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ARRAY AUTOMATED ASSEMBLY

PHASE 2

Quarterly Report
for the Quarter Ending March 31, 1979

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May, 1979

JPL Contract No. 954853

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1.0 SUMMARY

Integration of the process sequence using non-textured
2.125 inch square wafers was initiated during this period.
Considerable difficulties were encountered requiring pro-
cess and material modifications. These include:

1)   Replacement of N-250 spray-on diffusion source
      with PX-10 source.

2)   Modification of the firing cycles for printed
      silver and printed aluminum contacts is required
      to accommodate the change of wafer size and shape.

Preliminary results from cells processed through the entire
process sequence except laser scribe and spray on AR coat-
ing indicate that the process sequence is feasible.
Indicated cell conversion efficiency is 13 - 15%, however,
the process at this point is plagued with low shunt resis-
tance and high series resistance in the cells produced.

2.0 INTRODUCTION

This Quarterly Technical Progress Report covers the quarter ending March 30, 1979. The scope of the contract covers the investigation of technology readiness of a proposed process sequence for the low cost fabrication of photovoltaic modules as part of the Phase 2 of the Array Automated Assembly Task, Large Solar Array project.

The cell and module process sequence was revised by agreement with JPL and is shown in Table 2.1. The base line process is defined by the heavy line. This process sequence was shown to be technically feasible and cost effective during the first half of the Phase 2 effort, either by Spectrolab or by other contractors. There is, however, the opportunity and need for further process improvement of some of the steps. In some cases alternative processes may be more cost effective than those in the base line sequence. These are indicated in Table 2.1 by the alternative routes marked with solid light lines. The dotted line routes are fall-back routes in case the base line sequence encounters insolvable problems.

The process sequence presumes that the input sheet material will be in a form not suitable for texture etching. A brief plasma etch will be evaluated as a means of establishing a standard surface for input to the process sequence. The junction will be formed by diffusion from an N type polymeric spray-on source. A P+ back contact will be formed by firing a screen printed aluminum paste. After cleaning the back aluminum and removing the diffusion oxide, screen printed front contacts will be formed and a tin pad, to be used for interconnect soldering, will be ultrasonically applied to the aluminum back. The junction will be cleaned by a laser scribe operation and an AR coating formed by baking a suitable polymeric spray-on film.

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After testing, the cells will be assembled into solar circuits and laminated to superstrates or substrates, preferably using ethylene vinyl acetate as an encapsulant and laminating medium. After assembling the frame and termination hardware, the finished module will be tested.

During the period reported here, the base line process sequence from function formation through the "Tin Pad on Aluminum" step has been successfully integrated with indications of 14.5% or greater cell conversion efficiency.

Table 2.1

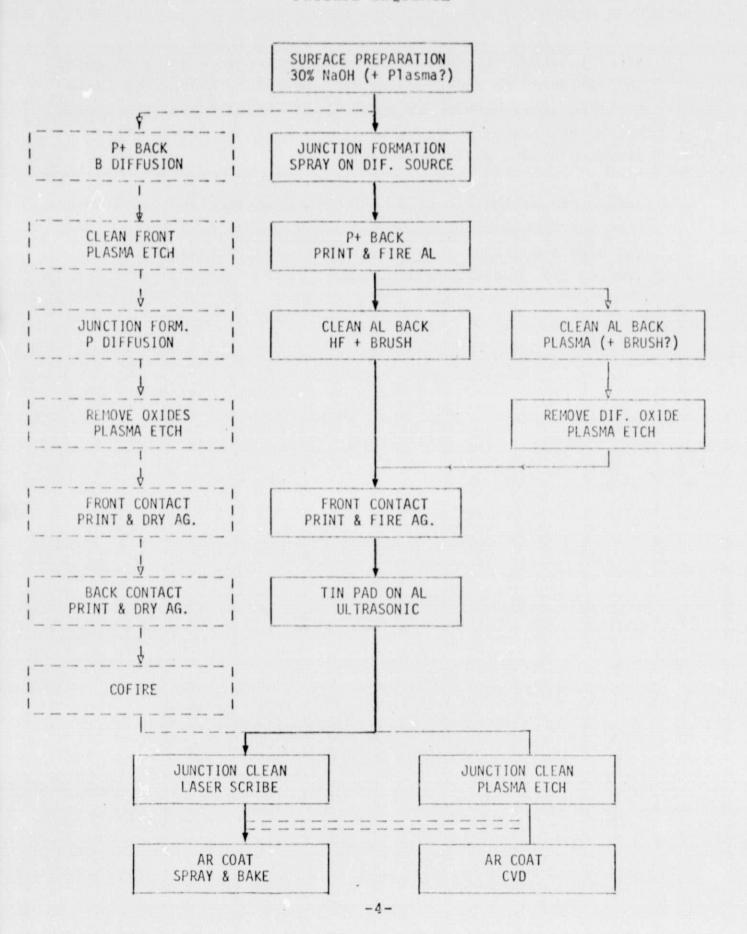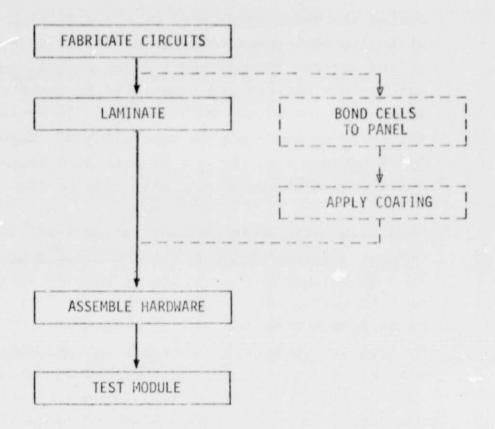## PROCESS SEQUENCE

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                          ┌─────────────────────────┐
                          │  SURFACE PREPARATION     │
                          │  30% NaOH (+ Plasma?)    │
                          └─────────────────────────┘
                                      │
      ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐  │
      │       P+ BACK             │  │   ┌─────────────────────────┐
      │       B DIFFUSION         │  └──▶│  JUNCTION FORMATION      │
      └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘      │  SPRAY ON DIF. SOURCE    │
              │                           └─────────────────────────┘
      ┌ ─ ─ ─ │ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐                 │
      │       CLEAN FRONT          │      ┌─────────────────────────┐
      │       PLASMA ETCH          │      │       P+ BACK            │
      └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘      │       PRINT & FIRE AL    │
              │                           └─────────────────────────┘
      ┌ ─ ─ ─ │ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐         │                    │
      │       JUNCTION FORM.       │  ┌──────────────┐   ┌──────────────────────┐
      │       P DIFFUSION          │  │ CLEAN AL BACK│   │  CLEAN AL BACK        │
      └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘  │ HF + BRUSH   │   │  PLASMA (+ BRUSH?)    │
              │                        └──────────────┘   └──────────────────────┘
      ┌ ─ ─ ─ │ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐         │                    │
      │       REMOVE OXIDES        │         │           ┌──────────────────────┐
      │       PLASMA ETCH          │         │           │  REMOVE DIF. OXIDE    │
      └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘         │           │  PLASMA ETCH          │
              │                               │          └──────────────────────┘
      ┌ ─ ─ ─ │ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐         │
      │       FRONT CONTACT        │  ┌──────────────┐
      │       PRINT & DRY AG.      │  │ FRONT CONTACT│
      └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘  │ PRINT & FIRE AG. │
              │                        └──────────────┘
      ┌ ─ ─ ─ │ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐         │
      │       BACK CONTACT         │  ┌──────────────┐
      │       PRINT & DRY AG.      │  │ TIN PAD ON AL│
      └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘  │ ULTRASONIC   │
              │                        └──────────────┘
      ┌ ─ ─ ─ │ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐         │
      │       COFIRE               │         │
      └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘         │
              │                               │
      ┌──────────────────┐          ┌──────────────────┐
      │ JUNCTION CLEAN   │          │ JUNCTION CLEAN   │
      │ LASER SCRIBE     │          │ PLASMA ETCH      │
      └──────────────────┘          └──────────────────┘
              │                               │
      ┌──────────────────┐          ┌──────────────────┐
      │ AR COAT          │          │ AR COAT          │
      │ SPRAY & BAKE     │          │ CVD              │
      └──────────────────┘          └──────────────────┘
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Table 2.1 (continued)

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        ┌─────────────────────┐
        │  FABRICATE CIRCUITS │
        └─────────────────────┘
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                   │ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐
                   ▼                                    ▽
        ┌─────────────────────┐          ┌─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─┐
        │      LAMINATE       │          │     BOND CELLS         │
        └─────────────────────┘          │     TO PANEL           │
                   │                     └─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─┘
                   │                                    │
                   │                                    ▼
                   │                     ┌─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─┐
                   │                     │     APPLY COATING      │
                   │                     └─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─┘
                   │ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
                   ▼
        ┌─────────────────────┐
        │  ASSEMBLE HARDWARE  │
        └─────────────────────┘
                   │
                   ▼
        ┌─────────────────────┐
        │     TEST MODULE     │
        └─────────────────────┘
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3.0 TECHNICAL DISCUSSION

3.1 DIFFUSION PROCESS

During the development work on the diffusion process, N-250 diffusion source was found to be suitable for use with text- urized wafers. During the present period, we evaluated alternative sources and have found Accuspin® PX-10 source to be superior to the N-250 source. In attempting to use the spray-on sources with non-texturized wafers, the diluted N-250 process was found to give erratic results. Non-diluted N-250 was investigated and also gave erratic results.

In a first experiment, alcohol-based N-250 (diluted) was compared with water-based Phosphorofilm® source (both obtained from Emulsitone Co.), and the effects of various atmospheres were investigated. NaOH polished (non-texturized) 2-inch round wafers were used for this experiment. The wafers were hydrophilic cleaned before spraying the source onto the wafers. Diffusions were carried out at $850^{\circ}C$ for 80 minutes. We also used a variety of atmospheres, Table 3.1. Cell fabrication was completed using printed aluminum backs, chemical cleaning of front oxide, aluminum back and junctions, printed silver front contacts and evaporated anti-reflection coating. The complete process sequence thus reflects the baseline process (Table 2.1) except for junction cleaning and AR coating. The best results were obtained with N-250 diffused in N_2 only for 70 minutes, then O_2 for 10 minutes at $850^{\circ}C$. This treatment gave open circuit voltage as high as 620 mV and load point current (I_{500}) as high as 600 mA with an evaporated AR coating.

There appears to be an interaction between the diffusion atmosphere and development of the P+ structure with the N-250. High open circuit voltages were obtained with mixed nitrogen- oxygen atmosphere and with nitrogen followed by oxygen. With

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Table 3.1

EFFECT OF DIFFUSION SOURCE
AND ATMOSPHERE ON CELL PERFORMANCE
$(T = 850^{\circ}C)$

DIFFUSION CONDITIONS				NO AR			EVAP. SiO AR		
Atmosphere	Source Sample Size	Statistics	ρ_s $\Omega/\square$	V_{oc} mV	I_{sc} mA	I_{500} mA	V_{oc} mV	I_{sc} mA	I_{500} mA
O_2 80 min.	N-250	$\bar{x}$	93.9	587.4	449.6	127.3	587.4	568.2	167.3
	$n = 10$	σ	11.8	6.3	50.4	41.6	6.3	82.6	43.4
N_2 80 min.	N-250	$\bar{x}$	34.2	578.1	551.4	378.9	586.2	729.4	498.8
	$n = 8$	σ	3.2	27.2	4.7	116.1	24.4	9.2	148.5
	Phosphorofilm®	$\bar{x}$	57.1	582.3	419.5	159.8	585.5	539.8	194.3
	$n = 10$	σ	16.4	15.0	59.8	94.2	14.0	90.3	128.0
N_2 70 min.	N-250	$\bar{x}$	33.7	609.4	547.0	540.8	615.3	716.2	538.7
	$n = 10$	σ	6.05	4.9	1.9	67.9	5.0	12.9	106.9
O_2 10 min.	Phosphorofilm®	$\bar{x}$	51.0	580.0	542.0	330.2	586.8	719.5	445.5
	$n = 4$	σ	8.7	20.3	9.2	90.4	19.1	7.6	111.1
87% N_2 + 23% O_2	N-250	$\bar{x}$	39.6	606.1	543.4	277.5	611.5	721.9	329.5
	$n = 8$	σ	3.7	1.5	5.3	52.0	2.4	12.3	74.3
80 min.	Phosphorofilm®	$\bar{x}$	50.3	540.0	543.7	233.7	551.0	723.3	280.0
	$n = 3$	σ	5.6	3.7	3.3	37.4	2.2	11.3	46.8

Cell structure:

2.12" round 2 ohm-cm wafers

TABLE 3.2
DIFFUSED SHEET RESISTANCE OBTAINED WITH
DIFFERENT SURFACE PRETREATMENTS

Wafer Number	Hydrophilic Clean $\Omega/\square$	Baked 15 Min.-200^0C $\Omega/\square$	NaOH Polished As Etched $\Omega/\square$
1	98-104	99-130	46-50
2	71-78	100-115	31-33
3	93-101	99-115	33-40
4	101-109	141-150	71-81
5	120-125	127-137	41-50
6	68-99	130-156	22-27
7	99-116	74-84	33-38
8	95-105	72-86	26-29
9	122-125	76-85	29-30
10	140-158	88-135	31-37

pure oxygen or pure nitrogen single atmospheres, open circuit
voltages were below 590 mV. In the case of pure oxygen
atmosphere, the sheet resistance was high, indicating a shallow
junction and probable shunting of the junction by the front
metallization. In the case of the nitrogen atmosphere,
the resulting film is poorly removed by hydrofluric acid,
presumably due to the presence of silicon nitride or oxy-nitride.
This may give rise to front contact resistance and/or interfere
with the P+ formation on the back surface.

The results with the Phosphorofilm source were quite erratic
and inferior as compared to those for the N-250. This may be
due to a shallower junction as evidenced by the higher sheet
resistance values observed for the Phosphorofilm source. No
satisfactory P+ (as evidenced by V_{oc}) was obtained for any of
the Phosphorofilm diffusions.

In a second experiment, the effects of different surface pre-
paration on diffusion from the N-250 source were evaluated.
The matrix, included (1) hydrophilic clean, (2) leave as etched
after NaOH polish, (3) bake in atmosphere for 15 minutes at
200°C. The only one of the three showing any sign of dewetting
was the third group, bake for 15 minutes at 200°C. This was
repeated a second time with the same results. At this time, it
appears that it may not be necessary to hydrophilic clean. We
diffused the three groups of cells at 850°C in nitrogen followed
by oxygen, and there was an erratically high sheet resistance
with the 'hydrophilic' group. Based on previous experience, it
should have been in the same range as the 'as etched' group
(see sheet resistance data in Table 3.1). Table 3.2 shows the
sheet resistance variations of each group.

The Phosphorofilm® was compared with the concentrated N-250 and
PX-10 diffusion sources. Diffusion was carried out at 900°C for
various times on as etched surfaces Table 3.3. The N-250 source

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showed the better uniformity in this experiment. The PX-10 produced the highest output cell. The Phosphorofilm® again was very erratic and inferior compared to the other two sources. Preliminary data on the PX-10 appears very good.

Time-temperature response surfaces were investigated for concentrated N-250 and Accuspin® PX-10. Cell fabrication was completed using printed aluminum backs, chemical cleaning of front diffusion oxide, aluminum backs and junctions, printed silver front contacts. The process sequence thus reflects the base line process (Table 2.1) except for junction cleaning and no AR coating applied. For the concentrated N-250 we used NaOH polish-etched (non-textured) 2" round wafers that were hydrophilic cleaned before spraying on the N-250 source. The diffusion time and temperature was varied. The results were very erratic, with the best results being obtained with N_2 only for 50 minutes then O_2 only for 10 minutes (Table 3.4). This gave open circuit voltage as high as 611 mV and load current (I_{500}) as high as 488 mA without AR coating.

Another matrix using NaOH polished (non-textured) 2-inch round wafers was run. One group was hydrophilic cleaned before spraying. The surfaces of the remaining wafers were left "as is" after NaOH polish etching before spraying on the diffusion source. Diffusion was carried out at $900^{O}C$ for various times, last three entries in Table 3.4. The results indicated that 50 minutes N_2 only then O_2 only for 10 minutes without hydrophilic treatment is capable of producing cells as good as the hydrophilic treatment process, however a higher proportion of defective cells was generated. It appears there was not a good P+ formation on any of the groups indicated by errativ V_{oc}.

These results suggest that N-250 is not a satisfactory spray-on diffusion source since excessively deep junctions ($\rho_s \simeq 10\text{-}15$) are required in order to obtain consistent results. The

Table 3.3

COMPARISON OF DIFFUSION FROM N-250 PHOSPHOROFILM® AND ACCUSPIN® PX-10 AT 900°C
MEASURED WITHOUT AR COATING

Time and Atmosphere	Source	Defective %	V_{oc} mV	V_{sc} mA	I_{500} mA
50 min. N_2 10 min. O_2	N-250	0	601	499	453
25 min. N_2 5 min. O_2	N-250	0	599	479	426
50 min. N_2 10 min. O_2	Phosphorofilm	20	553	473	287
25 min. N_2 10 min. O_2	Phosphorofilm	40	505	408	22
25 min. N_2 5 min. O_2	PX-10	20	602	507	424
10 min. N_2 5 min. O_2	PX-10	0	601	530	393

Table 3.4

TIME-TEMPERATURE RESPONSE SURFACE FOR DIFFUSION WITH CONCENTRATED N-250 SOURCE MEASURED WITHOUT AR COATING

Treatment		Defective %	Ps Ohms/□	V_{oc} mV	I_{sc} mA	I_{500} mA
NaOH polish etch / Hydrophilic treated surface	70 min. N_2 10 min. O_2 850°C	40	12	593	458	315
	70 min. N_2 10 min. O_2 875°C	60	69	589	510	210
	50 min. N_2 10 min. O_2 900°C	0	9.5	603	528	470
	30 min. N_2 10 min. O_2 925°C	0	17	587	462	364
	15 min. N_2 10 min. O_2 950°C	0	16	603	508	416
	50 min. N_2 10 min. O_2 900°C	14.2	13	598	487	420
NaOH polish etch	30 min. N_2 10 min. O_2 900°C	50	19	596	518	344
	15 min. N_2 10 min. O_2 900°C	37.5	40	581	502	329
	50 min. N_2 10 min. O_2 900°C	70	17	498	433	433

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observed load and short circuit currents for these deep junctions (Table 3.4) were deceptively high due to the spectral distribution of the tungsten light source used for the measurements.

The results with the PX-10 source were very good. Diffusion was carried out at 900°C for various times, Table 3.5. We used NaOH polished etched 2" round wafers with no hydrophilic treatment before spraying on the PX-10 source. Diffused wafers were given a back etch in concentrated HF acid. The best results were obtained with the PX-10 diffused in N_2 only for 10 minutes then O_2 only for 5 minutes, thus making a total diffusion time of 15 minutes. These conditions produced open circuit voltage as high as 608 mV and load point current (I_{500}) as high as 495 mA without AR coating. The sheet resistance range was 30-35 $\Omega/\square$.

Table 3.5

TIME-TEMPERATURE RESPONSE SURFACE
FOR DIFFUSION WITH ACCUSPIN® PX-10
MEASURED WITHOUT AR COATING
$900^{\circ}C$

Treatment	Defective %	Ps Ohms/□	V_{oc} mV	I_{sc} mA	I_{500} ma
10 min. N_2 5 min. O_2	10	30-35	607	550	478
15 min. N_2 10 min. O_2	10	25-30	604	530	453
30 min. N_2 10 min. O_2	14	20-22	604	507	438
60 min. N_2 10 min. O_2	11	15-18	600	494	400

3.2   ALUMINUM P+ BACK

Preliminary attempts to integrate the process sequence given
in Table 2.1 using non-texturized square cells produced cells
having very inferior performance.   Some of these early results
were undoubtedly influenced by the erratic and inadequate
performance of N-250 diffusion source on non-textured surfaces
and interactions between the diffusion, front metal and alumi-
num back processes due to refractory surface films formed
during the diffusion process (Section 3.2).

A second major source of difficulty has been found to be that
a large change in the optimum firing cycle for the printed
aluminum back is required in shifting from a 2.12 inch round
wafer to a 2.12 inch square wafer. Optimum firing for the
former had been previously determined to be 40 seconds at
$825^{\circ}C$ with AMPAL® aluminum powder. We have now determined
that with our furnace arrangement, printing paste made with
this aluminum powder has an optimum firing cycle on 2.12 inch
square wafers of about 80 seconds at $850^{\circ}C$.

In order to minimize the effects of other process steps
(diffusion, printed front contacts) the time-temperature
matrix experiment was performed using phosphine diffused
wafers, junction cleaning by saw cutting 2 cm X 2 cm wafers
from the aluminum fired 2.12 inch square wafers and applying
evaporated front contacts. Two sets were run, one with an
HF back-etch after diffusion to remove oxides, the second
with an $HF-HNO_3$ back-etch to remove both oxides and the
diffused layer. The results are reported in Table 3.6, wherein
the first parameter in each data cell is for the HF back-etch set
and the second is for the $HF-HNO_3$ back etch set. The number
of surviving 2 cm X 2 cm cells which were measured is shown
in parentheses.

Table 3.6

CELL PARAMETERS FOR TIME-TEMPERATURE MATRIX FOR FIRING ALUMINUM BACKS ON 2.12" SQUARE CELLS.

See text for description of cells and processing.
(No AR Coating)

Time	825°C	850°C V_{OC} (mV)	875°C
20 sec.	558 (4)	523 (3)	(0)
	–	583 (4)	586 (2)
40 sec.	580 (4)	593 (3)	585 (2)
	575 (4)	529 (1)	589 (3)
60 sec.	580 (1)	587 (3)	586 (2)
	587 (3)	594 (3)	592 (2)
80 sec.	580 (1)	586 (3)	572 (2)
	542 (3)	594 (3)	–

TABLE 3.6 Continued

	825°C	850°C	875°C
Time		i_{500} (mA/cm^2)	
20 sec.	14.4 (4)	5.9 (3)	(0)
		20.3 (4)	20.5 (2)
40 sec.	19.5 (4)	20.8 (3)	19.7 (3)
	16.8 (4)	8.8 (1)	24.9 (3)
60 sec.	19.8 (1)	22.0 (3)	21.1 (2)
	20.7 (3)	21.8 (3)	22.0 (1)
80 sec.	20.3 (1)	21.3 (3)	15.8 (2)
	11.3 (3)	23.0 (3)	–

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TABLE 3.6 Continued

Time	825°C	850°C		875°C
		R_{sh} (ohms/cm^2)		
20 sec.	3050 (4)	364 (3)		(0)
	–	217 (4)		550 (2)
40 sec.	18400 (4)	1190 (3)		1460 (3)
	925 (4)	870 (11)		1560 (3)
60 sec.	2500 (1)	1780 (3)		873 (2)
	3040 (3)	790 (3)		1820 (1)
80 sec.	6670 (1)	4760 (3)		1940 (2)
	1510 (3)	3250 (3)		–

Two sets of 2.12 inch square cells (with HF and HF+HNO_3 back-etch) were fired for 60 seconds at 850° and fabricated with printed silver front contacts to verify the preceding firing cycle determination. Results are reported in Table 3.7. Examination of this table shows that the open circuit voltage is very comparable to that obtained for a firing cycle of 60 seconds at 850°C using evaporated metal (Table 3.6), namely 587 and 592 mV. vs. 587 and 594 mV. The short circuit current is slightly lower (22.7 and 22.9 mA/cm^2 vs. 23.8 and 24.1 mA/cm^2). These results indicate that the aluminum firing cycle is suitable for use with the printed front contacts. The load point current is down substantially for the printed front contact cells (14.6 and 16.5 mA/cm^2 vs. 20.0 and 21.8 mA/cm^2) indicating other deficiencies in the cells made with printed front contacts.

A portion of this difference in load point current can be attributed to the difference in shunt resistance (315 and 700 $ohms/cm^2$ vs. 1780 and 790 $ohms/cm^2$). Examination of the shunt resistance data in Table 3.6 indicate an erratic behavior of this parameter. This suggests degradation of the shunt resistance associated with the aluminum back. This conclusion is not surprising in view of our prior observations regarding the exposure of the front junction to aluminum contamination and its consequences. In order to estimate the magnitude of these effects two control sets of cells were prepared with evaporated front and back contacts. These cells had shunt resistances of the order 50,000 $ohms/cm^2$ (Table 3.8) as compared with typical values of 500 to 2000 $ohms/cm^2$ for the aluminum back cells (Table 3.6). However, much of the excess shunt resistance of the cells with printed front contacts appears to be associated with the front contact (see section 3.3).

Table 3.7

EVALUATION OF 60 SECOND 850°C ALUMINUM BACK FIRING CYCLE
WITH PRINTED FRONT CONTACTS

(Sample size = 7, no AR Coating)

Back Etch	R_{sh} Ohms/cm^2	V_{oc} mV	I_{sc} mA	I_{500} mA
HF	315	587	22.7	14.6
HF + HNO$_3$	700	592	22.9	16.5

Table 3.8

CELL PARAMETERS FOR CONTROL LOTS
MADE WITH Ti-Pd-Ag EVAPORATED FRONT
AND Cr-Pd-Ag EVAPORATED BACK CONTACTS
ON PHOSPHINE DIFFUSED WAFER.

(No AR Coating, Sample Size = 3)

R_{sh} Ohms/cm^2	V_{oc} mV	I_{sc} mA	I_{500} mA
66,700	589	20.1	18.1
50,000	587	19.5	17.8

3.3   PRINTED SILVER FRONT CONTACTS

Attempts to integrate the aluminum P+ back process with the printed silver front contact process gave low shunt resistance (Section 3.2). Markedly lower shunt resistance of printed front contact cells as compared to those with evaporated front contacts (Tables 3.6 and 3.7) suggested that much of the shunting originated with the front printed metallization. In order to clarify these effects, data is presented in Table 3.9 comparing the cell parameters of printed front contact cells with aluminum P+ backs with those of similar cells made with aluminum doped silver back contacts.

In these experiments 2-inch round non-textured wafers were phosphine diffused and then back-etched with $HF+HNO_3$. After printing and firing the back and front contacts, 1.4 inch square cells were saw cut from the round wafers. Measurements were made without AR coating.

It will be seen that while the shunt resistance is lower on the aluminum backed cells, that of the silver back cells is also very low as compared with previous experience with textured cells ($\sim$200 ohms for 2.12 inch round cells $\overset{\sim}{=}$4000 ohms/cm^2). It is not known at this time whether this abnormally low shunt resistance is associated with lack of texturization or is due to other causes.

Table 3.9

COMPARISON OF PRINTED FRONT CONTACTS ON CELLS WITH PRINTED ALUMINUM (P+) BACK AND WITH PRINTED ALUMINUM DOPED SILVER BACK

(1.4 inch Square Cells Without AR Coating)

Sample Size	Back Contact	R_{sh} Ohms/cm^2	V_{oc} mV	I_{sc} mA	I_{500} mA
2	Al	163	596	23.5	18.3
5	Ag + Al	402	579	20.3	8.0
2	Al	186	597	22.7	18.0
5	Ag + Al	363	583	20.4	10.4

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3.4   AR COATING

No previous work had been done with spin-on or spray-on AR coatings at Spectrolab on this program. Previous work on another program using a mixture of titanium and silicon organocompounds in an alcohol solvent (obtained from Emulsitone Company) had given a moderate antireflection effect which was enhanced by encapsulation in silicone encapsulants. [1]

Two commercial solutions were selected for initial evaluation: Tantalum #151 (Allied Chemical) and Titanium-silica Film Type C (Emulsitone). All attempts to apply the Tantalum #150 material by spinning on blank nontexturized wafers resulted in dull gray films, probably due to excessive thickness. The characteristic blue-violet color desirable for an AR coating was obtained with the Titanium-silica Film when spun at 3000 RPM for 10 seconds, dried for 15 minutes at 200°C and fired at 700°C for 30 seconds. Further work was concentrated on the Titanium-silica Film.

Spinning proved ineffective as a means of applying the solution to finished cells, as the grid lines blocked the flow and prevented the formation of a complete and uniform film. Spraying with a hand-held air brush and dipping in dilute solution were also ineffective.

Somewhat better results were obtained by dipping followed by spinning. This treatment resulted in an increase of about 23.7% in the short circuit current of a sample of 5 cells (Table 3.10). This increase is somewhat lower than that typically observed with evaporated SiO AR coating.

Application of the AR coating over unfired printed front contacts and then cofiring the AR film and contact metal was

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Table 3.10

INCREASE OF I_{sc} FOR TITANIUM-SILICAFILM TYPE C
APPLIED BY DIPPING THEN SPINNING

Cell	Before AR I_{sc} mA	After AR I_{sc} mA	I %
1	513	655	27.7
2	536	661	23.3
3	536	649	21.1
4	513	641	25.0
5	538	655	21.7
Evap. SiO*	542	719	32.7

*From Table 3.1, N-250 diffused in N_2 for 70 minutes followed by O_2 for 10 minutes.

attempted using this technique. Results were unsatisfactory as the AR solution weakened the metallization adhesion causing the gridlines to detach during spinning.

SnO_2 and SiO_2 coatings were applied to cells by Watkins Johnson Co. using a continuous belt furnace CVD process. These cells showed the expected increase in short circuit current, but were degraded at the load point (500 mv). Replication of the thermal cycle using a tube furnace with intent atmosphere resulted in a comparable degradation of curve shape, and we have concluded that the CVD process is not compatible with the rest of our process sequence.

3.5 CELL PROCESS INTEGRATION

A test of the performance of the first five steps of the cell process sequence (Table 2.1) was performed using edge etching before applying the front contacts as a substitute for the laser scribe junction cleaning process. In this run the best procedures and materials which have thus far been identified were used. Parameters measured on cells without AR coating are listed in Table 3.11. The observed range of conversion efficiency corresponds to a range from 13 to 15% after AR coating. It is anticipated that further improvement of performance can be obtained by introducing the laser scribe for junction cleaning and optimizing the grid contact configuration.

Table 3.11

CELL PARAMETERS - CELL PROCESS INTEGRATION*
EXPERIMENT 3.18.9
2.12 INCH SQUARE CELL, NO AR COATING

Cell	V_{oc} mV	I_{sc} mA	i_{500} mA	η_{500} %	Comment
#1	606	773	661	11.4	
#2	599	759	592	10.2	
#3	604	770	658	11.3	
#4	-	-	-	-	broken
#5	606	772	657	11.3	
#6	606	778	635	10.9	
#7	604	779	638	11.0	
#8	598	759	566	9.8	
#9	604	777	633	10.9	
$\bar{x}$	603.4	770.9	630.0	10.85	
σ	3.2	8.0	34.0	0.57	

* Process sequence

2.12 inch square non-textured wafer

PX-10 spray-on diffusion source

Printed aluminum P+ back contact

HF soak + brush clean aluminum

Edge etch in HF + HNO_3

Printed silver front contact

3.6   MODULE ASSEMBLY

3.6.1   AR Coatings for Glass by CVD

Chemically vapor deposited (CVD) coatings of silicon dioxide
and stannic oxide were applied to glass panels by Watkins and
Johnson Company. Nominal coating thicknesses were 800, 1000
and 1200 $\overset{o}{A}$. Spectral light transmission in the 3000 $\overset{o}{A}$ to
10,000 $\overset{o}{A}$ wavelength range were measured on each specimen and
on an uncoated glass control using a Beckman DK-2A spectro-
photometer.

The results showed essentially the same pattern for all the sili-
con dioxide coated specimens. Comparison to the control
indicated approximately a 3% increase in transmission at 10,000
$\overset{o}{A}$ decreasing to less than 1% at 5000 $\overset{o}{A}$ and on out into the
ultraviolet.

The stannic oxide coated specimens showed transmission peaks at
about 7750 $\overset{o}{A}$ for the 1200 $\overset{o}{A}$ coating, 5750 $\overset{o}{A}$ for 1000 $\overset{o}{A}$, and
5300 $\overset{o}{A}$ for 800 $\overset{o}{A}$. These probably constitute quarter wavelength
antireflection peaks. However, the three stannic oxide-coated
specimens all showed generally poorer transmission than the con-
trol due to the unfavorable index of refraction. The 1200 $\overset{o}{A}$
coating showed about a one percent improvement over the control
in the immediate region of its peak, but all other regions
were significantly below the control. Transmission of the other
stannic oxide coatings did not exceed that of the control
sample anywhere in the measured region.

3.6.2   Primer Coupling Tests

Tests to evaluate the use of primers for control of permeation
and swelling or lifting of coating materials has been extended
from silicones to ethylene vinyl acetate (Elvax 150). Swelling

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effects of different solvents on the Elvax were evaluated
by weight change measurement. Methyl ethyl ketone and
isopropanol were selected as test solvents, the MET showing
significantly stronger swelling potential. Solar cell
back surfaces and glass were primed with various primers
and coated with a toluene solution of Elvax 150.
After at least 24 hours drying, the specimens were immersed
in the test solvents and the elapsed time to the first
detectable listing of swelling of the coating was observed.
Results of these tests are shown in Table 3.12.

Table 3.12

PRIMER COUPLING RESISTANCE TO SWELLING

Elvax 150 Coating

Time (min.) to detectable effect

Solvent	Primer*	Substrate	
		Cell	Glass
MEK	None	1	1
	SS 4179	1	1
	Piccotex/Z6020	1	1
	Z6020	30+	30+
Isopropanol	None	15	15
	SS 4179	1	1
	Piccotex/Z6020	30+	5
	Z6020	30+	30+

*Composition of Primers

Piccotex/Z6020: 9.5% Piccotex, 0.5% Z6020 silane in methyl ethyl ketone

Z6020: 6% Z6020, 0.25% water in isopropanol

SS 4179: As received

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4.0   CONCLUSIONS

The following conclusions have been reached during this period:

1) Accuspin® PX-10 is the preferred spray on diffusion source for use with non-textured surfaces.

2) Undesirable interactions have been observed between the diffusion and aluminum back processes when pure nitrogen or pure oxygen are used in the diffusion process.

3) The preferred diffusion atmosphere is pure nitrogen for the most of the diffusion followed by a short exposure to pure oxygen.

4) The surface generated by 30% sodium hydroxide etch is suitable for use with Accuspin® PX-10 diffusion source.

5) Substantial changes in the printed silver and printed aluminum firing cycles are required when the wafer size and shape is changed.

6) The base line process (Table 2.1) is a viable process sequence, and the fall-back alternative will not be required.

5.0   RECOMMENDATIONS

There are no recommendations.

6.0 NEW TECHNOLOGY

There was no new technology reported during the period.