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Stable, High-Efficiency, $CuInSe_2$-Based Polycrystalline Thin-Film Tandem Solar Cells

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R. W. Birkmire
J. E. Phillips
J. D. Meakin
Institute of Energy Conversion
University of Delaware
Newark, Delaware

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R. Mitchell

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Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401-3393

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ABSTRACT

The major obstacle to developing a high efficiency CdTe/CdS cell has been the lack of reproducibility and a number of process modifications have been made to overcome this. Some progress was made with a cell in which the CdTe is deposited onto a transparent ohmic contact however difficulties continued to be encountered in controlling the CdTe conductivity. Effort has been redirected to a cell in which the CdTe is deposited onto the CdS thus leaving an exposed CdTe surface to which ohmic contact can be made. Research on the $CuInSe_2$/CdS cell has established that high efficiency can be achieved over a broad $CuInSe_2$ composition range and a wide range of substrate temperature.

SUMMARY

The overall objective of the program is to develop the technology required to produce CdTe-$CuInSe_2$ tandem cells with efficiencies of 15%. In order to achieve this it is neccessary to develop $CuInSe_2$ and CdTe cells of high efficiency and areas of about 1 cm^2. Thus the research also contributes to the realization of high efficiency single junction cells.

The approach initially chosen was to fabricate a monolithic structure where the CdTe cell was deposited onto a high efficiency $CuInSe_2$ cell. Thus, a transparent interconnect between the CdTe and $CuInSe_2$ cells is required. The research focused on producing a transparent CdTe/CdS cell by vacuum evaporation. This required that the CdTe film be deposited on (or form) a transparent ohmic contact. The major problems were developing a transparent ohmic contact, controlling the CdTe conductivity and achieving reproducibilty.

The $CuInSe_2$ cell needs to be at least 10% efficient and furthermore it must be compatible with the overlying CdTe cell. At the start of the report period the best efficiency achieved with a 1 cm^2 cell was 8.8%, primarily as a consequence of the low fill factor, ~51%.

The approaches taken to solving the contact and conductivity problems with the CdTe cell were to use an ITO/Cu or SnO_2/Cu as an ohmic contact in combination with an air heat treatment to control the conductivity. This resulted in transparent CdTe cells with efficiencies of about 5-6%. However, the process was not reproducible. The contact properties and CdTe conductivities were not predictable. The incorporation of Hg into the CdTe films improved the reproducibility but did not eliminate the problem.

The fill factor problems with the 1 cm^2 $CuInSe_2$ cell were identified as being due to the spreading resistance of the top layer and the neccessary grid spacing to eliminate the losses was determined. As trial tandem junctions were produced a problem with severe shunting and shorts in the top cell was encountered. Examination of the $CuInSe_2$ cell surface revealed high protuberences which apparently had only minor affect on an isolated $CuInSe_2$ cell. An extensive investigation of the influence of deposition conditions, particularly substrate temperature, on the $CuInSe_2$ morphology was therefore carried out.

Towards the end of the reporting period, the focus of the research was directed toward a CdTe cell configuration where the CdTe is deposited on CdS. This eliminates the need to form an ohmic contact during deposition. This cell structure will be used for a four terminal tandem rather than a two terminal monolithic structure.

The experiments with $CuInSe_2$ deposition conditions showed that the cell performance was relatively insensitive to the substrate temperatures. Unfortunately the growth of protuberences also seems to be little influenced by this aspect of the growth process and other modifications are being sought to produce smoother layers.

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Film Growth and Cell Fabrication

About 80 depositions were carried out during the report period and were used to investigate the influence of substrate temperature on the material properties and device performance. The standard temperatures that had generally been used were 350°C for the first layer and 450°C for the second $CuInSe_2$ layer. The motivation for this work was the significant surface roughness and the existance of protuberances on the $CuInSe_2$ films which were causing problems with the production of tandem cells.

The temperature combinations investigated were 275/450, 300/400,450 and 500 and 325/450°C, in addition to the usual 350/450°C. No major loss of performance was observed for any of these combinations except for 275/450°C which in a very limited trial of only two depositions yielded cells of low Voc and Jsc and efficiencies below 7%. Tables 1 and 2 and Figure 1 summarize all the temperature combinations used during the contract period.

The cell performance parameters shown for each temperature combination in Table 1 are averages of the best performance recorded by each substrate that was made into cells. Table 2 gives the maximum values achieved for all conditions. All sets other than the 275/450°C contain some cells which exceeded 10% efficiency except for the 8 runs at 300/400°C which reached 9.3%. These results illustrate the insensitivity of cell performance to specific aspects of the cell processing. A similar insensitivity to $CuInSe_2$ composition was reported previously.

Deposition runs #31556, 31559 and 31560 were made with Alumina substrates in addition to the usual 7059 glass. The best efficiency for cells on Alumina was 8.7% compared to 10.8% for the parallel cells on glass. This difference is primarily due to the open circuit voltage, 0.42V on 7059 glass and 0.37V on the Alumina. However the basic cell process has been optimized for glass and the results on Alumina do not represent an upper limit. Further work on the influence of the substrate material may be carried out during efforts to eliminate the deliterious protuberences in the $CuInSe_2$ films.

Chronological scatter plots of the basic photovoltaic parameters for standard process devices are shown in Figures 2 and 3. The plots indicate a slight drop in efficiency for the later deposition runs caused primarily by a drop in short circuit current. The reasons for this drop are being investigated.

A set of cells were tested at SERI and showed active area efficiencies well over 10%.

Table 1

Device performance for cells made with 2 layer $CuInSe_2$ films deposited at the indicated temperatures. Average values of the best achieved on each substrate.

Tsub. First Layer (°C)	Tsub. Second Layer (°C) 400	450	500	ALL
275		2		2
		0.33385		0.33385
		31.275		31.275
		5.205		5.205
		44.675		44.675
300	8	27	2	37
	0.35260	0.38295	0.36985	0.37568
	32.480	33.011	35.940	33.054
	6.040	8.534	8.380	7.987
	47.430	61.347	60.645	58.300
325		3		3
		0.41453		0.41453
		32.763		32.763
		10.123		10.123
		67.843		67.843
350		32		32
		0.36772		0.36772
		32.661		32.661
		8.087		8.087
		57.639		57.639
ALL	8	64	2	74
	0.35260	0.37528	0.36985	0.37268
	32.480	32.770	35.940	32.824
	6.040	8.281	8.380	8.041
	47.430	59.277	60.645	58.033

Key

Number of substrates
Mean of Maximum Voc (V)
Mean of Maximum Jsc (mA/cm^2)
Mean of Maximum Eff (%)
Mean of Maximum FF (%)

Table 2

Device performance for cells made with 2 layer $CuInSe_2$ films deposited at the indicated temperatures. Maximum values achieved on each substrate.

Tsub. First Layer (°C)	Tsub. Second Layer (°C) 400	450	500	ALL
275		2		2
		0.36290		0.36290
		31.570		31.570
		6.050		6.050
		47.790		47.790
300	8	27	2	37
	0.39810	0.43090	0.40660	0.43090
	34.810	37.840	36.250	37.840
	9.290	11.200	10.120	11.200
	65.670	68.070	64.150	68.070
325		3		3
		0.41800		0.41800
		32.980		32.980
		10.540		10.540
		68.730		68.730
350		32		32
		0.43920		0.43920
		38.030		38.030
		11.000		11.000
		68.860		68.860
ALL	8	64	2	74
	0.39810	0.43920	0.40660	0.43920
	34.810	38.030	36.250	38.030
	9.290	11.200	10.120	11.200
	65.670	68.860	64.150	68.860

Key
Number of substrates
Maximum Voc (V)
Maximum Jsc (mA/cm^2)
Maximum Eff (%)
Maximum FF (%)

Maximum Voc (V)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
<0.30	7	
0.30	3	***
0.31	2	**
0.32	1	*
0.33	2	**
0.34	2	**
0.35	1	*
0.36	3	***
0.37	4	****
0.38	8	********
0.39	9	*********
0.40	6	******
0.41	10	**********
0.42	9	*********
0.43	5	*****
0.44	2	**

Maximum Jsc(mA/cm^2)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
<29.0	2	
29.0	3	***
30.0	3	***
31.0	7	*******
32.0	6	******
33.0	14	**************
34.0	20	********************
35.0	11	***********
36.0	5	*****
37.0	1	*
38.0	2	**

Maximum Efficiency(%)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
<5.0	8	
5.0	0	
5.5	4	****
6.0	5	*****
6.5	6	******
7.0	3	***
7.5	3	***
8.0	2	**
8.5	9	*********
9.0	2	**
9.5	8	********
10.0	9	*********
10.5	9	*********
11.0	6	******

Maximum Fill Factor (%)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
25.0	2	**
30.0	2	**
35.0	0	
40.0	6	******
45.0	0	
50.0	6	******
55.0	7	*******
60.0	15	***************
65.0	28	*************---------*
70.0	8	********

Figure 1. Histograms showing the distribution of cell performance parameters for the 74 substrates tested.

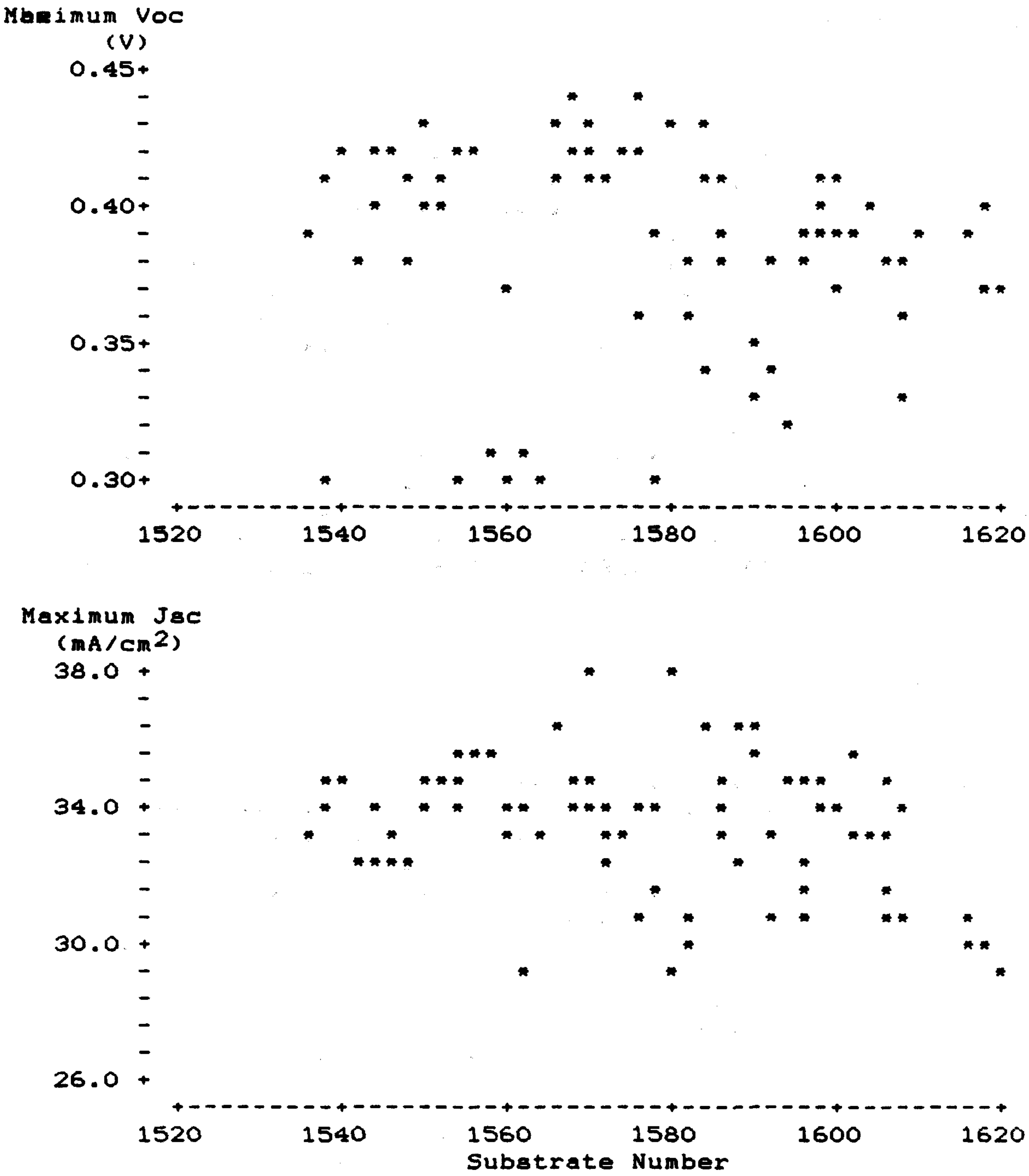


Figure 2. Chronological plots of open circuit voltage and short circuit current.

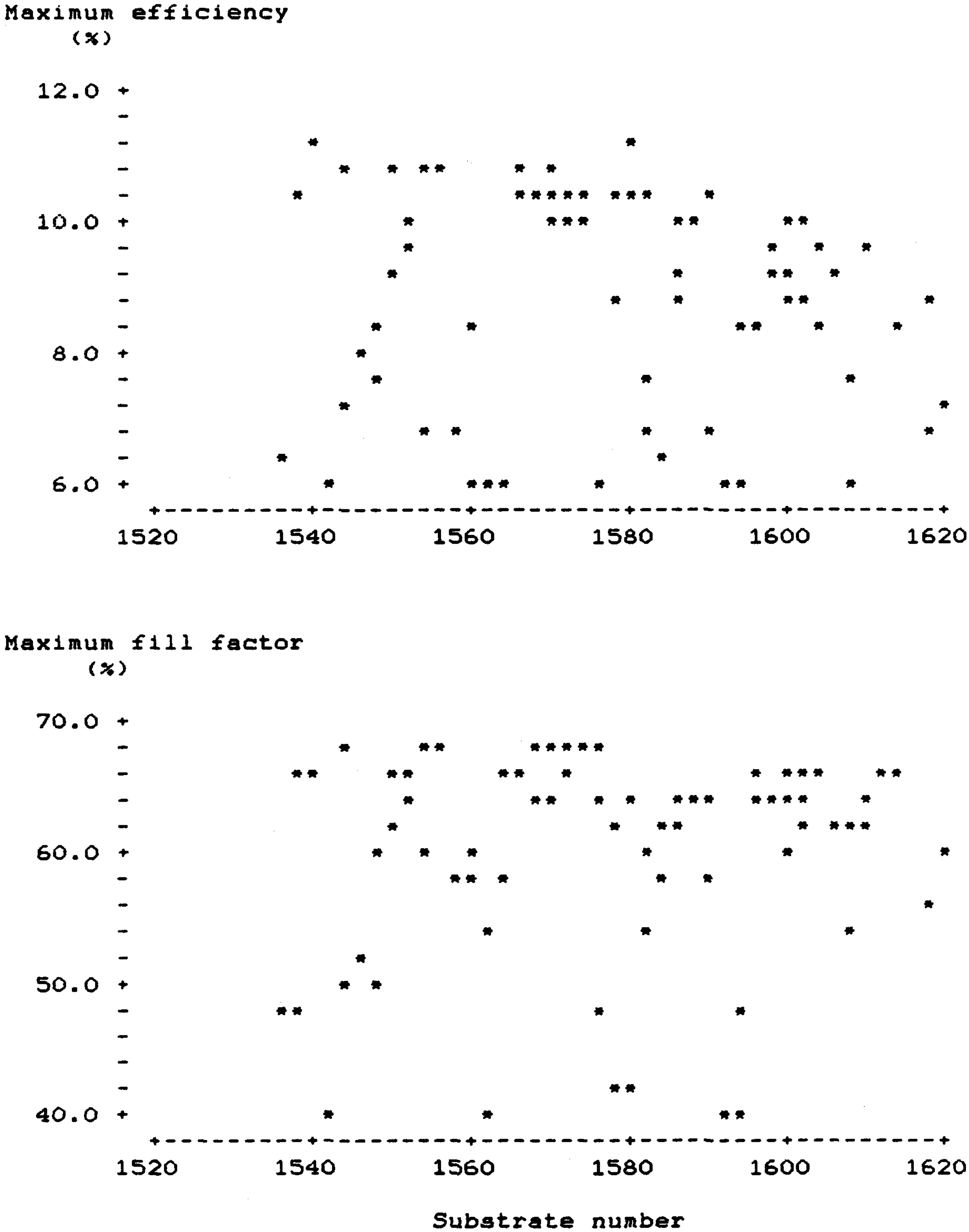


Figure 3. Chronological plots of maximum efficiency and fill factor

A limited number of 1cm^2 area devices were made with the results shown in Table 3. The cells show good voltages and currents but are severely limited by the fill factors. This is due to excessive series resistances which are attributable to the difficulties with the ITO/Al contact. Process modifications will be made to develop a satisfactory contacting system.

Table 3
Maximum performance parameters achieved with 1 cm^2 cells

Piece #	Cell #	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
31544.11	100	.3732	25.56	30.37	3.31
31544.11	101	.3758	23.13	27.81	2.76
31544.11	102	.3758	22.74	27.26	2.66
31551.11	100	.3995	12.79	27.44	1.60
31551.11	101	.4024	11.71	26.98	1.45
31551.11	102	.4023	10.93	27.16	1.37
31552.21	100	.3963	36.39	46.55	7.67
31552.21	101	.3987	34.34	33.90	5.30
31552.21	102	.3985	36.31	46.84	7.74
31556.11	100	.4062	36.75	51.29	8.75
31556.11	101	.4079	36.21	47.18	7.96
31556.11	102	.4081	36.50	50.02	8.51

Nickel current collection tabs have been applied to both sides of the 3x3 mm^2 $CuInSe_2$ devices. I-V testing was then carried out with either one or both of the tabs used to contact the cell to determine the Rs spreading resistance losses in the top ITO and CdS layers. The data given in Table 4 shows that fill factors improve by about 6-8 points when testing with both tabs connected. From the analysis given by Phillips (1) it can be shown that with the top layer spreading resistance of these cells a grid spacing of about 3mm would cause a loss in fill factor due to Rs of about 2-3 points. A grid spacing of 1mm should therefore eliminate this source of fill factor loss.

Table 4

Maximum cell parameters achieved on Piece #31569-11 using single or double tab testing.

Test Condition	Cell #	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Tab One	01	.4038	31.89	56.57	8.28
Tab Two	01	.4081	31.89	58.93	8.77
Dbl.Tab	01	.4074	32.39	65.04	9.63
Tab One	02	.4125	31.50	60.55	8.99
Tab Two	02	.4124	31.49	60.71	9.01
Dbl.Tab	02	.4127	31.91	66.17	9.87
Tab One	03	.4168	32.33	60.86	9.34
Tab Two	03	.4169	32.34	61.46	9.40
Dbl.Tab	03	.4160	32.48	66.66	10.15
Tab One	04	.4099	30.90	56.35	8.14
Tab Two	04	.4065	31.28	57.11	8.28
Dbl.Tab	04	.4078	32.07	62.17	9.09
Tab One	05	.4150	31.47	60.07	8.95
Tab Two	05	.4151	31.48	60.74	9.04
Dbl.Tab	05	.4145	31.89	66.56	9.86
Tab One	06	.4171	31.94	60.79	9.24
Tab Two	06	.4174	31.86	61.20	9.30
Dbl.Tab	06	.4169	32.26	66.77	10.07
Tab One	07	.4074	30.40	57.04	8.07
Tab Two	07	.4071	30.47	58.92	8.32
Dbl.Tab	07	.4061	31.67	65.86	9.37
Tab One	08	.4103	30.78	59.30	8.56
Tab Two	08	.4103	30.78	59.59	8.60
Dbl.Tab	08	.4097	31.57	66.15	9.59
Tab One	09	.4127	31.16	59.72	8.78
Tab Two	09	.4128	31.21	60.36	8.86
Dbl.Tab	09	.4124	31.82	66.44	9.77
Tab One	10	.4001	29.41	56.73	7.60
Tab Two	10	.4002	29.67	57.27	7.76
Dbl.Tab	10	.3997	30.90	65.38	8.96
Tab One	11	.4032	29.77	57.97	7.95
Tab Two	11	.4034	29.80	58.52	8.01
Dbl.Tab	11	.4031	30.85	66.15	9.15
Tab One	12	.4069	30.46	58.53	8.26
Tab Two	12	.4072	30.49	58.82	8.30
Dbl.Tab	12	.4066	31.27	66.08	9.35

Various CdS film thicknesses have been used with the results given in Table 5. Examination of the maximum parameters achieved shows that there is a gain in Jsc as the thickness is reduced but this is eventually accompanied by a loss in fill factor. (Note the small sample number for the thinnest and thickest CdS.) This loss in fill factor is due to an increase in sheet resistance as the CdS thickness in the present CdS/ITO contact structure is reduced while simultaneously there is a rise in Jsc. Below a CdS thickness of about 1 μm yield becomes a problem probably because the CdS film is then non-continuous.

Table 5

Influence of CdS thickness on cell performance

Maximum values for the given CdS thickness

CdS (μm)	Count	Jsc (mA/cm^2)	FF (%)	Eff (%)	Voc (V)
0.8	1	33.21	47.70	6.6	0.3929
1.2	4	35.71	66.44	10.6	0.4278
1.4	31	38.03	66.44	11.2	0.4392
1.6	12	35.05	68.51	11.0	0.4246
1.8	39	36.22	68.86	10.9	0.4207
2.0	35	35.68	68.80	10.5	0.4208
2.2	2	33.63	68.32	10.4	0.4163
ALL	124	38.03	68.86	11.2	0.4392

Mean values of the maximum achieved on each piece

CdS (μm)	Count	Jsc (mA/cm^2)	FF (%)	Eff (%)	Voc (V)
0.8	1	33.21	47.70	6.6	0.3929
1.2	4	34.07	65.11	10.2	0.4191
1.4	31	33.22	53.45	7.8	0.3835
1.6	12	33.25	62.10	8.9	0.3864
1.8	39	32.55	59.14	8.0	0.3653
2.0	35	32.60	61.08	8.1	0.3677
2.2	2	33.57	67.75	10.3	0.4117
ALL	124	32.87	58.79	8.2	0.3753

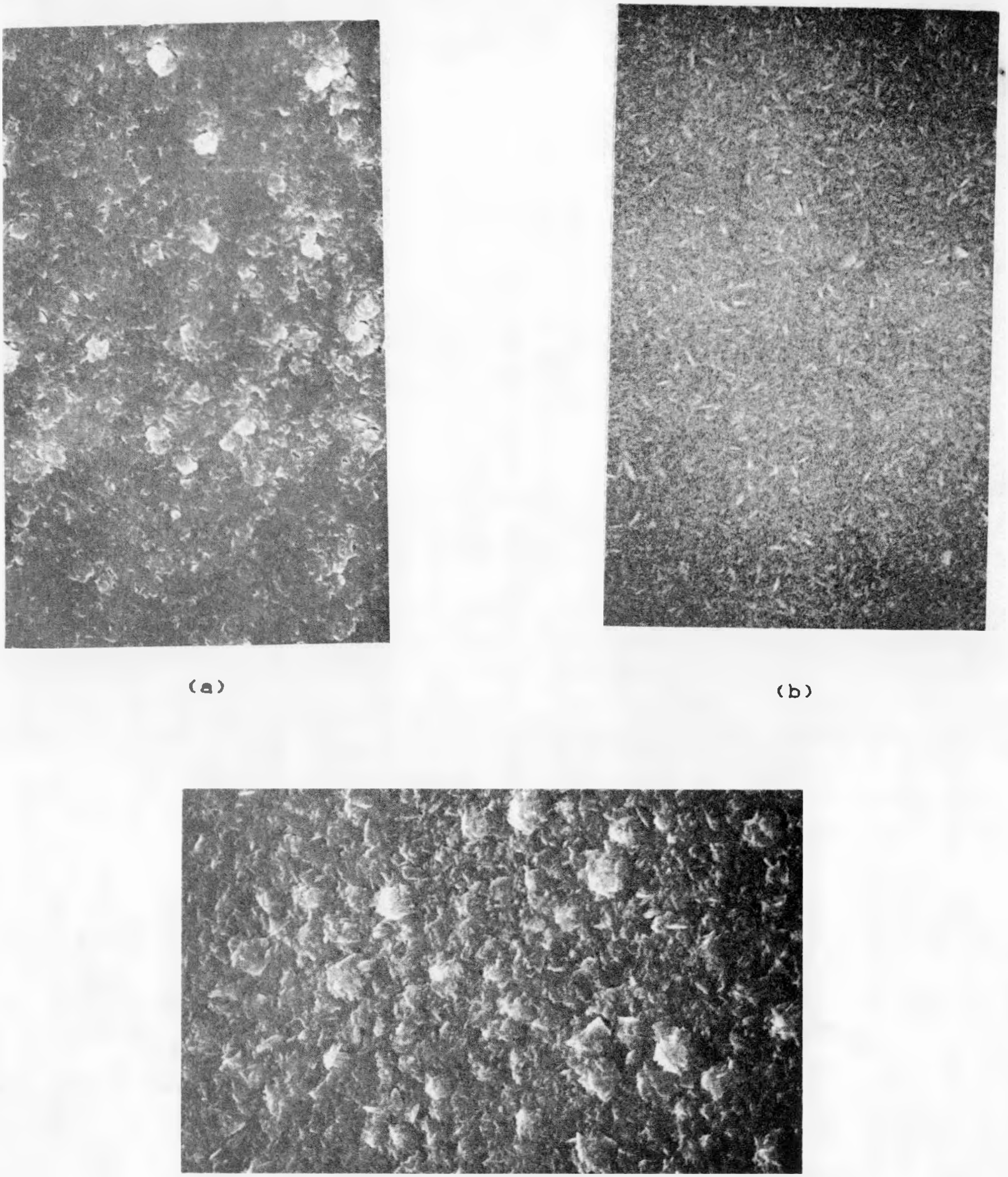
Material Analysis

The surface morphology and X-ray diffraction data show no major changes with substrate temperature as indicated by the data in Table 6 and Figures 4-7. In all cases the first (A) layer is highly (112) oriented and reveals a somewhat facetted surface in the SEM at x5000. The second (B) layer is much smoother and is essentially randomly oriented. The composite layer still shows some preferred orientation and is distinctly crystallographically facetted. It should be noted that the individual layers are deposited on bare 7059 glass (in order to allow resistivity measurements) whereas the composite films are on 7059/Mo substrates.

Table 6

X-ray diffraction intensities and composition for $CuInSe_2$ layers deposited at various substrate temperatures.

Run	Layer	Temp. (°C)	XRD Intensity (112)	(220) (204)	(116) (312)	Composition (%) Cu	In	Se
31576	A	275	12,600	90	60	27.6	22.6	49.8
"	B	450	300	500	30	15.6	28.6	55.8
"	C		1,050	300	180	22.6	26.3	51.1
31588	A	300	31,000	70	40	28.7	23.4	49.9
"	B	500	600	200	60	17.3	28.5	54.2
"	C		960	350	240	24.9	25.1	50.0
31580	A	300	33,000	60	40	29.7	21.8	48.5
"	B	450	390	470	60	14.8	28.9	56.3
"	C		1,200	360	200	24.3	25.3	50.4
31570	A	350	16,700	140	110	27.9	25.0	47.1
"	B	450	260	500	50	17.6	29.6	52.8
"	C		1,020	390	260	26.2	26.8	47.0



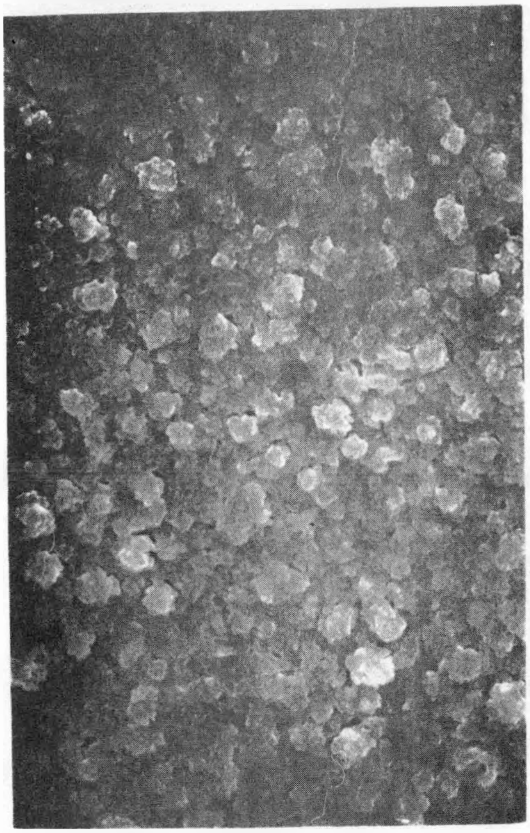
(a)

(b)

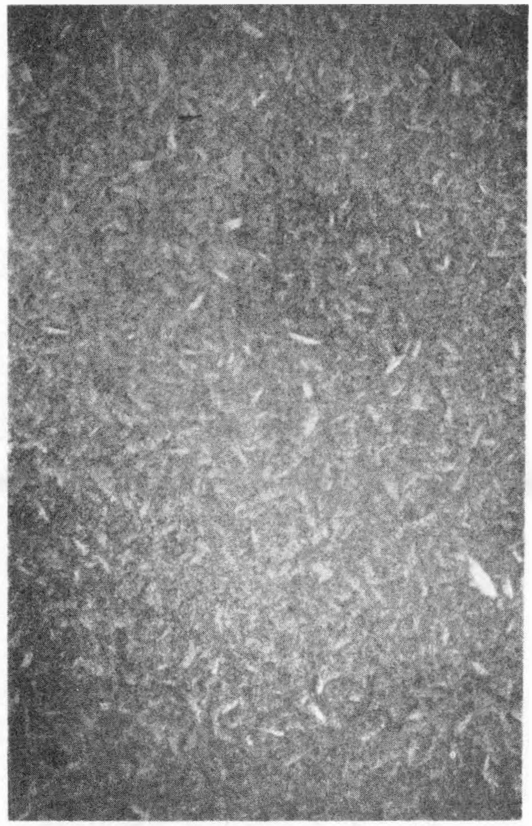
(c)

Figure 4. Run #31576 SEM x5000

(a) Layer A deposited at 275°C
(b) Layer B deposited at 450°C
(c) Composite layer on 7059/Mo



(a)



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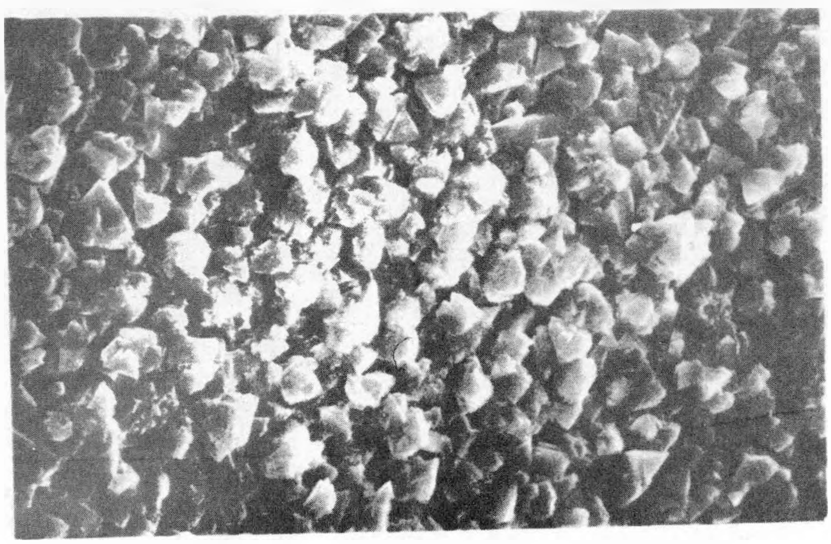
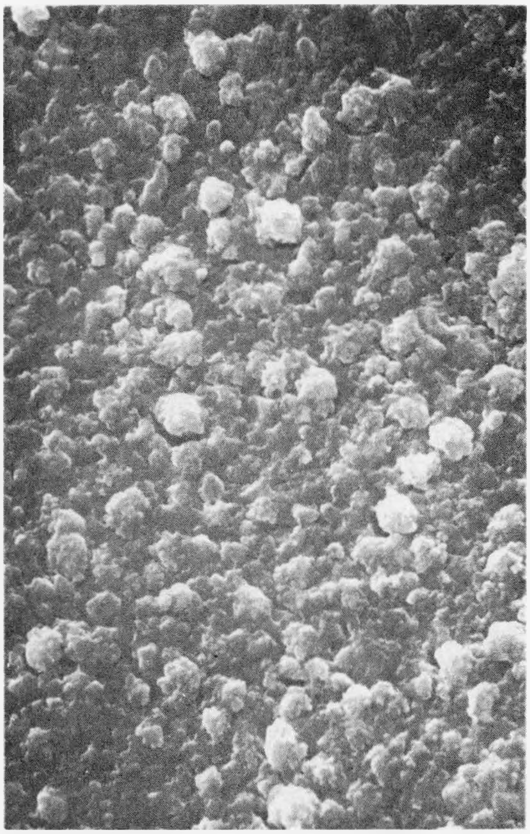


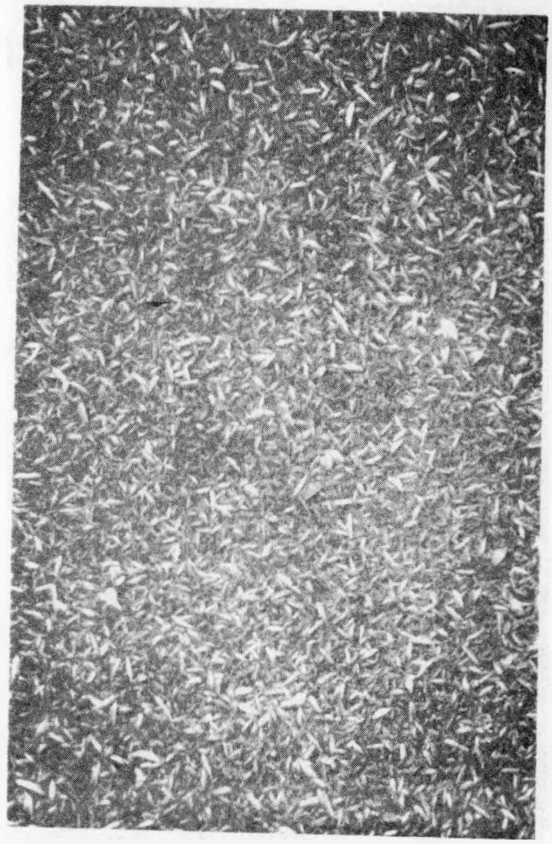
(c)

Figure 5. Run #31588 SEM x5000

(a) Layer A deposited at 300^oC
(b) Layer B deposited at 500^oC
(c) Composite layer on 7059/Mo



(a)



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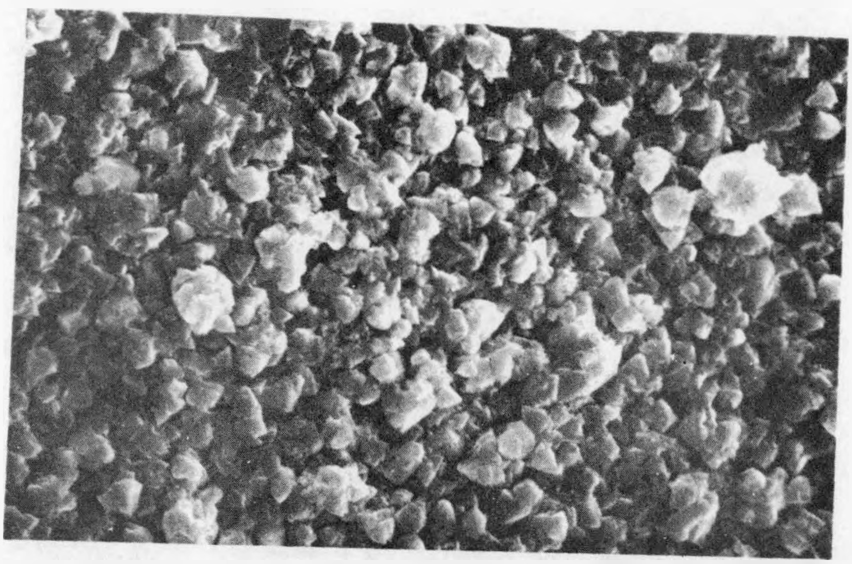
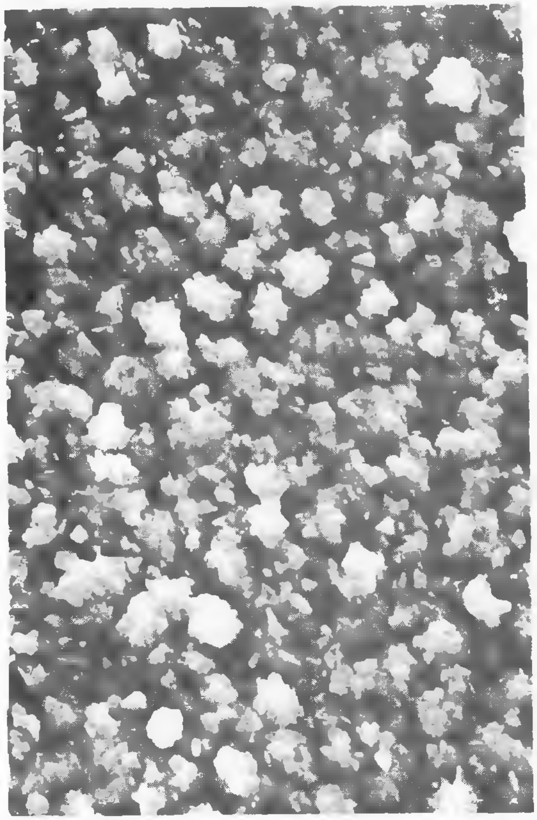


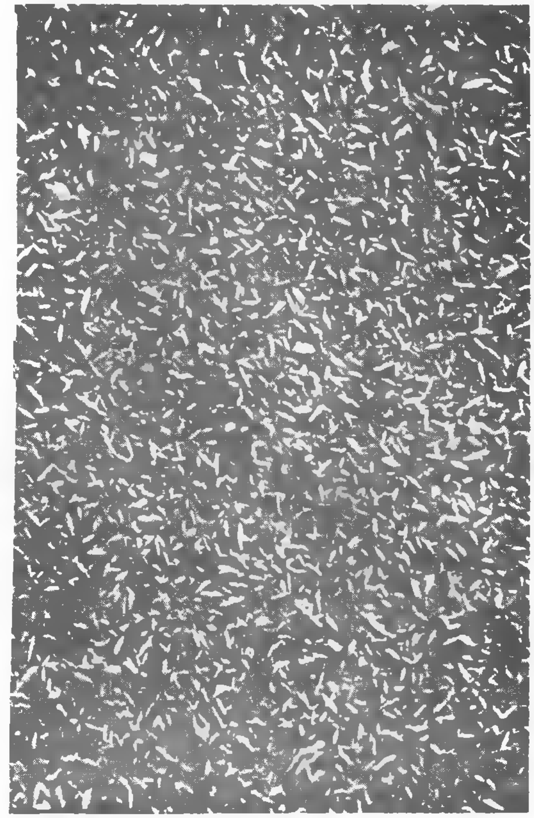
(c)

Figure 6. Run #31580 SEM x5000

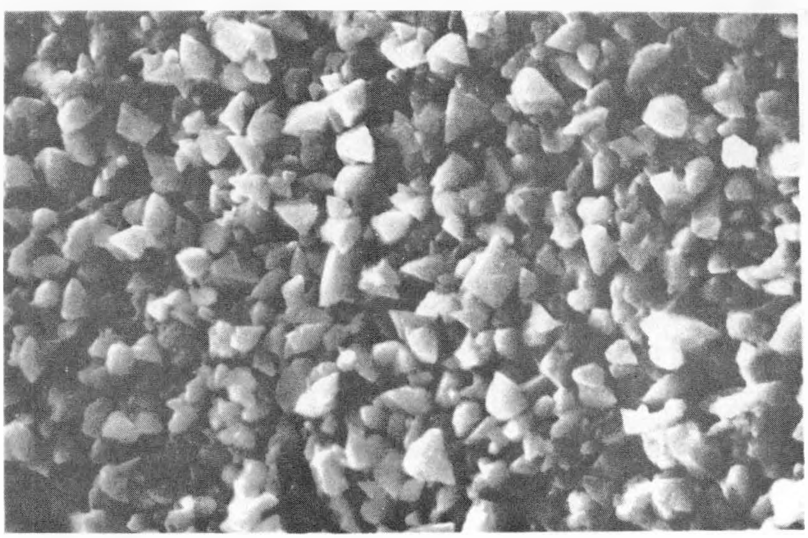
(a) Layer A deposited at 300°C
(b) Layer B deposited at 450°C
(c) Composite layer on 7059/Mo



(a)



(b)



(c)

Figure 7. Run #31570 SEM x5000

(a) Layer A deposited at 350°C
(b) Layer B deposited at 450°C
(c) Composite layer on 7059/Mo

2.0 (CdHg)Te/CdS Cell Development

Film Growth and Cell Fabrication

To deposit (CdHg)Te onto an existing $CuInSe_2$/CdS cell or on a substrate suitable for tandem devices requires a contact that: is conductive and transparent, makes ohmic contact to p-type (CdHg)Te, and is sufficiently robust to withstand the (CdHg)Te deposition process. These criteria are satisfied by a coating of ITO or SnO_2 on glass for conductivity followed by a layer of 2-10nm of Cu to provide a reasonable ohmic contact to (CdHg)Te. The SnO_2 coated glass is supplied by Cherry Electric and the ITO is sputter deposited in house. Both materials have a nominal sheet resistance of $20\Omega/\square$. Copper acts as a deep acceptor in (CdHg)Te and most of the 2-10nm of Cu is believed to be incorporated in the (CdHg)Te film during deposition and heat treatments. In addition to the transparent substrates, 7059/Mo/Cu substrates were used in the development of the (CdHg)Te process.

The (CdHg)Te is deposited by thermal evaporation from a powder source bottle where the effusion rate is determined by precisely controlling the source temperature. An Hg background pressure is established during the (CdHg)Te film growth using an elemental Hg source bottle. Films have been deposited at substrate temperatures from 140 to 250°C and at film growth rates of 0.01 to 0.2 µm/min. For substrate temperatures above 200°C, no Hg is incorporated into the film due to the high vapor pressure of the Hg. The additional of Hg during the evaporation allows single phase (CdHg)Te films to be grown at lower substrate temperatures for moderate flux rates. In general, the (CdHg)Te films contain less than 5% Hg which is mainly controlled by the substrate temperature.

The (CdHg)Te films are heat treated in air at 300°C for 30 minutes prior to the CdS deposition. This treatment has been found to improve the p-type conductivity of the film as well as the fill factor of the final device. The CdS is deposited by thermal evaporation from a powder source bottle at a film growth rate of 0.3 µm/min and a substrate temperature of 200°C. The resistivity of the CdS films is ~ 0.01 Ω-cm and is controlled by coevaporation of In during deposition. The low resistivity ensures that the depletion layer is entirely in the (CdHg)Te, thereby aiding current collection.

A sputtered ITO film 250nm thick and an Ni bus bar are deposited to provide the ohmic contact to the CdS. The cell area and contacts are defined by a photolithography-etching procedure yielding 12 cells each 3x3 mm^2 on a 2.5x2.5 cm^2 substrate.

Material Analysis

The degree of preferred orientation and the existence of Te second phases in the (CdHg)Te are routinely monitored using X-ray diffraction. Complete 2-Theta scans are not necessary for this purpose and the following peaks are spot checked.

	(CdHg)Te		Te	
(hkl)	(111)	(311)	(100)	(003)
I/Io Random	100	50	20	8

Figure 8 shows representative X-ray diffraction scans.

The total reflection and transmission of (CdHg)Te films deposited on ITO/Cu and SnO_2/Cu substrates for Cu thickness from 2-10nm were measured and are summarized in Table 7. Also included are R and T for (CdHg)Te on 7059 glass. As the amount of Cu increases the transmission drops to below 30% for 10nm Cu in the 850-1300nm range. After a 300°C air heat treatment for 3 hours, the transmission of samples with 10nm increased to over 30%. Table 8 shows the actual transmission through completed devices for different thickness Cu. For high efficiency tandem cells the transmission through the entire (CdHg)Te cell should approach 90%. To achieve this, reflection losses will have to be minimized by proper control of individual layer thicknesses and appropriate AR-coatings. Absorption in the (CdHg)Te films must be controlled by optimizing the Cu thickness and heat treatments.

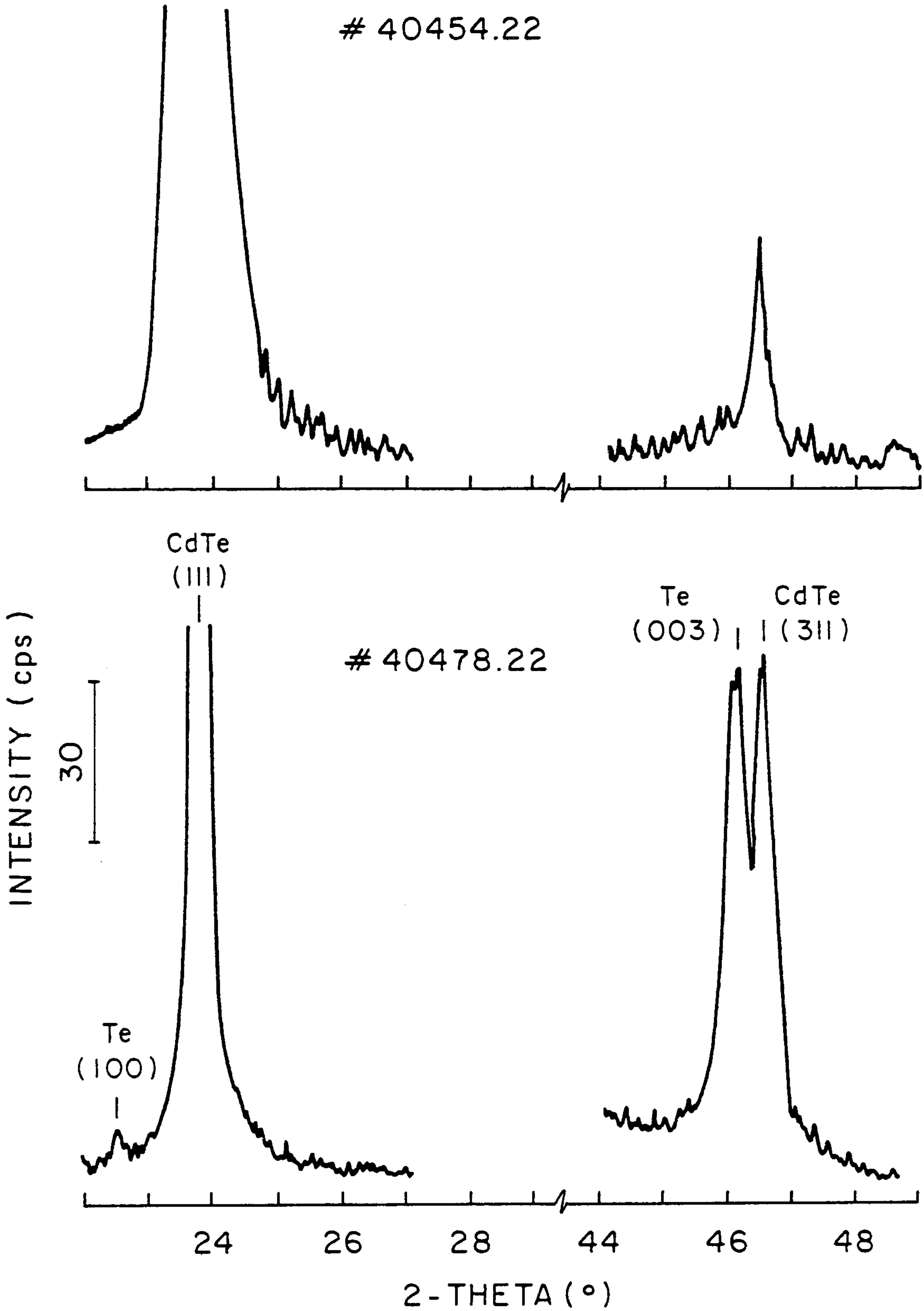


Figure 8. Representative X-ray diffraction scans showing the presence of elemental Te in substrate # 40478.

Table 7

Nominal Transmission and Reflection for (CdHg)Te Deposited on Different Contacts

Substrate	Cu Thickness (nm)	% Transmission at(nm) 900	1025	1150	%Reflection at(nm) 900	1025	1150
7059	0	65	70	70	30	30	30
7059/ITO	2	60	60	50	25	25	30
	5	45	40	40	20	20	20
	10	25	25	25	20	20	20
7059/SnO_2	5	45	45	40	20	20	20

Table 8

Transmission Through (CdHg)Te/CdS Cells

Cell #	Substrate	Cu Thickness (nm)	% Transmission at (nm) 900nm	1025nm	1150nm
40445.11	7059/ITO	2	55	54	52
40462.31		5	33	37	34
40447.21		10	35	34	28
40441.31	7059/SnO_2	2	60	62	60
40456.21		5	43	43	42
40449.21		10	33	33	32

Cell results

A summary of all cell results and processing parameters is given in Appendices E to H. The I-V characteristics of the best transparent (CdHg)Te cells are shown in Figures 9 and 10. Table 9 summarizes the cell characteristics. Included in Table 9 is the I-V characteristics of the best (CdHg)Te cell for which the contact was Mo/Cu.

Table 9

I-V parameters for the best (CdHg)Te/CdS Cells

Cell #	Contact	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
40447.21	ITO/Cu(10nm)	0.58	16.7	49.3	5.5
40449.12	SnO_2/Cu(5nm)	0.58	15.7	52.7	5.4
40430.12	Mo/Cu(2nm)	0.54	18.3	57.1	6.4

Although 5-6% transparent CdTe/CdS cells were made, the process was not reproducible as can be seen from the cell and processing data. Of the 79 samples with a transparent contact (either ITO or SnO_2), only 14 samples yielded devices over 3%. There was no correlation between deposition parameters or Cu thickness with device results. This lack of reproducibility made it impossible to optimize the deposition process. Furthermore, forming the CdTe transparent ohmic contact during deposition limits the ways in which the contact and CdTe properties can be modified after deposition. Due to this lack of reproducibility, work on the inverse cell structure was started during the later part of this reporting period. By depositing the CdTe film on an ITO/CdS substrate, the CdTe surface can be modified to form contacts and heat treatments may be more effective in controlling the CdTe conductivity. However with this cell structure, only four-terminal tandem devices are directly possible.

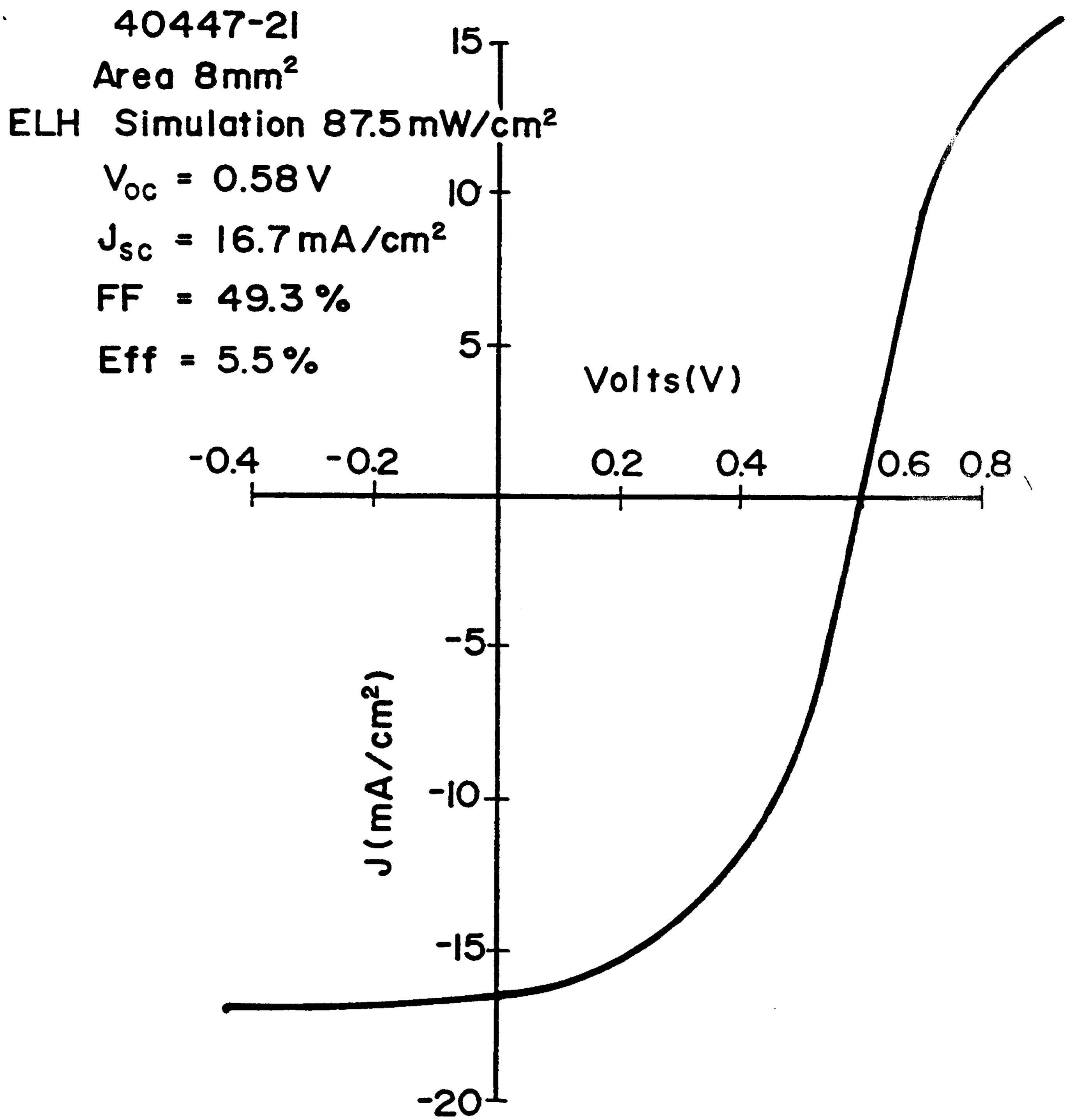


Figure 9. I-V curve for CdTe/CdS cell # 40447-21.

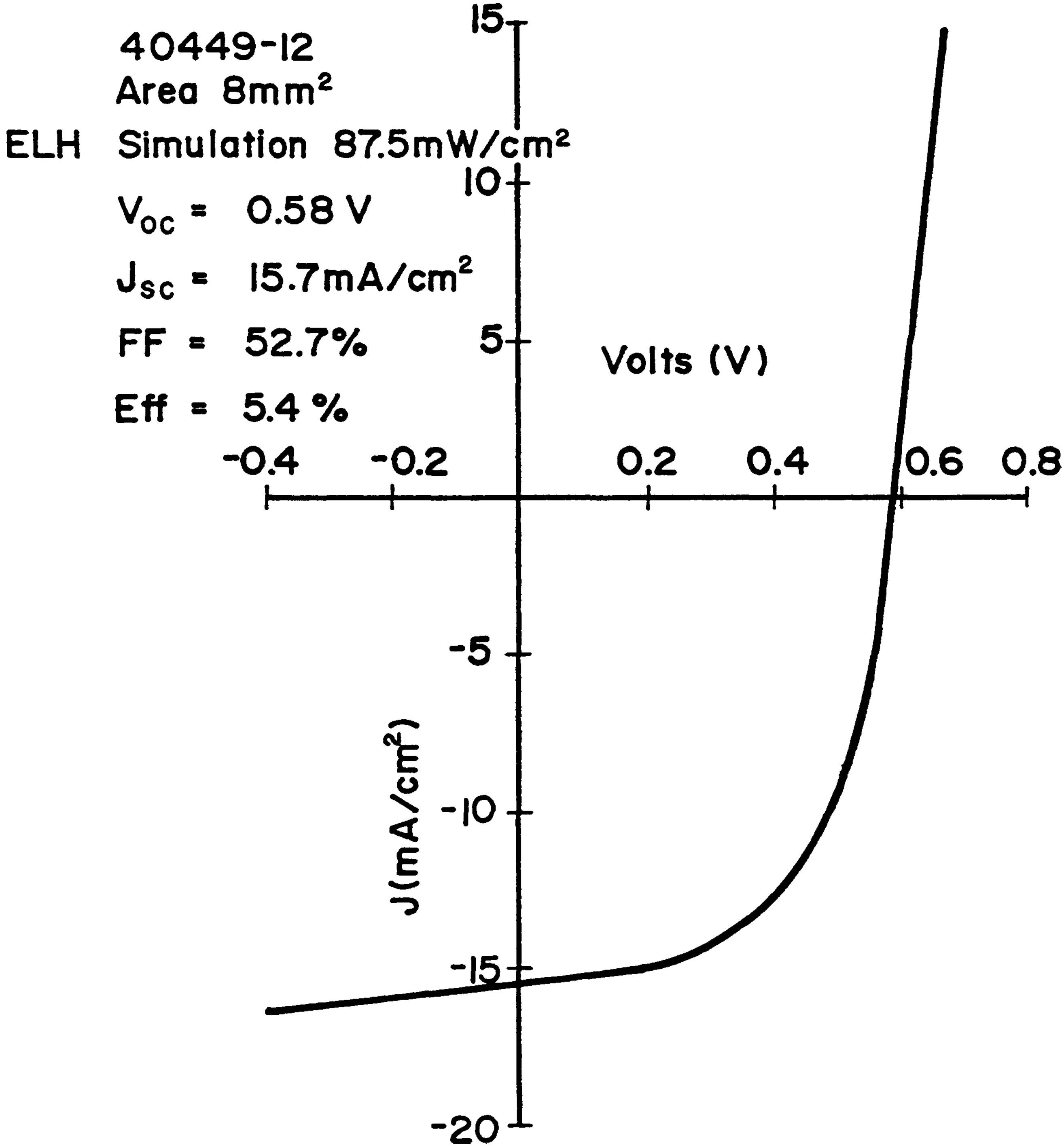


Figure 10. I-V curve for CdTe/CdS cell #40449-12.

3. References

1. J.E. Phillips, 18th IEEE Photovoltaic Specialists Conference, 1980 pp. 734-737

APPENDIX A

$CuInSe_2$ Data

from material

made in

Evaporator III

(Knudsen Source)

EV III

	Substr. Temp. (deg. C)	Thick-ness (microns)	Resis-tivity (ohm-cm)	% Cu	EDAX Compos. % In	$CuInSe_2$ % Se
			Substrate #31580			
			Evaporation Date 6/17/85			
Layer 1	300	1.9	5.9×10^{-2}	29.7	21.8	48.5
Layer 2	450	1.4	$3.1 \times 10^{+5}$	14.8	28.9	56.3
Composite		3.3	$9.2 \times 10^{+3}$	24.3	25.3	50.4
			Substrate #31581			
			Evaporation Date 6/18/85			
Layer 1	300	1.9	7.8×10^{-2}	17.6	21.8	60.6
Layer 2	450	1.3	$5.5 \times 10^{+5}$	16.8	28.3	54.9
Composite		3.2	$1.2 \times 10^{+4}$	24.3	25.4	50.3
			Substrate #31582			
			Evaporation Date 6/19/85			
Layer 1	300	1.9	7.0×10^{-2}	19.1	22.1	58.8
Layer 2	450	1.3	$5.7 \times 10^{+5}$	16.2	28.5	55.3
Composite		3.1	$2.6 \times 10^{+4}$	24.0	25.5	50.5
			Substrate #31583			
			Evaporation Date 6/20/85			
Layer 1	300	1.9	7.8×10^{-2}	18.3	21.2	60.5
Layer 2	450	1.3	$5.6 \times 10^{+5}$	16.0	28.1	55.8
Composite		3.3	$1.3 \times 10^{+4}$	25.7	27.5	46.8

	Substr. Temp. (deg. C)	Thick-ness (microns)	Resis-tivity (ohm-cm)	% Cu	EDAX Compos. % In	% Se
Substrate #31584						
Evaporation Date 6/25/85						
Layer 1	300	1.9	7.8×10^{-2}	19.2	21.0	59.8
Layer 2	450	1.3	$5.2 \times 10^{+5}$	16.3	28.3	55.4
Composite		3.1	$1.2 \times 10^{+4}$	25.6	25.3	49.1
Substrate #31585						
Evaporation Date 6/26/85						
Layer 1	300	1.9	8.2×10^{-2}	17.8	21.4	60.8
Layer 2	450	1.4	$5.5 \times 10^{+5}$	17.2	27.8	55.0
Composite		3.2	$2.4 \times 10^{+4}$	23.9	25.4	50.7
Substrate #31586						
Evaporation Date 6/27/85						
Layer 1	300	2.0	6.2×10^{-2}	19.0	21.3	59.7
Layer 2	450	1.3	$6.0 \times 10^{+3}$	17.7	27.3	55.0
Composite		3.3	$2.1 \times 10^{+4}$	25.6	25.0	49.4
Substrate #31587						
Evaporation Date 6/28/85						
Layer 1	300	1.9	6.8×10^{-2}	21.1	22.1	56.8
Layer 2	450	1.3	$5.6 \times 10^{+5}$	17.5	27.8	54.7
Composite		3.3	$3.2 \times 10^{+4}$	25.4	25.2	49.4

	Substr. Temp. (deg. C)	Thick-ness (microns)	Resis-tivity (ohm-cm)	% Cu	EDAX Compos. % In	% Se
			Substrate #31588			
			Evaporation Date 7/ 8/85			
Layer 1	300	1.9	6.8×10^{-2}	20.7	23.4	49.9
Layer 2	500	1.3	$3.8 \times 10^{+5}$	17.3	28.5	54.2
Composite		3.4	$4.4 \times 10^{+4}$	24.9	25.1	50.0
			Substrate #31589			
			Evaporation Date 7/ 9/85			
Layer 1	300	2.0	7.4×10^{-2}	30.6	20.9	48.5
Layer 2	500	1.3	$4.0 \times 10^{+5}$	17.2	27.7	55.1
Composite		3.3	$1.5 \times 10^{+4}$	26.1	24.9	49.0
			Substrate #31590			
			Evaporation Date 7/10/85			
Layer 1	300	2.0	5.8×10^{-2}	30.1	21.8	47.2
Layer 2	400	1.4	$5.9 \times 10^{+5}$	16.8	28.5	54.7
Composite		3.6	$9.0 \times 10^{+3}$	24.6	24.9	50.4
			Substrate #31591			
			Evaporation Date 7/12/85			
Layer 1	300	2.0	6.2×10^{-2}	28.9	22.1	49.0
Layer 2	400	1.3	$4.8 \times 10^{+5}$	16.2	28.2	55.6
Composite		3.4	$2.8 \times 10^{+4}$	23.2	25.7	51.0

	Substr. Temp. (deg. C)	Thick- ness (microns)	Resis- tivity (ohm-cm)	% Cu	EDAX Compos. % In	% Se
			Substrate #31592			
			Evaporation Date 7/15/85			
Layer 1	300	2.0	$7.4x10^{-2}$	18.1	22.3	59.6
Layer 2	400	1.2	$4.2x10^{+5}$	16.1	28.0	55.9
Composite		3.6	$1.4x10^{+4}$	24.6	25.2	50.2
			Substrate #31593			
			Evaporation Date 7/16/85			
Layer 1	300	2.0	$7.4x10^{-2}$	31.0	21.6	47.4
Layer 2	400	1.3	$4.9x10^{+4}$	16.0	28.3	55.7
Composite		3.9	$1.6x10^{+4}$	26.3	25.2	48.5
			Substrate #31594			
			Evaporation Date 7/12/85			
Layer 1	300	2.0	$6.6x10^{-2}$	32.3	20.9	46.8
Layer 2	400	1.3	$4.8x10^{+5}$	16.9	27.5	55.6
Composite		3.7	$4.4x10^{+3}$	26.5	25.1	49.3
			Substrate #31595			
			Evaporation Date 7/18/85			
Layer 1	300	1.9	$6.1x10^{-2}$	31.5	21.5	47.0
Layer 2	400	1.3	$3.6x10^{+5}$	16.5	28.1	55.4
Composite		3.5	$2.9x10^{+3}$	24.3	24.8	50.9

	Substr. Temp. (deg. C)	Thick-ness (microns)	Resis-tivity (ohm-cm)	% Cu	EDAX Compos. % In	% Se
Substrate #31596						
Evaporation Date 7/19/85						
Layer 1	300	2.0	4.6×10^{-2}	20.7	20.8	58.5
Layer 2	400	1.2	$5.0\times10^{+5}$	16.7	28.4	54.9
Composite		3.6	$2.2\times10^{+3}$	24.1	25.3	50.6
Substrate #31597						
Evaporation Date 7/22/85						
Layer 1	300	1.9	6.1×10^{-2}	27.3	21.5	51.2
Layer 2	400	1.3	$5.6\times10^{+5}$	16.3	27.7	55.9
Composite		3.5	$4.2\times10^{+3}$	23.2	25.5	51.3
Substrate #31598						
Evaporation Date 7/23/85						
Layer 1	300	2.0	6.4×10^{-2}	23.8	21.1	55.1
Layer 2	450	1.4	$5.6\times10^{+5}$	15.8	28.2	56.0
Composite		3.2	$4.5\times10^{+3}$	25.0	25.5	49.5
Substrate #31599						
Evaporation Date 7/24/85						
Layer 1	300	1.9	5.3×10^{-2}	23.8	21.1	55.1
Layer 2	450	1.3	$3.8\times10^{+5}$	15.8	28.2	56.0
Composite		3.0	$6.6\times10^{+3}$	25.0	25.5	49.5

	Substr. Temp. (deg. C)	Thick-ness (microns)	Resis-tivity (ohm-cm)	% Cu	EDAX Compos. % In	% Se
			Substrate #31600			
			Evaporation Date 7/25/85			
Layer 1	300	2.0	$5.4x10^{-2}$	30.5	21.7	47.8
Layer 2	450	1.3	$4.0x10^{+5}$	15.8	28.6	55.5
Composite		3.6	$3.5x10^{+3}$	25.5	25.4	49.1
			Substrate #31601			
			Evaporation Date 7/29/85			
Layer 1	300	2.0	$5.8x10^{-2}$	30.9	21.7	47.4
Layer 2	450	1.5	$6.0x10^{+5}$	15.9	28.4	55.6
Composite		3.6	$5.8x10^{+3}$	24.7	26.1	49.2
			Substrate #31602			
			Evaporation Date 7/30/85			
Layer 1	300	2.0	$6.2x10^{-2}$	29.9	21.4	49.6
Layer 2	450	1.3	$5.2x10^{+5}$	15.5	28.0	56.5
Composite		3.5	$6.0x10^{+3}$	25.0	25.7	49.2
			Substrate #31603			
			Evaporation Date 7/31/85			
Layer 1	300	1.9	$6.5x10^{-2}$	30.3	21.5	48.1
Layer 2	450	1.3	$5.5x10^{+5}$	16.9	28.0	55.1
Composite		3.4	$6.5x10^{+3}$	24.6	26.2	49.2

	Substr. Temp. (deg. C)	Thick- ness (microns)	Resis- tivity (ohm-cm)	% Cu	EDAX Compos. % In	% Se
			Substrate #31604			
			Evaporation Date 8/ 1/85			
Layer 1	300	2.0	$6.0x10^{-2}$	29.5	22.3	48.2
Layer 2	450	1.3	$5.3x10^{+5}$	15.2	28.3	56.5
Composite		3.6	$2.4x10^{+4}$	24.5	25.8	49.6
			Substrate #31605			
			Evaporation Date 8/ 2/85			
Layer 1	300	2.0	$5.2x10^{-2}$	19.3	21.5	59.1
Layer 2	450	1.4	$5.0x10^{+5}$	16.1	28.3	55.6
Composite		3.6	$1.2x10^{+4}$	23.0	25.6	51.4
			Substrate #31606			
			Evaporation Date 8/ 7/85			
Layer 1	300	1.8	$8.6x10^{-2}$	29.7	22.1	48.2
Layer 2	450	1.2	$5.5x10^{+5}$	15.9	28.4	55.7
Composite		3.4	$1.7x10^{+4}$	22.2	25.9	51.9
			Substrate #31607			
			Evaporation Date 8/ 8/85			
Layer 1	300	1.8	$6.5x10^{-2}$	27.5	23.3	49.2
Layer 2	450	1.3	$5.2x10^{+5}$	16.9	28.2	54.9
Composite		3.3	$1.8x10^{+4}$	20.5	26.7	52.7

	Substr. Temp. (deg. C)	Thick-ness (microns)	Resis-tivity (ohm-cm)	% Cu	EDAX Compos. % In	% Se
			Substrate #31608			
			Evaporation Date 8/ 9/85			
Layer 1	300	1.9	$5.7x10^{-2}$	14.8	21.1	64.1
Layer 2	450	1.4	$4.8x10^{+5}$	15.5	28.1	56.3
Composite		3.3	$1.6x10^{+4}$	21.6	26.2	52.2
			Substrate #31609			
			Evaporation Date 8/12/85			
Layer 1	300	2.0	$6.6x10^{-2}$	18.0	21.3	60.7
Layer 2	450	1.4	$6.3x10^{+5}$	16.4	28.0	55.5
Composite		3.6	$1.4x10^{+4}$	22.0	25.7	52.3
			Substrate #31610			
			Evaporation Date 8/14/85			
Layer 1	300	2.1	$5.9x10^{-2}$	18.2	20.0	61.8
Layer 2	450	1.5	$6.3x10^{+5}$	16.4	27.2	56.4
Composite		3.5	$2.2x10^{+3}$	22.9	25.5	51.5
			Substrate #31611			
			Evaporation Date 8/21/85			
Layer 1	300	2.0	$4.6x10^{-2}$	14.3	19.7	66.0
Layer 2	450	1.3	$9.4x10^{+4}$	18.4	26.9	54.7
Composite		3.2		26.6	24.7	48.7

	Substr. Temp. (deg. C)	Thick-ness (microns)	Resis-tivity (ohm-cm)	% Cu	EDAX Compos. % In	% Se
Substrate #31612						
Evaporation Date 8/27/85						
Layer 1	300	1.7	$1.2x10^{-2}$	40.7	16.3	43.0
Layer 2	450	1.2	$4.2x10^{+5}$	20.1	26.5	53.4
Composite		3.0		30.0	22.8	47.2
Substrate #31613						
Evaporation Date 8/29/85						
Layer 1	300	2.0	$1.7x10^{-2}$	37.1	19.2	43.7
Layer 2	450	1.3	$7.9x10^{+4}$	20.1	25.4	54.5
Composite		3.2		32.5	22.3	45.1
Substrate #31614						
Evaporation Date 9/ 3/85						
Layer 1	300	1.7	$2.6x10^{-2}$	38.0	18.4	43.6
Layer 2	450	1.2	$1.6x10^{+5}$	20.1	26.3	53.6
Composite		2.6		29.1	22.9	48.0
Substrate #31615						
Evaporation Date 9/ 5/85						
Layer 1	300	1.9	$4.0x10^{-2}$	46.7	19.6	43.7
Layer 2	450	1.4	$3.5x10^{+5}$	18.3	27.6	54.7
Composite		3.0		28.2	24.5	47.3

	Substr. Temp. (deg. C)	Thick-ness (microns)	Resis-tivity (ohm-cm)	% Cu	EDAX Compos. % In	% Se
Substrate #31616						
Evaporation Date 9/ 6/85						
Layer 1	300	1.9	$4.6x10^{-2}$	32.6	20.6	46.8
Layer 2	450	1.5	$6.8x10^{+5}$	16.3	28.3	55.4
Composite		3.2	$1.4x10^{+3}$	25.0	25.1	49.9
Substrate #31617						
Evaporation Date 9/11/85						
Layer 1	300	2.0	$4.8x10^{-2}$	31.2	21.5	47.3
Layer 2	450	1.5	$6.5x10^{+5}$	16.3	28.7	55.0
Composite		3.5	$3.9x10^{+3}$	24.5	25.8	49.7
Substrate #31618						
Evaporation Date 9/12/85						
Layer 1	300	1.9	$4.9x10^{-2}$	28.7	22.6	48.7
Layer 2	450	1.4	$5.9x10^{+5}$	14.7	29.0	56.3
Composite		3.2	$1.0x10^{+4}$	23.5	26.1	50.4
Substrate #31619						
Evaporation Date 9/13/85						
Layer 1	300	1.9	$7.0x10^{-2}$	25.9	23.4	50.7
Layer 2	450	1.4	$5.2x10^{+5}$	15.7	29.0	55.3
Composite		3.0	$3.9x10^{+3}$	20.9	26.6	52.5

APPENDIX B

CdS Evaporation Data

on

$CuInSe_2$/CdS Devices

made from

Evaporator III $CuInSe_2$

EV I & II

CdS Evap. Data

Evap.3 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
1580.11	22080.11	7/11/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1580.22	22077.23	6/28/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1580.23	11072.11	6/20/85	200	1000	980	0.95	1.9	$5.3x10^{-3}$
1581.11	11072.32	6/20/85	200	1000	980	0.95	1.9	$5.3x10^{-3}$
1582.21	11073.11	6/21/85	200	1000	980	0.90	1.8	$6.8x10^{-3}$
1583.21	22077.32	6/28/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1583.22	11073.33	6/21/85	200	1000	980	0.90	1.8	$6.8x10^{-3}$
1584.22	11075.32	6/27/85	200	1000	980	0.90	1.8	$5.0x10^{-3}$
1585.11	11075.12	6/27/85	200	1000	980	0.90	1.8	$5.0x10^{-3}$
1586.11	22080.12	7/11/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1586.21	11082.21	7/22/85	200	1000	980	0.90	1.8	$5.4x10^{-3}$
1587.21	22080.21	7/11/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$

Evap.3 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
1587.22	11082.32	7/22/85	200	1000	980	0.90	1.8	$5.4x10^{-3}$
1588.22	22080.23	7/11/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1588.23	11082.23	7/22/85	200	1000	980	0.90	1.8	$5.4x10^{-3}$
1589.21	11083.32	7/23/85	200	1000	980	0.80	1.6	$4.6x10^{-3}$
1589.23	22080.32	7/11/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1590.11	22081.11	7/18/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1591.21	22081.21	7/18/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1592.23	22081.32	7/18/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1593.33	22081.12	7/18/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1594.22	22081.23	7/18/85	200	970/1190	1000	0.65	1.3	$1.3x10^{-3}$
1595.11	11084.11	7/25/85	200	1000	980	0.95	1.9	$3.6x10^{-3}$
1596.21	11084.12	7/25/85	200	1000	980	0.95	1.9	$3.6x10^{-3}$
1597.22	11084.32	7/25/85	200	1000	980	0.95	1.9	$3.6x10^{-3}$

Evap.3 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
1598.11	11086.33	7/29/85	200	1000	980	1.00	2.0	3.8×10^{-3}
1599.21	11086.32	7/29/85	200	1000	980	1.00	2.0	3.8×10^{-3}
1600.22	11086.22	7/29/85	200	1000	980	1.00	2.0	3.8×10^{-3}
1601.11	11087.12	7/30/85	200	1000	980	0.90	1.8	4.1×10^{-3}
1601.231	11095.32	8/12/85	200	1000	980	0.90	1.8	4.1×10^{-3}
1602.21	11088.12	7/31/85	200	1000	980	1.00	2.0	4.0×10^{-3}
1602.231	11095.32	8/12/85	200	1000	980	0.90	1.8	4.1×10^{-3}
1603.22	11089.23	8/1/85	200	1000	980	0.95	1.9	3.6×10^{-3}
1603.231	11096.23	8/13/85	200	1000	980	0.95	1.9	4.2×10^{-3}
1604.11	11090.12	8/5/85	200	1000	980	0.95	1.9	3.4×10^{-3}
1604.231	11096.21	8/13/85	200	1000	980	0.95	1.9	4.2×10^{-3}
1605.21	11091.12	8/6/85	200	1000	980	0.95	1.9	3.6×10^{-3}
1605.231	11097.11	8/14/85	200	1000	980	0.75	1.5	4.5×10^{-3}

Evap.3 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
1606.22	11093.12	8/8/85	200	1000	980	0.95	1.9	$3.8x10^{-3}$
1606.231	11097.11	8/14/85	200	1000	980	0.75	1.5	$4.5x10^{-3}$
1607.11	11094.11	8/9/85	200	1000	980	0.95	1.9	$4.6x10^{-3}$
1608.21	11096.32	8/13/85	200	1000	980	0.95	1.9	$4.2x10^{-3}$
1608.231	11100.21	8/20/86	200	1000	980	0.90	1.8	$4.7x10^{-3}$
1609.22	11097.21	8/14/85	200	1000	980	0.75	1.5	$4.5x10^{-3}$
1616.21	11114.32	9/12/85	200	1000	980	1.00	2.0	$6.6x10^{-3}$
1617.22	11115.12	9/13/85	200	1000	980	0.95	1.9	$6.3x10^{-3}$
1618.23	11115.32	9/13/85	200	1000	980	0.95	1.9	$6.3x10^{-3}$
1619.21	11117.12	9/17/85	200	1000	980	0.90	1.8	$5.8x10^{-3}$

APPENDIX C

Contact Information

and

Substrate Type

for

EV III $CuInSe_2$/CdS Devices

EV III $CuInSe_2$/CdS Substrate & Contact Data

Piece #	Substrate Type	$CuInSe_2$ Contact	CdS Contact	Metal Tab
31580.11	7059 Glass	Mo	ITO	Ni
31580.22	7059 Glass	Mo	ITO	Ni
31580.23	7059 Glass	Mo	ITO	Ni
31581.11	7059 Glass	Mo	ITO	Ni
31582.21	7059 Glass	Mo	ITO	Ni
31583.21	7059 Glass	Mo	ITO	Ni
31583.22	7059 Glass	Mo	ITO	Ni
31584.22	7059 Glass	Mo	ITO	Ni
31585.11	7059 Glass	Mo	ITO	Ni
31586.11	7059 Glass	Mo	ITO	Ni
31586.21	7059 Glass	Mo	ITO	Ni
31587.21	7059 Glass	Mo	ITO	Ni
31587.22	7059 Glass	Mo	ITO	Ni
31588.22	7059 Glass	Mo	ITO	Ni
31588.23	7059 Glass	Mo	ITO	Ni
31589.21	7059 Glass	Mo	ITO	Ni
31589.23	7059 Glass	Mo	ITO	Ni
31590.11	7059 Glass	Mo	ITO	Ni
31591.21	7059 Glass	Mo	ITO	Ni
31592.23	7059 Glass	Mo	ITO	Ni
31593.33	7059 Glass	Mo	ITO	Ni
31594.22	7059 Glass	Mo	ITO	Ni
31595.11	7059 Glass	Mo	ITO	Ni
31596.21	7059 Glass	Mo	ITO	Ni
31597.22	7059 Glass	Mo	ITO	Ni
31598.11	7059 Glass	Mo	ITO	Ni

Piece #	Substrate Type	$CuInSe_2$ Contact	CdS Contact	Metal Tab
31599.21	7059 Glass	Mo	ITO	Ni
31600.22	7059 Glass	Mo	ITO	Ni
31601.11	7059 Glass	Mo	ITO	Ni
31601.231	7059 Glass	Mo	ITO	Ni
31602.21	7059 Glass	Mo	ITO	Ni
31602.231	7059 Glass	Mo	ITO	Ni
31603.22	7059 Glass	Mo	ITO	Ni
31603.231	7059 Glass	Mo	ITO	Ni
31604.11	7059 Glass	Mo	ITO	Ni
31604.231	7059 Glass	Mo	ITO	Ni
31605.21	7059 Glass	Mo	ITO	Ni
31605.231	7059 Glass	Mo	ITO	Ni
31606.22	7059 Glass	Mo	ITO	Ni
31606.231	7059 Glass	Mo	ITO	Ni
31607.11	7059 Glass	Mo	ITO	Ni
31608.21	7059 Glass	Mo	ITO	Ni
31608.231	7059 Glass	Mo	ITO	Ni
31609.22	7059 Glass	Mo	ITO	Ni
31616.21	7059 Glass	Mo	ITO	Ni
31617.22	7059 Glass	Mo	ITO	Ni
31618.23	7059 Glass	Mo	ITO	Ni
31619.21	7059 Glass	Mo	ITO	Ni

APPENDIX D

Cell Statistics

on

$CuInSe_2/CdS$ Devices

made from

Evaporator III $CuInSe_2$

EV III $CuInSe_2/CdS$ — Cell Statistics

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)

Piece # 31580.11
12 Cells 3 I-V tests
Last tested 7/17/85

Max.	.407	34.87	55.22	8.93
Min.	.370	32.66	43.13	6.20
Mean	.383	33.79	46.87	6.93
Std.Dev.	.011	0.74	3.56	0.87

Piece # 31580.22
12 Cells 6 I-V tests
Last tested 10/14/85

Max.	.428	37.84	63.94	11.20
Min.	.415	35.65	59.02	10.11
Mean	.424	36.96	62.16	10.73
Std.Dev.	.005	0.70	1.47	0.32

Piece # 31580.23
12 Cells 2 I-V tests
Last tested 6/24/85

Max.	.385	30.13	61.30	8.10
Min.	.265	29.50	32.86	2.94
Mean	.355	29.85	55.00	6.76
Std.Dev.	.032	0.25	7.49	1.37

Piece # 31581.11
12 Cells 2 I-V tests
Last tested 6/24/85

Max.	.362	30.90	60.02	7.60
Min.	.336	29.66	54.33	6.23
Mean	.352	30.01	57.76	6.98
Std.Dev.	.007	0.36	1.90	0.41

Piece # 31582.21
12 Cells 3 I-V tests
Last tested 6/27/85

Max.	.379	29.82	54.15	6.73
Min.	.352	28.23	51.85	5.81
Mean	.368	29.06	53.29	6.35
Std.Dev.	.009	0.45	0.71	0.27

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)

Piece # 31583.21
12 Cells 4 I-V tests
Last tested 7/ 8/85

Max.	.430	36.27	61.85	10.31
Min.	.412	33.21	55.28	8.87
Mean	.423	34.53	59.53	9.78
Std.Dev.	.006	0.89	1.99	0.45

Piece # 31583.22
12 Cells 3 I-V tests
Last tested 6/27/85

Max.	.409	30.17	68.11	9.39
Min.	.380	28.81	62.00	8.25
Mean	.400	29.62	65.92	8.89
Std.Dev.	.009	0.46	1.89	0.40

Piece # 31584.22
12 Cells 3 I-V tests
Last tested 7/ 5/85

Max.	.343	34.44	57.91	6.59
Min.	.219	28.47	38.09	3.78
Mean	.284	32.36	49.34	5.12
Std.Dev.	.034	2.09	6.16	1.01

Piece # 31585.11
12 Cells 3 I-V tests
Last tested 7/ 5/85

Max.	.381	33.46	61.64	8.61
Min.	.365	30.33	56.71	7.05
Mean	.376	32.47	60.10	8.12
Std.Dev.	.004	0.87	1.34	0.40

Piece # 31586.11
12 Cells 4 I-V tests
Last tested 7/17/85

Max.	.390	35.72	57.57	9.17
Min.	.182	15.81	26.92	0.88
Mean	.316	31.03	38.73	4.71
Std.Dev.	.072	5.70	10.80	2.72

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
	Piece # 31586.21 12 Cells 4 I-V tests Last tested 7/30/85			
Max.	.392	33.99	63.55	9.39
Min.	.220	30.98	34.51	2.67
Mean	.368	33.34	58.48	8.22
Std.Dev.	.047	0.82	8.20	1.86
	Piece # 31587.21 12 Cells 4 I-V tests Last tested 7/18/85			
Max.	.409	36.52	63.47	9.98
Min.	.358	33.04	53.19	7.91
Mean	.394	34.90	60.71	9.50
Std.Dev.	.014	1.02	3.18	0.63
	Piece # 31587.22 12 Cells 4 I-V tests Last tested 7/30/85			
Max.	.373	34.68	61.51	8.91
Min.	.145	26.71	31.09	1.28
Mean	.256	30.85	42.88	4.26
Std.Dev.	.082	3.50	12.73	2.95
	Piece # 31588.22 12 Cells 5 I-V tests Last tested 7/18/85			
Max.	.406	36.25	64.15	10.12
Min.	.209	31.04	32.22	2.01
Mean	.351	34.46	54.24	7.78
Std.Dev.	.074	1.83	13.12	3.31
	Piece # 31588.23 12 Cells 4 I-V tests Last tested 7/30/85			
Max.	.397	34.33	64.43	9.72
Min.	.379	32.13	59.27	8.25
Mean	.389	33.68	62.50	9.11
Std.Dev.	.005	0.58	1.64	0.49

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)

Piece # 31589.21
12 Cells 3 I-V tests
Last tested 7/30/85

Max.	.300	32.57	56.22	5.56
Min.	.154	25.02	34.07	1.73
Mean	.242	30.18	43.85	3.76
Std.Dev.	.041	2.12	8.16	1.33

Piece # 31589.23
12 Cells 3 I-V tests
Last tested 7/17/85

Max.	.333	35.63	57.14	6.64
Min.	.171	25.00	37.00	2.59
Mean	.278	32.93	47.15	4.92
Std.Dev.	.053	2.83	8.66	1.52

Piece # 31590.11
12 Cells 2 I-V tests
Last tested 7/23/85

Max.	.349	32.72	32.41	4.23
Min.	.252	24.12		1.69
Mean	.296	28.28	27.87	2.71
Std.Dev.	.028	2.46	2.38	0.71

Piece # 31591.21
12 Cells 2 I-V tests
Last tested 7/23/85

Max.	.378	32.91	38.70	5.40
Min.	.344	30.16	25.89	3.05
Mean	.361	31.55	33.54	4.38
Std.Dev.	.010	0.74	3.68	0.67

Piece # 31592.23
12 Cells 2 I-V tests
Last tested 7/23/85

Max.	.336	30.51	28.26	3.25
Min.	.249	15.97		1.13
Mean	.294	23.29	25.67	2.01
Std.Dev.	.024	4.84	1.02	0.63

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
	Piece # 31593.33 12 Cells 2 I-V tests Last tested 7/23/85			
Max.	.266	34.43	38.57	3.87
Min.	.203	29.98	26.98	2.12
Mean	.232	33.44	34.46	3.04
Std.Dev.	.016	1.18	3.31	0.48
	Piece # 31594.22 12 Cells 3 I-V tests Last tested 7/24/85			
Max.	.320	34.81	48.98	5.73
Min.	.051	10.52	25.33	0.16
Mean	.193	20.07	32.33	2.05
Std.Dev.	.104	9.41	9.60	2.23
	Piece # 31595.11 12 Cells 3 I-V tests Last tested 7/31/85			
Max.	.384	30.70	63.78	8.23
Min.	.360	28.47	55.08	6.31
Mean	.376	29.62	59.75	7.42
Std.Dev.	.008	0.68	3.04	0.70
	Piece # 31596.21 12 Cells 3 I-V tests Last tested 7/31/85			
Max.	.388	31.53	63.07	8.32
Min.	.160	24.10	31.22	1.58
Mean	.282	29.41	46.97	4.68
Std.Dev.	.087	1.95	10.81	2.39
	Piece # 31597.22 12 Cells 3 I-V tests Last tested 7/31/85			
Max.	.398	32.23	65.67	9.29
Min.	.323	30.15	46.74	5.25
Mean	.371	31.38	57.68	7.63
Std.Dev.	.025	0.63	6.86	1.41

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 31598.11 — 12 Cells, 4 I-V tests, Last tested 8/ 6/85				
Max.	.394	34.48	63.40	9.64
Min.	.281	29.88	33.43	2.99
Mean	.375	32.86	59.01	8.29
Std.Dev.	.029	1.30	8.16	1.71
Piece # 31599.21 — 12 Cells, 3 I-V tests, Last tested 8/ 5/85				
Max.	.390	33.84	64.80	9.35
Min.	.228	31.93	34.48	2.99
Mean	.361	32.94	57.12	7.71
Std.Dev.	.046	0.65	9.99	2.00
Piece # 31600.22 — 12 Cells, 4 I-V tests, Last tested 8/ 6/85				
Max.	.374	34.26	60.64	8.73
Min.	.167	30.60	41.59	2.74
Mean	.259	32.50	49.08	4.84
Std.Dev.	.074	0.91	6.06	1.99
Piece # 31601.11 — 12 Cells, 3 I-V tests, Last tested 8/ 6/85				
Max.	.376	32.39	62.16	8.37
Min.	.369	30.01	53.70	6.53
Mean	.372	31.19	59.12	7.60
Std.Dev.	.002	0.77	2.94	0.62
Piece # 31601.231 — 4 Cells, 3 I-V tests, Last tested 8/16/85				
Max.	.405	35.39	65.02	10.12
Min.	.392	33.12	62.78	9.67
Mean	.401	34.03	64.16	9.84
Std.Dev.	.005	1.01	1.00	0.20

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 31602.21 — 12 Cells, 3 I-V tests — Last tested 8/ 6/85				
Max.	.386	33.28	61.15	8.72
Min.	.325	31.89	54.37	6.70
Mean	.369	32.71	57.41	7.83
Std.Dev.	.016	0.45	2.12	0.58
Piece # 31602.231 — 4 Cells, 3 I-V tests — Last tested 8/16/85				
Max.	.385	34.70	57.73	8.42
Min.	.348	33.09	50.27	6.94
Mean	.368	33.80	55.02	7.78
Std.Dev.	.016	0.75	3.42	0.63
Piece # 31603.22 — 12 Cells, 4 I-V tests — Last tested 8/ 9/85				
Max.	.383	34.80	62.81	8.91
Min.	.248	30.45	37.80	3.26
Mean	.332	33.18	53.24	6.67
Std.Dev.	.054	1.40	10.63	2.38
Piece # 31603.231 — 4 Cells, 3 I-V tests — Last tested 8/21/85				
Max.	.405	33.46	65.40	9.80
Min.	.386	31.75	62.30	8.53
Mean	.397	32.53	63.88	9.19
Std.Dev.	.008	0.78	1.70	0.61
Piece # 31604.11 — 12 Cells, 3 I-V tests — Last tested 8/ 9/85				
Max.	.374	32.61	61.99	8.45
Min.	.356	30.70	58.59	7.35
Mean	.363	31.60	59.80	7.75
Std.Dev.	.005	0.59	0.99	0.33

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 31604.231 — 4 Cells, 3 I-V tests — Last tested 8/21/85				
Max.	.399	33.13	66.09	9.55
Min.	.389	31.25	64.25	8.79
Mean	.394	32.17	65.57	9.27
Std.Dev.	.004	0.78	0.88	0.34
Piece # 31605.21 — 12 Cells, 4 I-V tests — Last tested 8/13/85				
Max.	.389	33.23	64.96	9.27
Min.	.373	32.15	61.64	8.32
Mean	.383	32.72	63.64	8.84
Std.Dev.	.005	0.36	1.16	0.32
Piece # 31605.231 — 4 Cells, 3 I-V tests — Last tested 8/20/85				
Max.	.382	34.95	62.59	9.32
Min.	.336	33.69	47.39	6.19
Mean	.369	34.34	58.40	8.44
Std.Dev.	.021	0.52	7.35	1.51
Piece # 31606.22 — 12 Cells, 3 I-V tests — Last tested 8/14/85				
Max.	.380	31.84	61.81	8.26
Min.	.373	30.46	59.92	7.80
Mean	.377	31.38	60.75	8.10
Std.Dev.	.002	0.39	0.48	0.13
Piece # 31606.231 — 4 Cells, 2 I-V tests — Last tested 8/20/85				
Max.	.368	33.75	58.33	8.08
Min.	.271	31.95	30.50	3.20
Mean	.329	33.02	43.57	5.51
Std.Dev.	.041	0.77	11.59	2.02

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
	Piece # 31607.11 12 Cells 4 I-V tests Last tested 8/16/85			
Max.	.327	30.93	53.61	5.85
Min.		4.52		
Mean	.249	27.08	43.89	4.10
Std.Dev.	.118	8.14	11.71	2.31
	Piece # 31607.231 4 Cells 6 I-V tests Last tested 9/25/85			
Max.	.364	32.92	58.93	7.88
Min.	.354	31.52	57.74	7.34
Mean	.359	32.16	58.41	7.62
Std.Dev.	.004	0.72	0.50	0.25
	Piece # 31608.21 12 Cells 3 I-V tests Last tested 8/21/85			
Max.	.357	30.76	61.34	7.50
Min.		12.30		
Mean	.232	26.29	43.84	4.19
Std.Dev.	.154	6.31	15.60	3.20
	Piece # 31608.231 4 Cells 4 I-V tests Last tested 9/ 4/85			
Max.	.344	33.45	55.06	7.21
Min.	.248	30.63	32.73	2.85
Mean	.315	31.91	47.79	5.66
Std.Dev.	.044	1.30	10.32	1.96
	Piece # 31609.22 12 Cells 3 I-V tests Last tested 8/20/85			
Max.	.389	34.24	64.05	9.56
Min.	.340	33.25	39.17	5.16
Mean	.382	33.85	61.18	9.03
Std.Dev.	.013	0.30	6.96	1.23

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 31610.23 12 Cells 3 I-V tests Last tested 11/20/85				
Max.	.349	28.25	45.66	4.86
Min.	.308	20.19	36.65	2.43
Mean	.336	23.77	43.20	3.87
Std.Dev.	.011	2.53	2.44	0.66
Piece # 31616.21 12 Cells 4 I-V tests Last tested 9/18/85				
Max.	.394	30.39	65.59	8.51
Min.	.177	23.98	30.91	1.51
Mean	.342	29.28	55.08	6.53
Std.Dev.	.062	1.70	11.12	2.19
Piece # 31617.22 12 Cells 3 I-V tests Last tested 9/19/85				
Max.	.400	30.96	65.46	8.60
Min.	.331	30.05	37.85	3.84
Mean	.383	30.50	57.29	7.23
Std.Dev.	.019	0.28	8.42	1.45
Piece # 31618.23 12 Cells 3 I-V tests Last tested 9/19/85				
Max.	.373	30.14	56.75	6.75
Min.		16.75		
Mean	.226	27.40	38.13	3.29
Std.Dev.	.147	3.95	13.36	2.68
Piece # 31619.21 12 Cells 3 I-V tests Last tested 9/23/85				
Max.	.369	28.93	60.96	7.22
Min.	.354	27.39	53.09	5.75
Mean	.363	28.20	57.97	6.65
Std.Dev.	.004	0.46	2.59	0.48

APPENDIX E

CdTe

Physical Vapor Deposition

Data

Substr. #	Evap. Date	Substr. Temp. (deg.C)	Nozzle Temp. (deg.C)	Source Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Dopant
40410	6/17/85	160	740	730	.021	1.7	Hg
40411	6/18/85	160	741	730	.022	1.8	Hg
40412	6/19/85	160	741	730	.020	1.6	Hg
40414	6/24/85	160	740	730	.020	1.7	Hg
40415	6/25/85	170	740	730	.022	2.0	Hg
40416	6/26/85	170	741	730	.020	1.7	Hg
40417	6/27/85	180	740	730	.020	1.7	Hg
40418	7/10/85	160	741	731	.029	2.0	
40419	7/11/85	160	741	731	.032	1.9	
40420	7/11/85	160	741	731	.032	1.9	
40421	7/15/85	160	741	731	.030	1.8	Hg
40422	7/16/85	160	741	730	.024	1.8	Hg
40423	7/17/86	180	741	731	.023	1.8	Hg
40424	7/18/85	180	741	731	.025	1.7	Hg
40425	7/22/85	180	741	731	.023	1.6	Hg
40426	7/23/85	181	741	731	.024	1.6	Hg
40427	7/24/85	161	741	731	.023	1.6	Hg
40428	7/25/85	161	741	731	.024	1.7	Hg
40429	7/30/85	161	741	731	.022	1.6	Hg
40430	7/31/85	161	741	731	.021	1.6	Hg
40431	7/29/85	161	741	731	.025	1.7	Hg
40432	8/1/85	200	741	731	.021	1.6	Hg
40433	8/2/85	220	741	731	.017	1.3	Hg
40434	8/5/85	180	741	731	.021	1.6	Hg
40435	8/5/85	180	741	731	.019	1.9	Hg

Substr. #	Evap. Date	Substr. Temp. (deg.C)	Nozzle Temp. (deg.C)	Source Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Dopant
40436	8/8/85	180	741	731	.019	3.6	Hg
40437	8/9/85	180	741	731	.019	1.9	Hg
40438	8/12/85	180	741	731	.019	1.9	Hg
40439	8/13/85	180	751	741	.023	3.0	Hg
40440	8/14/85	180	751	741	.022	2.9	Hg
40441	8/15/85	180	751	741	.023	3.0	Hg
40442	8/16/85	180	751	741	.023	3.0	Hg
40443	8/19/85	180	751	741	.023	3.0	Hg
40444	8/20/85	180	751	741	.022	2.8	Hg
40445	8/21/85	180	751	741	.023	3.0	Hg
40446	8/22/85	180	751	741	.022	2.9	Hg
40447	8/23/85	180	751	741	.022	2.8	Hg
40448	8/25/85	180	751	741	.022	2.9	Hg
40449	8/26/85	180	751	741	.021	2.7	Hg
40450	8/27/85	180	751	741	.022	2.8	Hg
40451	8/28/85	180	751	741	.022	2.8	Hg
40452	9/3/85	180	751	741	.021	2.7	Hg
40453	9/4/85	180	756	746	.024	3.1	Hg
40454	9/5/85	180	765	746	.024	3.1	Hg
40455	9/6/85	180	756	746	.024	3.1	Hg

APPENDIX F

CdS Evaporation Data

on

CdTe/CdS Devices

made from

Physical Vapor Deposition

CdTe

EV I & II Evap.4 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	CdS Evap. Data Thick-ness (u)	Resis-tivity (ohm-cm)
410.32	11076.12	6/28/85	200	1000	980	0.85	1.7	$6.6x10^{-3}$
411.21	11073.12	6/21/85	200	1000	980	0.90	1.8	$6.8x10^{-3}$
412.21	11072.23	6/20/85	200	1000	980	0.95	1.9	$5.3x10^{-3}$
414.22	11075.11	6/27/85	200	1000	980	0.90	1.8	$5.0x10^{-3}$
415.21	11075.21	6/27/85	200	1000	980	0.90	1.8	$5.0x10^{-3}$
415.32	11076.32	6/28/85	200	1000	980	0.85	1.7	$6.6x10^{-3}$
416.11	11075.33	6/27/85	200	1000	980	0.90	1.8	$5.0x10^{-3}$
416.23	11076.33	6/28/85	200	1000	980	0.85	1.7	$6.6x10^{-3}$
417.23	11078.32	7/9/85	200	1000	980	0.90	1.8	$5.8x10^{-3}$
418.31	11079.32	7/15/85	200	1000	980	0.90	1.8	$5.9x10^{-3}$
419.31	11079.23	7/15/85	200	1000	980	0.90	1.8	$5.9x10^{-3}$
420.31	11081.11	7/17/85	200	1000	980	0.85	1.7	$5.9x10^{-3}$

Evap. 4 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg. C)	CdS/ZnS Temp. (deg. C)	In Temp. (deg. C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
421.23	11081.12	7/17/85	200	1000	980	0.85	1.7	$5.9x10^{-3}$
421.31	11081.32	7/17/85	200	1000	980	0.85	1.7	$5.9x10^{-3}$
422.11	11082.12	7/22/85	200	1000	980	0.90	1.8	$5.4x10^{-3}$
422.21	11082.11	7/22/85	200	1000	980	0.90	1.8	$5.4x10^{-3}$
423.21	11083.21	7/23/85	200	1000	980	0.80	1.6	$4.6x10^{-3}$
423.23	11083.23	7/23/85	200	1000	980	0.80	1.6	$4.6x10^{-3}$
424.11	11083.11	7/23/85	200	1000	980	0.80	1.6	$4.6x10^{-3}$
424.12	11083.12	7/23/85	200	1000	980	0.80	1.6	$4.6x10^{-3}$
425.23	11084.21	7/25/85	200	1000	980	0.95	1.9	$3.6x10^{-3}$
425.31	11084.23	7/25/85	200	1000	980	0.95	1.9	$3.6x10^{-3}$
426.23	11087.21	7/30/85	200	1000	980	0.90	1.8	$4.1x10^{-3}$
426.31	11087.11	7/30/85	200	1000	980	0.90	1.8	$4.1x10^{-3}$
427.21	11086.21	7/29/85	200	1000	980	1.00	2.0	$3.8x10^{-3}$

Evap.# Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
427.23	11086.23	7/29/85	200	1000	980	1.00	2.0	$3.8x10^{-3}$
428.11	11087.23	7/30/85	200	1000	980	0.90	1.8	$4.1x10^{-3}$
428.12	11087.32	7/30/85	200	1000	980	0.90	1.8	$4.1x10^{-3}$
429.11	11090.23	8/5/85	200	1000	980	0.95	1.9	$3.4x10^{-3}$
429.12	11089.32	8/1/85	200	1000	980	0.95	1.9	$3.6x10^{-3}$
429.21	11089.12	8/1/85	200	1000	980	0.95	1.9	$3.6x10^{-3}$
430.12	11094.12	8/9/85	200	1000	980	0.95	1.9	$4.6x10^{-3}$
430.211	11090.21	8/5/85	200	1000	980	0.95	1.9	$3.4x10^{-3}$
430.212	11090.21	8/5/85	200	1000	980	0.95	1.9	$3.4x10^{-3}$
431.21	11088.21	7/31/85	200	1000	980	1.00	2.0	$4.0x10^{-3}$
431.32	11088.32	7/31/85	200	1000	980	1.00	2.0	$4.0x10^{-3}$
432.11	11091.23	8/6/85	200	1000	980	0.95	1.9	$3.6x10^{-3}$
432.123	11091.21	8/6/85	200	1000	980	0.95	1.9	$3.6x10^{-3}$

Evap. 4 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg. C)	CdS/ZnS Temp. (deg. C)	In Temp. (deg. C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
432.213	11091.21	8/6/85	200	1000	980	0.95	1.9	3.6×10^{-3}
432.31	11091.32	8/6/85	200	1000	980	0.95	1.9	3.6×10^{-3}
433.11	11092.32	8/7/85	200	1000	980	0.95	1.9	3.4×10^{-3}
433.121	11092.23	8/7/85	200	1000	980	0.95	1.9	3.4×10^{-3}
433.31	11092.12	8/7/85	200	1000	980	0.95	1.9	3.4×10^{-3}
434.111	11093.23	8/8/85	200	1000	980	0.95	1.9	3.8×10^{-3}
434.121	11093.23	8/8/85	200	1000	980	0.95	1.9	3.8×10^{-3}
434.21	11093.32	8/8/85	200	1000	980	0.95	1.9	3.8×10^{-3}
434.32	11093.21	8/8/85	200	1000	980	0.95	1.9	3.8×10^{-3}
435.113	11094.32	8/9/85	200	1000	980	0.95	1.9	4.6×10^{-3}
435.121	11094.32	8/9/85	200	1000	980	0.95	1.9	4.6×10^{-3}
435.21	11094.23	8/9/85	200	1000	980	0.95	1.9	4.6×10^{-3}
436.12	11095.21	8/12/85	200	1000	980	0.90	1.8	4.1×10^{-3}

Evap. 4 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg. C)	CdS/ZnS Temp. (deg. C)	In Temp. (deg. C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
436.321	11102.12	8/22/85	200	1000	980	0.85	1.7	$5.4x10^{-3}$
437.11	11096.11	8/13/85	200	1000	980	0.95	1.9	$4.2x10^{-3}$
437.122	11096.23	8/13/85	200	1000	980	0.95	1.9	$4.2x10^{-3}$
437.211	11096.33	8/13/85	200	1000	980	0.95	1.9	$4.2x10^{-3}$
437.31	11096.12	8/13/85	200	1000	980	0.95	1.9	$4.2x10^{-3}$
438.11	11103.32	8/23/85	200	1000	980	0.90	1.8	$5.0x10^{-3}$
438.12	11124.11	9/26/85	200	1000	980	1.00	2.0	$7.4x10^{-3}$
438.21	11124.32	9/26/85	200	1000	980	1.00	2.0	$7.4x10^{-3}$
438.23	11097.33	8/14/85	200	1000	980	0.75	1.5	$4.5x10^{-3}$
438.31	11097.12	8/14/85	200	1000	980	0.75	1.5	$4.5x10^{-3}$
438.32	11124.33	9/26/85	200	1000	980	1.00	2.0	$7.4x10^{-3}$
439.11	11098.11	8/15/85	200	1000	980	0.90	1.8	$5.2x10^{-3}$
439.21	11098.12	8/15/85	200	1000	980	0.90	1.8	$5.2x10^{-3}$

Evap.4 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
439.22	11124.21	9/26/85	200	1000	980	1.00	2.0	$7.4x10^{-3}$
439.23	11124.12	9/26/85	200	1000	980	1.00	2.0	$7.4x10^{-3}$
439.32	11124.23	9/26/85	200	1000	980	1.00	2.0	$7.4x10^{-3}$
440.31	11099.23	8/16/85	200	1000	980	0.90	1.8	$1.0x10^{-3}$
440.32	11099.21	8/16/85	200	1000	980	0.90	1.8	$1.0x10^{-3}$
441.11	11100.23	8/20/86	200	1000	980	0.90	1.8	$4.7x10^{-3}$
441.21	11100.12	8/20/86	200	1000	980	0.90	1.8	$4.7x10^{-3}$
441.31	11100.11	8/20/86	200	1000	980	0.90	1.8	$4.7x10^{-3}$
442.11	11101.21	8/21/85	200	1000	980	0.95	1.9	$4.8x10^{-3}$
442.12	11101.11	8/21/85	200	1000	980	0.95	1.9	$4.8x10^{-3}$
442.31	11101.23	8/21/85	200	1000	980	0.95	1.9	$4.8x10^{-3}$
443.11	11102.32	8/22/85	200	1000	980	0.85	1.7	$5.4x10^{-3}$
443.23	11102.11	8/22/85	200	1000	980	0.85	1.7	$5.4x10^{-3}$

Evap.4 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
444.23	11102.21	8/22/85	200	1000	980	0.85	1.7	$5.4x10^{-3}$
444.31	11102.23	8/22/85	200	1000	980	0.85	1.7	$5.4x10^{-3}$
445.11	11103.12	8/23/85	200	1000	980	0.90	1.8	$5.0x10^{-3}$
445.31	11103.11	8/23/85	200	1000	980	0.90	1.8	$5.0x10^{-3}$
445.32	11103.33	8/23/85	200	1000	980	0.90	1.8	$5.0x10^{-3}$
446.12	11104.23	8/26/85	200	1000	980	0.85	1.7	$4.3x10^{-3}$
446.21	11104.21	8/26/85	200	1000	980	0.85	1.7	$4.3x10^{-3}$
446.22	11104.32	8/26/85	200	1000	980	0.85	1.7	$4.3x10^{-3}$
446.31	11104.12	8/26/85	200	1000	980	0.85	1.7	$4.3x10^{-3}$
447.12	11105.32	8/27/85	200	1000	980	1.00	2.0	$3.8x10^{-3}$
447.13	11105.21	8/27/85	200	1000	980	1.00	2.0	$3.8x10^{-3}$
447.21	11105.23	8/27/85	200	1000	980	1.00	2.0	$3.8x10^{-3}$
447.23	22097.23	9/11/86	200	970		0.47	2.8	$1.0x10^{-3}$

Evap.4 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
447.31	11105.12	8/27/85	200	1000	980	1.00	2.0	$3.8x10^{-3}$
448.12	11106.12	8/28/85	200	1000	980	0.95	1.9	$4.4x10^{-3}$
448.13	11106.23	8/28/85	200	1000	980	0.95	1.9	$4.4x10^{-3}$
448.21	11106.32	8/28/85	200	1000	980	0.95	1.9	$4.4x10^{-3}$
448.31	11106.21	8/28/85	200	1000	980	0.95	1.9	$4.4x10^{-3}$
449.11	11107.23	8/29/85	200	1000	980	0.90	1.8	$4.0x10^{-3}$
449.12	11107.12	8/29/85	200	1000	980	0.90	1.8	$4.0x10^{-3}$
449.13	11107.11	8/29/85	200	1000	980	0.90	1.8	$4.0x10^{-3}$
449.21	11107.21	8/29/85	200	1000	980	0.90	1.8	$4.0x10^{-3}$
449.31	11107.32	8/29/85	200	1000	980	0.90	1.8	$4.0x10^{-3}$
449.32	11107.33	8/29/85	200	1000	980	0.90	1.8	$4.0x10^{-3}$
450.11	11108.23	9/4/85	200	965	900	0.44	8.4	$5.0x10^{-3}$

Note: Two layer evaporation (no Indium in 1st layer)

Evap.4 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
450.12	11108.33	9/4/85	200	965	900	0.44	8.4	$5.0x10^{-3}$
		Note: Two layer evaporation (no Indium in 1st layer)						
450.13	11108.21	9/4/85	200	965	900	0.44	8.4	$5.0x10^{-3}$
		Note: Two layer evaporation (no Indium in 1st layer)						
450.21	11108.11	9/4/85	200	965	900	0.44	8.4	$5.0x10^{-3}$
		Note: Two layer evaporation (no Indium in 1st layer)						
450.23	11119.23	9/19/85	200	1000	980	0.95	1.9	$8.7x10^{-3}$
450.31	11108.32	9/4/85	200	965	900	0.44	8.4	$5.0x10^{-3}$
		Note: Two layer evaporation (no Indium in 1st layer)						
450.32	11108.12	9/4/85	200	965	900	0.44	8.4	$5.0x10^{-3}$
		Note: Two layer evaporation (no Indium in 1st layer)						
451.11	11109.21	9/5/85	200	965	900	0.45	8.5	$5.9x10^{-3}$
		Note: Two layer evaporation (no Indium in 1st layer)						
451.12	11109.12	9/5/85	200	965	900	0.45	8.5	$5.9x10^{-3}$
		Note: Two layer evaporation (no Indium in 1st layer)						
451.13	11109.11	9/5/85	200	965	900	0.45	8.5	$5.9x10^{-3}$
		Note: Two layer evaporation (no Indium in 1st layer)						

Evap.4 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
451.21	11109.23	9/5/85	200	965	900	0.45	8.5	5.9×10^{-3}
	Note: Two layer evaporation (no Indium in 1st layer)							
451.31	11109.33	9/5/85	200	965	900	0.45	8.5	5.9×10^{-3}
	Note: Two layer evaporation (no Indium in 1st layer)							
451.32	11109.32	9/5/85	200	965	900	0.45	8.5	5.9×10^{-3}
	Note: Two layer evaporation (no Indium in 1st layer)							
452.11	11110.33	9/6/85	200	965		0.64	4.5	
	Note: Two layer evaporation (no Indium in 1st layer)							
452.12	11110.11	9/6/85	200	965		0.64	4.5	
	Note: Two layer evaporation (no Indium in 1st layer)							
452.13	11119.32	9/19/85	200	1000	980	0.95	1.9	8.7×10^{-3}
452.21	11110.32	9/6/85	200	965		0.64	4.5	
	Note: Two layer evaporation (no Indium in 1st layer)							
452.23	11110.12	9/6/85	200	965		0.64	4.5	
	Note: Two layer evaporation (no Indium in 1st layer)							
453.11	11111.32	9/9/85	200	1000		0.98	4.9	1.0×10^{-3}
453.12	11111.11	9/9/85	200	1000		0.98	4.9	1.0×10^{-3}

Evap.4 Piece #	CdS run #	Evap. Date	Substr. Temp. (deg.C)	CdS/ZnS Temp. (deg.C)	In Temp. (deg.C)	Evap. rate (u/min)	Thick-ness (u)	Resis-tivity (ohm-cm)
453.13	11119.33	9/19/85	200	1000	980	0.95	1.9	$8.7x10^{-3}$
453.21	11111.12	9/9/85	200	1000		0.98	4.9	$1.0x10^{-3}$
454.12	11112.21	9/10/85	200	1000		1.00	5.0	$1.0x10^{-3}$
454.13	11112.23	9/10/85	200	1000		1.00	5.0	$1.0x10^{-3}$
454.21	11112.32	9/10/85	200	1000		1.00	5.0	$1.0x10^{-3}$
454.23	11120.23	9/20/85	200	1000	980	0.90	1.8	$6.8x10^{-3}$
454.31	11112.12	9/10/85	200	1000		1.00	5.0	$1.0x10^{-3}$
454.32	22097.32	9/11/86	200	970		0.47	2.8	$1.0x10^{-3}$
455.11	11113.32	9/11/85	200	1000		0.98	4.9	$1.0x10^{-3}$
455.13	11113.12	9/11/85	200	1000		0.98	4.9	$1.0x10^{-3}$
455.21	11120.32	9/20/85	200	1000	980	0.90	1.8	$6.8x10^{-3}$
455.23	11113.21	9/11/85	200	1000		0.98	4.9	$1.0x10^{-3}$
455.32	11113.23	9/11/85	200	1000		0.98	4.9	$1.0x10^{-3}$

APPENDIX G

Contact Information,

Substrate Type

and

Post Deposition Heat Treatment

for

EV IV CdTe/CdS Devices

EV IV CdTe/CdS Substr., Contact & Heat Data

Piece #	Substrate Type	CdTe Contact	Metal Layer Type	Metal Thickness (angstr.)	Heat Treatment (Hrs/deg/atm)
40410.21	7059 Glass	Mo	Cu	20	3.0/300/Air
40410.32	7059 Glass	ITO	Cu	20	3.0/300/Air
40411.21	7059 Glass	Mo	Cu	20	3.0/300/Air
40412.21	7059 Glass	Mo	Cu	20	3.0/300/Air
40414.22	7059 Glass	Mo			3.0/300/Air
40415.21	7059 Glass	Mo	Cu	20	3.0/300/Air
40415.32	7059 Glass	ITO	Cu	20	3.0/300/Air
40416.11	7059 Glass	ITO	Cu	20	3.0/300/Air
40416.23	7059 Glass	ITO	Cu	20	3.0/300/Air
40417.23	7059 Glass	ITO	Cu	20	3.0/300/Air
40418.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40419.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40420.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40421.23	7059 Glass	Mo	Cu	20	3.0/300/Air
40421.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40422.11	7059 Glass	ITO	Cu	20	3.0/300/Air
40422.21	7059 Glass	Mo	Cu	20	3.0/300/Air
40423.21	7059 Glass	Mo	Cu	20	3.0/300/Air
40423.23	7059 Glass	ITO	Cu	20	3.0/300/Air
40424.11	7059 Glass	ITO	Cu	20	3.0/300/Air
40424.12	7059 Glass	Mo	Cu	20	3.0/300/Air
40425.23	7059 Glass	ITO	Cu	20	3.0/300/Air
40425.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40426.23	7059 Glass	ITO	Cu	20	3.0/300/Air
40426.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40427.21	7059 Glass	Mo	Cu	20	3.0/300/Air

Piece #	Substrate Type	CdTe Contact	Metal Layer Type	Metal Thickness (angstr.)	Heat Treatment (Hrs/deg/atm)
40427.23	7059 Glass	ITO	Cu	20	3.0/300/Air
40428.11	7059 Glass	ITO	Cu	20	3.0/300/Air
40428.12	7059 Glass	Mo	Cu	20	3.0/300/Air
40429.11	7059 Glass	ITO	Cu	20	3.0/300/Air
40429.12	7059 Glass	Mo	Cu	20	3.0/300/Air
40429.21	7059 Glass	ITO	Cu	20	16.0/300/Air
40430.12	7059 Glass	Mo	Cu	20	3.0/300/Air
40430.211	7059 Glass	Mo	Cu	20	3.0/300/Air
40430.212	7059 Glass	Mo	Cu	20	3.0/300/Air
40431.21	7059 Glass	Mo	Cu	20	3.0/300/Air
40431.32	7059 Glass	ITO	Cu	20	3.0/300/Air
40432.11	7059 Glass	ITO	Cu	20	3.0/300/Air
40432.123	7059 Glass	SnO_2			3.0/300/Air
40432.213	7059 Glass	SnO_2	Cu	20	3.0/300/Air
40432.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40433.11	7059 Glass	ITO	Cu	20	3.0/300/Air
40433.121	7059 Glass	SnO_2			3.0/300/Air
40433.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40434.111	7059 Glass	ITO	Cu	10	3.0/300/Air
40434.121	7059 Glass	ITO	Cu	20	3.0/300/Air
40434.21	7059 Glass	Mo	Cu	20	3.0/300/Air
40434.32	7059 Glass	Mo	Cu	10	3.0/300/Air
40435.113	7059 Glass	ITO	Cu	20	3.0/300/Air
40435.121	7059 Glass	ITO	Cu	20	3.0/300/Air
40435.21	7059 Glass	Mo	Cu	20	3.0/300/Air
40436.12	7059 Glass	ITO	Cu	20	3.0/300/Air

Piece #	Substrate Type	CdTe Contact	Metal Layer Type	Metal Thickness (angstr.)	Heat Treatment (Hrs/deg/atm)
40436.321	7059 Glass	Mo	Cu	20	3.0/300/O_2
40437.11	7059 Glass	ITO	Cu	20	3.0/300/Air
40437.122	7059 Glass	SnO_2	Cu	20	3.0/300/Air
40437.211	7059 Glass	SnO_2	Cu	20	3.0/300/Air
40437.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40438.11	7059 Glass	Mo	Cu	20	3.0/300/O_2
40438.12	7059 Glass	ITO	Cu	20	1.0/500/O_2
40438.21	7059 Glass	ITO	Cu	20	1.0/500/O_2
40438.23	7059 Glass	ITO	Cu	20	3.0/300/Air
40438.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40438.32	7059 Glass	ITO	Cu	20	1.0/500/O_2
40439.11	7059 Glass	Mo	Cu	20	3.0/300/Air
40439.21	7059 Glass	ITO	Cu	20	3.0/300/Air
40439.22	7059 Glass	ITO	Cu	20	1.0/500/O_2
40439.23	7059 Glass	ITO	Cu	20	1.0/500/O_2
40439.32	7059 Glass	ITO	Cu	20	1.0/500/O_2
40440.31	7059 Glass	Mo	Cu	20	3.0/300/Air
40440.32	7059 Glass	ITO	Cu	20	3.0/300/Air
40441.11	7059 Glass	Mo	Cu	20	3.0/300/O_2
40441.21	7059 Glass	ITO	Cu	20	3.0/300/Air
40441.31	7059 Glass	SnO_2	Cu	20	3.0/300/Air
40442.11	7059 Glass	Mo	Cu	20	3.0/300/Air
40442.12	7059 Glass	SnO_2	Cu	20	3.0/300/Air
40442.31	7059 Glass	ITO	Cu	20	3.0/300/Air
40443.11	7059 Glass	ITO	Cu	20	3.0/300/O_2
40443.23	7059 Glass	Mo	Cu	20	3.0/300/O_2

Piece #	Substrate Type	CdTe Contact	Metal Layer Type	Metal Thickness (angstr.)	Heat Treatment (Hrs/deg/atm)
40444.23	7059 Glass	Mo	Cu	20	3.0/300/O_2
40444.31	7059 Glass	Mo	Cu	20	3.0/300/O_2
40445.11	7059 Glass	ITO	Cu	20	3.0/300/O_2
40445.31	7059 Glass	Mo	Cu	20	3.0/300/O_2
40445.32	7059 Glass	SnO_2	Cu	20	3.0/300/Air
40446.12	7059 Glass	Mo	Cu	50	3.0/300/O_2
40446.21	7059 Glass	ITO	Cu	100	3.0/300/O_2
40446.22	7059 Glass	ITO	Cu	50	3.0/300/O_2
40446.31	7059 Glass	Mo	Cu	50	3.0/300/O_2
40447.12	7059 Glass	ITO	Cu	20	3.0/300/O_2
40447.13	7059 Glass	ITO	Cu	50	3.0/300/O_2
40447.21	7059 Glass	ITO	Cu	100	3.0/300/O_2
40447.23	7059 Glass	ITO	Cu	100	2.0/500/O_2
40447.31	7059 Glass	Mo	Cu	100	3.0/300/O_2
40448.12	7059 Glass	Mo	Cu	50	3.0/300/O_2
40448.13	7059 Glass	ITO	Cu	50	3.0/300/O_2
40448.21	7059 Glass	ITO	Cu	100	3.0/300/O_2
40448.31	7059 Glass	Mo	Cu	100	3.0/300/O_2
40449.11	7059 Glass	ITO	Cu	50	3.0/300/O_2
40449.12	7059 Glass	SnO_2	Cu	50	3.0/300/Air
40449.13	7059 Glass	ITO	Cu	100	3.0/300/O_2
40449.21	7059 Glass	SnO_2	Cu	100	3.0/300/Air
40449.31	7059 Glass	Mo	Cu	100	3.0/300/O_2
40449.32	7059 Glass	ITO	Cu	100	3.0/300/O_2
40450.11	7059 Glass	Mo	Cu	50	3.0/300/O_2
40450.12	7059 Glass	TO	Cu	50	3.0/300/Air

Piece #	Substrate Type	CdTe Contact	Metal Layer Type	Metal Thickness (angstr.)	Heat Treatment (Hrs/deg/atm)
40450.13	7059 Glass	ITO	Cu	100	3.0/300/O_2
40450.21	7059 Glass	TO	Cu	100	3.0/300/Air
40450.23	7059 Glass	ITO	Cu	100	3.0/300/O_2
40450.31	7059 Glass	Mo	Cu	100	3.0/300/O_2
40450.32	7059 Glass	ITO	Cu	50	3.0/300/O_2
40451.11	7059 Glass	Mo	Cu	50	3.0/300/O_2
40451.12	7059 Glass	TO	Cu	50	3.0/300/Air
40451.13	7059 Glass	TO	Cu	100	3.0/300/O_2
40451.21	7059 Glass	SnO_2	Cu	100	3.0/300/Air
40451.31	7059 Glass	Mo	Cu	100	3.0/300/O_2
40451.32	7059 Glass	SnO_2	Cu	50	3.0/300/O_2
40452.11	7059 Glass	Mo	Cu	50	3.0/300/O_2
40452.12	7059 Glass	Mo	Cu	100	3.0/300/O_2
40452.13	7059 Glass	SnO_2	Cu	100	3.0/300/O_2
40452.21	7059 Glass	SnO_2	Cu	50	3.0/300/O_2
40452.23	7059 Glass	SnO_2	Cu	100	3.0/300/O_2
40453.11	7059 Glass	Mo	Cu	50	3.0/300/O_2
40453.12	7059 Glass	Mo	Cu	100	3.0/300/O_2
40453.13	7059 Glass	SnO_2	Cu	50	3.0/300/O_2
40453.21	7059 Glass	SnO_2	Cu	50	3.0/300/O_2
40454.12	7059 Glass	SnO_2	Cu	50	3.0/300/O_2
40454.13	7059 Glass	ITO	Cu	50	3.0/300/O_2
40454.21	7059 Glass	SnO_2	Cu	100	3.0/300/O_2
40454.23	7059 Glass	SnO_2	Cu	50	3.0/300/O_2
40454.31	7059 Glass	Mo	Cu	50	3.0/300/O_2
40454.32	7059 Glass	SnO_2	Cu	100	2.0/500/O_2

Piece #	Substrate Type	CdTe Contact	Metal Layer Type	Metal Thickness (angstr.)	Heat Treatment (Hrs/deg/atm)
40455.11	7059 Glass	Mo	Cu	50	3.0/300/O_2
40455.13	7059 Glass	ITO	Cu	50	3.0/300/O_2
40455.21	7059 Glass	SnO_2	Cu	100	3.0/300/O_2
40455.23	7059 Glass	SnO_2	Cu	50	3.0/300/O_2
40455.32	7059 Glass	SnO_2	Cu	100	3.0/300/O_2

APPENDIX H

Cell Statistics

on

CdTe/CdS Devices

made from

Evaporator IV CdTe

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)

Piece # 40410.21
12 Cells   3 I-V tests
Last tested 6/25/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.463	6.29	42.27	1.41
Min.	.374	1.11		0.11
Mean	.390	1.70	26.61	0.24
Std.Dev.	.025	1.45	4.97	0.37

Piece # 40410.32
12 Cells   3 I-V tests
Last tested 7/10/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.328	3.68	41.73	0.50
Min.	.247	2.09	28.53	0.16
Mean	.298	2.58	37.59	0.33
Std.Dev.	.026	0.56	4.87	0.11

Piece # 40411.21
12 Cells   2 I-V tests
Last tested 6/27/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.357	0.81		
Min.	.303	0.67		
Mean	.349	0.74		
Std.Dev.	.014	0.04		

Piece # 40412.21
12 Cells   2 I-V tests
Last tested 6/25/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.388	1.00		0.10
Min.	.034	0.45		
Mean	.301	0.62		0.01
Std.Dev.	.091	0.15		0.03

Piece # 40414.22
12 Cells   2 I-V tests
Last tested 7/ 8/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.416	0.97		0.10
Min.	.391	0.71		
Mean	.403	0.85		0.03
Std.Dev.	.006	0.08		0.05

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 40415.21 12 Cells 2 I-V tests Last tested 7/ 8/85				
Max.	.423	1.26		0.14
Min.	.378	0.72		
Mean	.402	0.93		0.04
Std.Dev.	.010	0.14		0.06
Piece # 40415.32 12 Cells 3 I-V tests Last tested 7/10/85				
Max.	.401	6.23	37.47	1.07
Min.	.064	3.22		
Mean	.342	4.98	34.76	0.71
Std.Dev.	.093	1.10	3.82	0.32
Piece # 40416.11 12 Cells 2 I-V tests Last tested 7/ 8/85				
Max.	.291	0.43		
Min.	.222	0.27		
Mean	.240	0.34		
Std.Dev.	.021	0.05		
Piece # 40416.23 12 Cells 4 I-V tests Last tested 7/16/85				
Max.	.297	2.56	40.25	0.31
Min.	.107	1.58		
Mean	.267	1.95	36.43	0.21
Std.Dev.	.053	0.23	4.40	0.08
Piece # 40417.23 12 Cells 3 I-V tests Last tested 7/15/85				
Max.	.450	6.53	41.48	1.26
Min.	.158	5.42	26.01	0.25
Mean	.402	5.99	39.12	1.09
Std.Dev.	.079	0.36	4.24	0.27

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
		Piece # 40418.31 12 Cells 2 I-V tests Last tested 7/19/85		
Max.	.341	2.05	27.82	0.20
Min.	.328	1.24		0.11
Mean	.336	1.66	25.63	0.15
Std.Dev.	.003	0.27	0.82	0.03
		Piece # 40419.31 12 Cells 2 I-V tests Last tested 7/19/85		
Max.	.320	0.61		
Min.	.302	0.24		
Mean	.313	0.41		
Std.Dev.	.005	0.11		
		Piece # 40420.31 12 Cells 2 I-V tests Last tested 7/19/85		
Max.	.348	3.22	36.38	0.41
Min.		1.66		
Mean	.302	2.66	33.01	0.30
Std.Dev.	.099	0.50	3.28	0.12
		Piece # 40421.23 10 Cells 2 I-V tests Last tested 7/23/85		
Max.	.277	3.14	43.98	0.42
Min.	.023	0.57		
Mean	.197	2.02	36.97	0.24
Std.Dev.	.118	0.99	8.45	0.17
		Piece # 40421.31 12 Cells 4 I-V tests Last tested 7/24/85		
Max.	.563	16.42	52.83	5.07
Min.	.414	3.72	35.16	0.62
Mean	.488	12.64	45.39	3.37
Std.Dev.	.045	4.56	6.34	1.54

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
	Piece # 40422.11 10 Cells 3 I-V tests Last tested 7/25/85			
Max.	.299	1.77	40.38	0.23
Min.	.128			
Mean	.261	1.41	36.75	0.16
Std.Dev.	.066	0.51	6.21	0.09
	Piece # 40422.21 12 Cells 2 I-V tests Last tested 7/24/85			
Max.	.413	5.08	26.77	0.60
Min.	.366	4.47	25.25	0.48
Mean	.385	4.74	26.09	0.54
Std.Dev.	.012	0.19	0.47	0.04
	Piece # 40423.21 12 Cells 4 I-V tests Last tested 7/29/85			
Max.	.587	16.61	50.60	5.32
Min.	.474	3.72	43.31	0.87
Mean	.552	13.90	47.39	4.25
Std.Dev.	.031	3.82	2.51	1.35
	Piece # 40423.23 12 Cells 4 I-V tests Last tested 7/30/85			
Max.	.451	10.78	43.32	2.22
Min.	.365	7.30	33.91	1.10
Mean	.437	8.76	40.04	1.67
Std.Dev.	.023	0.93	2.28	0.29
	Piece # 40424.11 12 Cells 4 I-V tests Last tested 7/30/85			
Max.	.448	12.22	42.75	2.58
Min.	.329	7.43	29.62	1.05
Mean	.402	9.57	38.53	1.70
Std.Dev.	.035	1.34	3.54	0.48

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 40424.12 — 12 Cells, 2 I-V tests — Last tested 7/25/85				
Max.	.408	3.54	31.51	0.38
Min.	.343	0.73		
Mean	.357	1.63	26.03	0.12
Std.Dev.	.024	0.99	2.41	0.13
Piece # 40425.23 — 8 Cells, 3 I-V tests — Last tested 8/ 1/85				
Max.	.301	2.16	34.18	0.25
Min.	.135	1.61		
Mean	.272	1.89	31.83	0.18
Std.Dev.	.056	0.20	3.03	0.08
Piece # 40425.31 — 12 Cells, 3 I-V tests — Last tested 7/30/85				
Max.	.409	12.56	35.65	1.67
Min.	.047	2.88		0.17
Mean	.323	5.56	27.47	0.57
Std.Dev.	.092	3.77	4.46	0.56
Piece # 40426.23 — 12 Cells, 3 I-V tests — Last tested 8/ 2/85				
Max.	.328	12.89	34.35	1.65
Min.	.042	8.15		
Mean	.287	11.57	30.17	1.15
Std.Dev.	.077	1.24	2.51	0.40
Piece # 40426.31 — 12 Cells, 2 I-V tests — Last tested 8/ 1/85				
Max.	.366	1.52		0.15
Min.	.352	0.88		
Mean	.359	1.10		0.07
Std.Dev.	.004	0.20		0.06

Piece # 40427.21
12 Cells 4 I-V tests
Last tested 8/ 2/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.533	18.73	50.53	5.66
Min.	.485	9.83	37.23	1.99
Mean	.512	14.76	44.56	3.87
Std.Dev.	.016	3.06	4.09	1.21

Piece # 40427.23
12 Cells 3 I-V tests
Last tested 8/ 1/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.306	3.50	40.24	0.42
Min.	.256	2.78	30.23	0.27
Mean	.293	3.02	37.81	0.36
Std.Dev.	.012	0.22	3.00	0.04

Piece # 40428.11
12 Cells 3 I-V tests
Last tested 8/ 2/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.365	13.72	46.87	2.49
Min.	.326	12.92	44.45	2.17
Mean	.341	13.37	45.34	2.33
Std.Dev.	.012	0.25	0.60	0.08

Piece # 40428.12
12 Cells 3 I-V tests
Last tested 8/ 2/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.459	19.45	58.74	6.00
Min.	.349	1.78		0.17
Mean	.420	10.19	42.16	2.66
Std.Dev.	.041	7.71	14.87	2.53

Piece # 40429.11
12 Cells 3 I-V tests
Last tested 8/ 8/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.379	12.19	41.21	2.06
Min.	.322	8.53	35.89	1.36
Mean	.366	10.48	38.76	1.68
Std.Dev.	.016	1.26	1.77	0.26

Piece # 40429.12
12 Cells 5 I-V tests
Last tested 8/ 9/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.538	14.49	46.95	3.64
Min.	.510	12.04	43.76	2.97
Mean	.522	12.98	44.68	3.30
Std.Dev.	.008	0.73	0.92	0.23

Piece # 40429.21
12 Cells 3 I-V tests
Last tested 8/ 7/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.348	1.64	35.10	0.21
Min.	.315	0.81		
Mean	.331	1.11	32.30	0.12
Std.Dev.	.008	0.23	2.89	0.05

Piece # 40430.12
12 Cells 3 I-V tests
Last tested 8/15/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.539	18.98	58.55	6.43
Min.	.510	18.01	49.99	5.27
Mean	.527	18.46	55.14	6.01
Std.Dev.	.009	0.29	2.44	0.33

Piece # 40430.211
8 Cells 2 I-V tests
Last tested 8/ 7/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.315	1.86		0.16
Min.		1.21		
Mean	.268	1.43		0.11
Std.Dev.	.108	0.22		0.05

Piece # 40430.212
4 Cells 2 I-V tests
Last tested 8/ 7/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.328	2.75	26.97	0.23
Min.	.285	1.98		0.16
Mean	.313	2.25	25.49	0.18
Std.Dev.	.019	0.35	0.99	0.03

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 40431.21 — 12 Cells, 4 I-V tests — Last tested 8/ 6/85				
Max.	.501	18.01	48.12	4.92
Min.	.301	4.16	27.28	0.41
Mean	.427	10.83	36.04	2.10
Std.Dev.	.065	4.76	6.46	1.40
Piece # 40431.32 — 12 Cells, 4 I-V tests — Last tested 8/ 6/85				
Max.	.482	10.80	45.96	2.66
Min.	.457	8.52	41.71	1.86
Mean	.475	9.97	44.41	2.39
Std.Dev.	.008	0.68	1.49	0.27
Piece # 40432.11 — 12 Cells, 3 I-V tests — Last tested 8/ 9/85				
Max.	.445	12.62	42.20	2.37
Min.	.346	2.07	32.06	0.30
Mean	.385	8.02	39.21	1.39
Std.Dev.	.026	4.08	2.87	0.74
Piece # 40432.123 — 4 Cells, 2 I-V tests — Last tested 8/ 9/85				
Max.	.019	1.77		
Min.		0.93		
Mean	.004	1.27		
Std.Dev.	.009	0.38		
Piece # 40432.213 — 3 Cells, 3 I-V tests — Last tested 8/13/85				
Max.	.322	1.12	34.76	0.11
Min.	.090	0.86		
Mean	.240	0.95	28.25	0.04
Std.Dev.	.130	0.15	5.63	0.06

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 40432.31 12 Cells 2 I-V tests Last tested 8/ 8/85				
Max.	.405	1.48		0.14
Min.	.356	0.90		
Mean	.376	1.19		0.09
Std.Dev.	.011	0.18		0.06
Piece # 40433.11 12 Cells 2 I-V tests Last tested 8/13/85				
Max.	.424	3.79	35.84	0.63
Min.	.068	2.94		
Mean	.383	3.47	34.47	0.54
Std.Dev.	.100	0.23	3.03	0.17
Piece # 40433.121 4 Cells 2 I-V tests Last tested 8/13/85				
Max.	.383	1.89	25.10	0.21
Min.		0.50		
Mean	.186	1.36	25.03	0.10
Std.Dev.	.215	0.60	0.05	0.11
Piece # 40433.31 12 Cells 2 I-V tests Last tested 8/ 9/85				
Max.	.352	1.97		0.17
Min.	.328	1.51		0.14
Mean	.347	1.71		0.15
Std.Dev.	.006	0.17		0.01
Piece # 40434.111 4 Cells 3 I-V tests Last tested 8/14/85				
Max.	.254	3.57	33.57	0.34
Min.	.047	2.57		
Mean	.110	3.14	27.14	0.08
Std.Dev.	.096	0.49	4.28	0.17

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 40434.121 3 Cells 3 I-V tests Last tested 8/14/85				
Max.	.147	6.06	26.72	0.27
Min.	.032	2.71		
Mean	.076	4.35	25.57	0.09
Std.Dev.	.062	1.68	0.99	0.16
Piece # 40434.21 12 Cells 3 I-V tests Last tested 8/14/85				
Max.	.511	15.88	49.01	4.53
Min.	.383	2.08		0.20
Mean	.431	4.66	30.24	0.91
Std.Dev.	.057	4.14	7.89	1.27
Piece # 40434.32 12 Cells 2 I-V tests Last tested 8/13/85				
Max.	.496	9.46	37.21	1.77
Min.	.394	2.13		0.21
Mean	.436	5.07	29.97	0.82
Std.Dev.	.039	2.93	4.94	0.63
Piece # 40435.113 4 Cells 2 I-V tests Last tested 8/14/85				
Max.	.348	12.80	42.32	2.09
Min.	.130	8.48	25.40	0.32
Mean	.280	11.16	35.97	1.43
Std.Dev.	.101	1.95	7.47	0.77
Piece # 40435.121 4 Cells 2 I-V tests Last tested 8/14/85				
Max.	.366	10.03	40.57	1.71
Min.	.112	7.46	25.48	0.24
Mean	.242	9.12	32.23	0.93
Std.Dev.	.133	1.16	7.70	0.72

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
	Piece # 40435.21 12 Cells 3 I-V tests Last tested 8/15/85			
Max.	.556	18.34	52.65	5.83
Min.	.402	14.17	43.49	3.55
Mean	.500	17.47	48.57	4.79
Std.Dev.	.044	1.10	2.42	0.73
	Piece # 40436.12 6 Cells 1 I-V tests Last tested 8/14/85			
Max.	.450	5.80	36.70	1.03
Min.	.322	0.39		
Mean	.383	2.94	33.45	0.47
Std.Dev.	.048	2.05	4.22	0.38
	Piece # 40436.321 4 Cells 2 I-V tests Last tested 8/28/85			
Max.	.476	2.21	26.57	0.28
Min.	.356	1.65		0.18
Mean	.433	1.92	25.85	0.23
Std.Dev.	.052	0.27	0.72	0.04
	Piece # 40437.11 12 Cells 3 I-V tests Last tested 8/21/85			
Max.	.456	14.09	45.20	3.23
Min.	.072	11.09	25.25	0.23
Mean	.364	13.17	36.92	2.14
Std.Dev.	.116	0.79	6.81	0.92
	Piece # 40437.122 4 Cells 2 I-V tests Last tested 8/16/85			
Max.	.341	1.84	26.03	0.17
Min.		0.95		
Mean	.247	1.49	25.49	0.12
Std.Dev.	.165	0.38	0.42	0.08

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)

Piece # 40437.211
4 Cells 3 I-V tests
Last tested 8/21/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.467	14.33	42.45	3.11
Min.	.368	5.74	35.69	0.89
Mean	.424	9.73	38.81	1.93
Std.Dev.	.044	4.33	2.93	1.12

Piece # 40437.31
12 Cells 2 I-V tests
Last tested 8/16/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.499	8.82	42.40	1.10
Min.	.324	3.17	28.55	0.50
Mean	.436	5.07	34.16	0.77
Std.Dev.	.047	1.67	4.78	0.17

Piece # 40438.11
12 Cells 3 I-V tests
Last tested 8/29/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.556	15.67	49.95	4.51
Min.	.514	9.99	38.48	2.29
Mean	.532	12.94	45.51	3.60
Std.Dev.	.012	1.71	3.40	0.64

Piece # 40438.12
8 Cells 4 I-V tests
Last tested 10/ 4/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.205	6.72	41.68	0.63
Min.		2.57		
Mean	.139	5.61	35.23	0.36
Std.Dev.	.082	1.32	7.26	0.24

Piece # 40438.21
8 Cells 4 I-V tests
Last tested 10/ 4/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.240	5.77	46.90	0.68
Min.	.214	5.02	43.75	0.50
Mean	.227	5.45	45.56	0.63
Std.Dev.	.008	0.27	1.17	0.06

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)

Piece # 40438.23
12 Cells 2 I-V tests
Last tested 8/20/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.442	14.97	41.02	3.07
Min.	.030	11.05		
Mean	.252	13.89	31.93	1.49
Std.Dev.	.163	1.10	7.07	1.22

Piece # 40438.31
12 Cells 2 I-V tests
Last tested 8/21/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.429	6.70	42.88	0.90
Min.	.277	0.96		
Mean	.374	1.72	27.61	0.18
Std.Dev.	.045	1.59	5.22	0.24

Piece # 40438.32
8 Cells 3 I-V tests
Last tested 10/ 3/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.021			
Min.				
Mean	.002			
Std.Dev.	.007			

Piece # 40439.11
12 Cells 2 I-V tests
Last tested 8/20/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.549	14.57	40.69	3.70
Min.	.399	4.90		0.54
Mean	.486	8.62	29.34	1.52
Std.Dev.	.043	3.54	5.76	1.10

Piece # 40439.21
12 Cells 2 I-V tests
Last tested 8/20/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.432	13.42	43.47	2.69
Min.	.133	10.21	25.51	0.38
Mean	.328	11.96	35.41	1.71
Std.Dev.	.106	0.86	7.31	0.85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)

Piece # 40439.22
8 Cells 4 I-V tests
Last tested 10/ 4/85

Max.	.220	7.08	43.09	0.72
Min.	.046	4.11		
Mean	.166	6.50	36.38	0.46
Std.Dev.	.060	0.99	7.12	0.25

Piece # 40439.23
8 Cells 4 I-V tests
Last tested 10/ 4/85

Max.	.229	5.20	45.84	0.59
Min.	.141	4.79	31.01	0.25
Mean	.198	5.05	41.46	0.46
Std.Dev.	.029	0.12	6.35	0.12

Piece # 40439.32
8 Cells 2 I-V tests
Last tested 10/ 3/85

Max.	.072			
Min.				
Mean	.025			
Std.Dev.	.026			

Piece # 40440.31
12 Cells 2 I-V tests
Last tested 8/21/85

Max.	.463	16.95	50.06	4.43
Min.	.412	4.46	30.78	0.68
Mean	.438	10.37	39.76	2.17
Std.Dev.	.017	4.36	7.40	1.25

Piece # 40440.32
12 Cells 2 I-V tests
Last tested 8/22/85

Max.	.329	13.93	41.22	1.92
Min.	.186	11.79	29.27	0.78
Mean	.276	12.90	37.23	1.53
Std.Dev.	.042	0.57	3.85	0.36

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 40441.11 — 12 Cells, 2 I-V tests, Last tested 8/23/85				
Max.	.550	16.53	39.66	4.07
Min.	.486	13.05	30.47	2.33
Mean	.523	15.02	35.55	3.22
Std.Dev.	.020	1.09	3.18	0.57
Piece # 40441.21 — 12 Cells, 2 I-V tests, Last tested 8/23/85				
Max.	.549	15.18	43.46	3.89
Min.	.043	8.14		
Mean	.364	13.60	33.59	2.14
Std.Dev.	.188	2.06	7.05	1.39
Piece # 40441.31 — 12 Cells, 2 I-V tests, Last tested 8/23/85				
Max.	.541	16.41	41.67	4.19
Min.		8.84		
Mean	.472	15.23	38.28	3.37
Std.Dev.	.152	2.10	4.93	1.19
Piece # 40442.11 — 5 Cells, 3 I-V tests, Last tested 8/29/85				
Max.	.530	17.23	46.88	4.40
Min.	.471	4.35	36.00	0.72
Mean	.512	12.74	42.96	3.10
Std.Dev.	.023	5.30	4.11	1.49
Piece # 40442.12 — 5 Cells, 3 I-V tests, Last tested 8/29/85				
Max.	.532	10.20	36.45	2.21
Min.	.498	7.33	33.08	1.31
Mean	.510	8.38	34.44	1.62
Std.Dev.	.014	1.08	1.43	0.35

Piece # 40442.31
5 Cells 3 I-V tests
Last tested 8/29/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.396	8.70	36.39	1.35
Min.	.326	2.33	33.22	0.29
Mean	.366	5.50	34.49	0.79
Std.Dev.	.029	2.46	1.46	0.42

Piece # 40443.11
12 Cells 4 I-V tests
Last tested 8/27/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.487	14.28	44.36	3.16
Min.	.407	12.35	35.85	2.11
Mean	.447	13.04	41.68	2.76
Std.Dev.	.027	0.60	2.42	0.30

Piece # 40443.23
12 Cells 2 I-V tests
Last tested 8/26/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.500	4.84	33.54	0.82
Min.	.429	1.51	26.88	0.23
Mean	.462	3.10	30.38	0.50
Std.Dev.	.022	0.88	1.99	0.16

Piece # 40444.23
12 Cells 4 I-V tests
Last tested 8/27/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.504	14.20	45.92	3.45
Min.	.397	11.93	31.56	1.71
Mean	.465	12.90	41.08	2.81
Std.Dev.	.028	0.67	4.02	0.47

Piece # 40444.31
12 Cells 4 I-V tests
Last tested 8/28/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.535	16.46	49.77	4.54
Min.		0.99		
Mean	.440	7.11	33.12	1.47
Std.Dev.	.143	5.40	9.01	1.49

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 40445.11 — 12 Cells, 3 I-V tests, Last tested 8/29/85				
Max.	.546	14.53	47.19	4.03
Min.	.468	12.51	39.30	2.79
Mean	.522	14.05	44.19	3.50
Std.Dev.	.023	0.56	2.36	0.37
Piece # 40445.31 — 11 Cells, 2 I-V tests, Last tested 8/28/85				
Max.	.551	9.51	43.88	2.42
Min.	.391	1.71	34.35	0.27
Mean	.464	5.77	39.73	1.30
Std.Dev.	.051	3.41	3.40	0.93
Piece # 40445.32 — 12 Cells, 3 I-V tests, Last tested 8/29/85				
Max.	.529	15.30	44.93	3.61
Min.	.473	12.58	40.38	2.86
Mean	.505	14.31	43.28	3.24
Std.Dev.	.018	0.95	1.22	0.26
Piece # 40446.12 — 12 Cells, 2 I-V tests, Last tested 8/29/85				
Max.	.328	1.43	48.45	0.20
Min.	.265	0.12		
Mean	.282	0.71	32.15	0.06
Std.Dev.	.016	0.36	10.67	0.08
Piece # 40446.21 — 12 Cells, 2 I-V tests, Last tested 8/29/85				
Max.	.100	4.82	25.33	0.14
Min.	.020	2.49		
Mean	.053	3.89	25.03	0.01
Std.Dev.	.019	0.64	0.10	0.04

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)

Piece # 40446.22
12 Cells 2 I-V tests
Last tested 8/29/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.449	9.43	44.94	1.95
Min.	.410	4.21	39.49	0.83
Mean	.427	5.24	42.32	1.08
Std.Dev.	.013	1.60	1.69	0.34

Piece # 40446.31
12 Cells 2 I-V tests
Last tested 8/29/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.251	0.88		
Min.	.012			
Mean	.080	0.26		
Std.Dev.	.077	0.26		

Piece # 40447.12
12 Cells 3 I-V tests
Last tested 8/30/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.534	12.69	47.90	3.44
Min.	.274	0.49		
Mean	.374	3.68	38.55	0.88
Std.Dev.	.098	4.64	10.10	1.30

Piece # 40447.13
12 Cells 4 I-V tests
Last tested 9/ 4/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.514	15.64	48.65	4.33
Min.	.413	13.77	39.84	2.77
Mean	.473	14.97	45.90	3.67
Std.Dev.	.035	0.47	3.08	0.56

Piece # 40447.21
12 Cells 5 I-V tests
Last tested 10/14/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.592	16.74	50.87	5.48
Min.	.107	11.54	25.26	0.36
Mean	.518	15.05	47.09	4.32
Std.Dev.	.132	1.33	7.04	1.34

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
		Piece # 40447.23 12 Cells 2 I-V tests Last tested 9/13/85		
Max.	.429	1.57	42.00	0.28
Min.	.348	0.87	31.19	0.14
Mean	.402	1.21	38.48	0.20
Std.Dev.	.026	0.23	3.11	0.05
		Piece # 40447.31 12 Cells 4 I-V tests Last tested 9/ 4/85		
Max.	.534	16.25	48.17	4.47
Min.	.465	4.65	42.35	1.05
Mean	.506	12.41	45.89	3.22
Std.Dev.	.023	4.37	2.08	1.25
		Piece # 40448.12 12 Cells 2 I-V tests Last tested 9/ 4/85		
Max.	.241	0.48		
Min.	.018			
Mean	.104	0.17		
Std.Dev.	.063	0.16		
		Piece # 40448.13 12 Cells 3 I-V tests Last tested 9/ 5/85		
Max.	.461	15.41	50.42	4.00
Min.	.069	12.41	26.46	0.26
Mean	.331	14.56	41.84	2.52
Std.Dev.	.128	0.99	8.30	1.24
		Piece # 40448.21 12 Cells 3 I-V tests Last tested 9/ 5/85		
Max.	.526	11.04	29.11	1.61
Min.	.159	7.42		0.37
Mean	.416	9.13	26.21	1.14
Std.Dev.	.123	1.10	1.42	0.39

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
		Piece # 40448.31 12 Cells 2 I-V tests Last tested 9/ 4/85		
Max.	.520	11.77	45.69	3.14
Min.	.115	0.17		
Mean	.237	1.74	31.49	0.36
Std.Dev.	.136	3.31	9.60	0.90
		Piece # 40449.11 7 Cells 2 I-V tests Last tested 9/ 5/85		
Max.	.252	0.56		
Min.				
Mean	.128	0.29		
Std.Dev.	.102	0.19		
		Piece # 40449.12 12 Cells 4 I-V tests Last tested 10/14/85		
Max.	.576	16.35	52.74	5.44
Min.	.415	15.22	37.72	2.84
Mean	.531	15.88	48.52	4.69
Std.Dev.	.056	0.36	5.09	0.92
		Piece # 40449.13 12 Cells 2 I-V tests Last tested 9/ 5/85		
Max.	.547	5.91	33.43	1.08
Min.	.425	3.67	30.14	0.68
Mean	.524	4.96	31.70	0.92
Std.Dev.	.032	0.65	1.05	0.14
		Piece # 40449.21 12 Cells 3 I-V tests Last tested 9/ 6/85		
Max.	.562	13.05	44.60	3.63
Min.	.534	9.46	37.96	2.03
Mean	.553	11.36	41.13	2.84
Std.Dev.	.008	1.17	1.97	0.46

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)

Piece # 40449.31
12 Cells 2 I-V tests
Last tested 9/ 5/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.093	0.40		
Min.				
Mean	.019	0.12		
Std.Dev.	.030	0.14		

Piece # 40449.32
12 Cells 2 I-V tests
Last tested 9/ 5/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.434	5.13	45.15	0.93
Min.	.262	3.63	26.81	0.32
Mean	.364	4.02	36.30	0.61
Std.Dev.	.068	0.48	6.40	0.21

Piece # 40450.11
10 Cells 2 I-V tests
Last tested 9/10/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.224	0.16		
Min.				
Mean	.053	0.03		
Std.Dev.	.089	0.07		

Piece # 40450.12
12 Cells 2 I-V tests
Last tested 9/10/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.295	2.24	42.26	0.32
Min.	.214	1.18	30.96	0.14
Mean	.262	1.68	40.40	0.21
Std.Dev.	.021	0.34	3.01	0.05

Piece # 40450.13
12 Cells 2 I-V tests
Last tested 9/10/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.222	0.39		
Min.	.194	0.30		
Mean	.207	0.34		
Std.Dev.	.008	0.03		

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 40450.21 — 12 Cells, 2 I-V tests, Last tested 9/10/85				
Max.	.256	1.32	37.43	0.14
Min.	.217	0.48		
Mean	.233	0.81	27.99	0.03
Std.Dev.	.014	0.28	5.40	0.06
Piece # 40450.23 — 12 Cells, 1 I-V tests, Last tested 9/23/85				
Max.	.280	0.43		
Min.	.078	0.31		
Mean	.226	0.37		
Std.Dev.	.070	0.03		
Piece # 40450.31 — 12 Cells, 2 I-V tests, Last tested 9/10/85				
Max.	.224	0.22		
Min.	.170	0.12		
Mean	.194	0.15		
Std.Dev.	.019	0.03		
Piece # 40450.32 — 12 Cells, 2 I-V tests, Last tested 9/10/85				
Max.	.323	2.97	38.59	0.38
Min.	.191	0.69		
Mean	.251	1.19	31.18	0.09
Std.Dev.	.032	0.63	6.53	0.12
Piece # 40451.11 — 10 Cells, 2 I-V tests, Last tested 9/10/85				
Max.	.075			
Min.	.023			
Mean	.050			
Std.Dev.	.018			

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 40451.12				
12 Cells 2 I-V tests				
Last tested 9/10/85				
Max.	.323	1.53	35.02	0.18
Min.		0.59		
Mean	.282	1.09	32.52	0.12
Std.Dev.	.089	0.23	2.64	0.04
Piece # 40451.13				
12 Cells 2 I-V tests				
Last tested 9/10/85				
Max.	.251	0.56		
Min.	.043	0.30		
Mean	.221	0.44		
Std.Dev.	.056	0.08		
Piece # 40451.21				
12 Cells 3 I-V tests				
Last tested 9/11/85				
Max.	.479	4.02	34.77	0.52
Min.	.321	1.39		0.16
Mean	.389	2.55	30.50	0.33
Std.Dev.	.052	0.80	2.53	0.12
Piece # 40451.31				
12 Cells 2 I-V tests				
Last tested 9/10/85				
Max.	.245	0.92		
Min.	.190	0.18		
Mean	.201	0.36		
Std.Dev.	.015	0.20		
Piece # 40451.32				
12 Cells 3 I-V tests				
Last tested 9/11/85				
Max.	.380	5.46	32.63	0.68
Min.	.336	2.61	29.16	0.33
Mean	.363	3.99	30.65	0.50
Std.Dev.	.013	0.99	1.18	0.12

Piece # 40452.11
12 Cells 1 I-V tests
Last tested 9/11/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.300	1.43		0.11
Min.	.212	0.12		
Mean	.254	0.59		0.01
Std.Dev.	.027	0.41		0.03

Piece # 40452.12
12 Cells 1 I-V tests
Last tested 9/11/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.046			
Min.				
Mean	.003			
Std.Dev.	.013			

Piece # 40452.13
12 Cells 3 I-V tests
Last tested 9/24/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.346	3.07	41.19	0.46
Min.	.293	1.36	38.16	0.18
Mean	.320	2.31	39.66	0.33
Std.Dev.	.015	0.52	0.77	0.09

Piece # 40452.21
12 Cells 2 I-V tests
Last tested 9/12/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.400	7.27	33.66	0.88
Min.	.353	4.11	29.12	0.55
Mean	.381	5.20	32.03	0.71
Std.Dev.	.014	0.79	1.32	0.09

Piece # 40452.23
12 Cells 1 I-V tests
Last tested 9/11/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.287	1.00	34.95	0.11
Min.	.274	0.78		
Mean	.282	0.91	31.25	0.07
Std.Dev.	.003	0.05	4.63	0.05

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)

Piece # 40453.11
9 Cells 1 I-V tests
Last tested 9/11/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.414	4.07		0.47
Min.	.181	0.17		
Mean	.251	0.87		0.05
Std.Dev.	.068	1.22		0.16

Piece # 40453.12
12 Cells 1 I-V tests
Last tested 9/11/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.				
Min.				
Mean				
Std.Dev.				

Piece # 40453.13
4 Cells 1 I-V tests
Last tested 9/23/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.283	0.66		
Min.	.243	0.56		
Mean	.268	0.61		
Std.Dev.	.017	0.04		

Piece # 40453.21
12 Cells 1 I-V tests
Last tested 9/11/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.221	0.37		
Min.	.153	0.26		
Mean	.209	0.30		
Std.Dev.	.017	0.04		

Piece # 40454.12
12 Cells 2 I-V tests
Last tested 9/13/85

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Max.	.456	8.87	33.56	1.50
Min.	.392	5.06	30.48	0.72
Mean	.411	6.02	31.69	0.88
Std.Dev.	.017	1.05	0.85	0.21

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
		Piece # 40454.13 12 Cells 2 I-V tests Last tested 9/13/85		
Max.	.378	5.32	29.69	0.59
Min.	.302	2.06	25.46	0.18
Mean	.357	3.42	27.44	0.37
Std.Dev.	.019	0.95	1.26	0.11
		Piece # 40454.21 12 Cells 2 I-V tests Last tested 9/13/85		
Max.	.534	10.17	30.84	1.77
Min.	.414	7.91	27.64	1.16
Mean	.476	8.93	28.64	1.38
Std.Dev.	.036	0.69	0.93	0.20
		Piece # 40454.23 12 Cells 2 I-V tests Last tested 9/25/85		
Max.	.463	10.18	43.47	2.02
Min.	.140	0.78		
Mean	.376	3.53	37.43	0.67
Std.Dev.	.095	3.68	5.32	0.81
		Piece # 40454.31 12 Cells 2 I-V tests Last tested 9/13/85		
Max.	.511	1.27	26.78	0.15
Min.	.422	0.83		0.10
Mean	.482	1.08	25.23	0.13
Std.Dev.	.024	0.14	0.51	0.02
		Piece # 40454.32 12 Cells 2 I-V tests Last tested 9/13/85		
Max.	.380	1.02	34.08	0.14
Min.	.297	0.32		
Mean	.350	0.66	27.50	0.04
Std.Dev.	.030	0.24	3.74	0.07

	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Piece # 40455.11 — 11 Cells, 1 I-V tests, Last tested 9/13/85				
Max.	.226	0.23		
Min.	.015			
Mean	.107	0.02		
Std.Dev.	.072	0.07		
Piece # 40455.13 — 12 Cells, 1 I-V tests, Last tested 9/13/85				
Max.	.295	0.79	40.36	0.11
Min.	.188	0.18		
Mean	.205	0.27	26.28	0.01
Std.Dev.	.028	0.17	4.43	0.03
Piece # 40455.21 — 12 Cells, 2 I-V tests, Last tested 9/25/85				
Max.	.547	9.50	41.30	2.45
Min.	.295	0.19		
Mean	.467	4.34	36.56	1.00
Std.Dev.	.081	3.23	5.63	0.83
Piece # 40455.23 — 12 Cells, 1 I-V tests, Last tested 9/13/85				
Max.	.264	0.82	40.56	0.10
Min.	.201	0.34		
Mean	.215	0.42	26.30	0.01
Std.Dev.	.016	0.13	4.49	0.03
Piece # 40455.32 — 12 Cells, 1 I-V tests, Last tested 9/13/85				
Max.	.236	0.48		
Min.	.205	0.28		
Mean	.221	0.38		
Std.Dev.	.011	0.08		

APPENDIX I

Thin-Film Tandem Solar Cells Based on $CuInSe_2$

R.W. Birkmire, J.E. Phillips, L.C. DiNetta and J.D. Meakin

Presented at the 6th E.C. Solar Photovoltaic Conference, London, April 1986

THIN-FILM TANDEM SOLAR CELLS BASED ON $CuInSe_2$

R. W. Birkmire, J. E. Phillips, L. C. DiNetta, J. D. Meakin
Institute of Energy Conversion
University of Delaware
Newark, Delaware 19716

Abstract
A monolithic optically and electrically coupled two junction tandem solar cell has been produced. The component cells are $CdS/CuInSe_2$ and CdS/(CdHg)Te polycrystalline heterojunctions. Devices with over 1.0 volt open circuit voltage and over 6 mA/cm^2 short circuit current have been achieved. It is estimated that an efficiency of over 20% should be practically achievable.

1. Introduction

For thin-film solar cells to be a competitive source of power requires a low-cost, high-throughput fabrication process yielding photovoltaic modules of high efficiency. Recent studies(1), suggest that module efficiencies of about 15% at air mass one will be required. To produce modules of this efficiency, the individual solar cells must have an efficiency of greater than 16% to compensate for interconnect, shading and other losses.

A single junction solar cell can only utilize photons of energy exceeding the bandgap of the absorbing semiconductor and has a thermodynamically limited efficiency under unconcentrated sunlight of about 30%(2). However polycrystalline and amorphous solar cells are expected to be limited to considerably lower efficiencies.

By positioning a second solar cell of smaller bandgap to intercept the lower energy photons which pass through a wider bandgap solar cell, the total conversion efficiency can be increased. In the limit of an infinite stack of cells, the thermodynamic limit in efficiency is 68% for unconcentrated sunlight(2).

The increase in complexity of device manufacture weighed against the improvement in efficiency, practically limits the number of cells in a multijunction device to 2 or 3 at present. Two cell tandem systems can either be electrically connected in series (two terminal) or electrically isolated (four terminal). The maximum efficiency of these tandem structures are between 36% and 37% under AM1 insolation(3). To date, major emphasis in tandem cells has focussed on single crystal III-V materials(4) and thin-films based on amorphous Si:H(5) and only recently has there been work on polycrystalline thin-film materials(6,7). Since all the polycrystalline thin-film devices with efficiencies over 10% have been based on CdS or (CdZn)S as a window material, design studies of cells based on these window materials have been carried out(8). The maximum efficiencies at AM1 computed for two junction tander devices are 21% for CdS based materials and 26% for (CdZn)S based materials.

In this paper we report on the development of a thin-film polycrystalline $CdS/CdTe-CdS/CuInSe_2$ tandem heterojunction cell. The CdS/CdTe and $CdS/CuInSe_2$ cells were used as the constituents of the tandem device since their bandgaps are close to optimum and both have a proven efficiency of over 10%(9,10).

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2. Approach

The practical efficiency limits for polycrystalline thin-film tandem cells will necessarily be lower than the idealized cases calculated previously. In order to assess the potential for further improvement, an analysis of the practical achievable performance parameters has been made. The maximum current has been computed using an AM-1.5 direct insolation spectrum normalized to 100 mW/cm^2(11). $(Cd_{0.7}Zn_{0.3})S$ was used as the window material in a calculation to assess the optimum V_{oc}.

Table 1 summarizes the results of the calculations for the individual and tandem cells. Both heterojunctions were assumed to be dominated by interface recombination with an interface recombination rate of $3x10^7$cm/sec. A 10% loss due to front surface reflection and contacting was used for all calculations. The quantum efficiency for the individual cells was assumed to be 100% for the $CuInSe_2$ and 80% for the CdTe. In the tandem structure the value was reduced to 90% for the $CuInSe_2$. Using the same assumptions but with CdS as the window material yielded individual cell results comparable to the experimental values reported for $CuInSe_2$ and CdTe cells.

3. Device Design and Preparation

Although efficiency limits have been discussed, little attention has been paid to the practical design features and fabrication of a monolithic tandem cell. Two major considerations that need to be addressed are: 1) the type of interconnect between the cells, and 2) the effects of the fabrication steps on the individual cell properties.

There are several ways to provide a transparent ohmic contact between the two cells. If a tunnel junction interconnect is used, the CdS and CdTe films must be highly conducting at the interface between the two cells. Since the properties of these films required at the heterojunctions will, in general, be different than at the tunnel junction, precise control of the film properties during deposition is needed. Another approach to interconnecting the cells is a transparent metal or grid structure which places less stringent requirements on the CdS and CdTe film properties. However, the interconnect must make ohmic contact to p-type CdTe and n-type CdS and have a transmission of at least 90% so that the loss in light generated current due to the interconnect is less than 10%. We have used ITO to make ohmic contact to the CdS and found that a 50 Å layer of Cu between the ITO and CdTe forms a reasonable contact to the CdTe. The optical transmission of this contact is ~ 80% at present. The copper is a p-type dopant in CdTe and is believed to be incorporated in the CdTe film during deposition modifying at least the contact region of the film. Bonnet(12) has previously reported the use of copper to improve contact to CdTe.

During fabrication of tandem devices, the process for making the second device must not adversely affect the initial cell. This places limits on both structural aspects and the temperature cycles to which the various components are subjected. For the $CdTe/CuInSe_2$ tandem cell, the fabrication procedure for the $CuInSe_2$ cell was chosen to minimize the surface texture onto which the CdTe cell is deposited and the formation process for the latter cell was selected to avoid high temperature steps.

Figure 1 shows a cross-section of the tandem cell structure. The $CuInSe_2$ film is deposited on a Corning 7059 glass slide sputter coated with approximately 1 μm of Mo. The $CuInSe_2$ evaporation system consists of three elemental source bottles where precise temperature control of the molten Cu, In, and Se is used to control the effusion rates and thus the film composition. The $CuInSe_2$ film is grown in two stages in a manner similar to Mickelsen and Chen[13], at an average growth rate of typically 10 Å/sec.

The CdS is deposited by thermal evaporation from a powder source bottle at a film growth rate of 0.3 µm/min and a substrate temperature of 200°C. The resistivity of the film is ~ 0.01 Ω-cm and is controlled by coevaporation of In during deposition. Essentially simimlar films are used to form both the $CdS/CuInSe_2$ and CdS/CdTe junctions, the low resistivity insures that the depletion layer is entirely in either the $CuInSe_2$ or CdTe.

CdTe is also deposited by thermal evaporation in the same way as the CdS. Hg is incorporated in the films during deposition and has been found to promote single phase CdTe [(CdHg)Te] films at substrate temperatures as low as 160°C and also to improve the reproducibility of the films. (CdHg)Te films with 1-5% Hg are deposited at growth rates of ~ 0.01 µ/min and are typically 2 µm thick. The films are heat treated in air at 300°C for 3 hours prior to the CdS deposition as this has been shown to generally improve the open circuit voltage of the CdTe cells.

The cell area and contacts are defined by a photolithography-etching procedure. This procedure yields 12 tandem cells each 3x3 mm^2 on a 2.5x2.5 cm^2 substrate. The cell has three terminals so the individual and tandem characteristics (J-V, spectral response, etc.) can be measured.

4. Results

The J-V characteristics of a $CdS/(CdHg)Te-CdS/CuInSe_2$ tandem cell are shown in Figure 2 along with the individual cells. The basic parameters for this device as well as one with a higher V_{oc} are given in Table 2. For both these cells, the efficiency is limited by the response of the $CdS/CuInSe_2$ cell. This device has low current due to high optical losses in the (CdHg)Te layer at present.

The spectral response of the individual devices is shown in Figure 3. The lack of response in the $CdS/CuInSe_2$ device at wavelengths shorter than the CdTe bandgap is indicative of a well defined pinhole free tandem structure.

5. Summary

The $CdS/(CdHg)Te-CdS/CuInSe_2$ device demonstrates that a two cell multi-bandgap tandem structure can be made from single junction polycrystalline thin-film solar cells. A low temperature (~ 160°C) process for depositing the (CdHg)Te cell was used to be compatible with the $CuInSe_2$ cell fabrication. ITO/Cu was used as a transparent ohmic interconnect between the two cells. By reducing optical losses of the device and improving processing techniques efficiencies >15% should be achievable.

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TABLE 1

Practical Efficiency Limits For (CdZn)S Based Thin-Film Devices

Device	V_{oc} (V)	J_{sc} @100mW/cm^2 (mA/cm^2)	FF (%)	Eff (%)
$Cd_{0.7}Zn_{0.3}S/CuInSe_2$	0.62	40	65	16
$Cd_{0.7}Zn_{0.3}S/CdTe$	1.0	20	80	16
Tandem	1.6	18	75	21

TABLE 2

I-V Results of Tandem and Individual Solar Cells

Device	V_{oc} (V)	J_{sc} † (mA/cm^2)	FF (%)	η (%)
Tandem	0.792	6.7	49	3.0
(CdHg)Te	0.465	9.7	36	1.9
$CuInSe_2$	0.327	6.3	51	1.2
Tandem	1.020	6.5	40	3.0
(CdHg)Te	0.683	8.3	30	1.9
$CuInSe_2$	0.336	6.1	46	1.1

† AM1 equivalent ELH illumination at 87.5 mW/cm^2

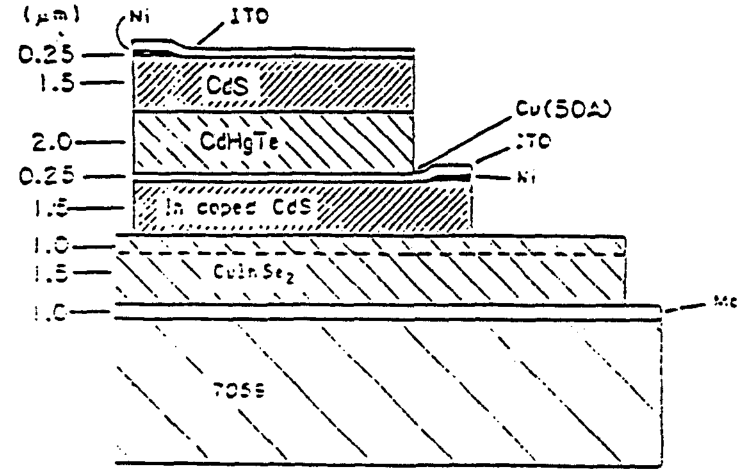

Figure 1. Cross-section of $CdS/(CdHg)Te-CdS/CuInSe_2$ polycrystalline cell.

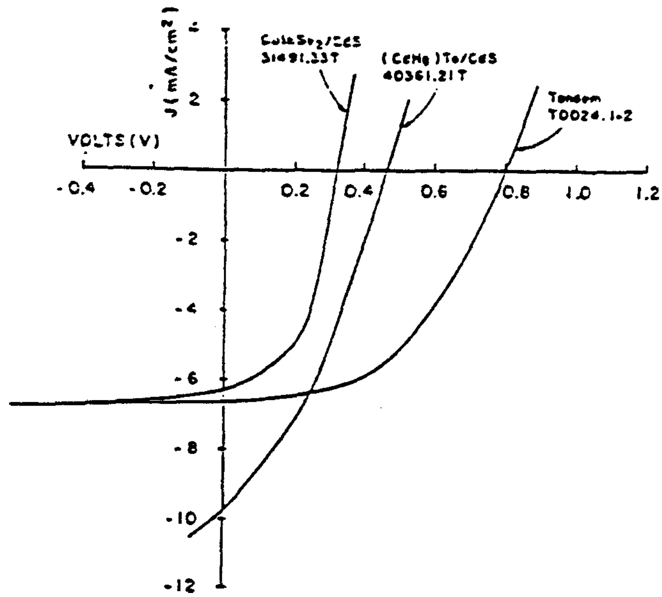

Figure 2. J-V characteristics of tandem and individual cells.

SPECTRAL RESPONSE FROM INDIVIDUAL JUNCTIONS

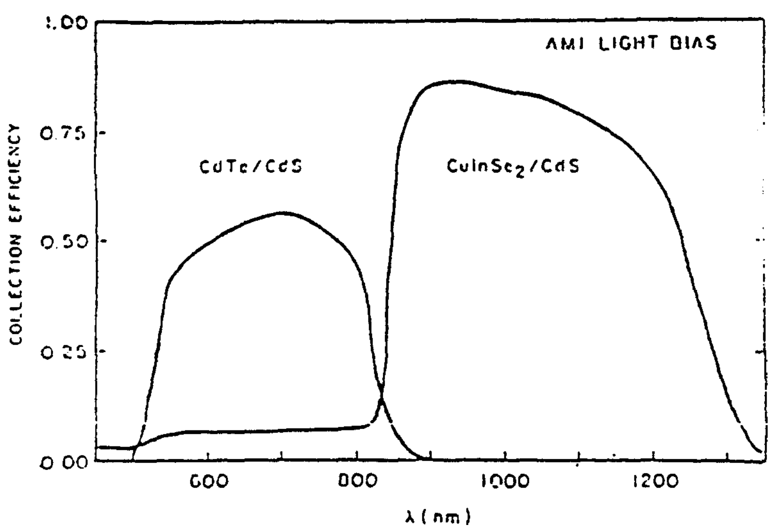

Figure 3. Spectral response of the individual devices of a tandem cell.