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CADMIUM SULFIDE/COPPER SULFIDE HETEROJUNCTION
CELL RESEARCH

Technical Progress Report No. 2, January 1—March 31, 1978

By
J. R. Szedon
F. A. Shirland
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August 9, 1978

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ABSTRACT

Poor adhesion of CdS films to zinc-plated copper foil substrates has been eliminated by depositing somewhat thinner films than earlier and by using the mat (as opposed to the smooth) side of the electroformed copper foil for deposition. Particle spatter effects have been reduced and cells of 4 cm² area have been produced with average efficiency of 5.4%. Use of Zn-plated Cu, Mo, Zn-plated Mo and glass substrates appears to influence the etching behavior of CdS films in dilute chromic acid. The results suggest a sensitivity to the presence of zinc. Laser scanned reflection and photocurrent response studies reveal some influence of substrate morphology. Direct correlations are weak, presumably because of strong local variations in topography, due to texturing and in carrier transport or junction collection efficiency. Similar types of studies on single crystal-based cells have established the feasibility of using localized photoresponse to characterize minority carrier transport in special test structures. Compositional analysis of Cu₂S layers on single crystal CdS have been attempted using ESCA and ion etching methods. A major problem is the formation of copper nodules, presumably due to the ion etching method, which do not permit obtaining a true profile of this element. Films of (Zn_xCd_{1-x})S alloys, deposited using electron beam evaporation, have been made with composition corresponding to that of the evaporant sources.

1. SUMMARY

During the second quarter of this program, problems encountered earlier with adhesion of CdS films to zinc-plated copper foil substrates have been solved. The most important factors involved in improving adhesion are maintaining thickness of the CdS layer to less than $30\mu\text{m}$ and using the mat surface of the electroformed copper foil for deposition. Thin film cells of 4 cm^2 area have been prepared using this type of substrate giving average conversion efficiency values of 5.4% on the most recently fabricated units.

Studies using various substrates for the CdS depositions suggest that etching behavior of the CdS is affected by the nature of the substrate. As reported earlier, etching in dilute chromic acid delineates areas comparable in size to the expected crystallite size when Zn-plated Cu foil substrates are used. For films on molybdenum foil or glass, no preferential etch delineation of such areas occurs. On zinc-plated molybdenum, preferential etching has been observed in certain areas, but the features are only reminiscent of those on zinc-plated copper. These results suggest that zinc in the grain boundary regions may affect etching as just described. The possibility is raised that similar sensitivity to zinc may affect the texturing produced by HCl etching prior to Cu_2S layer formation. Because of the high degree of surface roughness after HCl etching, it is difficult to design experiments comparable to those involving the chromic acid etch.

2. INTRODUCTION

2.1 Objective

The objective of this program is to conduct research on solar cells of the copper sulfide/cadmium sulfide and copper sulfide/cadmium sulfide-zinc sulfide alloy) types with the goal of producing thin film cells capable of 10% AM1 conversion efficiency with less than 5% degradation in performance over a use period of 20 years.

2.2 Background

In the present program, the approach deals with three topics: (1) Control of selected Cu_2S and CdS material and physical properties relevant to solar cell operation, e.g., thickness, crystallite size and electrical characteristics, and determination of the effects produced on cell mechanisms and performance. (2) Production and evaluation of structures with simple geometries, usually on single crystal substrates. (3) Extension of significant results in the foregoing as to thin film $\text{Cu}_2\text{S}/\text{CdS}$ or $\text{Cu}_2\text{S}/(\text{CdZn})\text{S}$ solar cells for a better understanding of the ultimate performance of such cells. The program planned to execute this work involves nine tasks. They are:

1. CdS preparation, evaluation, and control.
2. Cu_2S preparation and evaluation.
3. Prototype cell fabrication and evaluations.
4. $\text{Cu}_2\text{S}/\text{Zn}_x\text{Cd}_{1-x}\text{S}$ studies.
5. Model development and refinement.
6. Copper migration, oxygen, and heat effect studies.
7. Design, fabrication and evaluation of improved cells.
8. Assessment and extrapolation of program results.
9. Cell process cost analysis.

In the discussion of progress on the program which follows, individual technical topics may be referred back to these tasks.

2.3 Emphasis for this Quarter

During the previous quarter a problem was encountered in obtaining good adhesion of evaporated CdS film on zinc-plated copper foil substrates for the preparation of state-of-the-art thin film cells. This problem has been overcome, as described in Section 3.1. Additional influences of the substrate have been studied (Section 3.2). Performance of the thin film cells has been steadily improved (Section 3.3), although localized, large etch features in the CdS films are considered to be responsible for performance suppression. Some preliminary studies (Section 3.4) have been made using a scanned He-Ne laser (6330Å wavelength, $\sim 0.3 \mu\text{m}$ penetration in Cu_2S) to assess the uniformity of photocurrent response in a thin film cell.

Single crystal CdS substrates have been used for two different applications. In one, photocurrent response for different thicknesses of the Cu_2S layer was evaluated as a means of characterizing minority carrier transport (Section 3.5). In the other, ESCA profile studies were done on the major components of the Cu_2S film and the CdS substrate for selected preparation conditions (Section 3.6).

Preliminary work on preparing films of $(\text{ZnCd})\text{S}$ alloys using electron beam deposition is described in Section 3.7.

3. PROGRAM PROGRESS

3.1 CdS Film Preparation

Adhesion of CdS films on zinc plated copper foil substrates has been improved by a number of steps taken during this quarter. Poor adhesion had manifested itself in peeling of the CdS film from the substrates, particularly around the periphery of the 7" x 7" evaporated area, in the evaporator as the film was cooled down from the 220°C deposition temperature. Occasionally peeling occurred immediately after removal of the deposited film from the evaporator. A number of factors appear to have combined to aggravate the problem. With time, these factors have been isolated and brought under control.

Apparently oil contamination of the vacuum chamber was the initial cause of the problem. This occurred during regeneration of the molecular sieve used between the roughing pump and the vacuum. Presumably oil vapors driven out of the molecular sieve got into the roughing line and, eventually, into the vacuum chamber. Before this problem could be identified and eliminated, difficulties with the zinc plating bath also occurred. When tested, the bath was found to be out of specification and contaminated with organic matter.

While these difficulties were being experienced, changes were introduced in the evaporation parameters in an effort to minimize spatter from the CdS source. Such spatter produces pinholes in the film on further processing and leads to poor shunt characteristics of completed cells. One approach to alleviate the pinhole problem was to resort to slightly thicker CdS films than usual (30 to 35 μm instead of 25 to 30 μm). This further aggravated the adhesion problem, although this effect was not immediately recognized. It had been the practice at Westinghouse to deposit CdS films on the smooth surface of the electro-formed copper foil substrates rather than on the mat surface. Use of the

smooth surface results in CdS films with a better optical quality which are more readily examined visually for freedom from flaws, spatter, etc. As the CdS film thickness exceeds about 30 μm , the stresses due to thermal expansion mismatch between the CdS film and the substrate exceed the adhesion forces for the smooth substrates. This occurs even if the substrate is clean and all other parameters are under control. When the films were deposited on the mat surface of the substrate, adhesion was excellent.

3.2 Substrate Effects

Two topographic aspects of thin film CdS-based solar cells have been examined during this quarter with respect to possible substrate influences: etching at grain boundaries and so-called "growth anomalies." Both matters can influence cell performance. Differences in etching behavior of various CdS films can affect the surface texture. This controls the degree of light trapping and hence the short circuit current of otherwise identical cell structures.

Growth anomalies are regions of CdS ranging in diameter from several to about 10 micrometers which protrude noticeably above the average level of the CdS films, as prepared. One such growth anomaly of about 2 μm size is shown to right of center in the upper part of Fig. 1. After texture etching of the CdS in HCl prior to Cu_2S formation, holes are found having a size distribution and spacing corresponding to that of the growth anomalies. Fig. 2 is an SEM view of an etched film surface illustrating this.

The presence of large, deep holes is expected to degrade cell behavior by simple shunting or by introducing an area of poorer photovoltaic performance in parallel with the primary cell area. Currently, the only estimate of depth for these holes is $\sim 5 \mu\text{m}$ (as a minimum) by inference from SEM views such as that in Fig. 2.

One simple explanation for these anomalies is that they are not the result of growth at all, but are particles of CdS sputtered

Fig. 1 SEM View (45°) of CdS film on Zn-plated Cu foil

Fig. 2 SEM view of HCl etched CdS film on Zn-plated Cu foil

from the evaporation source. This may be true in some cases, particularly if high evaporation rates and poorly packed evaporation sources are used. When these influences are eliminated, the anomalies are found to have a preferential incidence over the 7 in x 7 in (17.8 cm x 17.8 cm) substrate area. For example, with zinc-plated copper foil, they tend to be more prevalent near the edges of the substrate in the areas of greater roughness of zinc plating. Also, in the central part of the substrate these features appear to be aligned with the pattern of microscopic ridges in the substrate. Both of these observations support the view that the features in question arise during growth and are not produced by spatter from the evaporant crucibles.

In the case of molybdenum and glass substrates, features of the same size distribution have also been observed. Such results indicate that the cause of these anomalies is in the growth process itself, with the substrate playing a secondary role.

When difficulties with poor adhesion were experienced on zinc-plated copper substrates (Section 3.1), a number of depositions were carried out on molybdenum foil. The close match of thermal expansion of molybdenum to CdS does not aggravate adhesion problems. Some depositions were also made on glass substrates.

Both arc cast and powdered metal base molybdenum sheets, partially recrystallized, have been used in thicknesses of .001" and .002" as a substrate with comparable results. Adhesion of the CdS films has been excellent. Cells fabricated from such films have generally exhibited good dark characteristics and high shunt resistances. Values of short circuit current density have been low for such cells, $\lesssim 13 \text{ mA/cm}^2$.*

The low values of short circuit current density observed from film cells on Mo substrates suggest that etch texturing may not be occurring as much as it normally does for CdS films on zinc-plated copper substrates. Since direct techniques to sensitively assess this do not

* See Reference 1, Table II, Cells 497-2 through 497-4.

exist, an indirect method was used. As reported earlier (Ref. 1, Section 3.2) etching in dilute chromic acid delineates CdS surfaces into regions about 1 μm across, presumably by preferential etching at grain boundaries. When this technique was used on the CdS films deposited on Mo foil, no preferential etching was observed, as shown in the SEM view of Fig. 3a. The view for 45° orientation of the sample plane (Fig. 3b) is qualitatively similar to that for an as-deposited film on Zn-plated copper (Fig. 1).

Results for a film prepared on Zn-plated Mo-foil substrate were different. In this case regions could be found in which delineation of the CdS by the chromic acid etch did occur (Fig. 4a). Other areas were as featureless as Fig. 3a. This and the absence of closed boundaries for the etched regions in Fig. 4a might be attributed to the uneven nature of the zinc plating.

The results of chromic acid etching of CdS films on molybdenum substrates and on glass substrates (which were also featureless) suggest that zinc might play a role in the chemical activity of CdS films during etching. Better methods of assessing etching effects are required, particularly as regards texturing and grain boundary effects.

3.3 Thin Film Cells

Cell fabrication in this period was limited by the lack of adherent pinhole-free CdS films on copper foil substrates until late in the quarter. Work on the adhesion problem preempted most of the effort on film deposition and it was not until the end of the quarter that adherent, good quality films were obtained. These were reasonably free from pinholes due to coarse CdS particle spatter or to other gross flaws such as cracks which had been present in poorly adherent films.

Several cells of greater than 5% conversion efficiency were obtained, but the yields of cells of 4% or more efficiency were in the 10 to 15% range of the number of cells processed. None of the cells processed on molybdenum substrates had conversion efficiencies greater

(a)

(b)

Fig. 3 SEM views of CdS film on Mo foil substrate after etching in chromic acid. (a) Viewed at 0° . (b) Viewed at 45°

(a)

(b)

Fig. 4 SEM views of CdS film on Zn plated Mo foil, after chromic acid etching. (a) Viewed at 0°. (b) Viewed at 45°.

than 3.5% and most were well below 3%. As discussed in Section 3.2, certain etching characteristics of these CdS films were different from those on copper substrates. This might be related to texturing or details of the Cu₂S layer formation that are required to obtain reasonably high short circuit current densities (in excess of 15 mA/cm²). Table I summarizes the yield problem that was experienced during the quarter. Table II summarizes the average characteristics of those cells that were considered usable. It can be seen that there was some improvement in open circuit voltage, efficiency and fill factor over the period. Improvement in short circuit current performance and in fill factor are expected with more attention to further reducing pinhole effects.

3.4 Scanned Laser Response of Thin Film Cells

Light spot scanner apparatus has been assembled at the Westinghouse R&D Center to study a variety of solar cells as well as other photosensitive devices. The equipment consists essentially of a laser source and a pair of galvanometer driven deflection mirrors capable of providing a raster scan of the focused laser beam over a convenient field of view. For the main optics a conventional microscope is used, providing the standard resolution available in such systems, i.e., down to the micron level. Fig. 5 shows the light spot scanner, with the HeNe (6330Å wavelength*) low power laser, scanning mirrors, optical microscope and auxiliary optics. Fig. 6 is a schematic of the optical arrangement.

The display usually consists of a TV type image on a CRT, with the video information provided from any of several inputs, such as:

- o by the light reflected from the specimen
- o by the light transmitted through the specimen
- o by the photocurrent, if any, induced in the specimen.

The first two modes provide images of the type that would be obtained in a conventional optical microscope. These are useful as location references for the main use of the system, which is under the third mode.

* In Cu₂S, light of this wavelength is estimated to penetrate about 0.2 μm.

TABLE I

YIELD OF USABLE CELLS - SECOND QUARTER

Month	No. of Cell Starts	Rejected Cells				Yield
		Shorted	Low Current	Other	Total	
Jan	33	13	9	6	28	15%
Feb	26	14	3	5	22	15%
Mar	28	9	5	9	25	11%

TABLE II

CHARACTERISTICS OF USABLE CELLS - SECOND QUARTER

(Tested at AM1 - Equivalent at Room Temp.)						
Month	V_{OC} (volt)	J_{SC} (mA/cm ²)	η (%)	Fill Factor	ρ_S	ρ_{SH} (DARK)
Jan	.433	17.6	4.4	0.55	1.1	267
Feb	.446	17.9	4.5	0.58	1.2	500
Mar	.471	15.8	4.8	0.63	1.1	233

Figure 5 Helium neon laser. Equipment consists of an optical bench with mirrors, two galvanometer driven scan mirrors (center) which sweep laser beam in a raster pattern through the microscope (right) where it is imaged in a 2 mm spot on the surface of a cell inserted into the holder mounted on an X Y micro-manipulator stage.

Figure 6 Diagram of the optics of the Westinghouse raster scanned light spot system for studying semiconductor devices.

For quantitative data on reflection, transmission or photocurrent, single line traces of signals proportional to these quantities can be displayed.

An example of the reflected light image for a $\text{Cu}_2\text{S}/\text{CdS}$ thin film cell is shown in Fig. 7. The main feature of this image is the presence of striations, at about 110° from the horizontal, associated with ridges in the electroformed copper foil substrate. The dark vertical feature in the middle of the image is an electronic artifact. The contrast for the CRT display was adjusted arbitrarily to provide the image quality necessary for photographic resolution of the surface features. In reality, even the brightest regions of this image are less than 10% reflecting.

A similar reflection image at ten times higher magnification is shown in the left part of Fig. 8. A photocurrent image for the same region is shown in the right part of Fig. 8. The primary purpose in considering this pair is to emphasize the lack of one to one correspondence of specific areas in either type image although some general associations can be made. View the display in terms of a Cartesian coordinate system with its origin at the center of a 10 division by 10 division area. The large feature with lower reflection in the second quadrant, includes three photo-responsive regions about $5\text{ }\mu\text{m}$ in size located at $x = -2.7$, $y = 0.4$; $x = -3.3$, $y = 1.4$ and $x = -3.6$, $y = 2.7$. Similarly the region of high reflection in the third quadrant is associated with lower photocurrent response centered near $x = -4.0$, $y = -3.0$. In these and other cases, the geometric correspondence of reflection and photocurrent regions is not very striking. The lack of detailed correlation is probably explained by the fact that variation of reflectivity and photocurrent with position are not very large, since arbitrary contrast settings were used to obtain the images of Fig. 8. A typical single horizontal line scan of photocurrent response amplitude is shown in Fig. 9. The largest excursions from the average are approximately +23% and -30%.

Fig. 7 Scanned reflection image of part of a thin film $\text{Cu}_2\text{S}/\text{CdS}$ solar cell. Striations are related to gross morphology of the copper foil substrate.

Fig. 8 Scanned reflection and photocurrent images of the same part of a $\text{Cu}_2\text{S}/\text{CdS}$ thin film cell illustrating the lack of strong correlation between features in either.

Fig. 9 Example of absolute photocurrent amplitude as a function of location on a vertical scan illustrating absence of large non-responsive areas. (Zero response level shown at bottom of display.)

Since photocurrent response involves products of parameters related to optical absorption and carrier collection better uniformity of either over areas about $5\text{ }\mu\text{m}$ or more across will be required for correlation of reflection and photocurrent features. A provocative preview of what might be possible is shown in Fig. 10. Within the boxed region, fine detail lines with just over $1\text{ }\mu\text{m}$ spacing appear in this photocurrent image. These lines, at approximately 40° from the horizontal, are the sharpest features observed in the course of the present work. If surface topography, uniformity of the Cu_2S layer and properties of the heterojunction can be adequately controlled over reasonably large areas, laser scanned studies such as these may be helpful in obtaining better understanding of cell operation.

3.5 Photocurrent Response of Cells on Single Crystal Substrates

One approach to characterizing the minority carrier diffusion length in the absorbing part of a solar cell structure is to measure photocurrent collection as a function of absorber thickness. For a material system such as $\text{Cu}_2\text{S}/\text{CdS}$, it is desirable to minimize effects of variation in preparation parameters. Ideally the range of thickness variation should be produced in a single sample, thus guaranteeing that other processing variables have been kept constant.

As a step in implementing this approach, cells have been prepared on single crystal CdS substrates, subjected to the surface preparation procedures described in Section 3.4 of Reference 1. The so-called "dry process" for forming the Cu_2S layer was used. That is, CuCl was evaporated on the CdS surface and subsequently heat treated to produce the desired Cu_2S layer. For the first samples, an aperture mask was used to delineate the area of CuCl evaporation. Half way through the evaporation the mask was moved to produce two adjacent regions, with one having about half the thickness of CuCl as the other. After heat treatment the Cu_2S layers were about 1500 to 3000Å thick in these regions.

Fig. 10 Photocurrent image of a $\text{Cu}_2\text{S}/\text{CdS}$ thin film cell region showing (boxed area) regular features of about $1.3\ \mu\text{m}$ size.

Laser scanned photoresponse of the structure was measured using the apparatus described in Section 3.3. A photocurrent image (Fig. 11a) clearly shows the suppressed response in the thicker part of the Cu_2S film due to loss of photogenerated carriers to bulk recombination. The small areas of high response in the thick region are probably due to shadowing of the CuCl evaporation by dust particles on the sample surface. High response along the diagonal line at the left is due to a band of Cu_2S of near optimum thickness produced by tapering of the Cu_2S layer thickness in the region shadowed by the aperture mask. The speckled appearance of the thinner portion of the Cu_2S layer is attributed to irregularities in the CuCl deposition.

Photocurrent amplitude as a function of position along the horizontal scan line indicated in Fig. 11a is shown in Fig. 11b. The irregularity of response in the thin region of Cu_2S is more easily appreciated. Also it is clear that the average response from the thicker region is not zero, but about a factor of ten lower than for the thin area. (The bright horizontal reference line in Fig. 11b is the system response with no laser excitation.)

These preliminary results indicate the feasibility of the proposed approach to characterizing minority carrier diffusion length in Cu_2S layers. The uniformity of the CuCl deposition must be improved by minimizing spatter from the evaporant source. Formation of a tapered thickness of Cu_2S by evaporating past the edge of an aperture mask positioned some distance above the CdS surface seems feasible as suggested by some of the edge effects in Fig. 11.

3.6 Compositional Analysis of Cu_2S Layers

Single crystal CdS substrates were treated by dipping in hot CuCl solution as an initial step in preparing Cu_2S layers (see Section 3.5 in Reference 1). One set of samples was annealed in air for two minutes at 250°C to produce a standard Cu_2S layer of estimated $1.5\text{ }\mu\text{m}$ thickness. Both types were then subjected to ESCA analysis of the

(a)

(b)

Fig. 11 Photocurrent response for a structure with a two-stepped Cu_2S layer on single crystal CdS (Horiz. scales: $200\text{ }\mu\text{m/maj. div.}$)

- (a) Photocurrent image for thick (top center) and thin (lower right) Cu_2S regions
- (b) Photocurrent response along the horizontal line scan indicated in (a).

original surface and after successive intervals of in situ argon ion beam milling (at a rate of about 200Å/min).

The following general results were obtained:

- (1) Surfaces of both types were found to contain Cu, Cd, S, Cl⁻, O₂ and C.
- (2) The heat treated samples had a much higher Cd/Cu concentration ratio than the ones without heat treatment.
- (3) Sulfur in the heat treated samples was detected in two different valence states. (One state disappeared after approximately three minutes of argon etching. No reference data was generated to identify the second valence state but it is believed to be SO₄⁼).
- (4) Cd in the heat treated samples was still present after 13 minutes of etching while in the one without heat treatment, it disappeared after about five minutes.

Figures 12 and 13 give results for profiles to a depth of about 2000Å. Etching was continued in an attempt to profile through the heterojunction. The cadmium signal reappeared after 41 minutes of etching for the heat treated sample. However, the copper signal did not disappear with further etching. Results for this sample are shown in Fig. 14, for milling times between 30 minutes and 150 minutes. The junction is located at the depth corresponding to 80 minutes of etching. When the sample was removed from the ESCA equipment, there were many small islands on the surface (Fig. 15) which the X-ray microprobe indicated to be elemental copper.

Copper apparently migrates out of the Cu₂S, possibly driven by the potential developed by the ion beam used for the etching. This beam is neutralized and charging on the sample can be measured directly by monitoring the position of a known element (i.e., C). This was done and no shift was observed. However, this can only detect changes greater than a few volts. Smaller values of potential might be sufficient to cause migration of copper.

Curve 695326-A

Fig. 12 - Single crystal CdS/Cu₂S cell - no heat treatment

Curve 695324-A

Fig. 13 - Single crystal CdS/Cu₂S cell - heat treated for 2 minutes @ 250°C-air

Fig. 14 - Single crystal $\text{CdS}/\text{Cu}_2\text{S}$ - heat treated for 2 minutes @ 250°C -air

Fig. 15 SEM photographs of single crystal $\text{Cu}_2\text{S}/\text{CdS}$ showing copper nodules after ~ 150 min. of ion milling for which about $3\text{ }\mu\text{m}$ of material was removed.

3.7 (ZnCd)S Studies

Studies on the mixed (ZnCd)S material are closely tied with the work on the single-crystal cell. Analytical techniques used to determine the properties of the $\text{Cu}_2\text{S}/\text{CdS}$ cell will be used on the mixed (ZnCd)S/ Cu_2S cell.

The initial approach will be to deposit the mixed (ZnCd)S directly onto a single crystal of CdS. The Cu_2S layer will be formed by the dry process, which should allow the use of a much thinner (ZnCd)S film. This will help to reduce effects of increased resistivity associated with Zn-rich film of (ZnCd)S.

Due to the difference in vapor pressures between ZnS and CdS, a simple thermal evaporation produces very severe segregations in the source. This problem should not be as severe with electron beam deposition, due to the localized heating at the surface.

To evaluate this concept, batches of $(\text{Zn}_x\text{Cd}_{1-x})\text{S}$ were prepared with x values at .10, .2 and .3. The first attempt to deposit on a 220°C substrate from the $(\text{Zn}_{.2}\text{Cd}_{.8})\text{S}$ powder produced a film of $(\text{Zn}_{.61}\text{Cd}_{.39})\text{S}$.

Subsequent runs with lower beam power gave better results in terms of compositional replication of the source, as shown in Table III.

TABLE III. Composition of (ZnCd)S Films Produced by EB-Deposition

Run No.	Source Composition (% ZnS)	Film Composition (% ZnS)*
1	10	8
2	20	20
3	30	29
4	20	22

* As determined by X-ray microprobe analysis.

These studies show that electron beam deposition can achieve good compositional control in the range of interest when a mixed source is used. A thermal evaporation source is being built which will allow independent variation of the ZnS and CdS rates. Use of a UTI mass analyzer with this system will allow monitoring of the Cd and Zn fluxes in the evaporant stream, thus permitting better correlation of deposition parameters and film properties.

4. PLAN FOR NEXT QUARTER

During the third quarter of this program (April 1, 1978 to June 30, 1978) effort will be applied to the first seven tasks listed in Section 2.2. Particular emphasis will be placed on the following items.

1. Continue studies to better understand the structure of Cu_2S films formed on thin film CdS.
2. Continue efforts to characterize minority carrier diffusion length in Cu_2S films on single crystal CdS substrates, particularly by producing films of tapered thickness on a single sample.
3. Continue fabrication of prototype thin film cells to correlate efficiency with structural and preparation parameters.
4. Prepare a vacuum evaporation system for (ZnCd)S films in which a quadrupole mass analyzer can be used to monitor Zn and Cd fluxes.
5. Continue to incorporate experimental results from film and single crystal CdS studies into a more comprehensive model for solar cells.
6. Utilize diffusion length characterization methods to determine if heat treatment schedules affect minority carrier transport properties of the Cu_2S layer.
7. Implement available results for CdS film preparation, etching and Cu_2S layer formation to begin work on thin film cells with improved efficiency.

5. ACKNOWLEDGEMENTS

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6. REFERENCE

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