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PHASE 2 OF THE ARRAY AUTOMATED ASSEMBLY TASK FOR THE LOW COST SOLAR ARRAY PROJECT

DRL

DOE/JPL 954873-78/01

Distribution Category UC-63

R. B. Campbell, et.al.

First Annual Report
October 1, 1977 - October 30, 1978

November 16, 1978

Contract No. 954873

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, under NASA Contract NAS7-100 for the U. S. Department of Energy, Division of Solar Energy.

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FOREWORD

The work reported here was carried out in the Semiconductor Research Department under the management of Dr. D. J. Page. The Technical Director was Dr. P. Rai-Choudhury and the Principal Investigator was Dr. J. R. Szedon from October 1, 1977 to September 1, 1978. However, after September 1, 1978 Dr. R. B. Campbell was Principal Investigator.

The following people contributed to the program and the report in the following areas: R. B. Campbell (cell separation and processing sequence); D. J. Page, M. W. Cresswell, J. R. Szedon and J. R. Davis (SAMICS costing); R. N. Ghoshtagore, H. Dickey and T. Temofonte (diffusion); M. H. Hanes (Interconnection); T. W. O'Keeffe (spectral response); P. Rai-Choudhury (technical director); J. Ostroski (electroplating); A. Rohatgi (metallization); L. C. Scala (encapsulation); E. J. Seman (ARRAY process sequence and cell fabrication); and B. E. Yoldas (antireflective coatings). Silicon dendritic web used in this program was supplied by the Crystal Science and Technology Department; R. Mazelsky, Manager. This report was prepared and edited by R. B. Campbell and S. Farukhi. Typing was done by the following: M. M. Thomas, E. S. McCarty, D. J. Labor, M. C. Santoro, J. Selchan, M. B. Warren, and K. B. Haun.

1. SUMMARY

During the program a process sequence has been proposed and tested for the fabrication of dendritic web silicon into solar modules. This sequence has been analyzed as to yield and cost and these data suggest that the price goals of 1986 are attainable. A number of the processes that make up this sequence have been further developed and studied as to cost reduction. Specifically, it has been shown that a low cost $POCl_3$ is a suitable replacement for the semiconductor grade, and that a suitable CVD oxide (either doped or undoped) can be deposited from a silane/air mixture using a "Silox" reactor. A dip coating method has been developed for depositing an antireflection coating from a metal-organic precursor. Application of photoresist to define contact grids has been made cost effective through use of a dip coating technique. Electroplating of both Ag and Cu has been shown feasible and cost effective for producing the conductive metal grids on the solar cells. Laser scribing has been used to separate the cells from the dendrites without degradation. Ultrasonic welding methods have been shown to be feasible for interconnecting the cells. A study of suitable low cost materials for encapsulation suggest that soda lime glass and phenolic filled board are preferred.

2. INTRODUCTION

The objective of this program is to specify a process sequence and to develop key process steps for the low cost manufacturing of solar arrays from single crystal dendritic web silicon. Specifically, all costs, including silicon web at $0.17/peak watt (1975 $) are to be considered with the aim of producing encapsulated modules with 10% efficiency for a selling price of $0.50/peak watt in 1975 dollars.

The processes studied for development were junction formation, antireflection coating applied by a dip process, metallization systems, laser scribing for separation of the cells, cell interconnect techniques and encapsulation methods.

Early in the program, it was decided to concentrate on diffusion techniques for both front and back surface juntions. Although this decision did not prohibit investigations of other methods, it recognized that diffused junctions at the present state of the art were superior to other methods. Thus, the major effort in designing a process sequence involved utilizing diffused junctions. Advances have been made in both phosphorus and boron diffusion methods. Materials and techniques have been developed which make the diffused junction solar cell cost effective. This work has now progressed where other forms of junction formation should be considered. Aluminum alloyed back surface fields and ion implanted front junctions appear to be the most feasible.

In the junction formation studies it was shown that reagent grade (as opposed to semiconductor grade) $POCl_3$ could be used as a diffusant source. This leads to a distinct cost advantage. The testing and utilization of equipment for rapid deposition of doped and masking oxides has been completed. Cell performance indicates that this method can be used in an automated process.

Antireflective coatings on the sun side of a solar cell can increase the photocurrent response up to 50%. These coatings (mainly SiO_2, TiO_2 or Ta_2O_5) are normally applied by an evaporation or sputtering procedure. These processes require a large expenditure of capital funds and are generally slow. Previous work at Westinghouse has shown that metal-organic compounds in an alcohol solvent can be applied by a dipping or spraying method. During this contract we have emphasized the deposition of TiO_2 and mixed TiO_2 and SiO_2 oxides using this metal-organic and have shown the feasibility of applying the proper thickness of TiO_2 to the web cells by dipping and withdrawing the web from the solution at a given rate. Solution viscosities, concentrations, and withdrawal rates have been optimized to provide the proper coating.

As with the junction formation processes, we chose a relatively conservative, proven metallization procedure as a basis for contact grid delineations. The procedure involves photoresist and evaporation techniques. These methods have been simplified and changed to meet the special demands of solar cell processing. Specifically, by using a positive photoresist, a contact metal rejection process was devised so that a second mask and expensive alignment techniques are not required. Also, electroplated silver as a conductive layer has been shown feasible, and a less expensive metal, Cu, has been tested as a substitute for Ag.

In the processing sequence, described later, the processes of junction formation, AR coating and contact grid delineation are performed with the dendrites still attached to the web. The technique selected for development for removing the dendrites and separating the cells was scribing by laser followed by a breaking out process. This technique is amenable to automation, and present day lasers have the required high traverse speed and power. We have shown that by scribing the web from the back, the resultant cells show no degradation.

Laser scribing completes the cell fabrication procedure. The interconnect and encapsulation processes produce the final module.

Interconnection processes generally use soldering techniques which are difficult to automate. In this program, we have shown that ultrasonic welding methods can be used for the interconnect process with minimum breakage and with high strength bonds. In addition, this method can be automated to permit rapid interconnects.

The encapsulation process imposes a great restraint on available materials. The conflicting requirements of high strength, high transmission, and reliability versus low cost make material selection a difficult problem. We have shown that the proprietary silicone adhesives are most satisfactory for bonding the cells to the glass and the backing plate to the cells. A phenolic filled fiber board as a substrate has been chosen as having the highest strength at the least cost. Soda lime glass, although not the best for transmission, was chosen mainly due to cost factors. We are presently holding preliminary discussion with glass manufacturers in an effort to obtain a more suitable glass at an acceptable price.

Progress has been made in all these processes which were selected for development. In the Process Sequence, described next, it will be shown that these processes are compatible, that is, the individual processes can be carried out in sequence without interaction.

The establishment of a processing sequence, amenable to automated, low cost manufacturing was a further objective of the program. A process sequence must be considered to be more than the sum of a number of process steps. The sequence must consider the throughput of the given steps so that a balanced manufacturing line can be maintained. The expenditure of a large amount of capital for a given step is not justified if that machine sits idle much of the time while the preceding operation tries to match its production. The process steps must also be matched so that the manufacturing can proceed from one step to another without an excessive amount of special treatment such as cleaning, mounting in special racks, etc. Compatibility is another attribute required of a process sequence in that a following step cannot negate the effect of a preceding step. A simple example of this is a high temperature treatment after the application of photoresist. Finally, the sequence must be cost effective so that the price goals can be met.

During this program we have proposed a process sequence that is suitable for both long lengths of web (greater than 10 meters) and parallel lengths of web (about 3 meters) that are processed simultaneously. This sequence incorporates several well tested techniques, such as vacuum evaporation of grid contact metals, in such a way as to make them cost effective. It also incorporates several new ideas such as dip coating of an AR film and ultrasonic welding of interconnects. This sequence has not been tested in a large scale manufacturing situation, but we have processed numerous short lengths of web (≈ 30 cm) through the sequence with considerable success. Although further work needs to be done, the selected process steps and the entire process sequence have been verified. In most cases we have been able to assign limits to the processing variables of temperature, time, length, etc. These limits have been set at the largest amount possible so that a given process can be used in a sequence with a minimum amount of control.

The IPEG and SAMICS methodology form the basis for determining the price of the solar arrays produced by a given process sequence.

We have taken advantage of both of these methodologies to study the process sequence we have selected. From these techniques it is also possible to identify cost drivers in a given process or sequence and thus determine where the greatest amount of cost reduction effort should take place. By using these programs, we have been able to show that the process sequence we selected, using either the long continuous lengths of web or the parallel processing of long lengths of web, is cost effective and should produce solar modules very near the 1986 price goals. Our model takes a conceptual factory producing 25 MW of solar modules per year per line, at a cost of $0.56/peak watt in 1975 dollars.

3. PROCESSES SELECTED FOR DEVELOPMENT

This Westinghouse program in the Low Cost Solar Array Project is concerned with the processing of single crystal dendritic web silicon into solar modules. Thus in the first part of this section we give some preliminary specifications for the web silicon that we believe are necessary to produce a high efficiency solar module.

The remaining sections discuss in some detail the various process steps on which development effort was spent.

3.1 Dendritic Web Silicon - Preliminary Material Specification

During the course of the program, we have developed a material specification for dendritic web silicon. This specification was derived from analyzing the data of cells prepared from various runs, and correlating this data with structural and electrical properties of the web crystal as defined in the Westinghouse Task 2 program (Contract 954654).

At this point, these specifications as given in Table 1 cannot be claimed to be either complete or all encompassing. They are a compilation of experience gained during the program, and are given as guidelines for web solar cell production.

3.2 Junction Formation

The development areas studied for junction formation included: (1) use of reagent (as opposed to semiconductor) grade $POCl_3$, (2) optimum time/temperature conditions for front junction diffusion, and (3) parameters involved in deposition and annealing of boron doped oxide films for the back surface field region.

3.2.1 Front Junction Preparation Using Reagent Grade $POCl_3$

A significant contribution to the cost of materials for cell fabrication is made by the electronic grade phosphorus oxychloride used in gaseous diffusion of the front junction. The cost of $POCL_3$ could be

TABLE 1

Material Specification
for
Dendritic Web Silicon

1. Single crystal - (111) orientation
2. The etch pit density, as determined after a 5 min Sirtl etch to be equal to or less than $3 \times 10^4/\text{cm}^2$. The etch pits should be of the small, shallow variety with a minimum of the large, deep pits.
3. For mechanical stability, the web should have a residual stress of less than 1.5×10^8 dynes/cm^2.
4. The web should be flat with no twist or bow.
5. The surface striations across the web should be no more than 0.5 μm in height.
6. The width, excluding dendrites, should be 19 mm or greater. (For a 1.6 x 7.0 cm cell.)
7. The thickness of the web at the center should be 120 μm ± 20 μm.
8. The web should be p-type.
9. The resistivity should be 12-18 Ω-cm.
10. The lifetime (OCD after boron and phosphorus diffusion) should be greater than 10 μsec.
11. The material should be supplied as grown.
12. The minimum preferred length per crystal is eight meters. This is required so that a statistically significant number of cells can be made from one crystal.

reduced to about 0.03 that of the electronic grade if the reagent grade could be used. However, the reagent grade has 200 times the specified heavy metal content of the electronic grade which could effect cell performance. (e.g. 0.21 ppm for electronic grade versus 40 ppm for the reagent grade). Therefore, experiments were made to determine if the cell parameters are affected by the purity of the $POC\ell_3$ diffusant source.

One base line group of cells was processed using Baker electronic grade $POC\ell_3$ for formation of the front junction. For a test group of cells, Baker Reagent grade $POC\ell_3$ was used in a parallel furnace arrangement. Both groups were made using 1 to 3 Ω cm p-type Czochralski silicon from the same wafer supply lot. Except for the $POC\ell_3$ diffusion step, the wafers were merged into a single group for the other cell processing steps. These cells were processed by a standard cell processing schedule(1). An outline of this sequence is shown in Table 2.

TABLE 2

Outline of n+/p Cell Processing Steps

Surface cleaning
$POC\ell_3$ diffusion
Front and back oxide removal
Top surface metal evaporation (1700 Å Ti, 500 Å Pd, 23 kÅ Ag)*
Lapping to remove back N+ layer
Photolithographic delineation of top metal
Back metallization (as front)
Contact sinering (550°C, H_2, 15 min.)
Mesa delineation using photolithography and $HF:HNO_3$, HAc etch

The finished cells were evaluated using a quartz halide source (91.6 W/cm^2). In addition to I_{sc} and V_{oc} data for each cell, four sets of current-voltage values were taken for computerized curve fitting to determine values of fill factor. A summary of the results of this curve fitting and of the comparisons between the baseline

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*non-optimized metal system

and test lots is given in Table 3. An overview of the comparisons between lots is afforded by the line marked "A" giving the test lot (i.e. reagent grade $POC\ell_3$) parameters as a percentage of the base line lot (i.e., electronic grade $POC\ell_3$) values. No significant differences exist in terms of V_{oc} and I_{sc}. Values of fill factor and efficiency for the test lot are approximately 3% higher than in the base line case. From the point of view of the experiment, this is not a significant change indicating that there is no distinction between the two grades of $POC\ell_3$ used as the diffusant source.

Table 4 gives the metallic element analyses, as supplied by J. T. Baker, for the particular lots of $POC\ell_3$ used in the experiment. Of particular interest are the Ti, Cr, Mn and Fe levels. Introduction of these species at levels of about 0.1 ppm in Czochralski silicon during growth result in minority carrier base lifetime reduction or recombination center density enhancement leading to severe reductions in solar cell efficiency (see Fig. 13 of Ref. 2). Of this set of elements, introduction of all but Ti at levels below 0.005 ppm have no measurable effect. In the case of titanium, as little as ∿ 0.001 ppm in the grown silicon crystal reduces cell efficiency by about 20% below that of an undoped control. Thus, the relatively high titanium content (∿ 20 ppm) of the reagent grade $POC\ell_3$ does not produce any detectable efficiency reduction which occurs with as little as five parts per billion of Ti deliberately incorporated in silicon crystals during growth.

Deliberate use of much higher concentrations of metallic impurities in the $POC\ell_3$ source was next studied to determine if a threshold concentration exists.

Reagent grade $POC\ell_3$ (20ppma Ti concentration) was contaminated with Ti to 100 and 500 ppma levels by liquid phase dilution with 99.9999% $TiC\ell_4$. Cells of the n+p type were fabricated using the three $POC\ell_3$ diffusion sources. Float-zone silicon wafers (2 to 4 ohm-cm, p-type, (111)-orientation) were used as substrates. Table 5 shows a summary comparison of these characteristics data for those cells. The 0.4% higher efficiency for cells from the 500 ppma Ti source is not significant.

TABLE 3

Cell Performance Comparison, AM1

Electronic vs. Reagent Grade POCℓ_3 -Diffusant Sources

71121 Test of Reagent (1P → 5P) vs. Electronic Grade (R1 - R4) POCℓ_3
AM1 (91.6 MW/cm^2)

I D	ISC	VOC	FF	EFF	EFF (AR coated)
1P	22.10	.573	.732	9.80	13.6
2P	22.60	.575	.733	10.07	14.0
3P	22.60	.575	.750	10.30	14.3
4P	22.60	.572	.707	9.67	13.4
5P	22.10	.571	.745	9.95	13.8
R1	22.40	.575	.767	10.44	14.5
R2	22.50	.576	.762	10.44	14.5
R3	22.40	.569	.728	9.81	13.6
R4	22.30	.571	.760	10.23	14.2

Averages 71121 Baseline

	22.40	.573	.733	9.96
STD	.24	.002	.015	.22

71121 Test of Reagent vs. elect. grade POCℓ_3

	22.40	.573	.754	10.23
STD	.07	.003	.015	.26

Percent of Baseline

A	100.0	99.9	102.8	102.7
STD %	1.4	.8	4.2	4.9

TABLE 4

Metallic Impurity Content (ppm) of J. T. Baker $POC\ell_3$, Reagent vs. Electronic Grade

Metallic Elements	Reagent Grade	Electronic Grade
Ti	< 20 ppm	< 0.02 ppm
Cr	50	Not detectable
Mn	30	0.002
Fe	300	< 0.02
Mg	70	< 0.1
Zn	< 20	.02

TABLE 5

Comparative Characteristics of Uncoated n+p Cells Fabricated with $POC\ell_3$ Sources of Several Ti Concentrations – AM1 (No AR Coating)

Ti Concentration in $POC\ell_3$ Source	τ_{OCD} (μs)	J_{SC} (mA/cm^2)	V_{OC} (mV)	Fill Factor	Efficiency %	No. of 1 cm^2 Cells
∿ 20 ppma	5.21	22.18	544	0.698	8.9	48
∿ 100 ppma	5.06	22.36	530	0.711	8.9	48
∿ 500 ppma	5.02	22.56	540	0.721	9.3	42

The lack of effect on cell performance of high concentrations of Ti in the $POC\ell_3$ source as compared with deliberate Ti doping of the growing crystal may reflect the fact that stable oxide glasses are formed during the n+ diffusion, making this particular cell degrading impurity unavailable for diffusion into silicon. To verify this contention, the oxide glasses formed during these diffusions (all less than 500Å thickness were analyzed by secondary ion mass spectroscopy (SIMS). The relative ratios of the integrated intensities for the mass numbers 47 (PO) and 48 (Ti) were computed for each type of glass and were found to give relative Ti concentrations ratios of 1:156:2.65; these ratios are to be compared with the starting ratios of Ti concentrations of the glass of 1:5:2.5. Taken with the results of Table 2, this supports the idea that the increased Ti concentrations in the formed glasses are not available for performance degradation of the cells.

Most of the difference between the experimental Ti ratios of 1:1.56:2.65 and the source Ti ratios of 1:5:25 can be accounted by the relative difference of vapor pressures of the two components ($P_{POC\ell_3}$ @ 20°C ≈ 35 mm Hg and $P_{TiC\ell_4}$ @ 20°C ≈ 10 mm of Hg). Furthermore, the mechanisms of oxidation of these two components would also make the solid glass poorer in Ti content. $POC\ell_3$ oxidizes in the gas phase to $P_2O_5(g)$. The homogeneously produced gaseous P_2O_5 is available to react with the silicon and form the glass diffusion source. On the other hand, $TiC\ell_4$ oxidizes to $TiO_2(s)$. The homogeneously formed solid TiO_2 particles should be exhausted. Those produced on the silicon surface are not incorporated into the glass, and are also probably exhausted.

3.2.2 Optimum Time/Temperature Conditions for Front Junction Diffusion

Several tests were carried out in a time-temperature matrix to determine the optimum time and temperature and thus acceptable limits for front surface diffusion. These data are more applicable to the process verification portion of the program and will be reported in Section 5.1.1

3.2.3 Back Surface Field Development

3.2.3.1 Doped Oxide Study

During the program, the main effort in forming the back p+p junction was by using a boron doped oxide prepared by a chemical vapor deposition. Good control of the uniformity and reproducibility of such a diffusant source is expected. For an effective back surface field region, good control of the doping profile is important. The CVD approach is particularly attractive since low temperatures are used to prepare the doped oxide.

The deposition of both the boron doped oxide film and the undoped capping oxide was carried out in an AMS-1000 "Silox" reactor. This reactor is an efficient, low-cost vapor phase oxidation system for depositing doped and undoped SiO_2 films at 350° to 450°C. It has a typical hourly throughput of 120 2-inch wafers with an overall film thickness uniformity of ± 5%. The AMS-1000 reactor system consists of a resistance heated wafer carrier and gas dispersion head about 100 mils above the carrier. Deposition is accomplished by placing wafers on the carrier mechanism which passes below the dispersion head at a pre-programmed rate of travel. The dispersion head injects an approximately laminar flow of oxygen or air, silane with or without the dopant hydride (PH_3 of B_2H_6) in a nitrogen carrier into the reaction zone where the reactants combine to deposit SiO_2. Between deposition cycles the dispersion head is automatically purged to ensure compositional purity, and it is water cooled to minimize gas phase reaction.

After initial studies were made to determine optimum operating conditions, a number of n+pp+ cell runs were made. These n+pp+ cells were processed by the standard boron doped oxide technique with the BSF source film being deposited under the following conditions:

(1) Nominal deposition temperature = 420° ±4°C.

(2) 15% SiH_4 flow = 160 cc/m, 5% B_2H_6 flow = 370 cc/m, total N_2 flow = 5.7 ℓ/m, and O_2 flow = 250 cc/m.

(3) Doped-film thickness $\sim$ 4600 Å (two passes), and undoped capping

film thickness $\underset{\sim}{\sim}$ 2000 Å (two passes) with the front surface masking undoped SiO_2 thickness $\sim$ 1000 Å. These thicknesses are in excess of what is needed and are not optimized.

The BSF film was annealed for 4 hrs. at 1000°C in 2.5 ℓ/min <u>each</u> of N_2 and O_2 with 2"/5 min. pull-rate to generate a boron-diffused layer with $X_j \underset{\sim}{\sim} 1.9\mu$ and $R_s = 35 \pm 0.5\ \Omega$ per square. The active n+p junction was formed by $POCl_3$ diffusion with a $R_s = 35 \pm 0.5\ \Omega$ per square. Evaporated Ti-Pd-Ag front and Aℓ back metallizations were used with no AR coating.

Cell characteristics data is shown in Table 6. Results for an earlier run using the same process, but with a horizontal cold-wall reactor are also given. The results using the Silox$^{(R)}$ reactor are slightly better, indicating that the Silox$^{(R)}$ reactor approach has no performance disadvantages in this application.

3.2.3.2 Single Crystal Wafer Cells With and Without BSF Regions

Four sets of cells were fabricated from both 2-4 Ω-cm float zone (FZ) and 20-30 Ω-cm Czochralski (CZ) wafers. Three of the runs were made on wafers thinned to about 100 μm by etching and then provided with back surface field (BSF) regions of several depths. The most shallow back boron concentration profile ($\sim$0.3 μm) was formed with a 20 min, 960°C BBr_3 diffusion. BSF regions having depths of 0.9 μm and 2.0 μm were prepared by diffusion from doped oxides at 1000°C for 1 hr. and 4 hrs. respectively. The fourth run, using 2 to 4 Ω-cm FZ material of $\sim$ 230 μm thickness was not provided with any BSF region. The front junction in all cases was formed by a $POC\ell_3$ diffusion of 50 min. at 825°C. The phosphorus diffusion conditions had been previously determined to produce optimum results on single crystal wafer material. A mask design was used to give twelve cells of 1 cm^2 active area for each wafer. In this way the statistical variations in cell characteristics could be assessed readily.

Table 7 gives performance data on n+p cells formed in the 2 to 4 Ω-cm float zone material. Part (a) of the table gives results on individual cells for a single wafer having the best average efficiency

TABLE 6

CHARACTERISTICS OF n+pp+ BASE-LINE CELLS FABRICATED WITH AMS-1000 REACTOR PRODUCED BACK SURFACE FIELD (Simulated AM1)

(NO AR COATING)

Cell Groups	τ_{OCD} (μs)	J_{sc} (ma/cm^2)	V_{OC} (mV)	Fill Factor	Efficiency %	No. of 1 cm^2 cells
2-4Ω-cm p (111) FZ Wafer (9 mils) without SiO_2 front mask	10.45	22.46	.569	0.772	10.43	36
2-4Ω-cm p (111) FZ Wafer (9 mils) with SiO_2 front mask	12.83	23.12	.564	0.768	10.60	35
2-4Ω-cm p (111) FZ Wafer (10 mils) with SiO_2 front mask (oxide layers by cold wall reactor)	---	22.2	.548	.72	9.3	4

TABLE 7

Performance Characteristics for Ohmic Back Contact Cells Using Single Crystal Float Zone Silicon*

a. Individual Cells
Best Wafer

Cell No.	J_{sc} (mA/cm)	V_{oc} (mV)	Fill Factor	η (%,Not AR Coated)
1	20.5	549	0.71	8.5
2	20.8	549	0.70	8.4
3	20.7	545	0.69	8.2
4	20.5	547	0.73	8.7
5	22.1	550	0.73	9.4
6	22.2	550	0.71	9.2
7	22.6	548	0.72	9.4
8	22.5	549	0.73	9.6
9	22.7	551	0.74	9.7
10	22.8	550	0.73	9.6
11	22.7	545	0.69	9.1
12	22.7	549	0.73	9.7

b. Average Values
for Each Wafer

1	22.2	548	0.72	9.3
2	22.3	541	0.67	8.6
3	22.0	545	0.72	9.1
4	22.3	540	0.68	8.7

---

* P-type, 2 to 4 Ω-cm; 2 in. diameter, thickness 230 μm. Simulated AM1 illumination, no AR coating.

(not AR coated) for the group considered. Data for the other wafers are similar in distribution. Part (b) of Table 7 gives mean values of the performance parameters for four wafers as determined on 10 to 12 cells of each wafer.

Table 8 gives individual and averaged performance parameters for BSF cells (0.3 μm diffusion from BBr_3). These were prepared using a float zone single crystal wafer of 2 to 4 Ω-cm resistivity. The wafer had been etched to a thickness of about 100 μm prior to fabrication in order to enhance the expected effect of the back surface field region. As an additional experiment 20 to 30 Ω-cm wafers of Czochralski silicon of the same thickness and the same BSF conditions yielded the following mean parameter values for 9 cells: J_{SC}, 23.3 ma/cm^2; V_{OC}, 568 mV; fill factor, 0.72; efficiency, 10.1%.[#] Thus the back surface field processing produced similar results in the two types of material

For the 2 to 4 Ω-cm float-zone material giving the results of Tables 7 and 8, the difference in average value of open circuit voltage for the 100 μm thick BSF cells and the 230 μm ohmic contact cells is about 34 mV. This value can be examined in terms of predicted differences for such cells as influenced by minority carrier diffusion length and cell base thickness.

Hovel(3) calculates, using a simplified approach, the open circuit voltage as a function of thickness in p-base cells with and without BSF regions for electron diffusion length values of 52 and 232 μm.* If the difference in V_{OC} values with and without the BSF region is considered as a function of sample thickness normalized with respect to the electron diffusion length, a single curve is produced, as shown in Figure 1.

In order to use Figure 1 in evaluating the results given in Tables 7 and 8, it is first necessary to resolve the effect of the greater base region thickness for the ohmic contact cells. If the base material were of high lifetime (∿ 15 μsec) and long diffusion length (∿ 232 μm) then V_{OC} for a 100 μm thick cell (comparable to the BSF types of Table

---

*Ref. 3 Figures 55 and 57

[#] No AR Coating

TABLE 8

Performance Characteristics for Single Crystal, Float Zone Cells Having Back Surface Field Regions Prepared by BBr_3 Diffusion (No AR Coatings)

AM1

	J_{sc} (mA/cm^2)	V_{oc} (mV)	Fill Factor	η (%)
	22.5	575	0.72	9.8
	22.8	583	0.76	10.7
	22.6	574	0.77	10.5
	23.0	576	0.77	10.8
	22.9	575	0.76	10.6
	22.7	585	0.78	10.9
	22.8	583	0.78	11.0
	23.1	584	0.79	11.0
	22.8	583	0.77	10.9
	22.6	577	0.77	10.6
	22.3	567	0.73	9.8
	22.4	575	0.76	10.3
	22.7	578	0.76	10.6
	23.1	580	0.75	10.6
	22.9	580	0.77	10.8
	23.5	581	0.77	11.1
	21.2	577	0.68	9.0
Mean Values	22.7	578	0.76	10.5

Curve 695835-A

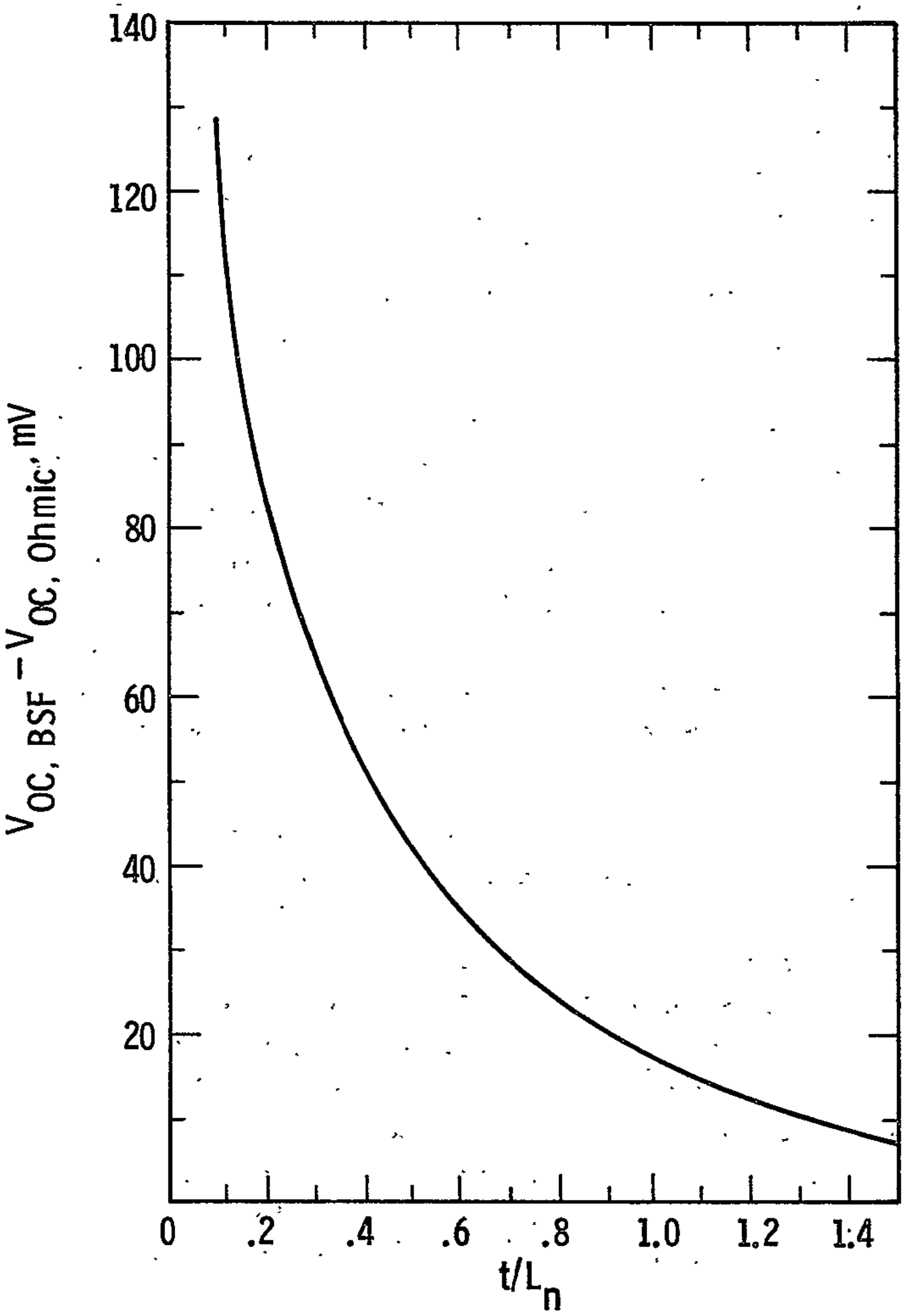

Fig. 1 Predicted open circuit voltage enhancement in p-base silicon cells as a function of thickness normalized to minority carrier diffusion length. (After Ref. 3).

8) would be about 10 mV lower than for 230 μm thick cells. Thus, the 34 mV difference in V_{OC} for the experimental cells would correspond to a 44 mV difference if the comparison were made for 100 μm thick cells. On the other hand, if the base material were of short diffusion length (∿ 50 μm or less), reduction of the base thickness from 230 to 100 μm would not be sufficient to cause a change in V_{OC} for the ohmic contact cell. Thus, we can use Figure 1 to estimate the values of (base thickness)/(electron diffusion length) for ΔV_{OC} = 44 mV and for ΔV_{OC} = 34 mV. This gives values of 0.47 and 0.61, respectively. The corresponding estimates for L_n are 220 μm diffusion length value corresponds to an electron lifetime of about 14 μsec in the base region.

3.2.3.3 Web Silicon Cells With and Without BSF Regions

Results have been obtained on the operation of back surface field regions in dendritic web silicon material. The samples reported on below were given the normal BBr_3 (20 min at 960°C) and $POC\ell_3$ (35 min at 850°C)* diffusions. Table 9 gives the data on these cells.

The data given is an average of several cells within the same run. The data show strong evidence of back surface field operation with a voltage difference of 57 mV in the high resistivity web materials and a somewhat smaller difference of 40 mV for the lower resistivity case. From Figure 1, the diffusion length values are estimated to be 288 μm and 470μm for the 4.5 and the 15 Ω-cm material respectively. These values and the corresponding ones for electron lifetime in the base region are given in Table 10. For comparison, values of open circuit decay time constant are given in the last column of Table 10. It is interesting that these values are in approximately the same ratio as the minority carrier lifetime values inferred from the open circuit voltage enhancement for the two samples.

---

*This diffusion condition was determined to be optimum for dendritic web silicon - see Section 5.

Table 9

Initial Results for Web Cells (Not AR Coated)
With and Without BSF Regions (AM1)

Sample	BSF	$\rho\,(\Omega\text{-cm})$	Thickness (μm)	V_{oc} (V)
WEB R225	No	4-5	150	.520
WEB R225	Yes	4-5	150	.560
WEB J21	No	15	165	.493
WEB J21	Yes	15	165	.550

Table 10

Estimated Diffusion Lengths and Electron Lifetimes in
Web Silicon Cells with BSF Regions (AM1)

Sample	Thickness (μm)	L_n (μsec)	τ_n (μsec)	τ_{ocd} (μsec)
WEB R225	150	288	23	6
WEB J21	165	470	60	19

The long diffusion lengths indicated in Table10 are obtained from web crystals that have not received any prediffusion gettering treatments. These diffusion lengths are comparable to state-of-the-art float zone and Czochralski crystals, thus indicating the suitability of web BSF cells.

The above process was used throughout the program in the preparation of web cells up to 1.6 cmX 7.0 cm.

3.3 Antireflection Coatings (AR)

3.3.1 Introduction

The reflection losses from a surface are related to the difference in index of refraction between the environment and the material For a high index material such as silicon, the surface reflection is about 35% of the incident light in an air environment. If the silicon solar cell is to be efficient and viable, this loss must be eliminated by antireflective coatings.

Minimum reflection from the coated surface is given by Fresnel's equation:

$$R_m = \left(\frac{n_c^2 - n_1 n_2}{n_c^2 + n_1 n_2} \right)^2 \qquad (1)$$

where n_c, n_1, and n_2 are the refractive indices of coating, medium, and substrate, respectively. In order for the reflectivity, R_m, to be zero in equation (1), the index of coating must satisfy the condition:

$$n_c = \sqrt{n_1 n_2} \qquad (2)$$

The thickness of the coating, then, is determined by the equation:

$$t_c = \frac{\lambda_o}{4\, n_c} \qquad (3)$$

λ_o is the wavelength where zero reflectivity is desired.

The antireflective coating on silicon solar cells in an air environment must have an index of 2 and a thickness of about 0.07 μm, as calculated from equations (2) and (3); where $n_1 = 1$, $n_2 = 4$, and λ_o is 0.06 μm. Such AR coatings must also be highly transparent in the solar spectrum stable and resilient to the environment. Titanium and tantalum oxides have been found to be suitable for this purpose. Quarter wavelength AR coatings are generally applied by vacuum deposition or vacuum sputtering. TiO_2 oxide coatings have also been deposited by spraying of a titanium alkoxide, e.g., $Ti(OC_3H_7)_4$, and water after they are mixed in a non-oxidizing carrier gas[4-8].

In studies made before this contract effort, workers at Westinghouse have demonstrated that films prepared from liquid metal-organic precursors can be used as very effective AR coatings on solar cells produced using Czochralski silicon wafers. The composition of the precursors can be formulated to yield simple oxides such as SiO_2, TiO_2 or Ta_2O_5 or mixtures of oxides with tailored optical properties. In the case of TiO_2, clear films have been produced with index of refraction of about 2.4. The technique has been used to produce multi-layer coatings as well. For the work to date, the thickness of the films has been controlled by adjusting viscosity of the precursor and by spinning the substrates, analogous to photoresist practice in the IC industry. Processing of lengths of dendritic web silicon required development of dip or spray application methods.

In initial work on this program, cells were spin-coated using liquid metal-organic precursors of TiO_2 and SiO_2. Ranges of values for coating viscosity and for spin-speed were used in these preliminary experiments. After coating, the samples were baked at 400°C in vacuum. The primary aim of this work was to determine the practical limits to short circuit current enhancement in state-of-the-art web silicon cells coated in this manner.

Table 11 gives values for I_{SC}, fill factor and efficiency of these cells before and after coating. The ratio is given to show improvement after coating. The first three cells in the table were fabricated on Czochralski crystals while the last seven were on dendritic web silicon. All but one of the samples were from the same diffusion run.

The data for sample 1 show the effect of a single layer of TiO_2 ($n = 2.4$); sample 2 a double layer of SiO_2 ($n = 1.4$) over TiO_2. The remainder of the samples were double coated (using TiO_2 and SiO_2) under various experimental conditions. For the web cells a maximum improvement of 43% in efficiency was noted.

3.3.2 AR Coatings by Dip Processing of Dendritic Web Silicon

After these initial experiments which showed that precursor solutions obtained from metal-organic compounds could be used as very effective AR coatings, the emphasis was shifted to examining techniques for applying the precursor in a reproducible, cost effective manner. It was

TABLE 11

Effectiveness of AR Coatings Prepared from Metal-Organics Precursors

SAMPLE		I_{SC} (mA)			FF			EFFICIENCY (%)			SILICON TYPE
		PRE	POST	POST/PRE	PRE	POST	POST/PRE	PRE	POST	POST/PRE	
1	(single)	22.8	29.5	1.29	.77	.73	1.00	10.4	13.9	1.34	CZ
2	(double)	22.0	30.5	1.39	.73	.77	1.05	9.4	14.0	1.49	"
3	"	20.8	28.9	1.39	.73	.77	1.05	8.7	12.8	1.47	"
4	"	20.1	27.9	1.39	.74	.76	1.03	8.5	11.8	1.39	Web
5	"	19.2	24.9	1.30	.71	.70	.99	7.6	9.5	1.25	"
6	"	21.1	29.4	1.39	.71	.72	1.01	8.6	12.2	1.42	"
7	"	21.6	31.0	1.44	.75	.73	.97	9.4	13.3	1.41	"
8	"	21.4	30.5	1.43	.74	.74	1.00	9.0	12.9	1.43	"
9	"	21.9	29.6	1.35	.76	.73	.96	9.5	12.4	1.31	"
10	"	21.1	29.5	1.40	.75	.73	.97	9.0	12.4	1.38	"

decided that due to cost considerations, further work would focus on single coatings. Double coatings would require vacuum baking and double handling of the web. A single coating can be air baked. Thus, the advantage of the small increase in efficiency that could be obtained from a double coat would be lost due to the extra cost. These dipping techniques were developed for processing either finite lengths of web in parallel or processing continuous lengths of web(s). The processing variables and the cost calculated from these tests are applicable to either type of processing. Experiments were carried out using 100 cm long X 1.3 cm wide stainless steel ribbons since initial studies had shown that these steel strips behaved the same as dendritic web silicon in so far as coating thickness etc. was concerned. These ribbons were immersed in AR coating solution with concentrations of 0.5, 1.0, 2.0 and 3.7 weight percent equivalent oxide. The ribbons were then withdrawn from the solution at various speeds up to 10M/min.. After baking the coating at 400°C, the thicknesses were measured and related to the rate of withdrawal.

The findings of this study showed that the thickness of coating applied to the ribbon was dependent on the nature of the solution and mechanical factors. The solution parameters are concentration of the oxides in the solvent, viscosity of the solution which is controlled by the type of solvent used and the degree of polymerization of the constituents. The mechanical factors were rate of withdrawal of the web from the solution and the width of the web.

Figure 2 shows the coating thickness on the ribbon as a function of various withdrawal rates at four solution concentrations. The solvent used was ethyl alcohol. (Ethyl alcohol was used in all tests since it can readily be obtained in pure form, which was necessary to investigate the basic parameters effecting the viscosity of the solution and polymerization of the constituents). The quarter wave thickness required for an effective AR coating is about 750 Å. Thus the horizontal line at 750 Å shows the withdrawal rates required to obtain this thickness at a given solution concentration.

Curve 696678-A

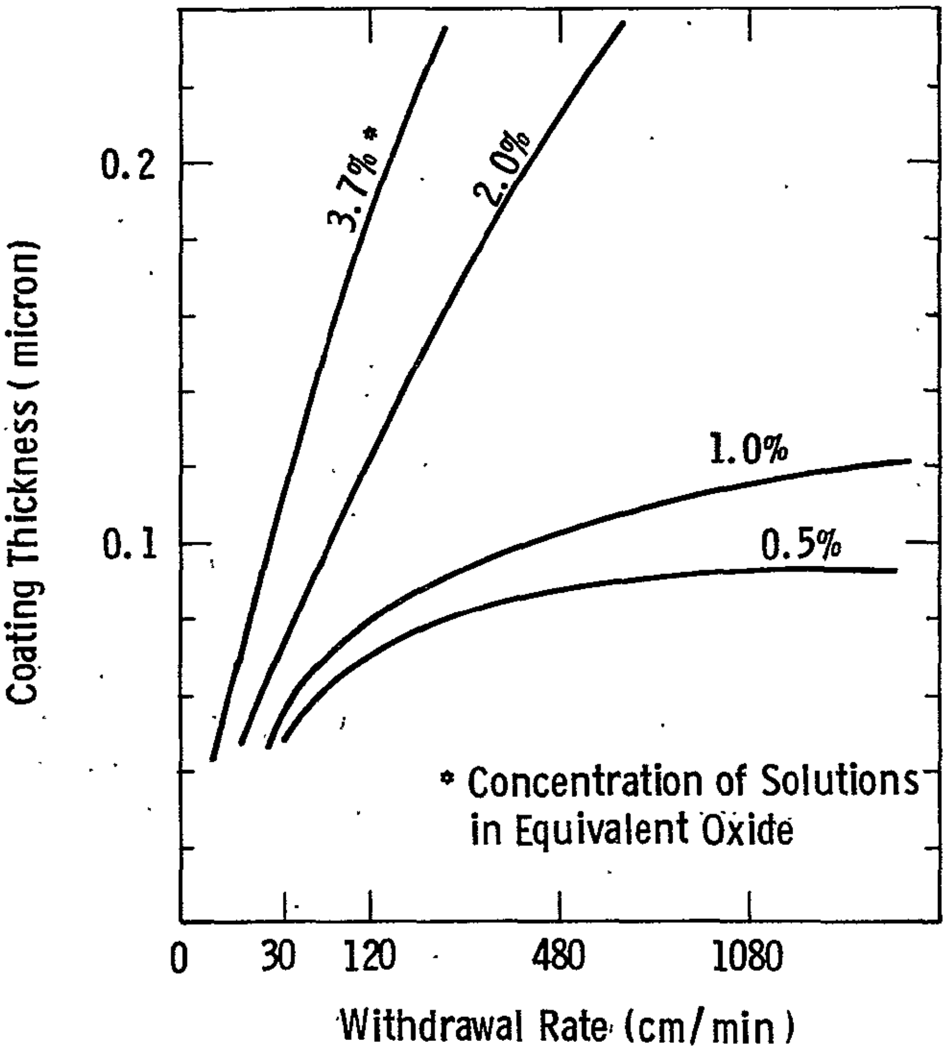

Fig. 2 Coating thickness as a function of solution concentration and withdrawal rate in dipping application.

Of especial interest is the behavior of the 0.5% solution, where the coating thickness becomes nearly independent of withdrawal rate. Although we have not made the test, it would appear that if a 0.3 to 0.4% solution were used, the proper thickness could be obtained at high withdrawal rates and would be insensitive to the withdrawal rate.

The viscosity of the solution is dependent only on the solvent if the oxide concentration is low (< 5%). It has been shown that the coating thickness-withdrawal rate curves can be moved up and down vertically by changing the solvent. This provides another control on the coating thickness.

3.3.3 Heat Treatment of the Coating

Reduction of the coating to an essentially organic-free oxide coating requires a heat treatment slightly in excess of 300°C.

During baking, the index and thickness of the film change as organics are liberated. The index of refraction of the unheated film is around 2.4 in vacuum firing and 2.2 in air firing. The film thickness decreases to approximately 50% of the original thickness. Again, almost all the changes in thickness and index are completed by 300°C (see Figure 3). It is also of interest to note that the ∿20% weight loss occurring by the removal of hydrogen organic groups is associated with 50% densification in the film as indicated by the thickness change.

3.3.4 Chemical Resistance of the Films

To check the chemical stability of the film, 1-1/4" diameter silicon wafers were coated with quarter-wave thick TiO_2 films. Half of the samples were fired in air and half in vacuum at 500°C. These samples were then immersed in 1% solutions of HCl, HNO_3, H_2SO_4, H_3PO_4, and NH_4OH as well as water. Conditions of the coatings were observed at various intervals. Tables 12 and 13 summarize the results.

It is obvious that both high temperature air- and vacuum-baked films have excellent resistance to acids. Against ammonia and,

Curve 690972-A

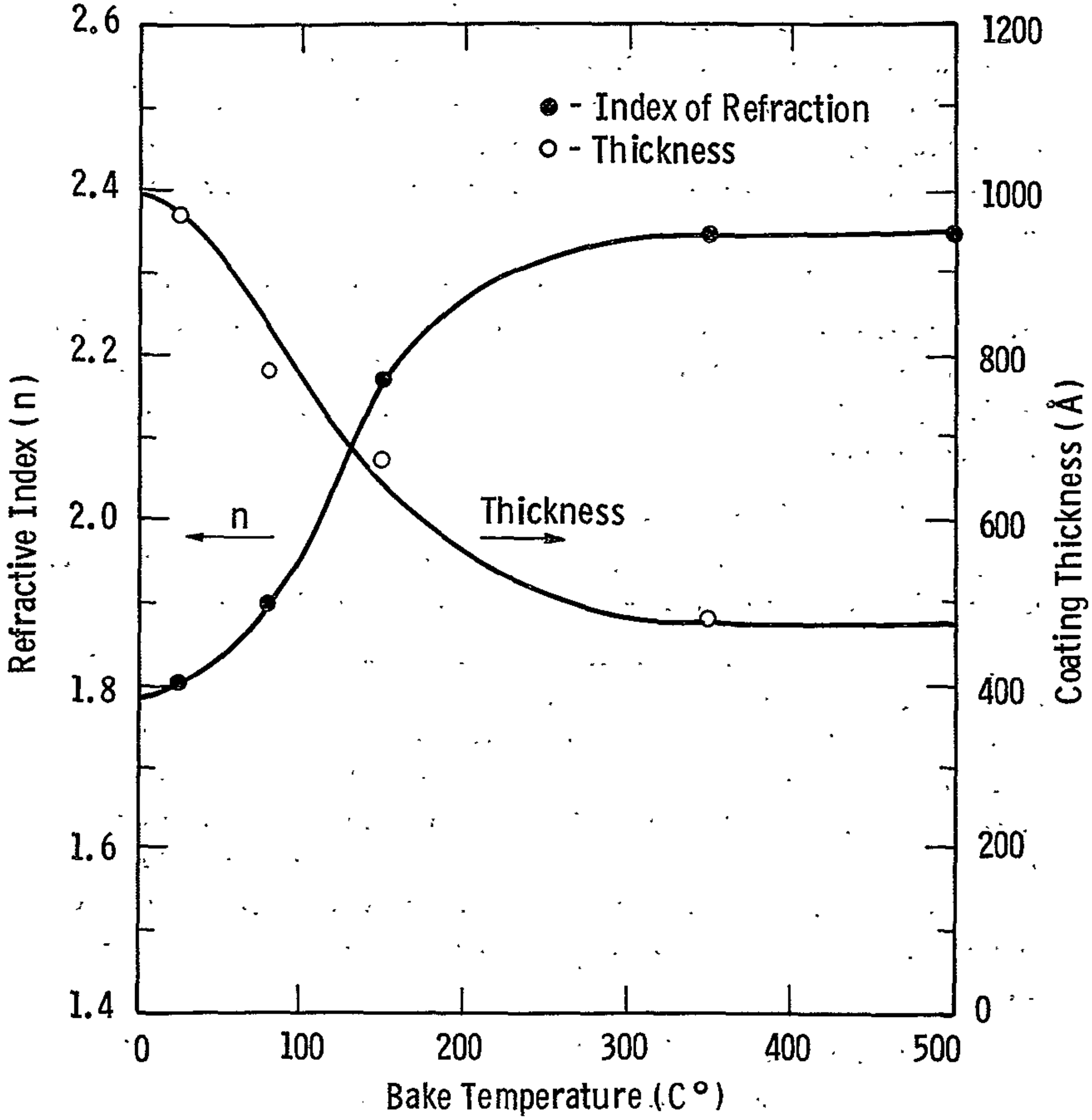

Fig. 3 Change in index of refraction and coating thickness during heat treatment.

TABLE 12

The Stability of Air-Baked TiO_2 Films in 1% Concentrated Solutions of Various Acids and Ammonia

Sample	Solution*	Condition of the Film in 75 Days
1	HCl	No observable deterioration
2	HNO_3	No observable deterioration
3	H_2SO_4	No observable deterioration
4	H_3PO_4	No observable deterioration
5	NH_4OH	Completely deteriorated (deterioration starts to become obvious after 7 days and is complete within 10-20 days)

TABLE 13

The Stability of Vacuum-Baked TiO_2 Films in 1% Solution of Various Acids and Ammonia

Sample	Solution*	Condition of the Film in 75 Days
1A	HCl	No observable deterioration
2A	HNO_3	No observable deterioration
3A	H_2SO_4	No observable deterioration
4A	H_3PO_4	No observable deterioration
5A	NH_4OH	No observable deterioration

* 1 weight % in H_2O

presumably, other basic solutions, the air-baked film does not seem to have good resistance, but the vacuum-baked film does.

We have also studied the resistance of the films as a function of their heat treatment temperature. In general, the films showed increasing resistance with increasing heat treatment temperature up to 400°C. An apparent anomaly was that the samples heat treated between 50 and 100°C showed better resistance to ammonia than the samples baked at higher temperatures. A possible explanation for this is the presence of organic groups retained at these temperatures.

It has also been noticed that once the films are coated, even without baking they are extremely difficult to remove. For example, alcohols or water, even with rubbing, were ineffective in removing the unbaked films.

3.3.5 Reflectivity

Specular reflection, as a function of wavelength, was measured for silicon wafers with quarter-wave thick coatings. Figure 4 shows the percent specular reflectivity of the TiO_2-coated silicon wafers baked at various temperatures. As shown, the sample baked at 80°C approaches ideal reflectance with less than 0.5% reflectivity at around 0.06 μm. The calculations indicate that a bake temperature of around 110°C is required to obtain essentially zero reflectivity around this wavelength. This is consistent with the refractive index-bake temperature relation indicated in Figure 3. The index requirements of $n = 2$ for silicon can only be met at these low temperatures. Figure 5 shows which wavelength corresponds with minimum reflection and the percent reflectivity at these minimums as a function of bake temperature.
Thus, although optically satisfactory quarter-wavelength AR films on silicon wafers can be obtained from titanium alkoxides without doping, this must be done at low bake temperatures, e.g., at around 100-150°C[7-8].

As shown above, films prepared at bake temperatures below 400°C are more susceptible to attack by acids; therefore, a higher bake temperature is preferred.

Curve 690988-A

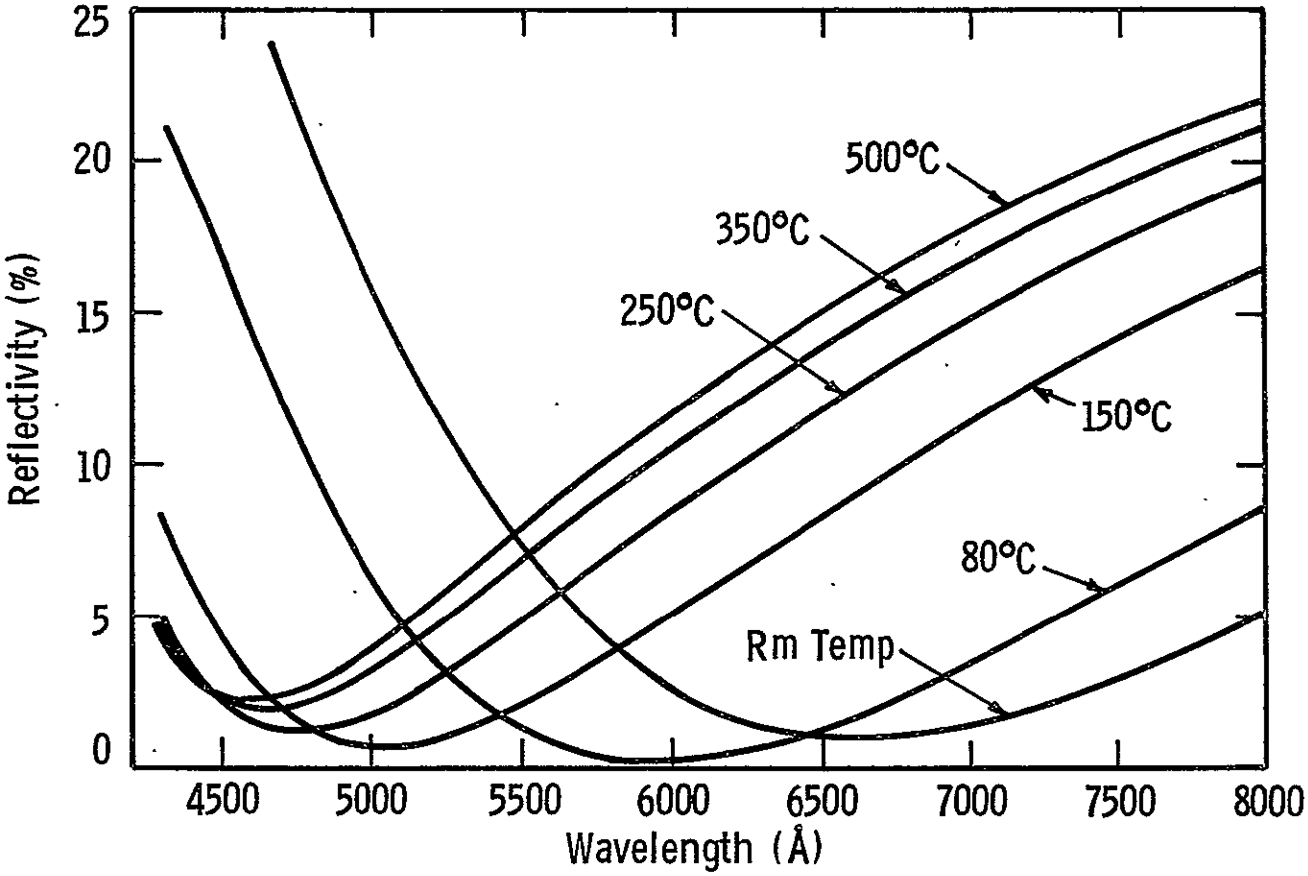

Fig. 4 Spectral reflectivities of coatings heat treated at various temperatures.

Curve 690975-A

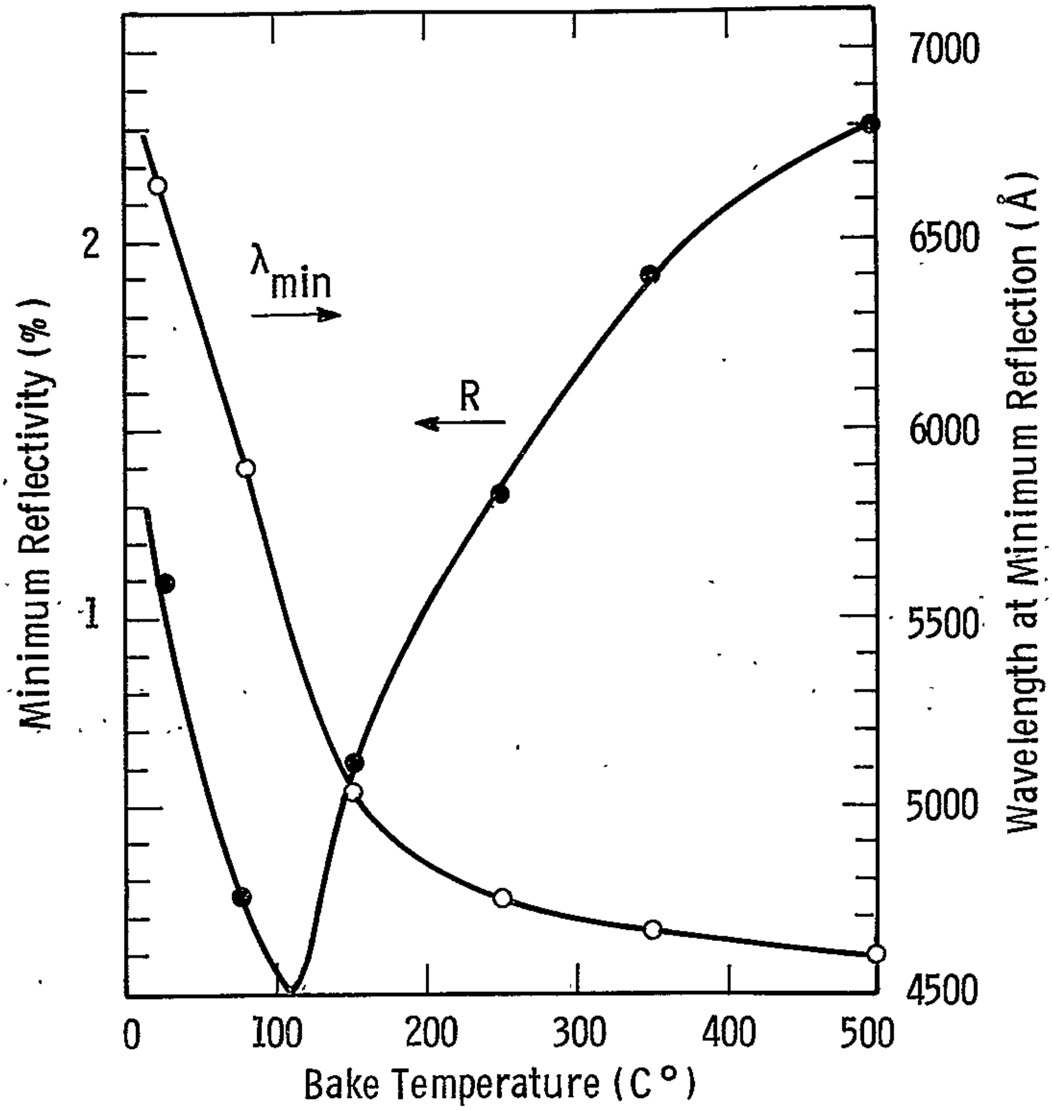

Fig. 5 Minimum reflection and wavelength as a function of heat treatment of undoped titania coating.

To accomplish both the higher bake temperature required for chemical stability and still maintain the proper film thickness, the composition of the coating was adjusted by adding SiO_2 to the TiO_2 to a composition of 88% TiO_2 and 12% SiO_2. The thickness and refractive index of this mixed oxide solution will vary in the same way as shown for the TiO_2 solution in Figure 4, but the final thickness after baking at 400°C will be near 0.07 µm.

Figure 6 shows the reflectivity of dendritic web silicon coated with this 88% TiO_2 - 12% SiO_2 solution and fired in air at 450°C. The curve shows a zero reflection at 6000Å; the film was about 750Å thick with an index of refraction of 2.0. This film gives nearly 48% improvement in solar cell efficiency over the uncoated state.

This oxide composition and bake temperature were used for all further antireflection coatings prepared during the program. Examples of cell performance with these coatings are given in Table 14.

TABLE 14
Effect of Metal-Organic Derived AR Coatings
on the Performance of Solar Cells

	I_{sc} (mA)		Efficiency (%) *		
Solar Cell	Uncoated	Coated	Uncoated	Coated	Improvement
1012 R-4	21.10	29.40	8.56	12.24	43%
1012 R-5	21.60	31.00	9.37	13.34	42%
1012 R-6	21.40	30.50	9.03	12.91	43%
R1009 B-3**	21.20	28.60	8.95	12.70	42%
1012 B-3	20.80	28.90	8.65	12.82	48%
1012 B-4***	22.00	30.50	9.43	14.04	49%

* Calculation of efficiency takes into account changes in open circuit voltage and fill factor (as well as the short circuit current, I_{sc}). However, these factors are relatively insensitive to AR coatings and therefore not given here separately.

** TaO_2 coating

*** Double coating

Curve 712896-A

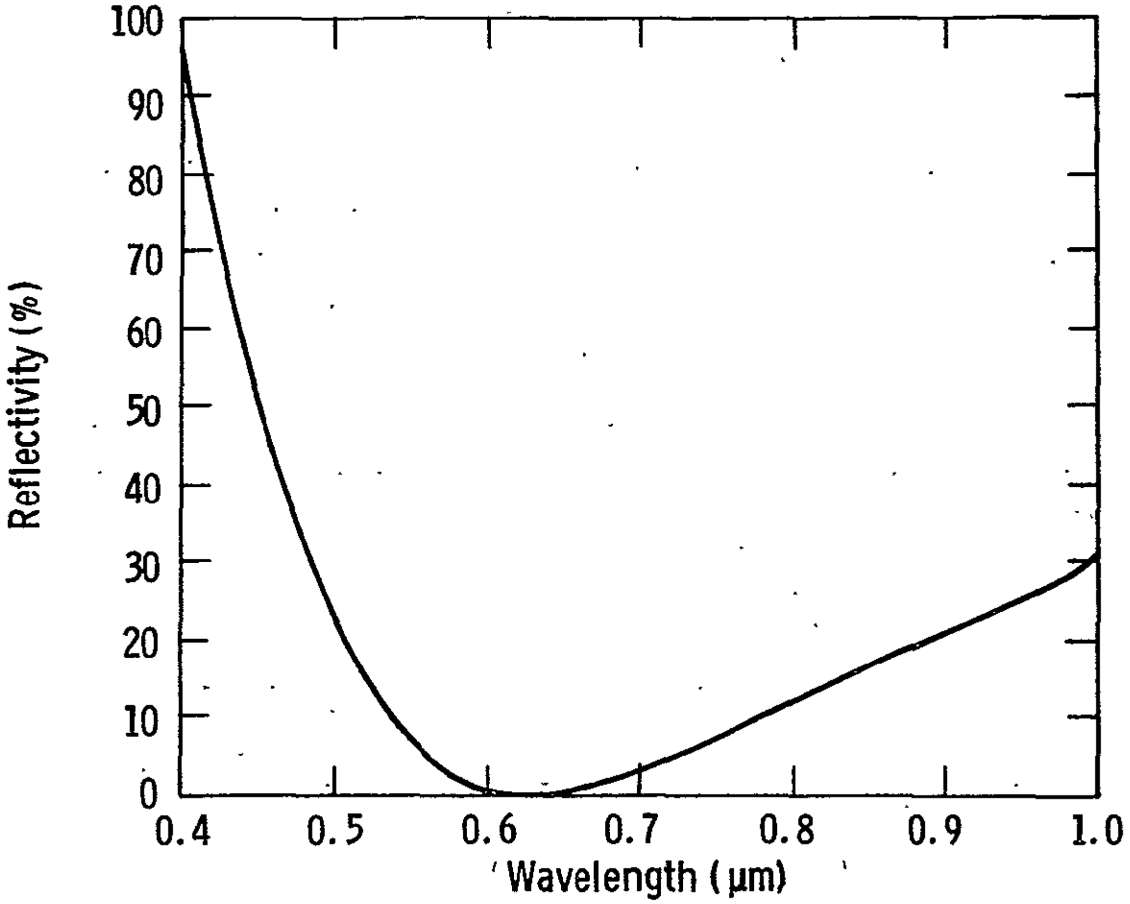

Fig. 6 Spectral reflectivity of a AR coating on a web silicon solar cell (composition 88% TiO_2 - 12% SiO_2, heat treated at 450°C).

3.4 Metallization Systems for Solar Cells

3.4.1 Systems Studies

Cost effectiveness is a key issue in the photovoltaics program. In meeting the objectives of this program, a well-developed, less expensive reliable contact system became a necessity. The experiments conducted, necessitates such contact systems so that cost-effectiveness could be maintained.

Among these systems, evaporated Ti-Pd-Ag is the most widely used. It performs well, but is not cost-effective because of the use of expensive silver, vacuum deposition technique,(3) and the waste of material during the evaporation. Also, at times a slight decrease in the cell performance resulting from high temperature sintering was observed. Detailed analyses have indicated that this loss is primarily due to the increased junction excess current which can result from the presence of defects or impurities in the depletion region of the solar cell. Some junction depth studies have indicated that deeper junctions are less susceptible to sintering-induced degradation. This supports the conjecture that impurities or defects diffuse from the top surface to the junction region to degrade the cell performance somewhat. Since Ti is a possible candidate for causing the degradation we have also investigated some other elements which can replace Ti, if necessary, without any loss in cell performance. Thus, the objectives of this study were: (1) to find a less expensive process than the vacuum deposition of metals, (2) to find a replacement for expensive Ag, (3) to reduce the waste of contact metals, and (4) to look for a good substitute for Ti.

The following contact systems have been studied:

1. Evaporated Ti-Pd-Ag
2. Evaporated Ti-Pd plus Electroplated Ag
3. Evaporated Ti-Pd plus Electroplated Cu
4. Evaporated Pd plus Electroplated Cu
5. Evaporated or Plated Cu
6. Evaporated Cr-Pd-Ag
7. Evaporated Ta-Pd-Ag

The conventional evaporated Ti-Pd-Ag contact was used as a base line to evaluate the other contact systems. The evaporated Ti-Pd electroplated system is much more cost effective than the first one because electroplating can be done over a well defined area which considerably reduces the waste of evaporated Ag. The evaporated Ti-Pd-electroplated Cu system was studied to see if Ag could be replaced. Because it is highly conductive, less expensive and easy to electroplate Cu was selected. Another advantage of Cu is that it has a potential to simplify the interconnects since Cu foils can be used for bonding which results in a more reliable one metal interconnect system. On the other hand, if Ag is the top metal then Al or Cu foils will be used to form the interconnects, which may give rise to a somewhat less reliabile multimetal system. The Pd-Cu system was investigated to determine if Ti is necessary in the Ti-Pd-Cu system. The fifth system studied was the evaporated or electroplated Cu, while sixth and seventh systems that were investigated in an attempt to find a substitute for Ti were evaporated Pd-Ag and Ta-Pd.

3.4.2 Solar Cell Fabrication and Characterization

In all cases 1 cm x 1 cm N^+P solar cells were fabricated by phosphorous diffusion at 850°C. The diffusion time was 35 minutes which gives an estimated junction depth of approximately 0.4 to 0.5 microns. The substrate material was p-base, 10-15 Ω-cm boron doped either Czorhralski or dendritic web. The contact metal systems were applied in the form of a five finger grid with approximately 5.4% area coverage. Most of the devices had back surface fields but no antireflection coating.

The solar cells were characterized by determining the cell efficiency (η) open circuit voltage (V_{oc}), short circuit current (I_{sc}), fill factor (FF), series resistance (R_s), shunt resistance, (R_{SH}), bulk (I_B) and the junction (I_j) current of the solar cell. η, V_{oc}, I_{sc} and FF were determined for the AM1 condition by the computer fit of the lighted I-V data to the following single exponential model.

$$I = I_{sc} - I_o \left(e^{q(V + IR_s)/nkT} - 1\right) \qquad (4)$$

The peak power point (V_p, I_p) was then determined by solving the following equation with the help of a computer program

$$\frac{dP}{dI} = V + I \frac{dV}{dI} = 0 \qquad (5)$$

Cell efficiency was determined by

$$\eta = \frac{V_p \cdot I_p}{91.6} \qquad \text{(Test lamp had output of 91.6 mw/cm}^2\text{)} \qquad (6)$$

and fill factor was obtained from

$$FF = \frac{V_p I_p}{V_{oc} \cdot I_{sc}} \qquad (7)$$

The series resistance, a combination of contact resistance and the resistances from the bulk and the diffused layer, was determined from a combination of dark and lighted I-V data. The I-V relationship of a solar cell in dark and under illumination aregiven by the following expressions:

$$I_d = I_{t1} = I_o \{e^{q(V_{e1} - I_d R_s)/nkT} - 1\} \qquad \text{in dark}$$

$$I_d = I_{sc} - I_{t2} = I_o \{e^{q(V_{t2} + [I_{sc} - I_d]R_s)/nkT} - 1\} \qquad \text{under illumination}$$

where V_t and I_t are terminal voltage and current.

Equating these two expressions, the following expression for R_s is obtained:

$$R_s = \frac{V_{t1} - V_{t2}}{I_{sc}}$$

for I_{sc} flowing through the diode; $V_{t2} = V_{oc}$

then

$$R_s = \frac{V_{t1}\Big|_{I = I_{sc}} - V_{oc}}{I_{sc}} \tag{8}$$

Shunt resistance was determined by the reverse dark I-V measurement where

$$R_{sh} = \frac{|\Delta V_R|}{\Delta I} \tag{9}$$

In order to see the effect of contact system on the bulk and the junction response, the measured dark I-V data was transformed. A schematic of this transformation is shown in Fig. 7 where the curve with solid circles represents the measured I-V data. Curvatures result when the contribution of the R_{sh} and the R_s are significant. If the effect of R_{sh} and R_s is very small then the curvatures are not seen. The effect of R_s and R_{sh} can be removed from the dark I-V data by the following transformation:

$$V^1 = V - IR_s$$

$$I^1 = I - \frac{V - IR_s}{R_{sh}} \tag{10}$$

The transformation results in a double exponential (I_{X1}, I_{X2}) which is a combination of the bulk and the junction response. I_B or the bulk response is obtained by extrapolating I_{X1} and subtracting it from I_{X2}.

$$I_B = I_{X1} - I_{X2} \tag{11}$$

I_B has an n factor of unity which is the true representation of the bulk response. I_j or the junction response is determined by

$$I_j = I_{x2} - I_B \tag{12}$$

Curve 692231-A

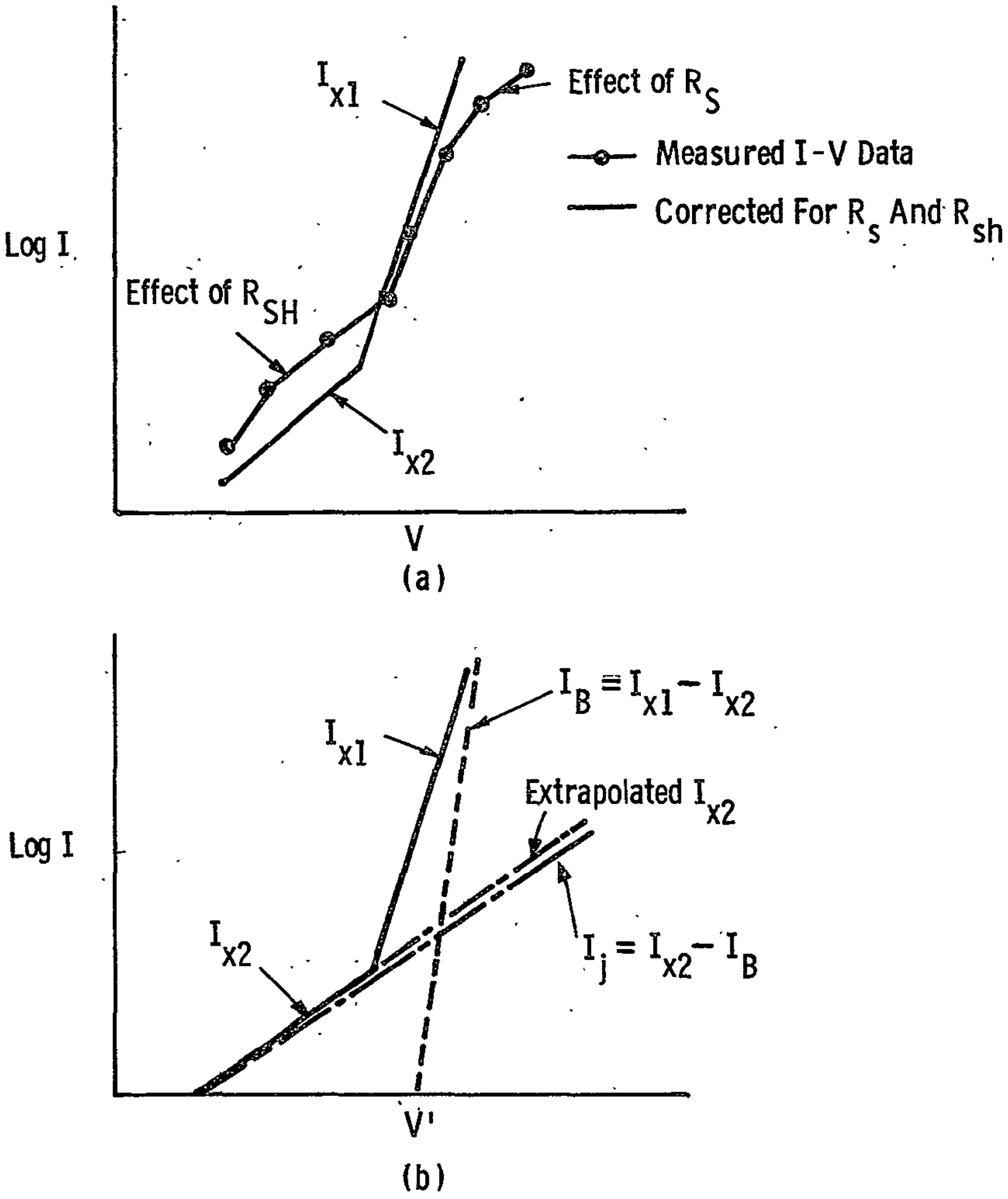

Fig. 7. Schematic diagram of the procedure for transforming the measured I-V data to separate the bulk (I_B) and junction (I_j) components.

If I_B moves up and to the left it indicates an increase in reverse saturation current or a decrease in bulk lifetime. The increase in the junction excess current (I_j) represents the loss of photocurrent in the junction which can also result in loss of cell performance. This is a very powerful technique which enables the detection of the response of the bulk and the junction regions separately. The transformed I-V curves will be used to quantitatively describe the effects of various contact systems on the bulk and the junction regions.

3.4.3 Results and Discussion

Table 15 shows a comparison of the evaporated Ti-Pd-Ag system with the Ti-Pd electroplated Ag. First, the Ag was removed from the evaporated Ti-Pd-Ag and then the same sample was electroplated with Ag using an AgCN solution of pH 13. Ag is electroplated only on the Ti-Pd grid which makes this system much more cost effective than the evaporated Ti-Pd-Ag system where most of the evaporated Ag is not utilized. The data demonstrate that plated Ag in all respects is capable of giving as good results as the evaporated Ag. Sintering characteristics of both systems were found to be very similar. The data shown on Table 16 were taken from CZ cells, although similar results were obtained on dendritic web material.

Table 16 summarizes the results of Cu contact directly applied on Si. This system gives a poor yield and the detailed analysis indicate that the degraded samples possess very low shunt resistance of the order of 10-100 Ω. This suggests diffusion of Cu into the Si. Cu is a fast diffuser and since the samples go through a 160°C photoresist bake, such a low yield is not very surprising.

Results of evaporated Pd-electroplated Cu are summarized in Table 17. First Pd was evaporated and grid pattern was etched and then 4-6 microns Cu was electroplated on Pd grid using an acidic $CuSO_4$ solution. Prior to the plating the samples goes through a cleaning and a striking solution. Results indicate that unsintered Pd-Cu contact system looks as good as the evaporated Ti-Pd-Ag. However like Cu, this

TABLE 15

(Evaporated Ti-Pd-Ag) Vs (Evaporated Ti-Pd - Plated Ag)

	Evaporated Ag	Plated Ag
η(%)	10.19	10.11
I_{sc} (mA)	22.5	22.8
V_{oc} (V)	.572	.578
FF	.749	.73
R_s (Ω)	.5	.7
R_{sh} (kΩ)	300	300
I_j/.3V (mA)	.04	.05
τ_{ocd} (μsec)	21	22

CZ cells with no AR coating

TABLE 16

Evaporated or Plated Cu

Yield — 30 — 40%
Reason — R_{sh} = 10 - 100
Survived Samples — η — 8-9%
R_s — .5Ω
R_{sh} — 2-5K

system cannot stand high temperature sintering. 300°C sintering in N_2 for 10 min. drastically lowers the cell performance and the effect is observed on the junction excess current which increases by three orders of magnitude. Thus unsintered Pd does not serve as a good barrier for Cu diffusion.

Table 18 compares the performance of evaporated Ti-Pd-Ag system to the evaporated Ti-Pd electroplated Cu system. Ag was removed from the Ti-Pd-Ag contact and then the same sample was electroplated with 4-6 μm thick Cu. Unsintered Ti-Pd-Cu system looks as good as Ti-Pd-Ag system in all respects. Unlike Cu or unsintered Pd-Cu system, Ti-Pd-Cu can stand much higher sintering temperatures. The data shows up to 300°C sintering in N_2 for 15 min. no degradation is observed. At 400°C, a slight decrease in cell performance is detected and at 500°C cell efficiency decreases from 10.1% to 7.5%. Thus Ti-Pd acts as a good barrier for Cu diffusion. Since Pd by itself was not very effective, it appears that titanium silicide at the Ti/Si interface could be responsible for the barrier. Figure 8 shows the transformed I-V plots for the Ti-Pd-Ag and the Ti-Pd-Cu systems. The upper segment represents the bulk response and the lower segment the junction response. It is quite clear that above 300°C sintering of the Ti-Pd-Cu contact, the cell performance degrades primarily due to the increased junction excess current. The junction excess current at the operating point represents the loss of the photocurrent in the space charge region. The increase in the junction excess current can result from the presence of impurities or defects, such as Cu precipitates, in the depletion region of the solar cell. Thus Ti-Pd-Cu system looks very promising from the point of view of cost effectiveness and performance. However, its long term reliability needs to be investigated.

Table 19 shows a comparison of evaporated Ti-Pd-Ag, Cr-Pd-Ag and Ta-Pd-Ag systems. Prior to sintering Cr-Pd-Ag system looks as good as Ti-Pd-Ag but Ta-Pd-Ag gives only 6.8% cell. Ta seems to form a barrier which reduces the open circuit voltage. However, sintering at 400°C removes that barrier and Ta-Pd-Ag gives equally good results as Ti-Pd-Ag or Cr-Pd-Ag. Cr is fast diffuser in Si so Cr-Pd-Ag system is unable to

TABLE 17

(Evaporated Ti-Pd-Ag) Vs (Evaporated Pd - Plated Cu)

	Ti-Pd-Ag	Ag-Cu	Pd-Cu 150°C Sinter	Pd-Cu 300°C Sinter
η (%)	10.19	10.3	9.91	1
I_{sc} (mA)	22.5	22.7	22.3	.146
V_{oc} (V)	.572	.574	.568	13.1
FF	.749	.751	.740	.49
R_s (Ω)	.45	.35	.35	.3
R_{sh} (kΩ)	300	2	2	2
I_j/.3V (mA)	.04	.29	.31	51.5
τ_{ocd} (μsec)	21	19.5	19.5	--

CZ cells with no AR coating

TABLE 18

(Evaporated Ti-Pd-Ag) Vs (Evaporated Ti-Pd - Plated Cu)

	Ti-Pd-Ag	Ti-Pd-Cu	Ti-Pd-Cu 300°C Sinter	Ti-Pd-Cu 400°C Sinter	Ti-Pd-Cu 500°C Sinter
η (%)	9.92	9.98	10.1	9.36	7.5
I_{sc} (mA)	21.8	21.6	21.7	21.9	19.2
V_{oc} (V)	.572	.580	.580	.574	.544
FF	.74	.754	.76	.731	.667
R_s (Ω)	.5	.6	.45	.5	.5
R_{sh} (kΩ)	2.5	2.5	2.5	2	1.1
I_j/.3V (mA)	.044	.044	.040	.27	1.4
τ_{ocd} (μsec)	11	11.5	11.5	10	6

Web cells with no AR coating

Curve 696900-B

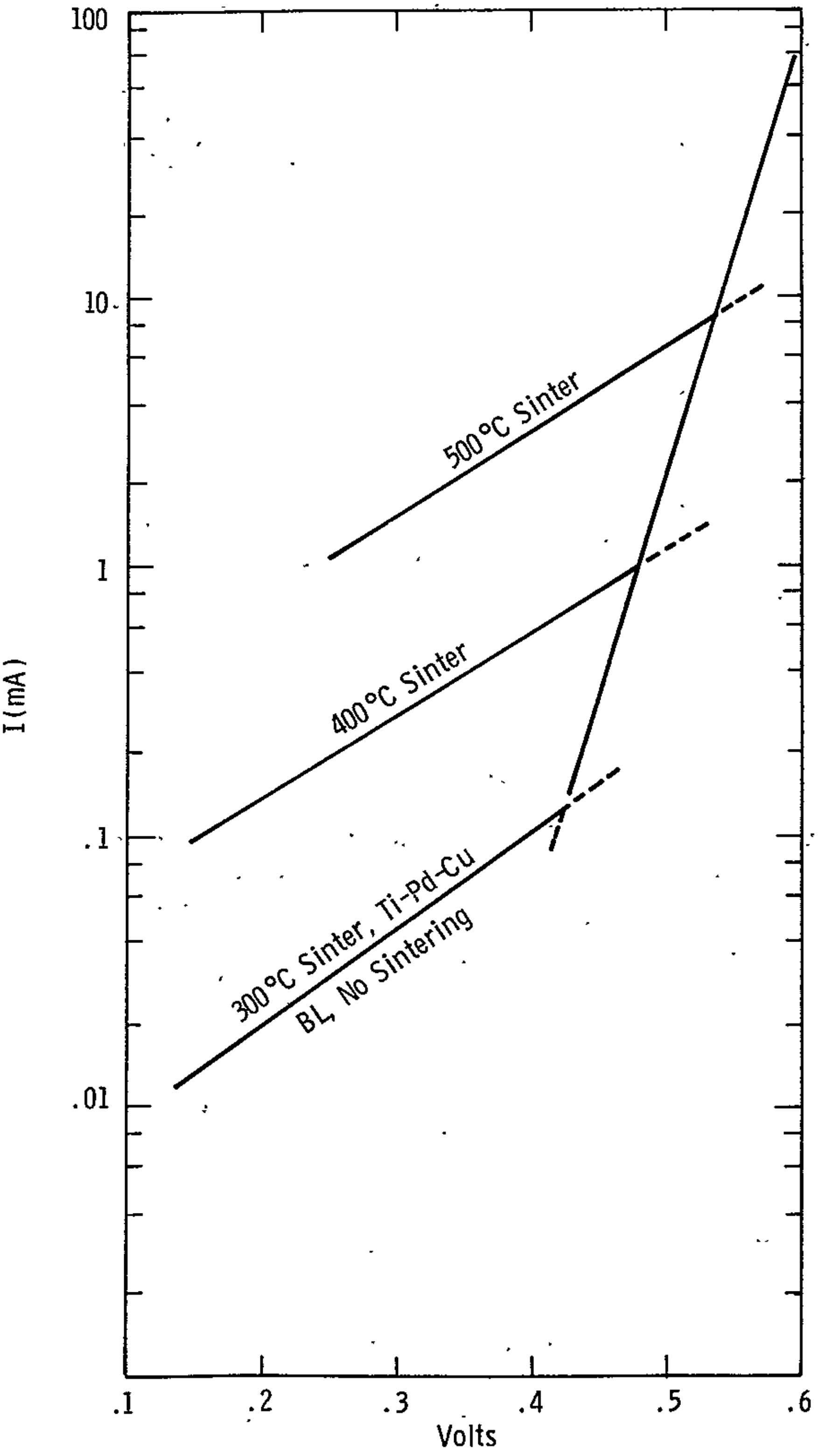

Fig. 8 Transformed I-V Plots for Ti-Ag and Ti-Pd-Cu

TABLE 19

EVAPORATED (Ti-Pd-Ag), (Cr-Pd-Ag) and (Ta-Pd-Ag) CONTACT SYSTEMS

BEFORE SINTERING

	Ti-Pd-Ag	Cr-Pd-Ag	Ta-Pd-Ag
η (%)	9.01	8.93	6.8
V_{oc}(V)	.537	.539	.437
I_{sc}(mA)	22.4	22.1	21.97
FF	.707	.71	.633
τ_{ocd}(μsec)	5	5	3.7

AFTER SINTERING AT 400°C

	Ti-Pd-Ag	Cr-Pd-Ag	Ta-Pd-Ag
η (%)	9.54	9.46	9.7
V_{oc}(V)	.55	.551	.55
I_{sc}(mA)	21.9	21.37	22.5
FF	.750	.76	.76
τ_{ocd}(μsec)	4.3	4.57	4.0

CZ CELL, NO BSF, NO AR COATING

stand higher sintering temperatures than 400°C. Ta-Pd-Ag system can stand sintering temperatures up to 550°C. Thus Ta can be used as an effective substitute for Ti.

3.4.4 Conclusions

Electroplated Ag can be used instead of evaporated Ag to effectively reduce the waste. Ti-Pd-Cu seems to be a promising contact for solar cells from the point of view of cost-effectiveness and cell performance. However, its long term reliability needs to be investigated. Ta can be used as an effective substitute for Ti in the Ti-Pd-Ag system.

3.5 Cell Separation by Laser Scribing

The process development plan for this program defines a processing sequence for dendritic web silicon in which the material is handled in a continuous or in a large number of shorter strips. The process of cell separation must be suitable to either sequence.

In the cell separation step, the dendrites must be removed from the web strip and the strip must be scribed transversely to separate the individual cells. The process, which seems most attractive for cell separation, is laser scribing because it is rapid and does not require mechanical support of the web and should have a high yield.

Work reported in the first quarterly report on this program showed that laser scribing could be used to remove the dendrites and to make transverse cuts across the web with high accuracy. This scribing and breaking can be accomplished with minimal loss. However, in the first several experiments the cell performance parameters were degraded by the laser scribing operation. In particular, laser scribing lowered fill factor and conversion efficiency values. It was also shown that cells scribed from the back degraded less than those scribed from the front. This degradation was identified as due to increased junction leakage current on the periphery of the cell. Chemical etching or mechanical lapping of the cell edges restored the initial cell parameter values.

A number of the back scribed cells were examined optically and with scanning electron microscopy. It was noted that, although on the average the laser spikes penetrated about 40% of the thickness of the silicon, certain areas were completely penetrated. These were areas where the scribe path had been retraced or spots at which the laser had been inadvertently permitted to dwell. This penetration of the melt region would be expected to cause significant damage to the junction and thus decrease fill factor and conversion efficiency of the cell.

Further experiments were carried out with the aim of eliminating this problem. The cells were scribed at the Westinghouse Advanced Technology Laboratory in Baltimore. A KORAD KRT laser (Nd doped YAG - $\lambda =$ 1.06 μm) with 5000W peak power, a repetition rate of 1000 Hz and a spot of 15 μm was used. The scribing speed was about 4 cm/sec.

To assure that there would be no penetration of the melt region to the front illuminated junction, the cells were scribed to a maximum penetration of 50-75 μm which required a power setting of 3500-4000 Wp. In addition, care was taken that there was no retrace of laser dwell at any point on the scribe line. Figure 9 shows a scanning electron micrograph of a cell scribed in this way. As can be seen, the maximum penetration never exceeded 40% of the thickness of the cell.

Thirty cell structures were scribed in this test. All had been previously prepared with back and front contacts. None had an AR coating. Seven of the samples had the dendrites attached to the edge of the cell and six samples were not mesa etched. The cells with a mesa etch were scribed within the mesa. Of the 30 cells, 8 were lost during laser set-up and calibration and four were lost due to breakage, mainly because of improper handling.

All cells were measured after scribing and breaking of the web with no further cleaning or etching processes.

The measurements made after scribing could be correlated directly with those before scribing; however, in some cases minor corrections or assumptions were required. First, when the cells were scribed

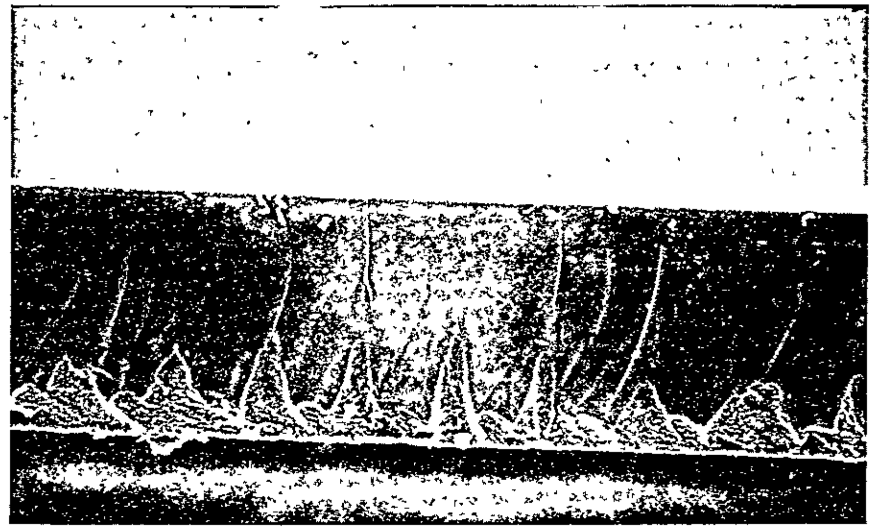

Fig. 9 Scanning electron micrograph of web silicon solar cell laser scribed from the back under conditions guaranteeing no penetration of the laser to the front surface.

within the mesa, the resultant cell area was less then 1 cm^2, and when the cells without mesas were scribed the cell size was often greater than 1 cm^2. In these cases, an area correction was used. Also, on the cells scribed with no mesa, data on mesa-etched cells in the same diffusion run of the same web crystal were used as the pre-scribing reference.

Figure 10 shows the efficiency values of the cells before and after scribing. In this plot, data points to the right of the 45° line indicate cells which improved on scribing, while points to the left indicate cells which degraded on scribing. The solid dots indicate cells scribed within an existing mesa, the open circles indicate cells with no mesa. The dotted lines on either side of the 45° line indicate changes of ± 5%, which is about the accuracy of the area corrections and of the measurement. Changes of -15% to +40% are also indicated on the figure. The data obviously clusters around the 45° line. Considering only those cells for which there was individual pre-scribe data, i.e. the solid dots, 11 of the 15 cells fall within about ± 7% of the 45° line indicating no significant change in the cell parameters. The remaining four cells in this category showed improvement from +14% to 40%. The two cells with changes of +34 and +40% were initially very poor with low I_{sc}, V_{oc} and fill factor. After scribing, all parameters improved with the largest effects being seen on the fill factor. This probably indicates the removal of a shunting resistance by scribing.

In cells with no previous etching, (circles in Figure 10) the initial efficiency values were taken from mesa etched cells in the same diffusion run. The spread of efficiency values is about the same as for the mesa samples. A decrease in efficiency by about 15% is indicated for one of these cells, but the initial reference value is based on a lot average and is not data for the cell in question.

The data of Figure 10 are shown in Figure 11 in a more graphic form.

From this data we conclude that dendritic web solar cells can be laser scribed from the back and broken out of the web substrate without

Curve 695347-A

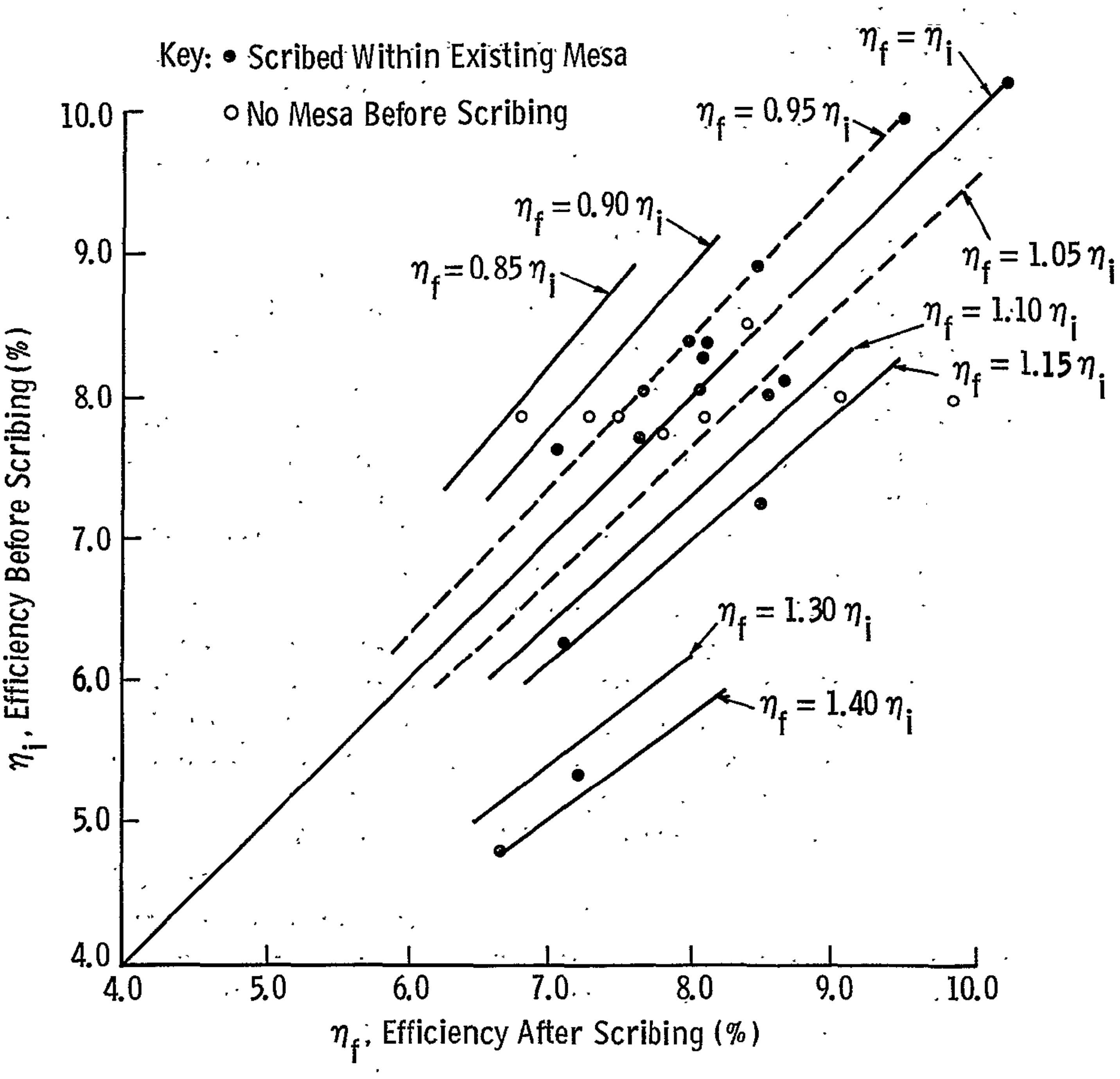

Fig. 10. Effects of controlled depth, back surface laser scribing on conversion efficiency of a group of web silicon solar cells. None were AR coated.

Curve 695344-A

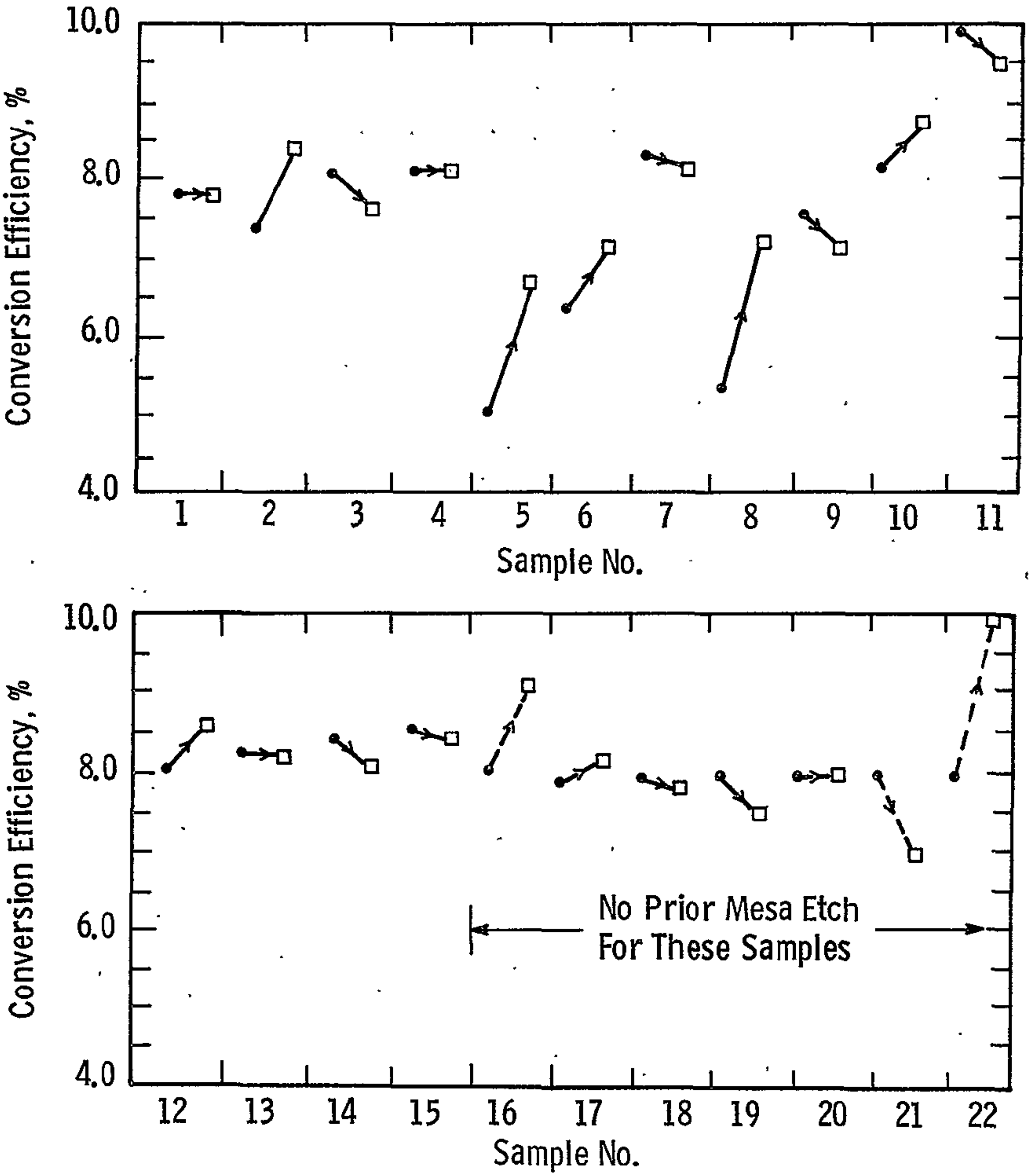

Fig. 11 Changes in web cell efficiency values due to limited penetration, back surface laser scribing. No AR coating.

significant degradation of cell parameters. Care must be taken during the laser scribing process however, to assure that the molten zone produced by the laser does not penetrate to the front junction and cause damage there.

The experiments described thus far in this section were carried out in the first six months of the program. Since that time, more than 400 cells, either 1.6x4.0 cm or 1.6x7.0 cm were laser scribed in the manner described. Of these cells about 8 were broken during removal of the dendrites and these losses were due to strain in the initial crystal rather than problems with laser scribing.

There is no question that laser scribing is a feasible, cost effective technique for cell separation.

3.6 Interconnections

3.6.1 Interconnection Requirements

Completed solar cells were to be interconnected in series and/or parallel arrangements within each module in order to furnish useful quantities of power.

The method of interconnections had to be one which was compatible with preceding and subsequent steps in the fabrication process. That is, the interconnection material had to be capable of successful attachment to the solar cell metallization and the process of attachment could not degrade the cell performance in any way.

The criteria for successful attachment are low contact resistance and high inter-cell conductance. These criteria are not difficult to meet with metal systems. The criteria for the attachment process are low temperature, cleanliness, and low physical forces. These criteria are not easily met.

Interconnect reliability is of major concern. Those phenomena which could limit reliability include corrosion, formation of undesirable intermetallic compounds, mechanical stresses due to module flexing and to thermal cycling, and metal fatigue, creep, and work hardening due to repeated or prolonged stresses. The prevention of these phenomena may be accomplished by a proper choice of metal systems, careful design of interconnect shape, and development of encapsulation, handling, and mounting techniques that minimize on the system strain solar cell modules.

In addition to meeting the technical requirements of performance and reliability, any interconnection scheme for the Automated Array Assembly Task 4 is required to meet rigid requirements of low cost and high throughput. These requirements imply the use of low cost materials in a system that is amenable to automation. In addition, reasonable capital cost, low input energy, minimum production of by-products and waste, and the ability to make a large number of attachments in a short period of time had to be considered. A very high yield of successful attachments is an absolute necessity in meeting the low cost criterion.

3.6.2 Interconnection Methods

Several methods of interconnecting solar cells had been proposed or considered. The following is a brief discussion of some of these methods.

3.6.2.1 Conductive Adhesive Bonding

Conductive, metal-bonded adhesives are widely used in integrated circuit technology, usually as a bottom contact between a silicon chip and a metal header. In a solar cell application, it has been proposed that conductive adhesive bonds be made between the solar cell metallization and a printed metal pattern on an insulating or on an insulating polymeric film. The chief disadvantages of conductive adhesives have been in high contact resistance and in high material cost. Unless and until these problems are solved, further development toward increased reliability is not justified.

3.6.2.2 Parallel Gap Welding

In parallel gap welding, the heat generated by the passage of current between closely spaced electrodes fuses two metal parts together. Factors which limit its application in solar cell interconnection are poor reproducibility in bonds and the need for frequent dressing of the electrodes. Parallel gap welding is applicable to one-at-a-time bonding; automation of a high throughput machine capable of simultaneous multiple bonds will be difficult.

3.6.2.3 Laser Welding

Pulsed high energy lasers deliver sufficient energy to fuse metals. If pulse widths are kept short, the heating of an underlying solar cell would be within acceptable limits. The applicability of laser welding to solar cell interconnections has not been demonstrated as yet.

3.6.2.4 Thermocompression Bonding

In thermocompression bonding, soft metals are swaged together under the influence of slightly elevated temperature and high pressure. This process has achieved excellent reliability in integrated circuit manufacture. It is doubtful that the process can be scaled up to high throughput. Additionally, material cost is high since gold is being universally used as the bonding metal.

3.6.2.5 Soldering

Tin-lead solder is widely used as a bonding medium in present solar cell modules. In general, soldering must be considered a good method of making interconnects; however, problems may arise in long term reliability and the design of an automated high throughput system might prove to be difficult.

3.6.2.6 Solder Reflow

Solder reflow is the process in which previously applied solder is remelted. This process must be seriously considered as a contender for a final, optimum interconnecting method. Throughput rate can be very high in an automated system, although the amount of energy consumed would be considerable. Further development might be required to assure long term reliability.

3.6.2.7 Ultrasonic Bonding

Because Westinghouse has chosen to investigate the applicability of ultrasonic bonding to solar cell interconnection, this process is discussed in some detail.

Bonding between two materials can be made to take place when the material surfaces are scrubbed against each other at ultrasonic frequencies. The detailed method by which the bonding takes place is not known in all cases. When thermo-plastic materials are bonded, the scrubbing action appears to generate sufficient heat that local melting of the surfaces occurs. When metals are joined, it is less likely that melting occurs; instead, it is hypothesized that either (1) surface oxides and contaminants are abrasively removed and atomic contact between clean metals is achieved, which in turn leads to chemical bonding or (2) the scrubbing action causes microfractures in the surfaces of the metals and these fractures interlock forming a strong metal-to-metal bond.

Whatever the exact mechanism of ultrasonic bonding between metals, the process is successful in applications ranging from joining large copper busbars onto electric motor alternators to attaching fine wires to thin films on integrated circuits.

Because the exact nature of the bonding process is not known, the achievement of acceptable ultrasonic bonds is largely an empirical process. A large number of parameters determine the quality of an ultrasonic bond. In so far as the materials are concerned, the thickness, temper, surface condition and the materials themselves are important. Among the bonding parameters are the ultrasonic frequency, the vibrational amplitude the size and shape of the tool, the tool material, the vibrational power input, the clamping force between the tool and the work piece, and the length of the time interval during which power is applied. It has also been shown that the properties of all the materials beneath the work piece have an effect. The large number of variables makes it very likely, once the materials to be joined have been chosen, that some combination of these variables will result in good ultraonic bonds.

Ultrasonic bonding machines are of two basic types. The simplest type--the spot bonder, is one in which the ultrasonically driven tool contacts the materials to be joined in a single area. After a bond is made, the tool is lifted and repositioned in preparation for the next bond. An analysis of this operation shows that the throughput rate of bonds is limited by the time required to reposition the tool between bonding operations. In the second type of machine, commonly called a seam bonder, the ultrasonically driven tool is in the shape of a wheel which is made to roll across the workpiece, making a continuous linear bond. This type of machine is widely used to splice the ends of metal foils and plastic sheets. The advantages of applying this type of machine to solar cell interconnection are obvious if the interconnect material is in the form of a continuous tape or web to be bonded along one edge of a solar cell. Even if the interconnect is in the form of discrete tabs bonded at points one centimeter apart, the use of a seam welder type of machine will result in increased bonding speed: a spot bonder can bond and position itself for another bond at a rate of about one bond per second; a seam welder can roll along a solar cell edge (or along a long line of solar cells) at a rate of 15 cm/sec, making 15 bonds per second.

For the reasons given above, Westinghouse has proposed that for the Automated Array Assembly Task, solar cell interconnection should be accomplished with thin metal foils (e.g. aluminum or copper) ultrasonically bonded to solar cell metallization.

3.6.3 Demonstration of Ultrasonic Bonding for Cell Interconnection

An experimental survey of materials and bonding parameters was undertaken. The purposes of this investigation were to (1) demonstrat the applicability of ultrasonic bonding to thin dendritic web solar cells and (2) to gain practical information on possible materials, process parameters, and bond characteristics.

The machine used in this investigation was a Sonobond (West Chester, PA) ML-6010 (W-1060D) spot bonder with a .062" diam tool having a two inch tip radius. This machine operates at a frequency of 60 kHz and has a maximum power output of 10W.

Interconnect materials were aluminum (.002", .001", 0.0005", and .0003" thickness), brass (.002" and .001" thickness), and copper

(.002" and .0015" thickness). Solar cell metallizations used were 4 μm thick silver (electroplated and vacuum evaporated), 4 μm thick electroplated copper, and 0.5 μm thick vacuum evaporated aluminum.

For the purposes of this survey, the bonding parameters were (a) tool force: 30, 150, 500, 700, and 1100 gm; dwell time: .028 and .044 sec; (c) power input: 0.36, 3.7, and 10.2W. No special cleaning or surface preparation of the bonding materials was used. Those material combinations which produced good and poor bonds under the above bonding conditions are summarized in Table 20. It must be emphasized that those combinations which made poor bonds under these conditions might be expected to produce good bonds under different conditions.

TABLE 20

Material Combinations Producing Good (G) and Poor (P) Ultrasonic Bonds under a Limited Number of Bonding Conditions

Cell Metallization Interconnect Material	4 μm Electroplated Silver	4 μm Vacuum Evaporated Silver	0.5 μm Vacuum Evaporated Aluminum	4 μm Electroplated Copper
.002" aluminum	G	G	G	G
.001 aluminum	G	G	G	G
.0005 aluminum	G	G	G	G
.0003 aluminum	G	G	G	G
.002" brass	P	P	P	P
.001 brass	G	G	P	G
.002 copper	P	P	P	P
.0015 copper	P	P	G	G

It is essential that interconnect bonds have low electrical resistance. The contact resistances of those bonds labelled as good (G) in Table 20 were measured. All of these bonds exhibited contact resistance of less than one milliohm. Since the bonded area was quite small (about .010" diam) because of the shape of the bonding tool, this figure must be regarded as very acceptable.

A limited number of pull tests were performed to demonstrate the mechanical strength of ultrasonic bonds. Even for the small bonded areas achieved in this investigation, the bond strengths were adequate for cell handling prior to encapsulation. Bond strengths are shown in Table 21 for several interconnect-metallization combinations.

Finally, solar cells fabricated on thin silicon dendritic web were connected in series as shown in Figure 12. Table 22 shows cell parameters as measured on individual cells before interconnects were attached and as measured on the series-connected cells in the case of four connected cells and two connected cells. The data show no damage to the cells as a result of the bonding.

3.6.4 Conclusions

Ultrasonic bonding of thin foil interconnects has been shown to be a technically successful method of interconnecting solar cells. When the proper processing parameters are used, strong, low resistance bonds can be made between a variety of metal foils and solar cell metallizations. The bonding process has no adverse effect upon cell characteristics.

Ultrasonic bonding is a clean, reliable process producing no waste products and consuming only small amounts of energy. With automation, ultrasonic bonding can be a fast process, especially if ultrasonic seam welding is used.

TABLE 21

45° Pull Strength Tests of Ultrasonically Bonded Interconnects

[Strength in grams (force)]

Cell Metallization / Interconnect Material	4 µm Silver	4 µm Copper	0.5 µm Aluminum
.002" aluminum	72 - 90	—	60 - 100
.001" aluminum	30 - 70	—	—
.0005" aluminum	5 - 30	—	—
.0003" aluminum	9 - 30	—	—
.002" brass	—	25 - 50	—
.001" brass	90 - 140	9 - 20	—
.002" copper	Weak	14 - 50	—
.0015" copper	54 - 150	60 - 95	32 - 40

Table 22

Cell Parameters Before Bonding and as Series-Connected Strings Cells AR Coated

Cell	I. D.	V_{oc} (volts)	J_{sc} (mA/m^2)	FF	Efficiency (1%)
RE 26	3.3	0.56	28.0	.76	13.1
J 53	3.2	0.49	28.0	.72	10.6
J 57	1.3	0.56	28.6	.75	13.1
RE 24		0.53	27.5	.76	12.0
4 Cells in Series		2.18	27.2	.744	12.0
J 55	2.6	.540	26.7	.76	12.0
RE 11		.564	27.2	.76	12.9
2 Cells in Series		1.09	26.3	.76	11.9

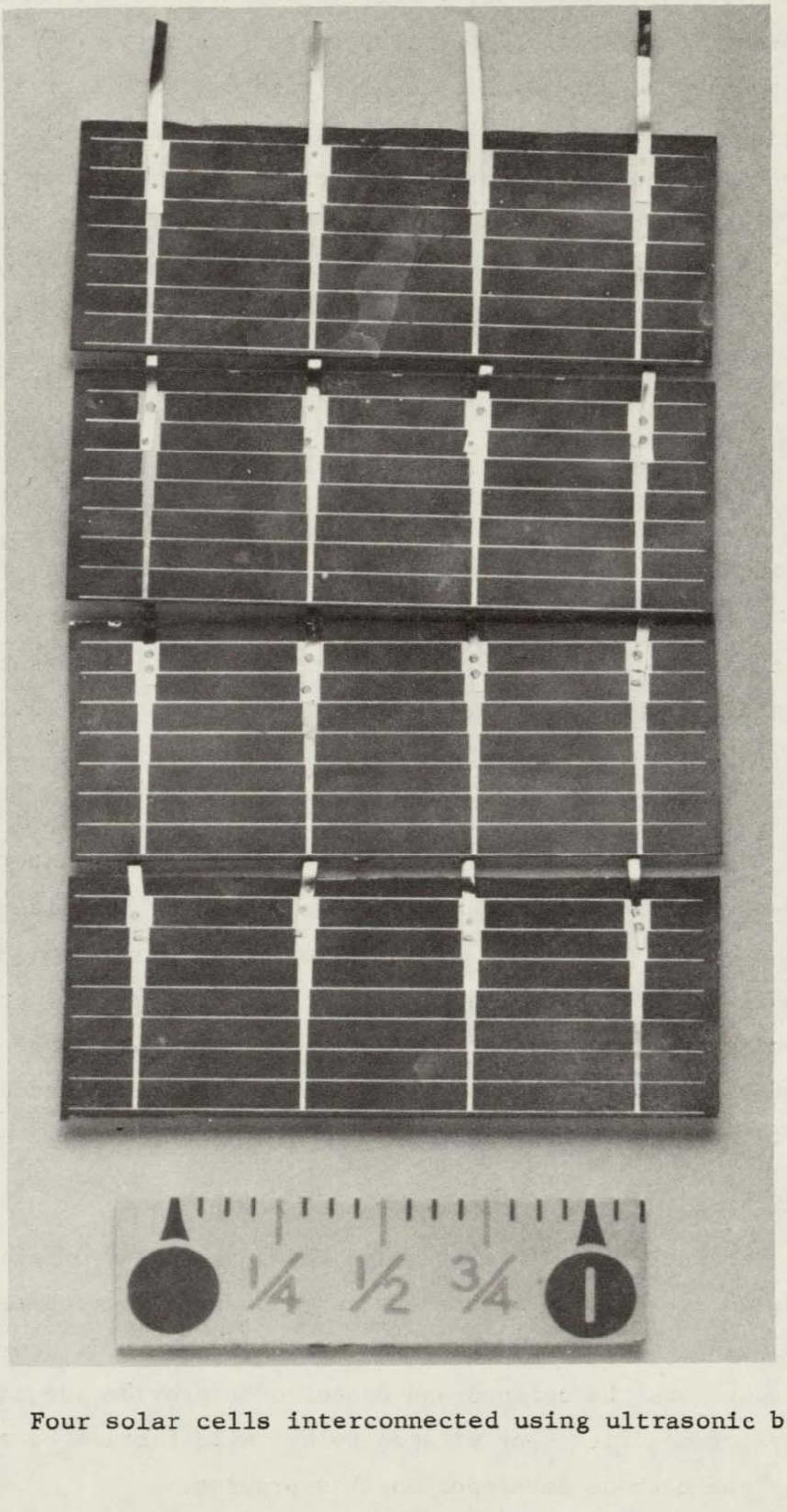

Fig. 12 Four solar cells interconnected using ultrasonic bonding

Additional development work is required to define reliability limits, especially as related to corrosion and cyclic mechanical stress. Ultrasonic bonding to more difficult metallization such as fired-on conductive inks or pastes and aluminum-silicon alloys is believed to be possible, but must be demonstrated. Proper tooling to permit seam welding of experimental samples must be developed. The exact material and form of the interconnects has yet to be determined; these will depend upon the results of reliability testing.

3.6.5 Conceptual Ultrasonic Bonded Interconnect Process (Automated System)

One system which utilizes ultrasonically bonded interconnects is described below.

Metallized dendritic web solar cells are placed sun side up upon a moving vacuum chuck and transferred to an ultrasonic seam welder. Interconnect material, in the form of a foil ribbon, is dispensed from a reel and aligned upon the solar cells. The interconnect foil is bonded to the cells at a linear rate of 15 cm/sec. The foil is cut, separating the cells, as they emerge from the bonder.

In the encapsulation process, the cells, with interconnect foil attached to the sun side, are adhesively bonded, sun side down, to a glass superstrate. When the adhesive has cured, the entire modular array passes beneath another seam welder which traverses the width of the module, bonding the interconnect foil to the dark sides of the cells. This completes the cell interconnection process and the encapsulation process continues from this point.

3.7 Encapsulation

Encapsulation of cell arrays between a sheet of glass and a substrate using appropriate adhesives was considered to require proof-of-operation within the current development program. That is, an encapsulation procedure must be defined and executed to provide adequate protection to the arrays of dendritic web silicon solar cells fabricated and interconnected by the methods developed on this program.

Proof-of-operation of the encapsulation method selection involves the choice and testing of solar cell materials from the points of view of both the projected performance of the module and the applicability of the encapsulation method to a low cost, automated solar array fabrication process. The encapsulation step, as envisioned at present, would involve the use of protecting organic materials which do not require the application of heat to be set up in their final, geometrically fixed form. In this manner the use of expensive ovens and of energy would be avoided or minimized.

The encapsulation approach taken involves use of RTV (room temperature vulcanizing) organic resin materials which will cure at room temperature within a length of time and under conditions compatible with a chosen automated solar cell manufacturing process. Although the curing times of most RTV resins are relatively long (0.5 to 12 hours), final curing of the encapsulant does not have to take place during the actual encapsulation process. The envisioned form of the encapsulated module is a sandwich of the solar cell array between a glass plate and a substrate. The cells would effectively be embedded in the encapsulating medium. Adhesion to the glass, substrate and to the cell, retention of optical clarity under a variety of environmental conditions, negligible shrinkage on curing and aging, ease of application, absence of degassing, are some of the factors considered in choosing an acceptable RTV-type encapsulant.

A variety of solvent-free adhesives, obtained commercially and formulated at Westinghouse, have been screened. A type of RTV, two-part epoxy system, made by the AMICON Company, Lexington, MA, was advertised as being optically clear when set up. Catalyzed samples of AMICON KT-11 (gel time 3 hrs, set-up in 24 hrs at RT) and KT-41 (gel time 6-7 mins, set-up in 1 hr at RT) were sandwiched between square microscope slides and allowed to cure at RT. The adhesion to the glass was excellent, but optical clarity was poor, the interposed adhesive layers exhibited a yellow cast which became darker with time. Exposure of such material to UV in a Fadeometer hastened the yellowing process greatly: after 502 hrs these materials had yellowed unacceptably.

An epoxy formulation made at Westinghouse consisting of a clear diglycidyl ether-bisphenol A matrix cured with triethylene tetramine (TETA) gave relatively clear layers (2-3 mils) whose optical clarity persisted after aging at 80°C and after exposure to UV at RT for several days. Shrinkage on curing appeared to be small for both types of epoxies as measured by the change of the position before and after cure of 5 mil thick 0.5" x 1" aluminum foil tabs encapsulated in the epoxies between two microscope slides.

It is well-known that epoxies in general do not possess the kind of optical properties required for optimum solar cell performance. Because of their adhesive properties, these materials have, however, been used here to obtain some experience of the conditions and parameters involving the production of encapsulated solar cell arrays as described above. For example, a problem was encountered on placing silicon chips on a 2-4 mil thick layer of catalyzed but non-cured encapsulant spread on a piece of glass. Under some conditions the silicon would "float" over the surface of the liquid encapsulant before the latter sets up. This would be aggravated when the top piece of glass, with its layer of catalyzed but non-cured encapsulant, was pressed upon the silicon pieces. When this happens, the geometry of the cell array is distorted appreciably. This problem was circumvented by applying to the bottom of the chips a drop of catalyzed, fast curing epoxy. The chips were then picked up and pressed through the encapsulant layer on the lower glass cover until contact was made between the bottom part of the chip and the glass surface. Adhesion between the chips and the glass was almost immediate. When this process was used with glass substrates marked with a geometric grid of lines, no discernible displacement of the chips from their original locations on the grids was noted even after several days at 80°C. For this placement function, epoxies are indicated, since the requirements are for fast curing, strong adhesive characteristics and not for optical properties.

A commercial RTV polyurethane (Uralane X87718; from Furane Chemicals), claimed by its manufacturer to be "solar cell" grade, tended to set up in thin layers while air bubbles were still present throughout the film. If this material requires a vacuum treatment step to obtain a bubble-free encapsulation layer, this requirement would complicate the continuous array manufacturing process beyond acceptable limits.

Several silicones were obtained from GE and Dow Corning. They are all of the solventless RTV type, and the GE and Dow Corning silicone resins of similar description have very similar properties and cost. We limited our work to three types of GE RTV silicones: RTV 602 (fast cure, volatile evolution), RTV 615 (firm set, very viscous) and RTV 619 (described as a less viscous gel). Both latter materials set completely in 24 hrs at RT, while the former silicone will set up in 0.5-1.0 hr at RT depending on concentration of catalyst.

Silicone 602 was used for the initial cementation of the silicon chips to the supporting glass substrate, and RTV 615 was used as the encapsulant. The sandwiches were made using rectangular microscope glass slides as the supporting substrate, and Sunadex glass with the textured surface placed outward, as the top layer. A small vacuum pick up device was used for this work. This design could be the forerunner of an industrial size lifting and turning module manufacturing component. It consisted of a copper plenum and rubber sheeting suction surface which had holes bored in positions corresponding to the predicted positions of actual silicon cells in arrays. Simulated cell arrays were made, each consisting of six rectangular silicon chips arranged in two parallel rows of 3 each. The chips were interconnected by means of narrow aluminum strips glued to the proper silicon chip faces. To make simulated silicon cell modules, the vacuum pick up device was activated and placed on one of the simulated modules, which was then lifted and turned over. A drop of catalyzed RTV 602 was placed on the exposed face of each of the six chips forming the simulated modules. The modules was then turned back to its original flat position and laid with the treated chip faces in contact with the substrate glass. On release of the vacuum, the simulated module settled on and stuck to the lower glass substrate. The Sunadex smooth surface, already covered with 3-5 mils of catalyzed RTV615, was placed gently on top of the simulated silicon chip array. The weight of the top glass was sufficient to spread out the encapsulant and to make it flow evenly over the chips to give a homogeneous conformal coating. A fully cured, completely transparent, bubble-free encapsulated sandwich was thus obtained. Heating of the same sandwich at 150°C for 24 hrs showed no change in the position of the chips on the glass and no change in the optical clarity of the silicone encapsulant. The operation, as described above, was straightforward and easy to perform. Although as described here, the p^+ (dark side) of the cell was placed on the substrate first, the process is ameanable to the reverse situation (Section 3.6.5) where the sun side of the cell is glued down first. It appears to be amenable to continuous coating procedures. The silicones tested as encapsulants show the best compromise properties of all materials investigated thus far; their main drawbacks may be high price and prolonged time for curing.

4. PROCESS SEQUENCE FOR DENDRITIC WEB SILICON SOLAR CELLS

4.1 Process Sequence Selected (ARRAY Process)

During the past year, a process sequence has been developed for fabricating solar cells from dendritic web silicon. The process as defined below is for long strips of web (up to 3 meters), but is equally adaptable to continuous lengths of web. All of our process verification has been carried out on these lengths of webs of about 30 cm since suitable processing equipment is not available (or designed) for the continuous processing.

The process described assumes an input of clean dendritic web in lengths up to 30 cm. In the following steps, any processing times and temperatures given are optimum values which have been derived from our development studies. A more complete description of the process step is found in the development sections. The process is as follows:

(1) The web is placed on a heated platen (420°C ± 4°C) of a AMS-1000 Silox$^{(R)}$ and boron-doped oxide is deposited on the bottom surface of the web. A doped oxide of 4600Å thickness is deposited during this step. The gases used in this step were 160 cc/min of 15% silane, 370 cc/min of 5% B_2H_6, 5700 cc/min of N_2 and 250 cc/min of O_2. A capping oxide on back (2000Å) and front surface mask oxide of 1000Å finish this process.

(In this process, we have not optimized the oxide thickness. Since silane is a major cost driver in the overall cost of the solar module, the minimum thickness of oxide that will still protect the top surface must be determined.) The web is heated at 960°C for 20 min to drive in the boron, and then slowly cooled.

(2) The web with diffused back surface is next given a front surface diffusion in $POCl_3$. In another section the techniques are described and the optimum temperature/time relationship is given as 850°C and 35 minutes.

(3) The diffused web strip is dip coated in a liquid precursor of $TiO_2 + SiO_2$ and then baked.

- The speed of withdrawal (25 cm/min) and the viscosity of the solution (4 centipoise) must be controlled to give the proper final thickness of the AR coating. The coating thickness is also a function of the width of the web being withdrawn. At present, a bake temperature of 400°C ± 10°C is used.

(4) The strip is dip coated in a positive photoresist (PR) solution (AZ-1350J) and prebaked only (90°C ± 5°C).

- The comments regarding speed and viscosity control, made above, apply here. Withdrawal speed = 34 cm/min.

(5) The grid pattern of the cell is exposed in the photoresist coating the front surface of the web. The back of the strip should also be exposed to light at this time.

(6) The grid pattern is developed in the front photoresist layer.

- AZ developer is used. The PR layer on the back of the cell is removed at this time with the developer.

(7) The grid structure is etched through the AR coating with an HCl/NH_4F etch.

- This etch will also remove the AR on the back surface of the cell.

(8) Thin layers of titanium and palladium are evaporated onto the top surface.

- For development work 1500Å Ti and 500Å Pd are applied by evaporation. The thicknesses of these films have been reduced to about 200Å each, and these thicknesses are suitable for production.

(9) The excess metal beyond the electrode grid pattern is rejected by removing the patterned PR layer.

- Acetone is used for PR removal.

(10) The grid electrode pattern is reinforced by plating 4-5 μm of Ag.

- The electroplating of Ag can be carried out without protecting either surface of the web strip. The silver will plate only on the metallized grid lines.

(11) The back surface of the strip is metallized.

- Both Ti/Pd/Ag and Al back metallization have been used. It is anticipated that Al or a less expensive substitute for Ag in the trimetal system will be used in the final process.

(12). The contacts are sintered, if this is required.

(13) The cell is delineated by laser scribing from the back and subsequent controlled fracturing.

This process is shown in Processing Log form in Figure 13. Figure 14 shows four strips prepared in the manner just described in steps 1 through 13. The individual cells are 1.6 cm x 7.0 cm in size. Figure 15 shows two 1:6 cm x 7.0 cm cells laser scribed from these strips.

During the development of this process, an experiment was run using an unfired AR coating. Figure 16 shows results of using the HCl/NH_4F etch on fired and unfired films of TiO_2. In the unfired

Start Date:	PROCESSING LOG 9 F50 ARRAY	Page	Run or Sample Array Module Samples
Material:			
Quantity:	Engr.		

Date Tech.	Process	Special Instructions, Measurements, etc.	Disp.	
			C	E
	CLEAN (1)	Remove oxide coating by swabing with cotton soaked with HF, rinse in D.I. H_2O; 4 min. H_2SO_4 - 160°C		
	IDENTI-FICATION (2)	Scribe serial numbers on either side of web near one end to identify P+ side of structure		
	CLEAN (3)	HF:H_2O (1 to 10 ratio) dip 15 sec. H_2O - NH_4, H_2O_2 - HCl		
	SILOX (4)	Side not numbered 420°C; 5000Å TK; Speed = 100		
	BORON DIFF. (5)	Boron Deposition, BBr_3 @ 960°C 2-20-2 min. Numbered side up. Very slow pull (5 min/2 inches)		
	REMOVE OXIDE (6)	3:1 (H_2O:HF) until all oxide is removed R_s = _________Ω/ (Target value = 60 Ω/□		
	SILOX (7)	Numbered side 420°C; 5000Å TK; Speed = 100		
	CLEAN (8)	HF:H_2O (1 to 10 Ratio) dip 5 sec. H_2O_2 - NH_4, H_2O_2 - HCl		
	$POCl_3$ DIFFUSION (9)	Diffusion Temp. 850°C Time 35 min. source temp. = 0° Flow Rates 200 cc/min - N_2 Source; 1560 cc/min - N_2 Carrier 62.5 cc/min O_2 Slow cool by pulling 3 inches/5 min.		
	REMOVE OXIDE (10)	Strip deposition oxide 3:1 (H_2O:HF) Measure, R_s = _________Ω/ (Target value = 60 Ω/□)		
	AR COAT (11)	Apply AR coating by dip process pull rate ______CM/Min (spin speed ________RPM		
	BAKE (12)	Bake out AR coating by placing in oven at room temperature, heat oven to 400°C hold 5 min. turn off oven, let samples cool in oven		
	PHOTO RESIST (13)	Apply photo resist by dip process. Pull rate _____CM/min Photo-resist AZB thinned (spin speed ____RPM). Bake at 90°C 15 min.		
	MASK (14)	Expose as many cells as possible/piece 16 mm x 76 mm mask		
	ETCH AR COAT (15)	Etch out AR coating from masked area by dipping in Ti etch until AR coat is removed in masked area. Approx 15-20 sec. Etch 150 H_2O 60 HCl 30 ammonium fluoride		
	METAL (16)	Top side not numbered Ti_____Å Pd_______Å		
	REJECT METAL (17)	Reject excess material and PR coat by gentle agitation in acetone		
	AG PLATE (18)	Apply 4 microns AG by electro plating process		
	METAL BACK (19)	Ti 1500Å Pd 500Å Ag 20 KÅ		
	SCRIBE (20)			

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Fig. 13

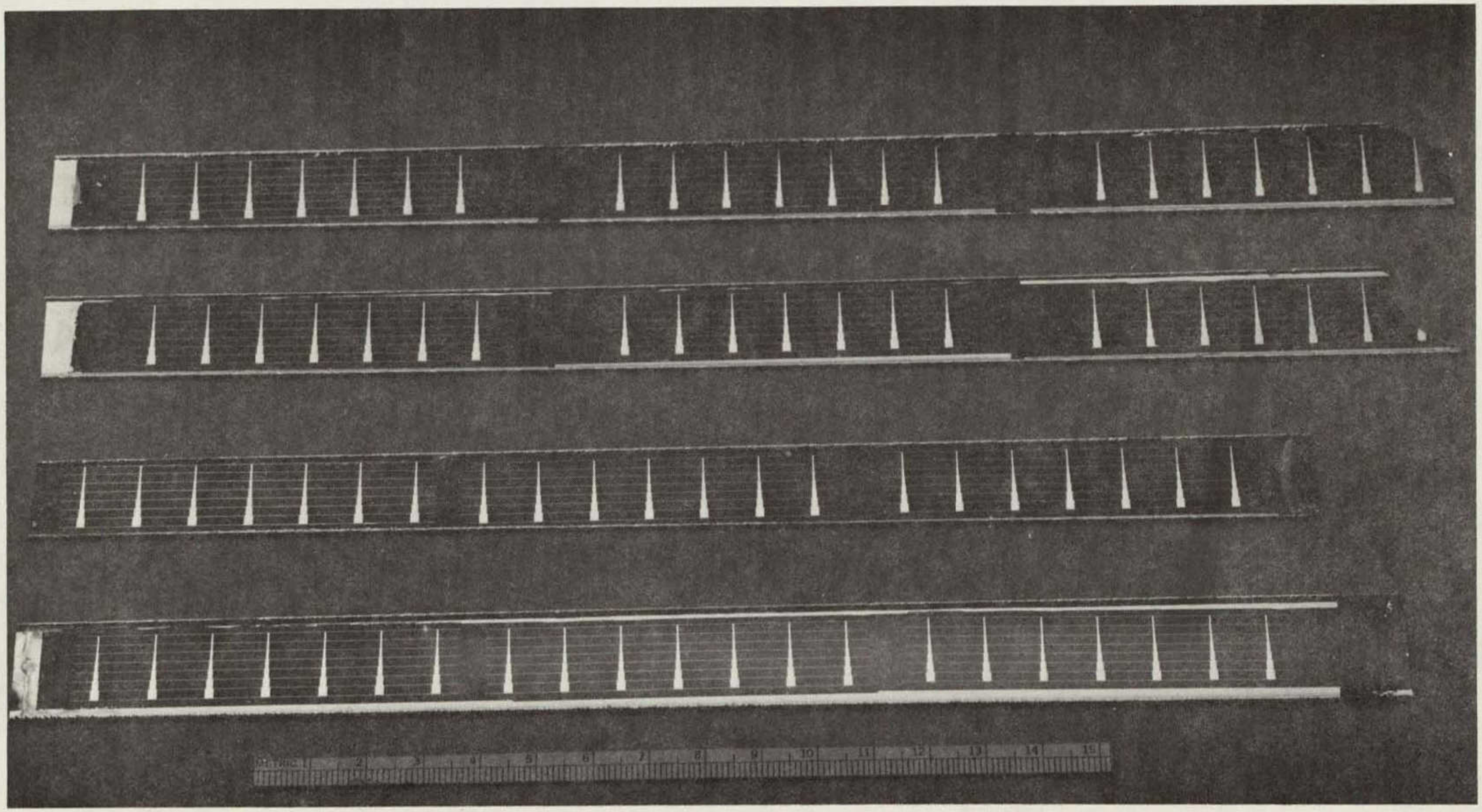

Fig. 14 Twelve solar cells fabricated on strips of dendritic web silicon. Dendrites are still in place.

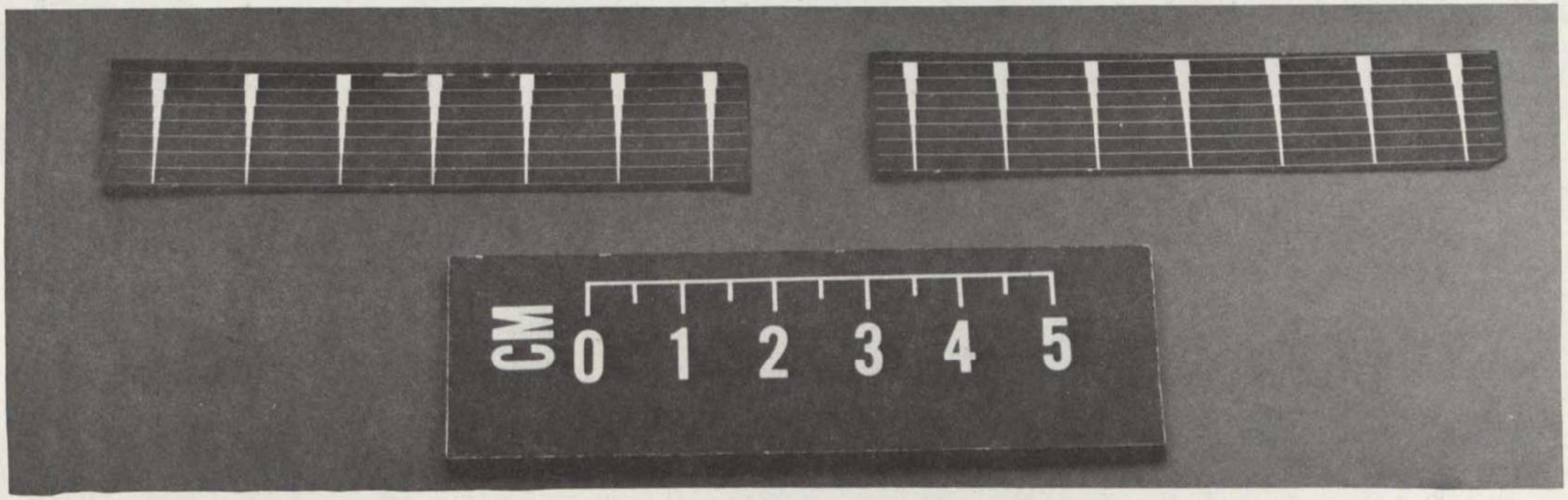

Fig. 15 Solar cells of 1.6 cm x 7.0 cm dimensions which have been laser scribed from dendritic web silicon

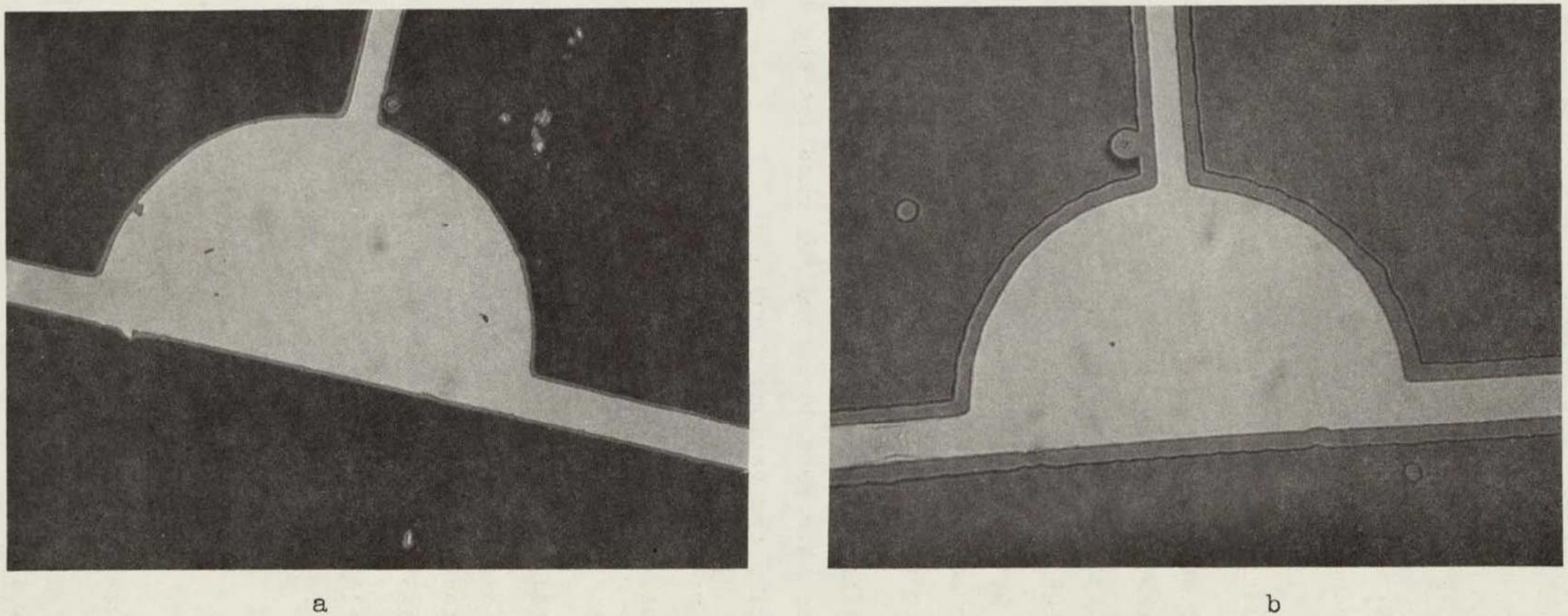

Fig. 16 Comparison of undercutting for (a) fired and (b) unfired TiO_2 coatings prepared from a liquid organometallic precursor.

condition (Figure 16b), the AR coating is etched back under the photoresist during the grid opening process, leaving bare silicon exposed under the PR coating. After metallization and rejection, there would be a small band of base silicon between the metallic contact and the AR coating. In the fired condition (Figure 16a), the coating is not significantly undercut.

The undercutting of the unfired AR coating may be acceptable for process simplification at some later date. Firing of the coating might be combined with contact sintering to reduce costs. The effectiveness of such a change would have to be considered in terms of the slight loss in cell performance due to reduced transmission into the silicon in the uncoated region. For the present, firing of the coating will be done prior to photolithography.

No specific problems have arisen during this processing sequence. Techniques have been developed for handling the long strips without breaking during the various steps.

We have prepared 1.6 x 4.0 cm, 2.0 x 4.0 cm and 1.6 x 7.0 cm cells by this process, and the data on various test runs is given in the appropriate section.

In general, we have found that cells prepared by this process, with one exception, track quite well with cells prepared on the same web crystal by a more standard but less cost-effective process. The one exception is that ARRAY process cells generally have a fill factor about 5% higher than the standard processed cells, e.g., .74 to .78. This gives a slightly higher efficiency. In the next section, the mask used will be discussed.

4.2 Mask Design

A mask was designed specifically for use in the processing of these web strips. Figure 17 is a contact print of the electrode mask for a 2.0 x 7.0 cm cell.

The vertical bus bars, nominally 1 cm apart, are perpendicular to a series of collecting grid lines with a nominal 0.20 cm spacing. The total area covered by metal is 8% and the specific resistance of the cell is 0.4 Ω-cm^2.

One feature of this mask is that the cell can be scribed halfway between any two bus bars without disturbing the basic cell design, thus cells of various areas can be obtained.

Various mask sizes from 1.6 x 4.0 cm to 2.0 x 7.0 cm were fabricated. These masks are of the same basic design with the bus bar dimensions varied to maintain a constant specific resistance. In addition, a long mask, 1.6 cm x 30.0 cm, was procured so that the entire strip could be masked in one operation. This has not been tested.

As mentioned in the last section, cells with grid patterns of this mask have showed higher fill factors. The improvement in cell parameters, specifically the efficiency, is lessened by the greater metal coverage.

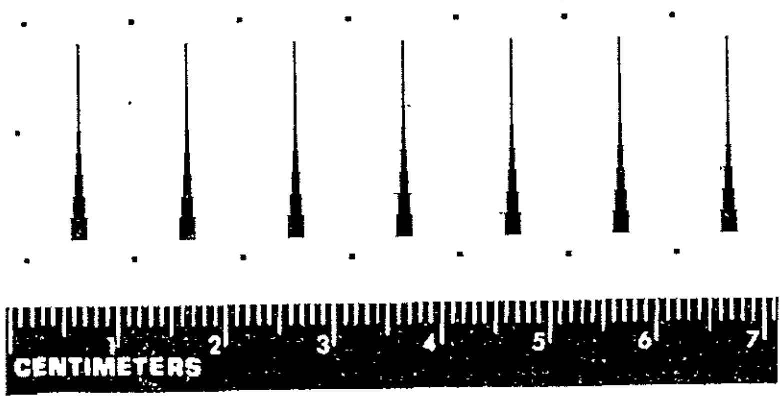

Fig. 17 Contact print of the grid electrode mask for z 2.0 cm x 7.0 cm dendritic web silicon cell.

4.3 Results - Cells

A total of 30 runs grouped into 7 experiments were carried out using this process. A total of 75 - 1.6 x 4.0 cm cells and 130 - 1.6 x 7.0 cm cells were fabricated and tested. Insofar as possible, small portions of the lengths of web used in these experiments had previously been run in a standard solar cell processing technique. This standard technique is shown in Processing Log form in Figure 18. The major difference between the two sequences are: (1) more extensive cleaning procedures in the standard process, (2) no AR coating applied in the standard process, and (3) no mesa etching in the ARRAY process.

Table 23 shows representative data for the first 150 cells fabricated by this process. Where more than one cell was fabricated from a given crystal of dendritic web, an average value of all the cells is given. (In several cases, data is given on all cells fabricated from one crystal to indicate crystal and processing uniformity.) The data for a 1.0 x 1.0 cm cell from the same crystal is given when available.

Comparing column 8 with column 15 (efficiency of the produced cell and the 1 cm^2 cell [η for the 1 cm^2 cell corrected for AR coating]) it is seen that the two processing methods track fairly well. Figure 19 shows this in graphical form. The figures scatter around the 45° line, and nearly all fall within the ±10% line.

Figure 20 shows the results for all cells fabricated using this ARRAY process. (We have eliminated those with obvious faults, such as missing metallization, very high series resistance, etc. This amounts to about 10% of the total number of cells.) The data peak between 12-13% with 83% of the cells having efficiencies greater than 11.5%.

Start Date:

Material:

Quantity:

Engr.

Page

PROCESSING
LOG

9 F50 ARRAY

Run or Sample
Web Qual
Run No.

Date Tech.	Process	Special Instructions, Measurements etc.	Disp.	
			C	E
	IDENTI- FICATION	Scribe serial numbers on either side of web near one end to identify P+ side of structure - Swab HF rinse D.I. H_2O 4 min. H_2SO_4 - 160°C		
	CLEAN (1)	$HF:H_2O$ (1 to 10 ratio) dip 15 sec. H_2O - NH_4, H_2O_2 - HCl		
	SILOX (2)	Silox side not numbered 420°C; 5000Å TK; Speed = 100		
	BORON (3) DIFF.	Boron Deposition, BBr_3 @ 960°C 2-20-2 min. Numbered side up. Very slow pull (5 min/2 inches)		
	REMOVE (4) OXIDE	3:1 ($H_2O:HF$) until all oxide is removed R_s = ____________Ω/ (Target value = 60 Ω/□		
	SILOX (5)	Silox numbered side 420°C; 5000Å TK; Speed = 100		
	CLEAN (6)	$HF:H_2O$ (1 to 10 Ratio) dip 5 sec. H_2O_2 - NH_4, H_2O_2 - HCl		
	$POCl_3$ (7) DIFFUSION	Diffusion Temp. 850°C Time 35 min. Source Temp. = 0° Flow Rates 200 cc/min - N_2 Source; 1560 cc/min - N_2 Carrier 62.5 cc/min O_2 Slow cool by pulling 3 inches/5 min.		
	REMOVE (8) OXIDE	Strip deposition oxide 3:1 ($H_2O:HF$) Measure, R_s = ____________Ω/ (Target value = 60 Ω/□)		
	CLEAN (9)	$H_2SO_4:H_2O_2$ 87°C, 5 min. Strip all oxides in darkness with buffered HF. 10/1 H_2O/HF Dip 10 sec		
	METAL (10)	Top Side (side not numbered) only Ti 1500 Å 20 Å/sec Pd 500 Å 10 Å/sec Ag 20000 Å 40 Å/sec		
	PHOTO (11) RESIST	Mask #1 (contact grid) Waycoat IC, 4000 rpm, h = 1.7 μm Exposure time = 3 sec (I_d = 0.2 μa)		
	ETCH (12) METAL	Ag-20-60 H_2O_2 & Ammonium Hydrox.-10-15 sec. Pd + 30 cc HCl + 10 cc HNO_3-5 sec. Ti-150 cc H_2O + 60cc HCl + 30cc Ammonium Fl. 5 sec		
	CLEAN (13)	H_2SO_4 at 75°C - 3 min HF Dip Rinse in D.I. H_2O		
	METAL (14) BACK	Ti 1500Å - Pd 500Å Back side is numbered Ag 20 KA		
	SINTER (15)	Temperature 550 °C Time 15 Min. Atmosphere = H_2, 500cc/min.		
	PHOTO- (16) RESIST	Mask #2 (Mesa) Waycoat SC, 7000 rpm, h - 4.0 μm Exposure time = 15 sec (I_2 = 0.6 μa), Apiezon wax back side		
	ETCH (17) SILICON	44 cc HF + 26 cc HNO_3 + 29 cc Acetic 5°C, Etch time = 5-10 sec Etch silicon between 5 to 8 μm deep, Talystep _____μm.		
	TEST (18)			

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Fig. 18

TABLE 23

Representative Data ARRAY Process vs Standard Process

1 No. Cells	2 Web No.	3 Cell Size (cm^2)	4 V_{oc} (V)	5 J_{sc} (mA) AR	6 FF	7 τ_{ocd} (μsec)	8 Eff. (%) AR CTD	9 Cell Size (cm^2)	10 V_{oc} (V)	11 J_{sc} (mA) no AR	12 FF	13 τ_{ocd} (μsec)	14 Eff. (%) no AR	15 Calc. Eff. w/ AR
			ARRAY PROCESS								STANDARD PROCESS			
	J21-5.2	11.2	.565	27.7	.75	5	12.6	1	.544	21.0	.70	6.0	8.7	12.2
	J14-2.3	11.2	.563	28.0	.75	8	13.0	1	.558	21.7	.72	14	9.5	13.3
	RE10-2.6	6.98 *	.566	31.2	.75	10	15.5	1	.554	22.9	.74	30	9.9	13.9
	RE9-3.4	7.45 *	.588	29.5	.76	26	14.5	1	.543	22.4	.74	10	9.6	13.4
		6.20 *	.581	30.0	.76	26	15.6							
2	RE23-3.5	11.2	.540	26.7	.74	25	11.8	1	.512	21.1	.72	7.0	8.2	11.5
2	RE11-4.3	11.2	.564	27.2	.76	10	12.9	1	.530	21.5	.68	7	8.3	11.6
	RE12-3.6	11.2	.564	27.8	.77	5	13.1	1	.56	22.7	.75	40	10.1	14.2
	RE10-2.8	11.2	.530	26.4	.77	4	11.8	1	.554	22.9	.74	3.0	9.9	13.9
2	RE24-1.4	11.2	.53	27.5	.76	9	13.3	1	.560	23.3	.73	24	10.0	14.0
2	RE25-3.2	11.2	.570	30.1	.75	12	13.9	1	.550	23.5	.75	24	10.3	14.4
	RE26-3.3	11.2	.560	28.0	.76	18	13.7	1	.565	22.7	.73	30	10.0	14.0
	RE27-1.4	11.2	.556	27.8	.74	11	12.5							
	RE30-2.3	11.2	.520	26.2	.77	4	12.1	1	.540	21.3	.74	18	9.2	12.9
	RE31-3	11.2	.555	27.5	.76	5	12.7							
	RE14-2.3	11.2	.577	27.9	.76	8	13.3	1	.520	21.5	.66	6	7.6	10.6
	W41-1.11	11.2	.590	28.4	.78	16	14.2	1	.562				9.7	13.6
	W41-1.11	11.2	.583	28.3	.77	13	14.0							
	J57-3.4	11.2	.581	28.2	.75	12	13.3	1	.549				9.1	12.7
	J57-3.4	11.2	.577	28.3	.74	11	13.3							
	W41-1.10	11.2	.554	27.7	.71	5	11.9	1	.560				9.3	13.0
			.560	28.1	.74	5	12.7							
			.562	27.1	.76	5	12.6							
	J55-2.5		.541	26.8	.75	6	11.8	1	.535				8.9	12.5
			.533	26.7	.74	4	11.6							
			.525	26.4	.75	4	11.3							
	W41-1.9		.566	26.1	.77	3	13.3	1	.549				9.8	13.8
			.543	25.3	.75	8	12.1							
			.527	25.0	.77	4	11.8							

* The cells marked were nominal 1.6 x 4.0 cm cells. The cells were laser scribed and in most cases the cell area was not 6.4 cm^2. After initial measurements, using a nominal cell area of 6.8 cm^2 (derived from measuring 5-6 cells) the cells were used in building several small panels. Only the three cells marked (*) were not used and after measured. The areas noted were determined. All other cells were cut more exactly ($A_o = 11.2$ cm^2 ± 0.05 cm^2) due to improved jigging on the laser scribe apparatus.

Curve 713536-A

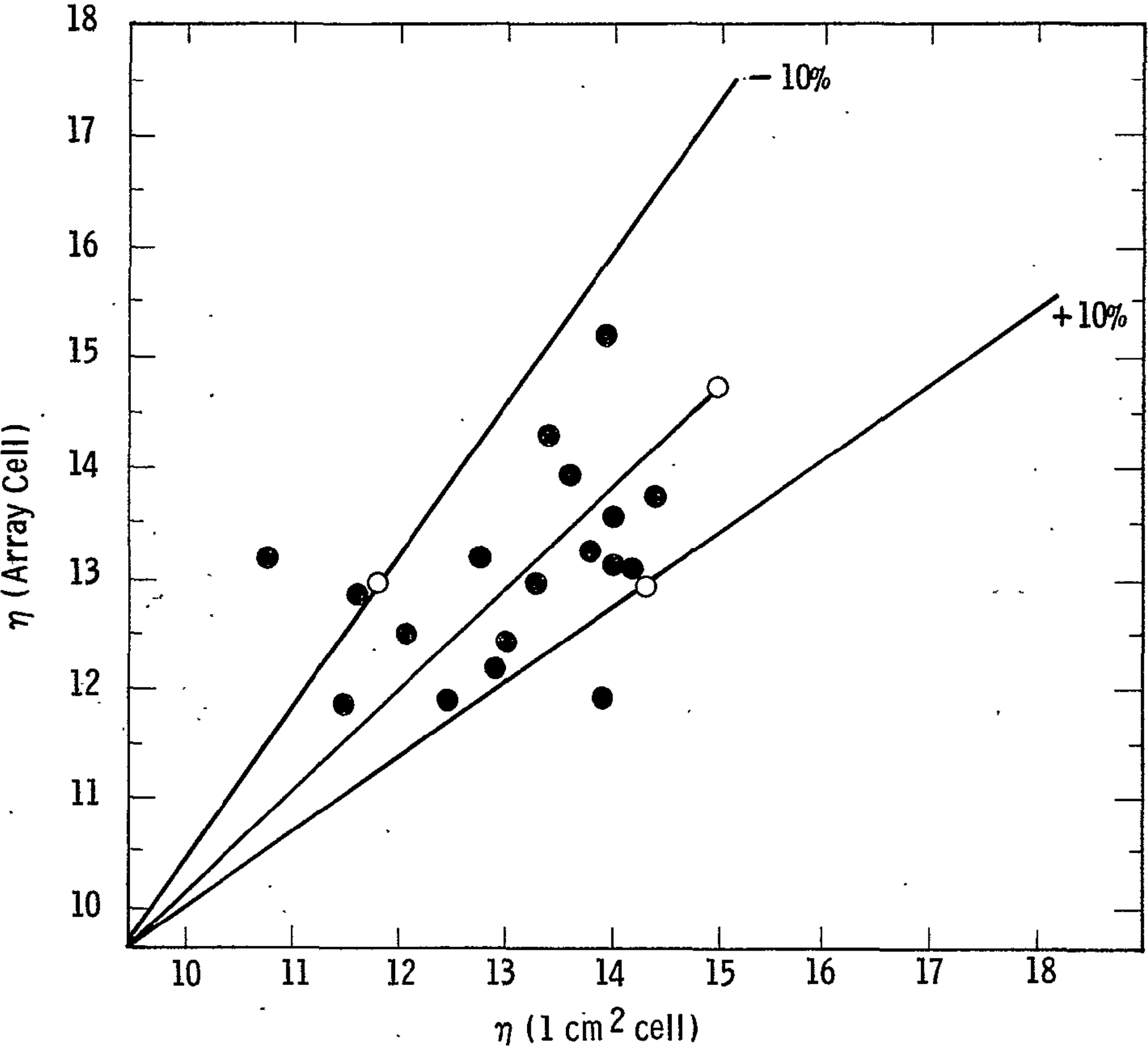

Fig. 19 Comparison of efficiency of 1.6 x 7.0 cm cells produced by Array process with 1.0 x 1.0 cm cells produced by standard process.

Curve 713531-A

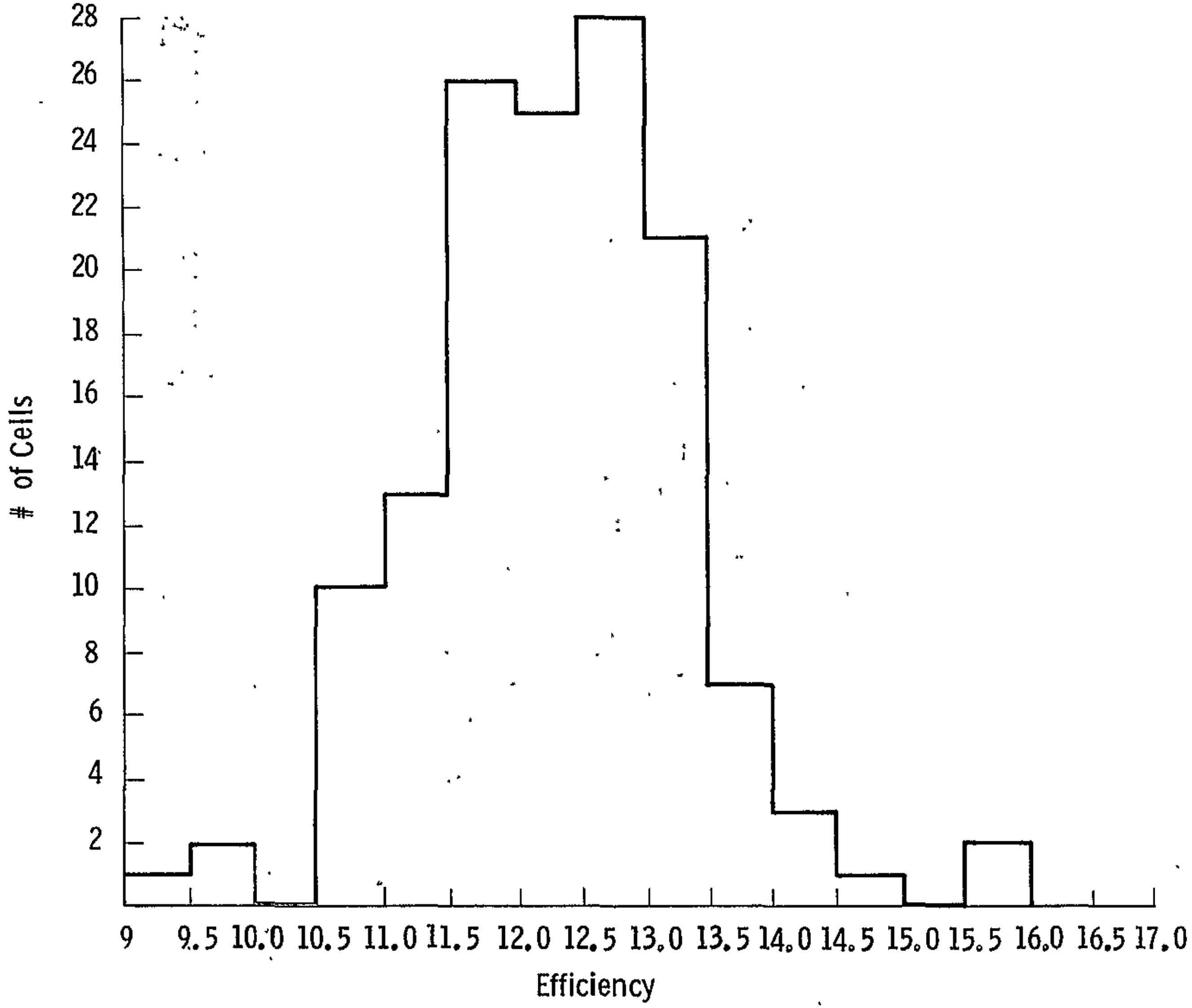

Fig. 20 — Cells fabricated by Array process AR coated

4.4 Results - Modules

4.4.1 Test Modules

Two small test modules, each containing 15 series connected cells, were built to test certain encapsulation techniques. The cells were a nominal 1.6 cm x 4.0 cm, although as mentioned earlier, the area varied from 6.2 cm^2 to 7.5 cm^2 due to problems in jigging the laser scribing apparatus.

The cells were interconnected with 0.002" copper foil strips, each about 0.100" wide. A 2% lead-tin solder was used. Although the ultrasonic bonding technique was shown to be feasible due to the lack of suitable production equipment on site these modules and other modules discussed in this report were interconnected using solder. Since each 4.0 cm cell has four contact points, the four Cu strips provide sufficient redundancy so that continuity is not lost if one or two become disconnected. The cells were completely interconnected and tested before mounting in the panel.

The first module was built by applying a thin layer of RTV-615* to a Sunadex** glass front plate and placing the cells on the RTV-615. The silicone had been degassed before it was placed on the glass. After curing, this assembly was mounted on a one-fourth inch thick anodized Al plate using further silicone.

In an attempt to improve the heat rejection capability of the structure, in the second module, the cells were first mounted on the Al plate with a thin layer of RTV. After curing, Sunadex glass was again used as a front plate.

The measured data on these modules are given in Table 24. This panel data is quite consistent with the data of the individual cells used in the construction. The overall series resistance of the module was 6 - 8 ohms.

---

[*] RTV-615 is a proprietary silicone manufactured by General Electric Co.

[**] "Sunadex" is the registered tradename of a textured glass manufactured by ASG Industries.

TABLE 24

Dendritic Web Silicon Test Modules
AM1 Illumination

Module #1	I_{sc} (mA)	V_{oc} (V)	I_p (mA)	FF	Panel Eff. (%)
1	190.6	8.168	181.5	.783	13
2.	212.0	8.430	199.8	.759	14

NOTES:
(1) 15 cells; series connected
(2) Each cell - nominal 1.6 cm x 4.0 cm - AR coated
(3) Area factor used in efficiency calculation was area occupied by cells including interconnect spacing plus 0.2 cm margin on sides (110 cm^2).
(4) Packing factor ≈ 0.95.
(5) I_p = current at peak power
(6) Measured at 25°C

The open circuit voltage of each panel was measured as a function of time under constant AM1 illumination. The decrease of V_{oc} is a measure of the temperature increase in the module. Figures 21 and 22 show this data for the two modules. Both modules continue to show a temperature increase for over one hour before they stabilize. This stagnation temperature, for both modules, was between 75°C - 80°C as determined by the decrease in V_{oc}. Thus it appears that the silicone is such a good insulator that even when the cells are mounted next to the Al plate, the thermal impedance of the system is quite high.*

The output of module #1 was measured at the stagnation temperature. These results, compared with the 27°C data, are shown in Table 25. The efficiency of the panel has decreased, due to the decreased V_{oc} and fill factor.

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* The work on the 1.6 x 4.0 cm cells and the small module studies was funded mainly by an internal Westinghouse development program.

Curve 713532-A

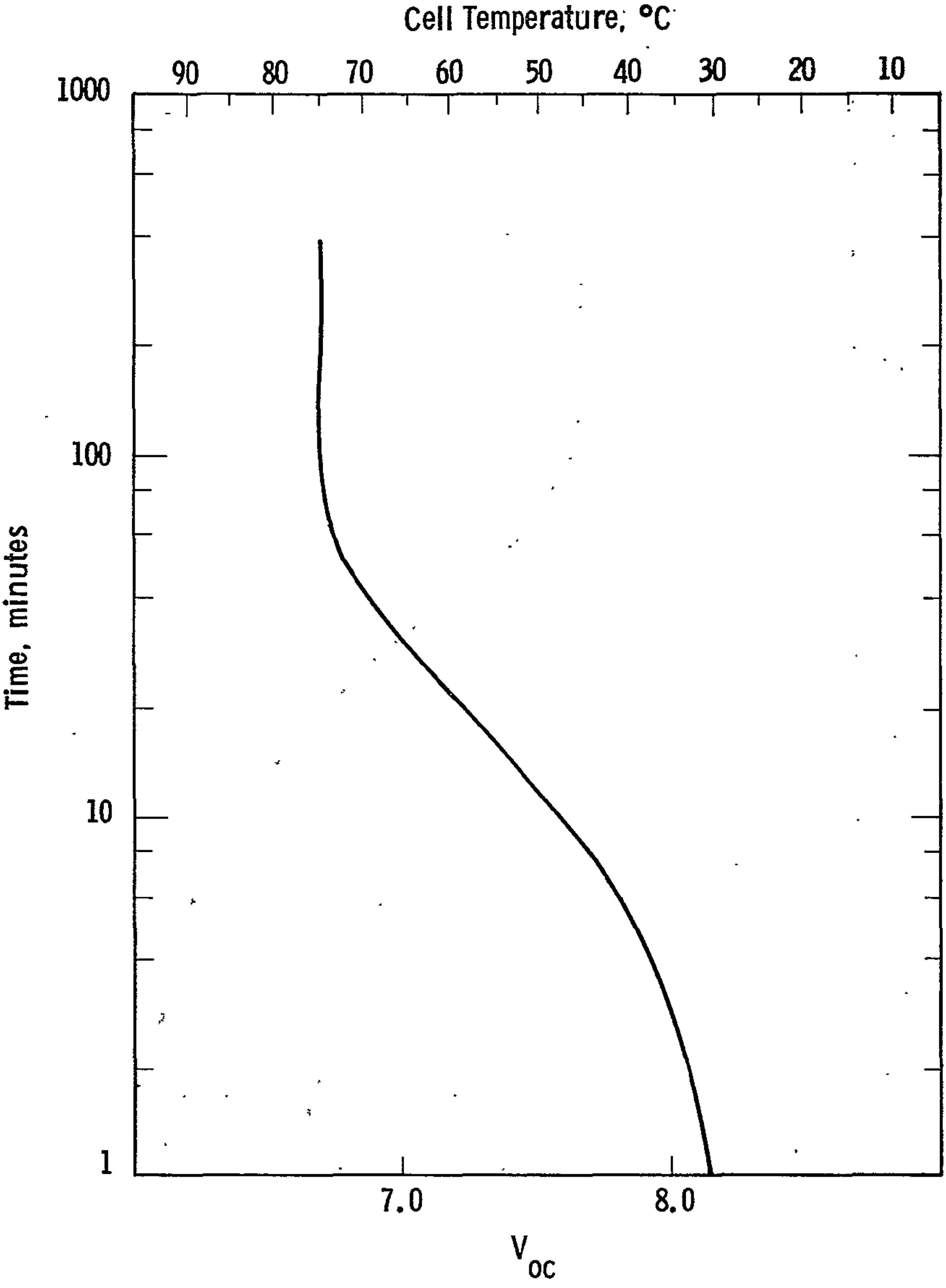

Fig. 21 Test Module #1 - Cell Temperature vs. Time at AM-1

Curve 713533-A

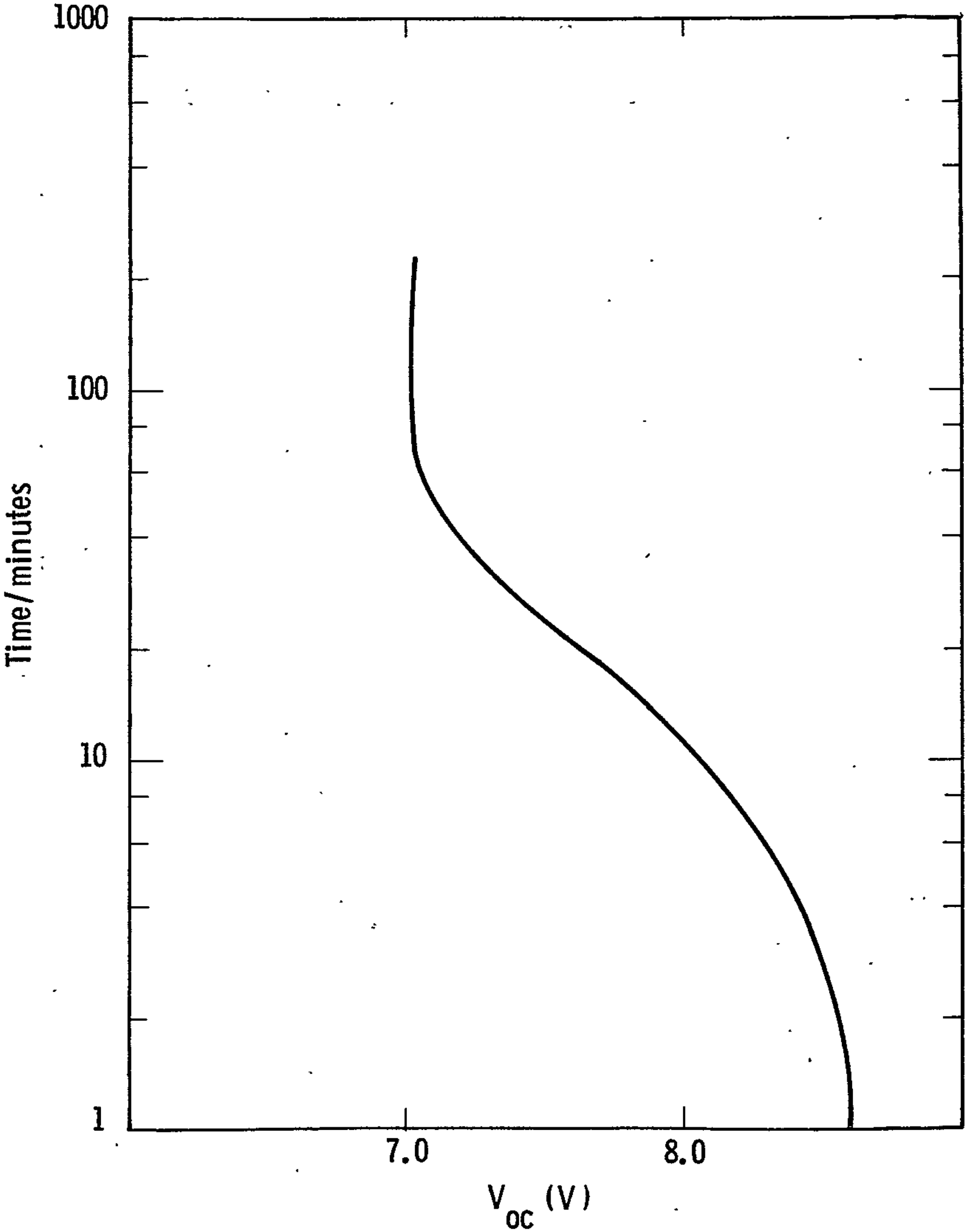

Fig. 22 Test Module #2 - Cell Temperature vs. Time at AM-1

These data, although only on one module, indicates that the temperature rise problem must be carefully studied and efforts made to reduce the thermal impedance of the modules.

TABLE 25

Module #1 - Parameters at 27°C and 75°C

Temp.	I_{sc} (mA)	V_{oc} (V)	I_p (mA)	Log I_o*	FF	Eff. (%)
27°C	190.6	8.26	181.5	- 12	.783	13
75°C	194.8	6.72	178.2	- 7	.714	10

*Log I_o is a measure of the excess junction current.

4.4.2 Demonstration Module

Several demonstration modules were fabricated using 1.6 cm x 7.0 cm cells of the type discussed. Seventy two cells were used with a total area of 806.4 cm^2. The substrate was a 1/4" aluminum plate which had been milled out to form a recess with a 0.030 lip around the edge. The Al plate was 28.45 cm x 29.34 cm or a total area of 834.6 cm^2. This gave a packing factor of cell area/substrate area of 97%.

The cells were interconnected with silver-plated copper foil straps soldered to the silver-plated contacts on the front surface and the evaporated silver on the back of the cells. All 72 cells were series connected. Table 26 lists 81 cells initially chosen for fabricating into the module. These cells had efficiencies from 12.0 to 14.2% and were selected from a number of different cell processing runs. During the fabrication nine cells were broken.

To fabricate the first module, four strips of interconnected cells (18 cells per strip) were made up. To fit into the Al plate, the spacing between the cells was held to 0.025 cm or less. A shallow layer of silicone encapsulant* was then poured into the milled-out Al plate and

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* General Electric Company RTV-615.

TABLE 26

Cells Used in Demonstration Panel

Cell #	I_{sc} (mA)	V_{oc} (V)	I_p (mA)	FF	Eff. (%)	τ_{ocd} (μsec)
1	294	.556	275	.765	12.2	3.9
2	301	.543	281	.768	12.2	5.2
3	308	.555	287	.764	12.7	5.2
4	312	.580	287	.752	13.3	16.9
5	296	.557	277	.759	12.2	5.2
6	301	.565	281	.765	12.7	10.7
7	309	.548	288	.768	12.7	7.8
8	305	.563	283	.759	12.7	3.9
9	302	.554	282	.764	12.5	5.9
10	304	.550	283	.765	12.5	8.5
11	311	.556	286	.740	12.5	10.8
12	311	.564	291	.767	13.1	5.5
13	295	.539	276	.775	12.0	3.6
14	312	.538	291	.759	12.4	6.5
15	310	.558	293	.792	13.4	5.2
16	314	.578	292	.763	13.5	15.6
17	320	.560	296	.748	13.1	10.4
18	314	.549	290	.757	12.7	9.1
19	315	.566	296	.734	12.8	11.7
20	300	.544	280	.765	12.2	4.9
21	305	.540	280	.767	12.1	5.5
22	320	.577	297	.761	13.7	14.3
23	312	.577	289	.760	13.3	7.8
24	311	.559	288	.732	12.4	18.2
25	298	.554	279	.768	12.1	3.9
26	337	.570	309	.743	13.9	11.7
27	313	.590	296	.775	14.17	15.6

TABLE 26 (cont'd)

Cell #	I_{sc} (mA)	V_{oc} (V)	I_p (mA)	FF	Eff. (%)	τ_{ocd} (μsec)
28	317	.583	296	.774	14.0	14.0
29	316	.581	292	.745	13.3	11.7
30	317	.577	294	.744	13.3	11.1
31	297	.534	280	.789	12.2	3.9
32	302	.532	284	.788	12.3	3.3
33	301	.542	285	.795	12.6	1.3
34	300	.551	277	.746	12.0	5.2
35	315	.560	290	.738	12.7	5.3
36	304	.562	281	.758	12.6	4.6
37	301	.573	278	.760	12.8	17.5
38	300	.558	277	.750	12.3	6.5
39	306	.541	287	.779	12.6	3.3
40	302	.541	284	.785	12.5	3.9
41	314	.566	293	.768	13.3	2.6
42	306	.542	284	.749	12.1	7.8
43	293	.561	273	.765	12.3	2.4
44	303	.575	282	.768	13.0	22.1
45	309	.575	287	.761	13.2	21.0
46	300	.530	280	.775	12.0	2.6
47	307	.578	282	.743	12.9	10.4
48	311	.544	289	.731	12.1	.52
49	306	.583	284	.770	13.4	18.2
50	313	.574	289	.759	13.3	18.2
51	308	.548	286	.753	12.4	9.1
52	314	.550	292	.753	12.7	9.1
53	317	.571	295	.756	13.3	13.0
54	318	.535	296	.764	12.7	6.5

C-2

TABLE 26 (cont'd).

Cell #	I_{sc} (mA)	V_{oc} (V)	I_p (mA)	FF	Eff. (%)	τ_{ocd} (μsec)
55	320	.565	294	.763	13.4	23.4
56	317	.537	294	.740	12.3	6.5
57	323	.577	300	.759	13.8	13.0
58	317	.583	292	.758	13.7	19.5
59	322	.586	299	.770	14.2	23.0
60	309	.572	285	.748	12.9	11.0
61	300	.542	279	.758	12.0	2.0
62	313	.532	295	.771	12.5	4.6
63	313	.537	293	.758	12.4	3.9
64	313	.537	294	.758	12.4	3.6
65	302	.546	278	.749	12.0	6.5
66	315	.550	291	.749	12.7	7.8
67	318	.551	292	.737	12.6	9.8
68	313	.534	289	.746	12.2	7.5
69	318	.552	294	.737	12.6	9.1
70	315	.550	292	.745	12.6	9.8
71	312	.562	291	.754	12.9	7.8
72	309	.551	290	.768	12.8	7.8
73	321	.556	300	.759	13.2	11.1
74	322	.550	298	.743	12.8	12.8
75	327	.561	299	.733	13.1	13.1
76	318	.538	294	.753	12.55	6.5
77	335	.560	305	.731	13.4	14.3
78	330	.552	303	.741	13.2	10.4
79	327	.540	303	.746	12.8	5.2
80	316	.531	289	.739	12.1	2.6
81	320	.552	299	.762	13.1	4.6

the strips of cells placed (sun side up) into the recess. The spacing between the strips of cells was held to 0.03 cm or less. The plan was to partially cure the silicone and then reposition the cells to assure no shorting occurred and make the final interconnects between the strips of cells. To effect this partial cure, the panel was placed in a warm oven (90°C) and evacuated to remove any remaining bubbles from the outgassed silicone. However, this combination of vacuum and temperature enhanced the polymerization rate and after 10 minutes the silicone was fully cured. Thus, no repositioning of the cells was possible. In this condition there were no cells shorting out; however, one or two of the cells were "shingled" so that a small portion was above the lip of the Al plate.

Since the next step was to place the glass plate[*] on top of the Al plate with more silicone, care was taken to use an excess amount so that the weight of the glass would not crack the cells partially above the Al plate. This was not completely successful and during the final curing stage (glass + Al) three of the cells were fractured. Since all cells were series connected, this reduced the total current from the module and therefore the module efficiency. The measured parameters (AM-1) of the module were:

I_{sc} (mA) — 250
V_{oc} (V) — 40.6
FF — .707
η (%) — 8.8

The area used in the calculation was the area of the Al plate; i.e., 834.6 cm^2. The panel is shown in Figure 23.

It should be noted that the multiple interconnections scheme on our mask was of benefit on this module. One of the cells was fractured in such a way that if only a single contact was made, the cell fracture would cause an open circuit and completely disable the module. The fact that

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[*] ASG Industries - "Sunadex" type.

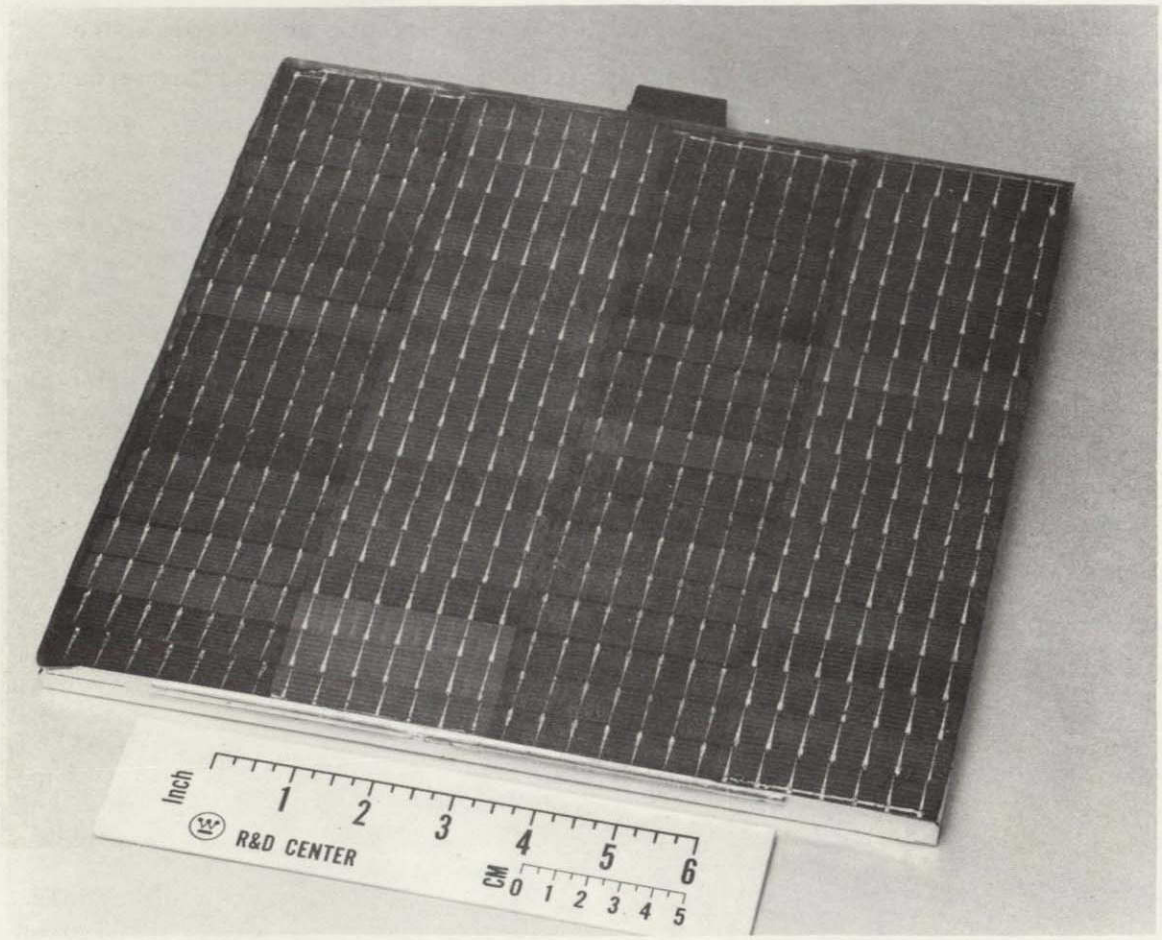

Fig. 23 (a) Demonstration module.

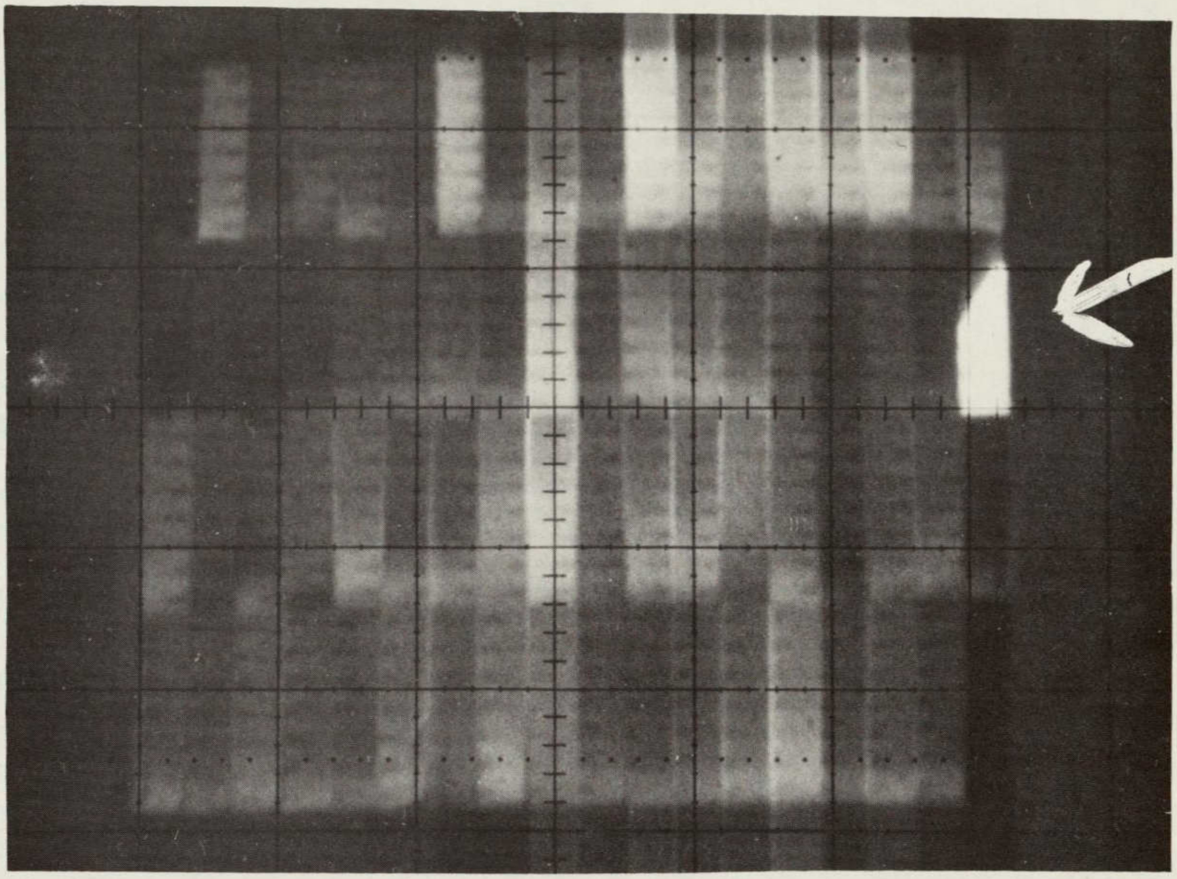

Fig. 23 (b) Photocurrent Trace of Module using Laser Scanning. Module Illuminated with Low Level White Light. Arrow shows broken cell.

the efficiency only dropped by about 25% indicates that redundancy in the interconnections was a good design feature.

The model was examined by laser scanning.(9) Figure 23B shows a photocurrent trace of the module under laser scanning with the module illuminated with a low level white flood light. Although there were three broken cells in the module, only one shows in this figure (see arrow). This cell shows up generally brighter due to a higher current density. This indicates that this cell is probably the main current limiting factor in this panel. The other broken or cracked cells, not obvious in this photograph, do not seem to be limiting the current.

The module was also examined with a Barnes-Bofors IR camera. With a 3 watt output the broken cell was only slightly hotter (0.05°C). This is near the limit of temperature resolution for this equipment, but it appears that overheating would not be a problem. (Data on the second demonstration module will be added to the final text).

5. PROCESS AND SEQUENCE VERIFICATION

5.1 Diffusion

5.1.1 Non-BSF Cells*

In general, high efficiency solar cells require shallow junctions. This is a consequence of two physical mechanisms: (1) A significant amount of incident solar energy consists of high energy photons with small absorption lengths, and are therefore absorbed near the cell surface; (2) the high dopant concentrations in the diffused region, required to obtain high voltage, results in a short carrier diffusion length. Thus as the junction depth is reduced, a greater proportion of incident photons reach the base region, where the diffusion length is long and carrier collection is efficient. Further, carriers generated in the diffused region, by the highest energy photons are more efficiently collected since the junction is closer to the point of generation.

These shallow junction requirements are most critical for an AMO spectra with its high ultraviolet content, but of lesser importance for terrestrial cells because of the reduced ultraviolet content. On the other hand, deeper junctions may have potential advantages such as lower sheet resistance and relatively less susceptibility to the process and surface-induced junction degradation. For example, sintering of contacts sometimes degrades the performance of very shallow junction cells and shows up as an increased junction excess current.

It is necessary, then, to study various diffusion times and temperatures to determine: (1) The optimum junction depth, (2) the optimum time and temperature to obtain this junction depth, and (3) time and

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* This work was carried out in conjunction with JPL Contract NAS-954654.

temperature limits that will still result in high-quality cells. Three diffusion temperatures, namely 825°C, 850°C, and 900°C were investigated. Diffusion times were estimated from diffusivity data to give similar junction depths at each temperature. The averaged results of a number of these experiments are shown in Table 27. Figure 24 illustrates the same results in graphical format. It is quite clear from the data that somewhat deeper junctions do give higher efficiency for silicon web cells. This was true, in particular, for the webs which had somewhat lower initial lifetime (η = 7.8%, no AR coating no BSF). The data seem to suggest that the optimum estimated junction for web is approximately 0.5 μm which can be achieved by 35 min diffusion at 850°C. The detailed transformed I-V plots (Figure 25) indicate that increasing the phosphorus diffusion time to get deeper junctions also results in lower reverse saturation current and increased bulk lifetime. Thus within our experience, optimum junction depth for the web comes about from the tradeoff between the loss of carriers in the upper layer and the improvement in the bulk lifetime.

These initial experiments defined a junction depth of about 0.5 μm but also indicated that this junction depth should be obtained by diffusion at a specific temperature. The reason for the importance of the temperature is not known at this time, but it could be due to a combination of gettering effects and lifetime killing mechanisms. At the lower temperature (825°C), gettering by the $POCl_3$ would not be as effective as at 850°C or 900°C, while at 900°C some lifetime killing mechanism that is not operable at 850°C or 825°C may exist.

To further define diffusion parameters, the experiment was repeated at temperatures 835°C, 850°C, and 860°C, with the cells having a boron-diffused BSF. These results are given in the next section.

5.1.2 BSF Cells

The experiment described in Section 5.1.1 was repeated at 835°C, 850°C, and 860°C with diffusion times calculated from diffusivity data to yield junction depths of 0.25 μm, 0.5 μm, and 1 μm. All runs

TABLE 27

Diffusion-Junction Depth/Time/Temperature Study

[No BSF; No AR Coating]

Diffusion Temperature			$X_j \sim 0.3$ μm	$X_j \sim 0.5$ μm	$X_j \sim 1.0$ μm	$X_j \sim 1.5$ μm
825°C	BASE	V_{oc}	.530	.540	.540	
		J_{sc}	21.9	22.8	22.7	
		FF	.725	.730	.728	
		η	9.20	9.64	9.59	
	WEB	V_{oc}	.525	.515	.520	
		J_{sc}	19.4	20.9	21.5	
		FF	.735	.712	.720	
		η	7.85	8.27	8.69	
		ρ_s	58	40	23	
850°C	BASE	V_{oc}	.552	.547	.550	
		J_{sc}	23.0	22.9	21.3	
		FF	.753	.763	.751	
		η	10.08	10.13	9.32	
	WEB	V_{oc}	.535	.537	.535	
		J_{sc}	20.6	21.5	19.1	
		FF	.726	.733	.734	
		η	8.47	8.94	7.83	
		ρ_s	58	40	23	
900°C	BASE	V_{oc}		.538	.530	.496
		J_{sc}		22.3	22.0	16.5
		FF		.720	.680	.680
		η		9.13	8.52	6.04
	WEB	V_{oc}		.515	.520	.442
		J_{sc}		21.0	19.8	17.3
		FF		.696	.671	.603
		η		8.10	7.31	4.88
		ρ_s		40	23	16

Units — V_{oc} - volts ρ_s - Ω/sq
J_{sc} - mA/cm^2 η - %

Curve 695899-A

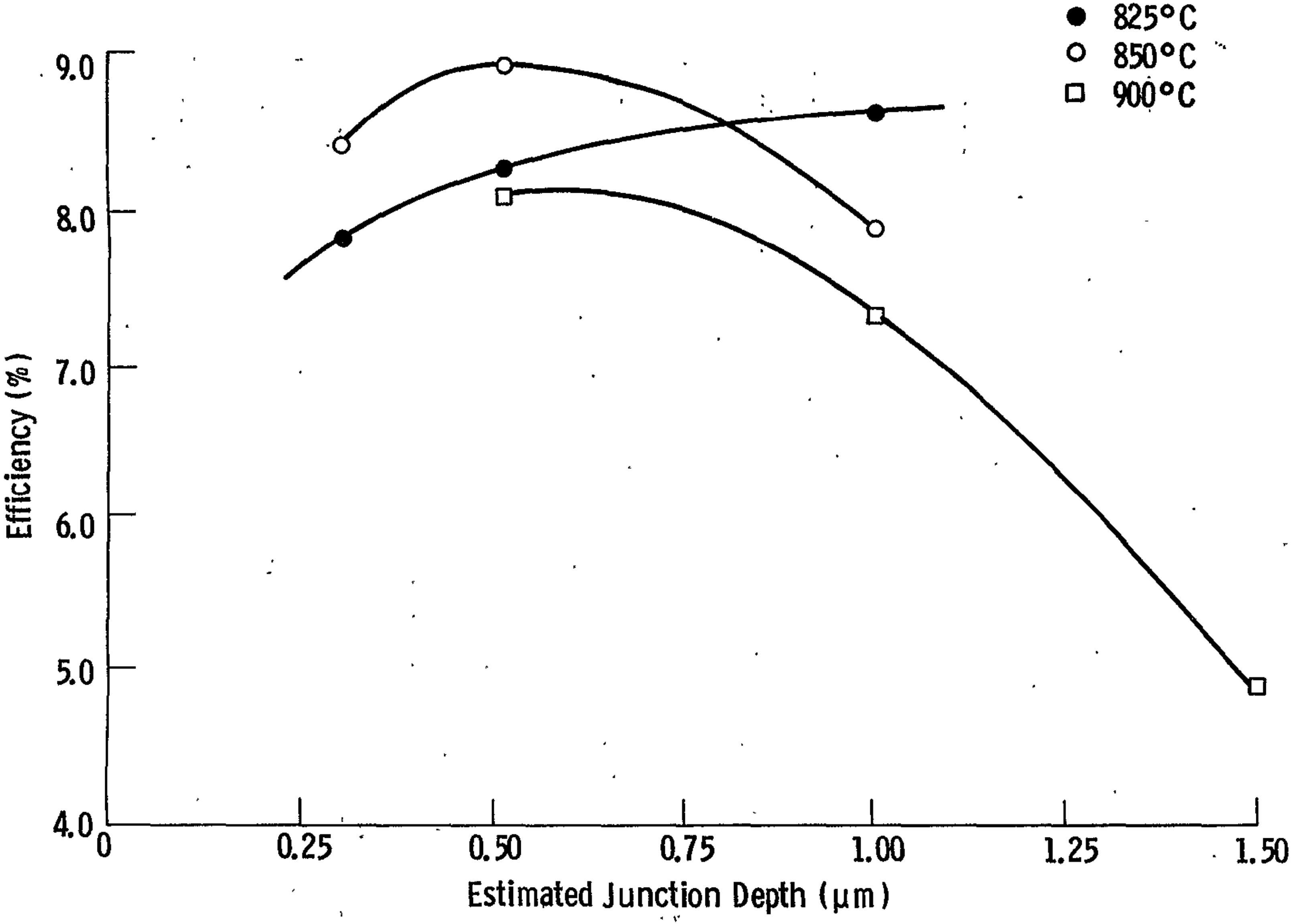


Fig. 24 Efficiency vs. Estimated Junction Depth Diffusions at 825°C, 850°C, 900°C.

Curve 695900-A

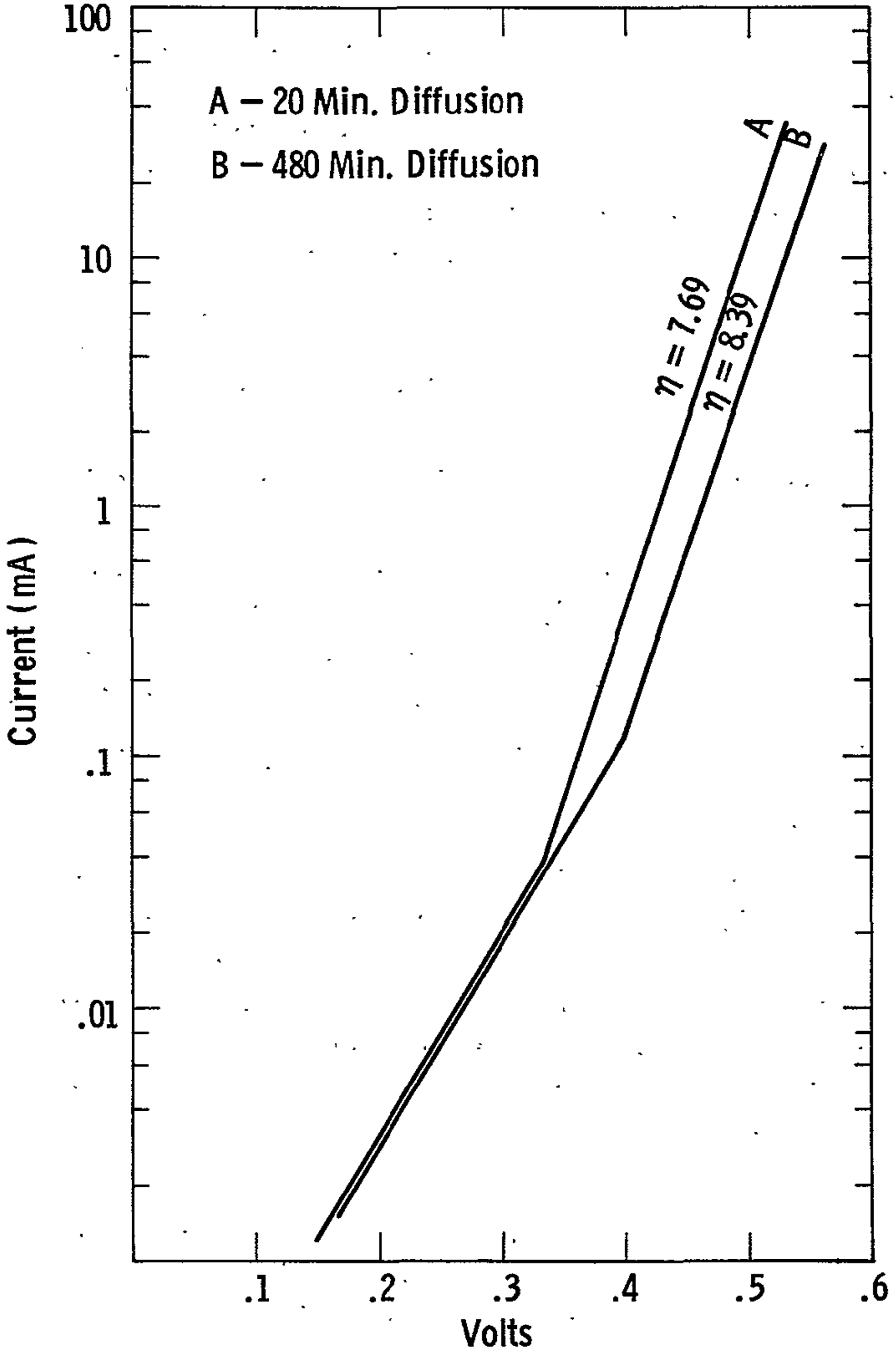


Fig. 25 Change in I-V performance of web cells with junction depth (diffusion time).

were made on a single web crystal (W41-1). The tests were made using the ARRAY process (see Section 4), and other than the different front junction diffusions, the samples were fabricated throughout the process as a single experiment. The data presented here are for cells with AR coating and with back surface fields. The averaged results are shown in Table 28. The cell size in this case was 1 cm^2.

These data again show that a diffusion temperature of 850°C yields optimum cells. What is surprising in the result is that those cells which diffused at 860°C are uniformly poorer than the lower temperature diffusions. The 0.25 μm junction depth at 835°C seems to show some processing connected problems due to a low V_{oc} and fill factor. These data are also shown in Figure 26.

Based on the data of 5.1.1 and 5.1.2 we define optimum diffusion times/temperatures for web solar cells as $850°C^{+0°C}_{-10°C}$ for 35 min ± 20 min. This gives a very wide range of operating conditions for a semiconductor device process; however, the data indicates such latitude is possible, with the resulting cells still having a very acceptable efficiency.

5.2 AR Coating by Dip Processing

The data given in Section 3.3 discusses the preparation and thickness control mechanisms of the TiO_2 (or mixed oxides) film as a function of solution concentration, withdrawal rate and baking temperature. In this section we will discuss the effect of different web widths and show the effect on solar cell parameters due to a variation of film thickness.

5.2.1 Web Width Considerations

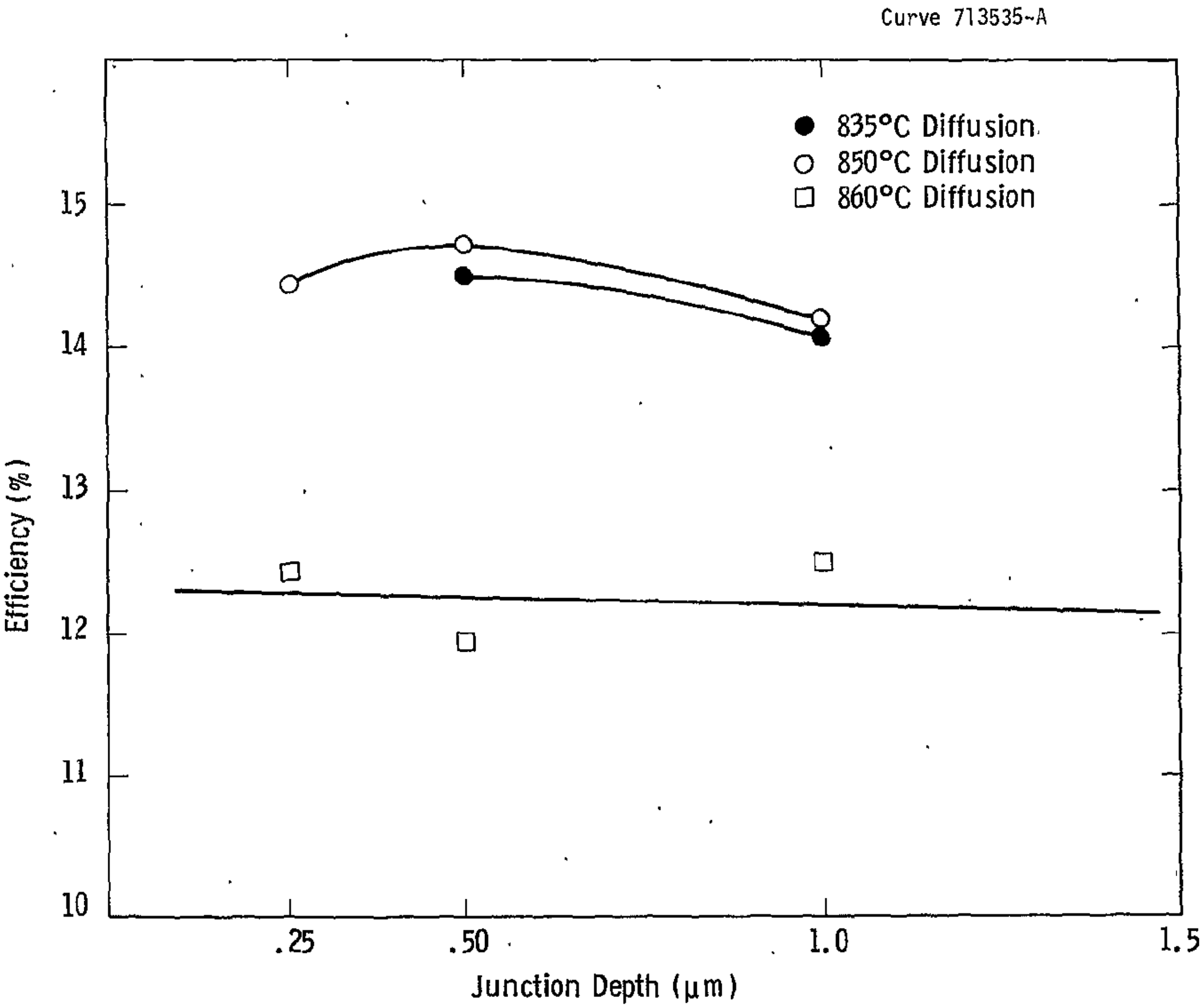
Previously, we have shown data based on a nominal web width of 1.25 cm (≈ 0.5 in.). The use of wider web effects the production costs in that the wider strip removes more precursor solution per unit width.

TABLE 28

Diffusion - Junction Depth/Time/Temperature Study

[Cells have BSF and AR Coating]

Temp. (°C)	Junction Depth (μm)	I_{sc} (mA)	V_{oc} (V)	FF	η (%)	τ_{ocd} (μsec)
835°C	0.25 (14 min)	30.2	.517	.53	9.0	2
	0.5 (50 min)	31.8	.563	.76	14.5	--
	1.0 (114 min)	30.9	.566	.76	14.1	14
850°C	0.25 (10 min)	32.3	.573	.74	14.4	18
	0.5 (35 min)	31.5	.578	.76	14.7	23
	1.0 (80 min)	31.0	.577	.75	14.2	24
860°C	0.25 (7 min)	31.1	.525	.72	12.4	4
	0.5 (25 min)	30.1	.525	.72	11.9	4
	1.0	29.7	.533	.75	12.5	4


Curve 713535-A
● 835°C Diffusion
○ 850°C Diffusion
□ 860°C Diffusion
Efficiency (%)
15
14
13
12
11
10
.25
.50
1.0
1.5
Junction Depth (μm)

It can be shown that if the width increases from 1.25 to 2.5 cm the withdrawal rate will increase by 26% to maintain a constant film thickness. An indirect benefit of the wider web is that edge effects due to the dendrites will be smaller in relation to the total web area.

Table 29 below shows the withdrawal rate required from a 2% solution for three widths of web.

TABLE 29

Withdrawal Rate as a Function of Web Width
[2% Solution]

Web Width (cm)	Withdrawal Rate (cm/min)
0.63	20
1.25	28
2.5	36

5.2.2 Variation of Optimum Film Thickness

The techniques for the control of the AR coating thickness have been discussed. It is of prime interest to determine the effect on cell parameters due to a variation of the AR coating thickness.

From Figure 3 we can obtain a measure of the change in reflectivity due to a change in baking temperature. This data can then be used in conjunction with Figure 4 to determine the thickness variation.

This data is plotted in Figure 27. This curve was derived by assuming that the optimum coating thickness gives an enhancement factor[*] of 1.42. Any variation from this thickness will then lead to an

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[*] The enhancement factor is the increase in short circuit current due to an antireflection coating on the cell.

increased reflectance off the surface of the cell and a decreased enhancement factor.

From the curve it is seen that a change in thickness of ± 50Å from the optimum will change the enhancement factor from 1.42 to 1.38, while a variation of ± 100Å changes it from 1.42 to 1.34.

If a 3% variation in J_{sc} due to the AR coating is accepted as a production standard (i.e., a ± 50Å variation in film thickness), the allowable variation in the withdrawal rate can be determined. For a 3.7% solution, the withdrawal rate of 30 cm/min ± 3 cm/min would be acceptable. Thus relatively simple and inexpensive controls could be used for this process.

5.3 Laser Scribing

In Section 3.5 of this report, work was described on the separation of cells by laser scribing. Figures 9 and 10 show that web solar cells can be separated from the web/dendrite matrix by laser scribing from the back followed by breaking.

During this initial testing it was noted that whenever there was any decrease in cell parameters, the cell showed a low shunt resistance (< 100Ω) and that the edge of the cell always showed an effect such as shown in Figure 28. This figure shows a region on the edge of the cell where the molten zone has completely penetrated the cell. This penetration will short out the junction in that region and cause a low shunt resistance.

All of the larger cells (1.6 x 4.0 cm and 1.6 x 7.0 cm) which are discussed in this report were separated from the crystal by laser scribing. Since it was not possible to test them before scribing (no mesa etch) there is no one-to-one comparison of cell parameters before and after laser scribing. However, by measuring the shunt resistance and examining the edge of the cell we can infer whether any damage occurred.

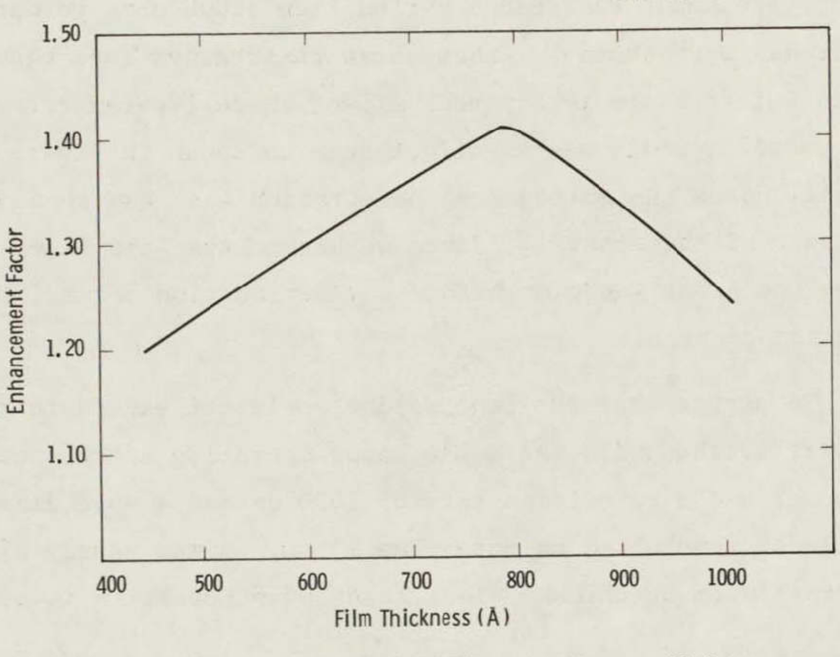

Fig. 27 — Antireflection film thickness vs enhancement factor

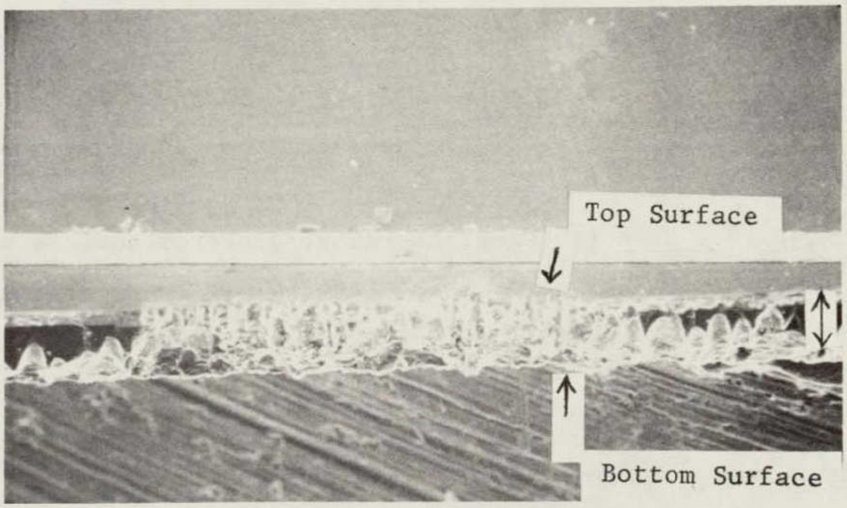

Fig. 28 2009 - 6LS Laser Scribed from back. Note total penetration after laser scribe dwell. Length of scale bar: 100 μm.

This examination was carried out on fifty cells of the larger size. The shunt resistance varied from 3,000 ohms to more than 3K ohms. It has been shown (1) that shunt resistances less than 300Ω are required before there is any real effect on cell parameters. Also, in none of these crystals was an effect such as shown in Figure 28 noted. In all cases the molten zone penetration was less than 50% of the total thickness of the crystal. Since we assume that the laser must penetrate to the front junction before any degradation occurs, this 50% penetration is acceptable.

To assure that the penetration would not exceed this amount, all cells were scribed with the KORAD laser operating at 70% power. With this power and a repetition rate of 1000 Hz and a spot diameter of 15 μm, the laser penetrated no more than 75 μm. Since nearly all of our cells are 150 μm or thicker, less than 50% penetration is assured.

5.4 Metallization and Sintering

5.4.1 Sintering vs Junction Depth*

Sintering is usually carried out to improve the contact resistance and the reliability of the metallurgical bond between the silicon and the contact. Our experience has been that sintering usually results in some loss of efficiency; therefore sintered devices were studied to determine the cause of this effect.

Completed solar cells, fabricated by a standard process (see Figure 18) were subjected to a 425°C sintering in H_2 for 15 minutes. This was to determine the mechanism of cell parameter degradation that is occasionally noted with sintering. The contact system was evaporated Ti/Pd/Ag with metal thicknesses of 1500Å, 500Å and 20,000Å, respectively.

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* The work reported in this section was carried out in an internally funded Westinghouse program in 1977 (SOLEP). The data were obtained on Czochralski crystals with a resistivity of 4-8 Ω-cm. The results, however, are immediately applicable to web and thus are reported here.

In these studies, both the solar cell parameters as well as the detailed I-V curves of the cell(1) were studied.

Table 30 shows the performance of 10 solar cells before and after sintering at 425°C for 15 min in H_2. Figure 29 shows that sintering primarily increases the junction excess current, hence reducing the cell efficiency. This was found true for <u>all the samples</u> whose performance deteriorated after sintering. Sintering did not affect R_s, I_o, or τ appreciably. The only systematic and significant variation was found in I_j. R_{sh} decreased at times but was found to be greater than 30K in all cases after sintering. However, if the contact resistance is initially high ($R_s > 5\Omega$) then sintering lowered the series resistance and improved the cell efficiency (Figure 30).

With the preliminary data a number of cells were prepared with varying junction depths from 0.2 μm to 1.0 μm to examine the effect of sintering as a function of junction depth. The parameters of these cells is shown in Table 31. In the column "Sample ID" the numbers refer to the diffusion time at 825°C and these are proportional to the junction depth. The letters (A,D,F) are simply cell designations to delineate different cells in the same run.

Contrary to what might be expected, there was no systematic variation in the cell efficiency with the junction depth. Instead, average efficiency was about 9.9% in all the cases. This suggests that somehow the increase in sheet resistance is balanced by the decrease in dead layer in shallow junctions and vice versa for the deeper junctions. Our light source is somewhat rich in infrared which could be partially responsible for the lack of significant performance variation. Also, the Syton polished surfaces we used may have mitigated the adverse surface effects on shallow junctions.

The samples with different junction depths were sintered first at 425°C and then at 550°C. Sintering at 425°C slightly degraded the cell efficiency in most cases. However, 550°C sintering affected the shallow junctions severely, while deeper junctions were hardly affected.

TABLE 30

Results from Sintering Experiment (425°C in H_2 for 15 min)

RUN ID SOLEP 133 DIFFUSION TIME AT 825°C = 50 MIN ($X_j = 0.3\mu$)

Sample Number	Sample State	I_{sc} (mA)	V_{oc} (Volts)	Efficiency
1 1	Not sintered Sintered	21.3 20.9	.570 .563	9.49 8.85
2 2	Not sintered Sintered	21.7 21.3	.565 .569	8.81 9.55
3 3	Not sintered Sintered	21.7 21.2	.574 .571	9.83 9.65
4 4	Not sintered Sintered	22.4 21.6	.573 .571	9.67 9.62
5 5	Not sintered Sintered	21.1 21.2	.572 .564	9.27 8.95
6 6	Not sintered Sintered	21.5 21.3	.574 .570	9.91 9.63
7 7	Not sintered Sintered	21.7 21.5	.572 .567	9.37 9.59
8 8	Not sintered Sintered	21.7 21.5	.576 .567	10.13 9.26
9 9	Not sintered Sintered	21.9 21.5	.575 .570	9.82 9.78
10 10	Not sintered Sintered	21.7 21.4	.576 .566	10.09 9.56

CZ cells; no BSF or AR coating

Curve 692237-A

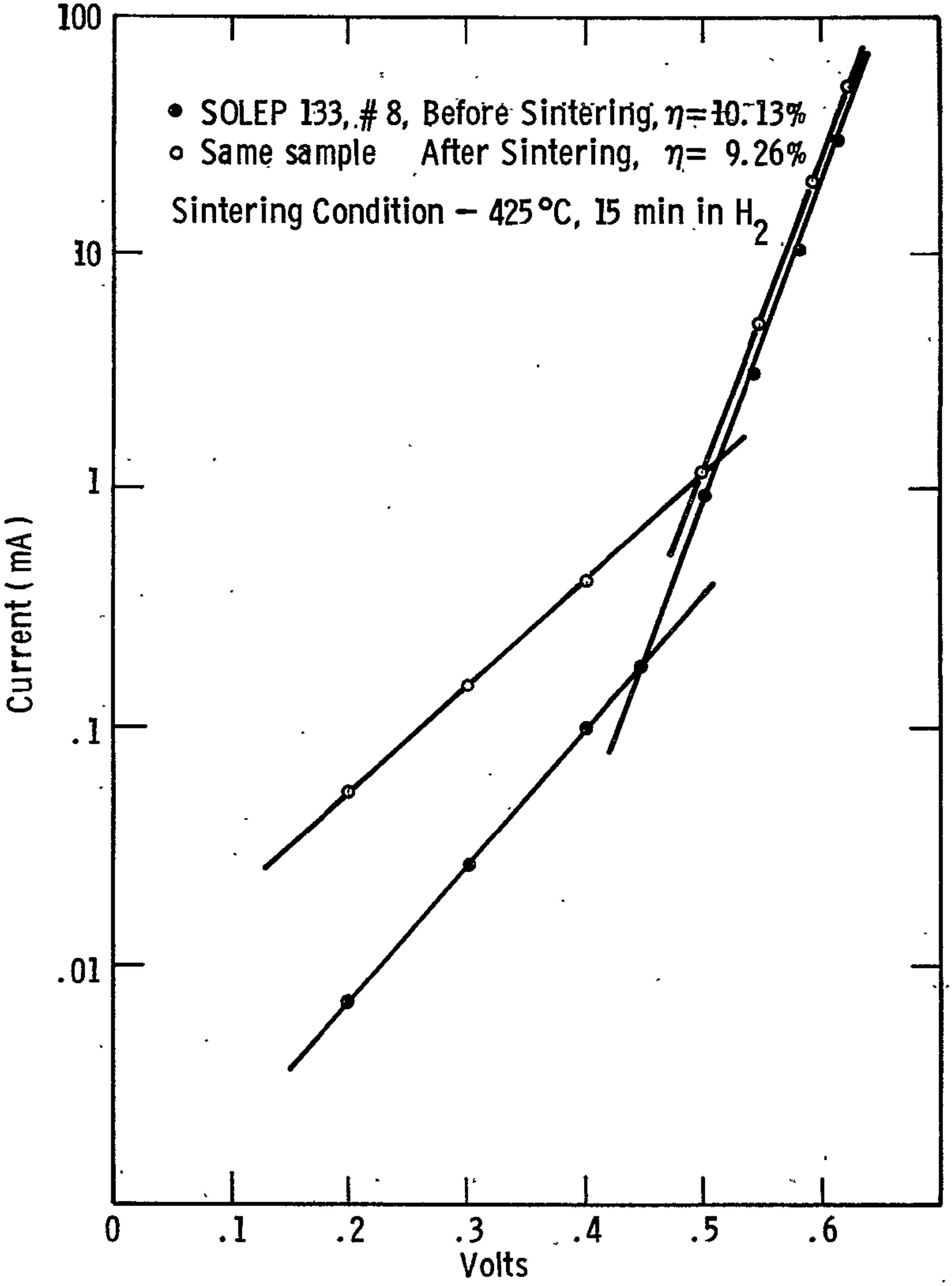

Fig. 29 Transformed Dark I-V curves for the sample SOLEP 133-8: • Before Sintering, • After Sintering at 425°C.

Curve 692233-A

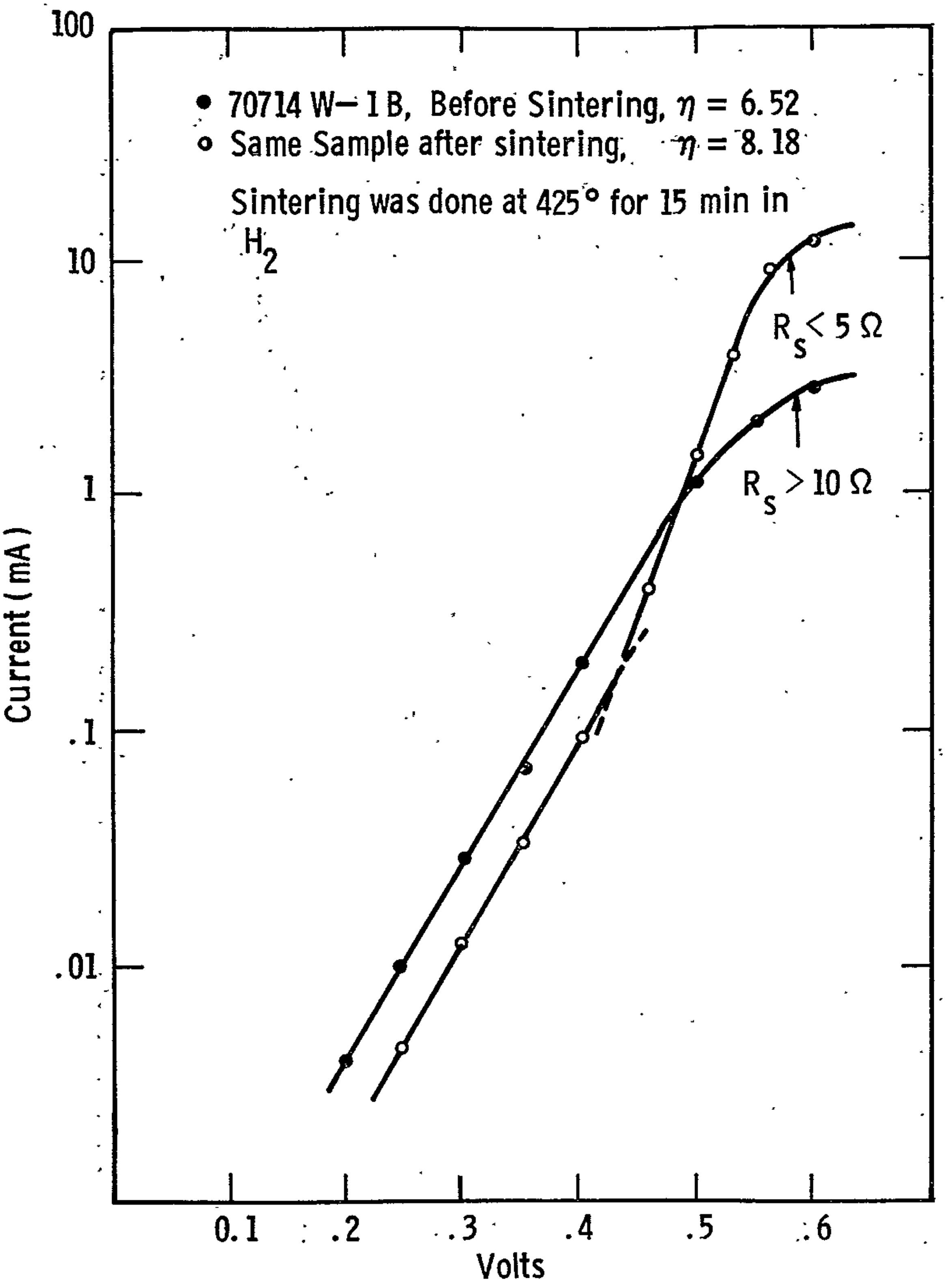

Fig. 30 Measured dark I-V curves for the sample 70714W-13: ● Before Sintering, ● After Sintering at 425°C.

TABLE 31

Effect of Sintering Parameters on Solar Cell Performance

[Diffusion Temperature = 825°C]

Sample ID	X_j (μm)	Sintering Condition	I_{sc} (mA)	V_{oc} (V)	τ_{ocd} (μsec)	Efficiency η	η unsint. / η sint.
20A	0.1	Unsintered	22.3	.577	3.25	10.22	.967
20A		425°C, 15 min, H_2	22.1	.570	3.25	9.89	
20A		550°C, 15 min, H_2	22.4	.562	1.56	8.70	
40A	0.25	Unsintered	21.9	.578	3.9	10.20	.979
40A		425°C, 15 min, H_2	21.6	.571	3.9	9.99	
40A		550°C, 15 min, H_2	21.4	.551	.26	6.67	
80A	0.35	Unsintered	22.0	.576	3.25	9.92	.962
80A		425°C, 15 min, H_2	21.6	.566	3.90	9.62	
80A		550°C, 15 min, H_2	21.6	.563	1.17	7.81	
100A	0.5	Unsintered	21.5	.575	3.9	10.06	.999
100A		425°C, 15 min, H_2	21.4	.572	4.29	10.01	
100A		550°C, 15 min, H_2	21.2	.562	1.04	7.60	
320D	0.7	Unsintered	21.5	.577	3.25	9.97	.962
320D		425°C, 15 min, H_2	21.2	.572	3.9	9.59	
320D		550°C, 15 min, H_2	21.2	.574	2.60	9.32	
480F	1.0	Unsintered	22.2	.577	3.64	10.20	
480F		425°C, 15 min, H_2	21.7	.575	4.55	10.21	
480F		550°C, 15 min, H_2	21.7	.575	2.99	9.78	

CZ cells; no BSF or AR coating

Figures 31 and 32 show a considerable increase in the junction excess current for the shallow junction compared to the deep junction devices. Thus deeper junctions, as expected, are found to be less sensitive to the sintering-induced degradation. The reason for this degradation is quite clear — increased I_j. The physical mechanism by which degradation occurs though not fully understood, probably involves titanium diffusion or migration into the junction region. This data, when taken into conjunction with the data in Section 5.1, indicates that junction depths of 0.5 μm are preferable in web, and that these junctions can be sintered up to 425°C for 15 min in H_2 without adverse effects.

The effect of sintering on the shallower junctions, for example, 0.1 μm and 0.25 μm, at 425°C is minimal. A decrease in the efficiency of 3% is noted with a 0.1 μm junction and 425°C sintering. Thus, for practical purposes, even the shallowest junction can be sintered at 425°C without undue effect on solar cell efficiency.

5.4.2 Sintering of Other Metal Systems on Web

During the period of this contract, several alternative contact systems were studied as replacement for the evaporated TiPdAg. Data on these systems were given in Section 3.3.

The cells discussed in that section were diffused at 850°C for 35 minutes (the optimum time/temperature and junction depth as determined earlier). The data given in Section 3.3 for the evaporated TiPdAg system, the evaporated TiPd plated Ag, and the evaporated TiPd plated Cu systems follow the same pattern seen in Section 5.5.1. That is, with junction depths of 0.5μ, sintering temperatures up to 400°C for 15 minutes in H_2 are permissible.

Curve 692229-A

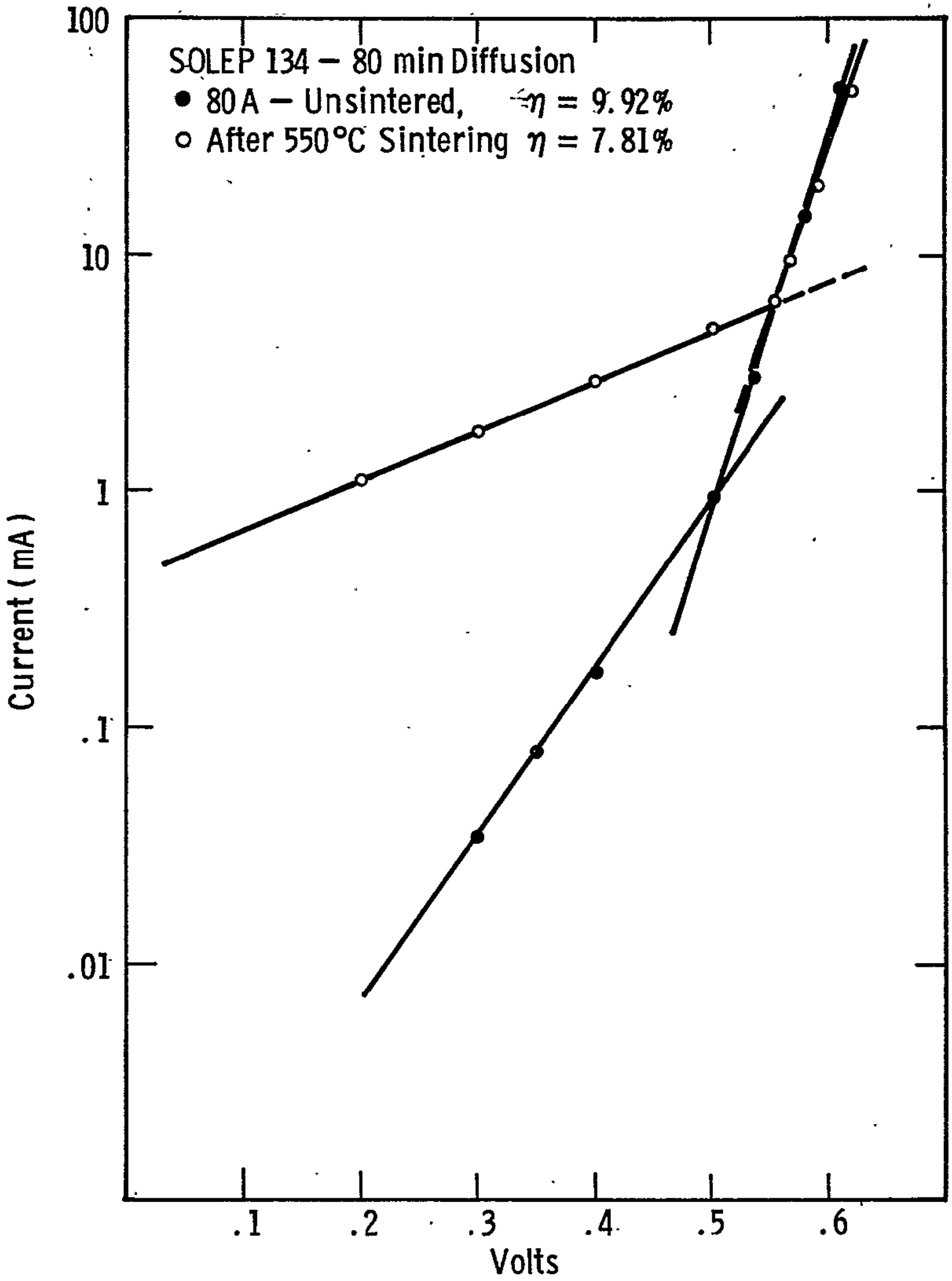

Fig. 31 Transformed Dark I-V Curves for the Sample SOLEP 134-80A: ● Before, ● After Sintering at 550°C.

Curve 692234-A

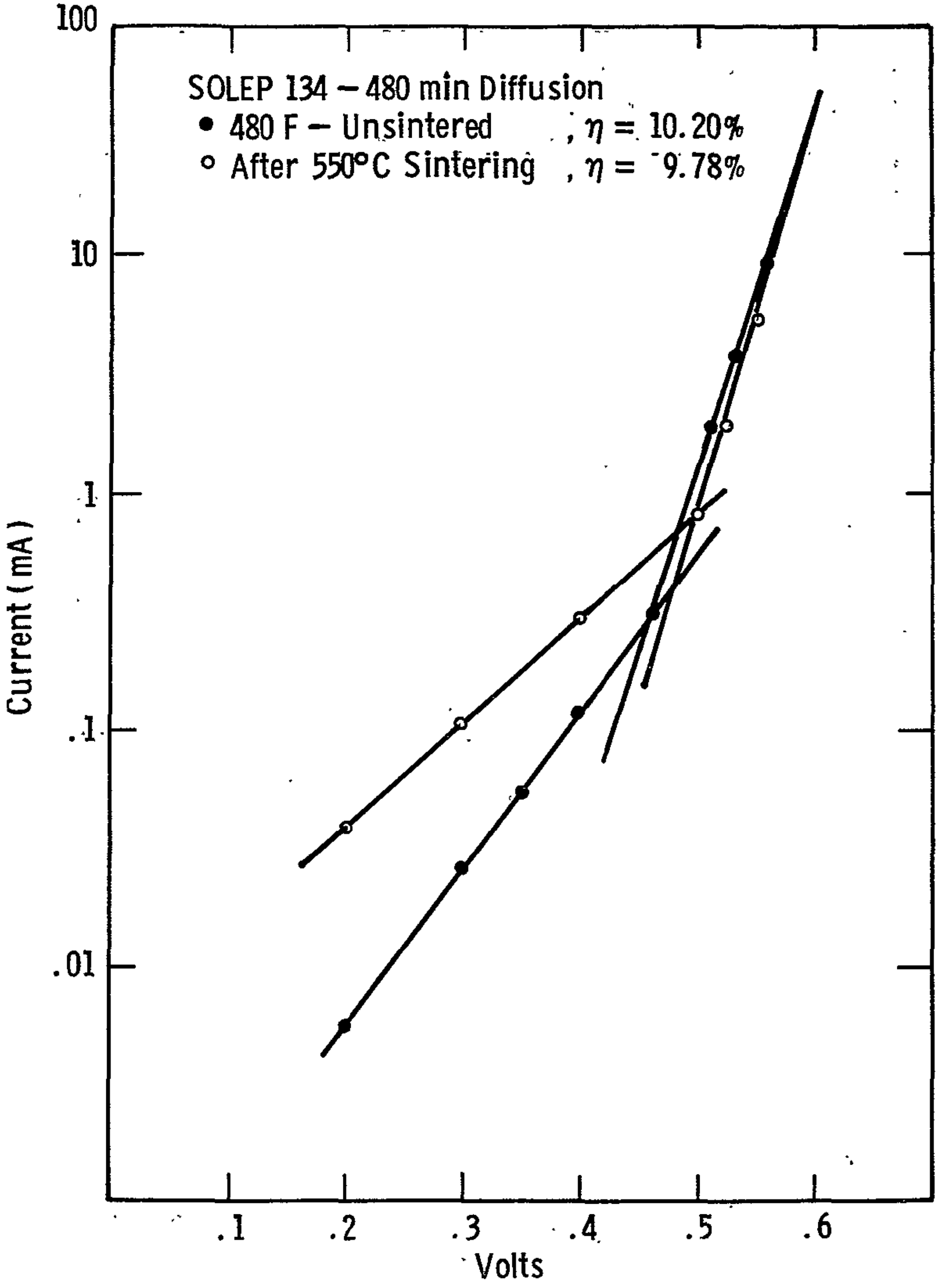

Fig. 32 Transformed Dark I-V Curves for the Sample SOLEP 134-480F: ● Before, ● After Sintering at 550°C.

6. COST ANALYSIS OF PROCESS SEQUENCE

A cost analysis of the process sequence was carried on throughout the contract. Initially, the IPEG methodology was used on the processing of continuous lengths of dendritic web. Later in the program a parallel processing of long lengths ($\simeq$ 3 meters) of web was considered, using both the IPEG and SAMICS models.

The results of these studies will be discussed in the following sections.

6.1 Continuous Processing of Dendritic Web

The first process sequence studied was the continuous processing of the web through the sequence discussed in Section 4. The equipment was designed to process 200 MW/yr (1.82 x 10^4 M^2 of web per year) and produce 11% modules.

The equipment descriptions used in the Format A's were generally a scaled up version of conventional existing processing machines. However, in several processes such an antireflection coating and photoresist dipping and encapsulation a conceptual design was used. Input from various equipment manufacturers was obtained to supplement these descriptions as well as provide information on required floor space. The materials and supplies usage was determined by extrapolating the usage in the laboratory processes. Labor and utilities were estimated, based on semiconductor industry experience.

These various Format A inputs were transferred to the company work sheet using the cost factors and inflation rates of the SAMICS Cost Accounting catalog.

The results of this analysis are given in Table 32. Section 1 (Input) is a compilation of data from the company work sheet for a 200 MW/yr production.

The yield factor is shown in the last column and gives a total process yield of 93%.

Section 11 (Output) shows the contribution to the selling price (in 1986 $ per watt) of the various processes and of the costs within the process. The total selling price given ($0.66/watt peak) is in 1986 dollars and does not include the cost of the silicon web. The web is targeted to be $0.17/watt (1975 $) in 1986. Thus the total cost in 1986 (in 1975 $) is about $0.50/watt peak.

Several points of information can be gained from these data in that certain cost drivers can be identified. The largest single cost in the process is the materials for the junction formation step. This cost is ≈ 25% of the total cost and is due almost entirely to the cost of silane at $183.40/lb (1975 $). Other cost driversare materials for encapsulation (mainly glass and backing board) and equipment for the metallization process. These data indicate where effort must be put to reduce the overall cost.

At this point in the program, we decided to investigate an alternate process, where a number lengths of webs were processed in parallel. A description of this process and the cost analysis are given in the next section.

6.2 Parallel Processing of Web Lengths

In a production situation, it may be advantageous to process lengths of web. Therefore, we have designed a process sequence that has an input of 50 three meter lengths of web which are processed in parallel.

The factor using this process sequence consists of eight parallel lines, each capable of producing 25 MW per year, with a total factory producing 200 MW per year.

TABLE 32

```
SECTION I - INPUT
-----------------
      PROCESS        YIELD       EQUIPMENT   TOTAL FLOOR  TOTAL DIRECT  TOTAL BYPRODUCT  TOTAL DIRECT   TOTAL DIRECT  PERCENT
                                   COST         SPACE        LABOR         EXPENSES      M&SUPPLIES     UTILITIES     YIELD
                     W5            W11          W13          W15           W16             W17            W18

      INTERCAP     .60000000     14.43292       649         154243          0             68480           337          .60
      LASCRIB     1.00000000     501299         549         154243          0                 0           265         1.00
      METAL       1.00000000    1239999         981         154243          0            143779          2850         1.00
      NUARCT      1.00000000     627399         599         154243          0             54389           826         1.00
      JUNCFORM    1.00000000    2577199        1161         197637          0            329963           591         1.00

                                   W20          W21          W22          W23              W24           W25
      TOTALS       .60000000    5534995        3939         814609          0            596611          4869

SECTION II - OUTPUT  - SELLING PRICE PER WATT PRODUCED
------------------------------------------------------

      PROCESS        YIELD       EQUIPMENT   FLOOR SPACE  DIRECT LABOR  BYPRODUCTS  MATERIAL&SUPP   UTILITIES     TOTALS

      INTERCAP     .60000000     14.43293      3.14765     16.19551      .00000       4.45120       .02190      38.24919
      LASCRIB     1.00000000     12.28183      2.66265     16.19551      .00000        .00000       .01722      31.15721
      METAL       1.00000000     30.37998      4.75785     16.19551      .00000       9.34563       .18525      60.86422
      NUARCT      1.00000000     15.37128      2.90515     16.19551      .00000       3.53528       .05369      38.06091
      JUNCFORM    1.00000000     63.14137      5.63085     20.75188      .00000      21.44759       .03841     111.01012

      TOTALS       .60000000    135.60737     19.10415     85.53394      .00000      38.77971       .31648     279.34166

     MULTIPLIER                    .49         97.00        2.10         1.30          1.30          1.30

     ANNUAL AMOUNT    .2000+07  MW
```

An artist's rendering of one 25 MW processing line in the 200 MW factory is shown in Figs. 33-38. Each line in the factory is considered as balanced, with a throughput of 5000 cm^2 of dendritic web per minute. For simplicity in costing, a yield figure is considered in the last processing step during final testing.

Figure 33 shows a number of web growth furnaces; each producing 25 cm^2/min of web.* The web being 5 cm wide between dendrites. Therefore, 200 furnaces are required to provide the necessary input to the processing line. The as grown web is wound on reels. Fifty such reels are ganged on a mandrel as the web fed through a laser cutter. Pieces of web, each 3M long are loaded into specially designed, light weight frames and held in a buffer station before moving to junction formation steps. Each frame holds 75,000 cm^2 of web, and thus to meet the throughput requirement, each frame must be processed in 15 minutes.

Figure 34 shows the junction formation processes in the sequence. The web enters the process and is washed in an organic solvent and dried. It then moves to a deposition apparatus where a protective oxide is formed on the front surface of the web and a boron doped oxide on the back. In the sequential steps the boron is driven in and the material passes through a phosphorous diffusion furnace and finally into an etching bath where all the oxides are removed. It should be noted that in this process step (as in all others) it is quite feasible to remove one sub-process and insert another. For example, the boron oxide deposition and drive sub-processes may be replaced by an aluminum deposition and firing step. This makes iterations in the costing studies fairly simple.

Figure 35 shows the application of the antireflection coating and the photoresist, both by dipping. The equipment is designed to handle the 37 x 37 frames. In station 7 of this process, the web lengths are passed (one at a time) into an exposure system where a suitable grid pattern is put onto the photoresist layer. The final stages etch the grid pattern into the photoresist and antireflective coatings and the webs are again loaded into frames for metallization.

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*This work is being carried on under Task 2 Contract 954654 and is included here only for the sake of completeness.

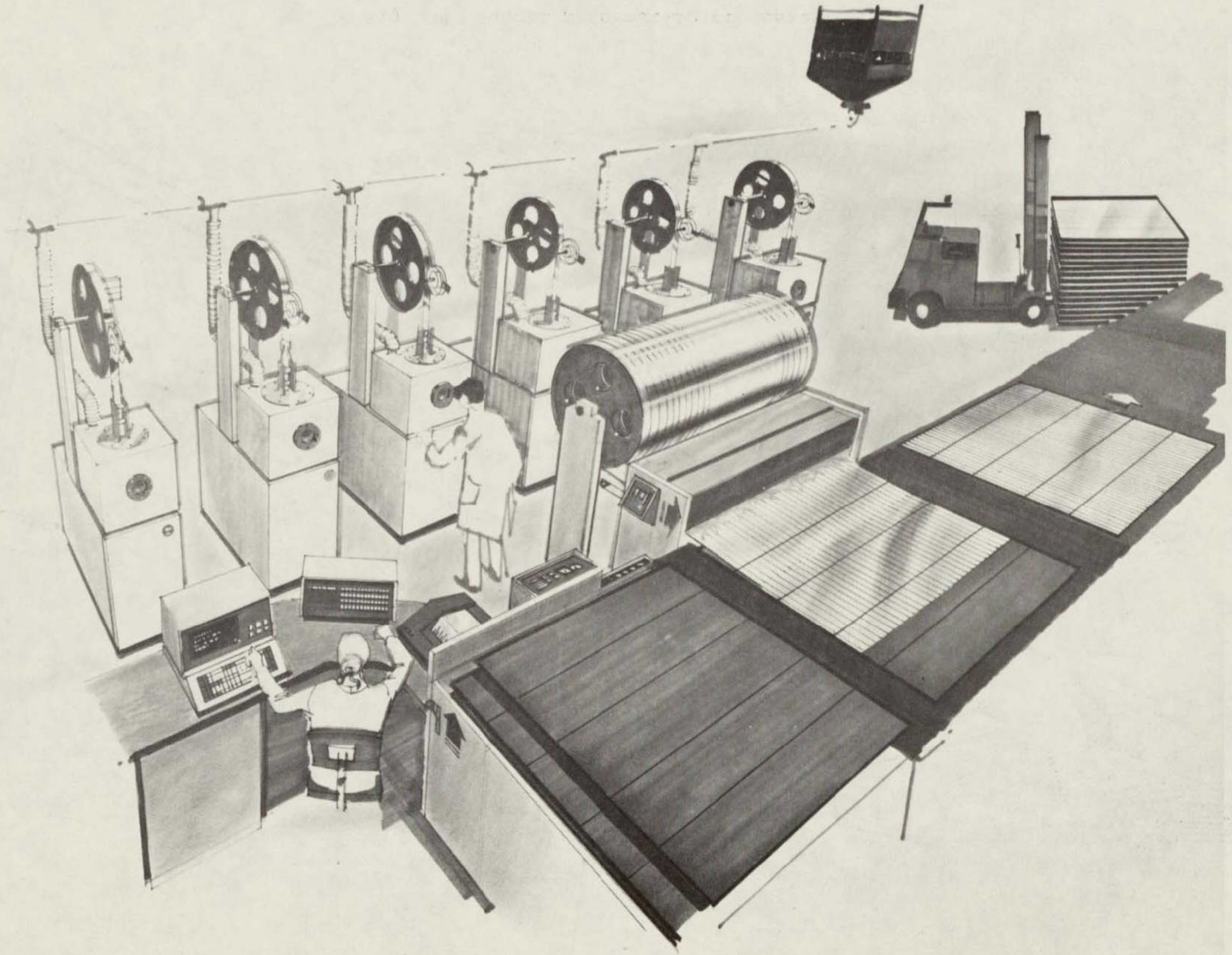

Fig. 33 Web growth furnaces.

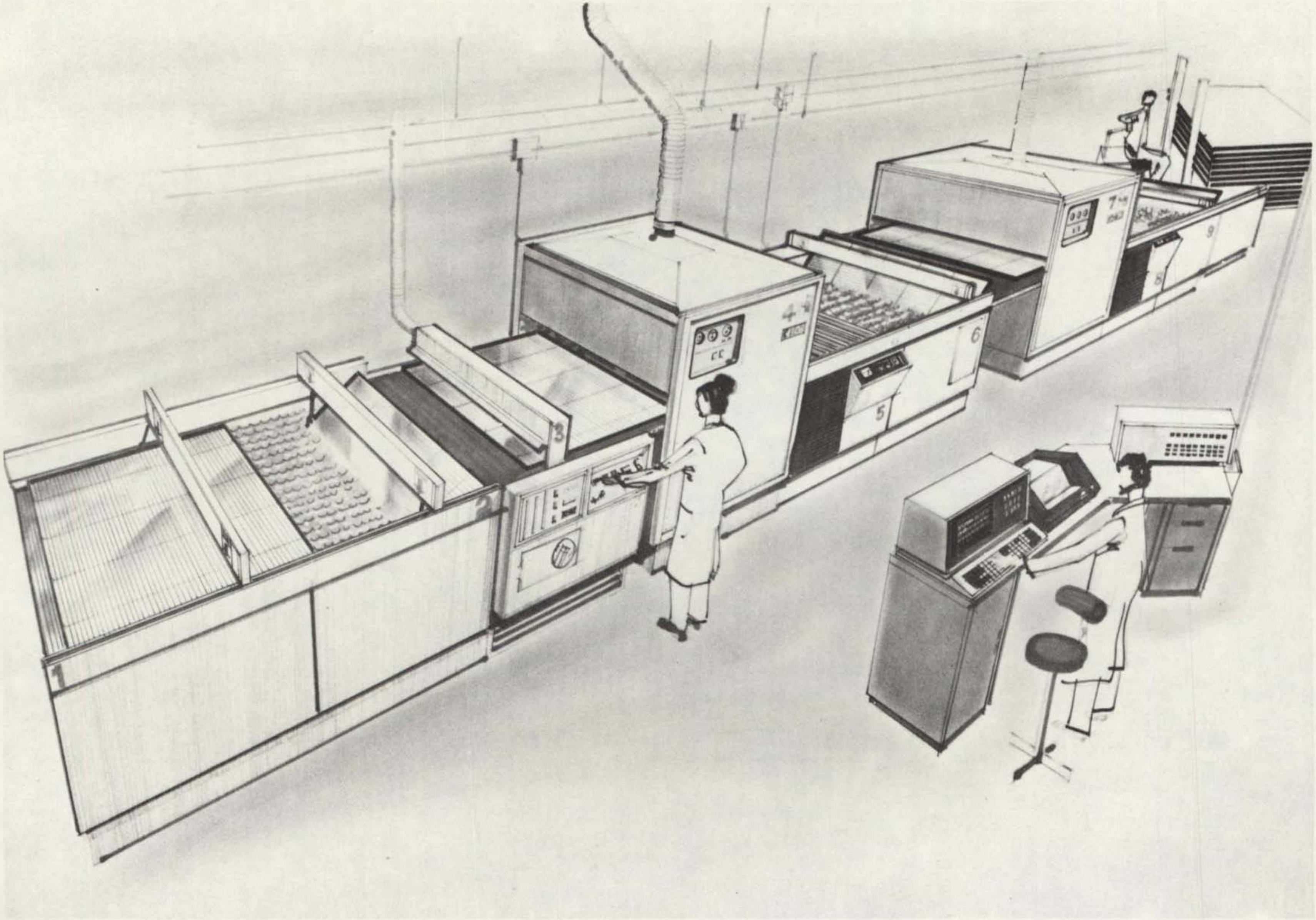

Fig. 34 Junction formation processes.

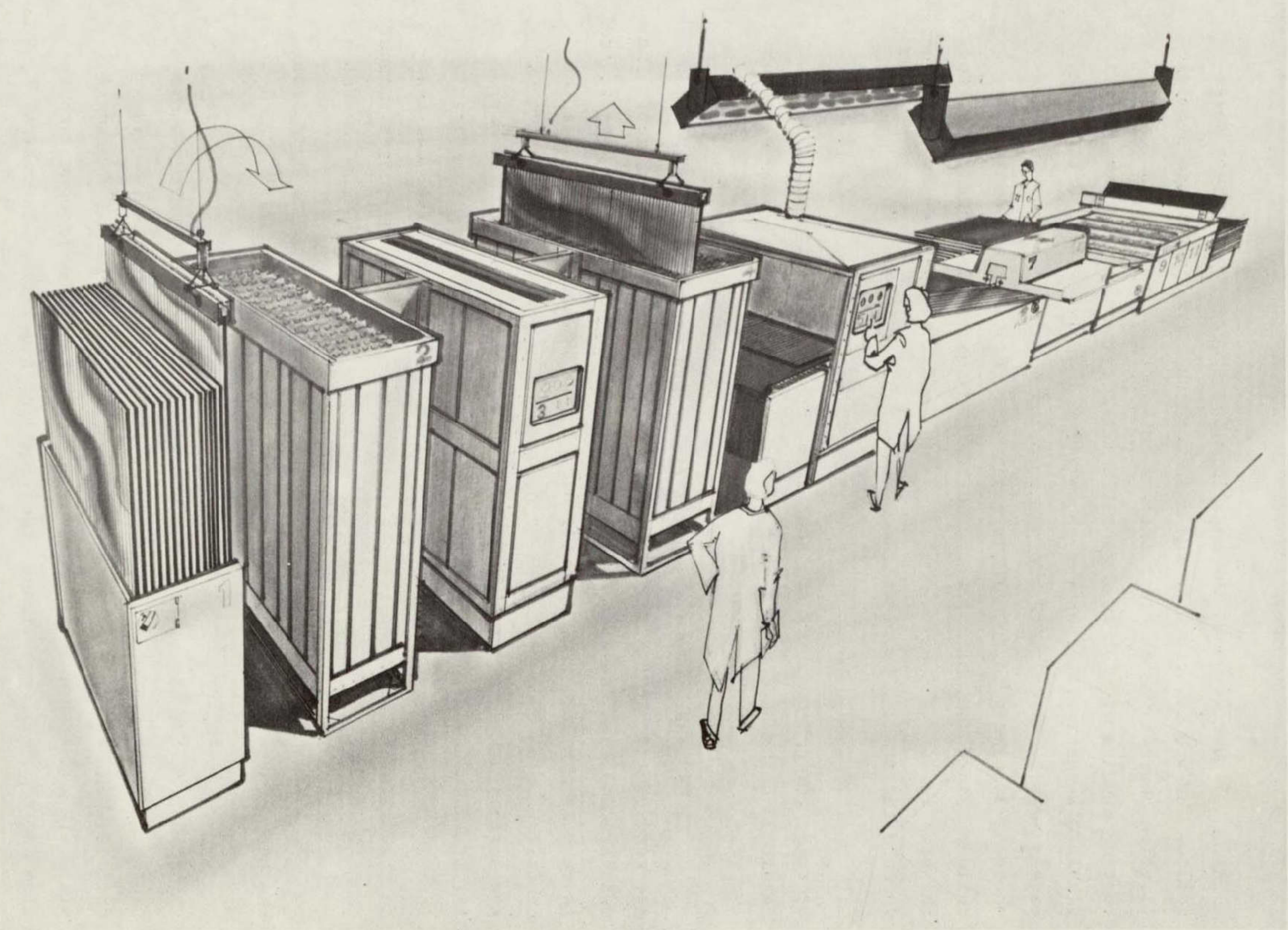

Fig. 35 Application of the antireflection coating and photoresist.

Figure 36 shows the metallization process for the web solar cells. The web strips, with the grid pattern opened pass into a metallization chamber where both front and back metals are applied. Our costing studies are for an evaporated metal system but sputtering is a viable alternative. After the photoresist is rejected (rejecting the excess metal) the contacts are sintered and move to a plating station where Ag is plated to the proper thickness. Plating is used in this build-up since the only silver used is that deposited on the cells, and the step is cost effective. After a final cleaning the webs are stacked in a buffer station before moving to a scribing process.

It should be noted that if an Al back surface field is substituted for a boron back surface field, no metallization would be required on the back of the cell, and the process would become somewhat simpler.

Figure 37 shows a laser scribing process where the dendrites are removed and the cells are cut to their final 5 cm x 20 cm size. The webs are unloaded one at a time where they first pass under a longitudinal laser scribe unit where two laser heads, 5 cm apart, scribe inside the dendrites. The webs move to a transverse laser scriber where the webs are scribed at 20 cm intervals. In station 5, the webs are run over rollers where the dendrites are broken off and the cell is fractured into 20 cm lengths. The final two stations perform an electrical test on the cells and pack the cells that pass the test into cassettes. About 5000 of the cells can be packed into one 5 cm x 20 cm x 125 cm cassettes.

It should be noted that the laser scribing must be done from the back of the cell to prevent any junction damage.

Figure 38 shows the final processing step. The cells are unloaded from the cassettes and pass under an ultrasonic welder where Al foil (cut from a roll) is bonded to the front of the cells. The foil is then bent up so that interconnections can be made. A glass plate (1M x 3M), previously coated with an adhesive is brought into the line and the cells are placed (face down) on the glass. The glass

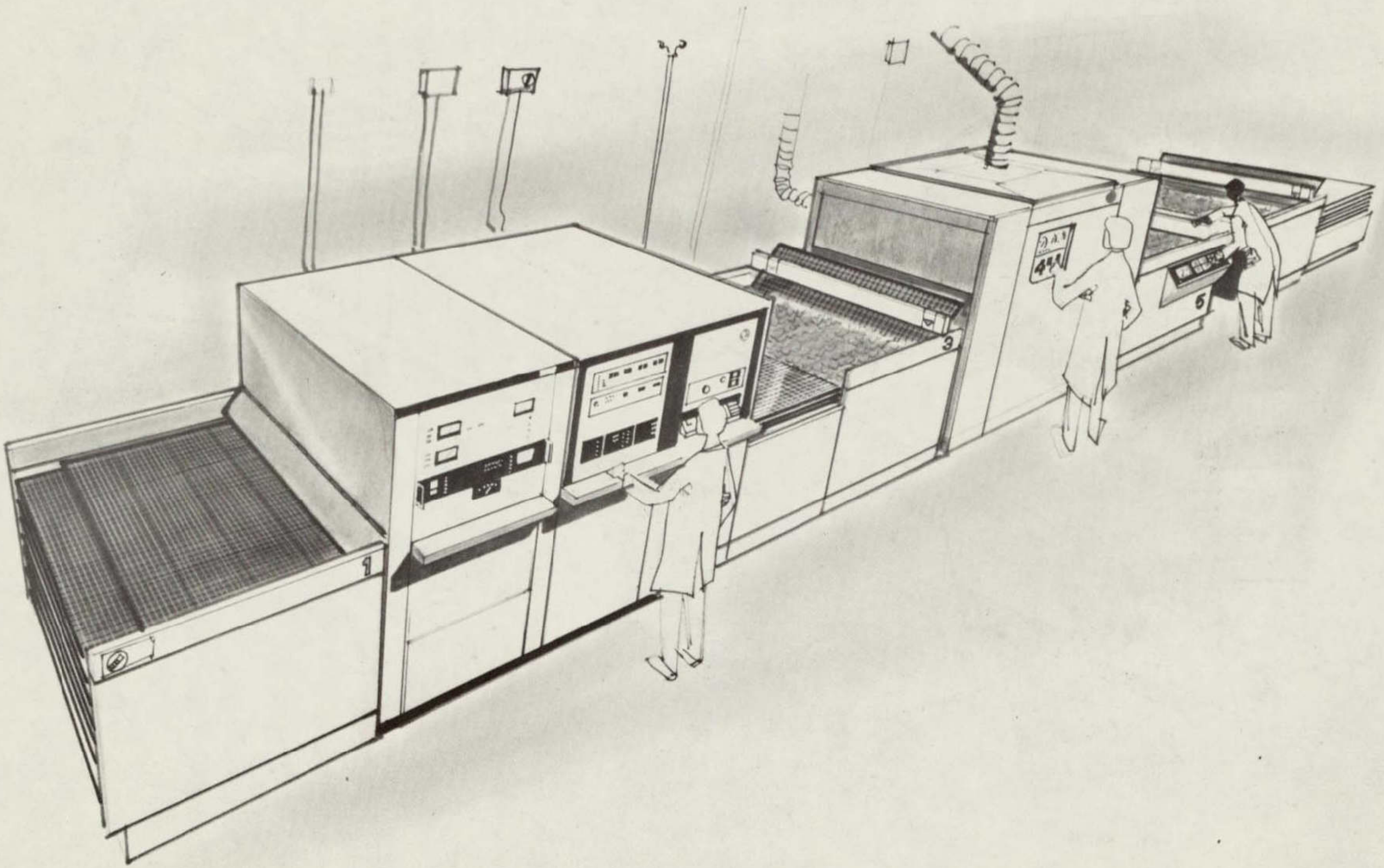

Fig. 36 Metallization process for the web solar cells.

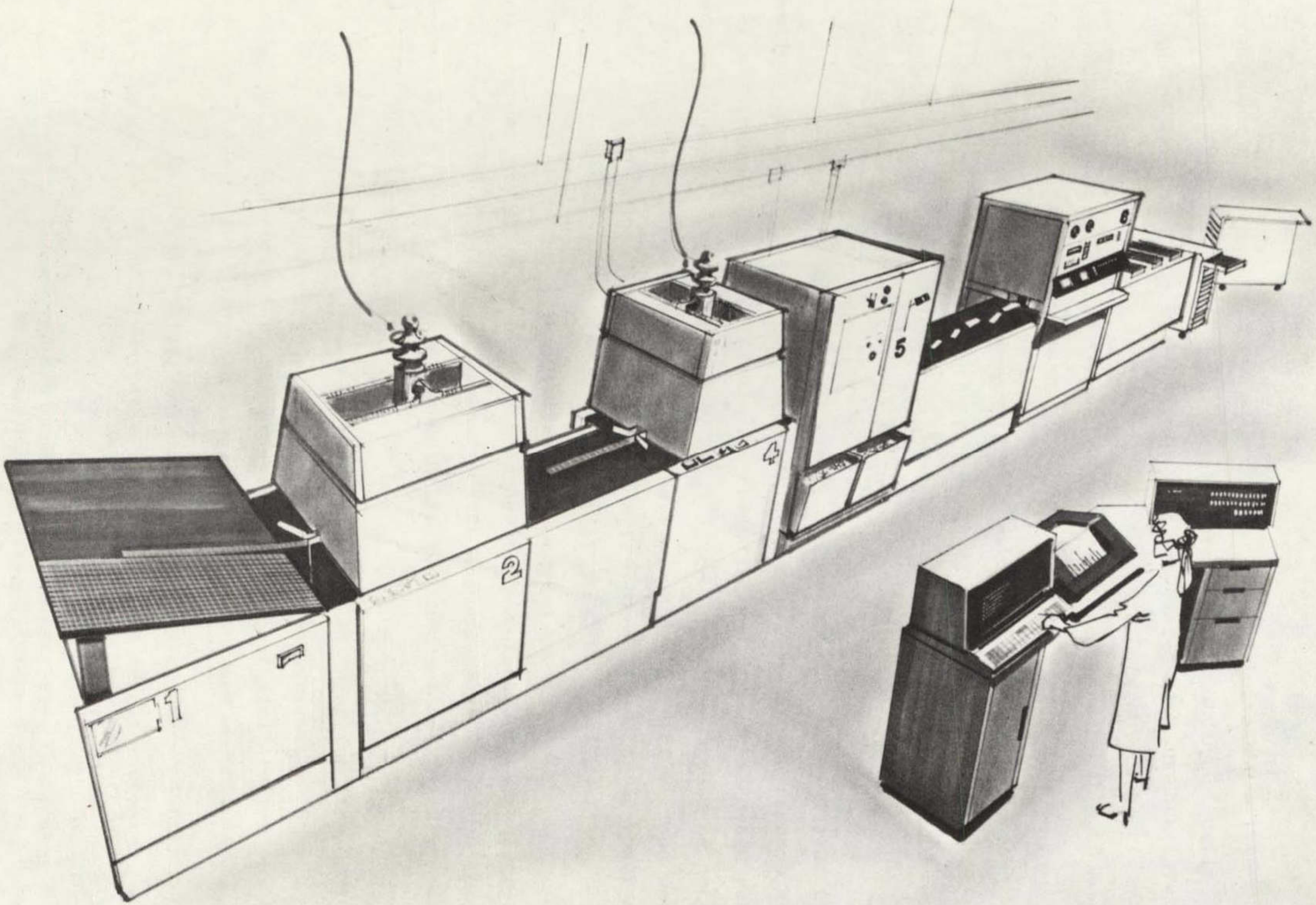

Fig. 37 Laser scribing process.

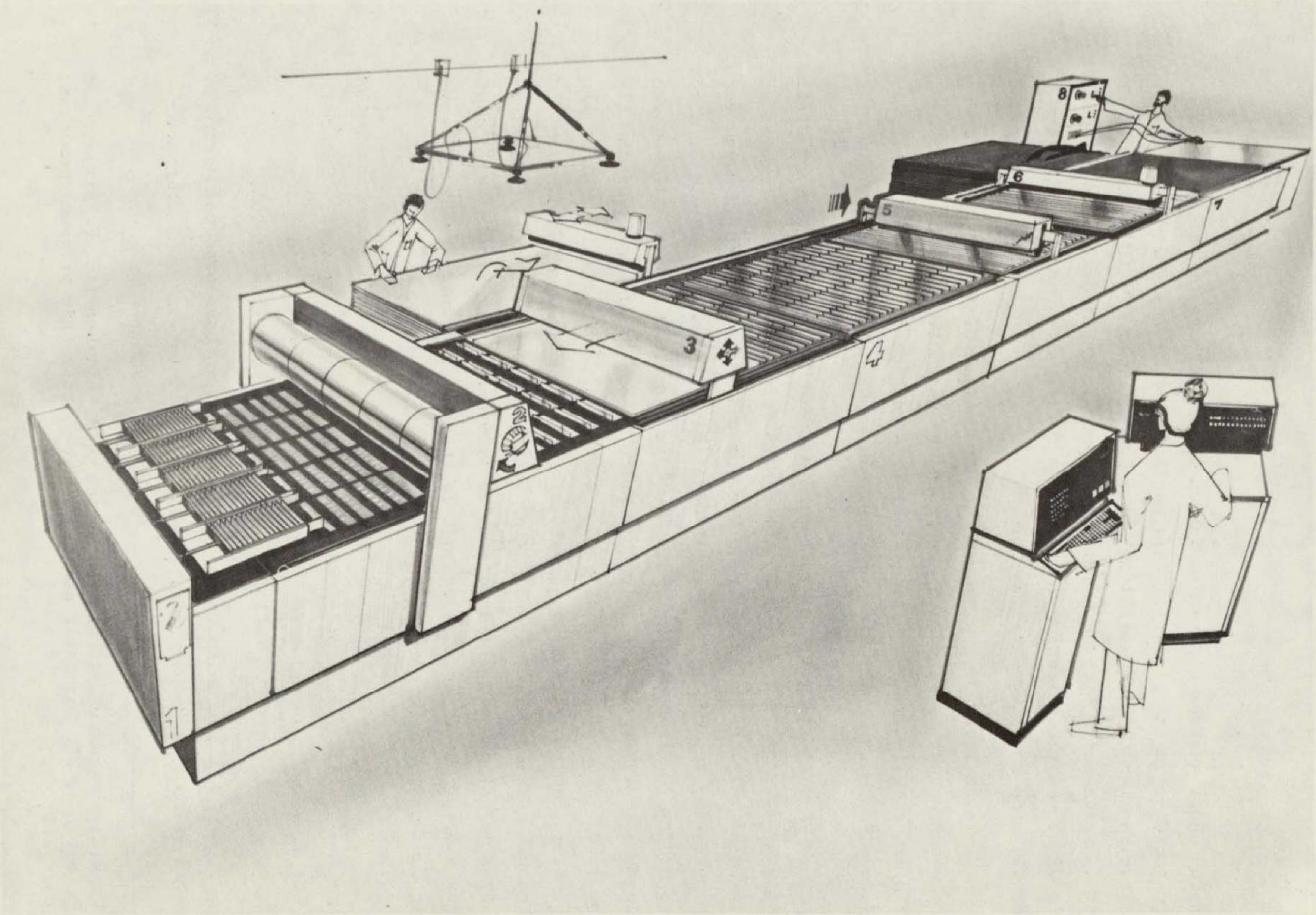

Fig. 38 The final processing step.

moves under another ultrasonic welder where the back of each cell is contacted with the Al foil. This would form a series string of cells along the length of the glass. The cells are coated with another layer of adhesive and a backing board (with appropriate external connections) is placed on the cells and removed to a curing area, and finally to a crating and shipping department.

In Table 33, we show a further outline of the sequence for this conceptual factory with the processes discussed in more detail. The sequence is divided into 44 sub-steps and for costing purposes, we do not include the dendritic web silicon growth station.

To the right of each process description is a listing of the various components required by the SAMICS Format A's. These figures are for a 25 MW/yr production rate. The commodities are given in usage per minute, and any costs given in 1978 $. Several features should be noted regarding the commodities. First we have assumed a cost of silicon web input at $0.17/watt (1975 $); this price is one of the goals of the LSA project. Second, we have assumed a cost of $50/lb for silane (1986 $). We feel that this price is justifiable (compared to the SAMICS cost account catalog price of ≃ $370/lb) since the manufacturers of polycrystalline silicon will be on stream in 1986 and silane should be in copious supply. Other cost inputs not in the cost account catalog are shown in our input to the program.

The data given in Table 33 were used as input into the SAMICS program* to determine costs and final selling price per watt. Subprocess 5.09 was inserted into the program as a no-cost yield buffer to enter a yield factor. In this case the yield was taken at 90%.

In the following pages (Table 34) we have produced pertinent parts of the SAMICS printout, as well as our input into the program.

(text continues on p. 166)

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*We wish to acknowledge the assistance of R. Chamberlain, P. Firnett and R. Aster of JPL for their assistance in getting this program running at our facility.

TABLE 33

DESIGN FOR A SOLAR PHOTOVOLTAIC FACTORY HAVING AN ANNUAL PRODUCTION CAPACITY OF 200 MW OF SOLAR ARRAYS PRODUCED FROM DENDRITIC SILICON WEB MATERIAL

The factory has an input of more than 40,000 cm^2 of dendritic web silicon per minute which goes through eight parallel production lines of 25 MW each. The production line will be divided into five sequential categories and each category will now be discussed in detail.

Cost data are given for a 25 MW/yr production into 1978 dollars. Labor figure indicates number of operators in place during running time.

JUNCTION FORMATION

Each of the eight identical production lines running in parallel handle 5000 cm^2 of sheet silicon a minute.

1.01 Load Buffer

Silicon in the form of dendritic web material 5 cm wide (not including dendritic web) is cut to three meter lengths and are loaded into a frame 50 strips of web wide. This frame will then be approximately 3m x 3m. The frame is then fed to the next station. At the rate of 5000 cm^2 a minute the speed of the frames would be one every 15 minutes through each station.

Labor	0.33 PY	Capital	$ 10,000
Floor Space	97 sq.ft.	Utilities	.5 KW

1.02 Silicon Clean

The whole frame containing the silicon is then lowered into a bath of solvent withdrawn and blown dry.

Labor	0.33 PY	Capital	$ 10,000
Floor Space	97 sq.ft.	Utilities	$ .5 KW

Commodities:
Acetone 0.063 ℓ/min

1.03 Oxide Deposition

Silane gas is blown at the junction side to form a deposited oxide.

Labor	0.17 PY	Capital	$300,000
Floor Space	97 sq.ft.	Utilities	1 KW

Commodities:
Silane 0.900 gm/min

1.04 Chemical Vapor Deposited Boron

Silicon is heated to 400°C and silane gas mixed with diborane is blown on the silicon surface to form a boron glass deposit.

Labor	0.17 PY	Capital	$300,000
Floor Space	97 sq.ft.	Utilities	1 KW

Commodities:

Nitrogen	.105 ℓ/min
Silane	2.724 gm/min
5% Diborane in H_2	.255 ℓ/min

1.05 Boron Drive

The rack containing the silicon is now fed through a furnace to heat the silicon to 960°C for twenty minutes.

Labor	0.5 PY	Capital	$380,000
Floor Space	97 sq.ft.	Utilities	8 KW

1.06 Buffer

At this stage the hot silicon sheet is allowed to cool to approximately room temperature for 15 minutes.

		Capital	$ 10,000
Floor Space	97 sq.ft.	Utilities	1 KW

1.07 Etch

A dip etch is used to etch off the oxide depositions from the front and back of the silicon.

Labor	0.5	Capital	$ 20,000
Floor Space	97 sq.ft.	Utilities	1 KW

Commodities:

HF 5.721 gm/min
Di H_2O 0.06 ℓ/min

1.08 Phosphorus Diffusion

The rack is fed into a furnace and heated up to 850°C in $POCl_3$ ambient for 35 minutes to produce an n^+ layer on the front side of the silicon. (Back side also diffused but not compensated.)

Labor	1.0 PY	Capital	$340,000
Floor Space	194 sq.ft.	Utilities	13 KW

Commodities:

$POCl_3$ 1.362 gm/min

1.09 Cooling Buffer

The silicon is allowed to cool to approximately room temperature in 15 minutes.

		Capital	$ 10,000
Floor Space	97 sq.ft.	Utilities	.5 KW

1.10 Etch

The silicon is dip etched to remove the oxides.

Labor	0.5 PY	Capital	$ 20,000
Floor Space	97 sq.ft.	Utilities	1 KW

Commodities:

HF 5.721 gm/min	
Di H_2O 0.6 ℓ/min	\$ 3,340/y

1.11 Buffer to Process 2

The silicon material has now finished the junction formation process and moves to the second process in the production line, "anti-reflection coating, photoresist coating and patterning."

Labor	0.5 PY	Capital	$ 10,000
Floor Space	97 sq.ft.	Utilities	$ 2,624

TOTALS FOR PROCESS
(Per Year in 1978$)

Labor	4 per shift
Floor Space (net)	1,160sqft
Capital	$1,410,000
Utilities	28 KW

2. ANTIREFLECTION AND PHOTORESIST COATING AND PATTERNING

2.01 Buffer

Labor	0.1 PY	Capital	$ 10,000
Floor Space	97 sq.ft.	Utilities	1 KW

2.02 Antireflection Dip and Drain

The cassette containing the diffused web silicon is lowered vertically into a bath of antireflection coating material having a controlled viscosity. It is then withdrawn at a constant rate and allowed to drain and dry for five minutes.

Labor	0.25 PY	Capital	$ 60,000
Floor Space	17 sq.ft.	Utilities	.5 KW

Commodities:

AR Dip	1.33×10^{-5} ℓ/min
Iso. Prop. Alcohol	6.3×10^{-3} ℓ/min

2.03 Bake and Cool

The silicon contained in the rack is moved to a baking oven at 400°C held there for five minutes and allowed to cool for a further 10 minutes.

Labor	0.25 PY	Capital	$ 20,000
Floor Space	48 sq.ft.	Utilities	4.5 KW

2.04 Photoresist and Drain

The rack containing the silicon is lowered into a bath of photoresist and withdrawn at a controlled rate and allowed to drain.

Labor	0.25 PY	Capital	$ 60,000
Floor Space	17.5 sq.ft.	Utilities	.5KW

Commodities:

Photoresist AZ-111	.021 ℓ/min

2.05 Bake

The rack of silicon passes into an oven held at 95°C and is baked for 15 minutes.

Labor	0.25 PY	Capital	$ 20,000
Floor Space	48 sq.ft.	Utilities	1 KW

2.06 Unload Cassette

Each of the 50 pieces of web material is fed one at a time into the next station.

Labor	.25 PY	Capital	$ 30,000
Floor Space	48 sq.ft.	Utilities	.5 KW

2.07 Expose Photoresist

Three meter lengths of web are fed in at the rate of one every 18 seconds and exposed with a pattern both on the front side and the back of the silicon. After exposure the strips of silicon are fed one at a time to the next station.

Labor	.25 PY	Capital	$ 50,000
Floor Space	65 sq.ft.	Utilities	2 KW

2.08 Load Cassette

As each piece of silicon is fed from the photoresist station it is taken and loaded flat into a cassette.

Labor	0.5 PY	Capital	$ 30,000
Floor Space	48 sq.ft.	Utilities	.5 KW

2.09 Dip Develop

The cassette containing 50 pieces of silicon is dipped into a bath of developer and withdrawn.

Labor	0.2 PY	Capital	$ 20,000
Floor Space	15 sq.ft.	Utilities	.5 KW

Commodities:
PR Developer 9×10^{-4} gal/min

2.10 Photoresist Clean Up

The cassette of silicon is now lowered into a bath of butyl acetate and withdrawn.

Labor	0.2 PY	Capital	$ 20,000
Floor Space	15 sq.ft.	Utilities	.5 KW

Commodities:
Butyl Acetate 6.3×10^{-4} ℓ/min

2.11 Antireflection Coating Etch

The cassette containing the silicon is lowered into a bath containing an etch to selectively remove the antireflection coating.

Labor	0.2 PY	Capital	$ 20,000
Floor Space	17 sq.ft.	Utilities	$ 328

Commodities:
HCl 2×10^{-7} ℓ/min
NH_4F 1.3×10^{-7} ℓ/min

2.12 Wash and Dry

The cassette is lowered into a bath of deionized water withdrawn and blown dry.

Labor	0.2 PY	Capital	$ 20,000
Floor Space	17 sq.ft.	Utilities	.5 KW

Commodities:
DI H_2O 0.6 ℓ/mm

TOTAL FOR PROCESS
(Per Year 1978 Dollars)

Labor	3 per shift
Floor Space (net)	355sqft
Capital	$390,000
Utilities	7 KW
Commodities	$195,982

3. METALLIZATION

3.01 Metal Deposition

The cassette containing the silicon is loaded into a vacuum system and pumped down in 15 minutes. A gate opens and the rack is then fed to a holding station for a further 15 minutes and then continuously fed through a deposition station where metal is deposited on both sides of the silicon. It is then fed through a second holding station where the whole rack is brought up to atmospheric pressure.

Labor	1.0 PY	Capital	$500,000
Floor Space	300 sq.ft.	Utilities	6 KW

Commodities:

Ti	0.045 gm/min
Pd	0.121 gm/min
Al	4 gm/min
Ni	0.027 gm/min

3.02 Buffer

Floor Space	97 sq.ft.	Capital	$ 10,000

3.03 Strip Photoresist

The rack containing the silicon strips is lowered into a bath of acetone and raised and blow dry. This rejects excess metal on silicon strip, leaving metal only in the grid area.

Labor	.5 PY	Capital	$ 20,000
Floor Space	129 sq.ft.	Utilities	2 KW

Commodities:

Acetone 2 cc/min

3.04 Sinter

The rack is placed in a belt furnace having a nitrogen gas curtain and sintered for five minutes at 400°C and allowed to cool down to room temperature.

Labor	.5 PY	Capital	$100,000
Floor Space	226 sq.ft.	Utilities	5 KW

Commodities:

N_2 132 ℓ/min (gas)
(Purchased as liquid)

3.05 Plating

The metal pattern on the silicon is thickened (on the front and back sides of the wafer) by electroplating.

Labor	.8 PY	Capital	$ 30,000
Floor Space	97 sq.ft.	Utilities	24 KW

Commodities:

Ag Bath 3.57 gm/min

3.06 Wash and Dry

The rack containing the silicon is lowered into a bath of water withdrawn and blown dry.

This ends the metallization step and the rack of silicon is now fed to the laser scribe operation.

Labor	.2 PY	Capital	$ 20,000
Floor Space	97 sq.ft.	Utilities	$ 2,624
Commodities:			
DI H_2O 0.6 ℓ/min			$ 3,340/yr

TOTALS FOR PROCESS
(Per year in 1978$)

Labor	3 per shift
Floor space (net)	946 sqf
Capital	$680,000
Utilities	33 KW
Commodities	$167,506

4. LASER SCRIBE

4.01 Unload

Each of the pieces of silicon is unloaded one at a time and fed to the next station.

Labor	.4 PY	Capital	$ 20,000
Floor Space	97 sq.ft.	Utilities	.5 KW

4.02 Longitudinal Laser Scribe

The single silicon strip is fed at 16 cm per second past the laser scribing head having two beams separated by 5 cm, thereby cutting off the dendrites. The silicon is then fed one piece at a time into the next station buffer.

Labor	.6 PY	Capital	$100,000
Floor Space	97 sq.ft.	Utilities	2 KW

4.03 Buffer

		Capital	$ 20,000
Floor Space	97 sq.ft.		

4.04 Transverse Laser Scribe

The silicon at this stage is face up in a rack and a laser moves across the direction of flow of the material and cuts the 3 meter pieces of silicon into 20 cm lengths.

Labor	.5 PY	Capital	$ 85,000
Floor Space	97 sq.ft.	Utilities	.5 KW

4.05 Break

Here the silicon material is bent so as to fracture it at those points where it is already being cut by the laser. The silicon in each rack now results in 750 solar cells. These are fed to the next station.

Labor	.5 PY	Capital	$ 30,000
Floor Space	97 sq.ft.	Utilities	.5 KW

4.06 Cassette Load, Test, Sort and Store

Here the 750 solar cells are loaded into cassettes after being tested and sorted.

Labor	1 PY	Capital	$ 30,000
Floor Space	65 sq.ft.	Utilities	1 KW

This then ends the laser scribe operation and the cassettes are then fed to the next operation, interconnections and encapsulation.

TOTALS FOR PROCESS (PER YEAR in 1978$)	Labor	3 per shift
	Floor space (net)	550 sq.ft.
	Capital	$285,000
	Utilities	4.5 KW

5. INTERCONNECTIONS AND ENCAPSULATION

5.01 Buffer

		Capital	$ 10,000
Floor Space	12 sq.ft.		

5.02 Interconnect Bonding

Aluminum foil cut from a roll in form of a comb is ultrasonically bonded to the sun side of a cell. The cells, complete with aluminum contacts are now loaded into a cassette.

Labor	1.0 PY	Capital	$ 100,000
Floor Space	43 sq.ft.	Utilities	1 KW
Commodities:			
AL foil 6.7 gm/min			

5.03 Cell Placement

A glass superstrate covered with RTV silicone adhesive is brought to this station and the cells are individually placed on the soft RTV with the sun side down towards the superstrate.

Labor	.5 PY	Capital	$ 50,000
Floor Space	65 sq.ft.	Utilites	1 KW
Commodities:			$ 65,720
RTV 615 silicone	6.8 gm/min		
Glass	5.3 ft^2/min		

5.04 Buffer and Cure

Here the RTV is allowed to cure.

		Capital	$ 20,000
Floor Space	65 sq.ft.		

5.05 Interconnect Second Bonding and Test

At this station the other end of the aluminum foil is ultrasonically bonded to the adjacent solar cell.

Labor	.5 PY	Capital	$ 70,000
Floor Space	86 sq.ft.	Utilities	1 KW

5.06 Cell Coating

A layer of RTV is coated over the back side of the solar cells.

Labor	.25 PY	Capital	$ 30,000
Floor Space	86 sq.ft.	Utilities	.5 KW
Commodities:			
RTV 108 Silicone	6.8 gm/min		
			$ 18,960

5.07 Back Attachment

A fiberboard is fed in at this stage and pressed onto the RTV coated in the previous operation.

Labor	.5 PY	Capital	$ 20,000
Floor Space	86 sq.ft.	Utilities	.5 KW
Commodities			
Phenolic board	5.3 ft^2/min		

5.08 Buffer Cure and Final Test

The RTV is allowed to cure at this stage and the panel is now tested.

Labor	.25 PY	Capital	$ 30,000
Floor Space	86 sq.ft.	Utilities	1 KW

5.09 Yield Buffer

No Costs

5.10 Crating and Shipping

The panel is now crated and moved to the Shipping Department.

Labor	1.0 PY	Capital	$ 10,000
Floor Space	110 sq.ft.		

TOTALS FOR PROCESS
(per year, 1978$)

Labor	4 Per Shift
Floor space (net)	640sqft
Capital	$340,000
Utilities	$ 13,120
Commodities	$1,247,740

TOTALS FOR PROCESS SEQUENCE

(25 MW)

	1978 Dollars
Labor (18 per shift)	$ 983,600
Capital	$3,105,000
Utilities	$ 216,480
Commodities	$3,044,332
Floor Space (net) 3651 sq.ft.	

TABLE 34

SAMICS Printout for
25 MW Processing Line

```
AVAILABLE COMPANIES (IN CORE)


   COMPANY: WESTCO, PHOTOVOLTAIC PANEL MANUFACTURER

DESCRIPTIVE.NAME IS
"PHOTOVOLTAIC PANEL MANUFACTURER"
THE FOLLOWING PRODUCTS ARE MANUFACTURED BY THIS COMPANY:
 CRATEMOD *
PERCENT.OF.CAPACITY =   100.0000
LEVERAGE =      1.2000
DEBT.INTEREST.RATE =      9.2500
OTHER.TAX.RATE =      2.0000
INSURANCE.RATE =      4.0000
FACILITY.LIFE =    40.0000
RATE.OF.RETURN.ON.EQUITY =     20.0000
MISC.EXPENSE.PERCENTAGE.OF.REVENUE =      3.0000
MISC.EXPENSE.PERCENTAGE.OF.OPERATING.EXPENSE =      4.0000
MISC.EXPENSE.PERCENTAGE.OF.BOOK.VALUE =      0.
FACILITIES.TAX.DEPRECIATION.METHOD = DDB
FACILITIES.BOOK.DEPRECIATION.METHOD = SL
FACILITIES.INFLATION.RATE.TABLE =
  1975.0000     7.0000  *
RAW.MATERIALS.INVENTORY.TIME =       .0400
PROCESSING.TIME.MULTIPLIER =     1.0000
FINISHED.GOODS.INVENTORY.TIME =      .0400
ACCOUNTS.RECEIVABLE.TURNOVER.TIME =      .0100
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
RUN-TIME OPTIONS WERE CONTROLLED BY THE IN-CORE
RUN.CONTROL: URD2, RUN CONTROL FOR ARRAY

DESCRIPTIVE.NAME IS
"RUN CONTROL FOR ARRAY"
INDUSTRY.SIZE.RANGE:
  25000000.00 *
QUANTITY.RECALCULATION.FLAG IS
INTEGRAL.MACHINES.FLAG IS ON
STEADY.STATE.FLAG IS OFF
LINE.LENGTH =  132
PROMPT.LEVEL.CODE =   1
MAX.NUMBER.OF.SCALE.ITERATIONS =  200
MAX.NUMBER.OF.PRICE.ITERATIONS =   20
EPSILON =     .00100000
REPORT.CHOICES:
          1          1          1          1          1          1
          1          1          1          1          1          1
          1          1          2          2          1          1
          1          0          1          1          0          1
          1          1          1 *
REPORT.OUTPUT.FILE =  12 (FILE)
```

TABLE 34

```
SAMIS III - RELEASE 1        INDUSTRY CONFIGURATION

INDUSTRY: WESTCORP, SILICON SOLAR PHOTOVOLTAIC POWER SYSTEMS

MANUFACTURE OF SOLAR ELECTRIC POWER SYSTEMS, EXPRESSED IN WATTS/YEAR
                      IS PROVIDED BY
CRATEMOD, CRATED PANELS, 10/CRATE, EXPRESSED IN CRATES CONTAINING 10 EACH 240 WATT PANELS/YEAR
                         OF WHICH
100.00% IS MADE BY WESTCO, PHOTOVOLTAIC PANEL MANUFACTURER

COMPANY: WESTCO                    PRODUCTS: CRATEMOD
REQUIRED PRODUCT: (NONE)
```

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SAMIS III - RELEASE 1        INDUSTRY SIZE INDEX =  1

INDUSTRY: WESTCORP, SILICON SOLAR PHOTOVOLTAIC POWER SYSTEMS

INDUSTRY OBJECTIVE: MANUFACTURE OF SOLAR ELECTRIC POWER SYSTEMS
FINAL PRODUCT: CRATEMOD, CRATED PANELS, 10/CRATE
PRODUCING 2400.00 WATTS PER CRATES CONTAINING 10 EACH 240 WATT PANELS

QUANTITY:   25000000. =  2.5E+07 WATTS/YEAR =>  1.042E+04 CRATES CONTAINING 10 EACH 240 WATT PANELS/YEAR

PRICE:    .5598 $(1975)/WATTS =>  1343.408 $(1975)/CRATES CONTAINING 10 EACH 240 WATT PANELS


   COMPANY: WESTCO, PHOTOVOLTAIC PANEL MANUFACTURER
   PRODUCTS: CRATEMOD
   QUANTITY: 1.042E+04
   PRICE:    1343.408
             $(1975)/
             CRATES
   ENERGY.PAYBACK TIME =   .022 YEARS
   COMPANY MARKUP =   1.729 TIMES (DIRECT EXPENSES PLUS EXTERNAL PRODUCT COSTS)
   COMPANY PROFIT =   2.4% OF PRICE

      CAPITAL VALUES
                 --------- IN $(1986)---------     --------- IN $(1975)---------
                  INITIAL      BOOK   TAXABLE       INITIAL      BOOK   TAXABLE
      FACILITIES 1451954.   307649.   261255.       766421.   162794.   137905.
      EQUIPMENT  5699864.  1958796.   904706.      3006068.  1033560.   477554.
      WORKING    1505085.  1505085.  1505085.       794469.   794469.   794469.
      LAND         46494.    46494.    46494.        24542.    24542.    24542.
                 --------- --------- ---------     --------- --------- ---------
         TOTAL   8698401.  3818027.  2717543.      4591494.  2015364.  1434468.

      FINANCIAL PARAMETERS
       COST OF     RATE OF RETURN      DEBT         LEVERAGE       INCOME TAX
       CAPITAL        ON EQUITY    INTEREST RATE  (TOTAL/EQUITY)      RATE
     -CALCULATED-      -INPUT-        -INPUT-        -INPUT-      -CALCULATED-
        17.44%         20.00%          9.25%          1.200           49.14%

      TIME PARAMETERS
      CONSTRUCTION LEAD TIME = 2.00 YEARS, STARTUP PERIOD = 1.00 YEARS
      RAW MATERIAL INVENTORY TIME (INPUT)       =  .040 YEARS (  14.6 DAYS)
      PROCESSING TIME (CALCULATED)              =  .001 YEARS ( 663.5 MINUTES)
         (MULTIPLIED BY 1.0 FOR WORKING CAPITAL CALCULATION)
      FINISHED GOODS INVENTORY TIME (INPUT)     =  .040 YEARS (  14.6 DAYS)
      ACCOUNTS RECEIVABLE TURNOVER TIME (INPUT) =  .010 YEARS (   3.7 DAYS)

         ALL COMPANY EXPENSES ARE IN $(1986)
         COMPANY DIRECT EXPENSES               15333925.
            COMPANY DIRECT LABOR EXPENSES                  1666417.
            COMPANY DIRECT MATERIALS AND SUPPLIES         13389881.
            COMPANY BYPRODUCT EXPENSES                         356.
            COMPANY DIRECT UTILITIES EXPENSES               277275.

         COMPANY INDIRECT EXPENSES              1143433.
```

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PROCESS: 1.01      , LOAD BUFFER, LOAD STARTING SILICON WEB INTO 3M X 3M FRAME
PRODUCT: RAWWEB    , UNCLEANED STARTING WEB
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: BUF1.01, LOAD BUFFER
      COST:   10000. $(1976)     INSTALLATION:    1000. $(1976)
      SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS

   QUANTITY 2.315E+09 CM2/YEAR AT      .0031 $(1975)/CM2
   NUMBER OF 1.01 MACHINES =  1.000, OF WHICH  .068 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                                9314758.
      DIRECT LABOR EXPENSES                                 25275.
      DIRECT MATERIALS AND SUPPLIES                       9289283.
      BYPRODUCT EXPENSES                                        0.
      DIRECT UTILITIES EXPENSES                               200.

   INDIRECT EXPENSES                                22182.
      INDIRECT LABOR EXPENSES                               19194.
      INDIRECT MATERIALS AND SUPPLIES                        2633.
      INDIRECT UTILITIES EXPENSES                             355.

   BYPRODUCT INCOME                          (          0.)

   CAPITAL EXPENSES                               1744991.
      EQUIPMENT REPLACEMENT                                  3091.
      FACILITIES REPLACEMENT                                  660.
      AMORTIZED ONE-TIME COSTS                            1563692.
      INTEREST ON DEBT                                      12221.
      RETURN ON EQUITY                                     132122.
      NON-INCOME TAXES                                        160.
      INSURANCE PREMIUMS                                    33045.

   INCOME TAXES                                   1905383.

   MISCELLANEOUS                                   754059.

   EXTERNAL PRODUCT COST                               0.
   INTERNAL (IMPLICIT) PRODUCT COST                    0.

   VALUE ADDED:    .006 $(1986)/CM2 =    .550 $(1986)/WATTS
   PROFIT =  1.0% OF PRICE
   MARKUP = 1.475 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUCT COSTS)
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS   .000 YEARS

   TO PRODUCE 2.315E+09 CM2/YEAR, THE 1.01
   PROCESS REQUIRES:

      ALL DOLLARS ARE IN $(1986)

      DIRECT REQUIREMENTS
QUANTITY      PRICE      COST   REFERENT  DESCRIPTIVE NAME        QUANTITY      PRICE     COST   REFERENT  DESCRIPTIVE NAME
 9.700E+01     83.79     8127. A2064D    MANUFACTURING SPACE (T
```

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      COMPANY INDIRECT LABOR EXPENSES             986956.
      COMPANY INDIRECT MATERIALS AND SUPPLIES     136184.
      COMPANY INDIRECT UTILITIES EXPENSES          20297.

   COMPANY BYPRODUCT INCOME         (        0.)

   COMPANY CAPITAL EXPENSES            4902129.
      COMPANY EQUIPMENT REPLACEMENT               791072.
      COMPANY FACILITIES REPLACEMENT               36299.
      COMPANY AMORTIZED ONE-TIME COSTS           3017051.
      COMPANY INTEREST ON DEBT                     58267.
      COMPANY RETURN ON EQUITY                    629912.
      COMPANY NON-INCOME TAXES                     23454.
      COMPANY INSURANCE PREMIUMS                  348076.

   COMPANY INCOME TAXES                3676323.

   COMPANY MISCELLANEOUS               1454911.

   COMPANY EXTERNAL PRODUCT COST             0.

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1.445E+00  17487.27     25275. B3064D     GENERAL ASSEMBLER (FLE

3.704E+03       .05       200. C1032B     ELECTRICITY

2.315E+09       .00   9289283. E-WEB001   SILICON WEB


            INDIRECT REQUIREMENTS
QUANTITY      PRICE      COST   REFERENT  DESCRIPTIVE NAME            QUANTITY      PRICE.       COST   REFERENT  DESCRIPTIVE NAME
 7.806E+01      57.46     4485. A2128I    OFFICE SPACE-ADMINISTR       3.062E+01     129.32       3960. A2256I    TOILET AND LOCKER ROOM
 6.447E+01      28.14     1814. A2224I    SOLVENT AND CHEMICAL S       3.137E+01      47.98       1505. A2040I    EXTERIOR WALLS
 1.000E+01     108.25     1083. A2016I    CAFETERIA AND LUNCHROO       1.081E+03        .73        789. A1080I    LAND
 3.22[illegible]E+00     163.29      527. A1112I    ELECTRICAL SERVICE FAC       3.084E+02       1.68        517. A1096I    LANDSCAPING AND IRRIGA
 1.4[illegible]E+01      34.47      511. A2112I    MECHANICAL EQUIPMENT R       1.370E+01      36.75        503. A2160I    PASSAGES AND CORRIDORS
 3.8[illegible]E+00     105.[illegible]      410. A2024I    COMPUTER ROOM                1.387E+02       2.00        397. A1368I    WALKS, CURBS AND GUTTE
 2.397E+02       1.42      341. A1064I    INDUSTRIAL WASTE CLARI       2.192E+02       1.27        278. A1256I    PAVING (HEAVY DUTY) FO
 2.206E+02        .86      189. A1272I    PAVING (LIGHT DUTY) FO       8.273E+01       2.00        165. A1352I    SITE LIGHTING
 7.396E+00      19.21      142. A2208I    SHIPPING AND RECEIVING       1.142E+01       9.00        103. A1016I    FENCING
 2.425E+00      38.98       95. A2272I    WAREHOUSE SPACE              1.081E+03        .07         77. A1048I    GRADING
 1.416E+00      49.98       71. A2144I    OFFICE SPACE-MANUFACTU       1.886E+00      37.15         70. A2032I    ELECTRICAL EQUIPMENT R
 3.394E+01       2.00       68. A1304I    SIGNS AND FLAGPOLE           1.322E+00      40.18         53. A2240I    TELEPHONE EQUIPMENT RO
 6.735E-01      76.96       52. A2048I    HEALTH SERVICE FACILIT       7.336E+00       7.00         51. A1192I    SANITARY SEWERS
 8.431E-01      48.98       41. A2192I    QUALITY CONTROL LABORA       5.515E+00       7.00         39. A1208I    STORM DRAINS
 1.292E+00      28.33       37. A1224I    TELEPHONE LINES              6.281E-01      23.99         15. A1320I    STORAGE AREA WALLS
 1.455E+00       3.00        4. A1336I    STORAGE SPACE                1.110E-01      12.99          1. A1240I    WATER SERVICE FACILITI
 [illegible]       1.48         . A2[illegible]I    AIR CONDITIONING FACIL       1.543E-06        .14           . A205[illegible]I    HEATING FACILITIES
 [illegible]        .26         . A1144I    NATURAL GAS SERVICE FA       1.676E-09       4.00           . A226[illegible]I    VENTILATION FACILITIES
 4.611E-09        .20         . A1128I    FUEL OIL SERVICE FACIL       2.337E+02       0.          0. A3048I    TOTAL SUPPORT FLOOR SP.
 3.306E+02       0.        0. A3016I    TOTAL FACTORY FLOOR SP       9.700E+01       0.          0. A3032I    TOTAL MANUFACTURING FL

 1.204E-01   30224.91     3640. B3320I    ASSEMBLY FOREMAN             1.445E-02   43955.66        635. B1448I    SUPERVISOR, TRAINING
 1.445E-02   43955.66      635. B1128I    EMPLOYMENT INTERVIEWER       1.445E-02   43178.45        624. B2208I    PURCHASING AGENT
 2.301E-02   24503.77      564. B1444I    SECRETARY III (UPPER M       2.891E-02   17832.70        515. B1352I    PERSONNEL CLERK
 1.336E-02   36701.67      491. B3336I    ASSEMBLY OPERATIONS SU       2.239E-02   21049.49        471. B1432I    SECRETARY I (LOWER MAN
 1.445E-02   30224.91      437. B2008I    ACCOUNTANT                   7.227E-03   50734.68        367. B3240P    MECHANICAL ENGINEER
 7.227E-03   50734.68      367. B3208P    ELECTRONICS ENGINEER         7.227E-03   50734.68        367. B1416I    SAFETY ENGINEER
 7.227E-03   49655.21      359. B3272B    QUALITY CONTROL ENGINE       7.227E-03   49655.21        359. B3256B    PRODUCTION PLANNER
 7.227E-03   49655.21      359. B3224B    INDUSTRIAL ENGINEER          1.671E-03  150632.75        319. B1384I    PRESIDENT
 1.655E-02   18998.51      314. B1272I    MAINTENANCE MAN (PLANT       1.445E-02   21589.22        312. B2032I    BOOKKEEPER
 7.227E-03   43178.45      312. B3288I    RESEARCH ENGINEER (ELE       1.445E-02   21157.43        306. B2160I    PROCUREMENT CLERK
 1.286E-02   22452.79      289. B1440I    SECRETARY II (MIDDLE M       2.501E-03  112263.94        281. B2272I    VICE PRESIDENT, FINANC
 9.636E-03   27854.09      268. B1336I    NURSE, PROFESSIONAL (G       3.413E-03   76209.94        260. B2048I    CONTROLLER AND CHIEF A
 1.445E-02   17832.70      258. B2144I    PAYROLL CLERK                1.445E-02   17832.70        258. B1240I    MAIL CLERK
 1.445E-02   17832.70      258. B1048I    CLERK GENERAL OFFICE (       2.237E-03  113343.44        254. B3304I    VICE PRESIDENT, MANUFA
 1.324E-02   18998.50      251. B1192I    JANITOR                      4.818E-03   51814.14        250. B3128B    CHEMICAL ENGINEER
 2.143E-03  113343.37      243. B1464I    VICE PRESIDENT, ADMINI       4.589E-03   50734.68        233. B3496I    PRODUCTION SUPERINTEND
 3.212E-03   71158.06      229. B1080I    DIRECTOR OFFICE ADMINI       4.818E-03   43178.45        208. B3352I    ASSISTANT PRODUCTION S
 4.818E-03   42098.96      203. B2240I    SYSTEMS ANALYST              4.818E-03   42098.96        203. B2096I    FINANCIAL ANALYST
 7.227E-03   27418.31      198. B3192I    DRAFTSMAN, MECHANICAL        2.409E-03   81175.44        196. B1016I    ADMINISTRATIVE ASSISTA
 2.610E-03   69085.50      194. B3144I    DIRECTOR, MANUFACTURIN       4.818E-03   38212.90        184. B2176I    PROGRAMMER, BUSINESS
 7.227E-03   23748.14      172. B3216I    ENGINEERING AIDE             2.409E-03   71158.06        171. B2256I    TREASURER
 2.409E-03   71158.06      171. B1112I    DIRECTOR PUBLIC RELATI       2.409E-03   71156.06        171. B1064I    DIRECTOR INDUSTRIAL RE
 1.103E-02   15328.34      169. B1160I    GUARD (SECURITY)             2.509E-03   64767.68        163. B2192I    PURCHASING ADMINISTRAT
 2.810E-03   57211.45      161. B1304I    MANAGER, PERSONNEL           8.269E-03   18998.51        157. B1144I    GROUNDSKEEPER
 2.409E-03   50734.68      122. B1208I    LAWYER, CORPORATE (BUS       2.007E-03   57211.45        115. B1288I    MANAGER, COMPENSATION,
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2.409E-03  45769.16     110. B1032I   AUDITOR, INTERNAL          4.318E-03  22884.57       110. B2080I   DIGITAL COMPUTER OPERA
2.409E-03  44473.80     107. B2016I   ACCOUNTING SUPERVISOR      3.171E-03  33679.19       107. B1256I   MAINTENANCE FOREMAN (P
1.673E-03  57211.45      96. B2128I   MANAGER, DATA PROCESSI     4.818E-03  18998.51        92. B2112I   KEY PUNCH OPERATOR
1.204E-03  69085.50      83. B3160I   DIRECTOR, QUALITY CONT     1.204E-03  60449.84        73. B3176I   DIRECTOR, RESEARCH AND
2.409E-03  26986.53      65. B1368I   PERSONNEL CLERK, SUPER     2.409E-03  22884.57        55. B1400I   RECEPTIONIST
8.350E-04  57211.45      48. B1320I   MANAGER, SECURITY AND      1.204E-03  37781.14        46. B2224I   PURCHASING SUPERVISOR
1.838E-03  23748.14      44. B1176I   GUARD CHIEF                1.379E-03  29145.46        40. B3448I   MECHANICAL MAINTENANCE
8.030E-04  38212.93      31. B2064I   DATA PROCESSING SUPERV     1.204E-03  22884.57        28. B1224I   LEGAL SECRETARY
2.783E-04  71158.06      20. B1096I   DIRECTOR.PLANT MAINTEN     2.020E+00      0.            0. B5032I   TOTAL PERSONNEL
5.751E-01      0.         0. B5048I   TOTAL STAFF PERSONNEL      1.445E+00      0.            0. B5016I   TOTAL DIRECT PERSONNEL

2.747E+03       .05     148. C1032B   ELECTRICITY                5.515E+03       .01        71. C1016B   DOMESTIC WATER
3.362E-01    204.96      69. C1112I   TELEPHONE SERVICE          4.477E+02       .14        61. C2144B   SOLID WASTE MATERIAL
1.025E+03       .01       6. C2064B   SEWAGE AND PROCESS WAS     1.239E-05       .03          . C1064B   NATURAL GAS
9.225E-08       .88        . C1048B   FUEL OIL                   3.893E+04      0.            0. C2160I   LIGHTING
8.326E-04      0.         0. C2128B   VENTILATION                1.278E-02      0.            0. C2112B   HEATING
3.876E-03      0.         0. C2096B   AIR CONDITIONING           5.513E+03      0.            0. C2080B   WATER SUPPLY
1.212E+00      0.         0. C2016I   CAFETERIA SERVICE          7.790E-02      0.            0. C2048B   POWER SUPPLY

4.477E+03       .00      13. D1096B   SOLID WASTE                5.513E+03       .00         4. D1048B   POLLUTED WATER:
2.686E+03       .00       3. D1080I   SEWAGE WASTE.

1.010E+03      2.17    2194. E1432I   OFFICE SUPPLIES            2.020E+02      2.17       439. E1256B   EXPENDABLE TOOLS

1.239E-05      0.         0. F1048B   NATURAL GAS,               1.233E-08      0.            0. F1032B   FUEL OIL.
5.513E+03      0.         0. F1080B   WATER                      6.450E+03      0.            0. F1016B   ENERGY

     THIS COMPANY, WESTCO, HAS THE FOLLOWING (ANNUAL) REQUIREMENTS:

        ALL DOLLARS ARE IN $(1980)

        DIRECT REQUIREMENTS
QUANTITY      PRICE     COST    REFERENT  DESCRIPTIVE NAME           QUANTITY        PRICE      COST   REFERENT  DESCRIPTIVE NAME
3.672E+05     83.79   307668. A2064D   MANUFACTURING SPACE (T

4.266E+01  21697.17   925596. B3672D   CHEMICAL OPERATOR II       1.577E+01  23748.14     374450. B3704D   ELECTRONICS TECHNICIAN
8.760E+00  25475.27   223157. B3736D   MAINTENANCE MECHANIC I     4.380E+00  21157.44      92667. B3656D   PACKAGER MACHINE
2.891E+00  17487.27    50551. B3064D   GENERAL ASSEMBLER (ELE

2.481E+03     89.20   221353. C1080D   NITROGEN (LIQUID)          7.952E+05       .05      42923. C1032B   ELECTRICITY
2.870E+04       .41    11649. C1144D   WATER - DEIONIZED          2.995E+05       .00       1146. C1128D   WATER - COOLING
3.241E+04       .01      204. C2064B   SEWAGE AND PROCESS WAS

1.451E+04       .02      356. D1032D   POISONOUS ACID             2.778E+08      0.            0. D1016B   FUMES

2.315E+09       .00  9289283. E-WEB001 SILICON WEB                2.593E+06       .43    1121999. E-TGLAS  TOP GLASS OF MODULE
2.593E+06       .41  1070999. E-PHENBO PHENOLIC BOARD FOR BAC     1.653E+06       .35     579366. E1592D   SILVER
1.713E+03    220.32   377400. E-AZ111  POSITIVE PHOTO RESIST      1.389E+06       .17     240113. E1180D   CRATES, WOODEN
1.991E+03    118.03   234964. E-PALLAD PALLADIUM METAL            6.944E+03     19.20     133329. E1560D   RTV 615 (SILICONE)
1.167E+05      1.09   127553. E1328D   HYDROFLORIC ACID           1.852E+03     54.30     100550. E1584D   SILANE 100%
6.944E+03      4.93    34211. E1552D   RTV 108                    7.949E+04       .37      29085. E1032D   ACETONE
1.389E+03     20.14    27972. E1504D   PCC1                       3.935E+03      1.74       6837. E1206D   DIBORANE 5% IN HYDROGE
4.074E+03      1.27     5162. E1096D   ALUMINUM                   1.852E+03      2.14       3971. E-303A   AZ111 DEVELOPER
4.630E+01     53.69     2486. E1704D   TITANIUM                   7.685E+02      2.86       2198. E1352D   ISOPROPYL ALCOHOL
5.463E+02      2.17     1186. E1104D   ALUMINUM RIBBON            6.019E+00    196.71       1184. E-ARSOL  ANTI REFLECTION COATIN
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2.731E+01      1.48       40. E-NICKEL  NICKEL METAL FOR PLATI   1.949F-01      1.76         . E1320D    HYDROCHLORIC ACID

           INDIRECT REQUIREMENTS
QUANTITY      PRICE      COST   REFERENT  DESCRIPTIVE NAME         QUANTITY       PRICE      COST   REFERENT  DESCRIPTIVE NAME
 4.079E+03     57.46    234349. A2128I    OFFICE SPACE-ADMINISTR   1.584E+03     129.32   204849. A2256I    TOILET AND LOCKER ROOM
 2.809E+03     42.80    120058. A2176I    PLANT MAINTENANCE AND    4.222F+03      28.14   118795. A2224I    SOLVENT AND CHEMICAL S
 1.849E+03     47.98     88671. A2640I    EXTERIOR WALLS           4.785E+02     163.29    78133. A1112I    ELECTRICAL SERVICE FAC
 5.173E+02    108.25     55994. A2016I    CAFETERIA AND LUNCHROO   6.367E+04        .73    46494. A1080I    LAND
 1.974E+04      1.68     33101. A1096I    LANDSCAPING AND IRRIGA   7.674E+02      34.47    26449. A2112I    MECHANICAL EQUIPMENT R
 1.171E+04      2.00     23407. A1368I    WALKS, CURBS AND GUTTE   1.570E+04       1.42    22343. A1064I    INDUSTRIAL WASTE CLARI
 2.015E+02    105.25     21208. A2024I    COMPUTER ROOM            5.760E+02      36.75    21168. A2160I    PASSAGES AND CORRIDORS
 1.291E+04      1.27     16406. A1256I    PAVING (HEAVY DUTY) FO   2.798E+02      37.15    10395. A2032I    ELECTRICAL EQUIPMENT R
 1.144E+04       .86      9797. A1272I    PAVING (LIGHT DUTY) FO   4.875E+03       2.00     9745. A1352I    SITE LIGHTING
 4.709E+02     19.21      9046. A2208I    SHIPPING AND RECEIVING   6.729E+02       9.00     6053. A1016I    FENCING
 6.367E+04       .07      4557. A1048I    GRADING                  2.000E+03       2.00     3998. A1304I    SIGNS AND FLAGPOLE
 7.297E+01     49.98      3647. A2144I    OFFICE SPACE-MANUFACTU   9.180E+01      38.98     3578. A2272I    WAREHOUSE SPACE
 4.064E+02      7.00      2844. A1192I    SANITARY SEWERS          6.865E+01      40.18     2758. A2240I    TELEPHONE EQUIPMENT RO
 3.483E+01     76.96      2681. A2048I    HEALTH SERVICE FACILIT   2.481E+03       1.04     2586. A1160I    LIQUID NITROGEN SERVIC
 3.250E+02      7.00      2274. A1208I    STORM DRAINS             4.343F+01      48.98     2127. A2192I    QUALITY CONTROL LABORA
 7.192E+01     28.33      2038. A1224I    TELEPHONE LINES          3.701E+01      23.99      888. A1320I    STORAGE AREA WALLS
 8.562E+01      3.00       257. A1336I    STORAGE SPACE            6.969E+00      12.99       91. A1240I    WATER SERVICE FACILITI
 1.344E-01      1.48          . A2008I    AIR CONDITIONING FACIL   9.092E-05        .14         . A2056I    HEATING FACILITIES
 3.175E-05       .20          . A1144I    NATURAL GAS SERVICE FA   9.876E-08       4.00         . A2263I    VENTILATION FACILITIES
 2.363F-07       .20          . A1128I    FUEL OIL SERVICE FACIL   0.000F+00       0.           0. A1288I    SECURITY CONTROL FACIL
 0.000E+00      0.           0. A1032I    FIRE LOOP AND SECONDAR   1.581F+04       0.           0. A3048I    TOTAL SUPPORT FLOOR SP
 1.948E+04      0.           0. [illegible] TOTAL FACTORY FLOOR SP 3.672E+03       0.           0. [illegible] TOTAL MANUFACTURING FL

 [illegible]  [illegible] [illegible] [illegible] CHEMICAL PROCESS FOREM 1.314E+00  29145.45  38296. B3384I  ELECTRONICS MAINTENANC
 7.446E-01  43955.66     32728. B1448I    SUPERVISOR, TRAINING     7.446E-01   43955.66    32728. B1128I    EMPLOYMENT INTERVIEWER
 7.446E-01  43178.45     32150. B2208I    PURCHASING AGENT         1.186F+00   24503.77    29053. B1444I    SECRETARY III (UPPER M
 1.489E+00  17832.70     26556. B1752I    PERSONNEL CLERK          1.155F+00   21049.49    24312. B1432I    SECRETARY I (LOWER MAN
 8.112E-01  29145.45     23644. B3448I    MECHANICAL MAINTENANCE   7.446E-01   30224.91    22505. B2008I    ACCOUNTANT
 3.723E-01  50734.68     18888. B3240I    MECHANICAL ENGINEER      3.723E-01   50734.68    18888. B3208R    ELECTRONICS ENGINEER
 3.723E-01  50734.68     18888. B1416I    SAFETY ENGINEER          9.750E-01   18998.51    18523. B1272I    MAINTENANCE MAN (PLANT
 3.723F-01  49655.21     18486. B3272I    QUALITY CONTROL ENGINE   3.723F-01   49655.21    18486. B3256B    PRODUCTION PLANNER
 3.723E-01  49655.21     18486. B3224I    INDUSTRIAL ENGINEER      8.616E-02  190632.75    16425. B1384I    PRESIDENT
 3.723F-01  43178.45     16075. B3288I    RESEARCH ENGINEER (ELE   7.446E-01   21589.22    16075. B2032I    BOOKKEEPER
 7.446F-01  21157.43     15753. B2160I    PROCUREMENT CLERK        4.218E-01   36701.67    15479. B3336I    ASSEMBLY OPERATIONS SU
 6.634E-01  22452.79     14896. B1440I    SECRETARY II (MIDDLE M   7.800E-01   18998.50    14815. B1192I    JANITOR
 1.288E-01 112263.94     14464. B2272I    VICE PRESIDENT, FINANC   4.964F-01   27850.09    13824. B1336I    NURSE, PROFESSIONAL (G
 1.758E-01  76209.94     13398. B2048I    CONTROLLER AND CHIEF A   7.446E-01   17832.70    13278. B2144I    PAYROLL CLERK
 7.446F-01  17832.70     13278. B1240I    MAIL CLERK               7.446E-01   17832.70    13278. B1048I    CLERK GENERAL OFFICE (
 1.153E-01 113343.44     13066. B3304I    VICE PRESIDENT, MANUFA   2.482E-01   51814.14    12860. B3128B    CHEMICAL ENGINEER
 1.108E-01 113343.37     12562. B1464I    VICE PRESIDENT, ADMINI   2.367E-01   50734.68    12007. B3496I    PRODUCTION SUPERINTEND
 1.655E-01  71158.06     11774. B1080I    DIRECTOR OFFICE ADMINI   2.482E-01   43178.45    10717. B3352I    ASSISTANT PRODUCTION S
 3.650E-01  29145.45     10638. B3560I    WAREHOUSE FOREMAN        2.482E-01   42098.96    10449. B2240I    SYSTEMS ANALYST
 2.482E-01  42098.96     10449. B2096I    FINANCIAL ANALYST        3.723E-01   27418.31    10208. B3192I    DRAFTSMAN, MECHANICAL
 1.241E-01  81175.44     10074. B1016I    ADMINISTRATIVE ASSISTA   1.448E-01   69085.50    10002. B3144I    DIRECTOR, MANUFACTURIN
 6.500E-01  15328.34      9963. B1160I    GUARD (SECURITY)         2.482E-01   38212.90     9484. B2176I    PROGRAMMER, BUSINESS
 4.872E-01  18998.51      9257. B1144I    GROUNDSKEEPER            3.723E-01   23748.14     8841. B3216I    ENGINEERING AIDE
 1.241E-01  71158.06      8830. B2256I    TREASURER                1.241E-01   71158.06     8830. B1112I    DIRECTOR PUBLIC RELATI
 1.241E-01  71158.06      8830. B1064I    DIRECTOR INDUSTRIAL RE   2.361E-01   35622.22     8411. B3464I    PROCESS MAINTENANCE SU
 1.293E-01  64767.68      8372. B2192I    PURCHASING ADMINISTRAT   1.448E-01   57211.45     8283. B1304I    MANAGER, PERSONNEL
 2.409E-01  30224.91      7281. B3320I    ASSEMBLY FOREMAN         1.241E-01   50734.68     6296. B1208I    LAWYER, CORPORATE (BUS
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1.869E-01  33679.19     6293. B1256I    MAINTENANCE FOREMAN (P   1.034E-01  57211.45      5916. B1288I    MANAGER, COMPENSATION,
2.442E-01  22884.57     5680. B2080I    DIGITAL COMPUTER OPERA   1.241E-01  45769.16      5680. B1032I    AUDITOR, INTERNAL
1.241E-01  44473.80     5519. B2016I    ACCOUNTING SUPERVISOR.   8.618E-02  57211.45      4930. B2128I    MANAGER, DATA PROCESSI
2.482E-01  18998.54     4715. B2112I    KEY PUNCH OPERATOR       6.205E-02  69085.50      4287. B3160I    DIRECTOR, QUALITY CONT
6.205E-02  69449.84     3751. B3176I    DIRECTOR, RESEARCH AND   1.241E-01  26986.53      3345. B1368I    PERSONNEL CLERK, SUPER
1.241E-01  22884.57     2840. B1400I    RECEPTIONIST             4.920E-02  57211.45      2815. B1320I    MANAGER, SECURITY AND
1.063E-01  23748.14     2573. B1176I    GUARD CHIEF              6.205E-02  37781.14      2344. B2224I    PURCHASING SUPERVISOR
4.137E-02  38212.93     1581. B2064I    DATA PROCESSING SUPERV   4.055E-02  35622.22      1445. B3544I    WAREHOUSE AND MATERIAL
6.205E-02  22884.57     1420. B1224I    LEGAL SECRETARY          1.640E-02  71158.06      1167. B1096I    DIRECTOR PLANT MAINTEN
1.045E+02      0.          0. B5032I    TOTAL PERSONNEL          3.005E+01      0.           0. B5048I    TOTAL STAFF PERSONNEL
2.805E+01      0.          0. B5064I    TOTAL MAINTENANCE PERS   7.446E+01      0.           0. B5016I    TOTAL DIRECT PERSONNEL

1.619E+05       .05     8738. C1032B    ELECTRICITY              3.463E+05       .01      4447. C1016B    DOMESTIC WATER
1.746E+01    204.96     3579. C1112I    TELEPHONE SERVICE        2.321E+04       .14      3139. C2144B    SOLID WASTE MATERIAL
6.254E+04       .01      394. C2064B    SEWAGE AND PROCESS WAS   7.302E-04       .03          . C1064B    NATURAL GAS
5.436E-06       .88         . C1048B    FUEL OIL                 2.294E+06      0.           0. C2160I    LIGHTING
4.906E-02      0.          0. C2128B    VENTILATION              7.528E-01      0.           0. C2112B    HEATING
2.284E-01      0.          0. C2096B    AIR CONDITIONING         3.462E+05      0.           0. C2080B    WATER SUPPLY
6.270E+01      0.          0. C2016I    CAFETERIA SERVICE        1.156E+01      0.           0. C2048B    POWER SUPPLY

2.321E+05       .00      696. D1056B    SOLID WASTE              3.462E+05       .00       268. D1048B    POLLUTED WATER
1.393E+05       .00      137. D1080I    SEWAGE WASTE

5.225E+04      2.17   113484. E1432I    OFFICE SUPPLIES          1.045E+04      2.17     22697. E1256B    EXPENDABLE TOOLS

7.562E-04      0.          0. F1048I    NATURAL GAS              7.267E-07      0.           0. F1032B    FUEL OIL
1.749E+05      0.          0. F1080I    WATER                    9.570E+05      0.           0. F1016B    ENERGY

   THIS COMPANY, WESTCO, BUYS THE FOLLOWING PRODUCTS FROM OTHER COMPANIES:
   (NONE)
THE COMPANY BALANCE SHEET IS NOT YET IMPLEMENTED
THE COMPANY INCOME STATEMENT IS NOT YET IMPLEMENTED
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CURRENT TECHNOLOGY (PROCESS DESCRIPTIONS IN CORE)

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PROCESS: 1.01      , LOAD BUFFER, LOAD STARTING SILICON WEB INTO 3M X 3M FRAME
PRODUCT: RAWWEB    , UNCLEANED STARTING WEB
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: BUF1.01, LOAD BUFFER
         COST:   10000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT     .0031 $(1975)/CM2
   NUMBER OF 1.01 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 1.01
      3.300E-01 PRSN*YRS OF B3064D, GENERAL ASSEMBLER (ELECTRONICS)
        IS REQUIRED BY EACH COPY OF PROCESS 1.01
   UTILITIES AND COMMODITIES
      8.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.01
      5.000E+03 CM2 OF E-WEB001, SILICON WEB
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.01

PROCESS: 1.02      , CLEAN WEB, WEB IN FRAME IS WASHED IN ACETONE AND DRIED
PRODUCT: CLEANWEB  , CLEAN WEB IN FRAME
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: CLEANFR1, WASHER FOR WEB IN FRAMES
         COST:   10000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT     .0032 $(1975)/CM2
   NUMBER OF 1.02 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 1.02
      3.300E-01 PRSN*YRS OF B3064D, GENERAL ASSEMBLER (ELECTRONICS)
        IS REQUIRED BY EACH COPY OF PROCESS 1.02
   UTILITIES AND COMMODITIES
      1.000E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.02
      1.293E-01 LBS. OF E1032D, ACETONE
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.02
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF RAWWEB, UNCLEANED STARTING WEB,
        PRODUCES  1.0000 CM2 OF CLEANWEB, CLEAN WEB IN FRAME

PROCESS: 1.03      , OXIDE DEPOSITION
PRODUCT: BOXWEB    , OXIDE COATED WEB
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: BOXMAC, OXIDIZING FURNACE
         COST:  200000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT     .0032 $(1975)/CM2
   NUMBER OF 1.03 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
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      FACILITIES AND PERSONNEL
         4.800E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
           IS REQUIRED BY EACH COPY OF PROCESS 1.03
         1.700E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
           IS REQUIRED BY EACH COPY OF PROCESS 1.03
      UTILITIES AND COMMODITIES
         7.000E-04 CU. FT. OF C1086D, NITROGEN (LIQUID)
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.03
         2.000E-03 LBS. OF E1584D, SILANE 100%
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.03
         8.500E-02 KW HR. OF C1032B, ELECTRICITY
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.03
      INTRA-INDUSTRY PRODUCTS
         EACH ONE CM2 OF CLEANWEB, CLEAN WEB IN FRAME,
            PRODUCES  1.0000 CM2 OF BOXWEB, OXIDE COATED WEB

   PROCESS: 1.04      , CVD BORON
   PRODUCT: OXWEB     , BORON DEPOSITION
   PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
   OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
         COMPONENT: OXMAC, CVD BORON COATING APPARATUS
            COST:  200000. $(1976)    INSTALLATION:    1000. $(1976)
            SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS
      QUANTITY 2.315E+09 CM2/YEAR AT     .0032 $(1975)/CM2
      NUMBER OF 1.04 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
      FACILITIES AND PERSONNEL
         4.500E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
           IS REQUIRED BY EACH COPY OF PROCESS 1.04
         1.700E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
           IS REQUIRED BY EACH COPY OF PROCESS 1.04
      UTILITIES AND COMMODITIES
         8.500E-02 KW HR. OF C1032B, ELECTRICITY
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.04
         2.000E-03 LBS. OF E1584D, SILANE 100%
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.04
         8.500E-03 CU. FT. OF E1206D, DIBORANE 5% IN HYDROGEN
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.04
         1.200E-01 CU. FT. OF C1128D, WATER - COOLING
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.04
      INTRA-INDUSTRY PRODUCTS
         EACH ONE CM2 OF BOXWEB, OXIDE COATED WEB,
            PRODUCES  1.0000 CM2 OF OXWEB, BORON DEPOSITION

   PROCESS: 1.05      , BORON DRIVE
   PRODUCT: PDIFFWEB  , BORON DIFFUSED WEB
   PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
   OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
         COMPONENT: BDMAC, DIFF FURNACE
            COST:  380000. $(1976)    INSTALLATION:    1000. $(1976)
            SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS
      QUANTITY 2.315E+09 CM2/YEAR AT     .0034 $(1975)/CM2
      NUMBER OF 1.05 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
      FACILITIES AND PERSONNEL
         5.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
           IS REQUIRED BY EACH COPY OF PROCESS 1.05
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      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 1.05
   UTILITIES AND COMMODITIES
      1.360E-01 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.05
      1.200E-01 CU. FT. OF C1128D, WATER - COOLING
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.05
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF OXWEB, BORON DEPOSITION,
         PRODUCES  1.0000 CM2 OF PDIFFWEB, BORON DIFFUSED WEB

PROCESS: 1.06      , COOLING BUFFER
PRODUCT: PCOOLWEB , COOL BORON DIFFUSED WEB
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: COLBUF1, COOLING STATION
         COST:    10000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0034 $(1975)/CM2
   NUMBER OF 1.06 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 1.06
      1.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 1.06
   UTILITIES AND COMMODITIES
      1.700E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.06
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF PDIFFWEB, BORON DIFFUSED WEB,
         PRODUCES  1.0000 CM2 OF PCOOLWEB, COOL BORON DIFFUSED WEB

PROCESS: 1.07      , ETCH OXIDE
PRODUCT: BOXETCH  , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: BOXETCHER, ETCHING UNIT
         COST:    20000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    2000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0034 $(1975)/CM2
   NUMBER OF 1.07 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 1.07
      4.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 1.07
   UTILITIES AND COMMODITIES
      1.260E-01 LBS. OF E1328D, HYDROFLORIC ACID
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.07
      2.000E-02 CU. FT. OF C1144D, WATER - DEIONIZED
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.07
      1.670E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.07
      1.600E-02 GALLONS OF D1032D, POISONOUS ACID
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.07
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   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF PCOOLWEB, COOL BORON DIFFUSED WEB,
         PRODUCES  1.0000 CM2 OF BOXETCH, *

PROCESS: 1.08       , POCL3 DIFF
PRODUCT: NDIFFWEB , JUNCTION FORMATION
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    30.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: NFURNACE, *
         COST:  340000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:   10000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0036 $(1975)/CM2
   NUMBER OF 1.08 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      1.940E+02 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 1.08
      9.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 1.08
   UTILITIES AND COMMODITIES
      3.000E-03 LBS. OF E1504D, POCL
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.08
      2.210E-01 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.08
      2.100E-01 CU. FT. OF C1128D, WATER - COOLING
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.08
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF BOXETCH, *,
         PRODUCES  1.0000 CM2 OF NDIFFWEB, JUNCTION FORMATION

PROCESS: 1.09       , COOLING BUFFER 2
PRODUCT: NCOOLWEB , COOL AFTER POCL3 DIFF
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    30.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: BUF1.09, COOLING BUFFER
         COST:   10000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:       0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0036 $(1975)/CM2
   NUMBER OF 1.09 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 1.09
      1.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 1.09
   UTILITIES AND COMMODITIES
      9.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.09
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF NDIFFWEB, JUNCTION FORMATION,
         PRODUCES  1.0000 CM2 OF NCOOLWEB, COOL AFTER POCL3 DIFF

PROCESS: 1.10       , ETCH PHOS GLASS
PRODUCT: PETCH      , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: PETCHER, HF/DI ETCHER
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        COST:   20000. $(1976)    INSTALLATION:    1000. $(1976)
        SALVAGE VALUE:     2000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT     .0036 $(1975)/CM2
   NUMBER OF 1.10 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 1.10
      5.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 1.10
   UTILITIES AND COMMODITIES
      1.260E-01 LBS. OF E1328D, HYDROFLORIC ACID
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.10
      2.000E-02 CU. FT. OF C1144D, WATER - DEIONIZED
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.10
      3.200E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.10
      1.600E-02 GALLONS OF D1032D, POISONOUS ACID
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.10
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF NCOOLWEF, COOL AFTER POCL3 DIFF,
         PRODUCES  1.0000 CM2 OF PETCH, *

PROCESS: 1.11      , PROCESS 1 OUTPUT BUFFER
PRODUCT: BPETCH    , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: [illegible]1.11, *
        COST:   10000. $(1976)    INSTALLATION:    1000. $(1976)
        SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT     .0037 $(1975)/CM2
   NUMBER OF 1.11 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 1.11
      5.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 1.11
   UTILITIES AND COMMODITIES
      1.7[illegible]E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 1.11
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF PETCH, *,
         PRODUCES  1.0000 CM2 OF BPETCH, *

PROCESS: 2.01      , INPUT BUFFER TO PROCESS 2
PRODUCT: BBPETCH   , HOLDING BUFFER
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: EQP2.01, HOLDING STATION
        COST:   10000. $(1976)    INSTALLATION:    1000. $(1976)
        SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT     .0037 $(1975)/CM2
   NUMBER OF 2.01 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.01
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        1.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
          IS REQUIRED BY EACH COPY OF PROCESS 2.01
     UTILITIES AND COMMODITIES
        8.000E-03 KW HR. OF C1032B, ELECTRICITY
          IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.01
     INTRA-INDUSTRY PRODUCTS
        EACH ONE CM2 OF BPETCH, *,
           PRODUCES  1.0000 CM2 OF BBPETCH, HOLDING BUFFER

  PROCESS: 2.02       , ANTI REFLECTION COATING DIP AND DRAIN
  PRODUCT: ARDIP      , *
  PRODUCES: 5000.0000 CM2/MINUTE, TAKING     15.000 MINUTES/CYCLE
  OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
        COMPONENT: ARTANK, AR COATING TANK
           COST:    60000. $(1976)     INSTALLATION:     1000. $(1976)
           SALVAGE VALUE:     2000. $(1976) AFTER  7.0 YEARS
     QUANTITY 2.315E+09 CM2/YEAR AT      .0037 $(1975)/CM2
     NUMBER OF 2.02 MACHINES =  1.000, OF WHICH  .066 ARE IDLE
     FACILITIES AND PERSONNEL
        1.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
          IS REQUIRED BY EACH COPY OF PROCESS 2.02
        2.500E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
          IS REQUIRED BY EACH COPY OF PROCESS 2.02
     UTILITIES AND COMMODITIES
        1.660E-03 GALLONS OF E1352D, ISOPROPYL ALCOHOL
          IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.02
        6.000E-03 KW HR. OF C1032B, ELECTRICITY
          IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.02
        1.300E-05 LITERS OF E-ARSOL, ANTI REFLECTION COATING SOLUTION
          IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.02
     INTRA-INDUSTRY PRODUCTS
        EACH ONE CM2 OF BBPETCH, HOLDING BUFFER,
           PRODUCES  1.0000 CM2 OF ARDIP, *

  PROCESS: 2.03       , CURE AR COATING
  PRODUCT: ARBAKE     , *
  PRODUCES: 5000.0000 CM2/MINUTE, TAKING     15.000 MINUTES/CYCLE
  OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
        COMPONENT: ARFCE, BAKE OVEN
           COST:    20000. $(1976)     INSTALLATION:     1000. $(1976)
           SALVAGE VALUE:     2000. $(1976) AFTER  7.0 YEARS
     QUANTITY 2.315E+09 CM2/YEAR AT      .0037 $(1975)/CM2
     NUMBER OF 2.03 MACHINES =  1.000, OF WHICH  .066 ARE IDLE
     FACILITIES AND PERSONNEL
        4.800E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
          IS REQUIRED BY EACH COPY OF PROCESS 2.03
        1.500E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
          IS REQUIRED BY EACH COPY OF PROCESS 2.03
     UTILITIES AND COMMODITIES
        7.500E-02 KW HR. OF C1032B, ELECTRICITY
          IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.03
        6.000E-02 CU. FT. OF C1128D, WATER - COOLING
          IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.03
     INTRA-INDUSTRY PRODUCTS
        EACH ONE CM2 OF ARDIP, *,
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         PRODUCES  1.0000 CM2 OF ARBAKE, *

PROCESS: 2.04      , PHOTORESIST DIP AND DRAIN
PRODUCT: PRDIP     , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: PRTANK, *
         COST:   60000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    3000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0038 $(1975)/CM2
   NUMBER OF 2.04 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      2.500E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 2.04
      1.800E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.04
   UTILITIES AND COMMODITIES
      8.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.04
      3.700E-03 GAL OF E-AZ111, POSITIVE PHOTO RESIST
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.04
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF ARBAKE, *,
         PRODUCES  1.0000 CM2 OF PRDIP, *

PROCESS: 2.05      , CURE PHOTORESIST
PRODUCT: PRBAKE    , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING      7.500 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: PRFCE, BAKE OVEN
         COST:   20000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    1000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0039 $(1975)/CM2
   NUMBER OF 2.05 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      4.800E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.05
      2.500E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 2.05
   UTILITIES AND COMMODITIES
      1.700E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.05
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF PRDIP, *,
         PRODUCES  1.0000 CM2 OF PRBAKE, *

PROCESS: 2.06      , UNLOAD CASSETTE FOR PR EXPOSURE
PRODUCT: UNLCAS    , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING      7.500 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: UNLOADER1, *
         COST:   30000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    2000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0039 $(1975)/CM2
   NUMBER OF 2.06 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
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   FACILITIES AND PERSONNEL
      4.800E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.06
      2.500E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 2.06
   UTILITIES AND COMMODITIES
      8.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.06
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF PRBAKE, *,
         PRODUCES  1.0000 CM2 OF UNLCAS, *

PROCESS: 2.07      , EXPOSE PHOTORESIST ON SINGLE WEB LENGTHS
PRODUCT: EXPPR     , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    10.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: EXPOSER, *
         COST:   50000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    3000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0039 $(1975)/CM2
   NUMBER OF 2.07 MACHINES =  1.000, OF WHICH  .069 ARE IDLE
   FACILITIES AND PERSONNEL
      6.500E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.07
      2.500E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 2.07
   UTILITIES AND COMMODITIES
      3.400E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.07
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF UNLCAS, *,
         PRODUCES  1.0000 CM2 OF EXPPR, *

PROCESS: 2.08      , RELOAD CASSETTE
PRODUCT: LDCAS     , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     7.500 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: LOADER2, *
         COST:   30000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    2000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0039 $(1975)/CM2
   NUMBER OF 2.08 MACHINES =  1.000, OF WHICH  .069 ARE IDLE
   FACILITIES AND PERSONNEL
      4.800E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.08
      5.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 2.08
   UTILITIES AND COMMODITIES
      8.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.08
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF EXPPR, *,
         PRODUCES  1.0000 CM2 OF LDCAS, *

PROCESS: 2.09      , DIP DEVELOP EXPOSED WEB
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PRODUCT: DIPDF     , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING      2.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPFRATING
      COMPONENT: DIPTANK, *
         COST:    20000. $(1976)     INSTALLATION:     1000. $(1976)
         SALVAGE VALUE:     2000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0040 $(1975)/CM2
   NUMBER OF 2.09 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      1.500E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.09
      2.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 2.09
   UTILITIES AND COMMODITIFS
      4.000E-03 GAL OF E-303A, AZ111 DEVELOPER
        IS REQUIRED EVFRY OPERATING MINUTE BY EACH COPY OF PROCESS 2.09
      1.700E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVFRY OPERATING MINUTE BY EACH COPY OF PROCESS 2.09
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF LDCAS, *,
         PRODUCES  1.0000 CM2 OF DIPDF, *

PROCESS: 2.10      ., PHOTORESIST CLEANUP
PRODUCT: PHCUP     , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     15.000 MINUTFS/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: DIPTANK, ACETONE TANK
         COST:    20000. $(1976)     INSTALLATION:     1000. $(1976)
         SALVAGE VALUE:     2000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0040 $(1975)/CM2
   NUMBER OF 2.10 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNFL
      1.500E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.10
      2.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 2.10
   UTILITIES AND COMMODITIFS
      2.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.10
      3.830E-02 LBS. OF E1032D, ACFTONE
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.10
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF DIPDF, *,
         PRODUCES  1.0000 CM2 OF PHCUP, *

PROCESS: 2.11       , ETCH AR COATING FOR CONTACTS
PRODUCT: ARETCH     , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING      2.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: ARETK, ETCH TANK
         COST:    20000. $(1976)     INSTALLATION:     1000. $(1976)
         SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0040 $(1975)/CM2
   NUMBER OF 2.11 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
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      1.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.11
      2.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 2.11
   UTILITIES AND COMMODITIES
      2.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.11
      4.210E-07 LBS. OF E1320D, HYDROCHLORIC ACID
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.11
      2.000E+02 CU. FT. OF D1016B, FUMES
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.11
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF PHCUP, *,
         PRODUCES  1.0000 CM2 OF APETCH, *

PROCESS: 2.12       , WASH AND DRY
PRODUCT: WADRY      , CLEANUP IN DI H20
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     2.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: WASHTANK, RUNNING DI H20
         COST:   20000. $(1976)    INSTALLATION:     1000. $(1976)
         SALVAGE VALUE:        0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0040 $(1975)/CM2
   NUMBER OF 2.12 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      1.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.12
      2.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 2.12
   UTILITIES AND COMMODITIES
      2.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.12
      2.000E-02 CU. FT. OF C1144D, WATER - DEIONIZED
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.12
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF APETCH, *,
         PRODUCES  1.0000 CM2 OF WADRY, CLEANUP IN DI H20

PROCESS: 2.13       , OUTPUT BUFFER FOR PROCESS 2
PRODUCT: BWADRY     , HOLDING BUFFER
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     2.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: BUF2.13, HOLDING STATION
         COST:   10000. $(1976)    INSTALLATION:     1000. $(1976)
         SALVAGE VALUE:     3000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0040 $(1975)/CM2
   NUMBER OF 2.13 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      1.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 2.13
      2.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 2.13
   UTILITIES AND COMMODITIES
      2.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 2.13
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      INTRA-INDUSTRY PRODUCTS
         EACH ONE CM2 OF WADRY, CLEANUP IN DI H20.
            PRODUCES  1.0000 CM2 OF EWADRY, HOLDING BUFFER

   PROCESS: 3.01       , METAL DEPOSITION, BOTH SIDES
   PRODUCT: METWEB    , *
   PRODUCES: 5000.0000 CM2/MINUTE, TAKING      45.000 MINUTES/CYCLE
   OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
         COMPONENT: VACDEP, VACUUM DEPOSITION
            COST:  500000. $(1976)      INSTALLATION:     2000. $(1976)
            SALVAGE VALUE:    50000. $(1976) AFTER  7.0 YEARS
      QUANTITY 2.315E+09 CM2/YEAR AT       .0042 $(1975)/CM2
      NUMBER OF 3.01 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
      FACILITIES AND PERSONNEL
         3.000E+02 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
           IS REQUIRED BY EACH COPY OF PROCESS 3.01
         9.000E-01 PRSN*YRS OF B3704D, ELECTRONICS TECHNICIAN, AUTOMATED PROCESSES
           IS REQUIRED BY EACH COPY OF PROCESS 3.01
      UTILITIES AND COMMODITIES
         1.000E-04 LBS. OF E1704D, TITANIUM
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.01
         8.800E-03 LBS. OF E1096D, ALUMINUM
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.01
         1.020E-01 KW HR. OF C1032B, ELECTRICITY
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.01
         7.000E-02 CU. FT. OF C1120D, WATER - COOLING
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.01
         4.300E-03 TROY.OZ OF E-PALLAL, PALLADIUM METAL
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.01
         5.900E-05 LBS OF E-NICKEL, NICKEL METAL FOR PLATING STRIKE
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.01
      INTRA-INDUSTRY PRODUCTS
         EACH ONE CM2 OF EWADRY, HOLDING BUFFER,
            PRODUCES  1.0000 CM2 OF METWEB, *

   PROCESS: 3.02       , HOLDING BUFFER FOR PROCESS 3.03
   PRODUCT: BMETWEB    , HOLDING BUFFER BEFORE PR STRIP
   PRODUCES: 5000.000  CM2/MINUTE, TAKING      15.000 MINUTES/CYCLE
   OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
         COMPONENT: BUF3.02, HOLDING TABLE
            COST:   10000. $(1976)      INSTALLATION:     1000. $(1976)
            SALVAGE VALUE:         0. $(1976) AFTER  7.0 YEARS
      QUANTITY 2.315E+09 CM2/YEAR AT       .0042 $(1975)/CM2
      NUMBER OF 3.02 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
      FACILITIES AND PERSONNEL
         9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
           IS REQUIRED BY EACH COPY OF PROCESS 3.02
         1.000E-01 PRSN*YRS OF B3704D, ELECTRONICS TECHNICIAN, AUTOMATED PROCESSES
           IS REQUIRED BY EACH COPY OF PROCESS 3.02
      UTILITIES AND COMMODITIES
         1.700E-02 KW HR. OF C1032B, ELECTRICITY
           IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.02
      INTRA-INDUSTRY PRODUCTS
         EACH ONE CM2 OF METWEB, *,
            PRODUCES  1.0000 CM2 OF BMETWEB, HOLDING BUFFER BEFORE PR STRIP
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PROCESS: 3.03      , ACETONE REJECTION TO DEFINE CONTACT GRID
PRODUCT: GRIDWEB   , REJECTION MASK REMOVAL
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    20.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: STRTAN, ULTRASONIC STRIPPING
         COST:  20000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    1000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0043 $(1975)/CM2
   NUMBER OF 3.03 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      1.290E+02 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 3.03
      5.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 3.03
   UTILITIES AND COMMODITIES
      3.400E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.03
      2.000E+02 CU. FT. OF D1016B, FUMES
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.03
      4.400E-03 LBS. OF E1032D, ACETONE
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.03
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF PMETWEB, HOLDING BUFFER BEFORE PR STRIP,
         PRODUCES  1.0000 CM2 OF GRIDWEB, REJECTION MASK REMOVAL

PROCESS: 3.04      , CONTACT SINTERING
PRODUCT: SINTWEB   , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    25.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: SINTFCE, SINTERING FURNACE
         COST:  100000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    5000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0044 $(1975)/CM2
   NUMBER OF 3.04 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      5.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 3.04
      2.260E+02 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 3.04
   UTILITIES AND COMMODITIES
      4.666E-03 CU. FT. OF C108CD, NITROGEN (LIQUID)
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.04
      3.300E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.04
      3.000E-02 CU. FT. OF C1128D, WATER - COOLING
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.04
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF GRIDWEB, REJECTION MASK REMOVAL,
         PRODUCES  1.0000 CM2 OF SINTWEB, *

PROCESS: 3.05      , SILVER PLATING OF CONTACTS
PRODUCT: PLATWEB   , PLATED CONTACTS
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     5.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
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      COMPONENT: PLATAN, PLATING TANK
         COST:   30000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    3000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0046 $(1975)/CM2
   NUMBER OF 3.05 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      8.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 3.05
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 3.05
   UTILITIES AND COMMODITIES
      4.040E-01 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.05
      7.000E-02 CU. FT. OF C2064B, SEWAGE AND PROCESS WASTE DISPOSAL
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.05
      2.000E+02 CU. FT. OF D1016B, FUMES
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.05
      3.570E+00 GRAMS OF E1592D, SILVER
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.05
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF SINTWEB, *,
         PRODUCES  1.0000 CM2 OF PLATWEB, PLATED CONTACTS

PROCESS: 3.06       , WASH AND DRY PLATED WEB
PRODUCT: WADWEB     , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: WASHTANK, WASHER DRYER
         COST:   20000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    2000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0046 $(1975)/CM2
   NUMBER OF 3.06 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      2.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 3.06
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 3.06
   UTILITIES AND COMMODITIES
      1.700E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.06
      2.000E-03 CU. FT. OF C1144D, WATER - DEIONIZED
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 3.06
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF PLATWEB, PLATED CONTACTS,
         PRODUCES  1.0000 CM2 OF WADWEB, *

PROCESS: 4.01       , UNLOAD FRAMES FOR LASER SCRIBING
PRODUCT: WFBUN      , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: UNLMAC, CASSETTE UNLOADER
         COST:   20000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    2000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0047 $(1975)/CM2
   NUMBER OF 4.01 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
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   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 4.01
      4.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 4.01
   UTILITIES AND COMMODITIES
      6.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 4.01
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF WADWEB, *,
         PRODUCES  1.0000 CM2 OF WEBUN, *

PROCESS: 4.02      , LONGITUDINAL LASER SCRIBE
PRODUCT: LONLAS    , SCRIBE FOR DENDRITE REMOVAL
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: LASCR1, FIRST LASER SCRIBE
         COST:  100000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    5000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0047 $(1975)/CM2.
   NUMBER OF 4.02 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      5.000E-01 PRSN*YRS OF B3704D, ELECTRONICS TECHNICIAN, AUTOMATED PROCESSES
        IS REQUIRED BY EACH COPY OF PROCESS 4.02
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 4.02
   UTILITIES AND COMMODITIES
      3.300E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 4.02
      1.700E-02 CU. FT. OF C1128D, WATER - COOLING
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 4.02
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF WEBUN, *,
         PRODUCES  1.0000 CM2 OF LONLAS, SCRIBE FOR DENDRITE REMOVAL

PROCESS: 4.03      , BUFFER FOR TRANSVERSE SCRIBE
PRODUCT: BLONLAS   , HOLDING STATION
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: BUF4.03, HOLDING TABLE
         COST:    20000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:       0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0047 $(1975)/CM2
   NUMBER OF 4.03 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 4.03
      1.000E-01 PRSN*YRS OF B3704D, ELECTRONICS TECHNICIAN, AUTOMATED PROCESSES
        IS REQUIRED BY EACH COPY OF PROCESS 4.03
   UTILITIES AND COMMODITIES
      1.700E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 4.03
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF LONLAS, SCRIBE FOR DENDRITE REMOVAL,
         PRODUCES  1.0000 CM2 OF BLONLAS, HOLDING STATION
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PROCESS: 4.04       , TRANSVERSE LASER SCRIBE OF CELLS
PRODUCT: TRALAS    , WEB CELLS ARE SCRIBLED INTO CELL LENGTHS .
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: LASCRII, TABLE AND LASER
         COST:   85000. $(1976)     INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:     2000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0048 $(1975)/CM2
   NUMBER OF 4.04 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 4.04
      5.000E-01 PRSN*YRS OF B3704B, ELECTRONICS TECHNICIAN, AUTOMATED PROCESSES
        IS REQUIRED BY EACH COPY OF PROCESS 4.04
   UTILITIES AND COMMODITIES
      3.200E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 4.04
      2.000E-02 CU. FT. OF C1128D, WATER - COOLING
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 4.04
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF BLOWLAS, HOLDING STATION,
         PRODUCES  1.0000 CM2 OF TRALAS, WEB CELLS ARE SCRIBLED INTO CELL LENGTHS

PROCESS: 4.05       , BREAK OFF DENDRITES AND SEPARATE CELLS
PRODUCT: WEBCELL   , CELLS
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     15.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: BREAKMAC, *
         COST:   30000. $(1976)     INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:     3000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0048 $(1975)/CM2
   NUMBER OF 4.05 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      9.700E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 4.05
      5.000E-01 PRSN*YRS OF B3704B, ELECTRONICS TECHNICIAN, AUTOMATED PROCESSES
        IS REQUIRED BY EACH COPY OF PROCESS 4.05
   UTILITIES AND COMMODITIES
      3.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 4.05
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF TRALAS, WEB CELLS ARE SCRIBLED INTO CELL LENGTHS,
         PRODUCES  1.0000 CM2 OF WEBCELL, CELLS

PROCESS: 4.06       , CELLS LOADED IN CASSETTES, TESTED AND STORED
PRODUCT: TESCEL    , TEST AND SORT
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     12.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: TESTAP, *
         COST:   30000. $(1976)     INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:     3000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0049 $(1975)/CM2
   NUMBER OF 4.06 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
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      6.500E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 4.06
      1.000E+00 PRSN*YRS OF B3704D, ELECTRONICS TECHNICIAN, AUTOMATED PROCESSES
        IS REQUIRED BY EACH COPY OF PROCESS 4.06
   UTILITIES AND COMMODITIES
      1.700E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 4.06
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF WEBCELL, CELLS,
         PRODUCES  1.0000 CM2 OF TESCEL, TEST AND SORT

PROCESS: 5.01      , INPUT BUFFER PROCESS 5
PRODUCT: BTESCEL   , HOLDING STATION
PRODUCES: 5000.0000 CM2/MINUTE, TAKING     2.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: BUF5.01, TABLE FOR HOLDING CASSETTES
         COST:   10000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:         0. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0049 $(1975)/CM2
   NUMBER OF 5.01 MACHINES =  1.000, OF WHICH  .069 ARE IDLE
   FACILITIES AND PERSONNEL
      1.200E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 5.01
      1.000E-01 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
        IS REQUIRED BY EACH COPY OF PROCESS 5.01
   UTILITIES AND COMMODITIES
      1.700E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.01
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF TESCEL, TEST AND SORT,
         PRODUCES  1.0000 CM2 OF BTESCEL, HOLDING STATION

PROCESS: 5.02      , AL FOIL INTERCONNECT ATTACHED TO CELL TOPS
PRODUCT: TOPBON    , TOP BONDED CELLS
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    10.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: INTMAC1, ULTRASONIC BONDER
         COST:  100000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    5000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0050 $(1975)/CM2
   NUMBER OF 5.02 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      4.300E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 5.02
      9.000E-01 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
        IS REQUIRED BY EACH COPY OF PROCESS 5.02
   UTILITIES AND COMMODITIES
      1.700E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.02
      1.180E-03 DOLLARS OF E1104D, ALUMINUM RIBBON
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.02
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF BTESCEL, HOLDING STATION,
         PRODUCES  1.0000 CM2 OF TOPBON, TOP BONDED CELLS
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PROCESS: 5.03     , CELLS PLACED ON GLASS SUPERSTRATE AND COATED WITH RTV
PRODUCT: GLUTOP   , *
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    10.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
    COMPONENT: CELPMA, ROTARY CELL POSITIONER
      COST:    50000. $(1976)    INSTALLATION:    1000. $(1976)
      SALVAGE VALUE:    2000. $(1976) AFTER  7.0 YEARS
  QUANTITY 2.315E+09 CM2/YEAR AT      .0054 $(1975)/CM2
  NUMBER OF 5.03 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
  FACILITIES AND PERSONNEL
    6.500E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
     IS REQUIRED BY EACH COPY OF PROCESS 5.03
    5.000E-01 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
     IS REQUIRED BY EACH COPY OF PROCESS 5.03
  UTILITIES AND COMMODITIES
    1.700E-02 KW HR. OF C1032B, ELECTRICITY
     IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.03
    1.500E-02 LBS. OF E1552C, RTV 108
     IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.03
    5.600E+00 FT2 OF E-TGLAS, TOP GLASS OF MODULE
     IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.03
  INTRA-INDUSTRY PRODUCTS
    EACH ONE CM2 OF TOPBON, TOP BONDED CELLS,
      PRODUCES  1.0000 CM2 OF GLUTOP, *

PROCESS: 5.04     , CELL/SUPERSTRATE ADHESIVE CURE
PRODUCT: CURTOP   , PARTIAL PANEL
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    10.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
    COMPONENT: BUF5.04, CURING BUFFER AREA
      COST:    20000. $(1976)    INSTALLATION:    1000. $(1976)
      SALVAGE VALUE:    1000. $(1976) AFTER  7.0 YEARS
  QUANTITY 2.315E+09 CM2/YEAR AT      .0054 $(1975)/CM2
  NUMBER OF 5.04 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
  FACILITIES AND PERSONNEL
    6.500E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
     IS REQUIRED BY EACH COPY OF PROCESS 5.04
    1.000E-01 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
     IS REQUIRED BY EACH COPY OF PROCESS 5.04
  UTILITIES AND COMMODITIES
    1.700E-02 KW HR. OF C1032B, ELECTRICITY
     IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.04
  INTRA-INDUSTRY PRODUCTS
    EACH ONE CM2 OF GLUTOP, *,
      PRODUCES  1.0000 CM2 OF CURTOP, PARTIAL PANEL

PROCESS: 5.05     , INTERCONNECT, SECOND BONDING AND TEST
PRODUCT: BACBON   , INTER BONDED CELL MODULE
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    12.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
    COMPONENT: INTMAC2, PROGRAMMED STEPPING ULTRASONIC BONDER
      COST:    70000. $(1976)    INSTALLATION:    1000. $(1976)
      SALVAGE VALUE:    2000. $(1976) AFTER  7.0 YEARS
  QUANTITY 2.315E+09 CM2/YEAR AT      .0054 $(1975)/CM2
  NUMBER OF 5.05 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
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FACILITIES AND PERSONNEL
   8.600E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
     IS REQUIRED BY EACH COPY OF PROCESS 5.05
   4.000E-01 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
     IS REQUIRED BY EACH COPY OF PROCESS 5.05
UTILITIES AND COMMODITIES
   1.700E-02 KW HR. OF C1032B, ELECTRICITY
     IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.05
INTRA-INDUSTRY PRODUCTS
   EACH ONE CM2 OF CURTOP, PARTIAL PANEL,
      PRODUCES  1.0000 CM2 OF BACBON, INTER BONDED CELL MODULE

PROCESS: 5.06      , APPLY RTV TO CELL BACKS
PRODUCT: GLUBAC    , PARTIAL MODULE
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    12.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: COATER1, RTV COATER
         COST:   30000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:    2000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT      .0055 $(1975)/CM2
   NUMBER OF 5.06 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      8.600E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 5.06
      2.500E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 5.06
   UTILITIES AND COMMODITIES
      8.000E-03 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.06
      1.500E-02 LBS. OF E1560D, RTV 615 (SILICONE)
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.06
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF BACBON, INTER BONDED CELL MODULE,
         PRODUCES  1.0000 CM2 OF GLUBAC, PARTIAL MODULE

PROCESS: 5.07      , ATTACH FIBERBOARD BACK TO CELL MODULE
PRODUCT: BACON     , PHENOLIC BACK, COMPLETE MODULE
PRODUCES: 5000.0000 CM2/MINUTE, TAKING    12.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: BACTAC, BACK POSITIONER
         COST:   20000. $(1976)    INSTALLATION:    1000. $(1976)
         SALVAGE VALUE:   1000. $(1976) AFTER  7.0 YEARS
   QUANTITY 2.315E+09 CM2/YEAR AT     .0059 $(1975)/CM2
   NUMBER OF 5.07 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      8.600E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 5.07
      5.000E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 5.07
   UTILITIES AND COMMODITIES
      2.400E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.07
      5.600E+00 FT2 OF E-PHENBO, PHENOLIC BOARD FOR BACK OF MODULE
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.07
   INTRA-INDUSTRY PRODUCTS
```

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      EACH ONE CM2 OF GLUBAC, PARTIAL MODULE,
         PRODUCES  1.0000 CM2 OF PACON, PHENOLIC BACK, COMPLETE MODULE

PROCESS: 5.08       , CURE AND TEST BUFFER
PRODUCT: PANTES     , FINAL TEST OF MODULE AND SCALE FROM CM2 TO PANELS
PRODUCES:      .2500 PANELS/MINUTE, TAKING      3.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: TESTORE, TESTING AND CURING APPARATUS
         COST:    30000. $(1976)     INSTALLATION:      1000. $(1976)
         SALVAGE VALUE:      1000. $(1976) AFTER  7.0 YEARS
   QUANTITY 1.157E+05 PANELS/YEAR AT  118.1202 $(1975)/PANELS
   NUMBER OF 5.08 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      8.600E+01 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 5.08
      2.500E-01 PRSN*YRS OF B3672D, CHEMICAL OPERATOR II
        IS REQUIRED BY EACH COPY OF PROCESS 5.08
   UTILITIES AND COMMODITIES
      1.700E-02 KW HR. OF C1032B, ELECTRICITY
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.08
   INTRA-INDUSTRY PRODUCTS
      EACH ONE CM2 OF PACON, PHENOLIC BACK, COMPLETE MODULE,
         PRODUCES    .0000 PANELS OF PANTES, FINAL TEST OF MODULE AND SCALE FROM CM2 TO PANELS

PROCESS: 5.09       , YIELD DUMMY
PRODUCT: GOODPAN    , GOOD PANELS
PRODUCES:      .2250 PANELS/MINUTE, TAKING     40.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: YIELDER, ARTIFICE FOR SETTING YIELD
         COST:          0. $(1976)     INSTALLATION:          0. $(1976)
         SALVAGE VALUE:         0. $(1976) AFTER 10.0 YEARS
   QUANTITY 1.042E+05 PANELS/YEAR AT  131.2446 $(1975)/PANELS
   NUMBER OF 5.09 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   INTRA-INDUSTRY PRODUCTS
      EACH ONE PANELS OF PANTES, FINAL TEST OF MODULE AND SCALE FROM CM2 TO PANELS,
         PRODUCES    .9000 PANELS OF GOODPAN, GOOD PANELS

PROCESS: 5.10       , CRATING AND SHIPPING
PRODUCT: CRATEMOD   , CRATED PANELS, 10/CRATE
PRODUCES:      .0225 CRATES/MINUTE, TAKING     30.000 MINUTES/CYCLE
OPERATES 1.00 OF THE TIME THE FACTORY IS OPERATING
      COMPONENT: PACKER, CRATING AND SHIPPING APPARATUS
         COST:    20000. $(1976)     INSTALLATION:      1000. $(1976)
         SALVAGE VALUE:         0. $(1976) AFTER  7.0 YEARS
   QUANTITY 1.042E+04 CRATES/YEAR AT 1343.4087 $(1975)/CRATES
   NUMBER OF 5.10 MACHINES =  1.000, OF WHICH  .068 ARE IDLE
   FACILITIES AND PERSONNEL
      1.100E+02 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE  A)
        IS REQUIRED BY EACH COPY OF PROCESS 5.10
      1.000E+00 PRSN*YRS OF B3656D, PACKAGER MACHINE
        IS REQUIRED BY EACH COPY OF PROCESS 5.10
   UTILITIES AND COMMODITIES
      3.000E+00 CU. FT. OF E1180D, CRATES, WOODEN
        IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.10
      3.400E-02 KW HR. OF C1032B, ELECTRICITY
```

```
      IS REQUIRED EVERY OPERATING MINUTE BY EACH COPY OF PROCESS 5.10
INTRA-INDUSTRY PRODUCTS
   EACH ONE PANELS OF GOODPAN, GOOD PANELS,
       PRODUCES'  .1000 CRATES OF CRATEMOD, CRATED PANELS, 10/CRATE
```

The analysis shows that using this process and the conceptual factory a 1986 selling price (in 1975 \$) of \$0.56 is obtained. This includes the cost of the silicon web at \$0.17/watt (1975 \$).

The pages headed by "Current Technology" are a print out of the various sub-processes showing the commodities and other direct costs by that process. The total direct requirements are shown in order of descending costs. This again gives an idea of the cost drivers in the system.

Figure 39 shows a bar chart of the costs involved in the process. The processes and materials which have a significant effect on the cost are the web itself and the encapsulating materials. Replacement of Ag with Cu would save almost \$0.01/watt. This chart also shows that the design and building of the capital equipment used in processing must be carefully considered. This is shown in Tabular form in Table 35. This data shows the equipment cost for a 25 MW processing line would be about 5.6×10^6 (1975\$) occupying over 8800 ft^2 of space. Thirty production people would be required. The most expensive commodity is the incoming silicon web which is about 70% of the total, while the glass and backing board are 16% of the total. These three commodities then account for 86% of the total materials cost.

6.3 Pilot Line

The input data used in 6.2 were revised and recalculated to determine the cost of the solar arrays produced in a conceptual pilot line. The following assumptions were made:

- 2 MW/yr productions - 2×10^4 M^2/yr for 10% module
- Capital costs = capital costs of a 25 MW module + 20%
- Labor = $\frac{1}{2}$ of a 25 MW module

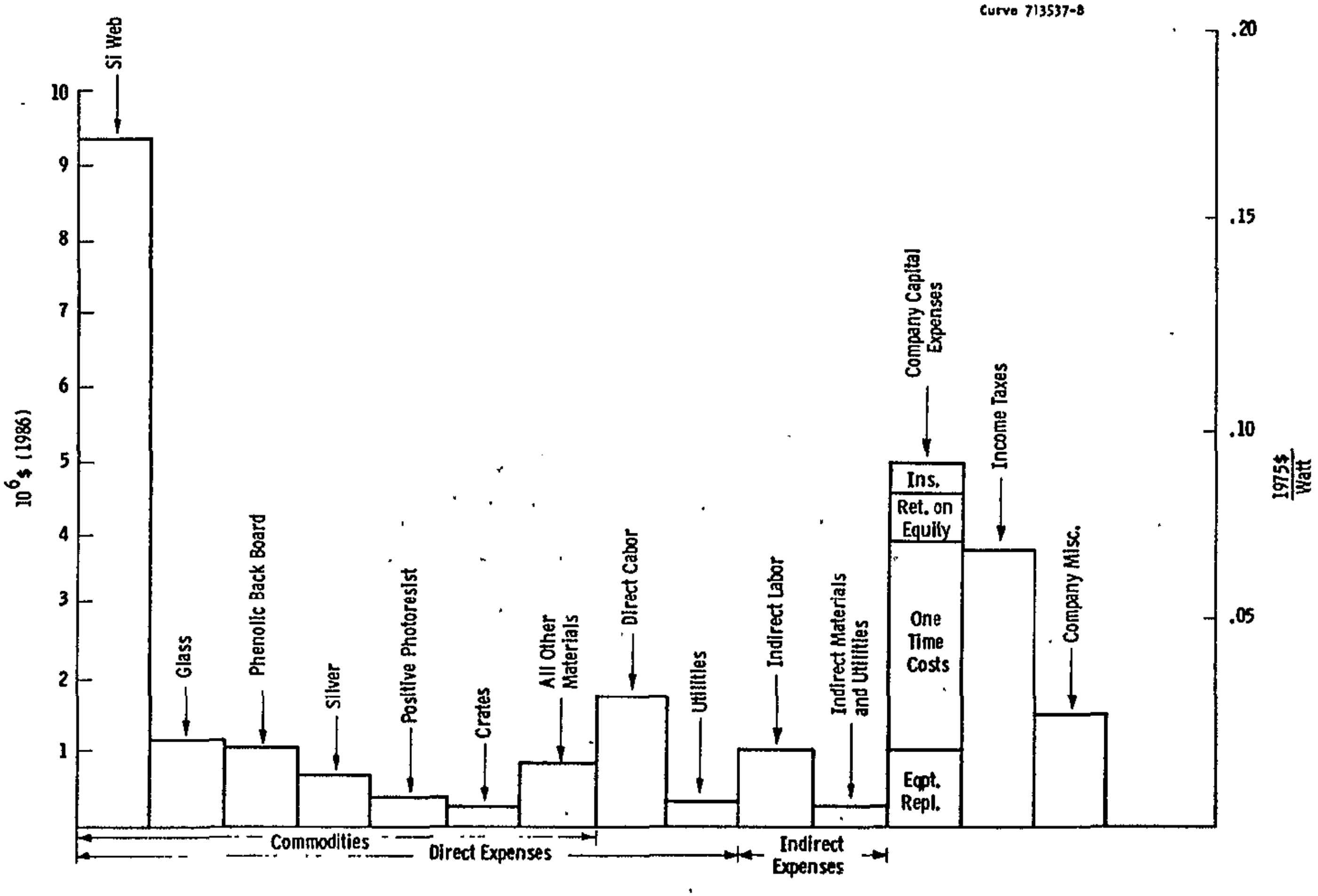

Fig. 39 Breakdown of Array Costs (total 1986$ for 25 MW and 1975$/watt)

TABLE 35

TOTAL PROCESS SEQUENCE - COST FACTORS - 25 MW/YR

Capital (1975 K$)	5,615
Labor (PY)	30
Utilities (KW)	685
Floor Space (sq.ft.)	8,845

Commodities	Usage/ Year	1975K$/year)
Si web (cm^2)	2.315×10^9	4,644
Glass (sq.ft.)	2.593×10^6	561
Back Board (sq.ft.)	2.593×10^6	535
Silver (gms)	1.653×10^6	289
Positive Photoresist) (gal)	1713	189
Crates (cu.ft.)	1.389×10^6	120
Palladium (tr.oz.)	1991	117
RTV 615 (lb)	6944	67
Hydrofluoric acid (lbs)	1.167×10^5	66
Silane (lbs)	1852	51
RTV 108 (lbs)	8944	17
Acetone (lbs)	7.949×10^4	15
$POCl_3$ (lbs)	1389	14
5% Diborane (lbs)	3935	3.5
Aluminum (lbs)	4074	2.5
AZ 111 Dev. (Gal)	1852	2
Titanium (lbs)	46	1.5
Isopropyl Alc. (lbs)	769	1
Aluminum Ribbon (lbs)	546	.5
		6,696

- Materials and utilities = $\frac{2}{25}$ of a 25 MW module
- Operation in 1983
- Floor space = same as that of a 25 MW module.

The IPEG results for this is shown in Table 36. The selling price would be about $1.40/peak watt plus the cost of silicon.

6.4 Conclusions

The cost analyses shown in the first three sections indicate that dendritic web silicon, processed according to the manufacturing sequence described earlier can meet the 1986 JPL goals.

The estimates used for the Format A's are generally conservative but it is possible that many mistakes still exist; however as seen in Figure 35 gross errors in estimating many of the material and labor costs would not appreciably change the overall cost. The main area that must be carefully reexamined is the cost of the capital equipment. Any on-going program should study the design of such equipment so that the cost estimates given in this section can be verified.

TABLE 36

SECTION I - INPUT

PROCESS	YIELD	EQUIPMENT COST	TOTAL FLOOR SPACE	TOTAL DIRECT LABOR	TOTAL BYPRODUCT EXPENSES	TOTAL DIRECT M&SUPPLIES	TOTAL DIRECT UTILITIES	PERCENT YIELD
	#5	#11	#13	#15	#16	#17	#18	
INTERCAP	.60000000	14.43292	649	154243	0	68480	337	.60
LASCRIB	1.00000000	501299	549	154243	0	0	265	1.00
METAL	1.00000000	1239999	981	154243	0	143779	2850	1.00
NUARCT	1.00000000	627399	599	154243	0	54389	826	1.00
JUNCFORM	1.00000000	2577199	1161	197637	0	329963	591	1.00
		#20	#21	#22	#23	#24	#25	
TOTALS	.60000000	5534995	3939	814609	0	596611	4869	

SECTION II - OUTPUT - SELLING PRICE PER WATT PRODUCED

PROCESS	YIELD	EQUIPMENT	FLOOR SPACE	DIRECT LABOR	BYPRODUCTS	MATERIAL&SUPP	UTILITIES	TOTALS
INTERCAP	.60000000	14.43293	3.14765	16.19551	.00000	4.45120	.02190	38.24919
LASCRIB	1.00000000	12.28183	2.66265	16.19551	.00000	.00000	.01722	31.15721
METAL	1.00000000	30.37998	4.75785	16.19551	.00000	9.34563	.18525	60.86422
NUARCT	1.00000000	15.37128	2.90515	16.19551	.00000	3.53528	.05369	38.06091
JUNCFORM	1.00000000	63.14137	5.63085	20.75188	.00000	21.44759	.03841	111.01012
TOTALS	.60000000	135.60737	19.10415	85.53394	.00000	38.77971	.31648	279.34166
MULTIPLIER		.49	97.00	2.10	1.30	1.30	1.30	

ANNUAL AMOUNT .2000+07 MW

7. CONCLUSIONS

Based on the work thus far on this contract we conclude:

(1) Reagent grade $POCl_3$ may be used as a substitute for semiconductor grade $POCl_3$.

(2) A CVD oxide, boron doped or undoped, is a suitable diffusion source for boron or a diffusion mask.

(3) An operational BSF field can be obtained using a boron back-diffused material.

(4) A precursor solution containing TiO_2 and SiO_2 in alcohol can be used as an effective AR coating.

(5) These precursor solutions can be applied to the dendritic web by dip coating and heat treating.

(6) Electroplated Ag is a cost-effective substitute for evaporated Ag as the conductive metal in a solar cell contact.

(7) Electroplated Cu can be used to replace Ag, although long-term stability should be investigated.

(8) Laser scribing from the back is a feasible, cost-effective technique for cell separation.

(9) Ultrasonic welding techniques are feasible for interconnecting cells.

(10) The process sequence we selected (ARRAY process) is suitable for fabricating dendritic web silicon into solar cells.

(11) Front junction depths of 0.4 μm or deeper are not affected by sintering in H_2 at 425°C for 15 min, regardless of the type of silicon base material.

(12) Dendritic web silicon, having the proper material characteristics, can be processed into solar cells equal to cells produced on Czochralski material.

(13) Dendritic web silicon can be processed to nearly meet the 1986 JPL goals of \$0.50/watt peak (1975 \$).

8. RECOMMENDATIONS

We recommend that:

- An optimum process sequence be selected that is specific to the requirements of web.
- A more complete process sequence verification study be carried out.
- A continuing economic analysis be carried out to assure that the 1986 price goals are met.
- Ion implantation be investigated as a front-junction and/or a back junction formation technique. This technique should be tested in conjunction with $POCl_3$ front junction diffusion and Al BSF back junction.
- Al BSF back junction be studied.
- The long-term reliability of a total Cu (contact plus interconnect) system be determined.
- Proper encapsulation materials be further studied to reduce the module cost.
- Thermal analysis be performed and module designs obtained that have lower thermal impedances (junction to ambient)

9. NEW TECHNOLOGY

The following new technology was developed during this period:

(1) Use of electroplated copper as a contact material.

(2) Separation of solar cells from matrix using laser scribing.

(3) Ultrasonic welded connections between Al and Cu foils to electroplated Ag or electroplated Cu layers.

(4) Definition of a suitable process sequence (ARRAY process).

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