SILICON DENDRITIC WEB MATERIAL
PROCESS DEVELOPMENT

R. B. Campbell, R. E. Stapleton, L. Sienkiewicz,
P. Rai-Choudhury

First Quarterly Report

March 28, 1980 - June 30, 1980

Contract 955624

This work was performed for the Jet Propulsion Laboratory,
California Institute of Technology under NASA Contract for
the U. S. Department of Energy.

Westinghouse R&D Center
1310 Beulah Road
Pittsburgh, Pennsylvania 15235

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NEW TECHNOLOGY

No new technology is reportable for the period covered by this report.

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1. SUMMARY

Initial values of pressure, power, and speed have been determined for seam bonding interconnects to dendritic web solar cells. Satisfactory bond strengths and high yield have been achieved without cell damage. However, in case of processing large numbers of cells for module fabrication, further testing is required to assure reproducibility of this technique. Various techniques have been developed for fabricating solar modules by lamination using ethylene vinyl acetate with a glass superstrate, and no cell breakage has been noted.

2. INTRODUCTION

This program -- Silicon Dendritic Web Material Process Development -- spans a period of six months and continues the process development studies of a previous contract⁽¹⁾ for the economic fabrication of solar cells and modules from dendritic web silicon.

In the previous program we had defined a process sequence for the fabrication of solar cells and modules, and had carried out development studies on specific key process steps. Using cost-effectiveness and cell performance as a criteria, we selected the final process sequence, analyzed the results by SAMICS, and met the JPL cost objectives.

This program focusses on the development effort, particularly on the refinement of the interconnect process and the lamination of interconnected cells into a module.

The first development task is to determine the conditions required to achieve a high yield of ultrasonic bonds to thin dendritic web solar cells. The main emphasis is on ultrasonic seam bonding although spot bonding will also be considered. These bonding experiments will be carried out in cooperation with Kulicke and Soffa, Inc. using Westinghouse purchased equipment.

Ultrasonic bonding has several advantages as compared to solder for interconnecting, such as no corrosive flux, no material buildup and low material costs. The feasibility of ultrasonic bonding has been shown⁽¹⁾, but yields satisfactory for module fabrication have not yet been demonstrated. The primary factors affecting yield are poor quality bonds (low pull strength) or cell fracture. Thus, the emphasis in this phase of the present program is to determine conditions for reliable bonds while maintaining the cell integrity.

The current effort has resulted in the specification of initial bonding parameters which provide good interconnects without cell breakage. Further work is required to demonstrate the interconnection of a large number of cells for a module.

A corollary of this task is the determination of the cost-effectiveness of ultrasonic bonding (both spot and seam) and the consideration of the process yield.

The second development area is the lamination of interconnected cells into a module. Two laminate plastics are being evaluated -- ethylene vinyl acetate and polyvinyl butyral. In the lamination process, the cells are sandwiched between two layers of a plastic sheet. This assembly is then bonded to a superstrate and substrate using a pressure/temperature cycle to form a package which is insensitive to environmental effects such as moisture and oxygen. This process is more cost effective than that used in our previous modules which used silicone potting, and in which, a thermo-setting silicon resin was poured over the interconnected cells and formed an adhesive for mounting the glass superstrate.

Another major effort in this program is the design of a conceptual factory using the selected process sequence with dendritic web silicon as the input material. A cost analysis of this conceptual factory will be made to define overall costs as well as to determine which steps are the cost drivers.

Finally, during the program we will fabricate four modules, each 30 cm by 60 cm to demonstrate the selected process sequence.

3. TECHNICAL RESULTS

3.1 Ultrasonic Seam Bonding

3.1.1 Previous Status

In our previous contract⁽¹⁾, we have shown the feasibility of ultrasonic bonding of metal interconnects to thin dendritic web solar cells. These tests were carried out with a spot bonder (Sonobond ML 6010) and copper, aluminum, nickel and brass interconnects were bonded to copper and silver contacts.

Initial runs using a Sonobond MS-6010 seam bonder to bond Al foil to the reacted Al layer on the back of the cell gave variable results. Adequate bonds were achieved in some cases, but overall, the results were not satisfactory.

The thinness of the dendritic web solar cells is of particular concern during handling and ultrasonic bonding. However, a number of good quality bonds have been made without damaging or cracking the silicon cells indicating that with proper fixturing and techniques, high yields can be achieved.

Although the required force, time, and power parameters have been determined for the ultrasonic bonding of various interconnect and contact materials, the yield of the process with cells with aluminum back surface fields is not satisfactory. The main failure mode was cracking of the cell during bonding of the front contacts. Thus, although the process has been shown feasible, further development was required before the necessary high yield could be attained.

3.1.2 Current Status

During this program Westinghouse has funded joint experiments with Kulicke and Soffa, Inc. to determine the fixturing and bond parameters required to achieve a high yield of reliable bonds using both

seam bonding and spot bonding. The first results on the seam bonding are given in this report.

In seam bonding, the ultrasonically driven tool (seam welder) is in the shape of a wheel which is made to roll across the workpiece, making a continuous linear bond. This type of machine is widely used to splice the ends of metal foils and plastic sheets. The advantages of applying this type of machine to solar cell interconnection are apparent if the interconnect material is in the form of a continuous tape to be bonded along one edge of a solar cell. Even if the interconnect is in the form of discrete tabs bonded at points one centimeter apart, the use of a seam welder type of machine results in increased bonding speed. A spot bonder bonds and positions itself for another bond at a rate of about one bond per second; a seam welder rolls along a work piece at a rate of 10 to 12 cm/sec. The speed which can be sustained during the interconnection of cells is not yet determined.

In this report we discuss the results obtained through the use of seam bonding on various contact metallizations with a holding fixture specifically designed to hold the web cells.

A sonobond ultrasonic seam welder (MS 6010) was used in these tests and a fixture was built for seam and spot bonding on web cells. It was necessary to modify the bonding tool (wheel) clamping mechanism so that the pressure can be reduced to zero. A lift cam was also installed to lower and raise the wheel gently onto the cell surface as it traverses the clamped assembly.

A preliminary series of bonding tests were made using this equipment with dendritic web cells and Al foil interconnects. A total of 70 cells were tested consisting of two basic types (boron back surface and aluminum back surface field cells). Although primary experimental interest on this program is with the Al BSF cells the boron BSF cells were included as a baseline control group. The metallization system used for the boron BSF cells was the same on front and back. The same metallization was used on the front of the Al BSF cells but 2 different metallization processes were used on the back. The metallization

systems are as follows:

BORON BSF CELLS

Front Evaporated 400Å Ti, 200Å Pd, 200Å Ag* followed by 8-12 µm of electroplated copper

Back same as front surface

ALUMINUM BSF CELLS

Front same as boron BSF cells

Back Type A Plasma sprayed aluminum, reacted or alloyed @ ~850°C followed by a surface burnishing to remove oxides, then overcoated with 10 µm of evaporated aluminum

Type B Same as Type A, except excess aluminum was etched away and surface overcoated with evaporated Ti/Pd/Ag as in boron BSF followed by 8-12 µm of electroplated copper

Die punched aluminum interconnects that were hand formed from a 2 mil thick 1145 alloy (99.95% aluminum) were supplied. After stamping the interconnects, they were annealed at 750°C for 45 minutes in hydrogen.

In the initial tests, a number of runs were made where the bonding pressure was varied from 150 gmf to 750 gmf and the power from 30 watts to 105 watts. The bond strength was measured on a pull tester fabricated for this purpose. During these shakedown tests, the following factors were noted.

* The Ag is evaporated to serve as a plating base for Cu

1. The fixturing performed its design function satisfactorily. Cell breakage did not occur with clamping forces in the 400 to 500 gram range (approx. 150,000 psi).
2. Weak or no bonds were produced at low pressures (150 grams). In some instances 10 good bonds (with fair strength) were produced out of 10 when higher pressure was used. The results, however, showed considerable variability and lack of reproducibility (low yields). In general, bond strength improved with increasing pressure and power.
3. The threshold for cell breakage appeared to be at clamping forces of 750 grams at 30 watts. Less cell breakage occurred when bonding to the sun side (as opposed to the back side) under these conditions.
4. Some batches of aluminum interconnects did not produce any bonds to the cell pads or to itself ($\approx$ 750 grams and 105 watts). Evidence of surface contamination (spotting) was visible indicating that care must be taken in the preparation of the interconnects.
5. Thinner aluminum foil interconnects (1 mil thickness) were found to produce better bonds at lower clamping forces than the 2 mil material.
6. About 30% of the cells with copper plated bonding pads exhibited very poor adherence between the copper plating and Ti/Pd/Ag.
7. The seam bonding wheel produced visible damage in the AR coating as it rolled over the space between bonding pads. A cam lifting mechanism was a potential solution but was judged to be difficult to implement in a production machine.
8. Continuous monitoring and adjustment of the current and voltage waveforms was necessary during bonding to achieve maximum tool resonance and therefore consistent bonding.
9. Increasing the tool width from 0.020" to 0.040" significantly improved bond quality. The wider tool face apparently reduced the tendency of the Al to flow during bonding (which broke the bond initially formed).

10. Sintering the cells at 350°C for 30 minutes in nitrogen improved the reproducibility of the bonds, presumably by increasing the adhesion of the contact metals to the silicon.

Based on these data, a more complete series of tests were made. Table 1 shows the results of these tests in the form of 90° pull test data with a pull rate of 35 gm increase per second. In all cases except for the Type A Al BSF cells, any surface oxide on the contact metallization was removed before bonding using steel wool. Without oxide pull strengths about one half those shown in the table were observed.

The back surface of the type A Al BSF cells could be bonded in the as is condition with bond strengths comparable to the copper plated cells which had been cleaned. It should also be noted that the bond strength doubled when the bonding pressure was increased to 600 gmf. However, this pressure approaches the limit for initiation of cell cracking.

In general, the average pull strength shown in Table I is in the 80-90 gram range for base line (boron BSF) as well as Al BSF cells. This is about 50% of the unbonded 1 mil aluminum ribbon strength. This was noted experimentally in that over half the bonds broke at the contact points. However, the bonds produced during these tests on all types of cells were sufficiently strong so that the process is satisfactory for fabricating cell strings and modules. It is important to note that no cell cracking was observed during any of the bonding runs.

Several factors remain to be addressed in this process. The contact resistance of TiPdCu or evaporated Al on the back of the cell has not been determined. The mechanical scrubbing operation caused cell breakage reducing the yield of the Type A, Al BSF cells. The economics of fabrication of the type A & B, Al BSF cells must be studied to select the most cost effective process.

Further cells are now being fabricated so that a statistically significant number of bonds and bond pull tests can be made thus assuring the applicability of this technique to module fabrication.

TABLE I

Results of Ultrasonic Seam Bonded Aluminum Ribbon
Interconnections to Metallized Dendritic Web Solar Cells

CELL TYPE	METALLIZATION	PULL TEST DATA								
		Average Pull Str. (Grams)	Std. Devi- ation	Max (Grams)	Min (Grams)	Number of Bonds Tested	Surface Prep- aration	Bond Parameters		
								Speed (in/sec)	Force (grams)	Power (watts)
BORON BACK SURFACE FIELD	Front Surface Ti/Pd/Cu (10 μ m plated Cu)	85	33	150	zero (1 bond)	49	steel wool scrub	1/4	500	30
	Back Surface Ti/Pd/Cu (10 μ m plated Cu)	75	37	155	30	33	steel wool scrub	1/4	500	30
ALUMINUM BACK SURFACE FIELD	<u>Type A</u> Front Surface Ti/Pd/Cu (10 μ m plated Cu)	75	23	120	30	29	steel wool scrub	1/4	500	30
	Back Surface Aluminum/re-acted and brushed + 10 μ m of evap. aluminum	70	22	105	30	27	As is	1/4	500	30
		144	40	240	75	17	As is	1/4	600	30
	<u>Type B</u> Front Surface Ti/Pd/Cu (10 μ m plated Cu)	95	25	145	65	19	steel wool scrub	1/4	500	30
	Back Surface Aluminum etched off (excess) - Ti/Pd/Cu + 10 μ m plated Cu	80	16	95	45	8	steel wool scrub	1/4	500	30

3.2 Lamination Studies

Our present task involves studying the lamination process for module fabrication. In the lamination technique a lay-up is prepared consisting of the glass superstrate, two layers of the laminating plastic with the interconnected cells between these layers, and a moisture barrier. This lay-up is subjected to a temperature-pressure cycle so that a bond is made between all the components. This method has several advantages over the silicone resin potting method in that the material cost is generally lower and the throughput time is shorter.

Two types of laminating plastics are being tested in this program. The tests described in this report used EVA (ethylene vinyl acetate). The first tests used a laminating fixture which was 13 by 20 cm, similar to that used by Springborn Laboratories*. Four cell modules (cell size 1.6 cm x 4.0 cm) were laminated with this fixture using the pressure-time cycle recommended by Springborn Laboratories.

During lamination there was no noticeable movement of the cells. The string of four cells had been soldered together, and in some cases where the interconnect strap contacted the top cell contact, there was an excess of solder with consequent elevations above the plane of the cells. During lamination, these elevations caused excess pressure on the cells causing microcracks around the contact area. Although these cracks did not affect the cell performance, these tests indicated that the interconnected string(s) of cells should be as near planar as possible, a requirement which can be met by ultrasonic bonding.

After these initial tests had indicated that there were no basic problems in laminating the thin dendritic web cells, a larger fixture was designed and fabricated. This fixture, suitable for fabricating a 30 cm x 60 cm module, is a scaled-up version of the smaller

*The assistance of Paul Willis of Springborn Laboratories, Inc. Enfield, Conn. is acknowledged.

Figure 1. Lamination Fixture for 30 x 60 cm Module

fixture with several improvements such as the use of an "O" ring instead of a flat gasket for vacuum sealing.

This fixture is shown in Figure 1. The numbers are explained below.

1. Bottom plate
2. Retaining ring; vacuum sealed to bottom plate. "Capran" held between retaining ring and top plate.
3. Top plate
4. "O" ring between bottom plate and top plate
5. Bolt holes top plate to retaining ring
6. Bolt holes top plate and retaining ring to bottom plate. (These are not used in normal operation.)

The first two test runs made using the scaled-up (52 x 83 cm) lamination fixture used EVA as the pottant material with 45 cm long strips of dendritic web material to simulate the solar cells. This fixture will be used for the demonstration modules. Figure 2 is a schematic drawing of the lay up assembly used for these mechanical samples which is representative of a superstrate configuration. The glass superstrate is made from 0.48 cm thick tempered float glass (Herculite) measuring 31 x 62 cm.

The fabrication steps were as follows:

1. Cut EVA, Korad and Crane Glass to same size as glass (31 x 62 cm).
2. Clean glass -- (primer coat was not used for these mechanical samples. Dow Corning Z6030 was used previously and produced an adherent bond between the EVA and glass).
3. Prepare lay-up as shown in Figure 2 which includes a sheet of FEP and aluminum for better heat and pressure distribution during lamination.

Figure 2. Lay up assembly for 1st 40x 70 cm modules (mechanical sample).

4. Seal all four edges of lay-up with masking tape to confine the EVA within the module assembly.
5. Set the module lay-up on the aluminum base plate with the glass down and the aluminum sheet facing the Capran diaphragm as shown in Figure 3.
6. Place the aluminum cover assembly on the base plate. The diaphragm will be about 1/8 inch from the surface of the aluminum sheet on the taped lay up.
7. Bolt down the cover assembly to the base plate to produce a vacuum seal (O-ring and diaphragm) between chambers 1 and 2.
8. Open valves to a mechanical vacuum pump and evacuate chambers 1 and 2 at the same rate. Hold both chambers under vacuum at RT for 10-15 minutes (28-29 inches gauge pressure).
9. Start cure cycle as shown in Figure 4. The procedure used for heating the large fixture (52 x 83) was to set the base plate on two 12 x 12 inch hot plates. At the start of the cure cycle (A) the hot plates were cold and then switched full on. This procedure required 70 minutes to reach B (110°C). The temperature was monitored with a thermocouple cemented to the surface of the diaphragm as shown in Figure 3.
10. At 110°C (Point B, Figure 4) chamber 1 was vented slowly to atmospheric pressure.
11. When the temperature reached 150°C (Point C, Figure 4) the hot plates were turned off. About 5°C overshoot was observed and then the fixture started to cool (no insulation was used for these trial runs).
12. The fixture required about 60 minutes to cool to 100°C (Point E, Figure 4). At this temperature the bottom chamber was valved off from the vacuum pump and vented to atmosphere.

Figure 3. Schematic Representation of Lamination Fixture for 30 x 60 cm modules.

13. After about 4 hours the fixture was cool enough to open. The lay up assembly was removed, disassembled and cleaned (tape, FEP and aluminum sheet).

The resulting laminations were free of bubbles from edge to edge and the dendritic web strips (dendrites were not removed) appeared undamaged. In general, the results were equivalent to or better than that obtained with the smaller fixture. Figure 4 shows that a wide latitude in cycle times is possible with EVA. The cure temperature of 150°C was reached in 35 minutes with the small fixture and 82 minutes with the larger fixture. The shorter cycle is necessary for production and work is underway to reproduce this cycle with the larger fixture. This can be accomplished using pre-heated platens and forced cooling.

In the next test several changes were made. First, a second layer of "Crane Glass" to aid in pumping the system and reduce the chance of bubbles, was placed between the sun side of the cells and the top EVA layer. Also a Dow-Corning primer (Z-6030) was used on the glass surface. A number of dendritic web cells were placed in the lay-up with several close to the edge to simulate a module with interconnected cells.

The results of this test were quite satisfactory. No bubbles or cell breakage was noted and the bond between the EVA and the glass superstrate was greatly improved due to the primer.

The second layer of "Crane Glass" on top of the cells caused the module to appear frosty when viewed from the sun side. This thin glass layer (0.005") will probably not decrease the insulation* reaching the cells. This will be confirmed before the demonstration modules are fabricated.

*Private communications from Spectrolab, Inc. and Springborn Laboratories indicate this is the case.

Cure Cycle-Small 13 × 20 cm Modules (→ | ← 5 minutes) Cure Cycle - 1st 30 × 60 cm Module (mechanical sample)

Figure 4. Comparison of Curing Cycles for Small (13 x 20 cm) and Large (30 x 60 cm) laminated modules.

4. CONCLUSIONS

Bonding parameters have been determined for the ultrasonic bonding of aluminum interconnects to dendritic web solar cells. Our initial results have shown that good bonds with no cell breakage are being made. The process seems satisfactory for module preparation. However, further statistical data must be obtained before the high yield required for module fabrication can be assured.

Contact sintering is required before ultrasonic bonding.

The importance of cleanliness of both the contact metal and interconnect foil has been established. The presence of oxide on the surface may reduce the bond strength by 50% or more.

Suitable techniques have been developed for laminating solar panels from dendritic web silicon using ethylene vinyl acetate as the laminate. Sample modules have been prepared and are bubble free with no indication of cell breakage. Successful module assembly with both single and double layers of "Crane Glass" has also been demonstrated.

5. PROGRAM STATUS

5.1 Present Status.

Further statistical data is required to assure high yield in the ultrasonic bonding of cells to fabricate solar modules.

The lamination process has been proven.

5.2 Future Work.

A number of cells are now being processed for further ultrasonic bonding tests.

The design of the module has been started. Data is being assembled for a cost analysis of an automated factory for solar module production.

6. REFERENCES

1. R. B. Campbell et al., "Phase II of the Array Automated Assembly Task for Low Cost Solar Array Project" Final Report, October 1979. JPL Contract #954873.

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