIDE AND
FIFTY-MICRON THICK SILICON SOLAR CELL MODULES

1.0 ABSTRACT

The TRW automated solar array assembly equipment was used for the module assembly of 300 GaAs solar cells and 300 50-μm thick silicon solar cells (2 x 4 cm in size). These cells were interconnected with silver plated Invar tabs by means of welding.

The GaAs cells were bonded to Kapton graphite-aluminum honeycomb-graphite substrates and the thin silicon cells were bonded to 0.002 inch thick single layer Kapton substrates.

The GaAs solar cell module assembly resulted in a yield of 86% and the thin cell assembly produced a yield of 46% due to intermittent sticking of weld electrodes during the front cell contact welding operation. (Previously assembled thin cell solar modules produced an overall assembly yield of >80%).

2.0 INTRODUCTION

This report covers work performed under JPL contract 956042 with the objective of using TRW's automated assembly equipment for the assembly of solar cell stacks and manual assembly of solar cell modules for (a) 300 GaAs solar cells and (b) 300 50-μm thick silicon solar cells, supplied by JPL.

This report describes the successful assembly of four 52-cell GaAs solar cell modules and four 27-cell 50-μm thick silicon solar cell modules, using a fully automatic welded interconnector attachment station and a fully automated glassing station. This program demonstrated the feasibility of automated welding and glassing of GaAs and 50-μm thick silicon cell assemblies using proven techniques that lend themselves to high volume low cost automated production. After hand loading the solar cells and the cover glass into magazines, the cells were not touched until the interconnected and glassed cell stack left the glassing station.

3.0 TECHNICAL DISCUSSION

3.1 Component Description

JPL furnished a total of 300 GaAs solar cells (350-μm thick and 2 x 4 cm in size), and 300 silicon solar cells (50-μm thick and 2 x 4 cm in size). The GaAs cells consisted of GaAs blanks without a junction, but had all standard metallization layers with silver being the last contact metal to which the weld joints were made. The silicon cells were electrically active having an average performance of about 135 mW/cell, at one Sun AM0 and 28°C. The silicon cells were supplied with silver evaporated contacts. The GaAs cells had very smooth cell contacts in comparison to the silicon cells. Due to the etching process that is required to bring the silicon cell thickness down to 50-μm the contact waviness is approaching conditions where actual weld joints are made predominately on the high spots of the cell contacts. Table 1 shows the front- and rear-cell contact waviness data for four cells. Cell bowing of the 50-μm thick silicon cells was eliminated by the cell vendor by omitting the standard rear cell full contact evaporation and replacing it with a grid pattern and back contact pads. This concept worked out very well and made the cells compatible with automated assembly magazines. The vendor evaporated a thin aluminum layer, 700 Å thick, to produce a back surface reflector. Another 100 of the silicon cells, showing a blue back surface, were coated with a 3000 to 5000 Å thick SiO dielectric insulation, and finally the last 100 silicon cells were without coating giving a typical gray appearance of bare silicon. Welding to the rear cell contacts was not affected by these coatings; the weld schedule turned out to be the same for all thin cells.

CELL TYPE	SUBSTRATES
GaAs	Graphite-Aluminum Honeycomb-graphite with Kapton insulation sheet
Silicon	2 mil thick Kapton sheet

3.2 Front Contact Welding

All front cell contact welding was performed on the Automatic Interconnector Attachment station. This machine consists of 12 rotating fixtures surrounded by eight work stations. The station is magazine fed and the completed cell assembly is returned into a second empty magazine. The interconnectors are spool fed and automatically cut and placed onto each cell assembly prior to the weld operation (four weld joints/cell). An improved parallel gap weld head positioning system was designed, fabricated and installed over one of the machine positions. A constant voltage power unit (MCW-550) made by Hughes Aircraft Company supplied the weld pulse to the weld head. The Moly electrode dimensions for front and rear cell contact welding were 0.025 by 0.045 inch, (0.64 by 1.14 mm).

3.2.1 GaAs Cells

In the process of developing a weld schedule for GaAs cells, excessive cell microcracking was experienced, presumably because the welds were made too close to the cell edge. Weld schedule changes did not solve that problem. The weld fixtures (12) were reworked in order to relocate the interconnector and a smoother fixture surface was provided which resulted in the elimination of micro-cracks in the GaAs. Pull strength (zero degree) values ranged from 0.1 to 1.3 kg (average = 0.73 kg). The front contact weld schedule is shown in Table II.

3.2.2 50-μm Thick Silicon Cells

The weld schedule for the silicon cells was determined on the Automatic Interconnector Attachment Station. Pull strength (zero degree) values ranged from 0.2 to 2.5 kg (average = 1.15 kg). Table II shows the weld schedule.

Initial welding went without problems, however, toward the end of the run the weld electrodes started to become sticky which caused cell breakage during the electrode upstroke (cells held to the fixture using vacuum), reducing the assembly yield at this station to 62%. Cells of conventional thickness may experience the same sticking; however, excessive breakage has not been noticed. Sticking can be eliminated in the future by weld equipment modification.

3.3 Cell Glassing

The solar cell glassing operation was performed on the Automatic Glassing Station, which consists of:

1. Automatic loading of glassing fixtures.
2. Placement of cells onto the glassing fixtures from the cell magazine.
3. Dispensing of adhesive (DC93-500) onto solar cell.
4. Dispensing of cover glass from the cover magazine and placement onto the solar cell.
5. Shifting of loaded glassing fixtures from the vertical conveyor belt onto the horizontal belt where the adhesive precure cycle is performed.

In order to process the thin silicon cells the following modifications were necessary: (a) modification of glassing fixtures, (b) minor modification at cell ejector, and (c) minor changes at the final positioning mechanism for cell and cover glass.

A major problem was encountered during the dispensing of the thin glass out of the cover glass magazine, because the cover glass was bowed downwards. During the dispensing cycle two covers were pushed out. This problem was overcome by turning the covers over (with JPL's permission) and loading them into a magazine that had a larger spacing between covers. Additional cover development work is required to eliminate bowing on thin covers. The GaAs cells and covers went through the glassing station like conventional silicon cells. The glassing yields, which include adhesive removal and inspection after glassing, were 93% for the GaAs cells and 81% for the 50-μm thick silicon cells, as shown in Table III.

Excess adhesive was removed from the glassed cells using a non-automated process.

3.4 Rear Contact Welding

The 50-μm thick silicon cells were characterized under the X-25 solar simulator after glassing in order to match the cells for optimum module performance. The GaAs cells were picked at random for the module assembly since they had no electrical output.

Welding of the rear contacts was accomplished on the Lab-Welder which has a small area x-y coordinate system; in principal this is the same system as the large x-y tables with tape control that are used on the production floor. The weld schedules were determined by using glassed cell assemblies. No abnormalities were encountered during this operation. The weld schedules for the rear cell contacts are presented in Table II.

The assembly yield for rear contact welding were 99% for the GaAs cells and 99% for the thin cells.

3.5 Module Assembly

The actual module string bonding to the various substrate materials went without difficulty. Single 50-μm thick silicon cell replacement took a little longer than replacing conventional cell assemblies, but other than that no problems were encountered.

The completed modules are shown in Figures 1 and 2 for the GaAs cells on graphite-honeycomb-graphite substrates having 1-mil Kapton sheets as an insulator and the thin cells on 2-mil Kapton, respectively. Figure 3 shows a rear view of the thin cell modules as seen through the Kapton sheet. Figures 4 and 5 show a front view close-up of the GaAs and the silicon solar cells, respectively. Figure 6 shows a close-up view of the gridded contact thin cell assemblies as seen through the transparent Kapton substrate material. The overall assembly yields have been summarized in Table III.

3.6 Module Performance

The electrical performance of the 50-μm thick silicon cell modules was measured with the Large Area Solar Simulator (LAPSS) at 135.3 mW/cm^2 at 28°C.

The typical I-V characteristics of these four modules are shown in Figures 7 through 10. All modules, with the exception of module serial number 004, were electrically matched for parallel interconnected cells. Single cell measurements could not be performed on the cells with the 3000 to 5000 Å SiO dielectric backside coating. Therefore module serial number 004 which contains these cells does not have a predicted output point.

4.0 CONCULSION

Although this was a limited test program, the results have been very encouraging and clearly demonstrate that the existing assembly equipment can handle both, the welded GaAs solar cell and the welded or soldered 50 micron thick silicon cell with only minor modification required to the existing assembly equipment.

The primary advantage of this approach is that the fragile solar cell and cover glass assemblies are handled by the machines exclusively until they are joined together and then are a much less fragile cell stack assembly that will be more forgiving in the assembly steps that follow.

The weld schedules developed have produced pull strength values comparable to those for previous welded thermal cycle test specimens which have withstood thousands of thermal cycles.

Weld electrode sticking can be overcome either by vibratory means prior to the upstroke, or other mechanical methods.

Table I. Surface Roughness

FRONT CELL CONTACT

CELL NO.	CONTACT	HIGH (μ INCH)	LOW (μ INCH)
1	A	185	110
	B	95	155
2	A	5	180
	B	90	100
3	A	50	305
	B	140	90
4	A	-	-
	B	-	-

REAR CELL CONTACT

CELL NO.	CONTACT	HIGH (μ INCH)	LOW (μ INCH)
1	A	185	190
	B	112	140
2	A	190	35
	B	50	375
3	A	100	150
	B	-	-
4	A	40	145
	B	70	235

Table II. Weld Schedule

FRONT CELL CONTACT

WELD PARAMETER	Ga As CELL	THIN CELL
PRESSURE	1.5 LB	2.2 LB
TIME	50 ms	100 ms
VOLTAGE	.64 V	.60 V
ELECTRODE SIZE	.025 x .045 INCH	.025 x .045 INCH
TEST VOLTAGE VOP	-	0.460 V

REAR CELL CONTACT

WELD PARAMETER	Ga As CELL	THIN CELL
PRESSURE	1.0 LB	2.2 LB
TIME	50 ms	100 ms
VOLTAGE	0.58 V	0.55 V
ELECTRODE SIZE	.025 x .045 INCH	.025 x .045 INCH

Table III. Solar Cell Accountability

SINGLE SOLAR CELLS	Ga As CELLS QTY.	Ga As CELLS # OF CELLS DAMAGED	Ga As CELLS YIELD	THIN Si CELLS QTY	THIN Si CELLS # OF CELLS DAMAGED	THIN Si CELLS YIELD
INTO WELDING	269	-		228	-	
OUT OF WELDING	249	20	93%	141	87	62%
OUT OF GLASSING	241	8		115	26	
OUT OF ADHESIVE REMOVAL	240	1	93% (glassing through inspection)	115	0	81% (glassing through inspection)
OUT OF INSPECTION	231	9		114	1	
OUT OF ELECTRICAL TEST	230	1		112	2	
OUT OF MODULE ASSEMBLY	198	3	99% (module assembly and left over cell stacks)	99	3	99% (module assembly and left over cell stacks)
LEFT OVER CELL STACKS	39	-		11	-	
OVERALL YIELD:			84%			48%
BROKEN DURING EQUIPMENT SETUP	8			42		
USED FOR WELD SCHEDULE DETERMINATION/PULL TEST	23			30		
TOTAL NO. OF CELLS RECEIVED:	300			300		

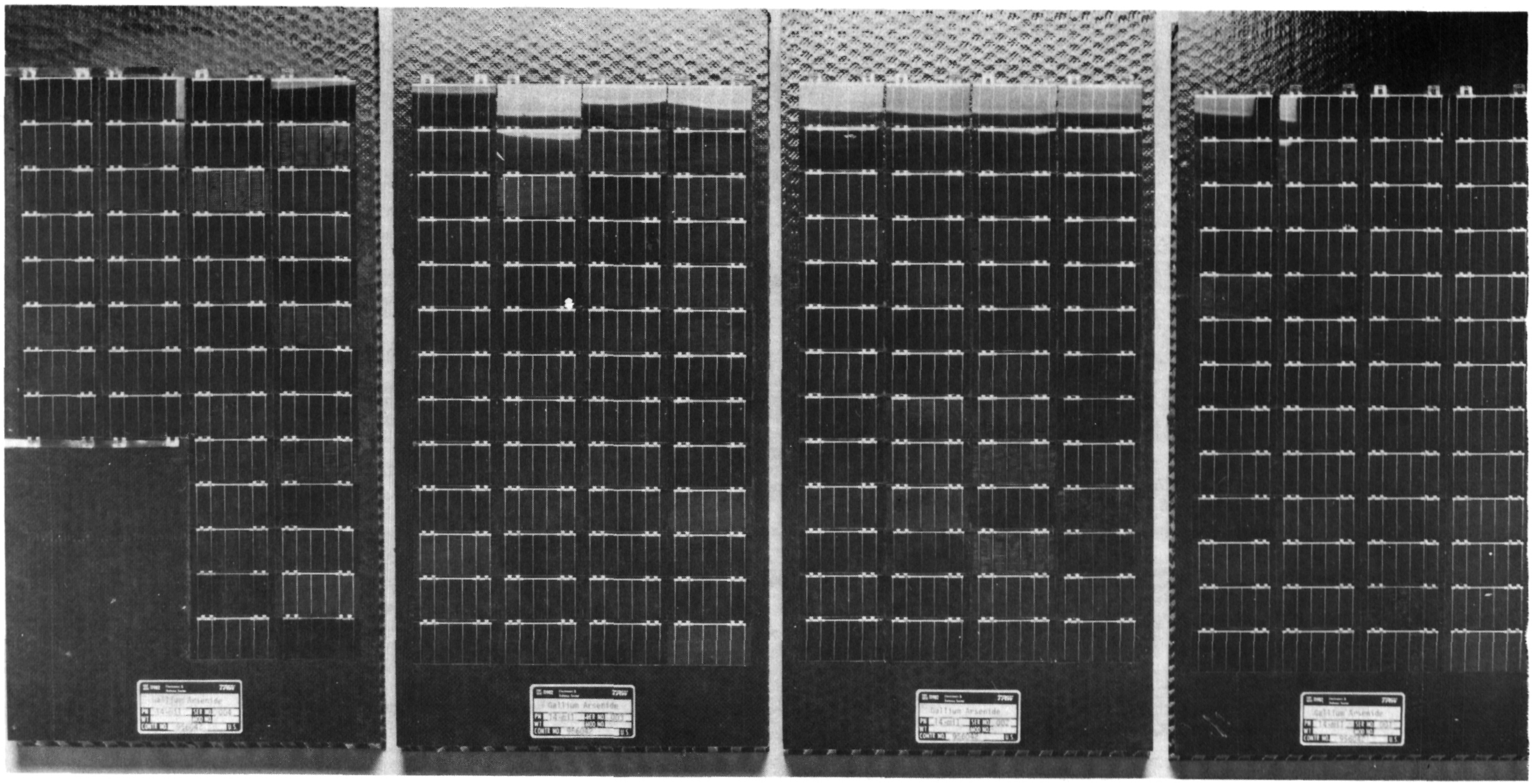

Figure 1. Front View of GaAs Solar Cell Modules Bonded to Graphite-Aluminum Honeycomb-Graphite Substrate

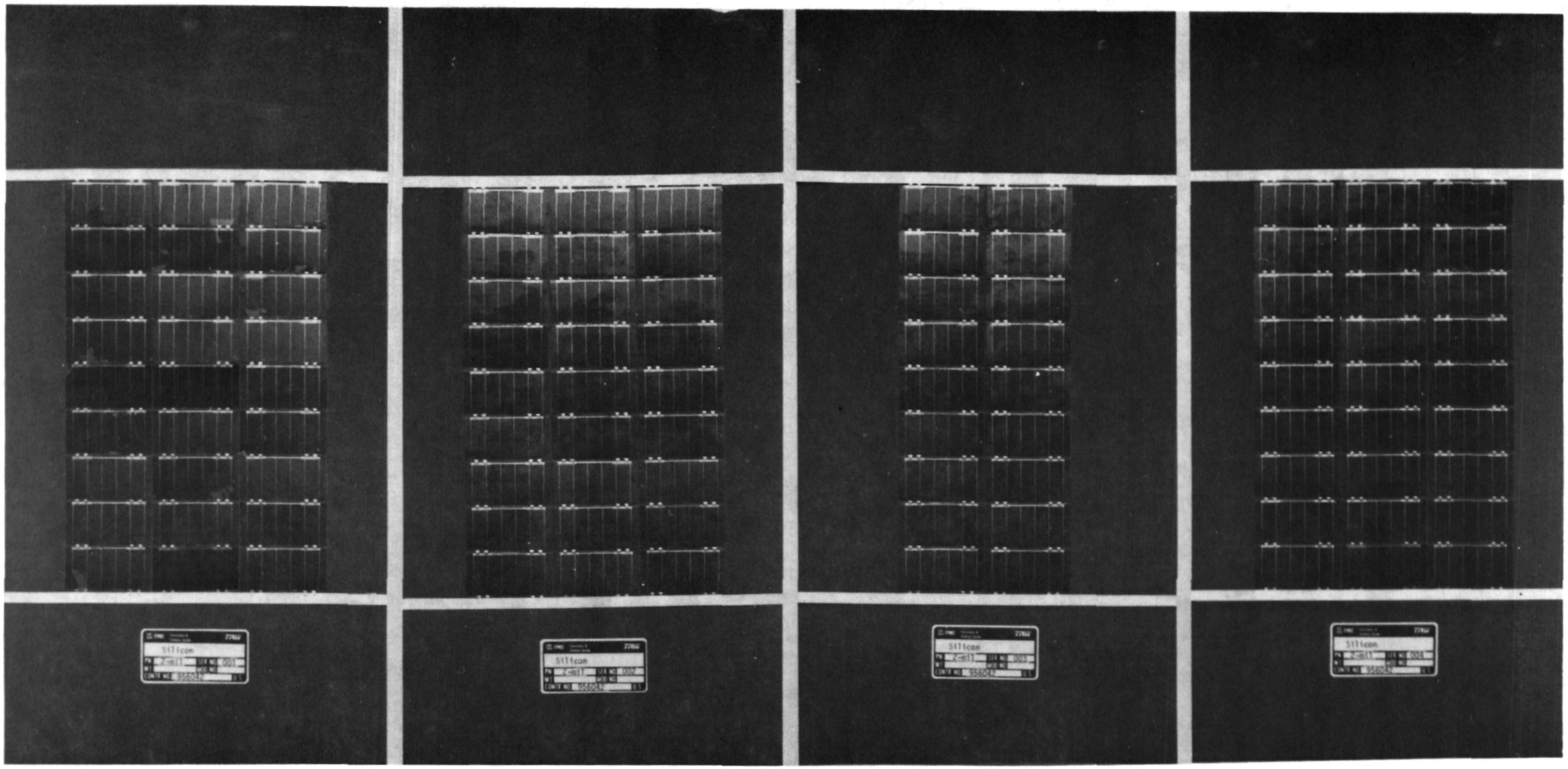

Figure 2. Front View of Thin Cell Modules Bonded to 50 Micron Thick Kapton Sheets

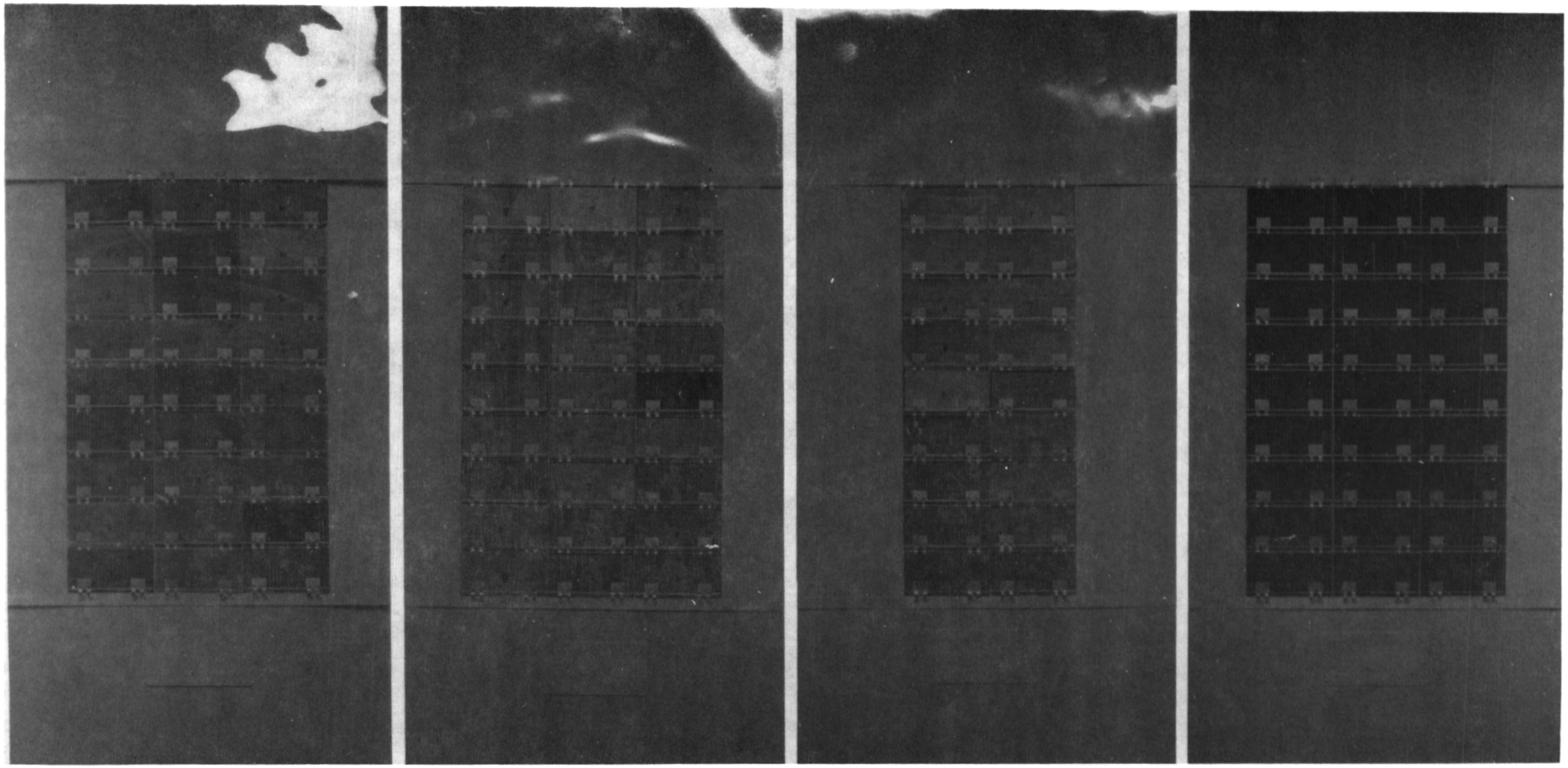

Figure 3. Rear View of Thin Cell Modules, as Seen Through 50 Micron Thick Kapton Sheet

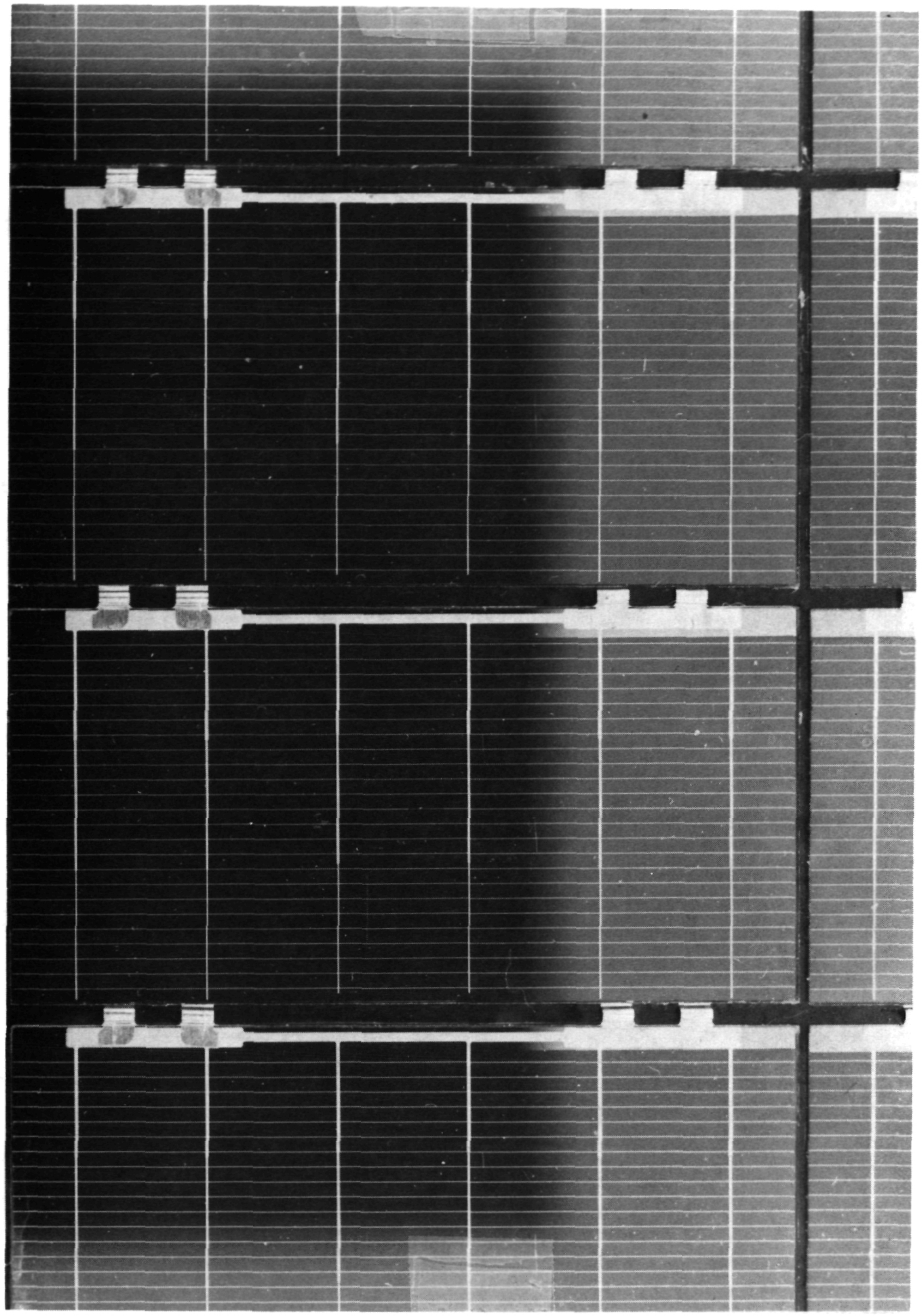

Figure 4. Front View Close-Up of GaAs Solar Cell Module

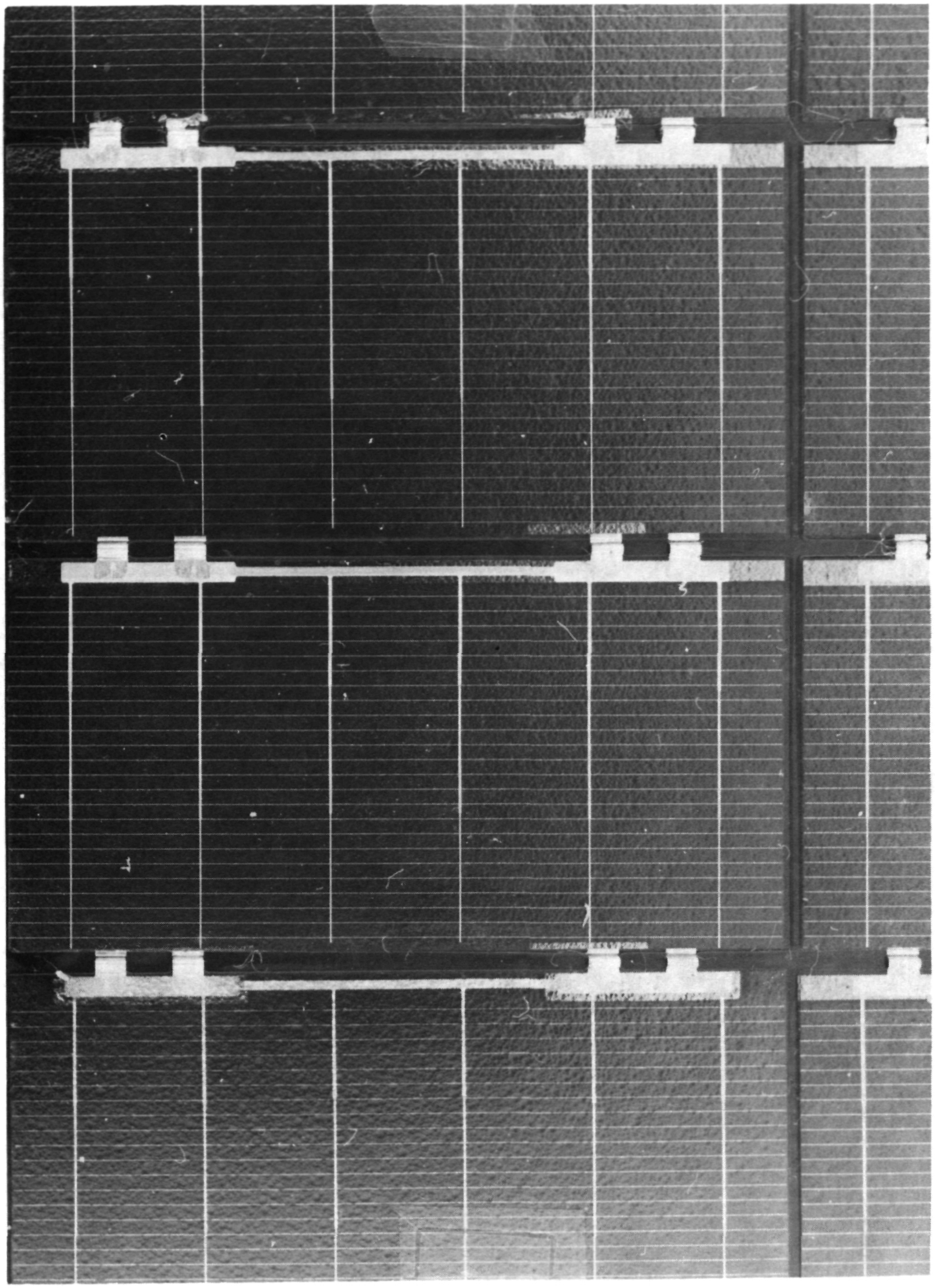

Figure 5. Front View Close-Up of Silicon Thin Cell Module

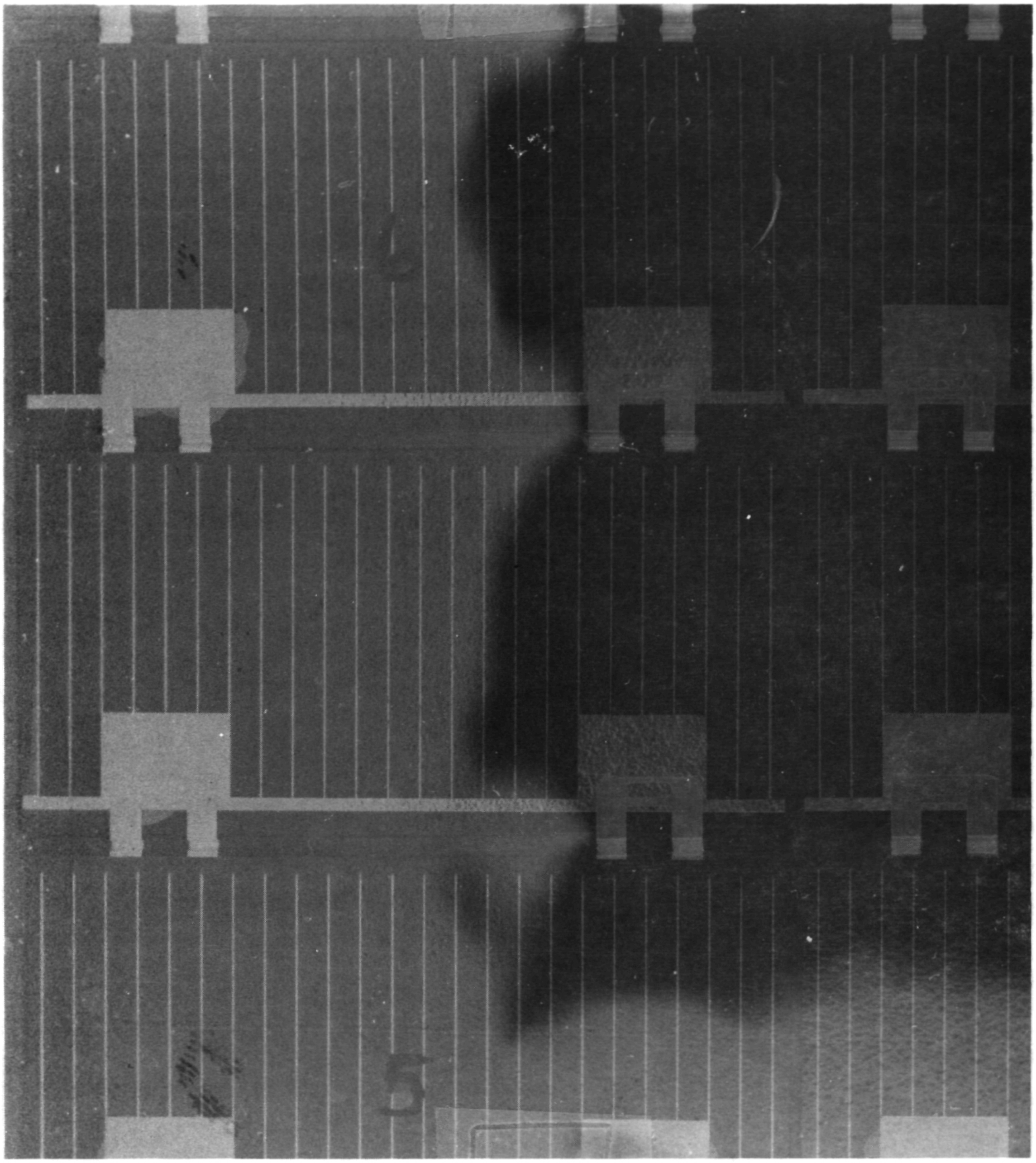

Figure 6. Rear View Close-Up of Silicon Thin Cell Module (Showing Gridded Back Surface)

PANEL SERIAL/STRING # 1
STD CELL S/N GPS-AS-006
ISC 0.3380 AMP
TEMP 22.5C
TEMP COEF 0.3570 %/DEG C

VOLTS	AMPS	WATTS	STD AMP
5.379	0.0007	0.0038	0.3350
4.654	0.6195	2.883	0.3365
4.547	0.6746	3.067	0.3347
4.459	0.7235	3.226	0.3370
4.345	0.7741	3.363	0.3346
4.251	0.7971	3.388	0.3339
3.895	0.8273	3.222	0.3344
3.346	0.8309	2.780	0.3332
2.744	0.8335	2.287	0.3324
1.430	0.8384	1.199	0.3348

SOLAR CELL

MATERIAL: SILICON
SIZE: 2 x 4 cm x 50 μm

MODULE

NP: 3 CELLS
NS: 9 CELLS

SUBSTRATE

MATERIAL: KAPTON (50 μm)

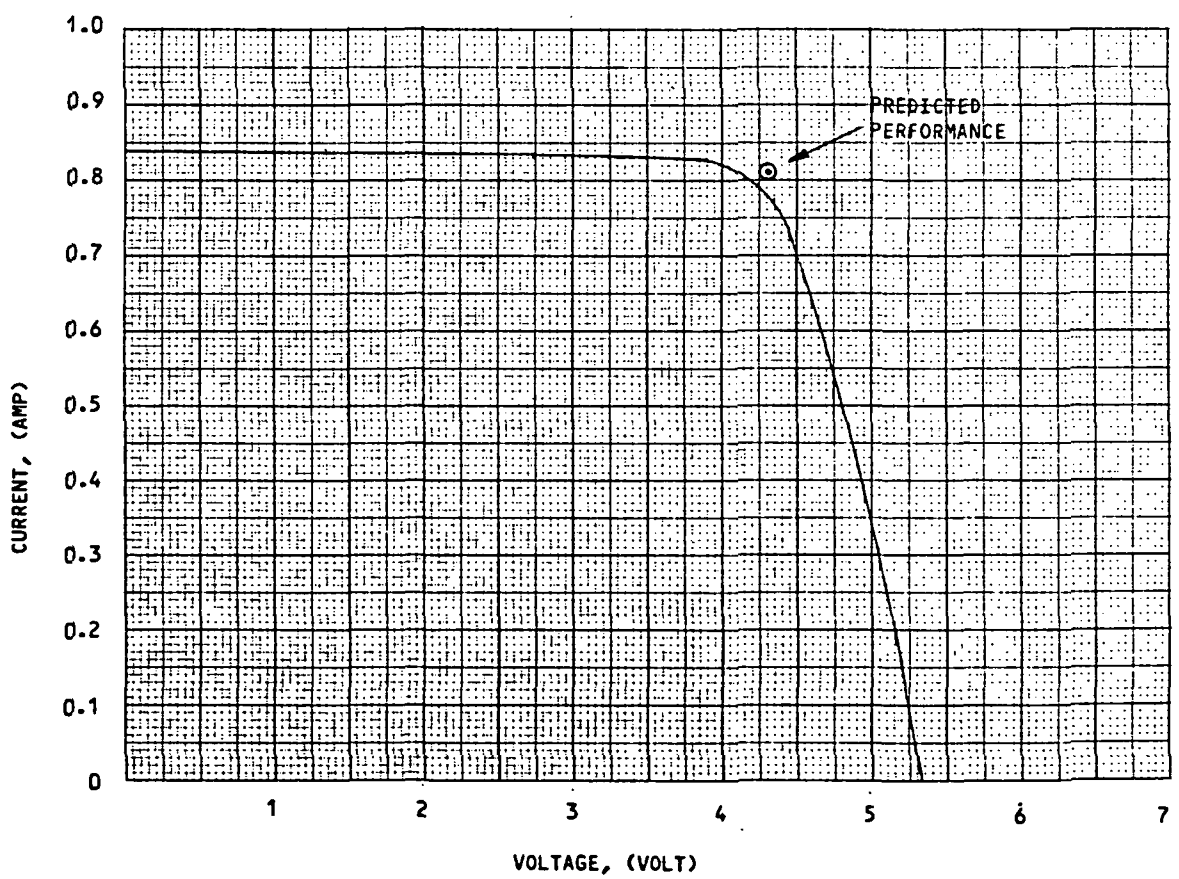

Figure 7. Module Electrical Characteristics, S/N 001

PANEL SERIAL/STRING # 2
STD CELL S/N GPS-AS-006
ISC 0.3380 AMP
TEMP 22.3C
TEMP COEF 0.3570 %/DEG C

VOLTS	AMPS	WATTS	STD AMP
5.409	0.0006	0.0032	0.3349
4.736	0.5720	2.709	0.3331
4.614	0.6453	2.977	0.3342
4.509	0.6940	3.129	0.3372
4.392	0.7452	3.273	0.3355
4.285	0.7787	3.337	0.3329
3.930	0.8192	3.219	0.3344
3.375	0.8321	2.808	0.3348
2.768	0.8451	2.339	0.3333
1.439	0.8673	1.248	0.3354

SOLAR CELL

MATERIAL: SILICON
SIZE: 2 x 4 cm x 50 μm

MODULE

NP: 3 CELLS
NS: 9 CELLS

SUBSTRATE

MATERIAL: KAPTON (50 μm)

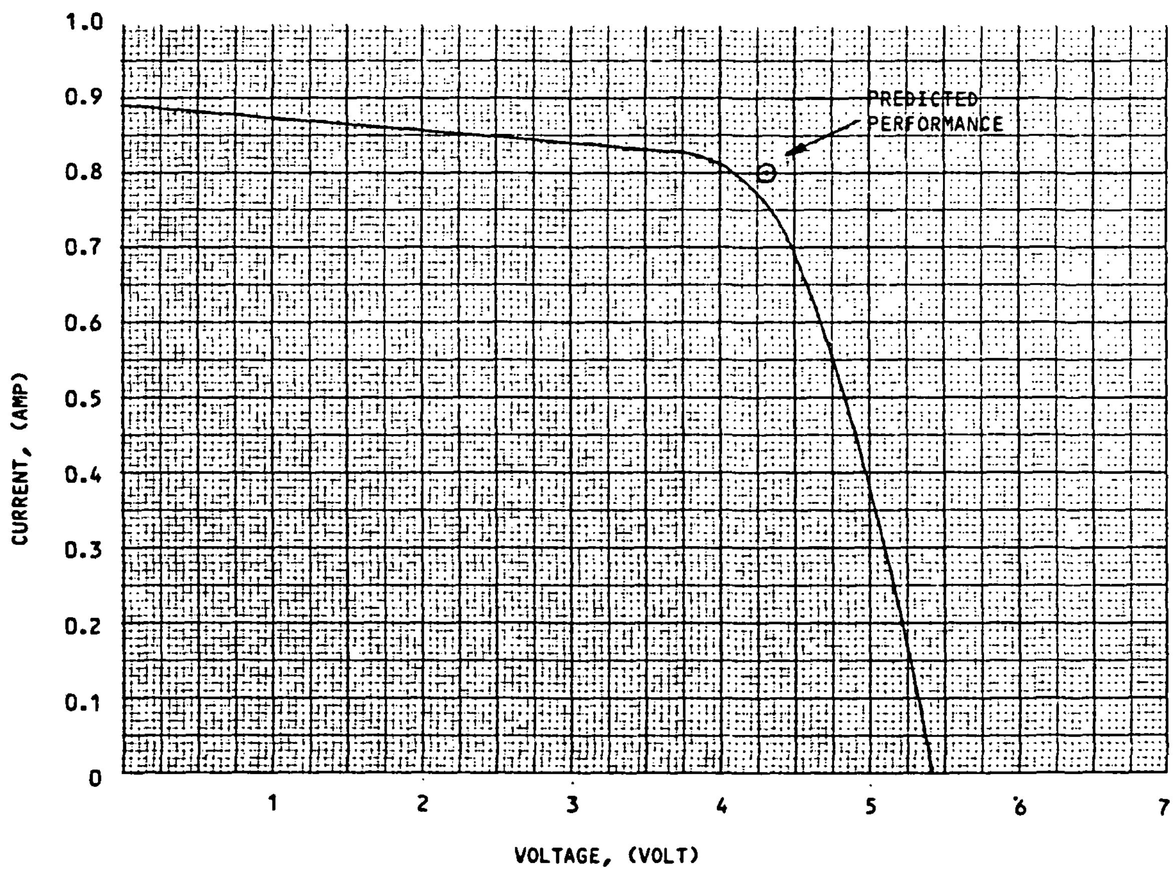

Figure 8. Module Electrical Characteristics, S/N 002

PANEL SERIAL/STRING # 3
STD CELL S/N GPS-AS-006
ISC 0.3380 AMP
TEMP 22.3C
TEMP COEF 0.3570 %/DEG C

VOLTS	AMPS	WATTS	STD AMP
5.423	0.0007	0.0038	0.3348
4.683	0.4666	2.185	0.3316
4.582	0.4924	2.256	0.3330
4.421	0.5024	2.221	0.3343
4.297	0.5405	2.323	0.3322
4.285	0.5630	2.412	0.3348
3.931	0.5873	2.309	0.3327
3.377	0.5892	1.990	0.3343
2.769	0.5902	1.634	0.3321
1.291	0.5912	0.7632	0.3349

SOLAR CELL

MATERIAL: SILICON
SIZE: 2 x 4 cm x 50 μm

MODULE

NP: 2 CELLS
NS: 9 CELLS

SUBSTRATE

MATERIAL: KAPTON (50 μm)

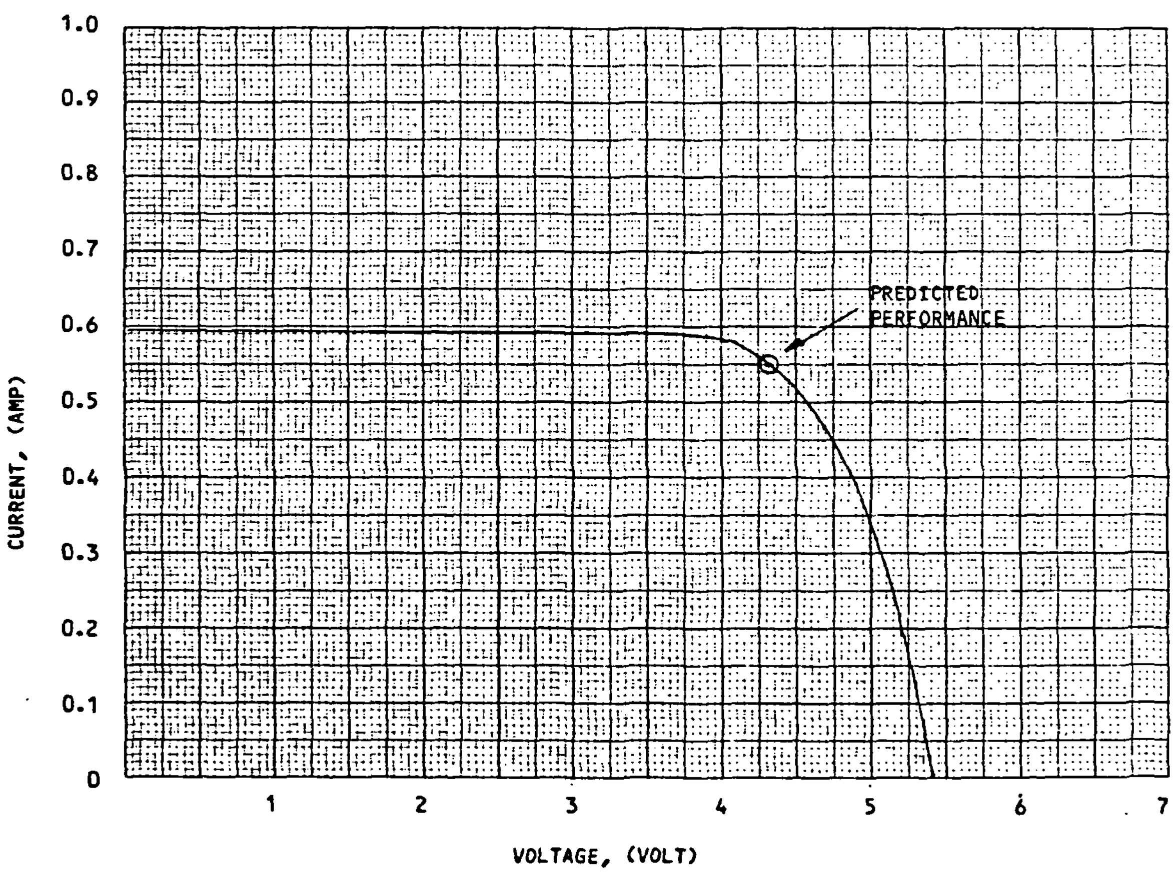

Figure 9. Module Electrical Characteristics, S/N 003

PANEL SERIAL/STRING # 4
STD CELL S/N GPS-AS-006
ISC 0.3380 AMP
TEMP 22.3C
TEMP COEF 0.3570 %/DEG C

VOLTS	AMPS	WATTS	STD AMP
5.398	0.0006	0.0032	0.3333
4.714	0.5833	2.750	0.3351
4.617	0.6613	3.053	0.3343
4.491	0.7170	3.220	0.3333
4.369	0.7770	3.395	0.3343
4.263	0.8194	3.493	0.3331
3.922	0.8837	3.466	0.3323
3.368	0.8969	3.021	0.3341
2.760	0.8985	2.480	0.3355
1.455	0.9005	1.310	0.3346

SOLAR CELL

MATERIAL:	SILICON
SIZE:	2 x 4 cm x 50 μm

MODULE

NP:	3 CELLS
NS:	9 CELLS

SUBSTRATE

MATERIAL:	KAPTON (50 μm)

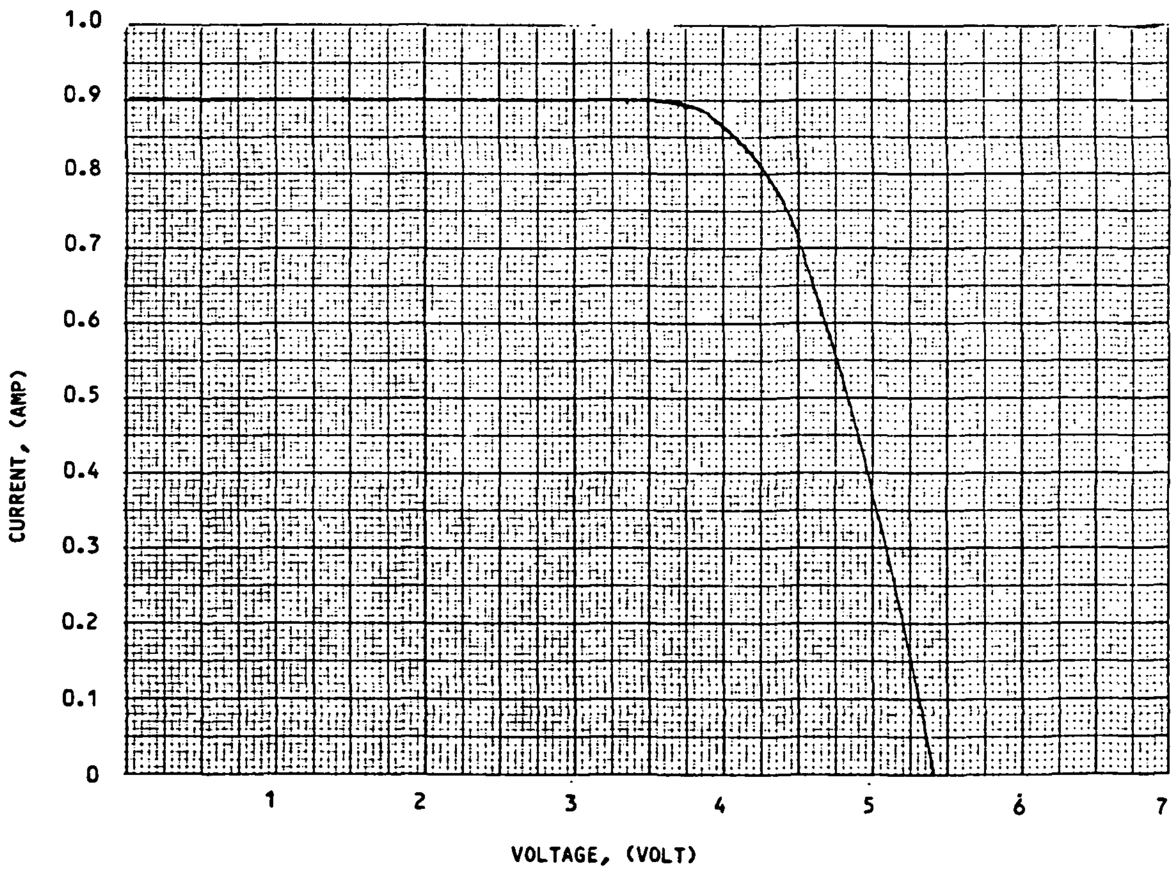

Figure 10. Module Electrical Characteristics, S/N 004