QR-10120-03
March, 1990

Quarterly Progress Report For: RADIATION-HARD-HIGH-EFFICIENCY InP SPACE SOLAR CELL DEVELOPMENT

Covering the Period:
12 November 1989 to 11 February 1990

Submitted Under:
Contract N00014-89-C-2148

Submitted to:
NAVAL RESEARCH LABORATORY
4555 Overlook Avenue SW
Washington, DC 20375-5000

Submitted by:
SPIRE CORPORATION
Patriots Park
Bedford, MA 01730

1.0 SUMMARY

Remarkable progress was made during this quarter. The persistent problems which had led to abnormally low voltages and fill factors since the beginning of the contract were solved, allowing production of cells with consistently high efficiencies. The first delivery, of 30 4 cm^2 cells, was made; ~~on February 2,~~ the efficiencies of these cells (according to Spire measurements) ranged from 15.7% to 18.9%. These efficiencies are essentially equal to those measured in 1987 on Spire epitaxial/implanted cells, which are apparently still a record for the material. These new cells, therefore, would represent the highest efficiency for an all-epitaxial structure as well as the highest efficiency for a large cell.

The sudden jump in efficiencies shows that the work done over the past six months on developing advanced thin emitters and refining the processing sequence has been fruitful. Increased collection efficiency due to the emitter improvements described in the last report contributed to the high efficiency of these cells, and simplification of the fabrication process made it possible to produce them on schedule.

2.0 MOCVD CELL GROWTH

Eighteen cell growth runs were made during this period (exclusive of calibration runs). Eight of these were considered experimental, being concerned mostly with development of the cap layer. The remainder were used to produce material to make the deliverable cells; only the base doping was varied in those runs.

2.1 Advanced Emitter Structures

The two-step emitter structure described in the second quarterly report was used for all the cells made in this period. Uniformity measurements (Figure 1) show that the sheet conductivity of the layer is higher at the bottom than at the top of the wafer, but the variation is still within the acceptable range for the mask design that we are using.

2.2 Cap Layers

The use of an InGaAs cap layer was crucial in the reproducible fabrication of high-efficiency cells (see Section 3). Cap layers were used on all of the deliverable cells, as described in Section 3.

Top of Wafer During Growth

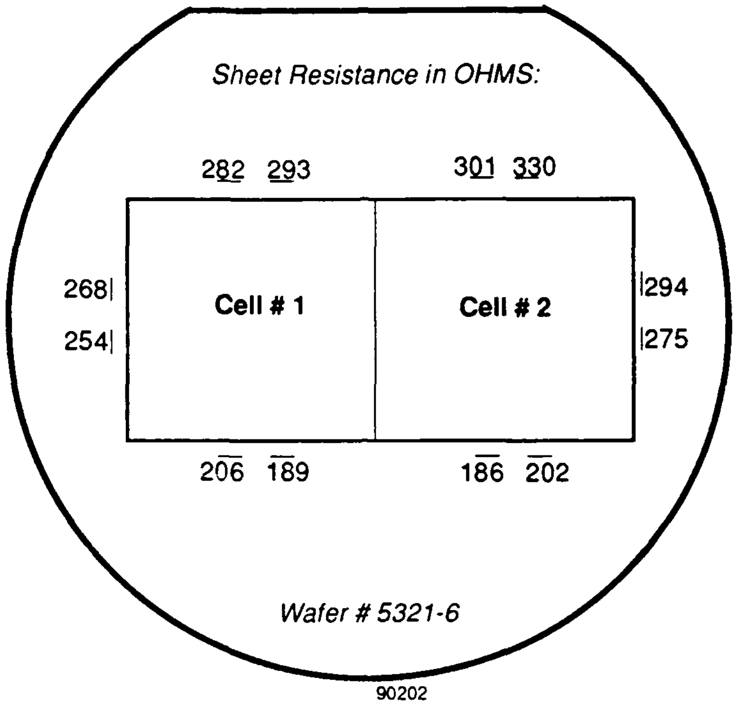


FIGURE 1. MEASUREMENTS OF THE SHEET RESISTANCE ON AN InP CELL WAFER. Considerable variation is seen, but the measured values are within the design limits.

One of the chief difficulties in growing the cap layer is maintaining control over the indium flow rate. Switching from trimethylindium to ethyldimethylindium improved the situation somewhat, but our experience indicates that the saturation of the carrier gas is still dependent on the level of liquid in the bubbler. Thus, frequent calibration of both the InGaAs composition and the InP growth rate are necessary. Although we do not have, at the moment, accurate calibration of the InGaAs composition, we expect to have our double-crystal X-ray diffractometer operating soon.

3.0 CELL PROCESSING

3.1 Cap Layers

The addition of the InGaAs cap layer made it possible to eliminate a step in the process. Previously, the front of the wafers had been coated with a layer of SiO_2 to protect it during the back contact evaporation and sinter. At first, this procedure was continued, and the oxide layer was deposited over the cap and subsequently removed. Although some good cells were made in this way, the first lots of deliverable cells showed low open-circuit voltage and fill factor, similar to the previous cells made without caps. Finally, when this step was removed, the cell performance improved dramatically. The explanation which seems most likely at this point for the previous low efficiencies is that the oxide deposition, which was done at 350°C and included rapid heat-up and cool-down steps, introduced cracks into the wafers through thermal stress. This is suggested by the great variation which is seen in the cell results; some wafers are barely affected while others are badly damaged. It also could explain why the same process was successful in earlier work, producing an 18.8% cell in 1987: the earlier work was all with small cells, and full wafers were rarely processed. However, there are other explanations which are consistent with the observations, so the this hypothesis can not be considered proven.

3.2 Front Contact Formation

As described in the second quarterly report, the problems with metal adhesion which have appeared previously have largely been solved. Of the eight evaporation lots intended for the deliverable cells, one showed loss of metal. In subsequent lots, the annealing step after front contact formation was omitted; some evidence suggested that the high temperature was actually increasing rather than decreasing the stress in the silver.

The deliverable cells all have metal lines which are five microns thick. According to the original grid design, ten microns should give slightly better fill factors. One of the priorities for the next quarter will be refining the front contact evaporation to the point where this increased thickness can be achieved reliably.

3.3 Back Contact Formation

The soldering of tabs to the back metallization of the cell was investigated. A number of test samples of InP with the normal Zn-Au back contact were made and annealed at various temperatures, from 350 to 475 °C. Tabs 1 mm wide were soldered to each piece and pulled off, and the pull strength was measured. The I-V characteristics of the contacts were measured on other pieces which were prepared together with the pull test samples. It was found that all the contacts annealed at 400 °C and above were ohmic and showed essentially the same contact resistance. Soldering was successful on all of these samples, with pull strengths ranging from 0.11 to 0.62 kgf. (1.1 to 6.1 N).

Most interestingly, it was discovered that the evaporation of a silver layer over the alloyed zinc-gold metallization is not necessary, since satisfactory soldering can be done to the zinc- gold. This will allow the cell process to be further simplified.

3.4 Process Yield

Considerable breakage was experienced in the first lots of deliverable cells, but after the process was simplified by the omission of the oxide cap layer, the yield improved dramatically. Of the last fifty cells processed, only two were lost due to breakage. It may be that the oxide cap step introduced cracks into many of the wafers due to thermal strains, and caused them to break later in the process.

4.0 CELL RESULTS

The efficiency measurements from all the cells made during this period are given in an appendix. In this section the results are summarized.

4.1 Advanced Emitter Structures

Quantum efficiency measurements were made of the cells with two-step emitters described in the last report. The results (Figure 2), confirm the improved blue response resulting from the two-step structure.

4.2 Cap Layers

The first cells made with cap layers showed greatly improved performance (Table 1), compared to the controls. Because these were made with thick emitters, their efficiencies are still relatively low, but the high voltages and fill factors show that they do not suffer from the unexplained recombination which has been seen in most of the previous cells.

4.3 First Deliverable Cells

Three batches, consisting of 21 wafers, a mixture of anodized and all-epitaxial structures, were begun to meet the deliverable requirements. A range of base doping concentrations was used. All the wafers in these lots, designated 5320, 5321, and 5322, had cap layers.

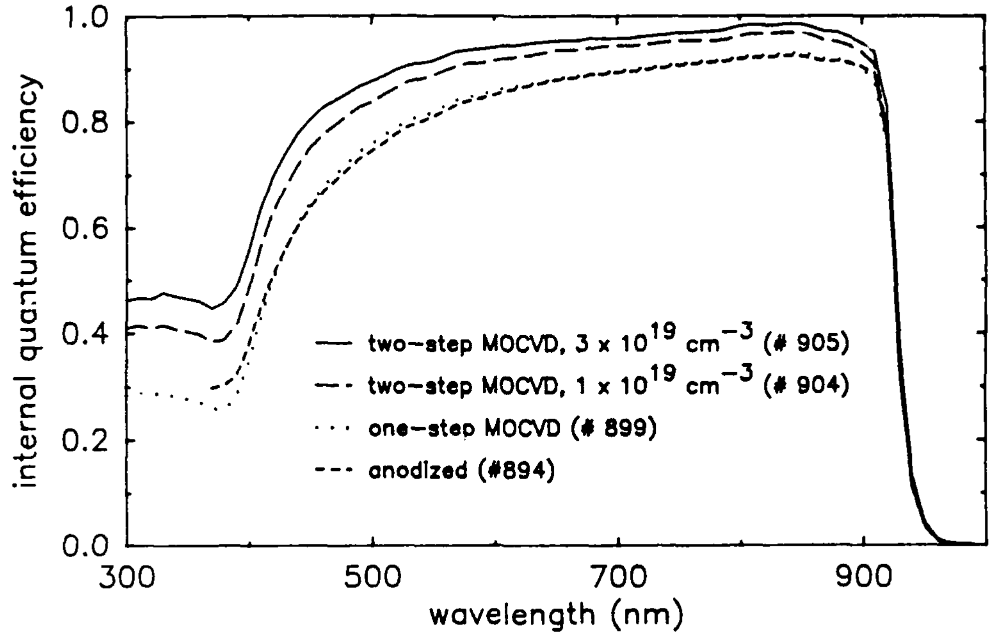


FIGURE 2. QUANTUM EFFICIENCY OF THE TWO-STEP EMITTER STRUCTURES.

TABLE 1. RESULTS OF FIRST CAP LAYER CELLS (Lot 5295).

emitter	structure	Cell#	V_{oc} (mV)	I_{sc} (mA)	J_{sc} (mA/cm^2)	fill factor	efficiency (%)
control	(1000 Å)	3-1	830	101.8	25.45	0.796	12.3
control	(1000 Å)	3-2	833	107.1	26.77	0.803	13.1
anodized	(200 Å)	4-1	700	130.3	32.58	0.714	11.9
with cap	(1000 Å)	2-1	869	100.6	25.14	0.829	13.2
with cap	(1000 Å)	2-2	868	98.52	24.63	0.836	13.0

Despite this improvement, however, the cells from these lots showed low yield and low efficiency; the addition of the cap layer alone was not the solution to the recombination problem. Table 2 shows the results of these lots.

Not only were the cells made in these lots inconsistent (resulting in only six cells that met the efficiency goals), but we also encountered an unusually large amount of wafer breakage in the processing. Accordingly, two changes were made in the fabrication

TABLE 2. LOTS 5320-5322 UNCORRECTED SIMULATOR DATA MEASURED AT AM0 (137.2 mW/cm^2), 25 °C

MOCVD run	doping (10^{16} cm^{-3})	Cell#	V_{oc} (mV)	I_{sc} (mA)	J_{sc} (mA/cm^2)	fill factor	efficiency (%)
				Lot 5320			
1002	38	1-2	729	119.9	29.97	0.732	11.6
1003	45	4-1	816	124.8	31.21	0.709	13.2
893	11	avg.	804	117.1	29.29	0.698	12.0
(5 cells)	1	std.	28	15.8	3.94	0.037	2.1
				Lot 5321			
1003		1-1	882	125.5	31.37	0.748	15.1
1003		1-2	815	124.1	31.02	0.750	13.8
892	10	avg.	850	128.7	32.18	0.726	4.5
(6 cells)	1	std.	17	2.2	0.54	0.048	1.2
				Lot 5322			
1006		1-1	873	133.6	33.39	0.821	17.4
1006		3-2	824	130.4	32.61	0.779	15.3
1007	4.0	avg.	783	120.4	30.09	0.760	13.1
(4 cells)	0.4	std.	12	2.2	0.55	0.014	0.5

process, as described in Section 3 above, and additional lots, designated 5327 through 5330, (20 additional wafers) were processed. Greatly improved performance was realized, as can be seen from Table 3.

One of these lots, #5328, suffered from loss of the front contact metal, but only two cells out of these 25 wafers were lost due to breakage. The best cell, #5330-6-2, was measured at Spire at 18.9% efficiency (884 mV V_{OC}, 141.2 mA I_{SC}, 0.831 FF).

5.0 DISCUSSION OF RESULTS

These cells show open-circuit voltages as high as any InP cells which we have ever made, and the short-circuit current is consistent with our current understanding of the emitter structure. However, the fill factors on many of the cells were slightly lower than expected; values of 0.82-0.83 should be possible, but only a minority of the cells reached

TABLE 3. LOTS 5327-5330 UNCORRECTED SIMULATOR DATA MEASURED AT AM0 (137.2 mW/cm^2), 25 °C.

MOCVD run	doping (10^{16} cm^{-3})	Cell#	V_{OC} (mV)	I_{SC} (mA)	J_{SC} (mA/cm^2)	fill factor	efficiency (%)
				Lot 5327			
1026	2.5	avg.	880	137.2	34.30	0.789	17.4
(4 cells)	0.4	std.	1	2.0	0.51	0.023	0.7
				Lot 5328			
1028		4-1	882	141.0	35.26	0.759	17.2
1028		5-2	884	141.3	35.32	0.575	13.1
				Lot 5329			
1027	3.1	avg.	882	138.6	34.65	0.780	17.4
(5 cells)	0.1	std.	0	1.3	0.32	0.042	0.9
1030	3.0	avg.	880	138.9	34.73	0.814	18.1
(4 cells)	0.4	std.	4	0.7	0.17	0.009	0.3
1032	5.1	avg.	885	140.5	35.12	0.801	18.1
(4 cells)	0.6	std.	1	0.8	0.19	0.008	0.2
				Lot 5330			
1027	3.3	avg.	882	140.6	35.15	0.808	18.3
(4 cells)	0.3	std.	3	0.4	0.09	0.017	0.4
1030	4.7	avg.	877	139.2	34.81	0.767	17.1
(4 cells)	0.6	std.	5	0.8	0.18	0.026	0.5
1032	4.9	avg.	885	141.0	35.25	0.798	18.1
(4 cells)	0.6	std.	1	0.5	0.13	0.025	0.5

this value. Dark I-V measurements, along with the fact that many of the fill factors were considerably higher before antireflection coating, suggest that series resistance is responsible. Since the cell structure was originally designed to use a metal thickness of ten microns, but these cells all have only five, due to the stress and adhesion problems, this is not surprising. Another factor may be nonuniformity of the emitter; high sheet resistance could also produce the observed results.

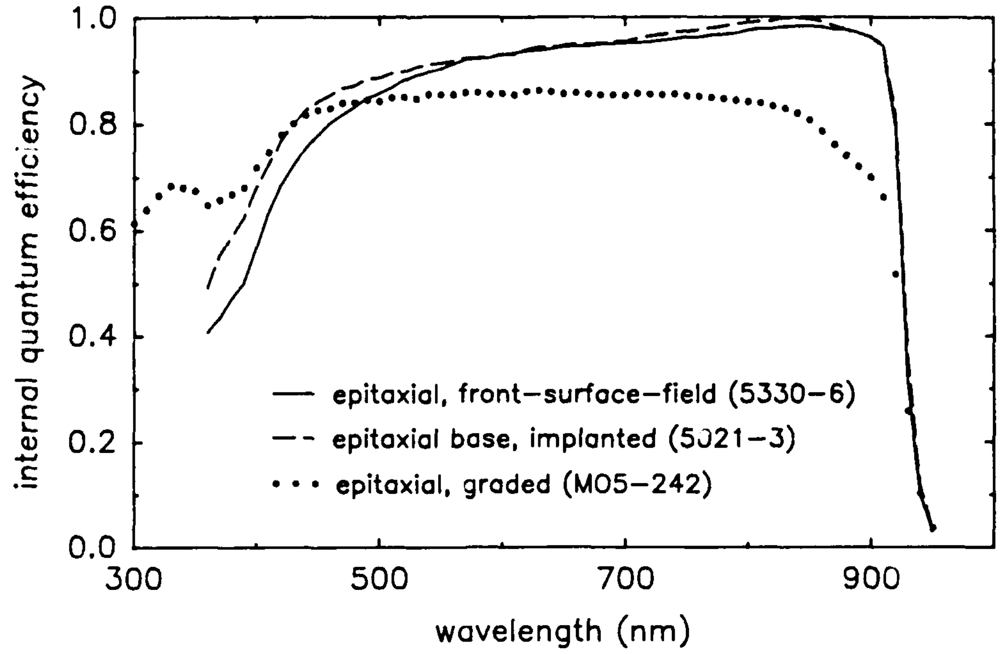


FIGURE 3. QUANTUM EFFICIENCY OF THE CURRENT BEST CELL, COMPARED TO THE HIGHEST VALUES FROM EARLIER WORK.

6.0 CURRENT PLANS

The cell fabrication process, which has now achieved success, requires some further refinement. In particular, the variables which control the adhesion of the front metal fingers to the surface must be clarified, so that the process will be more reliable. To this end, we will conduct experiments with different cleaning steps, and measure the effects of the evaporation rate and temperature on the stress in the silver films. Contact pull tests on soldered tabs will be used to quantify the strength of the adhesion. More cells will be made with a metal thickness of ten microns to verify whether this is the cause of the low fill factors seen this quarter.

Since better short-circuit current and blue response have been seen in some cells, particularly in the ion-implanted structures, it appears that some room for improvement remains. Figure 3 compares the quantum efficiency of one of the delivered cells to those of two earlier cells: the ion-implanted cell and a cell with a thin, graded emitter. Although the graded-emitter cell did not have a high efficiency, its high blue response shows that some improvement may yet be possible. Further work on the emitter structure will be needed to realize this.

APPENDIX A
DETAILED CELL DATA

This appendix contains performance data for all cells made during this period (Table A-1), I-V curves for ten selected cells, and quantum efficiency curves for five selected cells (attached).

TABLE A1. COMPLETE CELL RESULTS, LOTS 5295-5331.

Cell#	MOCVD run	doping	area	V_{oc}	J_{sc}	fill factor	efficiency
	(10^{16} cm^{-3})	(cm^2)	(mV)	(mA/cm^2)			(%)
			Lot 5295: cap layer experiment)				
5295-3-1	894		4.00	830	25.45	0.796	12.3
5295-3-2	894		4.00	833	26.77	0.803	13.1
5295-4-1	894		4.00	700	32.58	0.714	11.9
5295-2-1	894		4.00	869	25.14	0.829	13.2
5295-2-2	894		4.00	868	24.63	0.836	13.0
			Lot 5311: first base doping experiment)				
5311-1-1	972		4.00	860	21.40	0.759	10.2[a]
5311-1-2	972		4.00	857	21.49	0.727	9.8[a]
5311-1-4	972		0.25	767	19.99	0.685	7.7[a]
5311-1-5	972		0.25	845	13.34	0.792	6.5[a]
5311-2-5	973		0.25	841	17.23	0.820	8.7[a]
5311-2-4	973		0.25	801	20.63	0.666	8.0[a]
5311-3-1	990		4.00	724	22 17	0.776	9.1[a]
			Lots 5320-5331: small deliverable cells)				
5320-6-4	893	11.7	0.25	799	32.77	0.736	14.1
5320-6-5	893	10.4	0.25	779	31.06	0.739	13.0
5320-7-5	893	11.7	0.25	813	29.92	0.568	10.1
5320-8-5	893	9.4	0.25	824	29.13	0.782	13.7
5320-1-4	1002	37.8	0.25	807	30.35	0.769	13.7
5320-2-4	1002	22.3	0.25	779	31.52	0.766	13.7
5320-2-5	1002	26.2	0.25	885	36.98	0.739	17.6
5320-3-4	1003	45.2	0.25	890	31.56	0.831	17.0
5320-4-4	1003		0.25	755	30.77	0.748	12.7
5321-5-4	892	11.1	0.25	828	22.06	0.527	7.0
5321-5-5	892	9.9	0.25	863	31.19	0.784	15.4
5321-6-4	892	8.3	0.25	847	31.01	0.471	9.0
5321-6-5	892	9.1	0.25	867	30.36	0.791	15.2
5321-1-4	1003	51.8	0.25	859	31.88	0.763	15.2
5321-1-5	1003	45.2	0.25	874	32.45	0.804	16.6
5321-3-1	1004	18.9	1.00	777	30.62	0.766	13.3
5321-3-2	1004	15.8	1.00	860	30.99	0.811	15.8

TABLE A1 COMPLETE CELL RESULTS, LOTS 5295-5331. (Continued)

Cell#	MOCVD run	doping (10^{16} cm^{-3})	area (cm^2)	V_{oc} (mV)	J_{sc} (mA/cm^2)	fill factor	efficiency (%)
5321-3-3	1004	14.9	1.00	874	30.72	0.840	16.4
5321-3-4	1004	14.9	1.00	856	30.67	0.792	15.1
5321-3-5	1004	19.0	0.25	739	25.71	0.732	10.1
5321-3-6	1004		0.25	760	30.44	0.767	12.9
5321-3-7	1004	18.0	0.25	816	30.58	0.766	13.9
5321-3-8	1004		0.25	863	30.69	0.818	15.8
5321-3-9	1004	17.1	0.25	873	30.60	0.830	16.2
5321-3-10	1004		0.25	867	30.59	0.822	15.9
5321-3-11	1004	17.1	0.25	848	30.80	0.798	15.2
5321-3-12	1004		0.25	831	29.33	0.688	12.2
5322-1-4	1006	5.7	0.25	863	32.94	0.826	17.[illegible]
5322-2-5	1006	4.9	0.25	696	31.69	0.742	11.9
5322-4-4	1007	4.2	0.25	790	29.97	0.773	13.3
5322-[illegible]-5	1007	3.8	0.25	746	28.91	0.754	11.9
5322-5-4	1007	4.5	0.25	784	30.52	0.773	13.5
5322-5-5	1007	3.6	0.25	817	30.15	0.791	14.2
5327-1-5	1026	2.8	0.25	877	32.70	0.815	17.0
5327-2-4	1026	2.7	0.25	842	7.35	0.845	3.8
5327-2-5	1026	1.9	0.25	877	1.65	0.828	16.8
5328-2-4	1028		0.25	827	33.25	0.529	10.6
5328-3-4	1028	3.7	0.25	878	31.50	0.833	16.8
5328-4-4	1028		0.25	886	33.66	0.564	12.3
5328-4-5	1028		0.25	884	32.99	0.613	13.0
5328-5-5	1028		0.25	889	33.02	0.255	5.5
5329-1-4	1027	3.3	0.25	880	33.52	0.751	1[illegible] 2
5329-1-5	1027	3.0	0.25	878	33.21	0.777	16.5
5329-3-5	1027		0.25	878	33.59	0.745	16.0
5329-4-4	1030	2.9	0.25	883	34.18	0.798	17.5
5329-4-5	1030	3.1	0.25	882	32.82	0.317	17.2
5329-5-4	1030	3.9	0.25	881	33.27	0.788	16.8
5329-5-5	1030	3.1	0.25	881	33.22	0.823	17.6
5329-6-4	1032	5.7	0.25	883	33.86	0.827	18.0
5329-6-5	1032	4.4	0.25	883	33.70	0.813	17.6
5330-1-4	1027	3.7	0.25	879	34.38	0.820	18.1
5330-2-4	1027	2.8	0.25	884	34.33	0.847	18.7
5330-2-5	1027	3.3	0.25	884	34.15	0.849	18.7
5330-3-4	1030	5.6	0.25	887	33.42	0.820	17.7
5330-3-5	1030	4.1	0.25	880	33.59	0.833	17.9
5330-4-4	1030	4.5	0.25	885	33.[illegible]	0.848	18.4
5330-5-4	103[illegible]	4.9	0.25	884	33.[illegible]7	0.855	18.6

TABLE A1. COMPLETE CELL RESULTS, LOTS 5295-5331.
(Continued)

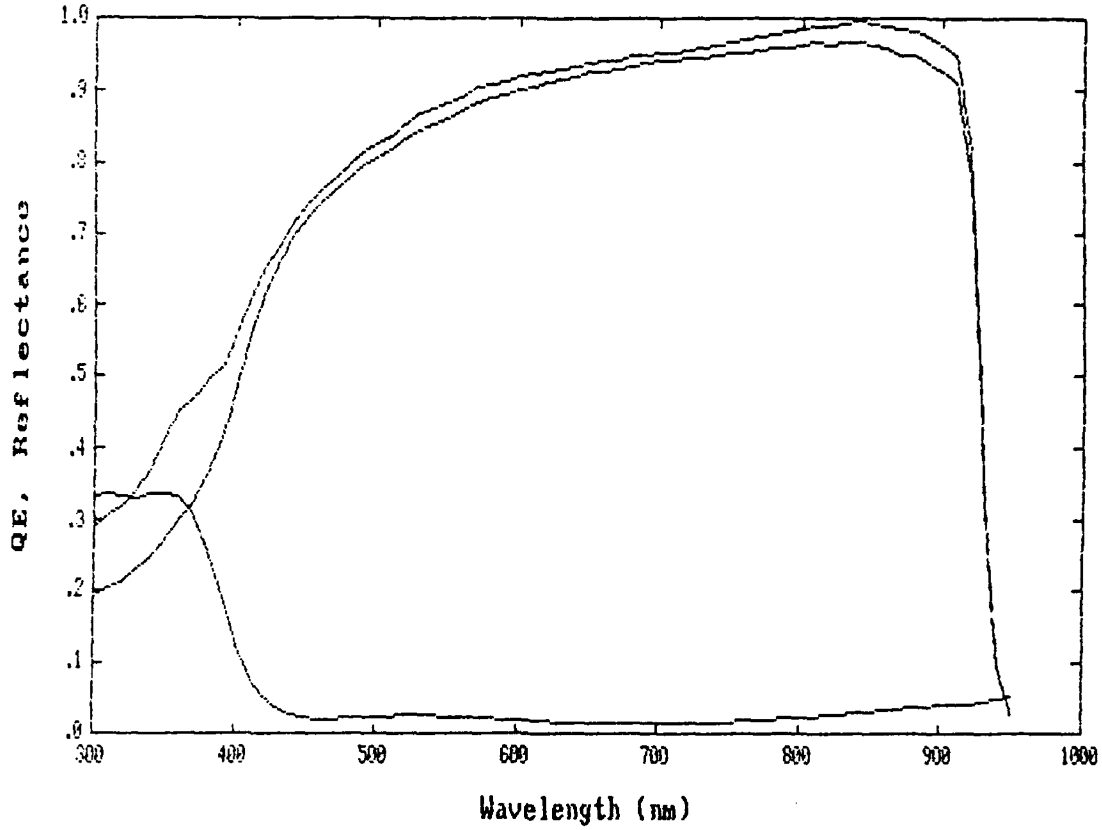
Cell#	MOCVD run	doping	area	V_{oc}	J_{sc}	fill factor	efficiency
	(10^{16} cm^{-3})	(cm^2)	(mV)	(mA/cm^2)			(%)
5330-5-5	1032	5.3	0.25	884	33.51	0.855	18.5
5330-6-4	1032	3.9	0.25	885	34.08	0.853	18.8
5330-6-5	1032	5.5	0.25	886	33.79	0.861	18.8
5331-4-4	972	36.2	0.25	842	30.49	0.359	6.7
5331-4-5	972	29.6	0.25	869	32.71	0.596	12.4
5331-1-5	1033		0.25	879	33.95	0.837	18.2
5331-2-5	1033		0.25	871	32.28	0.636	13.0
5331-3-4	1033	1.6	0.25	877	34.25	0.676	14.8
5331-3-5	1033		0.25	878	34.11	0.588	12.8
			Lots 5320-5331: large deliverable cells)				
5320-1-2	1002		4.00	729	29.97	0.732	11.6
5320-4-1	1003		4.00	816	31.21	0.709	13.2
5320-6-1	893		4.00	815	32.44	0.693	13.4
5320-6-2	893		4.00	752	31.68	0.694	12.1
5320-7-2	893		4.00	811	30.59	0.739	13.4
5320-7-1	893		4.00	836	30.14	0.730	13.4
5320-8-1	893		4.00	807	21.58	0.635	8.1
5321-1-2	1003		4.00	815	31.02	0.750	13.8
5321-1-1	1003		4.00	882	31.37	0.748	15.1
5321-4-1	892		4.00	826	32.09	0.687	13.3
5321-4-2	892		4.00	831	31.28	0.708	13.4
5321-5-1	892		4.00	871	33.04	0.737	15.5
5321-5-2	892		4.00	847	32.56	0.656	13.2
5321-6-1	892		4.00	867	32.01	0.796	16.1
5321-6-2	892		4.00	858	32.12	0.773	15.5
5322-1-1	1006		4.00	873	33.39	0.821	17.4
5322-3-2	1006		4.00	824	32.61	0.779	15.3
5322-4-2	1007		4.00	784	30.56	0.755	13.2
5322-5-2	1007		4.00	783	29.21	0.762	12.7
5322-6-1	1007		4.00	765	30.06	0.742	12.4
5322-6-2	1007		4.00	799	30.54	0.781	13.9
5327-1-1	1026		4.00	880	34.82	0.777	17.3
5327-1-2	1026		4.00	882	34.69	0.825	18.4
5327-2-1	1026		4.00	878	34.13	0.791	17.3
5327-2-2	1026		4.00	880	33.54	0.763	16.4
5328-4-1	1028		4.00	882	35.26	0.759	17.2
5328-5-2	1028		4.00	884	35.32	0.575	13.1
5329-1-1	1027		4.00	882	34.91	0.772	17.3
5329-1-2	1027		4.00	882	34.78	0.704	15.7

TABLE A1. COMPLETE CELL RESULTS, LOTS 5295-5331.
(Concluded)

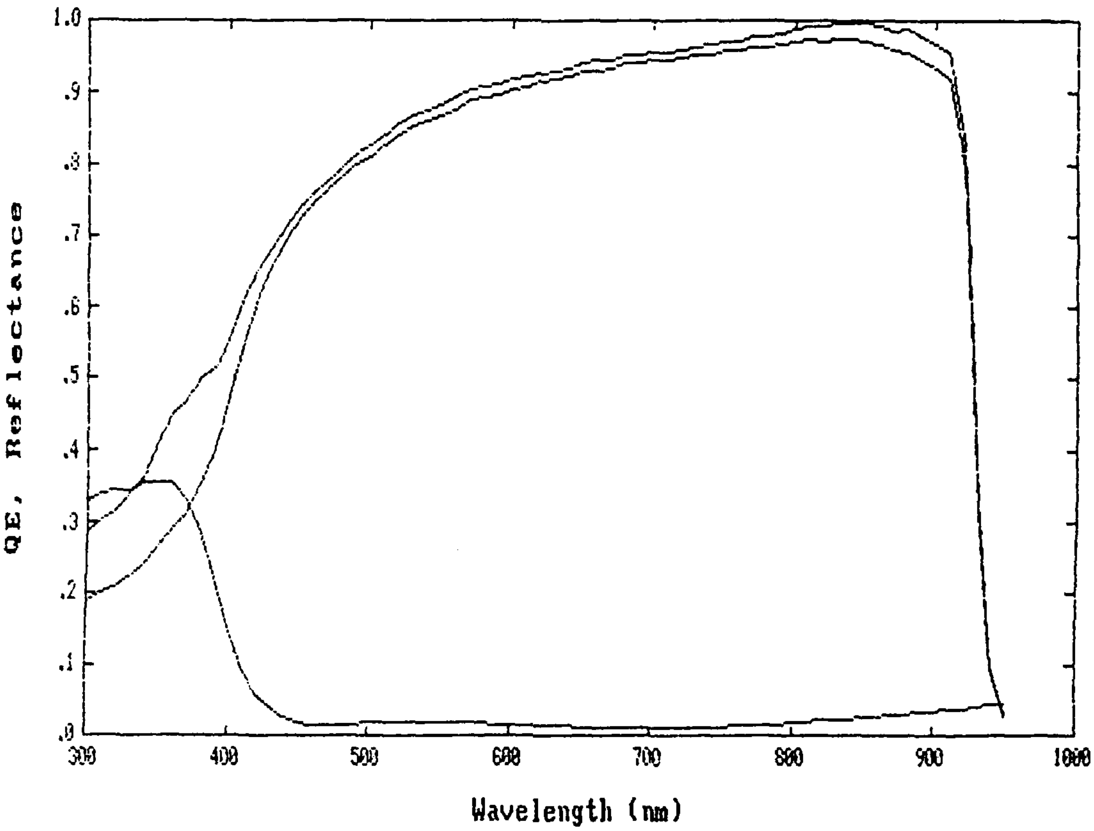
Cell#	MOCVD run	doping	area	V_{oc}	J_{sc}	fill factor	efficiency
	(10^{16} cm^{-3})	(cm^2)	(mV)	(mA/cm^2)			(%)
5329-2-1	1027		4.00	883	34.29	0.797	17.6
5329-2-2	1027		4.00	882	34.24	0.823	18.1
5329-3-2	1027		4.00	883	35.03	0.805	18.2
5329-4-1	1030		4.00	879	35.00	0.813	18.2
5329-4-2	1030		4.00	875	34.53	0.803	17.7
5329-5-1	1030		4.00	883	34.74	0.829	18.5
5329-5-2	1030		4.00	884	34.64	0.813	18.1
5329-6-1	1032		4.00	885	35.14	0.804	18.2
5329-6-2	1032		4.00	884	35.41	0.801	18.3
5329-7-1	1032		4.00	885	34.89	0.812	18.3
5329-7-2	1032		4.00	884	35.03	0.789	17.8
5330-1-1	1027		4.00	884	35.00	0.817	18.4
5330-1-2	1027		4.00	877	35.21	0.783	17.6
5330-2-1	1027		4.00	883	35.17	0.807	18.3
5330-2-2	1027		4.00	883	35.22	0.828	18.8
5330-3-1	1030		4.00	873	34.91	0.754	16.8
5330-3-2	1030		4.00	871	34.50	0.775	17.0
5330-4-1	1030		4.00	883	34.98	0.734	16.5
5330-4-2	1030		4.00	879	34.85	0.804	18.0
5330-5-1	1032		4.00	883	35.13	0.778	17.6
5330-5-2	1032		4.00	885	35.12	0.812	18.4
5330-6-1	1032		4.00	886	35.44	0.771	17.6
5330-6-2	1032		4.00	884	35.29	0.831	18.9
5331-1-1	1033		4.00	876	35.87	0.792	18.1
5331-1-2	1033		4.00	882	35.93	0.812	18.8
5331-2-1	1033		4.00	876	35.99	0.684	15.7
5331-2-2	1033		4.00	883	35.98	0.614	14.2
5331-3-1	1033		4.00	879	35.53	0.690	15.7
5331-3-2	1033		4.00	881	35.72	0.741	17.0
5331-4-1	972		4.00	871	32.96	0.444	9.3
5331-4-2	972		4.00	876	32.87	0.455	9.6

These measurements were made under a simulated AM0 spectrum at 25 °C. Currents were not corrected for the spectral mismatch between the InP cell and the GaAs reference cell. Current densities and efficiencies were calculated on a total area basis, using a value of 137.2 mW/cm^2 for the solar constant. Measurements marked [a] were made without antireflection coating.

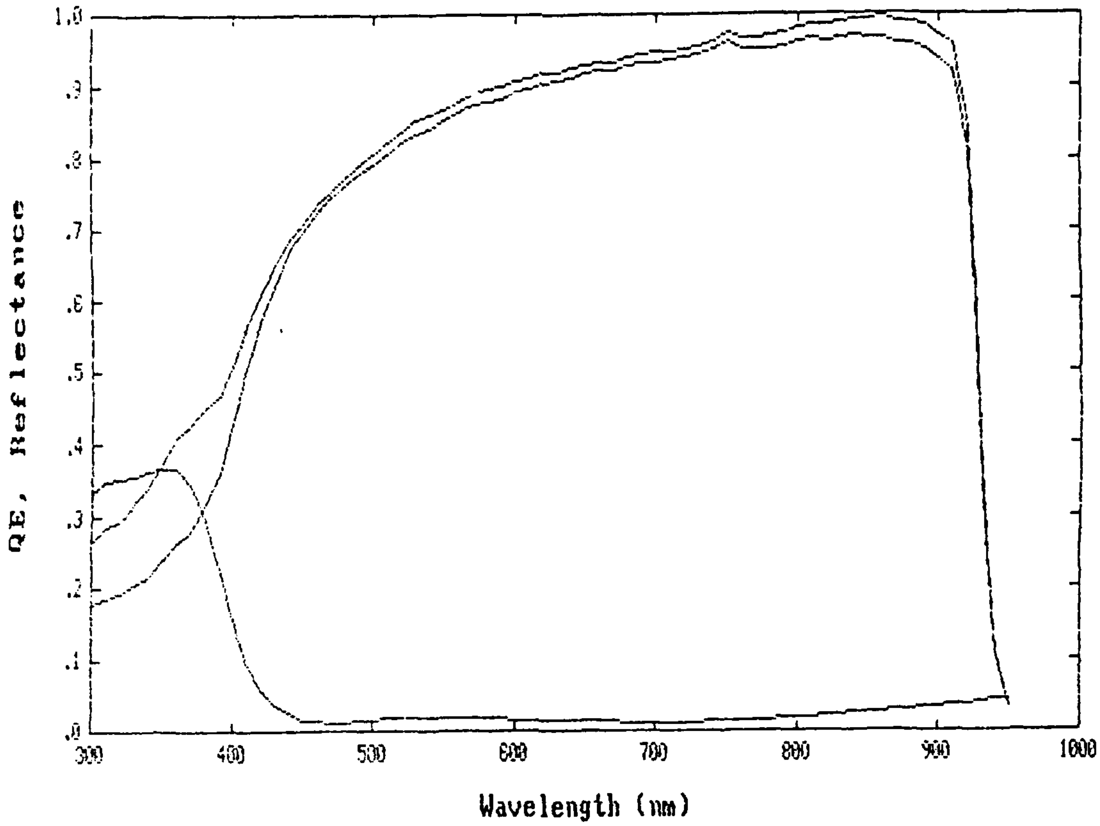
Sample ID: 5331-1-2
QE File: A:31 12.QE 02-01-1990 16:24:12 Shadow: .000
Ref File: A:31_12.REF 02-01-1990 16:14:59



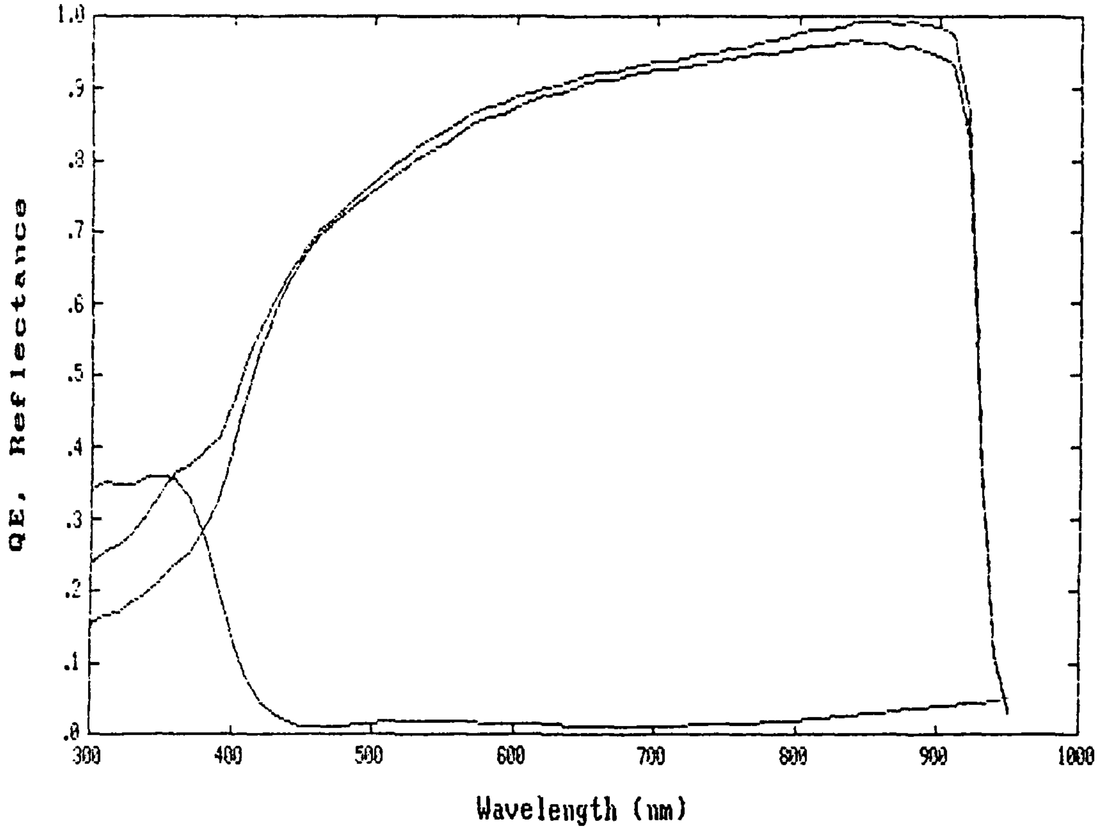
Sample ID: 5331-3-2
QE File: A:31 32.QE 02-01-1990 16:47:43 Shadow: .000
Ref File: A:31_32.REF 02-01-1990 16:55:07



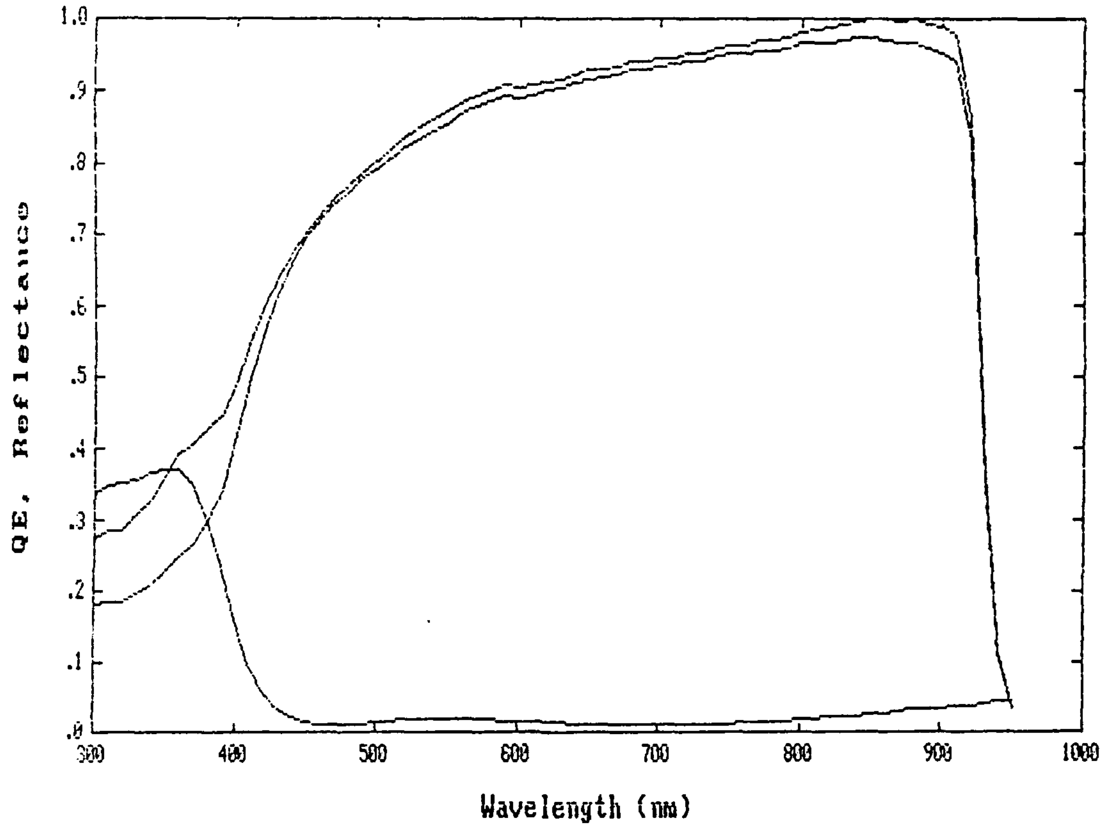
Sample ID: 5329-7-1
QE File: A:29 71.QE 02-01-1990 17:53:19 Shadow: .000
Ref File: A:29_71.REF 02-01-1990 18:00:26



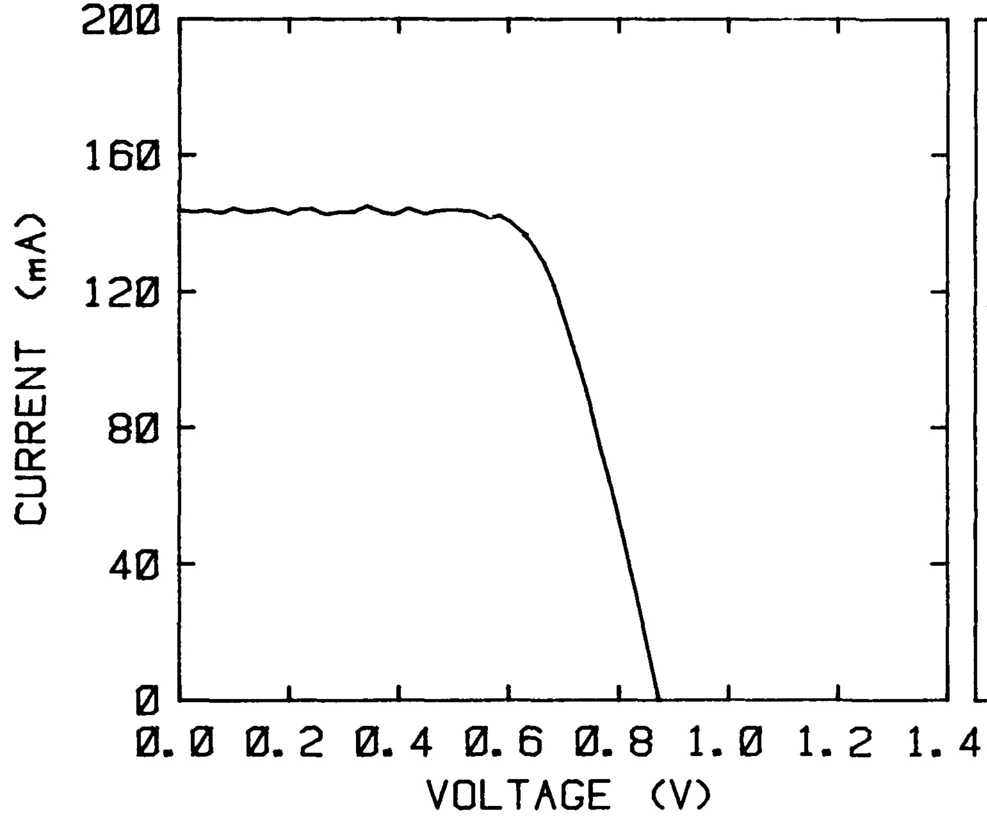
Sample ID: 5329-2-1
QE File: A:29_21.QE 02-01-1990 17:37:24 Shadow: .000
Ref File: A:29_21.REF 02-01-1990 17:44:51



Sample ID: 5329-5-1
QE File: A:29 51.QE   02-01-1990 18:59:07   Shadow: .000
Ref File: A:29_51.REF   02-01-1990 19:05:32



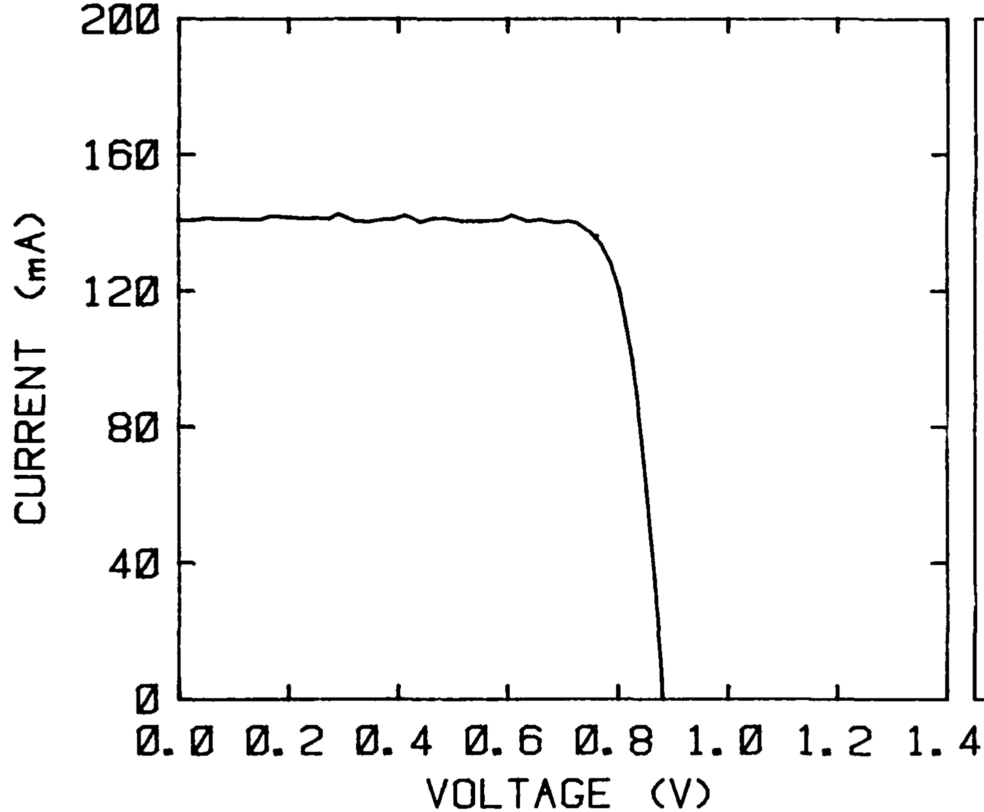
Lot: 5331 | Contract: 10120
Material: InP | AR Coat: None
Surface: Specular | Temp: 25C
Ref. Cell: ST17 | Ref Isc: 8.1 mA
Comment: BEFORE AR COATING-FOURTH LOT
Spectrum: AM0 (137.2 mW/cm2)
V Chan.: 3 I Chan.: 4 Cell Type: Sm. n/p



Cell 2-1 AR		
Area	4.000	cm2
Isc	143.962	mA
Jsc	35.99	mA/cm2
Voc	0.876	V
Pmax	86.306	mW
FF	68.44	%
Eff	15.73	%
Jsc1	35.99	mA/cm2
Suns	1.0	
Vm	0.633	V
Im	136.357	mA

01-31-1990 14:59:13

Lot: 5330	Contract: 10120
Material: InP	AR Coat: MgF2/ZnS
Surface: Specular	Temp: 25C
Ref. Cell: ST17	Ref Isc: 8.1 mA
Comment: AFTER AR COATING	
Spectrum: AM0 (137.2 mW/cm2)	
V Chan.: 3 I Chan.: 4	Cell Type: Sm. n/p



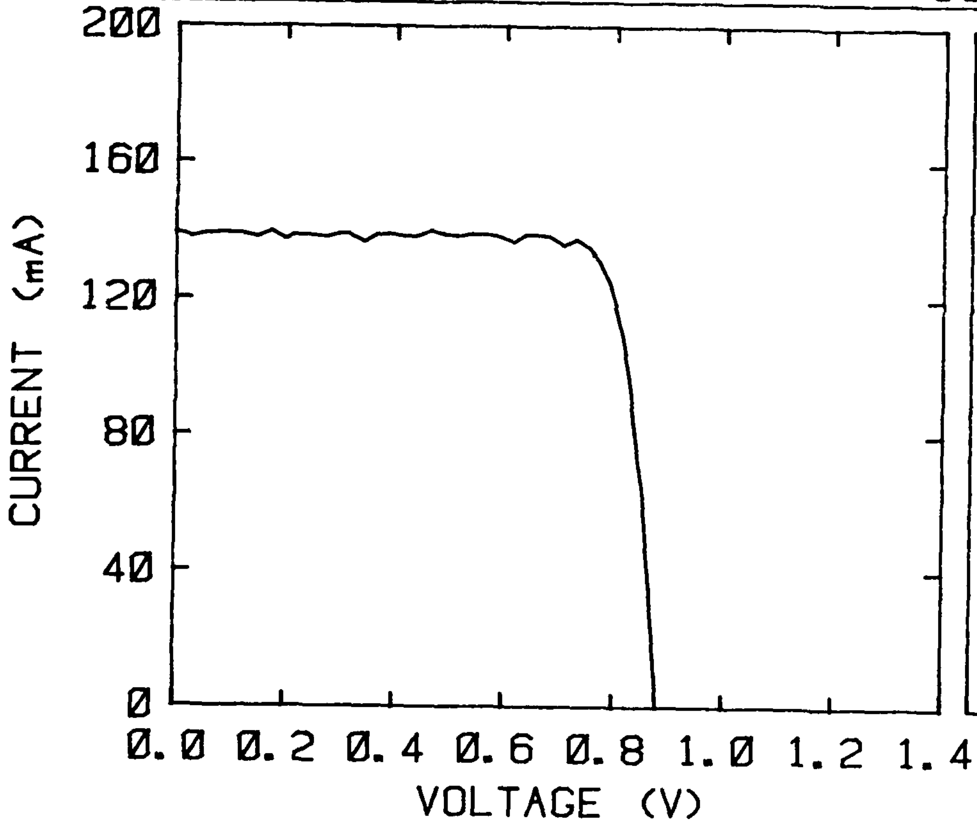
Cell 6-2		
Area	4.000	cm2
Isc	141.160	mA
Jsc	35.29	mA/cm2
Voc	0.884	V
Pmax	103.683	mW
FF	83.06	%
Eff	18.89	%
Jsc1	35.29	mA/cm2
Suns	1.0	
Vm	0.762	V
Im	136.043	mA

02-01-1990 14:50:20

Lot: 5329
Material: InP
Surface: Specular
Ref. Cell: ST17
Comment: AFTER AR COATING
Spectrum: AM0 (137.2 mW/cm2)
V Chan.: 3   I Chan.: 4

Contract: 10120
AR Coat: MgF2/ZnS
Temp: 25C
Ref Isc: 8.1 mA

Cell Type: Sm. n/p

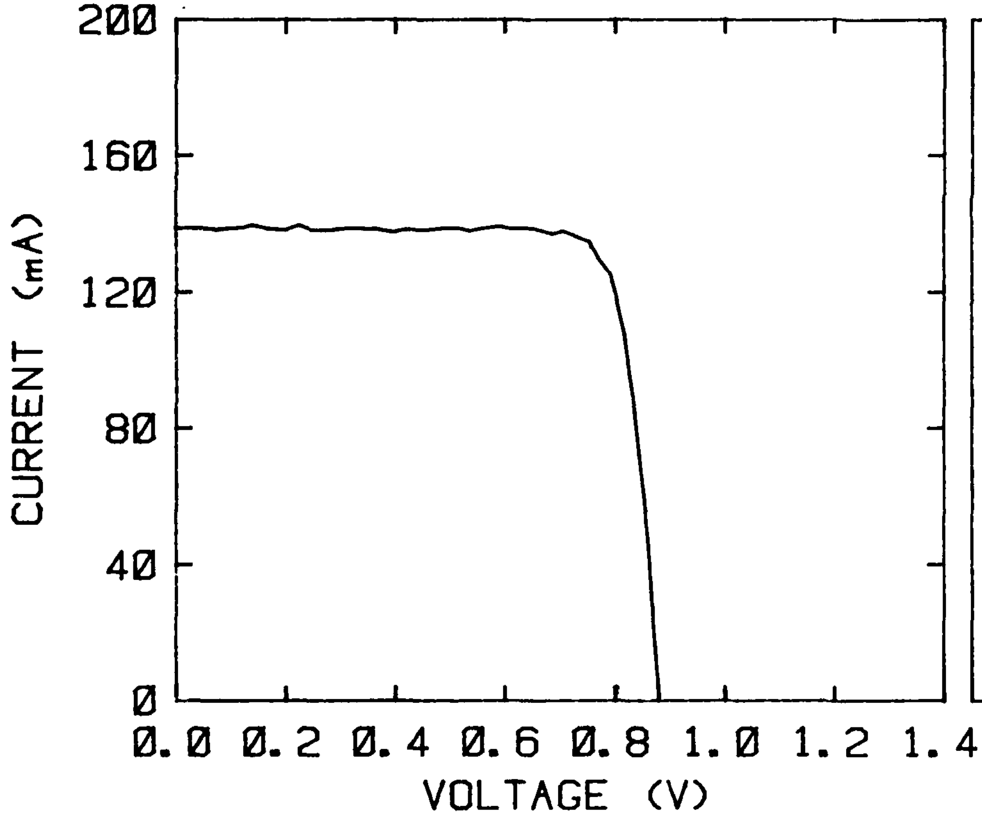


Cell 5-1

Area	4.000	cm2
Isc	138.946	mA
Jsc	34.74	mA/cm2
Voc	0.883	V
Pmax	101.659	mW
FF	82.85	%
Eff	18.52	%
Jsc1	34.74	mA/cm2
Suns	1.0	
Vm	0.762	V
Im	133.364	mA

02-01-1990 11:18:09

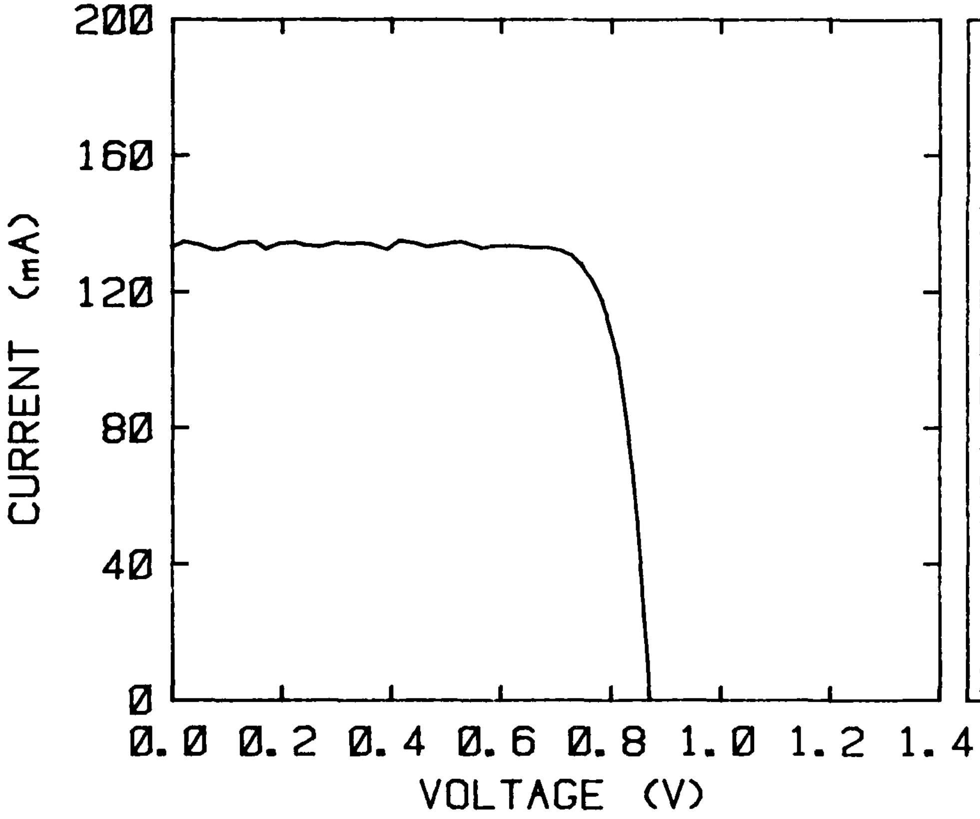
Lot: 5327	Contract: 10120
Material: InP	AR Coat: MgF2/ZnS
Surface: Specular	Temp: 25C
Ref. Cell: ST17	Ref Isc: 8.1 mA
Comment: AFTER AR COATING	
Spectrum: AM0 (137.2 mW/cm2)	
V Chan.: 3 I Chan.: 4	Cell Type: Sm. n/p



Cell 1-2		
Area	4.000	cm2
Isc	138.755	mA
Jsc	34.69	mA/cm2
Voc	0.882	V
Pmax	100.914	mW
FF	82.46	%
Eff	18.39	%
Jsc1	34.69	mA/cm2
Suns	1.0	
Vm	0.757	V
Im	133.238	mA

01-31-1990 09:31:42

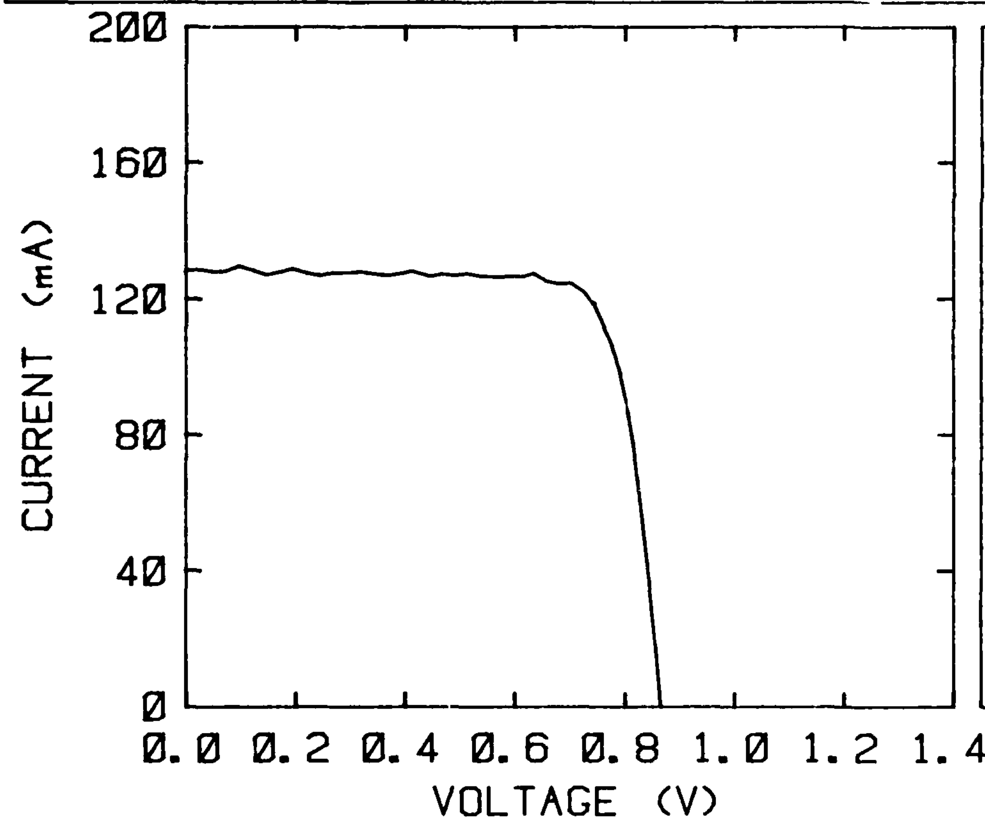
Lot: 5322	Contract: 10120
Material: InP	AR Coat: MgF2/ZnS
Surface: Specular	Temp: 25C
Ref. Cell: ST17	Ref Isc: 8.1 mA
Comment: AFTER AR COATING	
Spectrum: AM0 (137.2 mW/cm2)	
V Chan.: 3 I Chan.: 4	Cell Type: Sm. n/p



Cell 1-1 AR		
Area	4.000	cm2
Isc	133.562	mA
Jsc	33.39	mA/cm2
Voc	0.873	V
Pmax	95.706	mW
FF	82.07	%
Eff	17.44	%
Jsc1	33.39	mA/cm2
Suns	1.0	
Vm	0.747	V
Im	128.131	mA

01-29-1990 13:54:47

Lot: 5321	Contract: 10120
Material: InP	AR Coat: None
Surface: Specular	Temp: 25C
Ref. Cell: ST17	Ref Isc: 8.1 mA
Comment:	
Spectrum: AM0 (137.2 mW/cm2)	
V Chan.: 3 I Chan.: 4	Cell Type: Sm. n/p

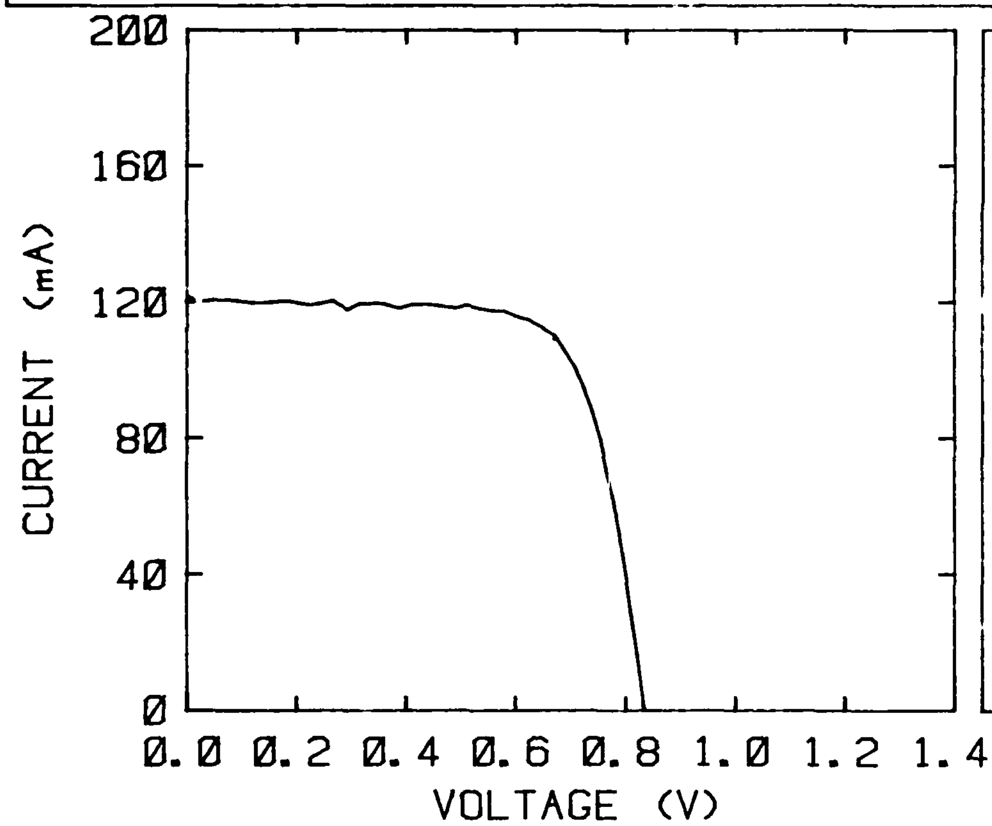


Cell 6-1 AR

Area	4.000	cm2
Isc	128.023	mA
Jsc	32.01	mA/cm2
Voc	0.867	V
Pmax	88.321	mW
FF	79.58	%
Eff	16.09	%
Jsc1	32.01	mA/cm2
Suns	1.0	
Vm	0.744	V
Im	118.660	mA

01-29-1990 16:50:22

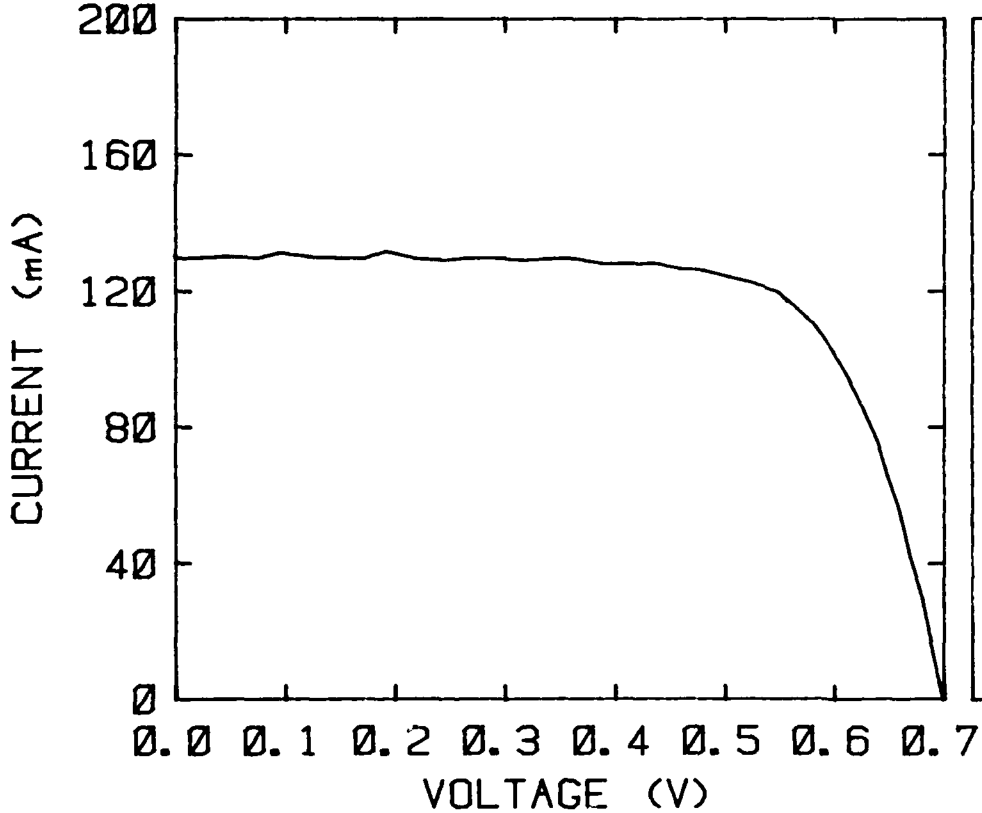
Lot: 5320	Contract: 1J120
Material: InP	AR Coat: None
Surface: Specular	Temp: 25C
Ref. Cell: ST17	Ref Isc: 8.1 mA
Comment:	
Spectrum: AM0 (137.2 mW/cm2)	
V Chan.: 3 I Chan.: 4	Cell Type: Sm. n/p



Cell 7-1		
Area	4.000	cm2
Isc	120.557	mA
Jsc	30.14	mA/cm2
Voc	0.836	V
Pmax	73.542	mW
FF	73.00	%
Eff	13.40	%
Jsc1	30.14	mA/cm2
Suns	1.0	
Vm	0.672	V
Im	109.377	mA

01-29-1990 16:25:49

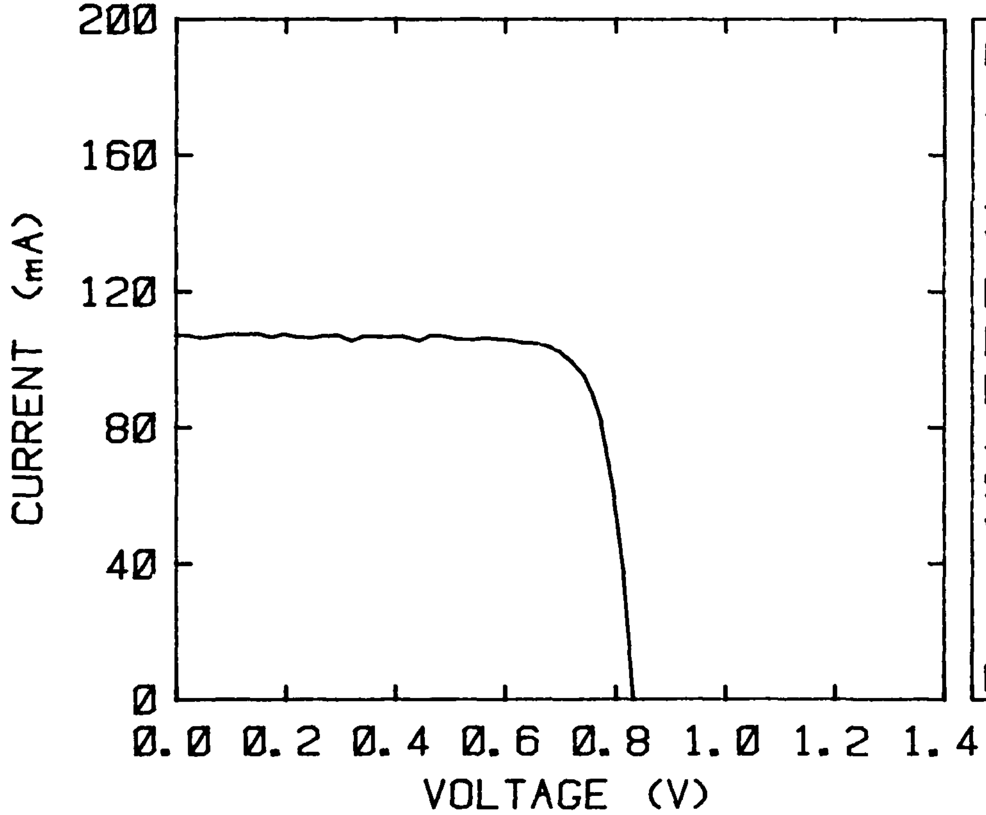
Lot: 5295 Contract: 10120
Material: InP AR Coat: None
Surface: Specular Temp: 25C
Ref. Cell: ST17 Ref Isc: 8.1 mA
Comment: AFTER SAWED
Spectrum: AM0 (137.2 mW/cm2)
V Chan.: 3 I Chan.: 4 Cell Type: Sm. n/p



Cell	4-1	
Area	4.000	cm2
Isc	130.329	mA
Jsc	32.58	mA/cm2
Voc	0.700	V
Pmax	65.119	mW
FF	71.43	%
Eff	11.87	%
Jsc1	32.58	mA/cm2
Suns	1.0	
Vm	0.557	V
Im	116.867	mA

01-10-1990 15:50:55

Lot: 5295 Contract: 10120
Material: InP AR Coat: None
Surface: Specular Temp: 25C
Ref. Cell: ST17 Ref Isc: 8.1 mA
Comment: AFTER SAWED
Spectrum: AM0 (137.2 mW/cm2)
V Chan.: 3 I Chan.: 4 Cell Type: Sm. n/p

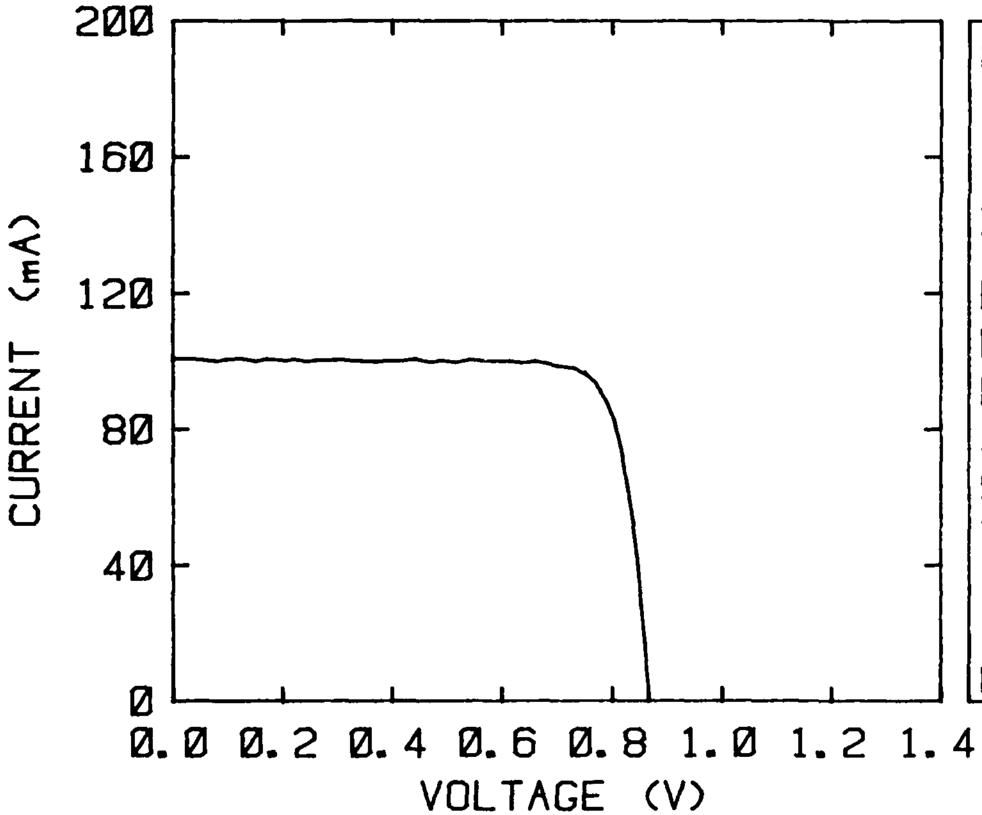


Cell 3-2		
Area	4.000	cm2
Isc	107.098	mA
Jsc	26.77	mA/cm2
Voc	0.833	V
Pmax	71.704	mW
FF	80.34	%
Eff	13.07	%
Jsc1	26.77	mA/cm2
Suns	1.0	
Vm	0.714	V
Im	100.464	mA

01-10-1990 15:48:47

Lot: 5295	Contract: 10120
Material: InP	AR Coat: None
Surface: Specular	Temp: 25C
Ref. Cell: ST17	Ref Isc: 8.1 mA
Comment: AFTER SAWED	
Spectrum: AM0 (137.2 mW/cm2)	

V Chan.: 3 I Chan.: 4 Cell Type: Sm. n/p



Cell 2-1		
Area	4.000	cm2
Isc	100.557	mA
Jsc	25.14	mA/cm2
Voc	0.869	V
Pmax	72.415	mW
FF	82.89	%
Eff	13.20	%
Jsc1	25.14	mA/cm2
Suns	1.0	
Vm	0.751	V
Im	96.414	mA

01-10-1990 15:42:19