FIRST QUARTERLY REPORT

STUDY OF THIN FILM LARGE AREA PHOTOVOLTAIC SOLAR ENERGY CONVERTER

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by

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PHOTOVOLTAIC SOLAR ENERGY CONVERTER

First Quarterly Report
October 25, 1965 through January 24, 1966

Contract No. NAS 3-8502

INTRODUCTION AND SUMMARY

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This report summarizes the first quarter's work on the development of the CdS thin film photovoltaic cell on Contract NAS 3-8502. This program is a continuation of the work on Contract NAS 3-6461. On that contract, the frontwall plastic and metal substrate CdS film cell constructions were developed to the point where 4 to 6% initial conversion efficiencies could be obtained regularly for 50 cm^2 area cells. Some efficiencies up to 8% were obtained.

It was determined that the barriers of those CdS thin film cells were inherently stable and that the instabilities observed on many cells were due to shortcomings of the collector grid contact or to the cell package. Several such causes of cell degradation were isolated and found to be of major significance.

In addition, several desirable cell design improvements were investigated. These included the use of alternate metal foils for cell substrate in place of molybdenum, thinner CdS films and substrates for lighter weight and more flexible cells, etched metal grids for lower cost, and the use of leads that were integral extensions of the substrate and collector grid for increased reliability.

Each of the above mentioned design changes were adopted as standard practice at the beginning of this period. Also, the pressure contact which had been found to be one of the main causes of cell instability was eliminated in favor of cementing the grid in place with conductive silver epoxy resin.

The introduction of all these changes at one time caused considerable disruption to the laboratory cell fabrication facility. At the end of the quarter the fabrication of metal substrate cells is just approaching the quality and yield levels that had been attained previously. The fabrication of plastic substrate cells is somewhat further behind. These difficulties in reproducibly fabricating the radically changed cell designs were expected, however, and are still believed justified in order to achieve the accelerated progress towards a superior design stable cell.

Continued study of the transient degradation effect following cell heating indicates that this is characteristic of copper and silver contacts to the barrier, but not of gold contacts. Also, contrary to earlier indications the effect is associated with the contact only and not with the bulk material. This transient effect now appears to have been the cause of failure on temperature cycling

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test of the cells with grids cemented down with conductive silver epoxy cement. Tests indicate that cells with gold plated copper grids cemented down with gold filled epoxy should be immune to the transient degradation effect.

STABILITY STUDIES

    a.   Shelf Storage

        1.   Long Term Stability (> 1 Year). That reasonably high efficiency CdS thin film solar cells can be stable on dry shelf storage was shown by several of the first cells fabricated by the revised Clevite process in the Fall of 1964 giving the same outputs at the end of 1965. These were listed in Table VIII, Pg. 34, of the Final Report on the previous contract.[1] These have been measured again after an additional 3-1/2 months storage, and the earlier conclusions are confirmed. Table I gives the data.

TABLE I

Long Term Shelf Stability of Early High Output CdS Film Cells

Cell No	Area	Initial Eff.	Nov. 1965		Feb. 1966	
			Age	Eff.	Age	Eff.
73C	4. 3 cm^2	4. 8%	14-1/2 mos.	4. 8%	18 mos	4. 8%
205	49. 0	4. 2%	11-1/2	4. 1	15	4. 25
213	46. 8	4. 2%	11-1/2	4. 2	15	4. 2

    (Frontwall molybdenum substrate cells with electroformed gold grids held in pressure contact by Mylar-Capran encapsulation.)

Clearly, these cells are showing no degradation at all -- the minor variations for cell no. 205 being attributable to accuracy of measurement.

        2.   Intermediate Term Stability (< 1 Year). Cells that were fabricated subsequently to those listed above gave higher initial outputs, but as it turned out exhibited less stability on shelf storage. The higher outputs were achieved by introducing a number of changes in the process. In particular lower lamination temperatures were used and these reduced the amount of Capran adhesive flowing beneath the grid and hence reduced the series resistance. Other design changes were made including the use of lower cost copper grids. In retrospect it appears that these changes also reduced the stability of the cells on shelf storage.

        Tables II, III, and IV present the up to date data on the shelf storage of cells made by the changed process discussed above. These are the same cells listed in Tables IX, X, and XI of the previous report. It is seen that the cells are continuing to degrade slowly. The rate of degradation is slightly greater for the latest cells which were also the cells with the highest initial outputs.

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TABLE II

SHELF STABILITY OF EARLY LARGE AREA FRONTWALL PLASTIC
SUBSTRATE CdS THIN FILM SOLAR CELLS

Cell No.	Conversion Efficiency at:								
	Initial	1/2 Mo.	1 Mo.	2 Mos.	3 Mos.	4 Mos.	6 Mos.	7 Mos.	8 Mos.
A490	5. 3%	3. 6%	3. 7%	3. 6%	4. 3%	4. 3%	4. 1%	4. 0%	4. 0%
A491	4. 0	3. 1	3. 5	3. 5	3. 8	3. 7	3. 6	3. 6	3. 6
A497	5. 0	4. 2	5. 0	4. 8	5. 5	5. 5	5. 1	5. 2	5. 2
A500	5. 7	5. 0	5. 3	5. 0	5. 7	5. 7	5. 8	5. 7	5. 7
A513	4. 6	4. 7	4. 8	5. 2	5. 2	5. 0	5. 0	5. 0	5. 0
A531	5. 2	4. 7	5. 0	5. 3	5. 2	5. 2	5. 0	4. 6	--
A538	5. 8	5. 4	5. 4	5. 6	5. 6	5. 7	5. 4	5. 4	5. 4
A550	5. 4	5. 6	6. 2	6. 2	6. 2	6. 2	6. 0	5. 7	5. 8
A552	5. 0	4. 6	4. 4	4. 9	4. 9	4. 9	4. 6	4. 6	4. 5
A554	5. 2	4. 7	4. 5	5. 3	5. 3	5. 2	5. 0	5. 0	4. 9
A565	4. 7	4. 6	4. 6	5. 0	5. 0	5. 0	5. 0	4. 8	4. 8
A568	5. 4	4. 5	4. 5	4. 8	4. 6	4. 6	4. 3	4. 1	3. 9
Avg.	5. 1	4. 6	4. 7	4. 9	5. 1	5. 1	4. 9	4. 8	4. 8

Note:

Frontwall Kapton plastic substrate cells, gold grids held in pressure
contact with Mylar encapsulation using Capran adhesive.

TABLE III

SHELF STABILITY OF LATER LARGE AREA FRONTWALL METAL SUBSTRATE CdS THIN FILM SOLAR CELLS

Cell No.	Conversion Efficiency at:						
	Initial	1/2 Mo.	1 Month	2 Months	3 Months	5 Months	8 Months
D16B	5.2%	5.0%	4.5%	4.7%	4.7%	4.5%	4.5%
D16E	4.7	--	--	4.4	4.3	3.9	3.9
D18E	5.3	5.0	5.1	4.8	4.7	4.3	4.2
D19A	5.3	4.7	4.7	4.7	4.6	4.4	4.4
D19F	5.4	5.3	5.0	5.0	4.9	4.6	4.4
D21B	5.5	4.7	--	4.7	--	4.4	4.3
D21F	4.7	4.4	4.4	4.4	4.4	4.2	4.0
Avg.	5.16	4.81	4.70	4.67	4.60	4.33	4.24

Notes:

Frontwall molybdenum substrate cells, copper grids, encapsulated in Mylar with Capran adhesive.

In computing averages, missing data points were interpolated.

TABLE IV

SHELF STABILITY OF SOME MORE RECENT LARGE AREA FRONT-WALL METAL SUBSTRATE CdS THIN FILM SOLAR CELLS

Cell No.	Conversion Efficiency at:							
	Initial	1/2 Mo.	1 Mo.	1-1/2 Mos.	2 Mos.	2-1/2 Mos.	3-1/3 Mos.	5-1/2 Mos
D56A	6.5%	5.7%	5.4%	5.3%	5.2%	5.1%	5.0%	4.8%
D56B	5.7	5.7	5.4	5.2	5.1	5.0	4.8	4.7
D57A	6.1	5.6	5.2	5.1	5.0	4.9	5.0	4.9
D58A	6.4	5.8	5.4	5.3	5.2	5.0	4.9	4.5
D60A	6.4	5.4	5.2	5.0	4.8	4.7	4.8	4.3
D60E	6.5	5.5	5.3	5.1	5.1	5.0	4.9	4.6
D62D	5.4	4.8	4.5	4.5	5.1	--	4.0	3.5
D62G	6.7	5.6	5.8	5.0	5.1	4.9	4.8	4.6
Avg.	6.2	5.5	5.2	5.1	5.0	4.84	4.78	4.49

Note:

Frontwall molybdenum substrate cells, copper grids, encapsulated in Mylar with Capran adhesive.

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This is in keeping with the change in processing which yielded the higher outputs. However, the evidence is that this degradation on dry shelf storage is associated with the contact to the barrier rather than to any change in the barrier itself. The output of degraded cells of this design can almost invariably be restored to the initial value by a simple re-lamination.

b. Temperature Cycling

1. Cells with Pressure Contact Grids. Very early CdS thin film solar cells with electroformed gold grids held in pressure contact to the cell barrier by the encapsulation gave difficulty when given repeated temperature cycling to simulate the expected behavior of solar panels on a space vehicle in an earth orbit alternating between full sunlight and earth shadow. However, the first Clevite high efficiency cells with the same electroformed gold grids held in pressure contact by the encapsulation held up on temperature cycling -- going to 3000 cycles without any failures. Later cells however, failed within a few hundred cycles or so due to short circuits that developed. These later cells were of the "improved" design with electroformed copper grids.

It was theorized at that time that the short circuits might be due to a rubbing action between the grid and the barrier resulting from the expansion and contraction of these members with alternating heating and cooling. Cells with grids applied by electroplating did not develop such shorts and a few cells with plastic substrates in place of molybdenum metal substrates did not develop the shorts. It was thought at the time that the electroplated grids were immune because there could be no relative motion of grid and barrier to cause them to wear through, and that the plastic substrate cells were immune because being poorer heat conductors the thermal effects from the temperature cycling would be more gradual.

Subsequent data throws some doubt on the original hypothesis of the shorts resulting from a rubbing action between grid and barrier. In this period several cells that had been on temperature cycling and had developed short circuits were carefully examined in this laboratory. In each case the actual short circuit was located and found to coincide with a pinhole in the CdS film situated beneath a grid wire. After a number of thermal cycles with the resultant expansions and contractions of the various cell members, the grids apparently touched the underlying substrate through the pinhole and shorted the cell. It is understood that in some cases the short could be removed by simply flexing the cell a few times.

It is assumed that cells with electroplated grids short out immediately when the grids are applied if such a pinhole is situated beneath a grid wire, and hence such cells would never be placed on thermal cycling test. This is in keeping with the low yields reported from the electroplated grid process and the absence of shorting on thermal cycling. That the plastic substrate cells did not develop shorts on thermal cycling is tentatively ascribed to somewhat better CdS film quality for the plastic substrates, though the answer may also be a matter of statistics since only a few such cells were tested.

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The validity of the above reasoning could of course be checked by fabricating cells with the original pressure contact gold grid process from pinhole free films and subjecting them to extended thermal cycling. However, it is not desirable to go back to the original cell design because of other shortcomings of that design. It is believed that the pinholes can be controlled for the present improved performance cells and the advantages of higher outputs, lighter weights, positive contacts, and more economic construction can be combined with the features which will give stable cells on temperature cycling as well as under the other required conditions of cell storage and use.

2.   Cells with Silver Cemented Grids. The process of attaching grids with conductive silver epoxy cement was developed over a year ago as a possible means of getting around the cell shorting on temperature cycling problem. Cells with the grids attached with conductive silver epoxy cement did not develop short circuits on temperature cycling, but these cells did fail in a different manner. They dropped steadily in output within a few hundred cycles, and then leveled off at about 1/3 to 1/4 of their initial output level. It appeared to be the open circuit voltage and fill factor that was affected rather than the short circuit current. When the cells were removed from the temperature cycling test, they recovered soon afterwards to their original output levels!

This effect has been studied in more detail in this period. A cell with a copper grid cemented in place with silver epoxy cement was heated at 110°C. After 18 hours (in nitrogen atmosphere) its OCV fell from 0.455 to 0.415 volts and its conversion efficiency at maximum power fell from 6.2% to 5.4%. Then it was heated for 40 hours more in vacuum at 110°C. Its OCV fell further to 0.370 volts and its efficiency to 3.7%. It was then placed in a desiccator at room temperature. After 5-1/2 hours the output of the cell had recovered to 0.435 volts and 5.5% efficiency. Another cell with a gold grid held in pressure contact to the barrier was given the same treatment and was virtually unaffected.

The drop in output on temperature cycling appears to be a transient effect resulting from the heating of the cells, and is associated with the type of metal contacting the barrier. It seems to be the same effect that makes it necessary to wait several hours after laminating cells with silver or copper grids before full output can be obtained. The cause of the effect is basically not understood, but it does not occur at all for gold contacts. Thus, the use of gold contacts as a means around this difficulty was evaluated.

3.   Cells with Gold Cemented Grids. A number of cells were fabricated using a gold filled conductive epoxy cement for grid attachment in place of the silver epoxy cement. Also, to ensure only gold contacts, the grids were gold plated. These cells were given various elevated temperature treatments in the range of 100 to 150°C for periods of several days to several weeks. None of them have shown the transient degradation effect that was experienced for the epoxy silver cemented grid cells.

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There are however several complicating factors that make a direct comparison of gold vs silver cement difficult. First, a commercial gold filled epoxy cement with the required high temperature properties could not be located, and it was necessary to concoct our own. Different epoxies require different curing cycles and in some cases several days may be required before a resin is fully cured. Second, the gold epoxy mixture that was developed is a solvent borne type that dries to a tack-free consistency (i. e. , a "B" stage) that permits handling before curing. This is applied to the grids by brushing rather than by a transfer plate. Third, before many such direct comparisons had been attempted, it was found desirable to replace the Capran laminating adhesive with another epoxy cement, and this introduced other complications which are discussed in more detail below.

c.   Effects of Process Changes

Because the present CdS thin film solar cell process has evolved largely on an empirical basis, there has been concern that some of the processing steps may be far from optimum, and in particular that some may be causes of inherent cell instability. For this reason, specific changes in some of the process steps have been tried in this period and an attempt made to determine whether these changes caused any difference -- pro or con -- to cell stability.

1.   Pre-Barrier Rinsing. The attempt here was to determine whether a more thorough rinse between the pre-etch and the barrier dipping steps, and whether a mid-rinse in $CdCl_2$ solution would improve cell stability. A controlled experiment showed no difference in this respect between doubly rinsed films, rinsed and $CdCl_2$ dipped films, and standard processed films. A total of 2 cells that were doubly rinsed in distilled water, 4 cells that were rinsed and given a $CdCl_2$ pre-dip, and 2 standard process cells are all essentially stable after 49 days on dry shelf storage.

2.   Ultrasonic Rinsing of Barriers. Two experiments were run with an ultrasonic rinsing of cell barriers. In one experiment the cells were placed flat in the bottom of a Pyrex beaker of distilled water and rinsed while being ultrasonically agitated for 2 minutes. Two cells gave poor initial outputs (approximately 3%) and deteriorated steadily over a 48 day period (to less than 2%). Control cells on the other hand were in the range of 5 to 6% and improved somewhat over the same period.

In a second experiment the cells were suspended vertically in a beaker of distilled water and agitated for 2 minutes ultrasonically. In only 5 days to date these and the control cells are all holding steady at their initial values of about 5%.

3.   Hot and Cold Rinsing of Barriers. Earlier experiments indicated that cells rinsed in a hot water transistor washer (after barrier formation) gave poor cell outputs and showed poor stability, while those rinsed in a cold water transistor washer did not as long as the time of the rinse was not extended too long. Subsequent experiments however did not verify the earlier indications.

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In this period controlled experiments with both hot and cold distilled water rinses were run with the rinsing time at 5, 10, 15, 20, 30, 40, and 50 seconds and with standard process control cells for each set. There has been only 3 and 4 days shelf storage data available to date for these runs and no real trend can be discerned at this time. However, reasonable initial output levels were obtained for both hot and cold water rinsed cells and for the controls, and the time of rinse between 5 and 50 seconds duration does not appear to make much difference to the initial cell output.

4. Non-Aqueous Barrier Processing. Three 12 cm^2 area cells were processed with the non-aqueous barrier formation process described earlier (ethylene glycol) along with one standard process cell cut from the same film. The non-aqueous cells were lower initially (3.7% vs 5.9%) but in 45 days had degraded only slightly while the standard process cell had degraded appreciably (to 3.5% vs 4.8%).

This is an additional indication that cells processed completely without water may be inherently more stable. However, further efforts are needed to secure higher outputs from the non-aqueous process.

d. Effect of Substituting Epoxy for the Capran Laminating Adhesive

As discussed in the report on the last contract, it has been found that the Capran (nylon) plastic used to laminate the Mylar or Kapton cover plastic to the cell barriers is actually hygroscopic. Hence, it was thought that the use of another (non-hygroscopic) adhesive in place of the Capran might make the CdS thin film solar cell much less susceptible to degradation from high humidity ambients.

An epoxy resin was selected for initial trials as an alternative cement because this resin is supposed to be relatively non-hygroscopic, is transparent, and can be used at moderately high and low extremes of temperature. For these trials, Astro Chemical Co. (Schenectady, N. Y.) No. BP 242-4A resin has been used with curing agent BP-242-2. This resin is particularly convenient because it can be dried tack-free for handling and storage without curing. Other epoxies would probably be equally satisfactory however.

For these tests, the epoxy was mixed with its curing agent, thinned with solvent and sprayed onto the Mylar cover plastic to a thickness of about 0.5 mils (when dry). It was dried in an oven at 70°C for 30 minutes to remove all traces of solvent. Curing of the epoxy is accomplished by heating at 190°C for 30 minutes.

In the initial trials cells were fabricated with the epoxy laminating adhesive using copper grids in pressure contact, silver plated and gold plated copper grids in pressure contact, and silver plated copper grids cemented with silver filled epoxy cement. Along with these tests, controls were run for each type of grid with the regular Capran-Mylar lamination.

In all cases the cells with epoxy laminating adhesive gave lower output initially, but continued to climb for periods of at least several weeks.

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The Capran adhered cells however reached full output within the first day and then started to drop. It soon became evident that some additional heat treatment was needed to bring the epoxy adhered cells to full output. Different heating cycles were tried and it appears as though temperatures on the order of 80°C to 150°C for periods of about a day are adequate to bring the cells up to full output. Further extended heating, for several weeks, does not seem to either help the cells further or to hurt them.

Initial indications are that the epoxy resin is successful in yielding a more stable cell package and in giving cells which are very much less susceptible to degradation from humid atmospheres than the Capran cement. One 4% cell that was packaged with a 1/2 mil thick epoxy cement and a 10 mil Kel-F cover plastic was kept under water for 3 weeks without noticeable degradation of cell output and with less than a 10% reduction in 4 weeks. More extensive tests are in progress.

CELL DESIGN

During the last few months of the previous contract a number of possible cell design improvements were evaluated. These were for purposes of decreasing cell thickness and weight, increasing cell reliability, simplifying the processing and reducing fabrication costs. Among the design improvements that were evaluated were: copper metal foil substrates in place of molybdenum foil; 1 mil thick substrates in place of 2 mil thicknesses (both metal and plastic substrates); special design etched copper grids in place of electroformed grids; positive and negative leads that were integral parts of the collector grid and substrate respectively; and the attachment of the grids with conductive cement.

The desirability of each of these design changes was generally established, but there had not been more than a preliminary evaluation of any of them completed. The experience was not extensive enough to determine many of the "bugs" that might be inherent in these design changes, and of course, the changes had not been tried out all at the same time. Though it was realized that the evaluation of these design changes was very incomplete and that many difficulties would probably be encountered, it was believed worthwhile to attempt to accomplish as many of these as possible with the beginning of the new contract.

Hence, all of these changes were introduced into the standard CdS thin film solar cell design as of the start of this period.

a. Copper Substrate

For the copper substrate, 99.95% pure electrolytic copper foil is used as secured from the Cleveland Graphite Bronze Division of Clevite Corp. This material is approximately 1.6 mils thick as received. It is reduced to 1.0 mils by etching in a 1:3 HNO_3 solution. A thin zinc coating is then applied by electroplating from a fluoborate bath. The zinc provides an ohmic contact for the CdS layer to the substrate -- otherwise there would be a tendency for a rectifying contact to occur.

In practice the zinc alloys with the copper when the substrate is heated prior to CdS deposition, and a surface layer of brass is formed. This appears to yield a satisfactory substrate for the CdS. Low resistance contacts are secured and the films have excellent adhesion.

b. Thinner Substrates

The change from 2 to 1 mil thick substrates has been achieved with minor difficulties only. Initially, the thinnest copper that could be obtained was 1.6 mils thick and this material had to be thinned to size by etching. The use of 1 mil thick Kapton apparently has given no additional difficulty in handling and processing than the 2 mil material used before.

c. Etched Grids

At first there was some difficulty in securing clean etched copper grids from the vendor that were intact. The problems were in removing the photoresist after etching. Apparently, the use of a different photoresist in the fabrication process has cleared these difficulties. There are still occasionally a few instances of broken grid wires, or of small areas not completely etched through, but these are of minor significance.

The etched grid is appreciably sturdier than the earlier electroformed grid. The .014" wide border helps to maintain the physical integrity of the grid during processing and handling, and of course makes a neater appearance cell package.

The grids are given a light silver coating by electroplating in order to secure better adhesion of the epoxy cement to the grid than can be obtained to bare copper.

d. Integral Leads

The use of an integral positive lead was put into effect simultaneously with the etched grid since the lead was designed as part of the pattern used as a photographic master for making the grids. The grid and the lead tab are only 0.5 mils thick, and hence have to be handled reasonably carefully to avoid tearing, wrinkling, or distorting the lead. Also, care must be exercised when the upper plastic layer is laminated in place not to cover too much of the lead tab or to squeeze out too much adhesive over the lead tab.

The tab has been designed so that a 1/8" margin of plastic extends beyond the active cell area over the lead tab and that a full 3/8" of uncovered lead tab extends beyond the plastic margin. The nine evenly spaced holes in the positive lead tab are intended as locating holes for the jigs planned for assembling the cells.

The negative lead is symmetrical with the positive lead extending as an integral extension of the substrate on the edge of the cell opposite the positive lead. The use of the integral negative lead has necessitated a change in the tooling for evaporating the CdS films since the tabs make the substrates

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larger than they were before. It was found that where 9 CdS films each 3" x 3" in size were accommodated before, only 4 films can be handled with an extra 1/2" tab. The tooling however is being re-designed and it is expected that 8 films will be able to be evaporated at a time with the lead tabs.

e. Grid Attachment

The process of applying silver epoxy cement to the grids and then placing the grids against the cell barriers and curing the epoxy was well developed last year. A good permanent bond was affected without difficulty and this bond was a major improvement over the pressure contacted grid process where the Capran adhesive held the grid against the cell barrier. This improvement was well established in the improvement in shelf life of such cells.

However, it has gradually become evident that the silver epoxy cement does not make an adequate electrical contact to CdS cell barriers during periods of elevated temperature such as might occur after many hours in full sunlight. As discussed elsewhere in this report, it appears as though the advantage of the positive mechanical contact can be secured along with a good electrical contact even under high temperature operation by substituting gold for the silver in the conductive cement.

f. Cell Finishing

With all of the above changes in the CdS cell design incorporated at one time, it was found desirable to make some changes in the packaging and finishing operations. In particular it was desirable to eliminate the lower plastic layer that had been used earlier with 2 mil thick molybdenum substrate cells. The copper substrate cell tends to curl more than the molybdenum substrate cell, and the curl can be controlled and eliminated for all practical purposes by leaving off the under layer of plastic. Thus, the upper plastic layer can be made to exactly counterbalance the forces due to thermal expansion mismatch between the substrate and the CdS. Another benefit is that the overall thickness and weight of the cell is also reduced.

The copper substrate tends to oxidize and discolor on the back during the cell processing. This has been readily taken care of by a final clean-up operation after completion of cell lamination.

The exposed copper tabs for both positive and negative leads are improved in appearance and in the ease with which contact can be made to the cells by silver plating them, or by a solder tinning operation.

Figure 1 illustrates the construction of the present design standard 3" x 3" CdS thin film solar cell. The positive lead is at the top of the illustration. Both positive and negative leads can be bent back up to 180° for purposes of interconnecting cells and for spacing cells closely together in an array. Also, the side edges of the plastic which extend 1/4" from the active portion of the cell can be trimmed back as closely to the cell edge as desired in order to improve area utilization of an array.
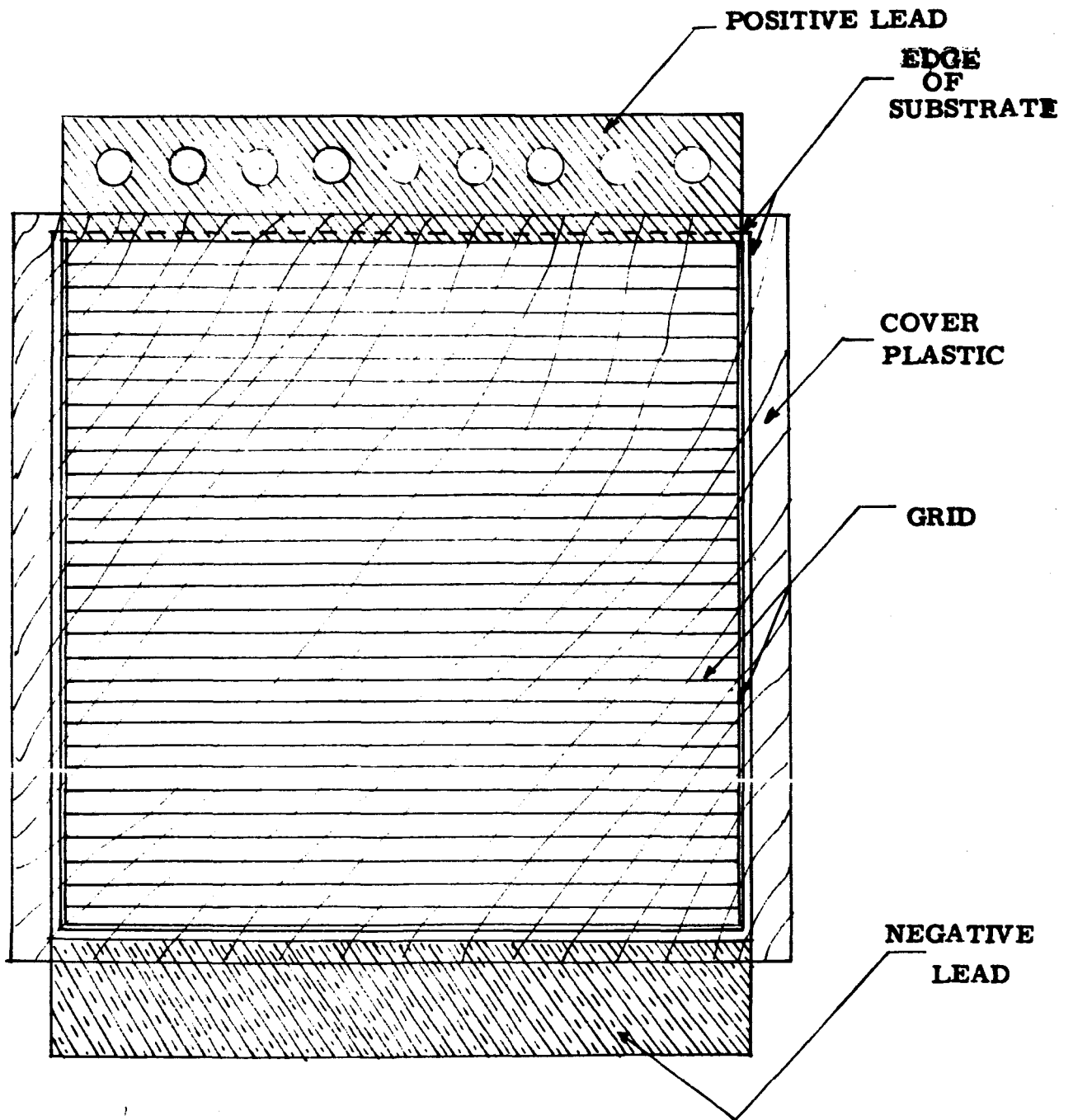
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FIG. 1. CONSTRUCTION OF PRESENT DESIGN STANDARD 3" x 3"
CdS THIN FILM SOLAR CELL

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The substrate size is 74 mm wide (left to right in Fig. 1) by 76 mm, with only 1 mm at the top not being covered with a barrier and 1 mm of the barrier at the top covered by an insulating strip which prevents shorting of the positive lead tab to the n-CdS or substrate at the edge of the cell. Hence, the active illuminated area is 74 mm x 74 mm or 54-3/4 cm^2. This is the area which is used for calculation of cell efficiency. Of this area, approximately 10% is actually covered by the grid itself.

CELL FABRICATION

a.   Standard Process Line

Table V summarizes the results of cells fabricated on the Laboratory Standard Process Line during the first three months of this contract. As expected, because of the many changes in the design and construction of these cells, fabrication rates, yields, and cell performance levels were all down from what had been achieved with the earlier design last year. However, with continued study, the difficulties that have contributed to these lower yields and output level have become better defined.

It appears that the changes in cell design were only partially responsible. Of greater significance in this respect have been changes in the various fabrication processes that were made in an attempt to increase production rates and in tightened quality control provisions. These changes have been necessary before cells that are delivered for testing and evaluation can be considered representative of a process that can be repeated at a later date. This condition has not been met as of the end of the first quarter, but it is believed that it is rapidly being approached.

In this three month period more than half of the cells that were started were scrapped in process before they could be counted as finished cells. Most of the difficulty was manifested by CdS films peeling after evaporation, or by faulty barrier formation that was visually evident. The real cause of the difficulty in both cases appeared to be traceable to the substrate preparation process for both copper metal substrate and metallized plastic substrate cells. Surface roughness and uneven zinc plating are two areas that proved most difficult to control and which are still receiving concentrated attention.

WORK PLANNED FOR NEXT PERIOD

In the second quarterly period efforts on the stability problem will be concentrated on characterizing the stability of the new design cell with conductive gold cemented grids and epoxy encapsulating adhesive. This characterization will include shelf storage, elevated temperature storage, exposure to high moisture ambients and submission of test samples for thermal cycling. Any remaining causes of cell instability will be studied and attempts made to isolate and cure them.

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TABLE V

STANDARD PROCESS LINE CELLS - FIRST QUARTER

Construction	Month	Total Cells	Scrap Cells	Efficiency Min. %	Max. %	Avg. %	Power/Wt. W/Lb.
Copper Substrate	1st	16	0	3. 2	6. 1	5. 0	42
	2nd	11	1	3. 9	6. 2	4. 9	45
	3rd	13	1	3. 9	6. 6	5. 2	43
	Total	40	2	3. 2	6. 6	5. 0	43
Plastic Substrate	1st	7	5	5. 4	6. 4	5. 9	77
	2nd	11	5	3. 1	5. 5	4. 3	53
	3rd	7	4	3. 9	4. 1	4. 0	57
	Total	25	14	3. 1	6. 4	4. 5	58

Note:

3" x 3" Cells -- 54-3/4 cm^2 Area -- All encapsulated in Mylar Plastic with Capran Adhesive. All with silver plated etched copper grids cemented in place with silver filled epoxy resin.

Cell fabrication efforts will be concerned with improving the standard fabrication process to yield good quality, high reliability, high efficiency cells. Particular attention will be placed on the elimination of such faults as excessive curling, torn grids, incomplete sealing, pinholes, and poor alignment of the cell components.

Cell design improvements will be attempted in the area of thinner CdS films and thinner cell substrates. Higher cell efficiencies will be sought via the use of alternate anions in the barrier fabrication process and via reduction of series resistance effects.

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