General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

DETERMINATION OF A DEFINITION OF SOLAR GRADE SILICON

First Quarterly Report

1 October — 31 December 1975

by

Henry W. Gutsche, Program Manager
Dale E. Hill, Principal Investigator

for

JET PROPULSION LABORATORY
Pasadena, California

Contract No. 954338

This work was performed for the Jet Propulsion Laboratory,
Pasadena, California, sponsored by the National Aeronautics
and Space Administration under Contract No. NAS7-100

(NASA-CR-147916) DETERMINATION OF A DEFINITION OF SOLAR GRADE SILICON Quarterly Report, 1 Oct. - 31 Dec. 1975 (Monsanto Research Corp., St. Peters, Mo.) 30 p HC $4.00 CSCL 11D G3/27
N76-23437
Unclas
40299

MONSANTO RESEARCH CORPORATION

P.O. Box 8
St. Peters, Missouri 63376

DETERMINATION OF A DEFINITION OF SOLAR GRADE SILICON

First Quarterly Report

1 October - 31 December 1975

by

Henry W. Gutsche, Program Manager
Dale E. Hill, Principal Investigator

for

JET PROPULSION LABORATORY
Pasadena, California

Contract No. 954338

This work was performed for the Jet Propulsion Laboratory, Pasadena, California, sponsored by the National Aeronautics and Space Administration under Contract No. NAS7-100

MONSANTO RESEARCH CORPORATION
P.O. Box 8
St. Peters, Missouri 63376

TECHNICAL CONTENT STATEMENT

This report contains information prepared by Monsanto Research Corporation under Jet Propulsion Laboratory Subcontract. Its content is not necessarily endorsed by the Jet Propulsion Laboratory, the California Institute of Technology, or the National Aeronautics and Space Administration.

NEW TECHNOLOGY

No New Technology is reportable for the period covered by this report.

ABSTRACT

The overall objective of this contract is to determine a definition of solar grade silicon by investigating the singular and the combined effect of the impurities usually found in metallurgical grade silicon on solar cell device performance. The impurity matrix was defined by Jet Propulsion Laboratory Technical Direction Memorandum. The initial work was focussed on standardizing our solar cell process and test procedure, growing baseline crystals, growing crystals "contaminated" with carbon, iron, nickel, zirconium, aluminum and vanadium, solar blank preparation, and material characterization. The status of progress, an updated program plan, and the projected activities for the next phase of the contract are discussed.

TABLE OF CONTENTS

		Page
	TECHNICAL CONTENT STATEMENT	ii
	ABSTRACT	iii
1.	SUMMARY	1
	1.1 PURPOSE AND OBJECTIVE OF WORK	1
	1.2 APPROACH	1
	1.3 TECHNICAL STATUS	1
2.	TECHNICAL PROGRESS	3
	2.1 HIGH-OXYGEN CRYSTALS (CZOCHRALSKI)	3
	2.2 LOW-OXYGEN CRYSTALS (FLOAT-ZONED)	3
	2.3 MATERIAL CHARACTERIZATION	5
	2.4 CHEMICAL/PHYSICAL ANALYSIS	9
	2.5 SOLAR CELL FABRICATION AND TESTING	9
	2.5.1 Diffusion	9
	2.5.2 Fabrication	10
	2.5.3 Testing	12
3.	PROJECTED ACTIVITIES FOR NEXT QUARTER	22
4.	REFERENCES	23

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

1. SUMMARY

1.1 PURPOSE AND OBJECTIVE OF WORK

The purpose of studying the influence of impurities and impurity content on the properties of single crystal silicon is to find maximum impurity concentrations that still make acceptable solar cell devices for terrestrial application.

The overall objective is to determine a definition of solar grade silicon from the data obtained during the course of this study. This definition will be in the form of specifications for polycrystal silicon suitable as starting material for single crystal sheet, ribbon, or slice preparation for the high volume manufacture of terrestrial solar cells with efficiency equal to or greater than 12%.

1.2 APPROACH

Both Czochralski and float-zone technology are being employed in growing experimental single crystals to study the influence of commonly found impurities on solar cell performance against high- and low-oxygen background in silicon. To investigate thoroughly the effectiveness of a sawed surface, solar cell pairs will be prepared on blanks with backside damage and on blanks which are completely damage free. All crystals are being characterized by electrical, metallographic, and chemical-physical analysis. A slice-locating system has been devised to correlate, without error, material characterizations with device performance. A simple solar cell manufacturing process is used which generates devices of reproducible efficiency from baseline, i.e. standard semiconductor grade 1-4 ohm-cm P-type Czochralski silicon. Precise information of impurity content of the material and device performance data will permit definition of maximum allowable impurity levels in "solar grade" silicon.

1.3 TECHNICAL STATUS

- A simple laboratory solar device fabrication process employing phosphine diffusion and titanium-silver metallization has been developed. The process delivers without anti-reflection coating and backside treatment 8% efficient cells reproducibly.

- All scheduled baseline material and experimental crystals with carbon, iron, nickel, zirconium, vanadium and aluminum as "secondary or contaminating" impurities have been grown.

- Material characterization and blank preparation is in progress.
- A slice identification system has been devised which allows locating any slice within a crystal.
- The first set of blanks has been delivered to Jet Propulsion Laboratory.

2. TECHNICAL PROGRESS

2.1 HIGH-OXYGEN CRYSTALS (CZOCHRALSKI)

The scheduled baseline Czochralski material, P-type, boron-doped, 0.5 - 0.015 ohm-cm, was grown on the (100) plane with no difficulty. When adding carbon as the secondary impurity, we found that 9×10^{17} atoms/cc, the literature value of the limit of solubility of carbon in solid silicon in contact with the melt, was not compatible with our "zero-dislocation" process. This process requires a crystallization rate away from the seed which is much too fast for carbon to comply with the equilibrium value of the segregation coefficient. To avoid precipitation or "feathering" we added, instead of the theoretical 8.6×10^{-4} mg carbon per gram melt, only 1.6×10^{-4} mg/g. To obtain sufficient single crystal with 10^{16} atoms/cc carbon content, the crystal must be grown at a much faster rate than usual. The new procedure is being employed in growing material with iron as the secondary or contaminating impurity. After experiencing failure because of loss of structure (=zero-dislocation) and feathering, lowering the iron content in the melt and accelerating the growth rate resulted in pulling 80% of the melt before feathering occurred. A sufficient portion of this material should have the desired iron concentration of 1×10^{15} atoms/cc.

2.2 LOW-OXYGEN CRYSTALS (FLOAT-ZONED)

The poly feed rods selected for the contract have low base levels of less than 0.3 ppb N-type impurities (effective value, i.e. N_D-N_A). The rods are 50 cm long, and 26 to 28 mm in diameter. Special care is taken in handling the rods to avoid any surface contamination.

The poly rod is set up in a zone refiner which has a chamber approximately 15 cm in diameter (I.D.) and 110 cm long. An r-f heating coil concentric to the top rod and the bottom seed is located in the center of the chamber. The coil used is a one-turn copper loop with silver plating. Its dimensions are 28 mm I.D. and 62 mm O.D. The generator used for the r-f power operates at 2.2 to 3.0 MHz and is capable of delivering up to 50 kW power.

The first pass smooths the somewhat rough poly surface and "sweeps" any metallic impurity present to the end of the rod. The first pass is started by preheating the poly rod and by forming a molten drop on the bottom of the rod. The seed is brought in contact with the molten drop. By individually controlling the rate that the poly rod is fed into the coil and the rate at which the seed is pulled away from the coil, a taper is established on the rod gradually increasing to the desired diameter.

After the first pass the rod is prepared for "contamination" with the metallic impurity. Since the zone volume increases steadily in the taper and becomes nearly constant only in the body, metallic impurities are added at about 1 in. above the end of the taper. The exact molten volume is difficult to measure directly. We estimated it at 2.355 cm^3 (zone volume). This value is used to calculate the amount of metallic impurities to be added.

Three notches of 1 mm width and 7 mm length are sawed in the rod at about 1/2 in. apart. The rod is then etched and thoroughly cleaned. The weighed amount of the metal (preferably in wire form) is inserted in these notches and the rod is set up for the final pass.

Boron doping is done by allowing a diborane/argon gas mixture to flow continuously around the molten zone. The various parameters used in the first and the final pass are listed in Table 1. Table 2 lists the crystals grown to date.

Table 1

PROCESS SPECIFICATION

A.	Poly feed rod	dia	$\sim$2.6 cm min.
		length	$\sim$50 cm
		bulk resistivity	>300 ohm-cm
B.	Seed crystal	dia	$\sim$0.6 cm
		length	4 cm
		orientation	100
C.	Machine setup	atmosphere	Argon
		purging rate	35 CFH
		chamber O_2 content	<8 ppm
		setup time	45 minutes
		cooling time	30 minutes
D.	Crystal growth - Parameters	1st Pass	Final Pass
	Zone travel mm/min.	4.0	3.2
	Bottom Rotation, rpm	6.0	6.0
	Top Rotation, rpm	2.0	2.0
	Diameter, cm	3.0	3.1
	Orientation	None	100 (dislocation free)

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Table 2

FLOAT-ZONE CRYSTALS PREPARED TO DATE

Crystal No.	Impurities Primary	Impurities Secondary	Resistivity Target (ohm-cm)
M1A	Boron	-	1.0
M1B	Boron	-	0.1
M1C	Boron	-	<0.1
M 2	Boron	Fe (∿ 10^{15} at./cc)	0.5
M 4	Boron	Ni (∿ 10^{16} at./cc)	0.5
M 5	Boron	V (∿ 5×10^{14} at./cc)	0.5
M 6	Boron	Zr (∿ to be determined)	0.5
M10	Boron	Al (∿ 10^{17} at./cc)	0.5

Amount of Metal Impurity to be Added

$$= \frac{C_s \times V_e \times A_w}{N_o \times K_o} \quad \text{(grams)}$$

V_e = Zone Volume, cc
A_w = Atomic Wt of the Metal, g
N_o = Avogadro's Number
C_s = Amount of impurity (atoms/cc) desired in the solid
K_o = Equilibrium segregation coefficient

2.3 MATERIAL CHARACTERIZATION

As of today, sixteen crystal sections and sample slices from ten sections have been received for characterization. The resistivity data gleaned so far are summarized in Tables 3 and 4. All crystals were P-type. The minority carrier lifetime was less than 20 microseconds in all specimens. Development of technique to determine lifetime in low resistivity and slice material is incomplete. Metallographic techniques, Sirtl-etching before and after oxidation,

Table 3

ELECTRICAL RESISTIVITY OF CRYSTAL SECTIONS

Section	Type	Center ρ		Gradient *R/2		Gradient 1/8"	
		SE	OE	SE	OE	SE	OE
		(ohm-cm)		%		%	
C-1-A	P	0.53	0.51	0.8	0.4	1.4	0.4
C-1-C	P	0.016	0.015	0.3	1.0	0.5	1.0
C-2-C	P	0.015	0.015	0.8	0.3	2.4	0.9
M-1-A	P	1.04	1.08	0.9	4.9	4.3	5.1
M-1-C	P	0.04	0.04	4.6	0.3	3.3	1.8
M-1-B	P	0.14	0.16	0.7	0.3	2.6	1.9
C-2-A (1)	P	0.52	0.50	2.0	0.7	0.9	0.9
C-2-A (2)	P	0.50	0.51	2.4	0.4	7.5	1.9
M-4-B (1)	P	0.45	0.43	2.8	0.2	6.2	1.6
M-2-B (1)	P	0.42	0.47	1.3	1.0	1.8	4.0
M-2-B (2)	P	0.35	0.36	0.7	2.3	5.6	4.9
M-2-C	P	0.05	0.05	1.1	5.6	0.1	9.8
M-4-B (2)	P	0.49	0.46	1.8	0.4	4.5	2.0
M-6-B	P	0.49	0.44	0.2	6.4	4.2	12.4 (?)
C-3-A	P	0.48	0.38	0	2.4	1.4	5.7

$$\% \text{ Gradient} = \frac{\text{Edge-Center}}{\text{Center}} \times 100.$$

Table 4

ELECTRICAL RESISTIVITY OF SLICES

	Slice Resistivity		Results of Slice Band Resistivity				
Section No.	Center	R/2 Gradient	1/8 Gradient	$\overline{X}$	Range	Sigma	% Sigma
C-1-C	0.01593	-1.9	3.5	0.01586	0.0009	0.00021	1.35
	0.01568	1.9	5.9	0.01598	0.0008	0.00019	1.19
	0.01620	-1.5	6.7	0.01610	0.0007	0.00017	1.03
	0.01585	0.3	5.0	0.01602	0.0007	0.00017	1.04
C-2-C	0.01593	-0.8	3.9	0.01580	0.0004	0.00009	0.60
	0.01493	1.1	4.5	0.01508	0.0008	0.00019	1.25
	0.01575	0.6	4.6	0.01587	0.0008	0.00019	1.19
	0.01613	0.3	4.5	0.01609	0.0009	0.00021	1.33
M-1-A	1.006	0.9	4.6	1.018	0.061	0.0172	1.68
	1.027	1.1	6.1	1.036	0.050	0.0141	1.36
M-1-C	0.0418	-0.5	1.7	0.0420	0.0032	0.0009	2.14
	0.0392	-0.3	1.3	0.0395	0.0023	0.0006	1.51

were employed to determine structure and to facilitate proper cropping of the as-grown crystal. A slice identification system was developed which enables us to pinpoint any processed slice's exact location in the crystal (Figure 1).

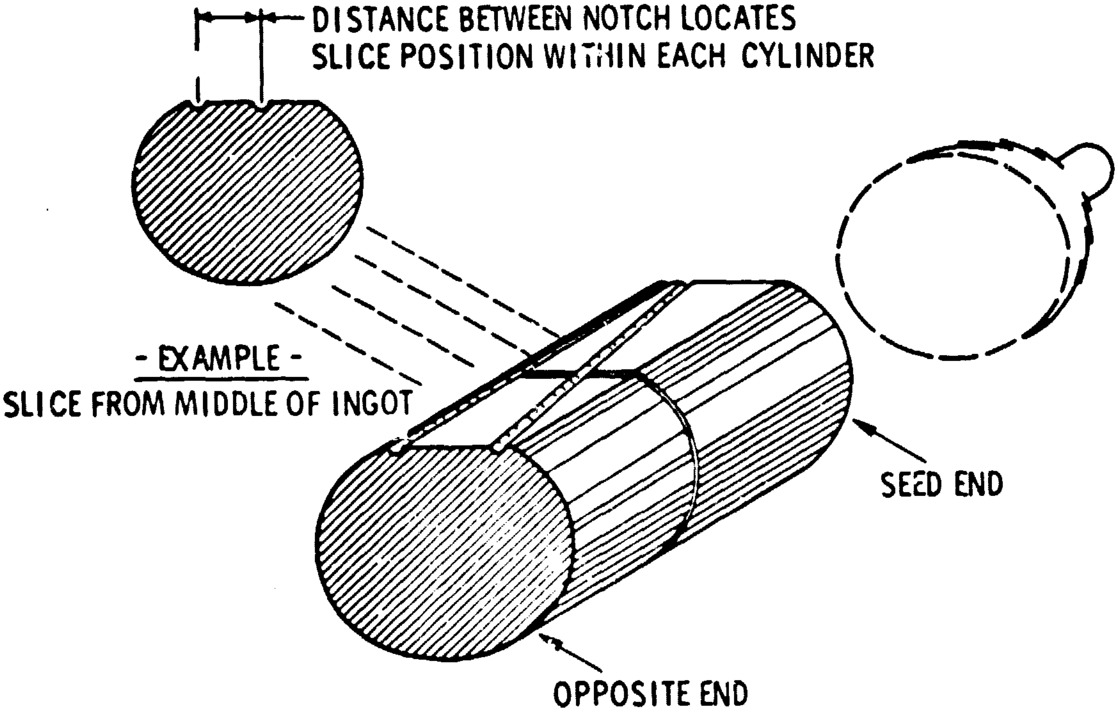


Figure 1. Slice identification

2.4 CHEMICAL/PHYSICAL ANALYSIS

Requirements for sample sizes, number of wafers, and thickness of wafers for analysis have been determined. The first series of crystals of Czochralski process (C-1 and C-2) and Mon-X process (M-1) have been received according to analytical requirements.

Several samples were taken from carbon-doped sample (C-2) and prepared for vacuum fusion analysis. The samples were sent to Leco Corporation for oxygen and carbon determination. Quadruplicate determinations of those elements were requested and the data will be used as references in analysis with infrared spectrophotometry (IR) and spark source mass spectrometry (SSMS).

Sample preparations for IR, SSMS, and emission spectroscopy (ES) are in process.

2.5 SOLAR CELL FABRICATION AND TESTING

2.5.1 Diffusion

The phosphorus diffusions in this work employ phosphine as a diffusant source. The diffusions are carried out at 850°C in a gas stream consisting of 800 cc/min. of 1% PH_3 in Ar, 140 cc/min. of O_2, and 3000 cc/min. of N_2. The wafers are given a 3-minute preheat in the hot zone in O_2 and N_2, and a 10 - 30 minute diffusion in the full gas stream, followed by a 10-minute oxidation and flushing operation in O_2 and N_2 and a 5-minute slow cool in N_2 in the end of the furnace tube.

In order to obtain the best reproducibility,[1] diffusion runs are spaced 30 minutes apart with a N_2 flow through the furnace during this period. A run without wafers is performed prior to each series of diffusions to condition the diffusion tube. Sheet resistances in the range of 50 to 100 ohms/□ are under investigation.

A boron solar cell diffusion for N-type substrates was under development during the first portion of this contract since the proposed matrix of experiments included equal numbers of N and P type substrates. The N-type substrates were essentially eliminated by a Technical Direction Memorandum from JPL so that the development of the boron solar cell diffusion has been postponed. The work done to date is summarized below.

The boron diffusion employed for this work makes use of Combat[2] boron nitride discs as the boron source. This method of diffusion has been investigated by Goldsmith[3] of RCA and others[4] and has some advantages over other boron diffusion methods.

Carborundum claims that the BN disc system results in improved sheet resistance reproducibility of ± 2% across the wafer, ± 3%

within a run, and ± 4% from run to run, and these claims seem to be born out by our experience. In addition, this system should be expandable to larger wafers and large numbers of wafers without the difficulties encountered in flow systems. Grade "A" BN wafers are currently being used in this work. Grade "M" BN wafers were used initially and resulted in solar cells which suffered from shorts.

The diffusions are carried out in the following manner. Before the initial oxidation the BN discs are solvent-cleaned, rinsed and etched, then rinsed again, dried, and placed in a diffusion boat. These discs are then thoroughly baked in flowing N_2 in the entrance of the furnace tube and then slowly pushed into the center zone of the furnace at 920°C. At this point the N_2 is turned off and the discs are oxidized in a flow of 1000 cc/min. of O_2 for 30 minutes. Then the discs are stabilized at the same temperature in 1000 cc/min. of N_2 for 1 hour. It is necessary to store the discs after oxidation in a dry N_2 atmosphere at a temperature of 200°C or greater. This is done in a diffusion tube extension near the entrance of the furnace. The discs are reoxidized every week.

The silicon wafers are placed in the diffusion boat back to back, with the front surfaces facing BN discs. The wafer surfaces are parallel to the BN discs and spaced about 1/8 in. apart. The BN discs used have a diameter at least 1/4 in. greater than the silicon wafers. The wafer and disc surfaces are perpendicular to the axis of the furnace tube and the diffusion is carried out in a 1000 cc/min. N_2-flow.

After deposition the wafers are cleaned and a drive-in diffusion and oxidation can be used if desired to obtain a deeper junction with lower boron concentration. To date the boron diffused solar cells have been investigated using only the deposition diffusion described here which results in a sheet resistance of 97 ohms/□ .

The above diffusion processes are being developed using semiconductor grade silicon in the range of 0.3 to 2 ohm-cm resistivity. This material will then be used as a control and a wafer will be run with each diffusion batch to insure that the diffusion was accomplished as intended.

2.5.2 Fabrication

Following diffusion the wafers are fabricated into solar cells using Ti/Ag contacts and photolithographic techniques to define the desired patterns. The principal steps in the fabrication process are described below:

1. Mask front of wafer with black wax.
2. Remove oxide from back of slice in 10% HF.

3. Remove diffused layer from back of slice in CP4.
4. Solvent clean and rinse in distilled H_2O.
5. Remove oxide from front of cell in 10% HF followed by a 1 minute rinse in 0.5% HF, rinse and spin dry.
6. Evaporate 500-800Å Ti followed by 10,000Å Ag on the front of the wafer and then on the back of the wafer.
7. Heat treat at 500°C for 10 minutes.
8. Photoresist and etch junction-side contact pattern. Protect backside metallization with photoresist and remove photoresist after etching.
9. Heat treat at 575°C for 10 minutes.
10. Scribe and break into 2 x 2 cm cells.
11. Solder dip.
12. Some cells will be antireflection-coated at this point. Sputtered Si_3N_4 has been successfully applied for this purpose.

The principal difficulties encountered in the fabrication have been related to the Ti evaporation. In the worst cases the adhesion was so poor that the metal pealed away from the silicon. In the least pronounced cases cells with the same V_{OC} and I_{SC} would exhibit different fill factors.

Initially, pieces of Ti "sponge" were evaporated from a tungsten basket. The poor thermal contact between the sponge and the basket required over-heating of the basket in order to melt the Ti. Consequently, the evaporation occurred almost instantaneously, creating difficulties in timing the shutter opening to avoid contamination of the solar cells from the hot filament and yet allowing the Ti to reach the silicon surface.

Titanium-loaded filaments of the kind used in sputtering pumps were evaluated as possible evaporation sources for Ti. These worked very well in a vacuum system which was pumped with Ti sputtering pumps. However, the system used for solar cell metallization is pumped by a liquid nitrogen trapped oil diffusion pump. The Ti-loaded filaments evaporate the Ti so slowly that it is deposited in a partially oxidized condition in this system.

The Ti source presently used for the evaporations overcomes these difficulties to a reasonable degree. It is a simple tungsten filament with a shallow dip in the middle. The center of the filament is wrapped with a measured length of Ti wire to provide good thermal contact between the Ti and the filament. It is then possible to melt the Ti on the filament in a controlled manner, open the shutter, and evaporate the Ti fast enough so that there is no evidence of oxidation.

The initial metallization work was carried out in a small, manually operated vacuum chamber of limited wafer capacity. The development of the Ti source was carried out on the larger, automatic cycling vacuum system to be used for metallization of solar cells. This system has been dormant for some time and at least the usual number of difficulties were encountered in rendering the equipment operational. The system now operates dependably and is capable of metallizing eight 2-1/4 in. diameter wafers or seventeen 1-1/4 in. diameter wafers at one time.

The metallization patterns are determined by photoresist and etching. The geometries of the metal patterns are shown in Figures 2 and 3, and are labeled C-71 and C-72, respectively, corresponding to the mask numbers. The C-71 design employs fairly close spaced metal conductors intended for use with higher sheet resistance diffusions while C-72 is a standard "6-fingered" solar cell pattern. The metal covers 16.74% of the cell surface in pattern C-71 and 12.53% in C-72. This translates into 5% more open space for the C-72 pattern. The masks are fabricated with 4 solar cells in a square array so that 4 cells can be processed together through photoresist and etching.

The resulting pattern from an additional mask, set No. T-28 is shown in Figure 4. This pattern employs an oxide mask and planar diffusion and results in multiple device patterns including a 2 x 2 cm solar cell and several smaller ones, geometries convenient for determining sheet and contact resistance, and a series of round diodes of various sizes. The devices resulting from this mask are useful for capacitance, lifetime, and spectral distribution studies.

Additional masks are currently being fabricated similar to C-71 and C-72 but with a smaller "buss bar" conductor yielding less metal coverage.

Also included in this mask set, above and below the solar cell patterns, are two rows of patterns similar to some of those on T-28. These will permit the measurement of contact resistance and sheet resistance as well as furnishing convenient small device geometries as described above, and eliminate the necessity of oxidizing any wafers.

2.5.3 Testing

In order to better understand the meaning of the efficiency measurements carried out on the solar cells produced in this contract it is necessary to know the spectral characteristic of the light source used in the tests. This light source was used in an Air Mass 2 Simulator developed at Lewis Research Center for NASA.[5] The lamps, designated Quartzline ELH, are manufactured by GE, and

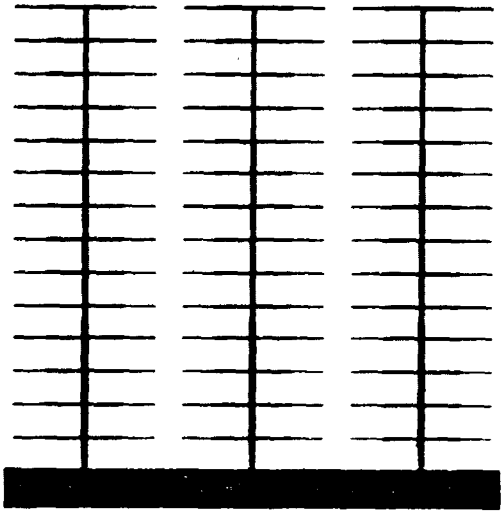


Figure 2. Solar cell metallization mask No. C-71, 2 cm x 2 cm Dimensions: buss bar - 0.060" x 0.771"; vertical arms, segment 1-0.012" x 0.222"; segment 2-0.010" x 0.300"; segment 3-0.080" x 0.205"; horizontal fingers, inner segment - 0.005" x 0.060", outer segment - 0.003" x 0.050"

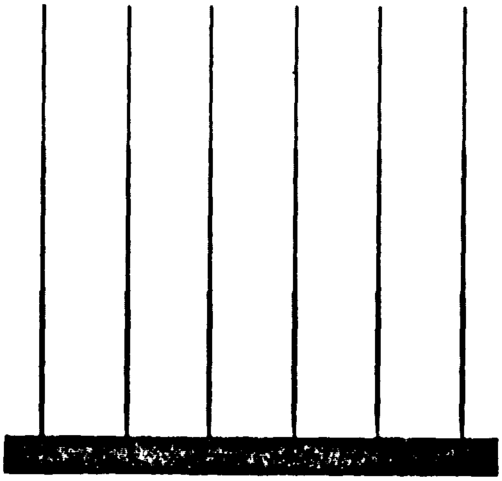


Figure 3. Solar cell metallization mask No. C-72, 2 cm x 2 cm Dimensions: buss bar - 0.060" x 0.771"; vertical arms, segment 1-0.010" x 0.218"; segment 2-0.008" x 0.218"; segment 3-0.006" x 0.218"

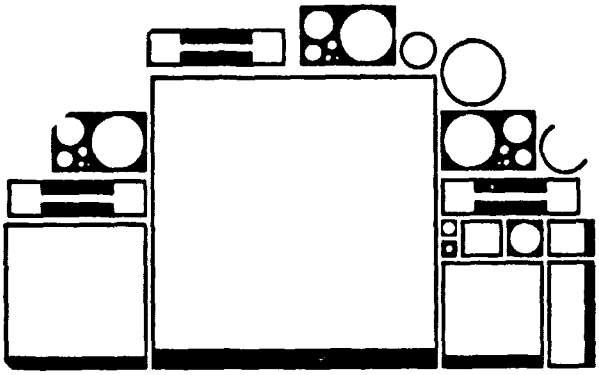


Figure 4a. Diffusion mask No. T-28-1 for solar cell diagnostic pattern

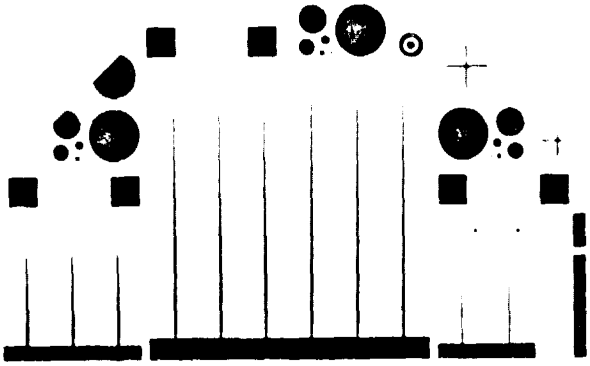


Figure 4b. Metallization mask No. T-28-2 for solar cell diagnostic pattern

rated at 300 watts at 120 volts. They are composed of tungsten-halogen bulb with an axial filament and a quartz envelope.

This bulb is set in a stippled reflector which has a front surface dichroic coating which reduces the infrared content of the reflected radiation. The lamp has a beam angle of 20°, a color temperature of 3350°K, and an average life of 35 hours.

The spectral output of the lamp was measured by placing the slits of a monochromator-photomultiplier combination at the solar cell position without additional lenses, etc. This radiation was then compared with that received by the same monochromator-photomultiplier combination using an Eppley Standard of Spectral Radiance -- lamp No. EPIR-1049.[6] The data were reduced to units of relative photons/second-cm^2 per wavelength interval. These data are shown in Figure 5 for the above light source at 110 volts, with and without a wafer filter. In addition, the Air Mass 2 spectrum is shown in the same units, obtained from the irradiance data reported in "Interim Solar Cell Testing Procedures for Terrestrial Applications."[7] Note that the Air Mass 2 spectrum is much flatter when plotted in terms of photons rather than energy units (as is usually done). However, this seems the most sensible type of plot, since the solar cell is basically a photon-sensitive device.

We see from Figure 5 that the dichroic reflector does a good job of minimizing the infrared light reaching the cell and that the water filter does only limited additional filtering. If one were to compare the light source and the Air Mass 2 spectrum at the same total energy content the light source would over-emphasize the 6000Å to 7000Å region and under-emphasize the blue and IR portions of the spectrum.

Figure 6 compares the spectral output from three different ELH type bulbs. Bulb #2 has a bluish appearing dichroic coating and was the only one of a group of six with that appearance. Bulbs with spectral response like numbers 1 and 3 will be used in this work to facilitate replacement of the bulbs with similar ones.

Figure 7 shows the spectral output of bulb No. 1 at different voltages. We note the expected shift to the blue for higher voltages, but the change in the output is relatively minor over the voltage range of 90 to 120 volts. This allows one to make minor intensity adjustments by varying the voltage without seriously disturbing the spectral distribution. For this work the lamp will be run at 110 VAC ± 5 volts.

All cells discussed here were diffused with the phosphine process described earlier and were measured at 110 mW/cm^2 using the quartz-tungsten-iodine source apparatus described above. The 100 mW/cm^2 was established using a radiation thermocouple with a calibration accuracy of ± 5%. None of the cells are antireflection coated and all have Ti-Ag contacts on both surfaces. No

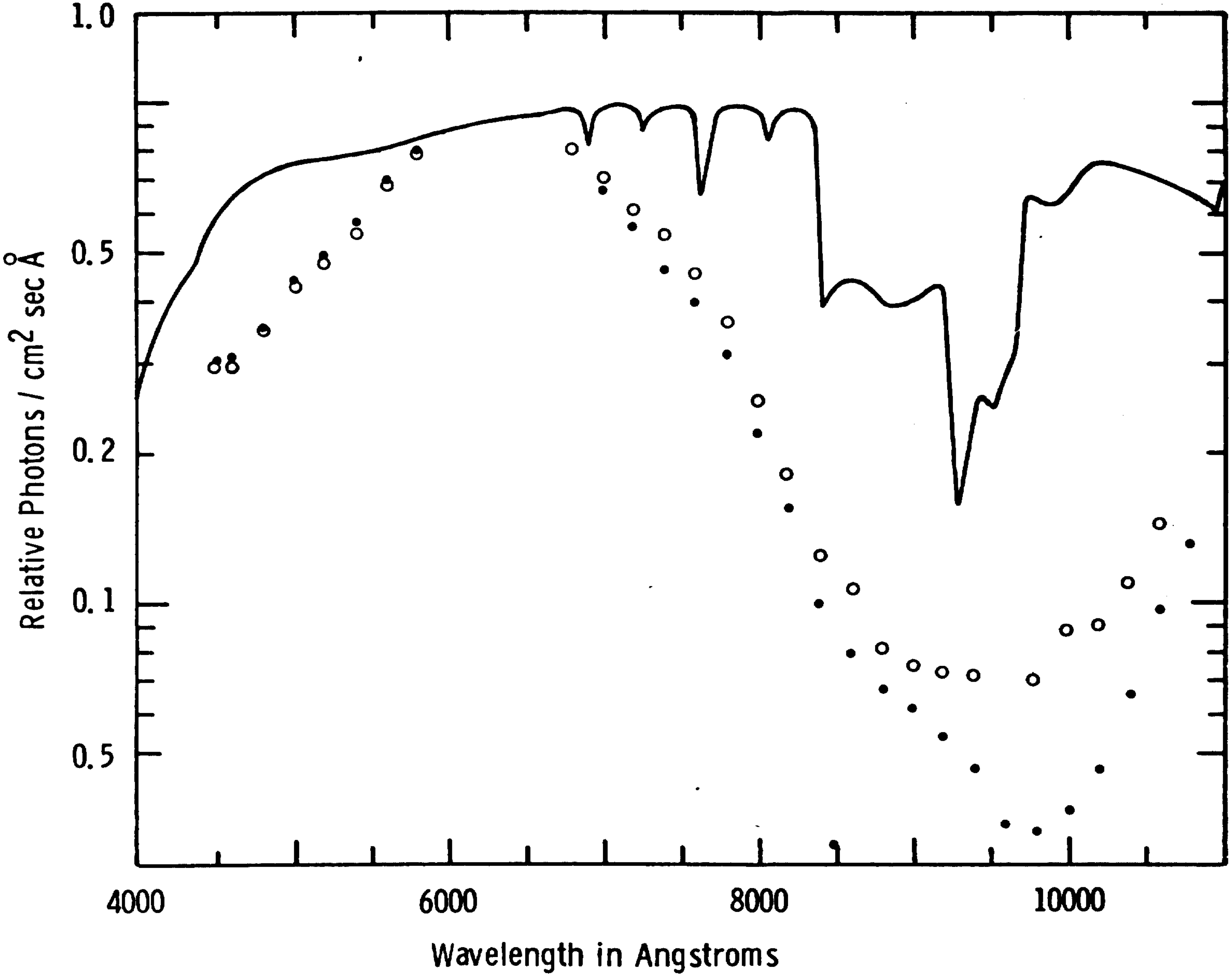


Figure 5. Spectral output of Quartzline ELH lamp compared to Air Mass 2 spectrum. ●--Lamp voltage = 110VAC with water filter; o--Lamp voltage = 110VAC, no water filter.

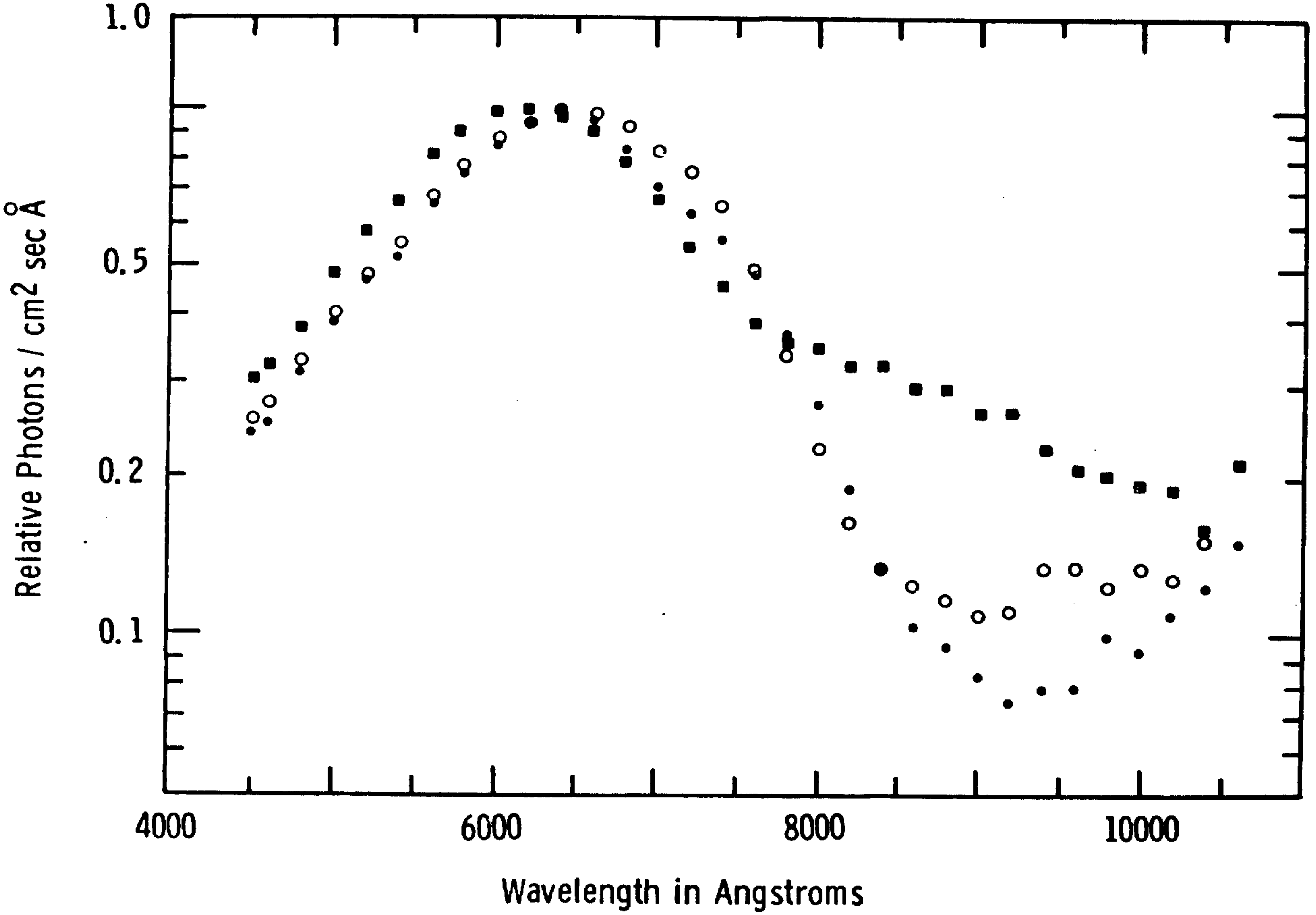


Figure 6. Comparison of the spectral output of three different Quartzline ELH lamps at 90VAC. ●--Lamp #1, ■--Lamp #2, o--Lamp #3.

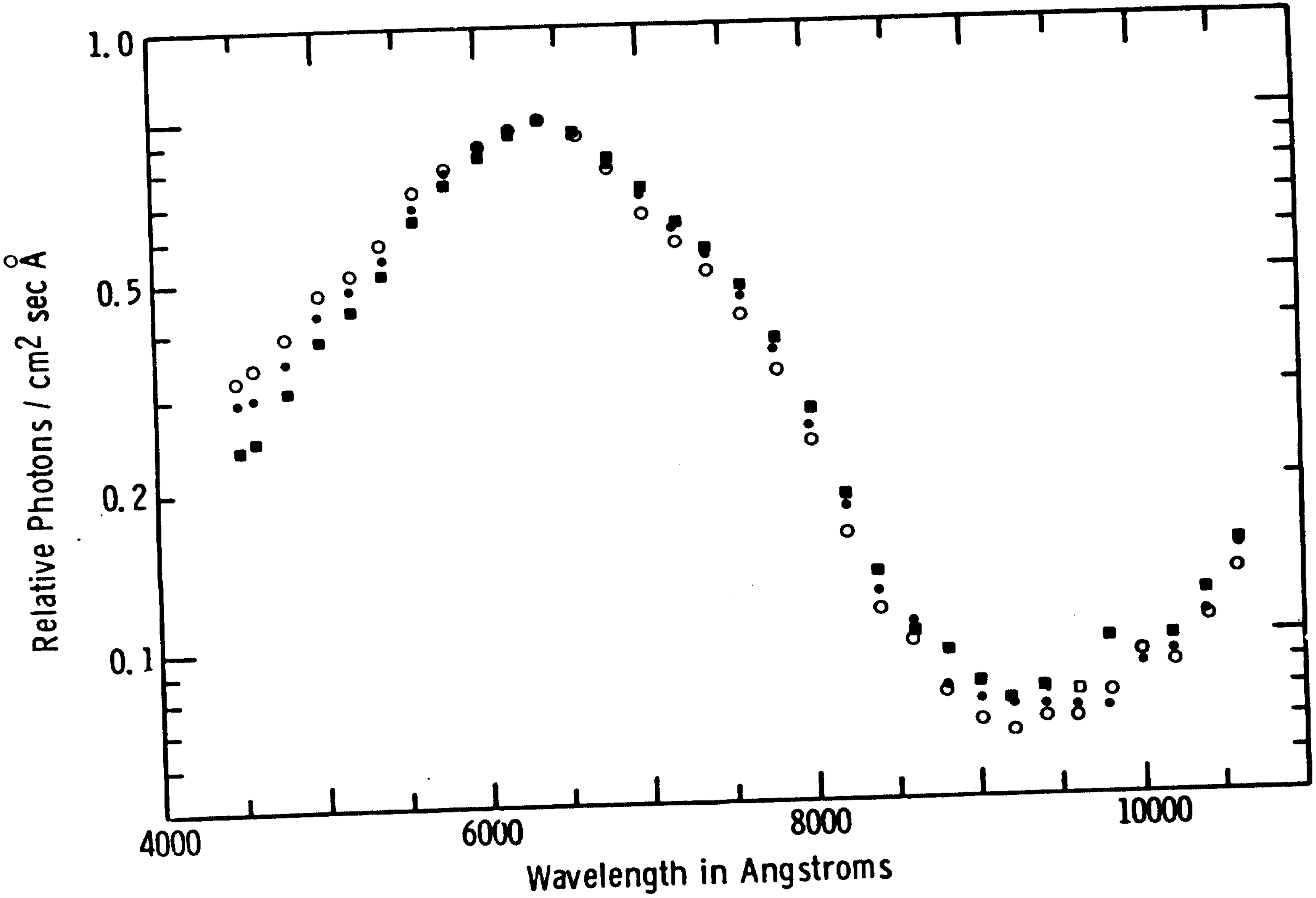


Figure 7. Comparison of spectral output of Quartzline ELH lamp #1 at three different operating voltages. ■--lamp voltage = 90VAC, ●--lamp voltage = 110VAC, o--lamp voltage = 120VAC.

drift field back contacts were used. All cells are 2 x 2 cm square and the efficiencies are computed using the full 2 x 2 cm cell area without any correction for metal coverage.

A sample data sheet showing results for cell #47-3-1 is shown in Figure 8. Table 5 lists average results on the last few diffusion runs. Data from cells with obvious metal lifting problems were not included. However, some of the variation of the short circuit current, efficiency, and fill factor may still be caused by problems with the metallization. More evaluations and reproducibility runs will be carried out during the next months.

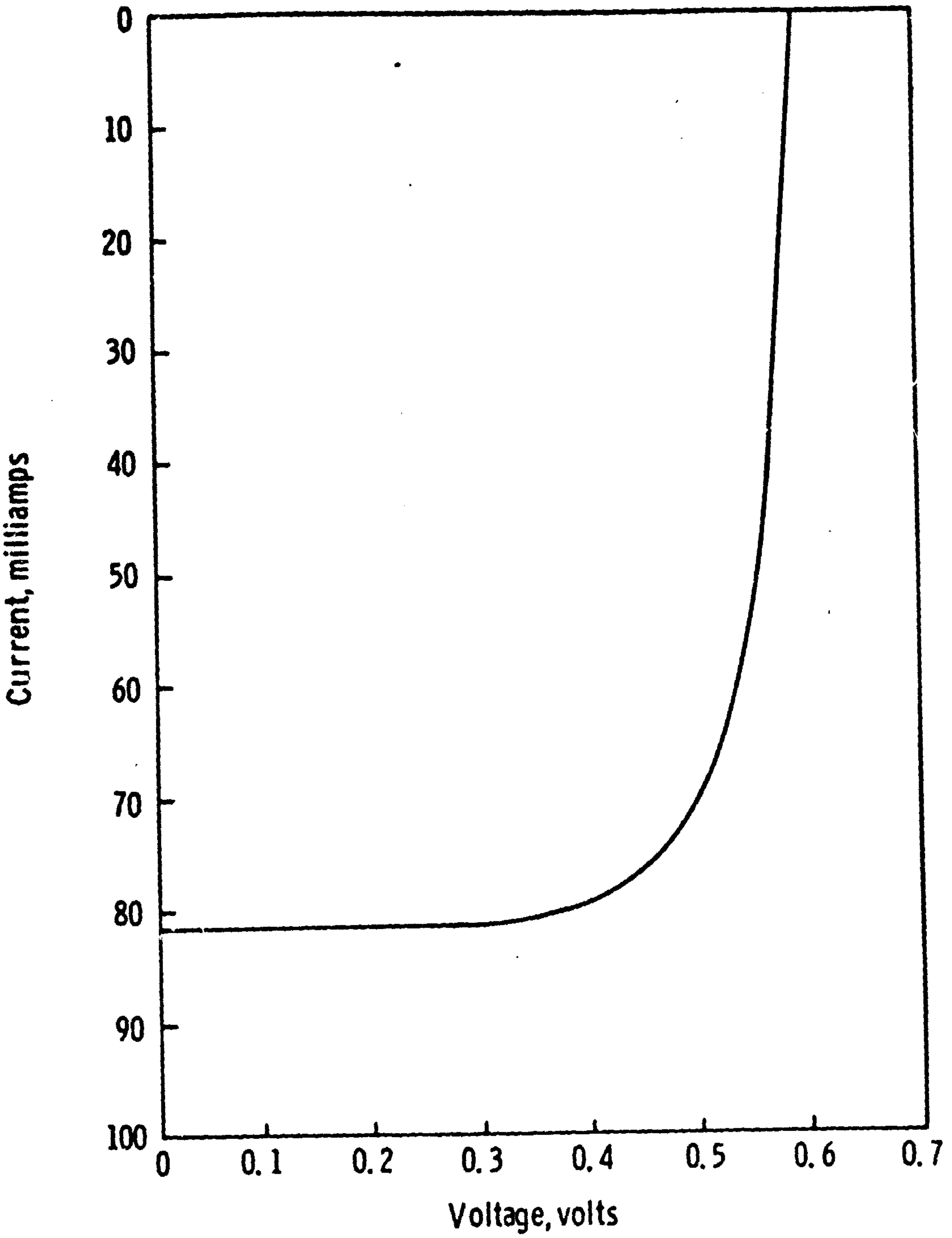


Figure 8. Solar cell #47-3-1 characteristic.

2 cm x 2 cm cell without antireflection coating measured with 100 mW/cm^2 incident flux.

V_{OC} = 0.585, I_{SC} = 81.8mA, Eff = 8.76%, FF = 0.732

Table 5

EVALUATION OF PHOSPHORUS DIFFUSED SOLAR CELLS WITHOUT ANTIREFLECTION COATING AT 100 mW/cm^2 INCIDENT ENERGY DENSITY

Diffusion No.	Material Resistivity (B Doped)	Mask No.	No. Cells	V_{oc} (Volts)	I_{sc}/A (mA/cm^2)	Eff (%)	F.F.
42	4 ohm-cm	C-71	6	0.546 ± .006*	20.4 ± .8	7.73 ± .55	0.697 ± .034
43	4 ohm-cm	C-71	6	0.554 ± .008	20.0 ± .2	8.34 ± .57	0.747 ± .049
44	4 ohm-cm	C-71	5	0.559 ± .003	20.2 ± .5	8.71 ± .21	0.769 ± .008
46	4 ohm-cm	C-71 & C-72	11	0.554 ± .005	19.9 ± .6	8.13 ± .49	0.738 ± .029
47	1 - 2 ohm-cm	C-72	8	0.582 ± .002	20.0 ± .6	8.41 ± .29	0.723 ± .028
55	1 - 2 ohm-cm	C-72	2	0.581 ± .002	20.0 ± .2	8.33 ± .01	0.716 ± .007
56	1 - 2 ohm-cm	C-72	9	0.580 ± .005	20.1 ± .7	7.99 ± .52	0.727 ± .02
57	1 - 2 ohm-cm	C-72	6	0.577 ± .005	18.9 ± .6	7.72 ± .63	0.726 ± .02
	Maximum Values			0.585	20.7	8.91	0.779

*Quantity listed as ± is the standard deviation of the results.

3. PROJECTED ACTIVITIES FOR NEXT QUARTER

- Complete experimental crystal growth.
- Continue blank preparation and material characterization.
- Begin chemical-physical analysis for impurity content.
- Develop lifetime measurement technique for low resistivity material in slice form.
- Manufacture solar cells from experimental blanks and measure cell performance.

4. REFERENCES

1. S. N. Gosh Dastidar, Solid State Technology V18, No. 11, pg. 37.

2. Available from the Carborundum Co., Refractories and Electronics Division, Technical Ceramics Plant, P.O. Box 311, Latrobe, Pa., 15650, phone (412) 537-3331.

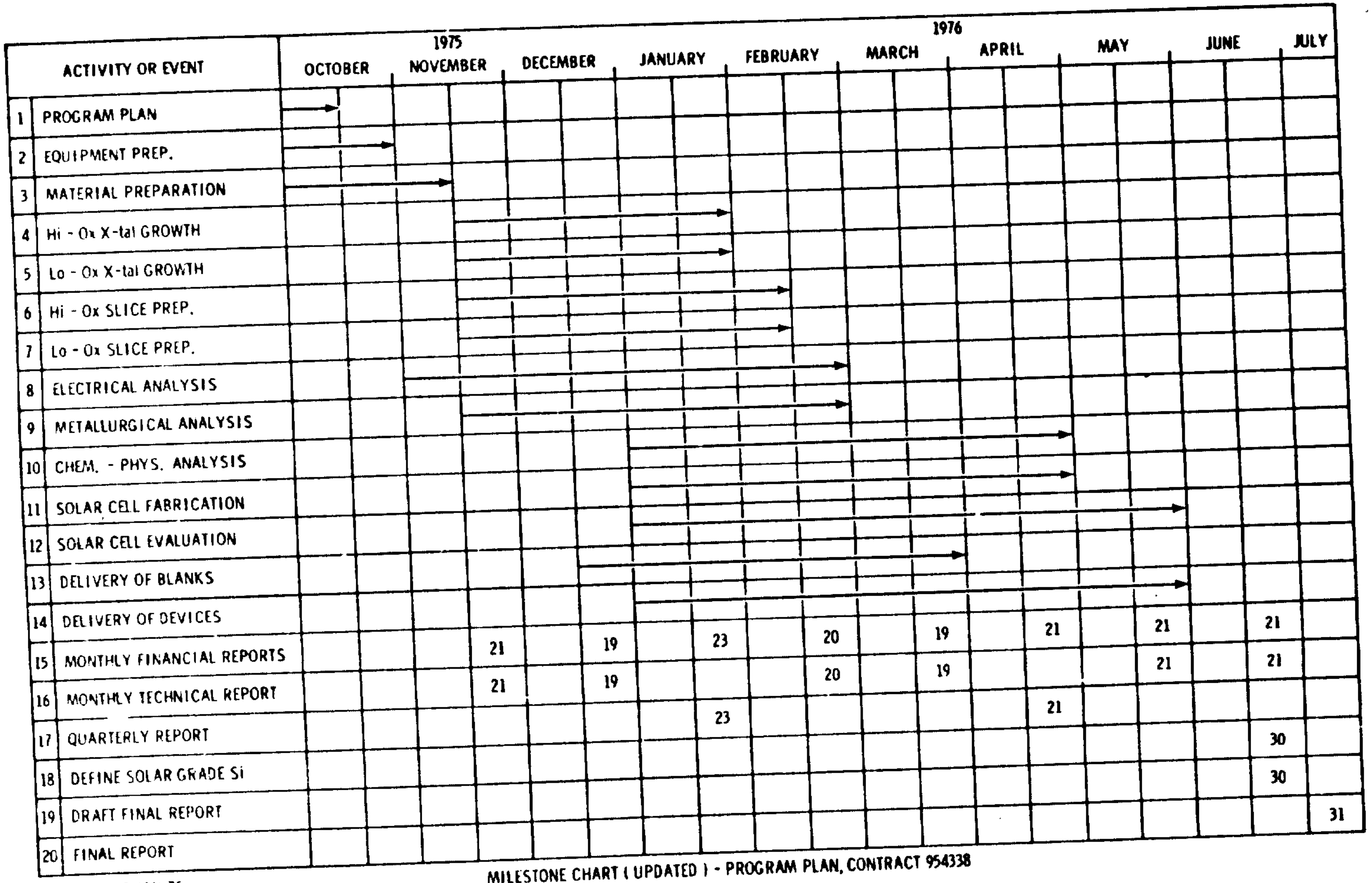
3. N. Goldsmith, J. Olmstead and J. Scott Jr., RCA Review 28, 344 (1967).

4. D. Rupprecht and J. Stach, J. Electrochem. Soc. 120, 1266, (1973); J. Stach and A. Turley, J. Electrochem. Soc. 121, 722 (1974).

5. K. Yass and H. B. Curtis "Low Cost Air Mass 2 Solar Simulator" NASA TM X-3059 June 1974.

6. R. Stair, R. G. Johnston and E. H. Halback, J. of Research of the National Bureau of Standards, Section A, Phys. & Chem., V 64 A, 291 (1960).

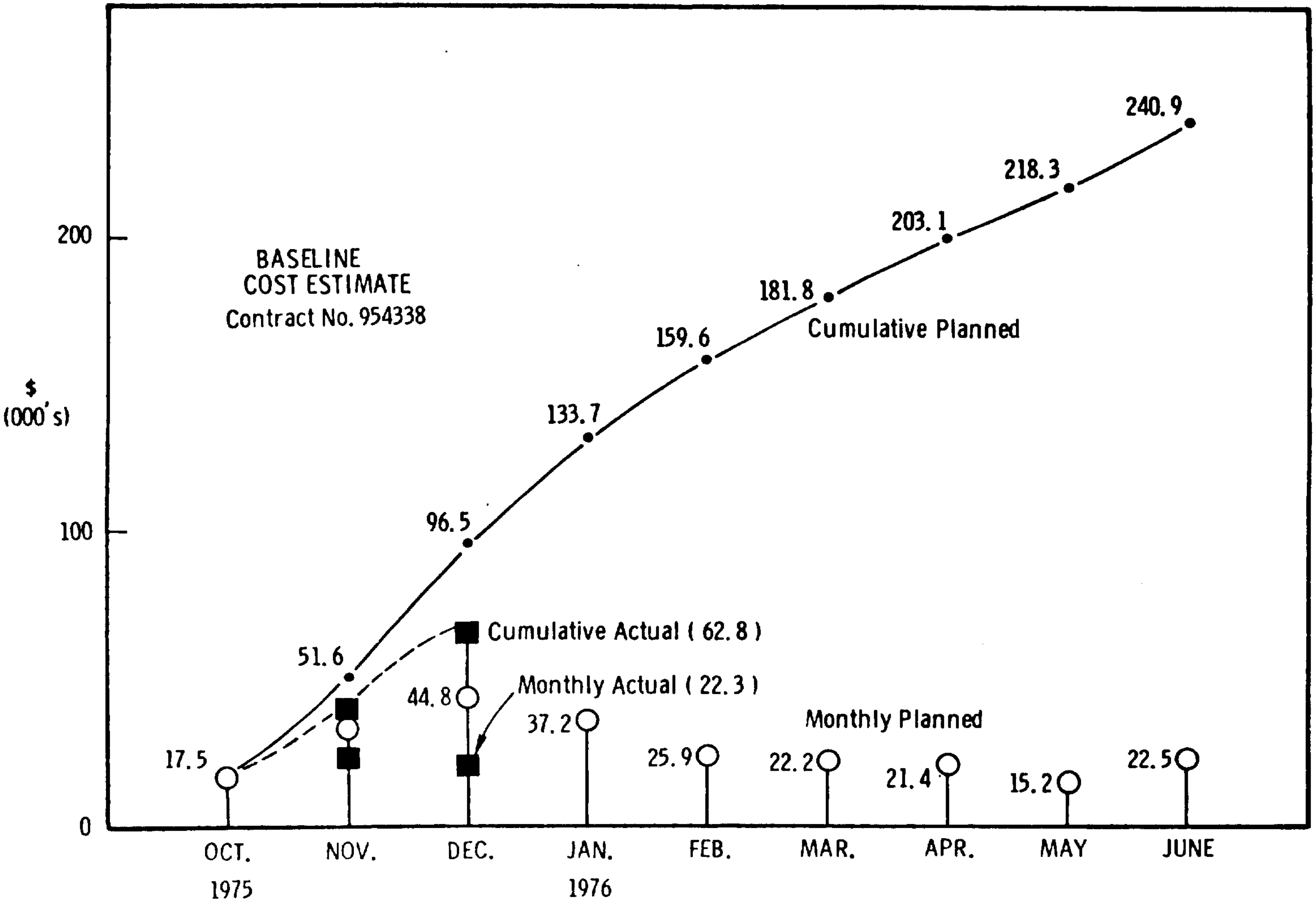
7. "Interim Solar Cell Testing Procedures for Terrestrial Applications," NASA TM-71771, 1975.



	ACTIVITY OR EVENT	1975 OCTOBER	NOVEMBER	DECEMBER	1976 JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY
1	PROGRAM PLAN										
2	EQUIPMENT PREP.										
3	MATERIAL PREPARATION										
4	Hi - Ox X-tal GROWTH										
5	Lo - Ox X-tal GROWTH										
6	Hi - Ox SLICE PREP.										
7	Lo - Ox SLICE PREP.										
8	ELECTRICAL ANALYSIS										
9	METALLURGICAL ANALYSIS										
10	CHEM. - PHYS. ANALYSIS										
11	SOLAR CELL FABRICATION										
12	SOLAR CELL EVALUATION										
13	DELIVERY OF BLANKS										
14	DELIVERY OF DEVICES										
15	MONTHLY FINANCIAL REPORTS		21	19	23	20	19	21	21	21	
16	MONTHLY TECHNICAL REPORT		21	19		20	19		21	21	
17	QUARTERLY REPORT				23			21		30	
18	DEFINE SOLAR GRADE Si									30	
19	DRAFT FINAL REPORT										31
20	FINAL REPORT										

5 JAN 76

MILESTONE CHART (UPDATED) - PROGRAM PLAN, CONTRACT 954338


BASELINE
COST ESTIMATE
Contract No. 954338
$ (000's)
200
100
0
240.9
218.3
203.1
181.8
159.6
133.7
96.5
51.6
17.5
Cumulative Planned
Cumulative Actual (62.8)
Monthly Actual (22.3)
Monthly Planned
44.8
37.2
25.9
22.2
21.4
15.2
22.5
OCT.
1975
NOV.
DEC.
JAN.
1976
FEB.
MAR.
APR.
MAY
JUNE