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EMERGING MATERIALS FOR SOLAR CELL APPLICATIONS—ELECTRODEPOSITED CDTE

Second Quarter Report for Period May 16—August 15, 1980

By
Robert L. Rod
Bulent Basol
Oscar Stafsudd

September 10, 1980

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Monosolar, Inc.
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Solar Energy

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PREPARED FOR THE
SOLAR ENERGY RESEARCH INSTITUTE
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ABSTRACT

During the second quarter of this seven month long effort, work was centered about improving electroplating processes and cell fabrication techniques, with emphasis being given to three differing n-CdTe/Au Schottky configurations. The highest values of efficiency-related parameters achieved with a simulated solar irradiation of 100 mW/cm^2 were 0.57V for open circuit voltage, 0.6 for fill factor, and 6 mA/cm^2 for short circuit current.

Four important parameters are known to control the quality of the Monosolar electrodeposition process and resultant solar cells. They are electrolyte temperature, Te concentration in the solution at a specific pH, deposition or quasi-rest potential, and flow pattern of the electrolyte (stirring). The first three considerations are believed to be fully understood and optimized. Work is underway to further understand the effects of stirring on the diffusion of ionic components and the effects on CdTe film performance.

Work was accelerated during the quarter to increase the short circuit current. Parallel programs using laser irradiation of finished CdTe films, heat treatment, and changes in the electodeposition process itself to recrystallize films were started. The surface etching technique has been highly refined, while the entire cell manufacturing process is now reproducible when defect-free substrates are used.

1. GENERAL REVIEW

The previous quarterly report for this effort reviewed the electroplating techniques involved as well as the general approach to making Schottky diode-type solar cells used for electrical characterizations. That report also gave values for the optical absorption coefficients for electrodeposited polycrystalline CdTe, the resistivity, and the hole diffusion length.

Work during the current effort has been concentrated mainly on device fabrication, with particular emphasis being given to maximizing efficiency. Work also continued on electroplating and characterizing p-CdTe films. All of the work was complicated by problems with the quality of ITO-coated substrates supplied by PPG Industries, Inc. An original and very large supply of good PPG ITO/glass ordered a year ago was exhausted at the beginning of the quarter, and newly received material proved uniformly unsatisfactory. Later investigation and a trip to PPG in Pittsburgh to discuss the situation with their key management personnel revealed that the good ITO was deposited on vertically drawn glass sheet that no longer is made by PPG. Later shipments were made on vertically drawn glass made in Europe. During sea transport to America, the salt air attacked and pitted the glass on which ITO later was deposited by PPG at their Huntsville, Alabama, plant. Quality control at Huntsville also left much to be desired in terms of glass washing and cleaning procedures, uniformity of temperature in the sputtering chamber, uniformity in thickness of the deposited ITO film and resulting grain sizes, and freedom from other defects.

In Fig. 1 it can be seen that good pinhole-free CdTe layers can be electrodeposited on good ITO films whereas poor ITO-coated substrates create undesirable plating results. Pinholes and other defects inthe ITO translate into larger ones in the CdTe films which, in extreme cases, result in severe cracks in the semiconductor films propagating between ITO flaws.

For quite some time during the quarter there were no satisfactory ITO substrates on hand, and emergency means were taken to secure others that could be used instead. Initial ITO films on glass supplied by OCLI also were unsatisfactory. However, in late August OCLI rectified their problems and delivered satisfactory material in suitable quantities. A dozen ITO-coated glass substrates also were plated by the Bunshah group at UCLA but they were not needed after the OCLI ones arrived.

Backing up the ITO program was an effort to obtain CdS substrates on glass from the University of Delaware group. Mo-coated glass substrates supplied by Monosolar were delivered to the University of Delaware and were coated there with several microns thick CdS. CdTe films plated at Monosolar on these CdS substrates produced Au Schottky diodes with the best performance achieved so far. Fill factors and open circuit voltages were in the order of 0.6, while short circuit current averaged around 6 mA/cm^2. The J_{sc} appeared limited by the short lifetime in the n-CdTe which in itself limited current collection to about a quarter of the 0.8 μm thickness of the CdTe film. It is apparent that longer diffusion length in CdTe should produce substantial increases in cell performance, and all efforts are directed toward this goal.

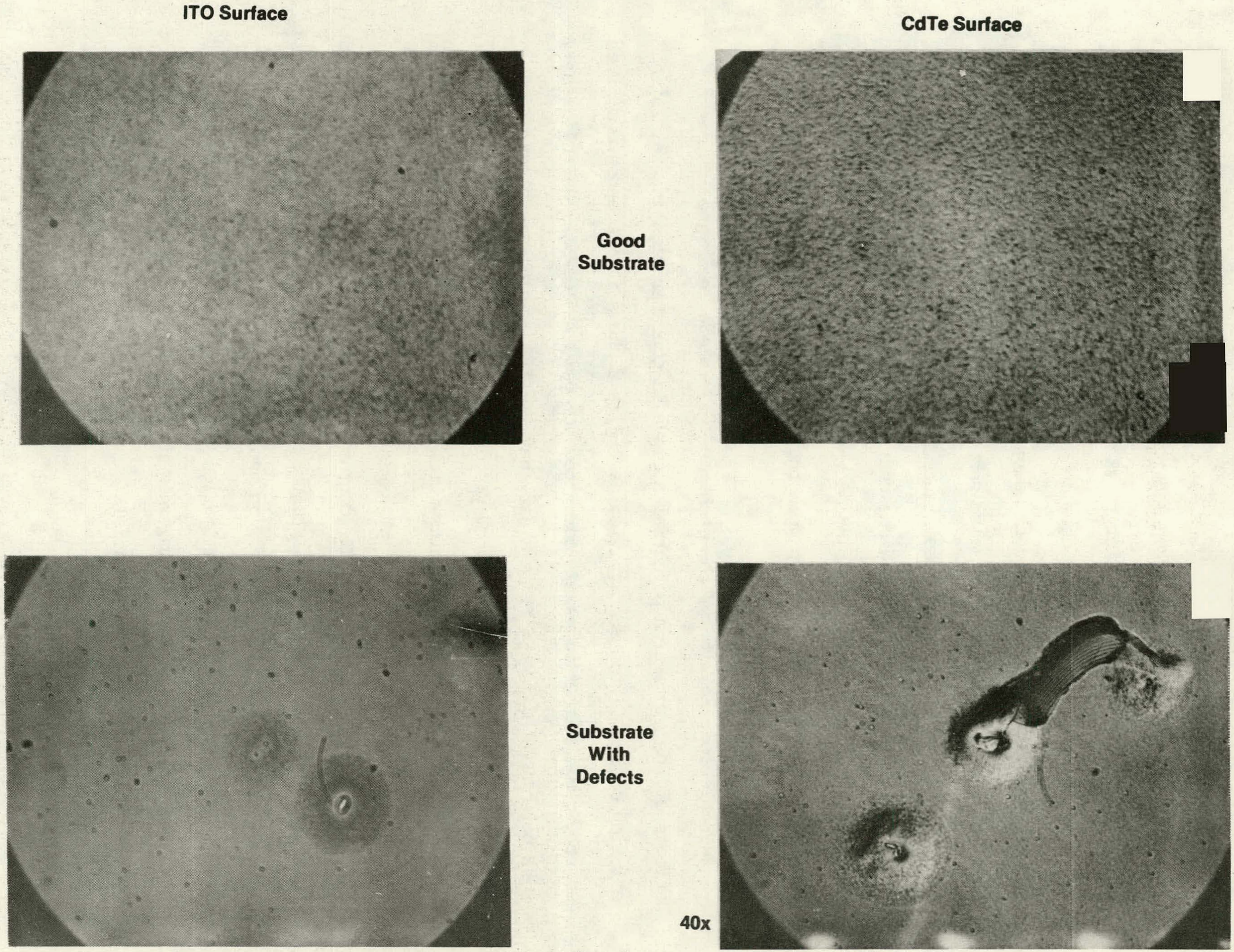
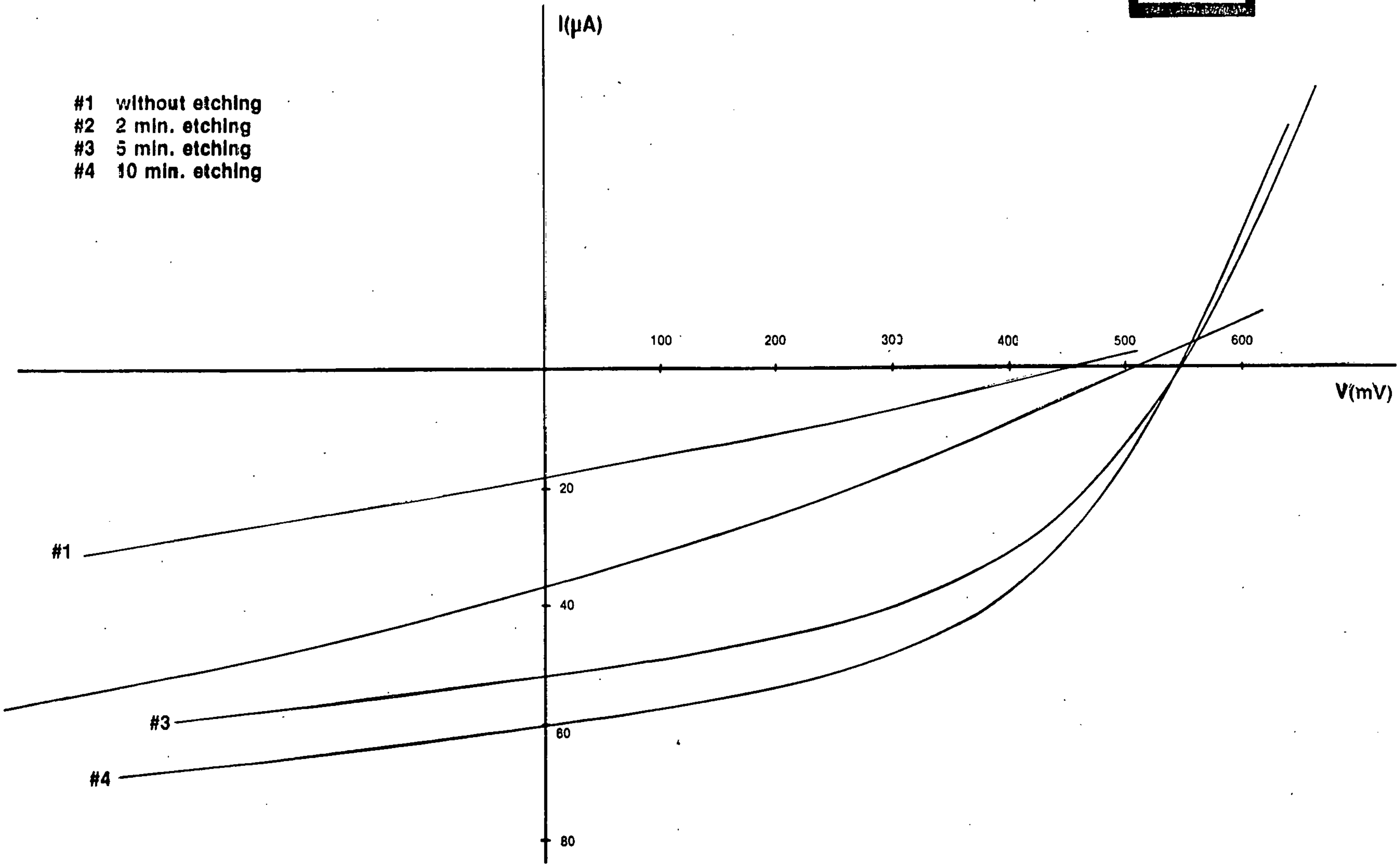

ITO Surface
CdTe Surface
Good Substrate
Substrate With Defects
40x

Fig. 1

2. PROCESS IMPROVEMENTS

The development of a hot KOH (30%) etch process for treating the surface of the n-CdTe layer prior to vacuum evaporation of Au forming a Schottky barrier was a major development during the period. Treatment in KOH for various times varied the device performance as is shown in Fig. 2. The untreated case is also shown for comparison. It is believed that the etch removes a high resistance oxide layer that forms in air and becomes so thick that the diode characteristics suffer from excessive series resistance. It was also noted that the characteristics of the completed devices improved further when they were rinsed in hot KOH solutions for 10 - 60 seconds.

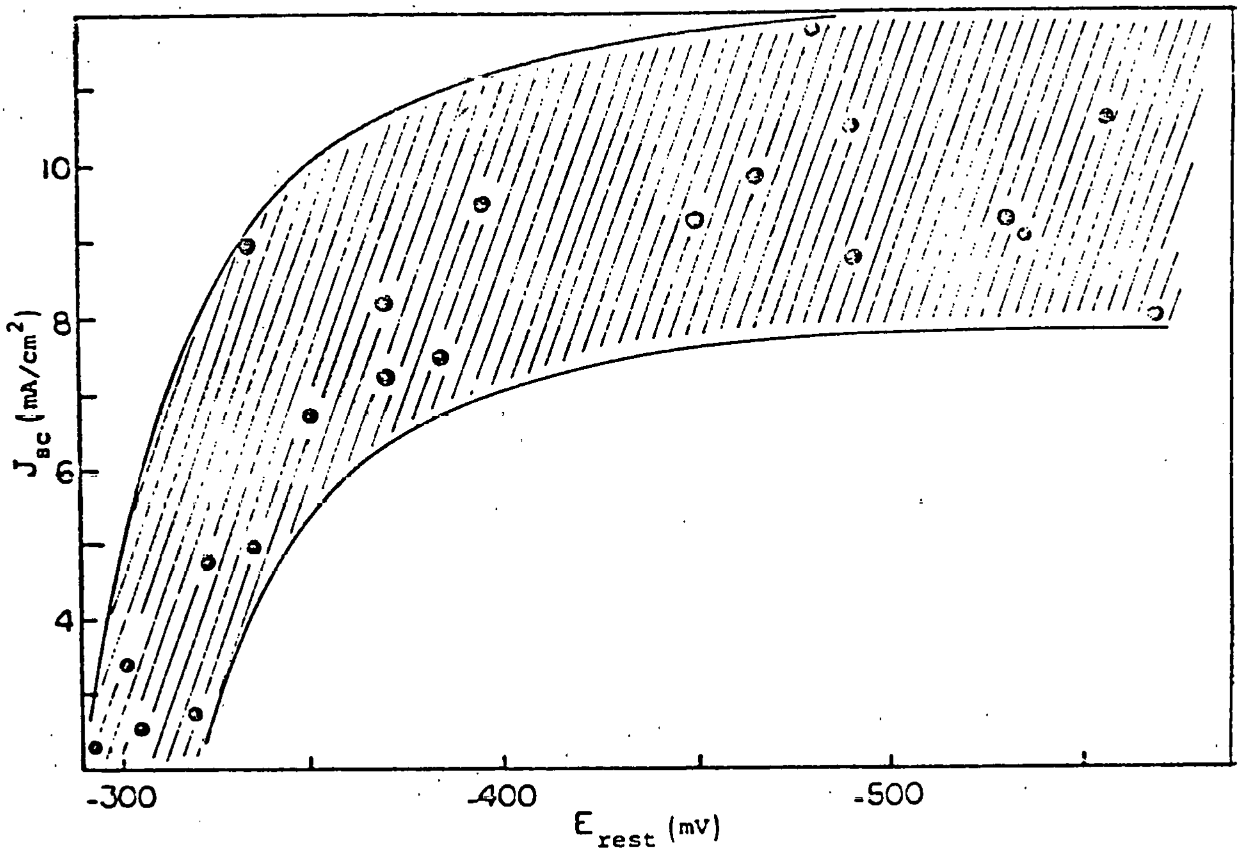
The reproducibility of the etch made possible a reexamination of the effects of the deposition potential and the Te concentration in the plating solution on the device characteristics. Fig. 3 shows the dependence of the short circuit current density (corrected for gold reflection) on the quasi-rest potential (E_{rest}). It is clear that the films which are prepared at rest potentials higher than 350 mV yield the best devices. This is in accordance with our previous results which showed that the lowest resistivity n-types films are obtained at high rest potentials. Fig. 3 also shows the effect of E_{rest} on the ITO/n-CdTe contact behaviour. Device #1 is on a film which is prepared at consistently high rest potentials and exhibits good solar cell characteristics. Device #2, on the other hand, shows a leaky barrier at the ITO/n-CdTe contact. Examination of the E_{rest} values, which were monitored during plating of the film, show that the CdTe close to the ITO contact was deposited at low rest potentials.

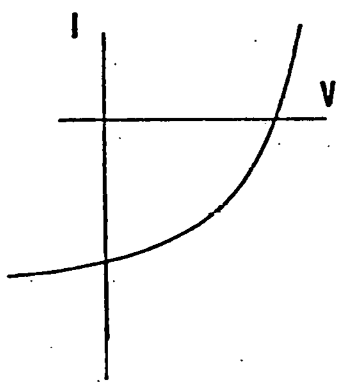


Effect of surface treatment on the solar cell I-V characteristics.

Au/n-CdTe Schottky device with an area of A = .015cm²

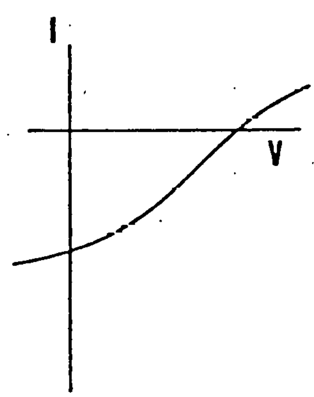
Fig. 2





DEVICE #1

Dep. time (min)	—Erest(mv)	
	Device #1	Device #2
3	425	230
10	420	220
30	416	330
45	400	360
60	410	350
75	420	
90	450	



DEVICE #2

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Fig. 3

Another important parameter of the electrodeposition process is the Te concentration in the plating solution. With the aid of the Atomic Absorption Spectra measurements we were able to control this parameter and determine its effect on the devices. Fig. 4 shows the dependence of V_{OC} values on the Te concentration in the plating bath. The trend is the same for other solar cell parameters. It is observed that the optimum Te concentration is between 17-22 ppm in a solution of 0.5 M $CdSO_4$ at $90^{\circ}C$. The rest potentials are kept high (-500 -600mV) in their experiments to eliminate their effect on the solar cell parameters.

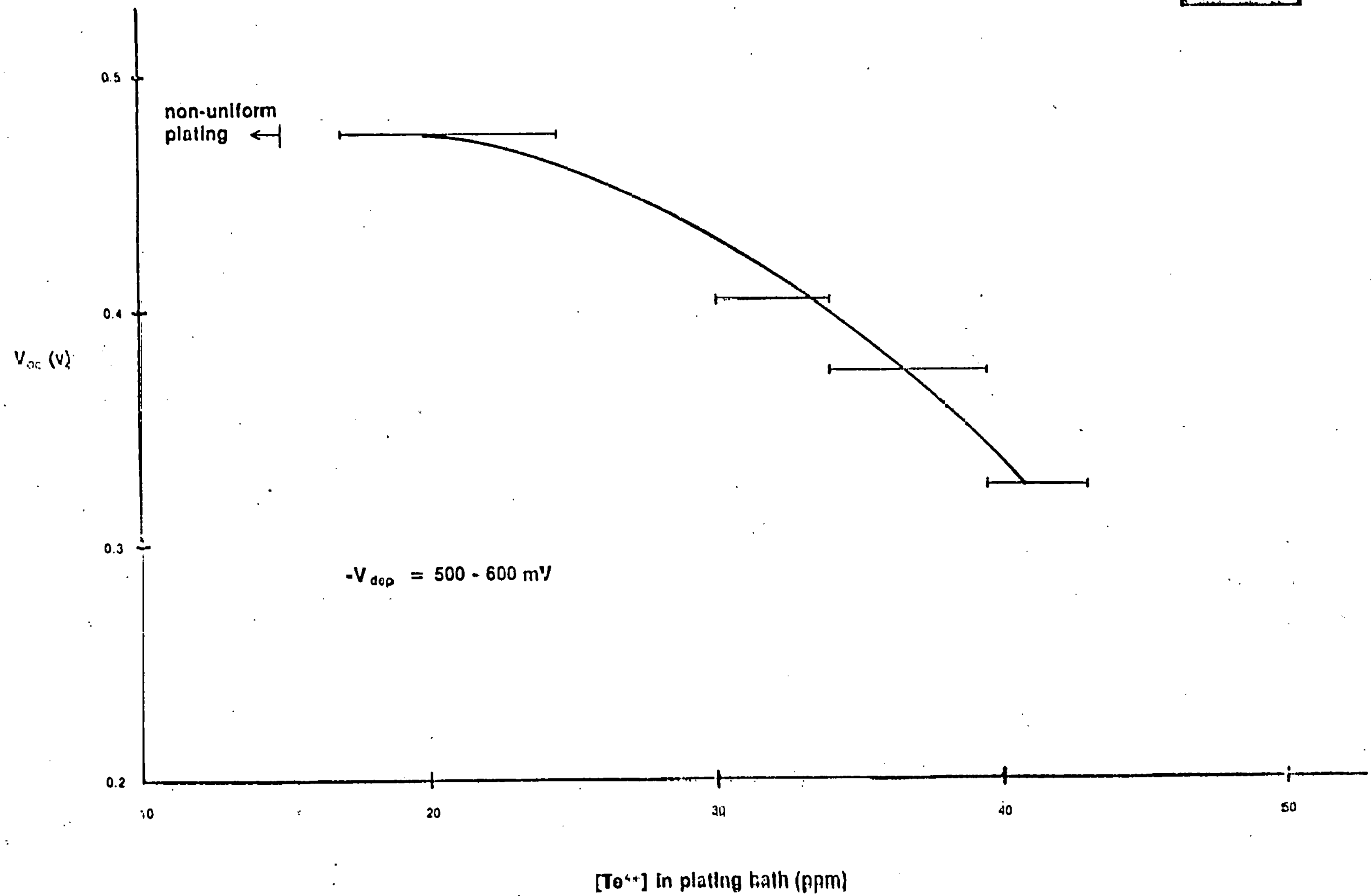

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Fig. 4

3. DEVICES

Three different Schottky barrier solar cell structures were studied during the quarter. The first continued to be the Schottky configuration glass/ITO/n-CdTe/Au wherein the ITO was that commercially available from PPG Industries, and the CdTe was electrodeposited on top to a thickness of about 0.8 µm. Approximately 110 Å of Au was vacuum deposited on the CdTe after the aforementioned KOH etch was applied. It was found that best results were obtained by depositing the gold at a rate of 5-10 Å/sec; this was manifested by a lower Au sheet resistance for a particular film thickness. Typical performance of this type cell is given in Table I.

The other two configurations made and tested used CdTe deposited over substrate applied either to PPG ITO or to metallized (Mo) glass substrates. In some cases Ni substituted for Mo with no change in cell performance. Again, typical results achieved for these two cell configurations are given in Table I. Of particular importance is the fact that the ITO-type CdS/CdTe/Au cell was illuminated through the ITO which serves also as a built-in A/R coating. It is this back wall configuration which is felt to have excellent near-term promise as a low cost, high efficiency solar cell in its optimized form.

Fig. 5 illustrates the electrical performance and the spectral response for the Mo-backed CdS/CdTe/Au cell $\lambda>0.55$ µm illuminated through the gold layer which had an average percentage transmission of about 40 at $\lambda>0.55$ µm. Low blue response is believed to be due to the Au absorption as well as the surface recombination. Particularly encouraging were the values of 0.56V for V_{oc} and 0.57 for fill factor. Short circuit current for this and the other two cell configurations remained low and is the subject of intensive study at this writing.

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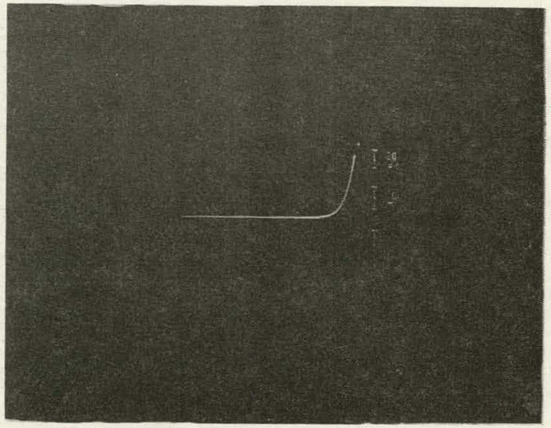
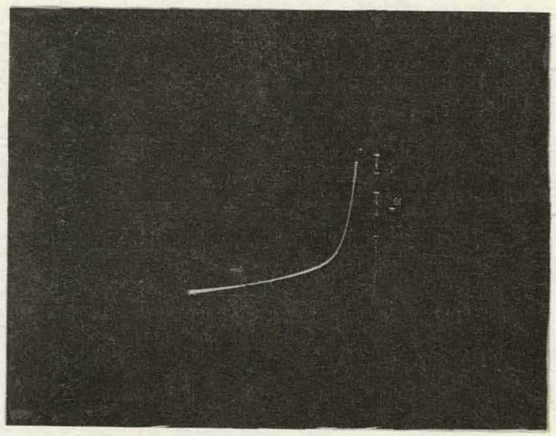
PRESENT STATUS
OF THE CdTe/Au SCHOTTKY
DEVICES

Structure	V_{OC}	J_{SC}	F.F.
ITO/n-CdTe/Au Front wall	0.5-0.53	4-4.5mA/cm^2	0.48-0.5
ITO/CdS/n-CdTe/Au Back wall	0.48-0.55	5-6mA/cm^2	0.5-0.6
Mo(Ni)/CdS/n-CdTe/Au Front wall	0.5-0.57	5-6mA/cm^2	0.5-0.57

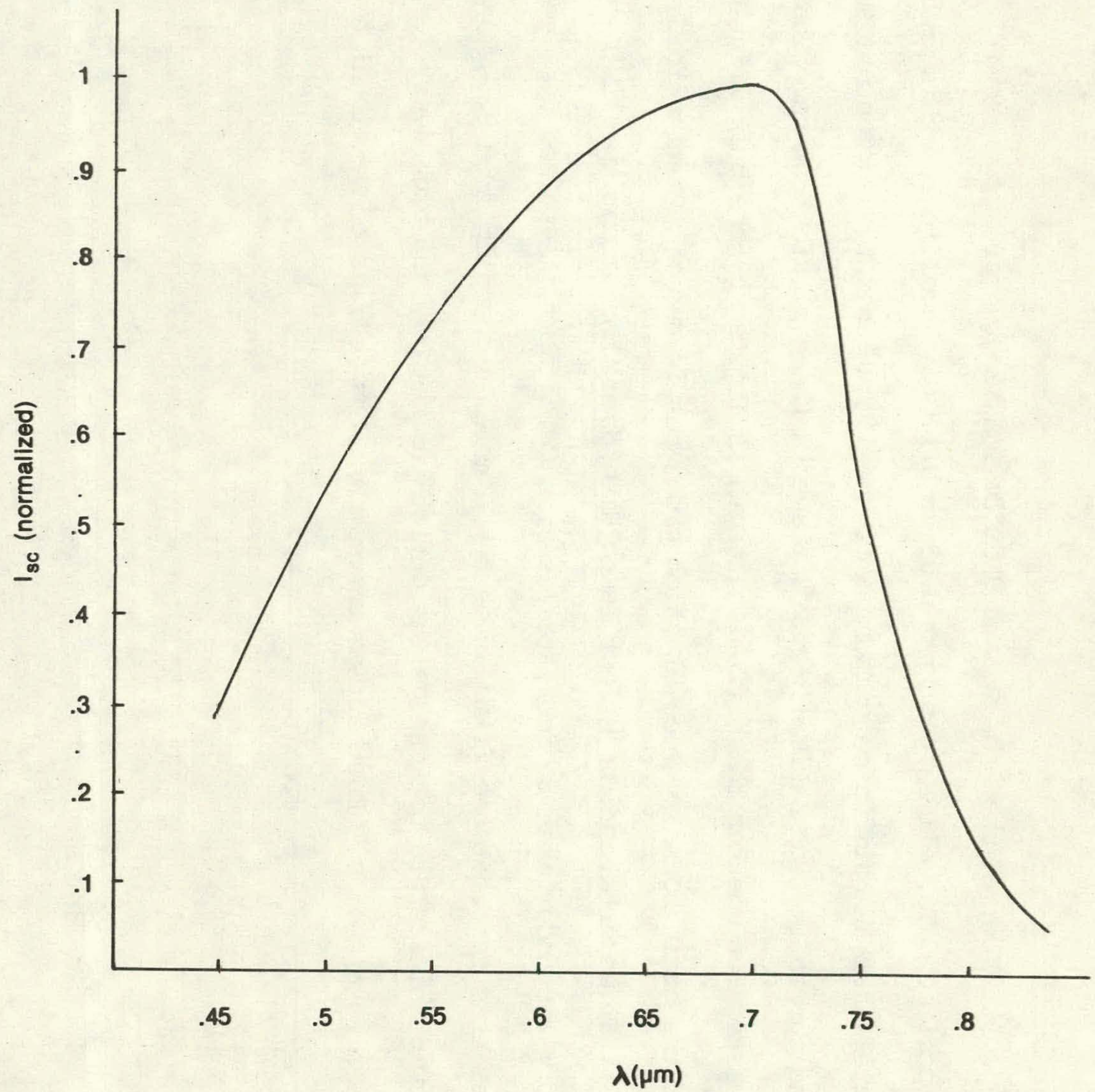
P_{in} = 100 mW/cm^2

Table I





Mo/DdS/n-CdTe/Au device
P_{in} = 85 mW/cm^2 V_{oc} = .56V
A = .02 cm^2 F.F = .57 I_{sc} = 80μA



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It is known that the measured diffusion length for our electrodeposited CdTe cell ranges from 0.05 to 0.1 μm. Accordingly, this indicates that the diffusion component of the light generated current is small and the collection basically takes place in the depletion region. The question of whether the diffusion length is limited by the bulk lifetime or the grain boundary recombination processes is under investigation.

To ascertain which effect is holding down the current, preliminary work was undertaken to recrystallize the CdTe films. A pulsed dye laser was used to treat the films at energy densities changing from 0.5-2 J/cm^2. Low densities did not change the device parameters, and high densities gave rise to pinholes. Further laser treatment, as well as conventional heat treatment, will be continued.