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INVESTIGATION OF PROPOSED PROCESS SEQUENCE FOR THE ARRAY
AUTOMATED ASSEMBLY TASK — PHASE II

Quarterly Technical Progress Report, for Quarter Ending September 29, 1979

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November 1979

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QUARTERLY TECHNICAL PROGRESS REPORT

on the

INVESTIGATION OF PROPOSED PROCESS SEQUENCE FOR
THE ARRAY AUTOMATED ASSEMBLY TASK - PHASE II

For Quarter Ending

September 29, 1979

JPL Contract 954853
CDRL 010

Prepared by:

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November 1979

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1.0 SUMMARY

The proposed process sequence that is being developed under this contract has been further refined during this reporting period. Plasma etching was investigated as a possible surface preparation process, the Radiation Technology Infrared Furnace was tested as a possible replacement for the currently used tube furnace, and the fixture for laminating 2' by 4' panels was completed and panels are currently being tested.

Three different applications of plasma etching were investigated during this reporting period: "dead layer" removal, diffusion oxide removal and prediffusion surface preparation. The Tegal Plasmaline 100 plasma etcher was found to etch at a rate of about 1800°C per minute when operating at 100-125 watts forward power and 1-5 watts reflected power using Freon 14 + 8% oxygen. The slowness and controllability of the plasma etching process suggest that it might be used to remove the front surface "dead layer" without causing excessive increase in series resistance. Cells etched from 12 to 18 seconds with Freon 14 + 8% oxygen showed significant improvement in short circuit current and current at load with no change in open circuit voltage.

Freon 14 + 8% oxygen, sulfur hexafluoride and Freon 23 were all considered as possible etching atmospheres for removing the diffusion oxide. Freon 14 + 8% oxygen etched samples showed a markedly lower shunt resistance and evidence of pitting. Freon 23 produced wafers that were electrically comparable to controls after 5-7 minutes of etching and sulfur hexafluoride produced comparable wafers after 3-24 seconds of etching.

Sulfur hexafluoride and Freon 14 + 8% oxygen were considered for the prediffusion surface preparation. Both sulfur hexafluoride and Freon 14 + 8% oxygen after 4-34 seconds and 2-17 seconds, respectively, showed comparable results to the controls.

The Radiation Technology Infrared furnace was also tested this quarter. The initial results of the infrared drying and firing of screen printed silver paste contact indicate possibilities of producing high efficiency four inch square cells at the rate of 350 per hour. The most effective drying and firing temperatures for this throughput are 260, 410, 750, and 750°C for zones 1, 2, 3 and 4, respectively. The belt speed is set at fifty inches per minute, which means that the wafers are being dried for forty-three seconds and fired for twenty-nine seconds.

The lamination fixture for making 2' x 4' modules was completed. Test modules were fabricated that developed ripples in the back surface. This defect has been minimized by the insertion of an 8 mil stainless steel sheet in the assembly layup. Springborn's A-9918-5 (clear) and A-9903-B (white) EVA were used as the encapsulant. Problems have also been encountered with cracking of the glass in the panel. Future modules will use glass which has been ground on the edges to help eliminate this problem.

2.0 INTRODUCTION

This quarterly technical progress report covers the quarter ending September 29, 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 Phase II of the Array Automated Assembly Task, Large Solar Array Project.

The cell and module process sequence is shown in Table 2.0-1. The baseline 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 II 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 baseline sequence. These are indicated in Table 2.0-1 by the alternative routes marked with solid light lines. The dotted line routes fall-back routes in case the baseline sequence encounters insolvable problems.

During the past quarter, some of the routes that are indicated by solid light lines were investigated as possible alternatives. These alternatives included a prediffusion plasma etch and a plasma etch to remove the diffusion oxide. Plasma etching was also considered as a method of removing the "dead layer" that is formed by the diffusion of the polymeric spray-on source.

The Radiation Technology Infrared furnace was introduced during this quarter as a possible replacement for the currently used tube furnace. Work has also been continued on improving the modules that have been produced with the recently developed lamination fixture.

Table 2.0-1
PROCESS SEQUENCE

Table 2.0-1
(continued)

3.0 TECHNICAL DISCUSSION

3.1 Silicon Ingot Evaluation

Crystals procured from Dymat (2 ohm-cm) have been sliced into 3" round (100) wafers. To evaluate the two ingots received, wafers were processed into cells simultaneously with control wafers from Spectrolab crystals. The normal process sequence was used to fabricate these cells except for laser scribing prior to front contract printing and no AR coating was applied. Square 2.12" wafers from different ingot lots were simultaneously processed with the 3" round wafer except they were chemically etched prior to front printing. All of the wafers in these runs were over-fired during firing of the front contact (750°C rather than 700°C). This higher firing temperature results in a somewhat lower output cells, Table 3.1.

An additional run (7.59.9) was processed with corrected firing temperature, Table 3.1. This run indicates that Dymat silicon is equivalent to the control Spectrolab silicon. The cells had an average efficiency of 10.3% (equivalent to 13.8% with AR coating).

3.2 Plasma Etching

During the past quarter plasma etching was extensively investigated. Plasma etch rates were determined, applications were suggested and hypotheses were suggested to explain the phenomenon that occurred. All samples were etched in a Tegal Plasmaline 100 plasma etcher at 100-125 watts forward power and 1-5 watts reflected power.

The etch rate of Freon 14 + 8% oxygen was found to be approximately $1800\text{\AA}$ per minute. Blank, chemically etched wafers were partially masked with photoresist and a step was etched in the surface. Step height was measured with a Talley Surf and used with the etch time to calculate the etch rate. As a further check on the etch rate

Table 3.1

INGOT EVALUATION

<u>Lot #</u>	<u>Vendor</u>	<u>Bulk ρ (Ω-cm)</u>	<u>Ag Fire Temp $^{\circ}$C</u>	<u>Sheet ρ ($\Omega/\square$)</u>	<u>V_{oc} (mV)</u>	<u>I_{sc} (mA)</u>	<u>I₅₀₀ (mA)</u>
<u>Laser Scribed</u>							
7.58.9 A	SL*	1-3	750	25-29	592	646	504
7.58.9 B	Dymat	1-3	750	27-44	584	620	363
7.58.9 C	SL	1-3	750	28-32	594	627	512
7.58.9 D	Wacker	1-3	750	28-38	593	669	500
<u>Chemical Edge Etched</u>							
7.58.9 E	SL	1-3	750	28-32	595	655	547
7.58.9 F	SL	1-3	750	29-32	589	632	476
7.58.9 G	SL	7-14	750	27-29	597	690	580
7.58.9 H	Wacker	7-14	750	27-37	596	708	565
<u>Laser Scribed</u>							
7.59.9 A	SL	1-3	700	27-38	603	670	584
7.59.9 B	Dymat	1-3	700	28-33	603	673	586
7.59.9 C	Dymat	1-3	700	27-32	600	662	580

*SL - Spectrolab

measurement, three diffused wafers were plasma etched for up to four minutes in Freon 14 + 8% oxygen. The etching process was interrupted at one minute intervals for sheet resistance measurements. The data obtained are plotted in Figure 3.1. For wafers two and three the diffused layer was completely removed after four minutes of etching. The diffused layer of wafer one was not completely removed by four minutes of etching. An etching rate of $1800\text{\AA}$ per minute implies a junction depth greater than $5000\text{\AA}$. This is considerable larger than the $3000\text{\AA}$ junction depth estimated from the original sheet resistivity. A $3000\text{\AA}$ junction depth would imply an etching rate less than $1000\text{\AA}$ per minute.

3.2.1 "Dead layer" Removal

The slowness and controllability of the plasma etching process suggest that it might be used to remove the front surface dead layer without causing excessive increase in series resistance. In order to investigate this hypotheses, a series of eleven finished, non-AR coated cells were etched from 12 seconds to 240 seconds. Current-Voltage (IV) curves were taken before and after each run. An increase in output was seen in the first cell etched for 12 seconds. Short circuit current increased 30 mA and open circuit Voltage decreased 10 mV. All but the first cell were severely degraded by the etching process. The longer etch times may have increased sheet resistance enough to have caused excessive series resistance. Cells etched for longer times had a gray to bluish film suggesting the possibility of an antireflection film effect, however, 10 second dip in 10% HF did not decrease the short circuit current. I-V curves for 12 second and 24 second etching are shown in Figures 3.2 and 3.3.

From these results it is clear that shorter and slower etching times are needed to evaluate the observed effects which may be due to removal of the dead layer or reduced junction depth. To

Figure 3.3 EFFECT OF 24 SEC. PLASMA
ETCH ON SOLAR CELL OUTPUT CURVE.

further investigate the effect of plasma etching in the shorter time periods, and experiment was performed to etch cells from 3 to 24 seconds at 3 second intervals. Cells etched from 12 to 18 seconds showed significant improvement in short circuit current and current at load (Figure 3.4) with no change in open circuit voltage. The data for these cells is shown below.

<u>Plasma Etch Time</u>		<u>Before</u>	<u>After</u>	<u>Increase</u>
12 sec.	I_{sc}	675	738	9.3%
	I_{450}	630	665	5.5%
15 sec.	I_{sc}	620	722	16.4%
	I_{450}	555	630	13.5%
18 sec.	I_{sc}	650	750	15.3%
	I_{450}	620	680	9.6%

The amount of material removed from the front surface (300-400 Angstroms) suggests that the improvement may come from elimination of minority carrier recombination losses by removal of the "dead layer", however, the replacement of dead layer recombination processes by surface recombination processes make this interpretation somewhat unlikely. If removal of the "dead layer" is the cause, the response to short wavelength light (.4 to .55 microns) should increase more than response to longer wavelengths. Spectral response measurements were taken before and after plasma etching for the cells reported in Figure 3.4. In all cases, cell response to wavelengths between .4 and 1.5 microns increased, the greatest percent increase was seen at .65 to .75 microns (Figure 3.5). The greatest increase was seen in the red rather than the blue which is not supportive of the hypothesis.

Earlier in this report it had been observed that long etch times produced a blue stain. The stain appears to be related to the presense of the silver contact metallization, since it did not develop on diffused (non-metallized) wafers. This observation

Figure 3.5

SPECTRAL RESPONSE CHARACTERISTICS
BEFORE AND AFTER 18 SECONDS
PLASMA ETCHING

suggested that the long wavelength effects might be due to an anti-reflective coating effect. The cells used in the second experiment (Figure 3.4) were AR coated with evaporated silicon monoxide. The normal expectancy is that this treatment will increase short circuit current by 35%. The observed increases are shown in Figure 3.6. It will be seen that the antireflective coating enhancement of I_{sc} did indeed decrease by an increasing amount as the plasma etch time increased. The combined enhancement of I_{sc} , however, due to plasma etching and AR coating exceeded 35% over much of the range of etching times which were used (Figure 3.7). For example at 15 seconds etch time, combined enhancement is 44% (28% for AR coating plus 16% for plasma etching). The excess of 9% over the normal 35% enhancement must be attributed to one or more of the front surface phenomena.

These phenomena could include a pre-etch passivation layer which might arise from high temperature sintering or diffusion processes. Plasma etching would remove the passivation layer increasing surface recombination velocity and temporarily decrease cell output (Figure 3.7; less than 10 seconds). Output gains from dead layer removal may overcome this effect as etch time increases (Figure 3.7; greater than 10 seconds). Other surface changes arising from plasma etching may work in tandem with the above phenomena. Microtexturing or pitting would reduce expected short circuit current enhancement from AR coating.

3.2.2 Prediffusion Plasma Etch

Both sulfur hexafluoride (SF_6) and Freon 14 (CF_4) plus 8% O_2 were investigated for possible use in a prediffusion plasma surface etch. Freon 14 was tested at $200^\circ C$ for three minutes and sulfur hexafluoride was tested at $200^\circ C$ for five minutes at the standard operating set-up for the plasma etcher. Examination of the wafers after etching showed that the short circuit current (I_{sc}) was increased by 6.6% and load

point current (I_{450}) was lower by 13.2% for Freon 14 compared to controls. For wafers etched in SF_6 , I_{sc} increased 2.3% and I_{450} decreased 1.5%. Open circuit voltage was lower by 3-4 millivolts for all samples in this experiment, (Table 3.2).

A second experiment was run examining shorter etch times at room temperature. Wafers were etched 2-17 seconds in $CF_4 + 8\% O_2$ and 4-34 seconds in SF_6 . Wafers etched in SF_6 showed I_{500} and I_{sc} readings that were comparable to controls for all etch times. After 8 seconds in SF_6 cells showed an average of 7 ohms shunt resistance improvement as compared to controls. Freon 14 etched wafers showed similar I_{sc} readings, but output was 0.1-0.4% lower than controls. Shunt resistance readings were 1-8 ohms lower than controls at 2 and 4 seconds etch time (Table 3.3).

I_{sc} increases in both SF_6 and $CF_4 + 8\% O_2$ etched wafers may be accounted for by one of several possible post-plasma etch surface conditions. Microtexturing or pitting during plasma etching would account for I_{sc} increases. A light blue film, symptomatic of pitting, was seen on non-metallized $CF_4 + 8\% O_2$ etched wafers that was not apparent on SF_6 etched wafers.

3.2.3 Diffusion Oxide Plasma Etch

Excess pitting may cause current leakage in cells etched for diffusion oxide removal. In an effort to verify this a series of non-contacted cells were plasma etched 3-48 seconds in $CF_4 + 8\% O_2$ and SF_6 . Evaporated contacts were applied and shunt resistance measurements (R_{sh}) were taken. All samples were etched under standard plasma etching conditions at room temperature and at a chamber pressure of less than one torr. Cells etched 3 to 24 seconds in SF_6 showed R_{sh} readings as good as controls with $CF_4 + 8\% O_2$ etched samples were lower by approximately 7000-8000 ohms. Low R_{sh} readings were taken from cells etched more than 24 seconds (Table 3.4). This result is consistent with suspected pitting from the Freon 14 + 8% O_2 etch.

Table 3.2
Prediffusion Surface Etch
Run 7.60.9

Control Wafers

	V_{oc} (mv)	I_{sc} (ma)	I_{500} (ma)	I_{450} (ma)	R_{sh} (Ω)	Etch Time (min)
	600	721	566	650	94.3	
	602	728	565	656	106	
	600	740	555	657	75.8	
	598	717	540	635	73.5	
	600	741	568	664	122	
	600	725	535	626	16.0	
	601	737	592	682	59.5	
	599	709	547	642	119	
	601	720	572	660	86.2	
	599	727	540	639	31.4	
Average	600	727	557	651	78.4	

Etched with $CF_4 + 8\% O_2$

	590	743	321	426	86.2*	3
	598	774	455	556	74.6	"
	598	771	455	560	53.7	"
	595	765	356	442	42.0*	"
	598	771	506	616	45.0	"
	598	763	496	599	45.0	"
	599	760	424	519	106	"
	598	799	451	557	102	"
	597	777	455	560	94.0	"
	601	788	455	554	79.0	"
Average	598	775	461	565	69.3	"

Table 3.2 (Continued)

Prediffusion Surface Etch

Run 7.60.9

Etched with SF₆

	V _{oc} (mv)	I _{sc} (ma)	I ₅₀₀ (ma)	I ₄₅₀ (ma)	R _{sh} (Ω)	Etch Time (min)
	588	730	528	646	72.4	5
	594	720	526	630	55.0	"
	596	732	471	205*	-	"
	599	743	567	665	57.0	"
	597	738	564	663	45.0	"
	596	775	515	633	70.4	"
	599	746	524	619	51.1	"
	596	749	512	620	75.2	"
	599	751	547	652	38.0	"
Average	596	744	535	641	57.9	"
STD #G-3	608	871	779	842		

* Broken grid lines not taken into average.

Table 3.3

Prediffusion Surface Etch

	V_{oc} (mv)	I_{sc} (ma)	I_{500} (ma)	R_{sh} (Ω)	η (%)
4 sec SF_6 (Avg of 3 cells)	600	678	580	30.8	10.2
8 sec SF_6 (Avg of 3 cells)	596	698	598	46.0	10.5
34 sec SF_6 (Avg of 3 cells)	596	680	586	58.1	10.3
2 sec $CF_4+8\%O_2$ (Avg of 3 cells)	595	694	564	38.6	9.9
4 sec $CF_4+8\%O_2$ (Avg of 3 cells)	599	692	562	30.4	9.9
17 sec $CF_4+8\%O_2$ (Avg of 3 cells)	599	656	568	52.6	10.0
Control (Avg of 4 cells)	601	681.8	591	39.6	10.3

Table 3.4

Plasma Etch of Diffusion Oxide

			R_{sh} (Ω)
<u>SF₆</u> etched	3 sec	1A ₁	16,667
		1A ₂	10,000
	12 sec	1B ₁	8,333
		1B ₂	12,500
	24 sec	1C ₁	12,500
		1C ₂	1,136
	48 sec	1D ₁	3,333
		1D ₂	225
<u>CF₄+8%O₂</u> etched			
	3 sec	2A ₁	4,545
		2A ₂	5,000
	12 sec	2B ₁	1,087
		2B ₂	7,143
	24 sec	2C ₁	5,000
		2C ₂	3,125
	48 sec	2D ₁	4,545
		2D ₂	5,555
Control		1	16,000
		2	8,000
		3	10,000
		4	<u>16,667</u>
		Average	12,667

Freon 23 was also tested for its ability to remove the diffusion oxide. Cells were etched from 30 seconds to 8½ minutes at room temperature, a pressure less than one torr and standard operating power output. Short circuit current was as good or better than controls. This might suggest surface effects such as AR coating, microtexturing or pitting during etching (Table 3.5). Cells etched for 30 seconds and 2 minutes showed 9.3% and 3.5% short circuit current increases, but showed a 30-70% current at load decrease as compared to controls. Open circuit voltage varied from 500 to 603 mV, 0.9% to 0.3% lower than controls over the whole range of etch times. After 5-7 minutes etch time, electrical characteristics were comparable with controls.

A cell etched for 6½ minutes showed 1% I_{sc} increase, no change in V_{oc} and a 1.2% decrease in current at load (450 Mv). A flaky post-etch residue was left on all specimens which cleaned off with a series of acetic acid, hot DI water, alcohol, and acetone rinses. Cell performance increased with ease of post-etch residue removal. It is clear that shorter etch times are needed which leave no post etch residue that require chemical rinses. In order to avoid chemical rinses, higher temperatures, shorter etch times, and lower chamber pressures (less than 500 millitorr) will be employed in future experiments.

3.3 FRONT METALLIZATION

The Radiation Technology Infrared furnace was investigated for possible use in the cell process sequence developed to date. The IR furnace consists of four controlled zones of IR lamps. Cells that pass through the furnace are carried under the lamps on a nine inch wide metal wire belt with a variable speed between ten and seventy inches/min. The first two zones were designed for drying and paste contact at a temperature between 0 and 400°C. The

Table 3.5

Plasma Etch of Diffusion Oxide
With Freon 23 (CHF_3)

Control Wafers

	V_{oc} (mv)	I_{sc} (ma)	I_{500} (ma)	I_{450} (ma)	R_{sh} (Ω)	Etch Time (min)
	600	721	556	650	94.3	
	602	728	565	656	106	
	600	740	555	657	75.8	
	598	717	540	635	73.5	
	600	741	568	664	122	
	600	725	535	626	16.0	
	601	737	592	682	59.5	
	599	709	547	642	119	
	601	720	572	660	86.2	
	599	727	540	639	31.4	
Average	600	727	557	651	78.4	
Etched with Freon 23						
	599	427	139	191	59.5	1
	599	716	390	478	122	1.5
	598	753	292	401	167	2
	601	735	382	540	53.8	2.5
	598	710	0	191	60.2	3.5
	600	716	409	521	98.0	4.5
	603	726	461	578	113	5.5
	601	734	553	643	61	6.5
	600	728	433	523	67	7.5
	600	736	487	592	89	8.5
	599	795	331	455	294	8.5
Average	600	738	415	526	118	
STD #G-3	608	871	779	842		

* Broken Grid Lines not taken into average.

combined length of these two zones is thirty-six inches. The second two zones were designed for the firing of either the aluminum P+ contact or the printed silver front contact at a temperature between 300 and 1100°C. The combined length of these two zones is twenty four inches.

In order to test the performance of the furnace wafers were processed in accordance with our standard process sequence, except that the wafers were laser scribed prior to front surface metallization. In our initial experiment (8.61.9) with the IR furnace, the wafers were dried in an oven at 125°C prior to IR firing. The front contacts were fired in the IR furnace with IR zones 3 and 4 set at 700°C. The belt speed was varied between 20 and 50 inches/min. The optimum belt speed was about 40 in./min., Table 3.6. The control wafers fired in a tube furnace were processed in parallel with the IR fired wafers, Table 3.7. These wafers were fired for 30 seconds at 700°C and had a higher output than the IR wafers processed on the 50 in./min. belt. The control wafers were compared with the 50 in./min. belt, because throughput is a major consideration. The IR fired wafer with a 50 in./min. belt speed remained in the 24 in. firing bank for 29 seconds and had a very low output. The 40 in./min. belt speed had a much better output. This indicated that the 700°C firing bank was too low for proper silver firing and throughput.

A second experiment (9.65.9), was run with the belt speed held constant at 50 in./min. (29 sec. in the firing zone) and the temperature of the last two firing zones was varied. The third zone was varied between 750 and 800°C, and the fourth zone was varied between 725 and 800°C, all these wafers were dried in an oven at 125°C. Nine additional wafers were fired under these conditions, Table 3.8.

Table 3.6

IR Firing of Silver Front Contacts
 Constant Temperature and Variable Belt Speed
 AR Coated 2.12x2.12 inch squares
 Run 8.61.9

Zone Settings: Zone 1, Zone 2, Zone 3, Zone 4: 0, 0, 700, 700 ($^{\circ}\text{C}$)

Belt speed	V _{oc}	I _{sc}	I ₅₀₀	R _{sh}
Inch/min	(mv)	(ma)	(ma)	
50	611	843	407	106
"	568	820	475	29.6
40	610	854	719	15.7
"	612	836	713	24.5
"	610	809	693	21.4
"	611	825	698	19.2
"	608	791	652	14.1
"	610	809	669	13.9
"	609	829	697	7.30
Average	610	822	692	16.6
30	607	796	646	27.6
"	609	824	675	18.3
"	608	811	665	24.0
"	606	793	643	20.3
Average	608	806	657	22.6
20	602	766	546	23.0
"	605	799	546	40.3

Table 3.7

Control Cells, Tube Fired Silver Front Contacts

AR Coated 2.12x2.12 inch squares

Run 8.61.9

Tube Fired at 700°C for 30 sec.

	V_{oc} (mv)	I_{sc} (ma)	I_{500} (ma)	R_{sh} (Ω)
	607	803	675	19.9
	607	787	675	22.4
	608	796	702	23.1
	610	804	715	22.1
	608	782	692	21.7
Average	608	794	692	21.8

Table 3.8

IR Firing of Silver Front Contacts
 Variable Temperature and Constant Belt Speed
 No AR Coating 2.12 x 2.12 Inch Squares
 Run 9.65.9
 Belt Speed 50 inch/min

Zone 1 Temp (°C)	Zone 2 Temp (°C)	Zone 3 Temp (°C)	Zone 4 Temp (°C)	V _{oc} (mv)	I _{sc} (ma)	I ₅₀₀ (ma)	R _{sh} (Ω)
0	0	800	800	593	663	574	44.3
				594	637	549	23.0
0	0	775	775	596	716	608	19.1
				599	657	570	27.5
0	0	800	750	600	663	585	45.5
				598	641	564	37.6
0	0	750	750	601	676	596	38.2
				599	654	572	29.8
0	0	775	725	601	688	601	43.9
				600	668	557	23.0
				601	674	562	55.0
				*602	663	393	34.5
				599	680	571	43.1
				599	677	530	32.9
				*600	674	524	42.4
				^600	684	401	31.9
				596	702	488	42.0
				600	699	584	47.6
				600	668	583	61.0
Average				600	682	560	43.6

* Broken grid lines not taken into average.

In a third experiment an attempt was made to simulate the oven drying by turning on the first two zones. The wafers were dried in zones 1 and 2 and were fired in zones 3 and 4. A drying temperature of 260°C and 410°C in zones one and two, respectively, was judged the optimum setting. Seven additional samples were fired under these optimum drying conditions when zone three was set at 750°C and zone four was set at 700°C, Table 3.9. The output of these cells was slightly lower than the control group which was fired in a tube furnace, Table 3.10.

Reexamination of the data of run 9.65.9 indicates that the setting of 260, 410, 750 and 750°C for zones 1, 2, 3, and 4, respectively, may be optimum. In run 9.66.9 four different (110) oriented lots of silicon were processed with half of each lot used as controls and half dried and fired under the optimum IR setting, Table 3.11, 3.12, 3.13, and 3.14. In all lots, the IR firing was better than the tube firing. The first two lots of wafers from Wacker were superior to those from the second two lots purchased from Texas Instruments.

These initial results of the infrared drying and firing of screen printed silver paste contact indicate possibilities of producing high efficiency four inchsquare cells at the rate of 350 per hour.

During the next period, infrared drying and firing of the aluminum P + contract will be investigated in combination with the silver firing.

3.4 LAMINATION

The fixture for the lamination of 2' x 4' modules was completed. A diagram of the fixture is shown in Figure 3.8. Eight mil stainless steel sheet was used as the bottom chamber's lowest sheet. A thermally conductive silicone grease was placed between this sheet and the flexible heater below.

Table 3.9

IR Drying and Firing of Silver Front Contacts
Variable Temperature and Constant Belt Speed

No AR Coating 2.12 x 2.12 Inch Squares

Belt Speed 50 inch/min.

Run 9.65.9

Zone 1 Temp (°C)	Zone 2 Temp (°C)	Zone 3 Temp (°C)	Zone 4 Temp (°C)	V _{oc} (mv)	I _{sc} (ma)	I ₅₀₀ (ma)	R _{sh} (Ω)
310	430	750	750	599	664	578	24.2
				598	652	553	25.6
225	360	750	750	599	661	585	15.8
				600	665	597	27.0
260	410	775	725	598	661	573	28.7
				598	664	577	41.0
260	410	750	750	598	703	600	23.6
				600	695	595	24.5
260	410	750	700	596	681	540	13.6
				601	670	559	50.5
				601	680	581	60.2
				601	684	476	25.0
				599	746	598	41.0
				601	671	557	58.9
				601	681	530	33.1
Average				600	688	549	35.3

Table 3.10

Control Cells, Tube Fired Silver Front Contacts

No AR Coating 2.12 x 2.12 inch squares

Run 9.65.9

Tube Fired at 700°C for 30 sec.

	V_{oc} (mv)	I_{sc} (ma)	I_{500} (ma)	R_{sh} (Ω)
	598	699	585	22.6
	600	669	583	40.3
	601	687	599	84.8
	602	690	602	70.4
	602	683	600	38.5
	601	669	578	46.3
	601	680	588	26.5
	601	677	590	46.7
Average	601	682	591	47.0

Table 3.11

IR Vs Tube Fired Front Silver Contacts
No AR Coating 2.12 x 2.12 Inch Squares

Run 9.66.9

Silicon Type: (110) (637A) Wacker (10.0 Ω -cm)

IR Fired Silver front contacts

Belt Speed 50 inch/min

Zone 1, Zone 2, Zone 3, Zone 4: 260, 410, 750, 750 ($^{\circ}$ C)

	V_{oc} (mv)	I_{sc} (ma)	I_{500} (ma)	R_{sh} (Ω)
	601	750	604	48.1
	600	747	601	64.1
	600	754	610	76.9
	602	751	607	55.0
	601	755	610	82.0
Average	601	751	606	65.2

Tube Fired at 700 $^{\circ}$ C for 30 sec.

	600	727	576	29.6
	596	665	517	64.1
	598	700	558	96.1
	698	694	559	65.8
	602	756	610	31.9
Average	599	708	564	57.5

Table 3.12

IR Vs Tube Fired Front Silver Contacts

No AR Coating 2.12 x 2.12 Inch Squares

Run 9.66.9

Silicon Type: (110) (512) Wacker (2.0 Ω -cm)

IR Fired Silver Front Contacts

Belt Speed: 50 inch/min

Zone 1, Zone 2, Zone 3, Zone 4: 260, 410, 750, 750 ($^{\circ}$ C)

	V_{oc} (mv)	I_{sc} (ma)	I_{500} (ma)	R_{sh} (Ω)
	598	747	593	45.9
	600	745	614	125.0
	604	718	609	30.9
	604	713	605	31.9
	596	757	605	75.8
Average	600	736	605	61.9

Tube Fired at 700 $^{\circ}$ C for 30 sec.

	602	702	576	17.7
	603	701	583	25.3
	596	702	557	82.0
	596	686	544	90.9
Average	599	698	565	54.0

Table 3.13

IR Vs Tube Fired Front Silver Contacts

No AR Coating 2.12 x 2.12 Inch Squares

Run 9.66.9

Silicon Type: (110) (4950-1) Texas Instrument (0.4 Ω -cm)

IR Fired Silver Front Contracts

Belt Speed 50 inch/min

Zone 1, Zone 2, Zone 3, Zone 4: 260, 410, 750, 750 ($^{\circ}$ C)

	V_{oc} (mv)	I_{sc} (ma)	I_{500} (ma)	R_{sh} (Ω)
	604	638	526	9.75
	603	615	529	14.0
	602	620	519	13.9
	603	620	532	20.9
	603	608	520	14.9
	603	616	528	18.0
Average	603	620	526	15.2

Tube Fired at 700 $^{\circ}$ C for 30 sec.

	600	598	482	20.1
	601	617	502	17.2
	599	602	479	14.2
	603	628	512	16.0
	604	636	536	12.6
	599	595	478	23.6
Average	601	613	498	17.3

Table 3.14

IR Vs Tube Fired Front Silver Contacts
No AR Coating 2.12 x 2.12 Inch Squares.

Run 9.66.9

Silicon Type: (110) (4950-2) Texas Instrument (0.4 Ω -cm)

IR Fired Silver Front Contacts

Belt Speed 50 inch/min

Zone 1, Zone 2, Zone 3, Zone 4: 260, 410, 750, 750 ($^{\circ}$ C)

	V_{oc} (mv)	I_{sc} (ma)	I_{500} (ma)	R_{sh} (Ω)
	596	584	431	7.80
	599	599	490	9.24
	595	567	463	8.58
	600	604	475	6.54
	599	614	485	6.00
	599	617	498	7.49
	599	604	440	5.64
	598	609	465	4.21
Average	598	600	472	7.90

Tube Fired at 700 $^{\circ}$ C for 30 sec.

	593	573	390	8.59
	600	616	491	13.2
	596	576	425	10.5
	591	568	394	10.0
	598	613	477	10.9
	599	615	466	10.3
	589	542	348	7.07
Average	595	586	427	10.1

LAMINATING FIXTURE

FIGURE 3.8

(NOT TO SCALE)

Springborn's A-9918-5 (clear) and A-9903-B (white) EVA were investigated as possible encapsulation materials. These materials appear to outgas more than the older formulations. To avoid the outgassing problem the cycle shown in Figure 3.9 was suggested by Springborn Laboratories. Modules made using this cycle showed fewer bubbles, but still contained bubbles which were not seen using previous formulations. Consultations with Springborn have suggested different cycles which will be tested in the future. Another problem encountered with the larger lamination fixture was that of back surface rippling. This has been successfully minimized by the insertion of an 8 mil stainless steel sheet between the FEP and silicone layer in the assembly layup. (See Figure 3.8).

The layer of clear EVA between the white EVA and the cell backs has been eliminated. Bleeding of the white pigment onto the cell front, which had been previously encountered, has not been seen. This is possibly due to the change in formulation of the white EVA.

A 9 7/8" x 15" mini module was attempted in the 2' x 4" lamination fixture. The module showed no bubbling or rippling, but was severely cracked. Analysis of the glass edges showed crack propagation from poorly cut glass edges. Future modules will use glass which has been ground on the edges to help eliminate this problem.

Figure 3.9
TIME/TEMPERATURE/PRESSURE
CYCLE - SOLAR MODULES

(DOUBLE VACUUM BAG TECHNIQUE)

1. ASSEMBLE MODULE, LOAD INTO DOUBLE VACUUM BAG.
2. EVACUATE BOTH CAVITIES FOR 20 MINUTES, START HEATING.
3. RELEASE TOP CAVITY VACUUM AT 120°C POINT.
4. ALLOW 10 MINUTES HEATING AT 140 - 150°C.
5. COOL, REMOVE MODULE.

(Presented by Springborn Laboratories at the LSA 13th PIM)

4.0 CONCLUSIONS

The following conclusions have been reached during this quarter.

- 1) The silicon ingot that was tested from Dymat is equivalent to the ingot supplied by Spectrolab.
- 2) An investigation of the plasma etch apparatus has shown an etch rate in the range of 1800⁰Å per minute for a mixture of Freon 14 and 8% oxygen.
- 3) Etching the front surface of a solar cell for twelve to 18 seconds in Freon 14 + 8% oxygen increased the performance of the cell. Longer etch times caused serious degradation of solar cell performance.
- 4) Up to 50% of the cell performance improvement by plasma etching may be attributable to AR effects, but a significant amount of improvement cannot be accounted for in this way.
- 5) The Radiation Technology Infrared furnace shows possibilities of producing high efficiency four inch square cells at the rate of 350 per hour.

5.0 RECOMMENDATIONS

There are no recommendations.

6.0 NEW TECHNOLOGY

There was no new technology reported during this period.