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

Quarterly Technical Progress Report for Quarter Ending December 29, 1979

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February 1980

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Spectrolab, Inc.
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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

December 29, 1979

JPL Contract 954853
CDRL 010

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The JPL Low-Cost Silicon 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.

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The proposed process sequence being developed under this contract has been further refined during this reporting period. A sulphur hexafluoride plasma etch was investigated as a possible surface treatment to improve the performance of the cell, the Radiation Technology Infrared Furnace was qualified for use in the process sequence, and work was initiated on junction clean up by laser scribing through the junction. An evaluation of the minority carrier diffusion length of silicon crystals received from various vendors was also included in this quarters activities.

The minority carrier diffusion length in crystals supplied by various vendors was measured by the surface photovoltage method. A 60 micron minority carrier diffusion length was found to be the minimum acceptable level to produce high efficiency (14%) solar cells.

The work done on plasma etching included an investigation of both the removal of the diffusion oxide and an investigation of possible etching treatments to improve performance of the solar cell. The diffusion oxide experiments were not completed because a flaky post etch residue prevented the front metallization from adhering to the front of the cell. The investigation of possible plasma etching atmospheres showed that Freon 14 plus 8% oxygen resulted in excessive pitting and resultant shunting. A sulphur hexafluoride plasma etch did not exhibit these problems and was selected for further investigation. Further experimentation with SF_6 showed that a 12% increase in performance could be achieved after a 60 second plasma etch. This increase in performance has been attributed to the junction shallowing that resulted from the plasma etching.

Experiments with the Radiation Technology infrared furnace compared solar cells fired in the resistant tube furnace with other cells fired in the infrared furnace. All results indicated that the two methods of firing the cells were equivalent for both the front metallization and the back surface field.

Work was initiated on junction isolation. Initial experiments have examined the type of scribe line that results from a pulsed laser with a power output of two watts.

2.0 INTRODUCTION

This Quarterly Technical Progress Report covers the quarter ending December 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 the Phase 2 of the Array Automated Assembly Task, Large Solar Array Project.

The cell and module process sequence is shown in Table 2-1. 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 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 baseline sequence. These are indicated in Table 2-1 by the alternative routes marked with solid light lines.

During the past quarter, some of the routes indicated by solid light lines were investigated as possible alternatives. These alternatives included a plasma etch to remove the diffusion oxide. Also investigated during this reporting period, was the effect of a sulphur hexafluoride plasma etch on finished silicon solar cells.

In addition to the work done on plasma etching, an evaluation of the Radiation Technology infrared furnace was completed, along with an investigation of the laser scribe junction clean step in the process sequence. Samples were also prepared for a Transmission Electron Microscope evaluation of processing effects.

Table 2-1

PROCESS SEQUENCE

Table 2-1
(continued)

3.0 TECHNICAL DISCUSSION

3.1 MINORITY CARRIER DIFFUSION LENGTH

The quality of the Czochralski crystal is an important factor in the performance of the finished processed cell. One measurement of this quality is the minority carrier diffusion length. During this reporting period cell performance was correlated with crystal minority carrier diffusion length. The experiment was devised after what appeared to be systematic variations associated with crystals obtained from different vendors were observed.

Minority carrier diffusion length is a measurement of the distance the carrier travels before it recombines. The distance is dependant on structural defects or impurities in the crystal lattice. These act as a recombination center for the carriers. Many defects can be found in the form of grain boundaries, twins, dislocations and point defects. Impurities that affect the quality of the crystal include carbon, oxygen, boron, phosphorus and other elements. Since the intended dopant may act as a recombination center for the carriers as well as other stray impurities, low resistivity silicon will have a shorter minority carrier diffusion length than equivalent high resistivity silicon.

Slices, 350 microns thick, from each ingot were cut into 2 x 2 cm wafers and chemically polished. The minority carrier diffusion length was measured by the surface photovoltage method. Photon flux at constant surface photovoltage was plotted against reciprocal absorption coefficient for a given range of wavelengths. The straight line that resulted was extrapolated to the minority carrier diffusion length, (Figure 3.1). These measurements were taken at JPL by Kathy Dumas. Table 3.1 is a tabulation of the data and other available information.

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Sample I.D. #W-124129-4

PLOT OF INVERSE ALPHA VS. INTENSITY
Stress-relieved model

Diffusion Length is 92.30 ± 13.51 Microns.

Table 3.1

MINORITY DIFFUSION LENGTH OF CZ CRYSTALS

	Sample ID	Supplier	ρ (Ω -cm)	MDL (μ)	Orientation	$i_{sc}(ma)/cm^2*$	$i_{500}(ma)/cm^2*$
∞	S/L-2608-1	A	7-14	110 ± 8	(100)	---	---
	S/L-2608-2	A	7-14	71 ± 3	(100)	---	---
	S-77806-4	B	0.5-1.0	72 ± 2	(100)	24.8	21.8
	D-1122-S1-A-6	C	1.0-3.0	47 ± 3	(100)	23.2	20.2
	D-1122-S1-B-4	C	1.0-3.0	49 ± 3	(100)	22.7	18.8
	TI-4837-6	D	0.5-1.0	10 ± 5	(100)	21.1	14.1
	TI-4950-1-4	D	0.1-0.5	40 ± 1	(110)	21.4	18.1
	TI-4950-2-3	D	0.1-0.5	22 ± 1	(110)	20.7	16.3
	W-170512	E	1.0-3.0	61 ± 5	(110)	25.8	21.5
	W-169637-4	E	7-14	134 ± 14	(110)	25.9	20.9
	W-168570-4	E	7-14	75 ± 11	(110)	24.5	21.0
	W-124129-4	E	7-14	92 ± 14	(110)	---	---

*No AR Coating

The orientation of the wafers were either (100) or (110). The 30% NaOH has a slight texturing effect on the (110) wafers. This reduced the reflectance of the surface and increased the i_{sc} by about 5 to 8%.

After examining the data it appears that the crystals supplied by supplier D have a low minority carrier diffusion length. This resulted in cells of low i_{sc} and poor output at load. The material supplied by supplier C had a longer minority carrier diffusion length which improved the i_{sc} and output at load. The material supplied by vendors B and E had the longest minority carrier diffusion lengths and cells fabricated from this material had the highest i_{sc} and output at load. A 60 micron minority carrier diffusion length appears to be the minimum acceptable level to produce high efficiency (14%) solar cells by the process we are using.

3.2 PLASMA ETCHING

Plasma etching experiments performed during this reporting period focused on removal of the diffusion oxide, a comparison of Freon 14 plus 8% oxygen and SF_6 , and improvement of a solar cell's performance by plasma etching in sulphur hexafluoride. Work done on the removal of the diffusion oxide resulted in cells that could not be tested due to a flaky post etch residue. Comparison of Freon 14 plus 8% oxygen and SF_6 showed that Freon 14 plus 8% oxygen resulted in more pitting of the wafer surface than SF_6 . Further tests with SF_6 showed that its use could improve that performance of a solar cell by as much as 12% after a 60 second etch.

Diffusion oxide removal experiments were set up to etch wafers from 30 seconds to 7 minutes with Freon 23 at a chamber pressure of ~500 mtorr. Etch temperatures varied from 25°C to 200°C.

Little or no removal of diffusion oxides was seen at short (.5 to 3.5 min.) etch times. Several samples showed oxide removal in and near the center indicating possible non-uniformities in diffusion oxide thickness. A 3-7 minute Freon 23 plasma etch resulted in a flaky residue which rinsed clean after treatment with alcohol and water. Cells fabricated from these wafers could not be tested because printed front metallization would not adhere. These experiments will be repeated in a different plasma etch device because we suspect problems with the Tegal Plasmaline 100. The platen is very susceptible to corrosion and difficult to keep clean. System impurities may deposit causing varied etch problems. This was partially verified in a subsequent experiment.

A comparison was made of sulfur hexafluoride and Freon 14 + 8% oxygen by plasma etching non-metallized silicon solar cells after removal of the diffusion oxide. A hopelessly slow etch rate prohibited examination of Freon 14 without O_2 . Three groups of wafers were fabricated for the experiment. The first group was P type, 1-3 ohm-cm material that had only been given the standard 30% NaOH surface etch. These wafers were kept as the controls. The second group of wafers was also P type, 1-3 ohm-cm material that had been given the standard surface etch, but these wafers were plasma etched for five and ten minutes in both Freon 14 + 8% O_2 and SF_6 . The third group of wafers was chemically etched P type, 1-3 ohm-cm material that had been diffused with phosphorus. These wafers were also etched for five and ten minutes in both Freon 14 + 8% O_2 and SF_6 . These samples were examined with a scanning electron microscope and photos were taken (Figures 3.2 - 3.6). The brightly colored spots appearing on all samples were shown to contain iron by EDAX measurements. This residue is a suspected corrosion product

Figure 3.2 - Phosphorus
diffusion on boron doped
base etched 10 min with
Freon 14 + 8% O₂ at 26°C
Mag. 4000X

Figure 3.3 - Boron doped
base material etched 10 min.
with Freon 14 + 8% O₂ at
26°C
Mag. 4000X

Figure 3.4 - Control sample
standard boron doped base
given standard 30% NaOH sur-
face etch.

Mag. 4500X

Figure 3.5 - Phosphorus dif-
fusion on boron doped base
etched 10 min. with SF_6 at
 26°C .

Mag. 4000X

Figure 3.6 - Boron doped base
material etched 10 min. with
 SF_6 at 26°C .

Mag. 4500X

of the plasma etch platen. Careful examination of all samples showed the iron compound to be nonuniformly distributed over the samples. This explains the absence of contaminants on some photos.

Comparison of both diffused and non-diffused samples plasma etched with SF_6 or Freon 14 + 8% reveal dramatic differences. Most notable are the large pits on Freon 14 + 8% O_2 etched samples which do not appear on the relatively smooth post SF_6 etched wafer surface. This confirms suspicions of pitting raised from previous experiments. Phosphorous diffused samples etched with Freon 14 + 8% O_2 and contacted, displayed shunt resistance readings 50% lower than those measured from SF_6 etched or control samples.

Phosphorus diffused samples etched with Freon 14 + 8% O_2 appear to have larger pits than non-diffused wafers (Figure 3.2). Surface damage and near surface phosphorous precipitates formed during diffusion may enhance plasma etch pitting action. Precipitates removed during etching leave voids which may broaden and deepen with further etching.

Further work was done with SF_6 in order to determine its effect on finished cells. A series of 12 finished cells was etched 6 to 90 seconds. Short circuit current and load point current (500 mV) measurements were taken before and after each run. The results showed maximum cell performance improvement (approximately 12%) after a 60 second etch (Figure 3.7). The SF_6 plasma etch rate of (100) orientation silicon is 900-1000 Å/min. This rate was determined by step etching and step measurement with a Talysurf profilometer.

There are several mechanisms that would account for this cell improvement also seen in experiments done in Freon 14 + 8%

Figure 3.7

CHANGE OF SHORT CIRCUIT AND LOAD
POINT CURRENT WITH PLASMA ETCHING
IN SULFUR HEXAFLUORIDE

12/79

Figure 3.8

SOLAR CELL SPECTRAL RESPONSE BEFORE
AND AFTER 60 SECONDS ETCHING IN
SULFUR HEXAFLUORIDE

12/79

oxygen. These mechanisms include removal of lattice damage and phosphorous precipitates (the so-called dead layer) in the first 300-500 Å, junction depth shallowing, and plasma induced surface pitting. Removal of the dead layer is an unlikely explanation for cell improvement, because dead layer recombination processes are likely to be replaced by surface recombination processes after 500 Å of silicon removal. Moreover, the cells that showed the greatest improvement had over 1000 Å of material removed from the front surface. Plasma induced surface pitting was also an inadequate explanation for the I_{sc} increases in the SF_6 experiment because SF_6 does not pit the surface of the wafer. Junction depth shallowing is a more likely explanation, because greater than 1000 Å of material removed from the front surface after plasma etching. Special response measurements performed before and after plasma etching support this hypothesis. The largest increase in the short circuit current response is seen at the short wavelengths (Figure 3.8). Data scatter at longer wavelengths require further spectral response measurements in order to obtain an unambiguous result.

The performance increases observed with sulphur hexafluoride support previous conclusions about a Freon 14 + 8% oxygen etching atmosphere. Earlier it had been determined that about fifty percent of the cell improvement after etching with Freon 14 + 8% oxygen was attributable to AR effects. This was verified by etching 500 Å off the front surface of the silicon solar cell with both Freon 14 + 8% oxygen and sulphur hexafluoride. A fifteen percent and six percent improvement was seen with Freon 14 + 8% oxygen and sulphur hexafluoride, respectively. About nine percent of the improvement seen with Freon 14 + 8% oxygen was attributed to the antireflective effects of pitting. The pitting was not noticed with sulphur hexafluoride.

3.3 QUALIFICATION OF INFRARED FURNACE

During the previous period, cells fired in the infrared furnace were reported to have comparable output to those fired in the tube furnace. In order to further verify that the infrared furnace was equivalent to the tube furnace, more tests were conducted. These tests were conducted on both the front metallization and the aluminum back surface field with positive results.

In our first verification run on the front metallization (9.67.9), cells were processed in accordance with our standard sequence, except the wafers were laser scribed prior to front metallization. One group was tube fired and the other was IR fired, Table 3.2. The results of these experiments indicate that the two methods of firing the silver front contacts are equivalent. The fabricated cells in this run had poor performance, which is attributed to the short minority carrier diffusion length of about 10 microns.

As a further verification a different lot of silicon was used to duplicate run 9.67.9 (run 10.71.9). The results of this run also indicate that the tube and IR firing are equivalent, Table 3.3.

Two different lots of silicon were chosen for our verification run on qualification of the infrared furnace for the back surface field, 0.1 to 0.5 Ω -cm TI silicon and 7 to 10 Ω -cm Wacker silicon. To simulate the normal 80 second tube firing of the back contact, the belt speed was held constant at 18 inches/min. and the temperature was varied between 800 and 900⁰C in 25⁰C intervals. These wafers were dried in an oven prior to firing. The optimum temperature was between 825 and 850⁰C, Table 3.4.

Table 3.2

RESISTANT HEATED TUBE FIRING VS. INFRARED FIRING
OF FRONT SILVER CONTACTS

Run 9.67.9

Tube Fired Cells

	<u>V_{oc}</u> (mV)	<u>I_{sc}</u> (mA)	<u>I₅₀₀</u> (mA)	<u>R_{sh}</u> (Ω)
	592	586	322	3.5
	592	604	394	2.8
	596	612	445	3.6
	585	576	350	2.5
	591	612	364	4.6
	596	618	446	3.5
	591	602	392	2.6
	592	604	405	3.1
	587	575	372	2.8
	591	593	423	3.3
	<u>589</u>	<u>579</u>	<u>387</u>	<u>3.6</u>
Average	590.5	596.5	391	3.25

IR Fired Cells

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

Belt Speed 50 inches/min.

	583	575	324	2.1
	593	595	392	2.7
	596	607	462	4.2
	587	580	417	3.3
	596	612	443	3.4
	590	592	425	5.3
	588	600	354	3.1
	595	622	431	4.0
	591	604	402	3.3
	<u>597</u>	<u>635</u>	<u>468</u>	<u>6.0</u>
Average	591.6	602	411	4.2

Table 3.3

RESISTANT HEATED TUBE FIRING VS. INFRARED FIRING
OF FRONT SILVER CONTACTS

Run 10.71.9

Tube Fired Cells			
V_{oc} (mV)	I_{sc} (mA)	I_{500} (mA)	R_{sh} (Ω)
601	641	568	18.7
598	622	547	14.6
599	624	546	19.0
599	624	542	13.6
600	624	566	26.7
600	633	576	24.0
598	613	555	25.9
599	628	561	19.8
599	616	540	17.4
599	642	574	19.3
600	645	582	20.8
600	626	564	25.6
596	610	541	20.0
600	629	569	21.7
600	627	569	21.9
600	625	568	31.9
600	639	563	16.8
599	632	571	25.1
599	636	569	17.4
Average	599.3	628	20.1

IR Fired Cells

Zone 1, 2, 3, 4: 260, 410, 750, 750 ($^{\circ}\text{C}$)
Belt Speed: 50 inches/min.

600	628	569	18.5	
599	625	561	18.5	
597	621	554	14.2	
599	624	565	18.0	
598	631	555	10.6	
598	618	551	17.2	
600	633	581	28.6	
599	623	566	20.9	
600	626	569	22.0	
598	631	574	28.9	
599	629	572	19.8	
598	635	571	16.1	
599	632	570	17.0	
599	633	568	16.7	
600	638	568	13.9	
600	627	563	17.3	
601	642	572	14.2	
598	647	546	7.4	
599	644	545	7.6	
Average	599	631	564	17.2

Table 3.4

IR FIRING OF ALUMINUM BACK SURFACE FIELD
 VARIABLE TEMPERATURE AND CONSTANT BELT SPEED
 NO AR COATING 2.12 x 2.12 INCH SQUARES

Run 10.73.9
 Dried in Oven for 20 min. @ 200°C
 Belt Speed 18 inches/min.

	<u>Silicon</u>	<u>Zone 1</u>	<u>Zone 2</u>	<u>Zone 3</u>	<u>Zone 4</u>	<u>V_{oc}</u>	<u>I_{sc}</u>	<u>I₅₀₀</u>	<u>R_{sh}</u>	<u>Comments</u>
	<u>Type</u>					<u>(mV)</u>	<u>(mA)</u>	<u>(mA)</u>	<u>(Ω)</u>	
20	TI	0	0	800	800	581	571	303	2.0	
	TI					592	583	402	3.0	
	Wacker					595	706	597	43.0	
	TI	0	0	825	825	592	593	402	2.4	
	Wacker					600	718	615	35.5	
	TI	0	0	850	850	578	585	281	1.9	
	TI					591	582	408	3.4	
	TI					581	572	285	1.7	
	TI					590	585	387	2.2	
	TI					597	593	473	4.2	
	Wacker					601	706	600	34.0	
	Wacker					602	698	606	43.0	
	Wacker					600	707	612	28.4	
	TI	0	0	875	875	598	570	490	7.8	Bumps
	Wacker					600	690	599	45.9	Bumps
	TI	0	0	900	900	Broken				Bumps
	TI					Broken				Bumps
	Wacker					585	686	547	20.0	Bumps

In an attempt to obtain a better understanding of the time-temperature effects, the belt speed was increased to 36 inches/min. (40 sec. firing cycle) and the temperature was varied between 875 and 925°C in 25°C intervals. The optimum temperature was 875°C, Table 3.5. Some of the high temperature, long firing cycles caused bumps and unalloyed areas to occur on the aluminum. To determine whether these unalloyed areas were caused by organics remaining in the paste, the wafers were sent through a 400°C drying cycle in zone 1 and 2 prior to firing at 875°C at a belt speed of 18, 24 and 36 inches/min. No improvement occurred with this extra drying step, Table 3.6. The bumps and unalloyed areas appear to be caused by firing cycles that are too long and/or too hot.

3.4 JUNCTION ISOLATION

Junction isolation was first evaluated by laser scribing the perimeter of the front face of finished cells. All work was performed in the TEM₀₀ laser mode. Chuck speed, laser pulse rate and laser power output were all adjusted to produce a shallow continuous scribe. Chuck speed was 8"/sec., laser pulse rate was 50 KHZ and laser power output was 2 watts. Results (Table 3.7) indicated a 20% shunt resistance (R_{sh}) increase. SEM examination of the laser cuts revealed pulse overlap discontinuities and also showed slag free laser drilled holes (Figure 3.9).

Finished cells, except for the junction clean step, were also laser scribed. This allowed comparison with those cells that had been given the junction isolation step and the control cells. Laser output was varied from 2 to 3 watts and the Q factor (pulse rate KHZ ÷ chuck speed) was varied from 6.25 to 25. Control cells were laser scribed from the rear of the cell and cleaved to eliminate leakage current. Experimental cell characteristics

Table 3.5

IR FIRING OF ALUMINUM BACK SURFACE FIELD
VARIABLE TEMPERATURE AND CONSTANT BELT SPEED
NO AR COATING 2.12 x 2.12 INCH SQUARES

Run 10.73.9
Dried in Oven for 20 min. @ 200°C
Belt Speed 36 inch/min.

<u>Silicon Type</u>	<u>Zone 1</u>	<u>Zone 2</u>	<u>Zone 3</u>	<u>Zone 4</u>	<u>V_{oc} (mV)</u>	<u>I_{sc} (mA)</u>	<u>I₅₀₀ (mA)</u>	<u>R_{sh} (Ω)</u>	<u>Comments</u>
TI	0	0	875	875	596	577	464	5.5	
Wacker					600	704	613	54.3	
TI	0	0	900	900	594	578	461	6.4	
Wacker					598	700	601	56.2	
TI	0	0	925	925	591	584	470	6.6	Bumps
Wacker					582	667	495	70.4	Bumps

Table 3.6

IR FIRING OF ALUMINUM BACK SURFACE FIELD
 CONSTANT TEMPERATURE AND VARIABLE BELT SPEED
 NO AR COATING 2.12 x 2.12 INCH SQUARES

Run 10.73.9

Dried in Oven for 20 min. @ 200°C

Zone 1, Zone 2, Zone 3, Zone 4: 260, 410, 875, 875°C

<u>Silicon Type</u>	<u>Belt Speed (inch/min.)</u>	<u>V_{oc} (mV)</u>	<u>I_{sc} (mA)</u>	<u>I₅₀₀ (mA)</u>	<u>R_{sh} (Ω)</u>	<u>Comments</u>
TI	18	588	584	414	4.3	Bumps
TI		594	577	472	8.1	Bumps
Wacker		597	705	606	49.0	Bumps
TI	24	593	575	451	7.7	
TI		593	586	465	6.0	
Wacker		601	705	614	82.0	
Wacker		598	700	600	119.0	
TI	36	591	577	456	7.1	
TI		595	580	455	4.6	
Wacker		600	693	588	72.5	
Wacker		599	687	586	42.4	

Table 3.7

LASER SCRIBED FINISHED CELLS

	V_{oc}	I_{sc}	I_{500}	R_{sh}
Before (3 samples)	598.3	663.3	564.3	13.9
After (3 samples)	594.0	663.3	528.7	16.7
Δ	- 1%	0	- 6.3%	+ 20%

Table 3.8

LASER SCRIBE NON-EDGE ETCHED CELLS

	V_{oc}	I_{sc}	I_{500}	R_{sh}	Q factor	Laser Output
Controls (4 samples)	585	691	502	14.2		
A	576	700	305	120.1	12.5	3 W
B	579	690	349	92.9	8.3	3 W
C	561	670	293	193.3	6.25	3 W
D	577	668	241	120.5	25	2 W
E	562	590	129	92.9	12.5	2 W
F	525	520	043	146.5	6.25	2 W

Figure 3.9 - Laser scribe o
finished cells shows pulse
overlap discontinuities and
slag free laser drilled
holes.

Q factor = 5000 pulses/in.
Laser power output = 2 watt
Magnification = 1000X

Figure 3.10a- Non-junction
isolated cell shows pulse
overlap discontinuities

Q factor = 3000 pulses/in.
Laser power output = 2 watt.
Mag. = 1400X

Figure 3.10b- Non-junction
isolated cell shows pulse
overlap discontinuities.

$Q_f = 4000$ pulses/in.
Laser power output = 2 watts
Mag. = 1000X

Figure 3.10c- Non-junction
isolated cell shows pulse
overlap discontinuities

$Q_f = 8300$ pulses/in.
Laser power output = 2 watts
Mag. = 1000X

compared unfavorably with control cells (Table 3.8). SEM examination showed pulse overlap discontinuities at all Q factors examined (Figure 3.10a,b&c). Quantronix has recommended that increasing laser output to >5 watts would reduce pulse irregularities enabling clean continuous groove formation, which would significantly reduce or eliminate current leakage.

3.5 TEM ANALYSIS OF CELL PROCESSING

It has been suggested that low-cost cell processing may induce damage or undesirable defects into the silicon wafers. In an initial attempt to identify some of these problems, 10 wafers were processed through different stages of our standard process and etched down to 125 μm . Analysis will be conducted on a Transmission Electron Microscope (TEM). The areas of interest included in this investigation are:

- 1) Surface preparation, NaOH etched wafer.
- 2) Defects associated with the surface of a PX-10 diffused wafer.
- 3) Defects associated with the surface of a PX-10 diffused wafer after a 60 second SF_6 plasma etch. Approximately 6% increase in I_{sc} with Tungsten light source.
- 4) Defects associated with the surface of a PX-10 diffused wafer after the wafer has been processed with the aluminum back contact and cleaned.
- 5) Defects associated with the surface of a good PX-10 diffused cell.
- 6) Defects about the laser scribe on the back of a wafer.
- 7) Defects associated with the silver paste on a diffused wafer.
- 8) Defects associated with the silver paste on a NaOH etched wafer.
- 9) Defects associated with the P/P^+ interface of an aluminum back contact wafer.
- 10) Defects associated with the P^+ back surface layer.

The TEM analysis will be performed at UCLA by Dr. A. J. Ardell. Dr. Ardell has received 10-3" round wafers which will be sectioned and etched in preparation for the TEM.

4.0 CONCLUSIONS

The following conclusions were reached during this period:

- 1) Variations in minority carrier lifetime of silicon crystals used to fabricate solar cells can have a significant effect on cell performance.
- 2) The infrared furnace is equivalent to the resistance tube furnace when firing both the back surface field and the front metallization.
- 3) Plasma etching solar cells in sulphur hexafluoride can increase the performance of the cells.

5.0 RECOMMENDATIONS

There are no recommendations

6.0 NEW TECHNOLOGY

Plasma etching of finished solar cells in sulphur hexafluoride can improve cell performance.