FLAT-PLATE SOLAR ARRAY PROJECT
PROCESS DEVELOPMENT AREA

PROCESS RESEARCH OF NON-CZ SILICON MATERIAL

QUARTERLY REPORT NO. 1
November 4, 1983 to December 31, 1983

Contract No. 956616

The JPL Flat-Plate Solar Array Project is sponsored by the U. S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE.

Prepared by:

R. B. Campbell
Principal Investigator

Approved by:

C. M. Rose
Project Manager

Advanced Energy Systems Division
WESTINGHOUSE ELECTRIC CORPORATION
P. O. Box 10864
Pittsburgh, PA 15236-0864

TECHNICAL CONTENT STATEMENT

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A. CONTRACT GOALS AND OBJECTIVES

The objective of this contract is to investigate high risk-high payoff research areas on advanced processing techniques for non-CZ silicon sheet material that indicate promise of improving cost effectiveness of photovoltaic module production. The specific goals are as follows:

1. Simultaneous Diffusion of Front and Back Junctions

In this part of the program, the simultaneous diffusion of liquid boron and liquid phosphorus metallorganic precursors* into N-type dendritic silicon web is being investigated. The diffusion parameters required to achieve the desired P^+NN^+ cell structure will be determined, and the resultant cell properties will be compared to cells produced in a sequential diffusion process.

In addition to a standard tube diffusion furnace, a series of experiments will be carried out in a belt furnace. The parameters of cells produced using this method will be compared with cell parameters of tube diffused cells.

2. Process Control Parameters and Sensitivities

During the program, the control parameters of the process will be analyzed; and the sensitivity of cell parameters to variations in these control parameters will be determined. Process control parameters to be studied are diffusion time and temperature; ambient gases and flow rates; liquid diffusant source thickness and pre-bake conditions; and initial silicon material base resistivity.

3. Cost Analysis

A cost analysis will be performed on the simultaneous junction formation process using SAMICS-IPEG methodology. The results will be compared to a sequential diffusion process.

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*For brevity, these liquids will be referred to as liquid phosphorus and liquid boron dopants.

B. SUMMARY

This report describes work performed on JPL Contract 956616, "Process Research of Non-CZ Silicon Material," during November and December, 1983. In this program, which started November 4, 1983, the fabrication of solar cells on N-base silicon using simultaneous diffusion of liquid boron and phosphorus dopants to form the desired P^+NN^+ cell structure will be studied. This simultaneous junction formation method will be compared to the sequential junction formation method where phosphorus will be diffused first to form an N^+N back surface field followed by a boron diffusion for the P^+N front junction.

In the standard Westinghouse baseline sequence, P-type dendritic web silicon crystals are grown and processed into solar cells. Simultaneous junction processing dictates the use of N-base crystals in order to reverse the front and rear junction dopants. With this reversal, the faster diffusing source (phosphorus) will form the deeper back junction while the slower diffusing source (boron) will form the more shallow front junction. During this period, several lots of N-type crystals were grown on standard Westinghouse pre-pilot line dendritic web growth furnaces. Growth parameters and growth characteristics were not affected by the switch from boron doped to phosphorus doped silicon charges.

Several experiments have been carried out to define the gas compositions and flows and the oxide stripping solutions required to produce a stain-free surface on the cell. Any residual staining after diffusion, especially on the P^+ (sun) side of the cell, has been found to degrade cell performance.

C. TECHNICAL PROGRESS

1. Dendritic Web Growth

Three lots of N-type dendritic web silicon have been grown and will be used for initial experiments on this program. The N-type web was grown by replacing the boron doping pellets in the silicon melt with phosphorus pellets to achieve the desired bulk resistivity. The three lots grown have bulk resistivities of 0.5 Ω-cm, 1.0 Ω-cm, and 6 Ω-cm. The growth characteristics of the web were not noticeably affected in switching from P-type to N-type material.

Various bulk resistivities are currently being investigated for the N-type web to determine an optimum resistivity for the P^+NN^+ cells. The optimum resistivity for the N-type web will not necessarily be the same as for the P-type web due to the different lifetimes and diffusion lengths of the minority carriers (electrons in P-type material and holes in N-type material).

2. Process Experiments

In the previous Westinghouse program (JPL Contract 955909), the boron back surface field was prepared using a liquid boron compound as the diffusion source. In those studies, it was noted that there was residual staining of the back surface due to incomplete removal of the boron glass after diffusion. That stain, believed to be a silicon-nitrogen compound, could not be removed using the normal $HF-H_2O$ stripping solution.

Experimental data indicated that those stains did not adversely affect the cell parameters in these N^+PP^+ cells. However, stains on the front (sun) side of the cell will degrade cell performance since the antireflective solution coats non-uniformly over the stain.

Thus, the first several processing experiments were carried out to determine conditions where the stain would not occur.

Table 1 gives a summary of conditions used for these tests. The XB-150 dopant was diluted with toluene in several runs based on data from previous work where

TABLE 1

DIFFUSION CONDITIONS FOR FRONT JUNCTION - N-TYPE WEB[1]

Diffusion Temp. (°C)	Diffusion Time (min.)	Gas Flow and Composition	Sheet Res. (Ω/□)	Dopant	Stripping Solution	Comments
980	20	1000 cc/min N_2	40-50	XB-150	1/10-HF/H_2O Cold	Stained
980	20	750 cc/min N_2 +750 cc/min O_2	100-1000	DIL XB-150[2]	1/10-HF/H_2O Hot	Slight stains
980	20	750 cc/min N_2 +750 cc/min O_2	100-1000	DIL XB-150[2]	1/10-HF/H_2O Cold	No stains
980	20	750 cc/min O_2	200-2000	DIL XB-150[2]	1/10-HF/H_2O Cold	Slight staining
980	20	750 cc/min N_2	40-50	DIL XB-150[2]	1/10-HF/H_2O Cold	No stains

(1) Web Used - Run 1.208 (0.7 Ω-cm)

(2) XB-150 diluted 50% with Toluene (XB-150 is a tradename of a boron dopant prepared by Allied Chemical Co.).

the staining was less pronounced with a diluted dopant. The web strips which had sheet resistivities in the 40-50 Ω/□ range (Rows 1 and 5 in Table 1) had junction depths of 0.3 to 0.4 μm. This is slightly deeper than desired but can be readily adjusted by varying the diffusion times and temperatures.

These data, which show higher sheet resistivities when using oxygen in the ambient gas, are similar to results obtained in earlier work[1] [2]. The referenced papers suggest that as the oxygen concentration is increased, thermal oxidation of the dopant competes with the diffusion process; and there is less dopant available for diffusion.

From these tests, it is concluded that when using the XB-150 dopant, optimal results are obtained using nitrogen as the ambient gas and a diluted dopant (eg. XB-150 diluted 50% with toluene).

A similar test using nitrogen as the ambient gas was carried out using a liquid phosphorus dopant source (PX-10, Allied Chemical). The diffusion conditions were held the same as those given in Table 1. Sheet resistivities of 10-30 Ω/□ were obtained. Thus, the back junction (N^+N) can be prepared under the same diffusion conditions as the front P^+N junction.

After analyzing these data, an initial simultaneous diffusion run was completed. In this test, one side of the N-type web was coated with diluted XB-150 while the other was coated with PX-10. After an initial bake cycle at 200°C, the strips were diffused at 980°C for 20 minutes in 750 cc/min of nitrogen. After diffusion, the pieces were stripped in cold 1/10-HF/H_2O. The sheet resistivity of both sides was generally 5-10 Ω/□ with small areas on the boron doped side where it was 40-50 Ω/□. The conductivity of both sides was generally N-type with small areas of P-type (corresponding to the higher sheet resistivity). Testing of cells from this test confirmed the contamination of the P^+ side with phosphorus.

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(1) D. L. Flowers and S. Y. Wu, J. Electrochem. Soc., 129, 2299, (1982).
(2) T. C. Chandler et al, J. Electrochem. Soc., 124, 1409, (1977).

This test indicated that cross contamination of the web surfaces during simultaneous diffusion is a problem which must be eliminated. Experiments are now underway where techniques to avoid this contamination (e.g., capping) are being investigated.

D. ACTIVITIES PLANNED FOR NEXT PERIOD

1. Continue experiments to eliminate cross contamination during simultaneous diffusion.

2. Initiate a sequential diffusion run.

3. Complete first scheduled delivery of dendritic web and cells to JPL.

E. PROGRAM DOCUMENTATION AND DELIVERABLES STATUS

All programmatic and technical documentation specified in the subject contract (956616) have been prepared and submitted in accordance with contract schedular requirements. Table 2 summarizes submittal status of all routine reports (financial and monthly/quarterly technical reports). Table 3 summarizes submittal status of contract required documentation. All milestones scheduled to date have been met as shown on the Program Milestone Chart, Figure 1.

TABLE 2

ROUTINE PROGRAM DOCUMENTATION SUBMITTAL STATUS

Item	Submittal Date
1. Monthly Technical Reports	
A. November 1983	December 12, 1983
2. Financial Management Reports	
A. November 1983	December 12, 1983
3. Quarterly Progress Reports	
A. No. 1	January 15, 1984

TABLE 3

SUMMARY PROGRAM DOCUMENTATION STATUS

Initial Baseline Cost Estimate	November 17, 1983
Program Plan	November 17, 1983

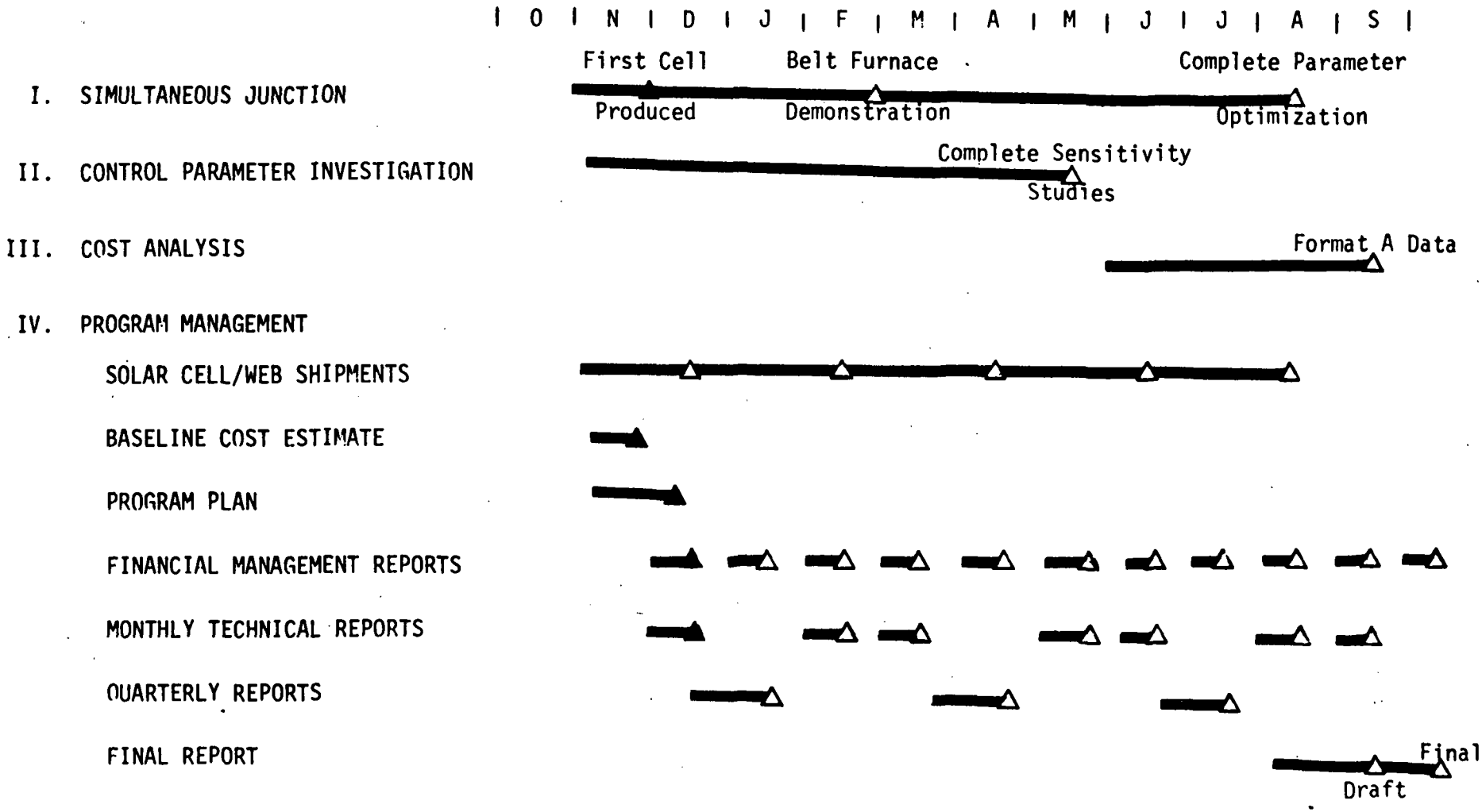

Figure 1. Process Research of Non-CZ Silicon Material Milestone Chart