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HIGH RESOLUTION, LOW COST SOLAR CELL CONTACT DEVELOPMENT

Quarterly Technical Progress and Schedule Report for Period Ending
December 31, 1980

By
A. Garcia

January 12, 1981

Work Performed Under Contract No. NAS-7-100-955725

Spectrolab, Inc.
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Quarterly Technical Progress and Schedule Report
"HIGH RESOLUTION, LOW COST SOLAR CELL CONTACT DEVELOPMENT"

For the Period Ending December 31, 1980

Contract 955725

CDRL 4

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Aeronautics and Space Administration.

ABSTRACT

During the second quarterly period of this contract, Spectrolab has optimized the MIDFILM[®] process and produced cells comparable to those produced using conventional metallization techniques. A prefiring process step has been developed to remove organic materials from the contact prior to sintering.

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1.0 INTRODUCTION

This second Quarterly Technical Progress and Schedule report covers the quarter ending December 31, 1980. The scope of the contract covers the development and evaluation of forming solar cell collector grid contacts by the MIDFILM[®] process. This is a proprietary process developed by the Ferro Corporation which is a subcontractor for the program.

The MIDFILM process attains line resolution characteristics of photoresist methods with processing related to screen printing. The surface to be processed is first coated with a thin layer of photoresist material. Upon exposure to ultraviolet light through a suitable mask, the resist in the non-pattern area cross-links and becomes hard. The unexposed pattern areas remain tacky. The conductor material is applied in the form of a dry mixture of metal and frit particles which adhere to the tacky pattern area. The assemblage is then fired to ash the photo-polymer and sinter the fritted conductor powder.

Figure 1
MIDFILM PROCESS SEQUENCE

2.0 TECHNICAL DISCUSSION

2.1 PROCESS SEQUENCE

The process sequence has been altered slightly to improve cell performance and reproducibility. The junction cleaning step of laser scribing and breaking has been moved to a position in the sequence after contact firing (see Figure 1).

This change avoids contamination of the edges during the "MIDFILM" process. Spectrolab has found that shunting occurs during the process due to silver contamination at the edges. This shunting was highly variable dependent on operator meticulousness. By having the laser scribe at the end of the process, edge contamination is no longer a concern.

The laser scribing may also be done after AR coating with good results.

2.2 POWDER AND RESIN SELECTION

Powder #3347-D consisting of 95% TFS Spherical Type Powder and 5% 3347 TFS frit has been chosen to be used for the remainder of the contract. MIDFILM Resin #RC-4933 showed no humidity sensitivity and has been selected as the optimum resin.

2.3 EXPOSURE SYSTEM

The photoresist is now exposed by a mercury vapor lamp system. Lamp #BH6-1B-6441 from Illumination Industry, Inc. is used as the light source. The lamp is run at 700 VDC and 1.4A ($\sim 1000W$), $7\frac{1}{2}$ " from the wafer to be exposed. A collimating lens is placed $\sim \frac{1}{4}$ " above the mask which is 5-10 mils above the wafer.

Using this system, an exposure time of 10 seconds has been found to be optimum.

2.4 PRELIMINARY PROCESS SPECIFICATION

Appendix A is the Preliminary Process Specification prepared by Ferro Corporation.

2.5 PROCESS OPTIMIZATION

The use of a medium temperature (575°C) step prior to the firing of the front cover was investigated to lower series resistance. It is felt that the high series resistance in the MIDFILM cells is due to incomplete burn-off of the organic materials in the resin at the cell/front contact interface. By prefiring, these organics will have exposure to atmospheric oxygen through the still porous powder before it is sintered into a continuous layer.

The first test matrix for optimization is shown in Table 1. In addition to the prefire, the use of a second UV exposure after powder applications was investigated. It was hoped that this second exposure of the resin would aid in the removal of powder between the gridlines by further hardening of the resin.

Figure 2 shows the best cell of the group at varying light intensities. A series resistance of $31\text{ m}\Omega$ was calculated.

From these results it was concluded that the second exposure was unnecessary and the single 10 second exposure is the optimum. Qualitatively it was found that the silver was harder to remove from the doubly exposed wafers. To clarify the results of the prefire, another experiment was run. The experimental matrix is shown in Table 2. The resulting curves are shown in Figures 3 through 8.

Table 1
EXPERIMENTAL MATRIX
PREFIRE EXPERIMENT #1
(Includes Second Exposure Data)

	Dry		Prefire			Fire		
Zone→	1	2	3	4	Speed	3	4	Speed
Run								
AA	0*	800*	575°C	575°C	48"/min	675°C	675°C	48"/min
BB	0	800	575°C	575°C	9"/min	675°C	675°C	48"/min
CC	0	800	575°C	575°C	18"/min	675°C	675°C	48"/min
DD	0	800	575°C	575°C	24"/min	675°C	675°C	48"/min
EE	0	800	575°C	575°C	36"/min	675°C	675°C	48"/min

Each run consisted of 4 cells, two of which had an additional 60 sec. exposure after the initial powder application.

* The settings of zones 1 and 2 at 0, 800 causes a temperature of 200°C in zone 1 and 300°C in zone 2.

Table 2
EXPERIMENTAL MATRIX
PREFIRE EXPERIMENT #2

Zone→	Dry		Prefire		Speed	Fire		Speed
	1	2	3	4		3	4	
Run								
A	0*	800*	575°C	575°C	24"/min	675°C	675°C	48"/min
B	0	800	575°C	575°C	36"/min	675°C	675°C	48"/min
C	0	0	575°C	575°C	24"/min	675°C	675°C	48"/min
D	0	0	575°C	575°C	36"/min	675°C	675°C	48"/min
E	0	800	575°C	575°C	24"/min	675°C	675°C	36"/min
F	0	800	575°C	575°C	36"/min	675°C	675°C	36"/min

Each run consisted of 5 cells.

* The setting of zones 1 and 2 at 0, 800 causes a temperature of 200°C in zone 1 and 300°C in zone 2.

To finalize the process parameters, two runs of 25 cells were done. The firing parameters for the first run were 575[°] prefire at 24" per minute and 675[°] fire at 36" per minute. The second run was the same except it was prefired at 36" per minute. Table 3 shows the results for the 24" run and Table 4 shows the results for the 36" run. Figures 9 through 12 show curves of representative cells at differing light intensity. The series resistance measured by the illuminated curve method is shown in each case. Series resistance measured in this way has been 40 - 70 mΩ for the latest runs.

From these two runs it was concluded that the optimum firing schedule includes a prefire at 575[°]C and 24"/min. These parameters are being used in the demonstration run of 500 cells.

2.6 SOLDERABILITY

Work on the soldering of front interconnects to the MIDFILM contacts is continuing. Table 5 shows the results of 45[°] pull tests on the latest cells. Pull strengths greater than 350 grams were recorded on all cells tested except for one soldered at the lower temperature. A soldering specification of 1 sec. with a head temperature of 370[°]C will be adopted.

Figure 2

36"/min Prefire

Series Resistance 31 MΩ

No AR Coating

Figure 3

No AR Coating

Figure 5
No AR Coating

VOLTAGE (VOLTS X _____)

Figure 6
No AR Coating

Figure 7

No AR Coating

Table 3

24" Per Minute, No AR Coating

<u>Cell #</u>	<u>V_{oc}</u>	<u>I_{sc}</u>	<u>I₅₀₀</u>	
2	596	639	559	
22	596	628	534	
21	593	621	545	
36	597	642	574	
24	595	626	543	
13	594	633	553	
23	596	615	528	Bad Ohmic
14	594	610	525	
17	596	623	552	
15	596	639	567	
16	598	647	581	
19	597	633	547	
27	597	644	552	
20	595	613	541	
34	596	625	563	
18	595	640	472	
33	599	661	592	
26	594	612	526	
32	595	635	538	
30	596	628	553	
25	596	614	544	
35	600	661	570	Bad Scribe
28	598	660	581	
Average	596	632.6	549.6	
Standard Deviation	1.7	15.5	20.9	
# of Cells Surviving Laser Scribe	23	23	23	

Table 4

36" Per Minute, No AR Coating

<u>Cell #</u>	<u>V_{oc}</u>	<u>I_{sc}</u>	<u>I₅₀₀</u>	
42	594	628	546	
9	598	648	538	
45	594	653	529	
3	589	611	473	Bad Scribe
8	593	651	489	
41	594	635	471	
4	594	617	537	
10	596	616	517	
5	592	610	496	
7	599	656	581	
1	597	637	533	
43	597	642	540	
47	595	635	540	Bad Scribe
44	597	646	552	
38	595	607	515	
11	592	601	484	
39	597	634	564	
48	599	643	573	
6	596	632	543	
46	598	665	566	
40	594	597	499	Bad Scribe
49	598	642	520	Bad Scribe
Average	595.3	632.1	527.5	
Standard Deviation	2.56	18.9	31.7	
# of Cells Surviving Laser Scribe	22	22	22

Table 5

Soldering Results
45° Pull Test

<u>Parameter</u>	<u>Average Pull Strength</u>	<u>Notes</u>
1 sec, 340°C	283 grams	One cell tab had no strength
1 sec, 370°C	643 grams	All cells at least 550 grams
1 sec, 400°C	531 grams	All cells at least 375 grams

5 cells were tested in each group.

3.0 CONCLUSIONS

A prefiring step is necessary before firing contacts using the MIDFILM process to reduce series resistance. The optimum resin is #RC-4933 and the optimum power is #3347-D.

4.0 RECOMMENDATIONS

There are no recommendations for this period.

5.0 NEW TECHNOLOGY

There is no new technology to report.

Appendix A

PRELIMINARY PROCESS SPECIFICATION

SPECTROLAB, INC.

PRELIMINARY PROCESS SPECIFICATION

HIGH RESOLUTION, LOW COST SOLAR CELL CONTACT DEVELOPMENT

September 30, 1980

1. SCOPE

This specification describes the requirements necessary to obtain a collector grid on the P+ diffused silicon wafer using the Mid-Film process.

2. INPUT MATERIALS

- 2.1 Clean Back Surface Field Wafers
- 2.2 Silver printing powder
- 2.3 Mid-Film photosensitive resin

3. INPUT SUPPLIES

- 3.1 Photomasks
- 3.2 Long-nap pads or rollers for powder rub-out and cleaning.
- 3.3 1,1,1 Trichloroethane
- 3.4 #600 Scotch tape

4. EQUIPMENT AND FACILITIES

- 4.1 Equipment for applying resin (see 9.2).
- 4.2 Hg-Arc ultraviolet light source; collimated, capable of producing an intensity of about 30 m W/cm², for the 3650 A.U. line of Hg, on the surface of the wafer.
- 4.3 Equipment for deposition of silver powder and clean-off (see 9.3).
- 4.4 Firing equipment; to burn-off resin and mature silver powder at 600°C to 800°C, 40 to 60 seconds, air atmosphere.
- 4.5 Type A manufacturing space for above equipment
- 4.6 Utilities for above equipment
- 4.7 Heating, air conditioning, and equipment to comply with safety standards for above manufacturing space.

4.8 Waste disposal containers or recovery of solids (powder residues, paper, etc.) and liquids (waste solvents).

4.9 Pull test equipment.

5. THROUGHPUT AND LABOR CONTENT

Assuming round-the-clock (3 shifts/day) operation and 0.90 operating minutes per minute (see 9.1).

5.1 Output rate: 112 front contacted wafers (4 x 4)/operating minutes

5.2 Labor Content:

5.2.1 Semi-skilled Operator: 0.25 persons/shift

5.2.2 Maintenance: 0.1 persons/shift

6. PROCESS SEQUENCE AND PARAMETERS

6.1 Apply Mid-Film resin on front surface of wafers.

6.2 Expose to UV light through photomask.

6.3 Apply silver powder and develop pattern.

6.4 Clean-off and recycle excess powder.

6.5 Fire, air atmosphere, temperature and time to be determined under present contract.

6.6 Allow wafers to cool to room temperature.

6.7 Transfer wafers to next station.

7. BY-PRODUCTS

7.1 Chlorinated hydrocarbon vapors at resin application station (see 9.2).

7.2 Resin vapors during firing.

7.3 Cleaning solvent vapors when cleaning equipment.

7.4 Total estimated amount of fumes: 0.05 cu. ft./operating minute.

7.5 Silver powder for reclaim.

8. PRODUCT REQUIREMENTS AND Q.A.

8.1 In Line None. (Alludes to equipment in production machine that would signal malfunction.)

8.2 Q.A. Process Control Tests

8.2.1 Front Grid Pattern:

8.2.1.1 Silver must be adherent and be able to pass #600 Scotch tape test.

8.2.1.2 Should pass same test as above after 2 weeks of environmental exposure (70°C and 100% humidity). Ten test cells run once per week (10/162,000 frequency).

8.2.2 Ohmic solder pads:

8.2.2.1 Silver contact pad must be solderable with 62 Sn, 36 Pb, 2 Ag solder.

8.2.2.2 Silver contact pad should pass a 90° pull test of at least 500 grams when a #22 gauge solid copper wire is soldered to it. One test cell run once per hour (1/1350 frequency).

8.2.2.3 Should pass same test as above after 1 week of environmental exposure (70°C and 100% humidity). Ten test cells run once per week (10/162,000 frequency).

9. NOTES

9.1 Specification based on prototype equipment currently under development. Data used is that generated for SAMICS-Format A, revised in discussion with Brian Gallagher (JPL) on July 25, 1979.

9.2 Spray, roller-coat, spin are procedures under consideration for application of resin. Chlorinated hydrocarbon vapors are heavier than air. Equipment will include collection of low-lying vapors. Resin is being applied by spinning in preparing the samples for Task I of the present contract.

9.3 Prototype to be developed.

Prepared by:

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