470
4-25-78

Lib. 29

DOE/JPL/954521-4

INTEGRAL GLASS ENCAPSULATION
FOR SOLAR ARRAYS

fifth Quarterly ~~Progress~~ Report No. 5

By
P. R. Younger
W. S. Kreisman
A. R. Kirkpatrick

November 1977

Work Performed Under Contract No. NAS-7-100-954521

California Institute of Technology
Jet Propulsion Laboratory
Pasadena, California

MASTER

U.S. Department of Energy

Solar Energy

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy \$4.00
Microfiche \$3.00

INTEGRAL GLASS ENCAPSULATION
FOR SOLAR ARRAYS

Contract Number 954521

November 1977

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Prepared for:

JET PROPULSION LABORATORY
California Institute of Technology
Pasadena, CA 91103

✓ Prepared by: Peter Younger
Principal Investigator

Approved by: ALL R. Kibben
Program Manager

SPIRE CORPORATION
Patriots Park
Bedford, MA 01730

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ABSTRACT

✓
This is the fifth quarterly report under a program to develop integral glass encapsulation for solar cell arrays. The report describes the status of development to establish techniques for employing electrostatic bonding in conjunction with terrestrial solar cells.

TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1.0 INTRODUCTION	1
2.0 PROGRAM STATUS	2
2.1 General	2
2.2 Facility Modifications	3
2.3 Bond Quality Measurement	5
2.4 Glass Studies	6
2.5 Metallization Studies	6
2.6 Physics of Electrostatic Bonding	9
2.7 Module Production	9
2.8 Module Testing	16
3.0 CONCLUSIONS	16
4.0 PROGRAM PLAN	19
5.0 APPENDIX	20
5.1 New Technology	20

LIST OF ILLUSTRATIONS

<u>NUMBER</u>		<u>PAGE</u>
1	AMO I-V Curve of Cell with Trapped Wire Mesh Front Contact	8
2	Four Cell Module with Total Glass Encapsulation	10
3	AMO I-V Curve of Four Cell Series Module, Type II, M2003	11
4	AMO I-V Curve of Four Cell Series Module, Type II, M2004	12
5	AMO I-V Curve of Four Cell Series Module, Type II, M2005	13
6	AMO I-V Curve of Four Cell Series Module, Type II, M2006	14
7	Standard LSSA Thermal Cycle Test Used on Electrostatically Bonded Demonstration Modules	17
8	Standard LSSA Humidity Cycle Test Used on Electrostatically Bonded Demonstration Modules	18

1.0 INTRODUCTION

This is the fifth quarterly report under a program to develop integral glass encapsulation of silicon solar arrays. The work reported represents the first three months of Phase II of this effort. A brief discussion of the goals of Phase II will be given below.

Electrostatic bonding is a process through which metals, semiconductors, and insulators may be joined to glass. Consider a silicon/glass system being bonded. Elevated temperature allows electrical conductivity via ions produced by the dissociation of alkali oxides within the glass. Application of a high voltage causes ion migration and establishes a depletion layer within the glass just below the interface. Oxygen ions move from the glass to the interface where chemical bonding to the silicon occurs.

The process takes between one and three minutes and requires temperatures between 450 and 600°C. Results are reproducible and equipment need not be sophisticated.

Phase I of this program was completed in August 1977. The success of this effort was demonstrated by the production of functioning solar modules with cells electrostatically bonded to glass. Phase II continues development of electrostatic bonding according to the following five part approach:

- 1) Facility modifications
- 2) ESB process characterization
- 3) Module development
- 4) Investigation of the physics of ESB
- 5) Module preparation

Facility modifications will improve equipment performance and increase throughput. Process characterization involves systematic study of the effects of bonding parameters so that optimum process conditions can be established. Module development will continue the efforts of Phase I with emphasis upon practical configurations, processes and techniques that can be scaled up to large size, and development of high efficiency solar modules. The physics of electrostatic bonding will be investigated primarily through the application of various surface analysis techniques to the study of the bond interface. Four series of deliverable modules will demonstrate bonding developments throughout the program.

2.0 PROGRAM STATUS

2.1 General

This quarterly report covers the initiation of Phase II of the program to develop total glass encapsulation of solar arrays through electrostatic bonding. Appreciable effort has gone into facility modifications to improve and extend performance of the present electrostatic bonder. Module development and preparation have also received considerable attention.

Work during this reporting period has included:

- 1) Facility modifications including addition of microprocessor control and multiple sample handling capabilities to the bonder.
- 2) Addition of other programmable functions such as high voltage and sample heating.
- 3) Establishment of bond quality measurement capabilities.
- 4) Study of new glasses for bonding.
- 5) Investigation of low cost metallization systems.
- 6) Preliminary work on the investigation of the physics of ESB.
- 7) Fabrication of Type II demonstration modules.

2.2 Facility Modifications

Major facility modifications involve addition of programmed control of bonding operations. A Tektronix 4051 graphics system will function as the central unit, providing microprocessor control of bonding parameter values. Real time data display will provide complete monitoring of the bonding process.

The electronic interface linking the microprocessor to each bonding component system has been designed. Hardware fabrication is in progress with some parts complete. Partial programmable control will be available in December 1977. All systems should be operational in January 1978.

Other modifications will provide improved glass heating techniques. The mechanism through which heaters close upon the glass has been improved so that breakage of cold glass can be eliminated. Sample preheating will also be added. Heater redesign has improved temperature uniformity over large area (to 8 x 8 inch) samples.

A programmable high voltage supply has been ordered. This unit will allow either constant voltage or constant current bonding. An additional feature is automatic polarity reversal so that bi-directional or double bonding can be accomplished in a single operation. Delivery of this system will be in late January 1978.

A multiple sample handling facility has been added to the bonder. A five sample cassette eliminates the need to cycle the unit between each bond. Throughput has increased significantly with use of this system. When all systems are fully operational, process time should be improved by a factor of two or three.

The modified bonder system is expected to provide highly reproducible bonding conditions. This process uniformity coupled with extensive data logging will allow a systematic study of the effect of each bonding parameter. The object of this study will be to optimize the bonding process and to reduce cell degradation possibilities.

2.3 Bond Quality Measurement

Assessment of electrostatic bonding results requires techniques for measuring bond quality. Measurement methods are under development. In particular bond strength and hermeticity must be evaluated.

A lap shear strength measurement capability has been established at a local testing laboratory. Design of fixturing is based on the developments made at JPL under Phase I of this program. Samples are being prepared to test the operation of this facility. Although bond strength measurements are limited to 2000 psi by glass breakage it is felt that any bond of this quality is more than adequate for solar array encapsulation applications.

Bond hermeticity will be measured in two ways. Helium mass spectroscopy leak detection will be used to measure the degree of seal leakage that might exist in bonded samples. Two glass sheets will be bonded together with a cavity left between them. This sample will be placed in a chamber pressurized with helium. Subsequent leak detection would indicate the presence of helium within the test cavity and quantitate the leak rate. The helium chamber has been constructed and glass samples with cavities have been prepared. After bonding initial tests of this system will be made. The second test of bond hermeticity and durability will be made by placing samples in boiling water for an extended period. Coupled with helium leak detection, this test should provide a quantitative measure of bond integrity.

2.4 Glass Studies

Evaluation of four developmental glasses from Corning Glass Works has begun. Initial tests on small (1 inch square) samples were made to verify the relative viscosities of the four materials at bonding temperature. Bonding was nonuniform and results were inconclusive. A more important test involved bonding large area (2 1/4 inch diameter) cells to each glass. Because thermal expansion data from Corning did not extend to the bonding temperature, this test was necessary to determine if excessive residual stress was present in the glass after bonding.

Initial samples of glasses 3 and 4 formed acceptable bonds to bare silicon wafers but delamination and cracking of the silicon occurred after several days. Similar results were obtained with one of two samples of glass 2. No delamination of bonded samples of glass 1 were observed. Thermal cycling between liquid nitrogen temperature and 100°C caused no changes in the samples of glasses 1 and 2.

2.5 Metallization Studies

Metallization studies are concentrating on inexpensive alternatives to vacuum deposited cell contacts. Two systems that are being investigated are pre-formed wire meshes and screen processed metal applied to the glass. Some promising results have been obtained with wire meshes while a test matrix has been established for the screen processed contacts.

Wire meshes consisting of twenty 1.9 mil lines per inch were bonded between bare cells and sheets of 7070 glass. Mesh materials were nickel, silver and titanium coated silver. Best results were obtained with the TiAg system. Figure 1 shows the I-V curve of a cell with this type of trapped mesh front contact. Maximum output power, 0.11 Watt, is 85% of that from an equivalent cell with evaporated and electroplated TiAg contacts. Contact resistance between silicon and metallization remains the most serious problem.

Results with nickel were poor with serious shunting being the main problem. Shunting may have been caused by rapid formation of silicide at the cell/metal interface. Bare silver mesh also did not perform as well as titanium coated silver. Although the titanium was added so that good ohmic contact between the silicon and the mesh could be obtained, the problem with bare silver was again shunting rather than series resistance. Measured series resistance was nearly as low for bare Ag as for the TiAg system. Shunt resistance however was considerably lower for bare Ag than for the coated Ag. This effect may be due to rapid diffusion of impurities in the silver through the silicon.

Work will continue with variations in the bare metal material and coating thickness. Lightly metallized cells will also be made for this development effort. A finger pattern only 1000 Å thick, should significantly reduce contact resistance problems associated with preformed metallization.

Figure 1. AMO I-V Curve of Cell with Trapped Wire Mesh Front Contact

2.6 Physics of Electrostatic Bonding

During Phase II of this program, an investigation of the physics of the electrostatic bonding process is to be conducted. Using a variety of surface analysis techniques, the bond interface will be studied. Ion profiles will be established if possible. Effects of bonding parameters will be studied.

Samples are being analyzed to evaluate the applicability of various experimental approaches. Among the techniques being considered are Scanning Electron Microscopy (SEM), Electron Spectroscopy for Chemical Analysis (ESCA) and Auger Electron Spectroscopy (AES) combined with ion sputter-etching, and Secondary Ion Microscopy (SIM).

2.7 Module Production

Four Type II modules were delivered to JPL during the quarter. These modules incorporated total glass encapsulation. Four series connected cells were bonded to the front glass. Interconnection was by welded silver ribbons. A hollow back glass was bonded to the front via a silicon interfacial film evaporated onto a 1/4 inch wide perimeter around the outside edge of the module.

Figure 2 shows a photo of one of the modules, while Figures 3 through 6 show the AMO I-V curves of the four deliverable modules. Variation in module performance is due to differences in cells and bonding results. Table I compares the electrical properties of module M2005 with those of its component cells prior to bonding. Output power, 1.05 Watts, is somewhat decreased (87% of pre-bond value). This is probably due to a 5% loss in fill factor and to optical losses that reduce the short circuit current by 7%.

Figure 2 Four Cell Module with Total Glass Encapsulation

Figure 3. AMO I-V Curve of Four Cell Series Module,
Type II, M2003

Figure 4. AMO I-V Curve of Four Cell Series Module, Type II, M2004

Figure 5. AMO I-V Curve of Four Cell Series Module, Type II, M2005

Figure 6. AMO I-V Curve of Four Cell Series Module, Type II, M2006

Table I
Comparison of the Electrical Performance
of Module M2005 with the Pre-bond Behavior
of the Component Cells

	Sample	V _{OC} (V)	I _{SC} (A)	P _{max} (Watts)	Fill Factor
Before Bond	Cell 925-3	.57	.72	.30	.73
	Cell 925-8	.57	.71	.30	.74
	Cell 925-9	.57	.72	.31	.75
	Cell 925-14	.56	.71	.30	.74
	Totals	2.27	2.86	1.21	--
	Average	.57	.71	.30	.74
After Bond	M2005	2.27 (100%)	.66 (93%)	1.05 (87%)	.70 (95%)

2.8 Module Testing

Two Type I modules, previously delivered to JPL, have successfully undergone thermal cycling and humidity testing. These integral front modules consisted of four cells bonded to a single sheet of glass. Interconnection was through evaporated films on the glass. An organic backing was used to protect the cell backs and interconnects.

Thermal cycling and humidity exposure were according to standard LSSA acceptance testing procedures. Fifty (50) cycles between -40 and +90°C were followed by a seven day humidity test reaching 95% RH. Figures 7 and 8 detail these tests. Although there were signs of attack upon the metal films by moisture penetration through the organic backing, there was no evidence of any effect on the electrostatic bonds. No degradation of module electrical performance was observed.

3.0 CONCLUSIONS

During this quarter the following progress can be reported:

- 1) Installation of microprocessor control of bonding operations is near completion.
- 2) Facilities that have greatly reduced process time have been installed and are operational.
- 3) Bond quality measurement techniques have been identified and established.

Figure 7. Standard LSSA Thermal Cycle Test Used on Electrostatically Bonded Demonstration Modules

Figure 8. Standard LSSA Humidity Cycle Test Used on Electrostatically Bonded Demonstration Modules

- 4) Developmental glasses from Corning Glass Works have been evaluated.
- 5) Promising results have been obtained with preformed metallization applied to bare cells.
- 6) Techniques for investigation of the physics of electrostatic bonding are being assessed.
- 7) Four modules, demonstrating total glass encapsulation of solar cells, have been delivered to JPL.
- 8) Thermal cycling and humidity testing of Type I modules produced no degradation in cell electrical performance and no detectable effect upon electrostatic bonds.

4.0 PROGRAM PLAN

Efforts during the next quarter will concentrate on completion of the modifications to the present electrostatic bonder and on module development. It is expected that microprocessor control of bonding functions will be totally operational by mid-January 1978.

Preparation of Type III modules is anticipated by early January 1978. The following series of demonstration modules will incorporate a new, hermetically sealed, feed-through and output terminal design.

Other efforts during the second quarter of Phase II will involve investigation of the physics of electrostatic bonding.. Bond shear strength measurements and hermeticity testing will also begin.

5.0 APPENDIX

5.1 New Technology

No new technology has been identified during the period of this report.