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**INTEGRAL GLASS ENCAPSULATION
FOR SOLAR ARRAYS**

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ENCAPSULATION FOR SOLAR ARRAYS Quarterly
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**QUARTERLY PROGRESS REPORT NO. 9
DECEMBER 1978**

"THE JPL LOW-COST SOLAR ARRAY
PROJECT IS SPONSORED BY THE
U.S. DEPARTMENT OF ENERGY AND
FORMS PART OF THE SOLAR PHOTO-
VOLTAIC 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."



**PREPARED UNDER CONTRACT NO. 954521 FOR:
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA 91103**



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ABSTRACT

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

SECTION 1 INTRODUCTION

This is the ninth quarterly report under a JPL/DOE program for the development of permanent, integral glass encapsulation of terrestrial solar photovoltaic arrays by electrostatic bonding. The goal of this program is to develop electrostatic bonding to the point of being a cost-effective, practical, and automatable process for the large-scale production of arrays with 20-year-plus lifetimes. This report covers work done during the period of 23 August through 22 November 1978.

Electrostatic bonding is a technique for sealing silicon (or other dielectrics and metals) to glass. It results in a permanent chemical bond which is stronger than the component materials. No materials other than the encapsulating glass are used, and the process is rapid and easily automatable. Due to the nature of the seal, optical coupling is achieved without use of gels or secondary encapsulants; thus, total encapsulation cost in an automated bond facility will be little more than the cost of the glass.

Functioning solar modules have been made by electrostatic bonding (ESB) in several configurations, including ESB total glass encapsulation, ESB/PVB hybrid encapsulation, and ESB front/organic back systems. All have shown no noticeable degradation, electrically or mechanically, in accelerated testing. These tests show that electrostatic bonding will be fully capable of meeting the specification of a 20-year lifetime in a cost-effective manner.

SECTION 2

TECHNICAL STATUS

2.1 GENERAL

During this quarter, efforts concentrated on the development of a practical, electrostatically bonded, totally glass encapsulated module. This module consists of square cells integrally bonded to a front glass, with a partially hollowed back glass integrally bonded to this front. Other efforts consisted of the development of module components, preformed metallization, interconnects, and future module designs.

2.2 OUTPUT TERMINAL DEVELOPMENT

Electrostatic bonding provides a fundamentally hermetic module seal. The development of module output terminations which preserve this hermetic seal is an essential element of this program. The use of bonded metal foils which perform the dual function of sealing and current conduction has been demonstrated. Workable structures have been fabricated from aluminum foils up to a few mils in thickness, but while aluminum performs well both as a bonding agent and conductor, joining other materials to it by conventional welding and soldering techniques is difficult. Other foils have thus been investigated.

Metals that might be acceptable candidates for this application include Kovar, molybdenum, and tungsten. Past attempts to bond 1 mil (25 micrometer) foils of these materials to 7070 glass have failed. The most recent experiments evaluated the effects of atmosphere and temperature upon bond formation. Two bonding temperatures, 580°C and 620°C, and two atmospheres, nitrogen and vacuum, have been tried. Table 1 presents the results of these latest tests. No permanent bonds could be formed. Some metal samples adhered well to the glass when removed from the bonder, but later released. One tungsten sample, after processing at 620°C in vacuum, showed indications of strong adhesion. Although the foil released from the glass, splinters of glass were removed from the bulk material. This effect was presumably caused by stresses set up as the sample cooled from the bonding temperature. A better match in thermal expansion would be required in this case.

TABLE 1. RESULTS OF ATTEMPTS TO BOND METAL FOILS TO 7070 GLASS

	<u>580°C-N₂</u>	<u>580°C-Vac.</u>	<u>620°C-N₂</u>	<u>620°C-Vac.</u>
Kovar	No bond	No bond	Temporary adhesion	No bond
Molybdenum	No bond	No bond	Temporary adhesion	No bond
Tungsten	Temporary adhesion	No bond	No bond	Splintered glass, indication of adhesion

Since thermal expansion mismatch may be preventing bond formation, experiments will be run with glasses that are very closely matched to these metals. Table 2 gives the net differential expansion in parts per million between these metals and several glasses at the set point of the glass. General rules of thumb used in conventional glass-to-metal sealing indicate acceptable differences in net expansion. No stress problems would be expected if the differential expansion is less than 100 ppm. In the range 100-500 ppm good seals can be made with care. Differentials in the 500-1000 ppm range limit the size and thickness of seals.

TABLE 2. NET DIFFERENTIAL EXPANSION BETWEEN METALS AND GLASSES AT THE SET POINT OF THE GLASS

	<u>7070</u>	<u>7740</u>	<u>7052</u>	<u>7056</u>	<u>9741</u>
Kovar	770	>1000	20	130	0
Molybdenum	690	>1000	50	-80	170
Tungsten	290	550	-320	-490	-180

Note: Differentials are in parts per million; minus signs indicate lower expansion for the metal than the glass.

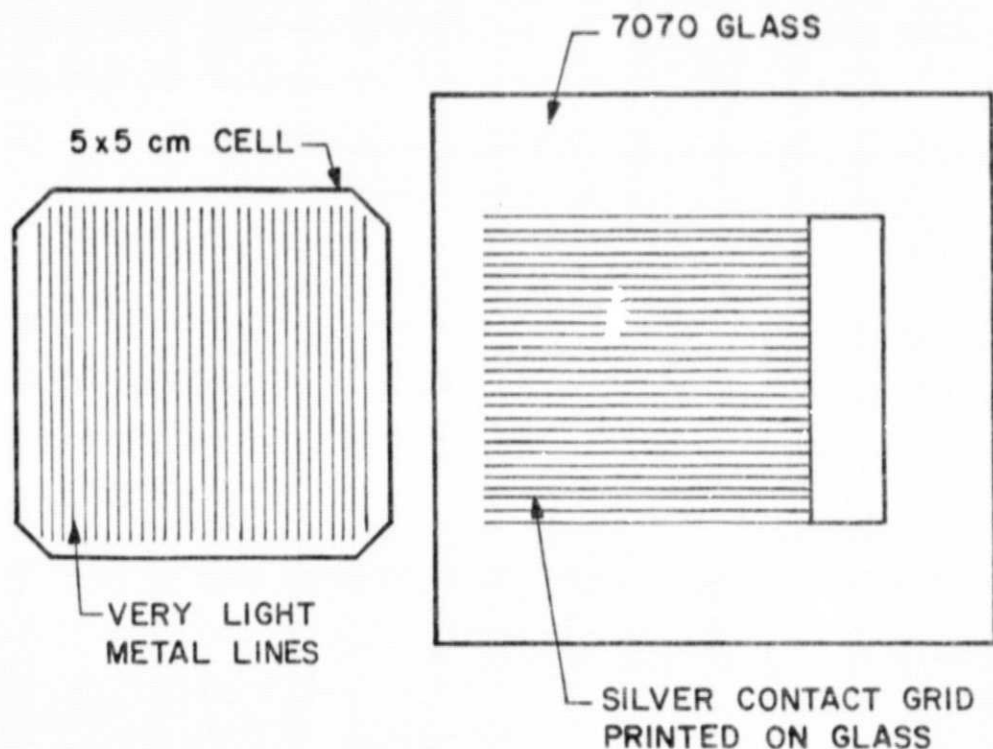
Use of aluminum foil output pads will continue until a better material is identified. Soldering to these foils has been a problem, since the flux required for cleaning the aluminum attacks the thin foil at the soldering temperature. Lower melting point solders are being investigated. Solders tested are:

<u>Company</u>	<u>Solder</u>	<u>Melting Point</u>
Eutectic Castolin Institute	Alutin 51-S	
	Alutin 51 Flux	160°C
Chemetron Corporation	All-State Strongset	
	Solder Kit No. 509	265°C
Indium Corporation	In-Sn #1	120°C
	In-Ag-Pb #2	150°C
	In-Ag-Pb #6	285°C
	In-Sn-Pb #9	165°C
	In-Pb #10	265°C
	Aluminum Flux	

For precise heating control and to minimal temperature differential, heating has been done in a regulated oven.

2.3 CONTACT METALLIZATION DEVELOPMENT

One electrostatically bonded cell configuration that is of interest employs screen-printed metallization on glass. Printed metallization on the glass provides both the interconnection of cells and front contact grids. The cells, bonded to the glass, complete the structure. In principle the cells need have no metal on their front surface. In practice some metal, in the form of very thin lines, may be helpful in forming an ohmic, low resistance contact to the silicon. Figure 1 shows the test configuration now in use: a 5 x 5 cm cell with fine-line metal is bonded to a piece of 7070 glass on which a silver contact grid has been printed.



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FIGURE 1. CELL AND GRID PATTERN FOR TESTING OF
SCREEN-PRINTED CONTACTS ON GLASS

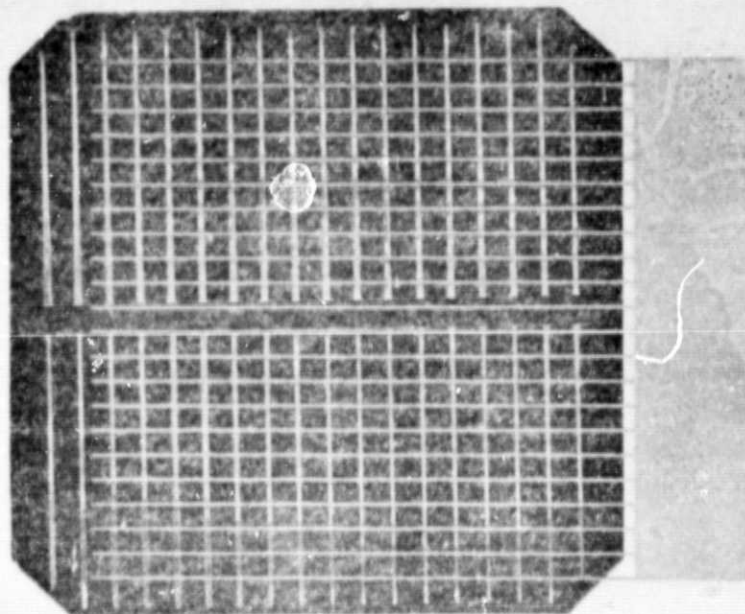
Figure 2 is a photograph of a typical sample of these initially bonded cells. The I-V curve of one such assembly is shown in Figure 3. Current is low for two reasons. First, the metallization on the cell, which forms the ohmic interface, was applied through an existing evaporation mask. No attempt to optimize the line width and spacing was made. Accordingly, a large amount of the cell surface area (greater than 25 per cent) is shadowed. The second reason for low current is the lack of antireflective coating on the cells. The significant feature of this result is the fill factor of 0.68. This value demonstrates the feasibility of the approach. Process optimization should improve the current and fill factor on later samples. Future experiments using premetallized cells will test four different thick-film inks, fired at three different temperatures.

2.4 MODULE DEVELOPMENT

The rate at which modules can be processed in the present developmental bondor is determined to a large degree by the time required to align the cells on the front glass and prepare the interconnect ribbons for bonding. Operations are now performed manually. Experiments are being conducted to identify the production techniques that would eventually be used in an automated process.

In an effort to speed up the process and reduce the failure rate, a special electrode is being fabricated, with machined cavities to hold the cells in position. This fixture will also include small grooves to allow the interconnect ribbons to be joined to the cell backs prior to bonding. In a preliminary experiment, slots approximately 0.08 inch wide were cut into pieces of 0.001 inch thick stainless steel, which were cut to the size and shape of the cells. When a module was processed with these pieces as electrodes on the cell backs — the slots accommodating the interconnect ribbons — bonding was good and no problems associated with the unsupported areas were seen.

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FIGURE 2. BONDED SAMPLE WITH CONTACTS SCREEN-PRINTED ON GLASS

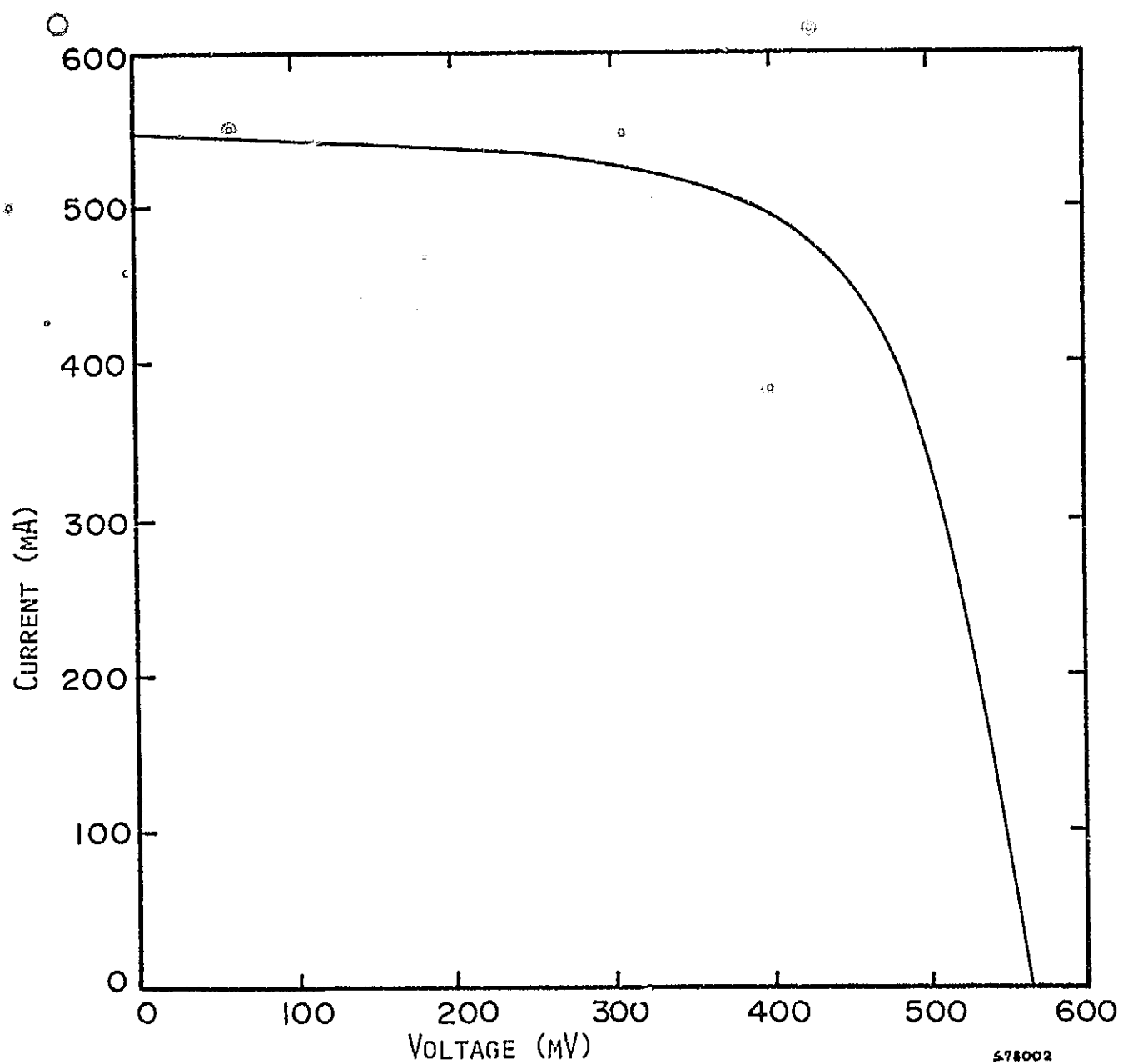


FIGURE 3. I-V CURVE OF CELL WITH CONTACTS SCREEN-PRINTED ON GLASS

In that experiment the cells were successfully bonded with an intercell separation of only 1/16 inch. Subsequently, we have achieved good bonding of cells separated by less than one millimeter, or about 1/32 inch, demonstrating that the bonding process intrinsically imposes no serious limitations on packing density. We expect separations of less than 1/16 inch to be standard in next year's baseline modules.

Another approach to the problems associated with the present interconnect system is the replacement of silver ribbon with expanded silver mesh. The expanded mesh should be much less subject to breakage during module processing and thermal cycling. Preliminary experiments indicate that the mesh can lie on the cell backs during the bonding of a module front without causing cracking, the large open area of the mesh allowing it to be pressed flat across the cell back contact. The module I-V curves, however, show severe loss of fill factor. The degradation was initially attributed to shunting of the cells by the mesh, but protection of the cell edges with mica had no apparent effect. Since calculations indicate that the series resistance losses in mesh interconnects should be only marginally greater than in ribbons, the source of the damage remains unidentified. Folding the mesh between the cells will be attempted, in order to isolate the effect of pressing the mesh onto the cell backs.

The inherent advantages of mesh over ribbon in strength, reliability, module yield, and process improvement, although apparent even in the present system, could be enhanced significantly by the use of cells and interconnects optimally designed for this application. An improved cell design would include, for example, redundant contact pads for the attachment of interconnects. For ease and strength of welding, the interconnects might have solid ribbon ends with expanded mesh only in the central region, where its advantages in durability under thermal cycling are most important.

The constraints of glass availability and present bonder size do not permit the production of single ESB assemblies of the size of the JPL standard minimodule. A design consistent with standard minimodule dimensions incorporates more than one multicell ESB assembly. For the immediate future, six Type I

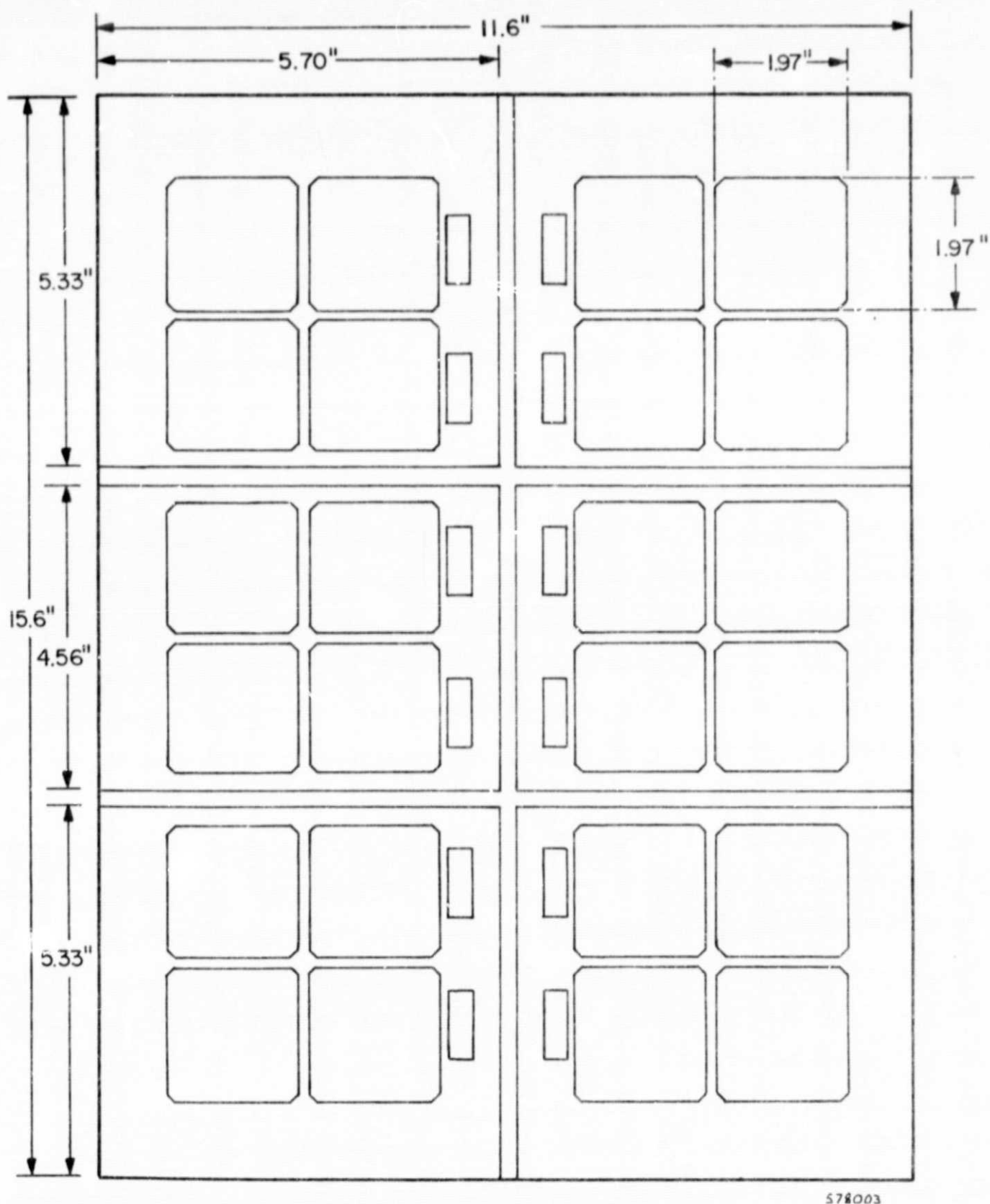
assemblies, each containing four standard 5 cm square cells, will be used. This design is shown in Figure 4. These modules differ in no fundamental way from those now routinely produced, and test production has begun. Production of deliverables will begin as soon as the bonding of Type II modules is completed. Although the cells will cover only 56 percent of the available minimodule area due to the restrictions on glass availability and present bond size, the packing density in the regions occupied by the cells themselves will be greater than 90 percent. A support structure is being built to hold the assemblies firmly within the minimodule frame.

When larger sizes of Corning 7070 glass become available, and the tooling necessary for larger cells has been obtained, four ESB assemblies per minimodule will be used, each incorporating six cells approximately 5.6 cm square. This design will give an overall area coverage of over 70 percent, with a local packing density in excess of 90 percent, as shown in Figure 5.

To demonstrate better materials usage and higher packing densities, cells for advanced minimodule usage will be 2.22 inches (5.64 cm) square, cut from 3 inch (7.62 cm) silicon slices. The result is a square cell with the corners clipped by the wafer edges (see Figure 6). This results in cells of 4.9 in² area (31.7 cm²), effectively using 70 percent of the available silicon in a close packed configuration. The cell has been designed with two redundant interconnect points at the end of the current bus. For optimum bonding, metallization height has been reduced to 5 micrometers, and a contact pattern optimized for this height of metal (see Figure 7). To minimize resistance losses along the cell bus, current collection lines have been angled slightly. Total shadow coverage for this mask is 7 percent; the total series resistance due to the front contact is approximately 45 milliohms.

2.5 MODULE FABRICATION

The production of deliverable Type II modules is continuing, and although processing is as yet neither optimal nor fully routine, adequate procedures and process parameters have been defined, so that completion of deliverables should present no particular difficulties. One completed module, number M4003, has been subjected to thermal shock testing, consisting of transfer directly from boiling water into ice water, and vice versa, without visible damage or any loss of hermeticity.



578003

FIGURE 4. CELL LAYOUT FOR INCORPORATION OF SIX ELECTRO-STATICALLY BONDED ASSEMBLIES INTO ONE MINIMODULE (APPROXIMATELY 1/2 SCALE)

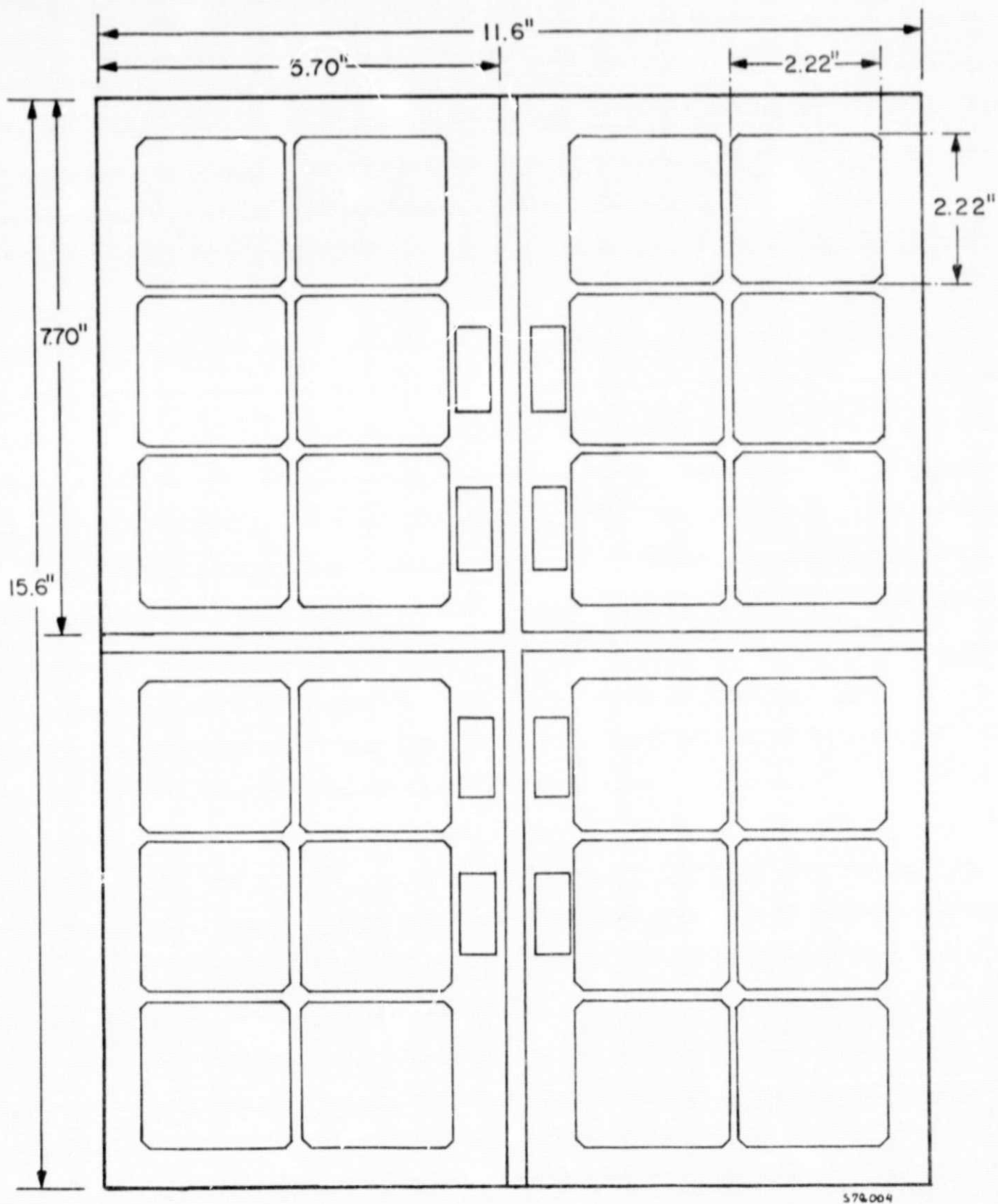
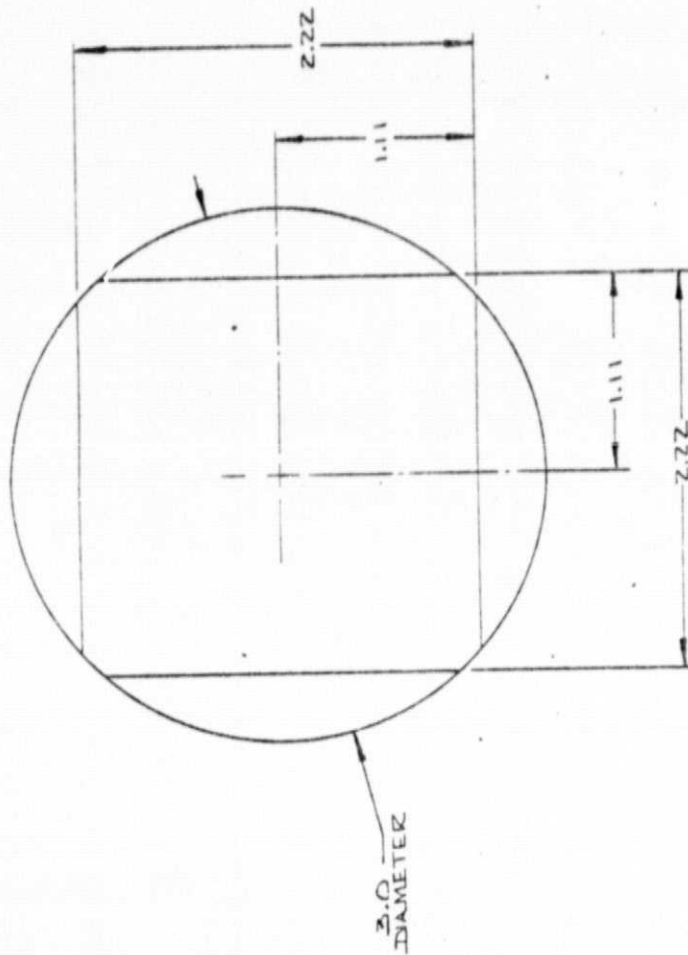


FIGURE 5. CELL LAYOUT FOR INCORPORATION OF FOUR ELECTRO-STATICALLY BONDED ASSEMBLIES INTO ONE MINIMODULE (APPROXIMATELY 1/2 SCALE)

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NOTES

REVISIONS		DATE	APPROVED
ZONE/ATH	DESCRIPTION		
INITIAL	CELL A-5		



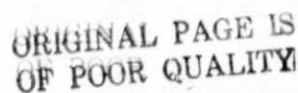
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ITEM	ITEM	QTY	CODE IDENT. NO.	PART NO. OR IDENTIFYING NO.	DESCRIPTION	MATERIAL	SPEC
PARTS LIST				NOV 30 1978			
DIMENSIONS ARE IN INCHES DIMENSIONS IN PARENTHESES ARE IN MILLIMETERS UNLESS OTHERWISE SPECIFIED TOLERANCES ARE DECIMALS INCHES 3 PLACES 2 PLACES 1 PLACE FRACTIONS				CONTER NO. DR R. J. Schuman CHK. J. A. Schuman APPRO. APPRO. CONTER DESIGN ACT APPRO. CONTER ACT APPRO.			
CONTER NO. DR R. J. Schuman CHK. J. A. Schuman APPRO. APPRO. CONTER DESIGN ACT APPRO. CONTER ACT APPRO.				SPIRE CORPORATION BEDFORD, MASS 01730 ADVANCED BOULDER CELL DIE			
SIZE CODE IDENT. NO. C 4D656				DRAWING NO. 060-0108			
SCALE 2/1				SHEET 1 OF 1			

FIGURE 6. ADVANCED BONDER CELL DIE

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0.0002 Titanium/silver evaporated metallization on silicon wafer

[illegible]

Production has begun on Type I module fronts for incorporation into minimodules, as shown in Figure 4. Since these four-cell assemblies do not differ fundamentally from standard ESB module fronts, no particular difficulties in production are anticipated.

2.6 ELECTROSTATIC BONDING PROCESS STUDIES

A test of the effect of various process parameters on bond strength is underway. Using the standard lap shear test configuration, this experiment will evaluate the effect of various bond current and voltage levels upon the strength of silicon-to-glass bonds. Both constant current and constant voltage bonds will be investigated. Table 3 lists the parameter values to be tested. To date, two samples bonded at each value has been prepared. A total of five samples bonded at each set of values will be prepared before lap shear testing begins.

TABLE 3. ELECTROSTATIC BONDING PARAMETER TEST SCHEDULE

1. Effect of Bond Current and Total Charge Transfer on Bond Strength - Constant Current Bonds					
	Total Charge Transfer (millicoulombs)				
<u>Bond Current</u>	<u>90</u>	<u>180</u>	<u>360</u>	<u>720</u>	<u>1440</u>
6.0 mA	X	X	X	X	X
3.0 mA	X	X	X	X	X
1.5 mA	X	X	X	X	X
2. Effect of Bond Voltage and Total Charge Transfer on Bond Strength - Constant Voltage Bonds					
	Total Charge Transfer (millicoulombs)				
<u>Bond Voltage</u>	<u>90</u>	<u>180</u>	<u>360</u>	<u>720</u>	<u>1440</u>
1.0 kV	-	-	X	X	X
0.5 kV	-	-	X	X	X

Note: Configurations to be tested are marked with X's.

2.7 BONDING OF ALTERNATE SILICON MATERIALS

Initial experiments have been performed to test the bonding of ribbon, textured and polycrystalline silicon. Ribbon silicon has been successfully bonded, without visible damage, at 600°C. The uneven surface of textured silicon has presented more difficulties, since full deformation of the glass around the surface tetrahedra has proved elusive. Bonding of texturized silicon has been shown to be feasible, but a routine process must be developed that achieves 100 percent bonding of the textured surface while leaving the material undamaged. Longer cycles, coupled with higher bond voltages, are expected to permit complete bonding of the textured surface.

In the case of polycrystalline silicon, surface irregularities have again resulted in added difficulties in bonding. Wacker Chemical Corporation's SILSO polycrystalline silicon has been bonded to 7070 glass. Careful processing is required to achieve uniform bonding, but no fundamental problems have been identified.

SECTION 3

CONCLUSIONS

During this period the following progress can be reported:

1. Hermetic output terminals for all-glass modules have been developed.
2. A combined process for cell metallization and encapsulation, based on contacts screen-printed on the glass, has been demonstrated.
3. Development of cell positioning and interconnection for modules has proceeded.
4. Module components and cells for the JPL minimodule have been designed.
5. Fabrication of all-glass module deliverables has started.
6. Successful bonding of ribbon and polycrystalline silicon has been demonstrated.

SECTION 4

PROGRAM PLAN

Efforts during the next quarter will complete Phase II of this program. All glass module fabrication will be completed for the second set of deliverables under this program; glass front modules designed for the JPL minimodule configuration will complete the third and fourth demonstration module deliverables. Presently active experiments will be concluded.