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

Quarterly Technical Progress Report for Quarter Ending March 28, 1980

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MASTER

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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

March 28, 1980

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1.0 SUMMARY

Evaluation of infrared drying (at approximately 300°C) PX-10 diffusion source in about one minute or less, revealed comparable results to the conventional oven drying at 150°C for 15 minutes.

Initially investigation of the fritted-nickel paste front contact indicated high series resistance. Series resistance was reduced upon solder dipping.

Further experimentation on junction isolation by laser scribing the front edge of finished, non-AR coated, solar cells continued this period. All scribing was done in the TEM₀₀ laser mode. Non-AR coated cell efficiency as high as 10.4% was achieved at a laser output level of 7 watts/cm² and a Q-factor of 3000 pulse/inches. This performance was equivalent to non-AR coated control cells processed by back side scribing and breaking.

Further evaluation of the titanium-isopropoxide base spray-on AR solution applied with the Advanced Concepts spray system located at Sensor Technology, Inc., revealed no new results. System is still plagued with problems that interfere with the atomization of the source.

A new lamination lay-up procedure has been successfully demonstrated using Crane-Glas to prevent gas entrapment and aluminum foil as a vapor barrier.

2.0 INTRODUCTION

This quarterly technical progress report covers the quarter ending 28 March 1980. 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 2 of the Array Automated Assembly Task, Large Solar Array Project.

The baseline cell and module process is shown in Figure 1. This quarter effort was concentrated on evaluation of IR drying of the spin-on diffusion source, air fired fritted-nickel paste contacts, junction isolation by laser scribing the front edge of non-AR coated solar cells and spray-on antireflective coating. Lamination of modules using Crane-Glas was also demonstrated during this period.

Figure 1
PROCESS SEQUENCE

3.0 TECHNICAL DISCUSSION

3.1 JUNCTION FORMATION

During this quarter, evaluation of the effect of IR baking of spin-on PX-10 on the cell performance was completed. These cells were fabricated in a conventional way except that baking of the PX-10 prior to diffusion was performed in an IR belt furnace and the wafers were laser scribed and cleaved prior to metallization. Detailed process sequence of the cells was outlined in Figure 1.

The hot zone of the IR furnace, 18" in length, was originally set at 300°C. By adjusting the belt speeds at 20, 30, 40 and 50 inches per minute, the baking times at temperature were varied from 0.9, 0.6, 0.45 and 0.36 minutes, respectively. Photovoltaic behavior of the IR baked and conventional baked cells were compared (Table 1). The measured photovoltaic parameters (V_{oc} , I_{sc} , I_{500} and R_{sh}) indicated no significant difference between both types of baking. The sheet resistance for all tested cells ranged from 30 to 40 $\Omega/\square$. The results of this work therefore suggests that the conventional baking, 15 minutes at 150°C, may be replaced by a short-term baking in an IR belt furnace of reasonable length.

3.2 METALLIZATION

During this past quarter metallization was emphasized on the replacement of the more expensive Ag paste by certain base metal pastes. Our choice for the replacement was air firable Ni paste with 20% frit from Thick Film Systems, Inc.

Presently we are concerned with three problems: 1) The electrical behavior, 2) adherent nature of the air fired Ni contact, and 3) the solderability of air fired Ni contact with conventional solder (Pb-Sn-Ag).

Table 1
PX-10 IR BAKE

Time (sec.)	# of Cells	V _{oc} (mV)	I _{sc} (mA)	I ₅₀₀ (mA)	R _{sh} (Ω)
108	4	600	698	630	56
72	6	598	688	619	68
54	5	600	694	640	74
43	7	599	682	626	65
Conventional Bake 150°C, 15 min.	11	603	702	637	49

Ni paste was first screen printed on cells and then dried in oven as usual. Various temperatures (650°C to 750°C) and times (30 to 120 sec.) were applied for the determination of optimum air firing schedule of the Ni thick film contact. Electrical performance indicated series resistance to be the major problem. Nickel paste-silicon junction interaction appears to be minimal. Solderability of the contact was very poor.

One sample from each sintering condition was etched in a 5% NH_4OH solution for 10 seconds to remove the possible "oxide layers" on the contact surfaces and prepare the surface for soldering. Samples before and after etching were electrically tested, and their properties (V_{oc} , I_{sc} , I_{500} and R_{sh}) are listed in Table 2. In general, etching seems to improve the electrical performance of the cells but destroys adhesion between the contacts and the silicon substrates.

Several samples of cells fired in air were dip-soldered (Sn-Pb-Ag solder and organic acid flux), typical electrical behavior before and after soldering are shown in Table 3. Significant improvements on electrical behavior of cells after soldering were measured. Microscopic examinations of these two soldered samples revealed substantial layers of the solder on the Ni contacts.

Cells printed with Ni paste of high frit (20%) content, fired at various temperatures and times in N_2 gas atmosphere were not able to be soldered. However, resintering of these specimens in air seemed enhancing their solderability. Electrical testing data of some selected specimens before and after resintering and soldering are presented in Table 4.

Similar studies were performed on cells screen printed with air firable Cu paste. Low shunt resistances were measured. This is

Table 2

Sintering Temp ($^{\circ}\text{C}$)	Sintering Time (Sec.)	V_{oc}	I_{sc}	I_{500}	R_{sh} at 500	Etching 5% NH_4OH	V_{oc}	I_{sc}	I_{500}	R_{sh} at 500
650	30	566	129	30	1250	10 sec.	565	125	0	1000
650	60	545	199	30	52	10 Sec.	546	192	0	64
650	120	126	103	0	3	10 Sec.	153	111	0	4
700	30	148	106	0	3	10 Sec.	152	105	0	4
700	60	0	0	0	∞	10 Sec.	0	35	0	∞
700	120	0	24	0	∞	10 Sec.	0	0	0	∞
750	10	516	253	17	47	10 Sec.	512	239	0	53
750	30	0	42	0	∞	10 Sec.	0	42	0	∞
750	60	0	29	0	∞	10 Sec.	0	32	0	∞
750	120	0	22	0	∞	10 Sec.	0	36	0	∞

Table 3

Sintering Temp. ($^{\circ}\text{C}$)	Sintering Time (Sec.)	V_{oc}	I_{sc}	I_{500}	R_{sh}	Dip Soldering	V_{oc}	I_{sc}	I_{500}	R_{sh}	Adherence
650	30	569	148	35	41	Sn-Pb-Ag with Organic Acid Flux	586	291	88	132	Good
650	60	513	205	12	23		551	352	58	40	Good

Table 4

Sintering N ₂ 650°C	V _{oc}	I _{sc}	I ₅₀₀	R _{sh}	Re- Sintering Air 650°C	V _{oc}	I _{sc}	I ₅₀₀	Dip- Soldering Pb-Sn-Ag	V _{oc}	I _{sc}	I ₅₀₀	R _{sh}
60 Sec.	586	259	65	238	60 Sec.	581	221	0	Org. Acid Flux	591	550	166	116
60 Sec.	576	289	65	122	60 Sec.	567	317	0	"	591	811	328	40
60 Sec.	414	313	0	5	60 Sec.	284	263	0	"	376	404	0	3
60 Sec.	395	270	0	5	60 Sec.	294	237	0	"	387	462	0	3

believed to be due to excessive penetration of Cu into the junctions during sintering. Work on copper screen printed cells will therefore be discontinued.

3.3 JUNCTION CLEAN LASER SCRIBING

The capability of junction isolation by laser scribing the front surface of finished, non-AR coated solar cells was demonstrated. High laser power output levels and a low Q-factor (laser pulse rate kHz/chuck speed, IPS) are necessary to produce a clean, continuous groove. Many factors determine laser cut integrity. However, many cannot be reliably controlled with our present machine. All work was done in the TEM₀₀ laser resonator mode.

In this experiment laser output was varied between 3 and 7 watts/cm² and Q-factor between 3000 and 9000 pulses/inch. A laser cut was made between 5 and 10 mils from each edge on the front side of the cell. Control cells were laser scribed through the Al(P+) back and cleaved. Current at 500 mV (I_{500}) and shunt resistance (R_{sh}) were plotted as a function of Q-factor. A family of curves were produced representing laser power output levels of 3, 5, and 7 watts/cm² (Figure 2). The best I_{500} and R_{sh} were achieved at a laser output level of 7 watts/cm² and a Q-factor of 3000 pulses/inch. This represents a non-AR coated cell efficiency of 10.4% which was equivalent to non-AR coated control cells. A maximum deviation of 10% from the mean was seen in I_{500} values. R_{sh} values varied by as much as 20% from the mean. Five samples each were measured to generate each data point. Machine limitations prevented the examination of lower Q-factors and higher power levels.

Laser cut integrity was examined with a scanning electron microscope as a function of Q-factor and laser output. A clean continuous cut was achieved at a Q-factor of 3000 pulses/inch over a range of 3 to 7 watts/cm² laser output (Figure 3). However, a change from a Q-factor of 3000 to 7000 pulses/inch at 7 watts/cm²

Figure 2

VARIATION OF SHUNT RESISTANCE AND
CURRENT AT 500 mV WITH Q-FACTOR

Figure 3

3 watts/cm² Qf = 3000 pulses/inch
1000X Mag.

7 watts/cm² Qf = 3000 pulses/inch
1000X Mag.

laser output produced increasing amounts of slag material which may contribute to current leakage (Figure 4). A low laser output of 3 watts/cm² and a high Q-factor of 7000 pulses/inch also produced non-optimized groove characteristics (Figure 5).

Many factors contribute to laser cut integrity and process reliability. Laser pulse fluctuations, laser beam size and shape, and the orientation of the cell surface with respect to the laser beam have been identified as problem areas. Machinery designed for precise control of these parameters will improve process reproducibility.

A beam monitor device is available which will enable precise adjustment of laser pulse amplitude to within 5%. Other undesirable beam characteristics may be detected and eliminated with this device.

A second harmonic generator is also available which converts the wavelength of the laser emission from 1.06 μ to 0.53 μ . The Si absorption coefficient (α Si) at 0.53 μ is 100X that of 1.06 μ light. Therefore, a far greater portion of 0.53 light is absorbed in the near surface region than that 1.06 μ . Use of 0.53 laser should give rise to complete evacuation of silicon from the laser scribe groove which would minimize current leakage paths and improve process reliability.

3.4 ANTIREFLECTIVE COATING

Development of spray-on antireflective (AR) coating techniques continued this month. Attention was focused on a titanium-isopropoxide base spray-on AR solution developed by RCA (RCA-I). An Advanced Concepts spray system located at Sensor Technology, was utilized in all experiments. Atomization of the AR source has been identified as the critical factor in obtaining a uniform, pinhole-free, antireflective coating.

Figure 4

7 watts/cm² Qf = 5000 pulses/inch
1000X Mag.

7 watts/cm² Qf = 7000 pulses/inch
1000X Mag.

Figure 5

3 watts/cm² Qf = 7000 pulses/inch
1000X Mag.

Several JPL contracts have reported that they were successful in applying spray-on AR coatings to polished silicon wafer surfaces. To determine the suitability of spray-on AR coating of 30% NaOH etched, "pillowed," wafer surfaces. Experiments were performed with Advanced Concepts spray equipment at Sensor Technology, Inc. Coating uniformity was optimized by properly adjusting spray parameters. After some experimentation spray parameters were fixed as follows:

Source flow rate	10 cc/min.
Atomization pressure	40 psi
Reciprocation velocity	90 CPM
Conveyor velocity	2 ft./min.
Nozzle height from substrate	6 in.
Nozzle orifice size	10 mils

Experimental results from cells spray coated at these parameter values were as follows:

	<u>V_{oc}</u>	<u>I_{sc}</u>	<u>I₅₀₀</u>	
Before	591.6	707.8	597.0	(Average of 5 samples)
After	592.0	910.0	710.0	
Δ%	+0.06	+28.6	+19.0	

These wafers were processed in an IR furnace peaking at 250°C followed by a 60-90 second 200°C hot plate bake-out, a two-step bake-out of 70°, for 10 seconds and 200°C for 3 minutes. A spray coated cell viewed through an optical microscope was characterized by pinholes. The spray coverage was susceptible to pinholes because the AR source is likely to flow between pillows exposing the highest surfaces. Proper source atomization must be maintained to ensure uniform coverage and prevent source flow. Inspection of the spray system by an Advanced Concepts engineer revealed problems in the nozzle head apparatus which prevented proper AR source atomization.

These results and problems are similar to those reported in the quarterly report of June 30, 1979. Further investigation of the AR coating source, applied with the Advanced Concepts spray system, located at Sensor Technology, Inc., will not be attempted due to inability to control critical parameter. When spray equipment is available at Spectrolab, Inc. further evaluations shall commence.

3.5 MODULE FABRICATION

Several 2' x 4' modules have been laminated using the double vacuum bag technique previously described*. The following list represents the layup order of material which is recommended:

- 1/8" tempered glass
- 3 mil Crane-Glas 230
- Clean EVA
- 3 mil Crane-Glas 230
- Cell Circuit
- 3 mil Crane-Glas 230
- White EVA
- 3 mil Crane-Glas 230
- 1 mil Al foil
- 1 mil Mylar

A module has been produced using 5 mil Crane-Glas in front of the cells. Next month, samples will be quantitatively tested using the recommended layup in order to determine encapsulation losses. We are currently using Springborn Laboratories A-9918 clear EVA ~ .016" thick and A-9930 white EVA ~ .012" thick.

The lamination cycle is 25 minutes long with release of upper vacuum bag vacuum when 105°C is reached at the module.

*Spectrolab Quarterly Technical Progress Report, DOE/JPL 954853 79/4, Quarter Ending September 29, 1979.

The use of Crane-Glas on both sides of the EVA is necessary to ensure the timely removal of all entrapped gases. The Crane-Glas also tends to inhibit cell shifting which was an earlier problem.

The Al layer serves as a vapor barrier. Any polymer would in time allow moisture penetration. Mylar is recommended on the back surface to protect the Al from abrasion as well as minimize the possibility of shock hazards.

4.0 CONCLUSIONS

Infrared drying of PX-10 diffusion source is readily accomplished in a short time (less than one minute) at 300°C. A further evaluation will be performed in the next few months.

Fritted-nickel paste has been shown to make good contact to silicon without interfering with the junction. The major problem with the paste is that the resultant contact has a high series resistance. Attempts to etch and solder coat the nickel contact resulted in peeled contacts. Solder coating using suitable flux has shown to improve electrical performance without destroying the adherence between the contacts and silicon substrate.

Further experimentation into the air firable nickel paste will be emphasized on modifying the paste in order to reduce the series resistance.

Laser scribing the front edge of finished, non-AR coated, solar cells is a capable process for junction isolation.

Evaluation of the titanium-isopropoxide base spray-on AR solution applied with the Advanced Concepts spray system located at Sensor Technology, Inc., revealed continuing source atomization problems which cannot be solved under our present arrangement with Sensor Technology, Inc. The results of cells coated at Sensor Technology, Inc. were similar to those reported in the June 30, 1979 Quarterly Report.

A new lamination procedure has been demonstrated using Crane-Glas to prevent gas entrapment and aluminum foil as a vapor barrier.

5.0 RECOMMENDATIONS

There are no recommendations.