Large-Area, Triple-Junction a-Si Alloy Production Scale-Up

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1.0 INTRODUCTION

In the first six months of the second phase of the PVMaT contract, Solarex has continued to improve the efficiency of large-area, multi-junction amorphous silicon alloy modules. Equipment capable of producing modules up to 0.74 m² in area has been brought on-line and process development initiated. Preliminary cost analysis/reduction has begun to ensure that these development efforts will result in a commercialization of this large-area technology.

The approach has been to transfer the high efficiency multi-junction from R&D into the manufacturing environment by using three different substrate sizes. Initial attempts to transfer the multi-junction silicon process were made using a 0.1 m² substrate (approximately one square foot). These efforts resulted in a module with a measured aperture area efficiency of 10.32%. Simultaneous to the transfer of the silicon technology, the most complicated aspect of the technology transfer, we initiated process development techniques on large-area by using the 0.37 m² substrates. These efforts resulted in modules with total area efficiency of 7%. Finally, initial runs on substrates 0.74 m² were made to de-bug the large-area equipment and prepare ourselves to transfer the knowledge gained in the processing of the smaller substrates.

2.0 TASK 8: FRONT CONTACT DEVELOPMENT

2.1 Introduction

The efforts during the first six months of this phase have been focused on developing and refining the large-area atmospheric pressure chemical vapor deposition (APCVD) equipment and processes. This work has resulted in significant improvements in film uniformity and in the front contact optical properties. The testing and evaluation of the 0.76 m (30 inch) wide Solarex injector has been a central focus during this time. In addition, alternate feedstocks for the metal oxide film and the dopant have been evaluated. The chemical delivery system has also been made more reliable by implementing several equipment changes.

2.2 Large-Area Development

During this phase, the first ≥ 0.56 m² (6 ft²) front contact plate was fabricated. Although the film properties were good, the coating was uniform on only one half of the plate due to process and equipment limitations.

We removed some of the equipment constraints by modifying the hardware to improve our control of the tin IV chloride flow rate. Due to the highly reactive nature of tin IV chloride, the system had to be kept meticulously dry to avoid clogging the delivery tubes. These modifications made the system more reliable and improved the quality of our tin oxide films.

The process factors contributing to the film non-uniformity were identified by running several sets of designed screening experiments. By using this method, we reduced a large number variables that could potentially affect film uniformity to four significant factors (tin IV chloride flow, tin:methanol ratio, reactant gas temperature, and feedstock gas flow uniformity at the injector nozzle). As a result of these experiments, the film uniformity has been improved on 70% of the width of the substrate. (See Figure 2.1) The non-uniformity on the one edge is believed to be caused by the injector vent assembly, which is critical in determining the flow path of the reacting gases over the substrate. The injector vent assembly has been redesigned and is expected to eliminate this edge non-uniformity. This component will be put into service as soon as possible and the uniformity re-evaluated.

Work has continued with our proprietary dopant system. Two alternate fluorocarbon based materials have been tested on large-area substrates and have been shown to work efficiently in doping the tin oxide films. Resistivities in the range of $0.36 - 2.0 \times 10^{-3} \Omega\text{-cm}$ have been obtained using this process. The latest material has been selected for its low cost ($< \$0.01/\text{m}^2$) and its high TLV (1000 ppm). Work is planned to continue evaluating and optimizing the films made using these dopants.

The multi-injector APCVD system has been designed and is ready to be fabricated. The construction of the system has been put on hold while we explore other options to meet our

large-area front contact needs. It is likely that we will shift our emphasis to the scale-up of the zinc oxide process in the future, due to the encouraging results recently obtained by R&D.

2.3 Film Property Optimization

The tin oxide film properties have been optimized for triple-junction devices using our small-area deposition systems on 76 x 76 mm (3 x 3 in) substrates. Designed experiments were performed to optimize the specular and textured layer thicknesses, the amount of dopant, and the amount of methanol incorporated in the film. We optimized the process to a new standard which improved the efficiency of small-area triple-junction cells by 3 - 6%.

As a part of determining the optimum film properties for the front contact, we compared the performance of our "typical" tin oxide with tin oxide deposited by a leading glass manufacturer. Triple-junction devices were deposited on each type of substrate using both research and production sized machines. In all cases, the devices deposited on our "typical" tin oxide have resulted in cell efficiencies that are 6 - 10% higher than when deposited on the glass company's tin oxide. Analysis of the optical data (see Table 2.1) reveals that the most significant difference between the two substrates is the amount of haze. It is possible that insufficient scattering of light in the lower haze substrates allows light to escape the device instead of being utilized for power generation.^{1,2,3} As a result of this study, we are working with the glass company to optimize their tin oxide for use in our multi-junction devices.

Typical Properties of Solarex vs. Glass Company's Tin Oxide		
	Solarex	Glass Company
Sheet Resistance	13 ohm/square	8 ohm/square
Transmission*	79%	79%
Haze*	24%	11.5%

*Measured in air on a Gardner XL-211 Hazegard system.

Table 2.1

2.4 Alternate Materials

Three feedstock materials have been selected for evaluation to determine their suitability as alternative precursors for transparent conductive oxide films. These materials include tin IV chloride, diethylzinc, and a proprietary organotin mixture developed by a major producer of tin based chemicals.

Tin IV Chloride

This is our current material and is our standard process for all manufacturing, engineering and research work. We have a good understanding of how to use the material to get the results we want and we have been able to fabricate high efficiency devices on this tin oxide. The films made with this material are the benchmark to which films made with other source materials are compared.

Diethylzinc

Diethylzinc (DEZ) has been evaluated as a potential source material to make zinc oxide films. Zinc oxide is an attractive substitute for tin oxide because of its larger band gap (2.2 eV vs. 2.0 eV for tin oxide) which makes it more transparent over the visible spectrum.

The APCVD of zinc oxide using DEZ met with mixed results. Specular films doped with fluorine were fabricated with excellent conductivity and uniformity (7 Ω /square, 800 nm thick), however the textured films resulted in powder formation and optical non-uniformities. Day to day variations were common which indicated to us that there were some important variables not being controlled. The most repeatable results were obtained with process conditions which controlled the deposition rate limiting step, the diffusion of the gases to and from the substrate. The transmission of the best zinc oxide films offered significant improvements over tin oxide as shown in Table 2.2, but the gas diffusion could not be controlled well enough and so the films were never reliably uniform.

COMPARISON OF APCVD TIN OXIDE TO APCVD AND LPCVD ZINC OXIDE			
PROPERTY	APCVD TIN	APCVD ZINC	LPCVD ZINC
Sheet Resistance	13	14	14.5
Haze*	24	15	19
Transmission*	79	83	83
Thickness (nm)	840	860	1,500
Uniformity	Good	Poor	Very Good

*Measured in air on Gardner XL-211 Hazegard system.

Table 2.2

In an attempt to control the gas diffusion to the substrate, low pressure CVD (LPCVD) was examined. The films produced by this method were extremely uniform films over a 0.1 m² area (see Table 2.2). The films were tested by making electrical and optical measurements as well as by using them as substrates for devices. It became apparent from these measurements that the zinc oxide has superior transmission when evaluated apart from a solar cell but when incorporated into a device, there were other problems which needed to be addressed (e.g. lower V_{oc} and fill factor). If the fill factor and V_{oc} of devices deposited on zinc oxide can be improved to the quality observed on devices deposited on tin oxide, we expect to see a 10 - 12% increase in performance due to the expected increase in current.

Based on these results, we are exploring the possibility of scaling-up the DEZ zinc oxide process for large-area modules. There is a possibility of using the LPCVD process as a manufacturable method for depositing the high reflectivity back contact, as well. We continue to search for ways to resolve the issues concerning device performance: The higher transmission of the zinc oxide will provide a significant boost in efficiency and assist us in attaining our goals for this contract.

Organotin Mixture

The organotin mixture is currently under investigation. The material has been obtained and we are undergoing safety and process reviews with its manufacturer to determine its suitability for our process. The potential benefits of this material are high and include a simpler gas distribution system in addition to possible film property improvement. We have decided that this material deserves an in-depth study before a final decision is made and so experiments are planned to be run in the coming months to determine its suitability for our process.

3.0 TASK 9: LASER SCRIBING PROCESS DEVELOPMENT

3.1 Introduction

This effort has been focused in two main areas over the past six months:

1. Investigating new methods and types of laser processes to improve device efficiency and speed throughput.
2. Effect hardware modifications to the laser system to accommodate large-area modules and improve manufacturability.

3.2 Laser Process

In order to expand the parameter space of factors that might improve our laser scribing process, we studied the effects of scribing with different wavelengths of light in the production of multi-junction devices. During this reporting period, ultraviolet (UV) and infrared light (IR) were evaluated. Results of the IR scribing were poor: More development needs to be done at this wavelength.

In the UV experiments, a Nd:YAG laser was frequency doubled, thereby halving the wavelength to 532 nm, then frequency doubling again to obtain 266 nm light. Experiments were performed optimizing tin oxide scribing, a-Si scribing, and metal scribing. One consequence of doubling the frequency twice to get the desired UV wavelength is a corresponding loss of power. This loss in power is somewhat compensated for by improved coupling between the material and the photon. The tin oxide scribing was done at 40 mW which is 96% less than the current process. The scribe kerf (channel) was reduced from 0.38 mm (0.015 in.) to 0.008 mm (0.0003 in.). The a-Si scribe was done at 100 mW which is 79% less than the current process. This scribe kerf was reduced from 0.1 mm (0.004 in.) to 0.013 mm (0.0005 in.).

A test plate was produced using a UV tin oxide and a-Si scribes. (Metal and isolation scribes were standard). The plate had a total scribe kerf (all three scribes) of 0.17 mm (0.0066 in.), a 61% area reduction over standard. If this were to be done on a 406.4 x 914.4 mm (16 x 36 in.) plate, aperture area efficiency would be 98.5%. The plate was tested and had a power conversion efficiency of 5.59%.

Attempts at scribing the back metal contact with UV met with little success. Developing a process to ablate the metal back contact, while leaving the semiconductor intact, is proving to be a real challenge. In order to increase the power absorbed by the material at 266 nm, flat black paint and tin were evaluated as potential absorbers. Neither material proved successful.

The UV system was modified to increase the power conversion output, which limited the speed at which scribes could be done. A new system was designed and installed. With this higher power and higher speed, about 90% of the metal back contact could be removed while leaving the semiconductor material intact. However, small "fingers" of metal along the scribe edge still caused segment shorting. It was found that by scribing in UV and then going through a wet chemical process, a good metal scribe could be obtained. To test this process, a 76 x 101 mm (3 x 4 in.) plate was produced and its tested efficiency was 2.2%. Failure analysis of this plate revealed that although the UV metal scribe kerf was narrow, the heat affected zone was found to be four times greater than that produced in our standard process scribe. Work is continuing in this area.

A new type of a-Si scribe is under investigation. At present we use a "dot" pattern. A typical series resistance for this type of scribe is 33 Ω/cm^2 . A new, continuous a-Si scribe is under evaluation. It is hoped that this will translate into a series resistance of 22 Ω/cm^2 .

3.3 Laser System

The large-area gantry system was fitted with optics, vision, autofocus and a laser. The system is being optimized in order to maintain the required dimensional tolerance on 0.74 m² modules. An alternative laser drive system was evaluated. The maximum linear scribe speed of this drive is 1.4 m/sec. If a laser process could be developed that could operate at that speed, a 0.41 x 0.91 m (16 x 36 in) plate could be processed in 30 seconds.

4.0 TASK 10: AMORPHOUS SILICON BASED SEMICONDUCTOR DEPOSITION PROCESS

4.1 Introduction

Work continued in transferring the high efficiency triple-junction a-Si process from R&D into a manufacturing system. The manufacturing system is capable of depositing over a 0.37 m² area. Two different substrates are used in this system: We either run one 0.37 m² substrate or run three 0.1 m² substrates simultaneously. We run the smaller substrates so that we can perform all other processing steps in the R&D equipment in order to insure that we are not confounding presumed silicon effects with effects generated by the other large-area equipment.

4.2 Process Development

Two significant improvements to the process were made during this reporting period.

- 1) Microcrystalline N-Layers⁴
- 2) Low-temperature, hydrogen diluted I-layers⁵

The high-conductivity microcrystalline n-layers boost the FF and V_{oc} of the multi-junction devices by improving the n junction. Current generation is also increased because of lower absorption losses in the n-layer. The low-temperature i-layer process increases V_{oc} while decreasing Staebler-Wronski degradation. Together, these process improvements have resulted in boosting the aperture area efficiency of a 0.1 m² module to 10.32% (Figure 4.1). Uniformity of the process over the 0.37 m² is excellent. Three 0.1 m² modules deposited in the same a-Si run had aperture area efficiencies of 10.16, 10.09 and 10.09%. The best 0.74 m² module produced so far measures 7.0% total area efficiency.

Figure 4.1: I-V curve of 10.32% module produced using manufacturing equipment

4.3 Large-Area Development

The large-area silicon deposition system was initialized. An i-layer deposition was made to measure the system uniformity. As can be seen in **Figure 4.2**, the uniformity of the silicon is mostly within 10% of the nominal thickness. The measurements were made at five equally spaced intervals along the 1.8 m length of the plate. Measurements were taken at each edge and at the center of the plate at each of the five locations. Modification to the system is expected to improve the uniformity to within 5% of the nominal thickness.

Figure 4.2: Uniformity of 0.74 square meter i-layer. The nominal thickness is taken as the mean thickness.

5.0 TASK 11: REAR CONTACT DEPOSITION PROCESS

5.1 Introduction

During this period the large-area metalization system was modified to improve the degree of process control possible in this system. The large-area system was qualified to deposit aluminum rear contacts on large-area substrates as a first step to developing a high reflectivity rear contact. Experiments directed at establishing the viability of the proposed large-area zinc oxide/silver

deposition process were completed and the development of a zinc oxide deposition process in the large-area machine was initiated. This development work led to several of the equipment modifications.

5.2 Equipment Modifications

A number of equipment modifications and upgrades that are directed at improving the reliability and degree of process control were completed in this period. The substrate heaters and temperature controllers were modified to achieve improved temperature control, the sputtering target coolant circuit was upgraded to increase the flow of coolant to the targets, and downstream (sputtering) gas pressure control was added to the system.

A 450 Kilohertz power supply and an AC/DC combiner box were recently installed on the large-area metalization system. Applying a combined AC/DC voltage to the sputtering target will enable us to achieve the high deposition rates characteristic of dc magnetron sputtering and at the same time avoid the adverse effects of insulating layers that develop on the target surface during reactive sputtering. The 450 KHz frequency is high enough to sustain a uniform glow discharge yet low enough to avoid the complications associated with higher frequency radio frequency discharges. Process development work using this combination AC/DC voltage to drive the sputtering targets has been started recently.

5.3 Zinc Oxide / Silver Deposition

When depositing reliable, high throughput, low cost rear contacts over large-areas, it is desirable to complete the deposition in a single pass of the substrate past the sputtering target. A multiple pass deposition process, a process that involves several passes of the substrate in front of the target, requires the substrate transport system to be more complex and may result in a lower effective throughput than a single pass process.

The oxide / metal sputter deposition processes that have been developed to date have all been multiple pass processes. One approach to increasing the potential throughput of the metalization process is to develop a single pass deposition process. A series of experiments was performed to demonstrate the feasibility of a single pass oxide / metal rear contact deposition process and to provide some guidance in the large-area development efforts. These experiments were performed in a system capable of handling substrates 0.1 m² in size. The single-junction device structure was used in these experiments to make the comparisons straightforward. We found no detectable difference in the performance of the solar cells metalized using the multiple pass process and those solar cells metalized using the single pass process. These results suggest that a single pass large-area metalization process is feasible and that the current machine configuration will be adequate for the development of a large-area process.

5.4 Large-Area Zinc Oxide Deposition

Based upon the results above, development of a single pass zinc oxide deposition process has been initiated in the large-area system. The initial work was directed at achieving an ohmic contact between the zinc oxide film and the n-layer of a single-junction solar cell. The single-junction device structure was used because the higher current density of the single-junction device provides a more sensitive test of the contact than does the multi-junction structure. Aluminum metal rather than silver metal was used for convenience in these tests.

Representative current - voltage measurements performed on equivalent single-junction solar cells are given in **Table 5.1**. Initial trials resulted in solar cells with extremely poor fill factors due to a high series resistance. The fill factors of solar cells in later trials improved significantly. Investigations of this type suggested two modifications to the metalization system that have been implemented. First, the substrate heater assemblies were upgraded to obtain better control of the substrate temperature. Substrate temperature is an important factor in obtaining not only films that are transparent, but also films that make a good ohmic contact to the amorphous silicon. Second, the power supply used in these trials was replaced with the 450 KHz power supply and a AC/DC combiner mentioned above. This configuration should help to increase the rate of film deposition. Increasing the film deposition rate will help us to obtain the zinc oxide film thickness necessary to make ohmic contact in a single pass process.

RUN I.D.	Voc (volts)	Jsc (mA/cm ²)	Fill Factor
GT5-1	0.868	9.9	0.33
GT3-2	0.834	12.9	0.60
GT3-3	0.851	12.9	0.67

Table 5.1 - Photovoltaic Parameters of Zinc Oxide / Aluminum Rear Contact Trials

6.0 TASK 12: BUS/WIRE/ENCAPSULATE/FRAME

6.1 Introduction

Progress within Task 12 has focused on two main areas:

- 1) Development of reliable, surface-mountable connectors
- 2) Development of a conductive silver frit with improved processing capability.

6.2 External Connector

In a joint effort with a connector manufacturer, we modified an existing waterproof terminal block to meet our requirements. We classified this evaluation by the two major components - the contact and the housing.

6.3 Contact

We soldered attached prototype contacts to conductive-frit bus bars and analyzed the quality of the attachment using pull strength as the metric. We measured the average pull strength to be approximately 50% less than that value achieved using our standard process with 18 awg wire. We investigated methods for increasing the pull strength and discovered that reflowing the pre-tinned contact to the frit pad without the application of additional solder produced better results. Pull strengths improved by more than 80% when we used this new method of attachment.

Figure 6.2: Measurement of attachment strength as a function of solder pad width.

Figure 6.1: Measurement of attachment strength for different processing methods and levels of environmental stress.

Thermal cycling was completed and pull testing performed on the contacts solder attached using the standard process. The average bond strength increased by more than 40% after both 50 and 200 thermal cycles. Refer to Figure 6.1 for the pull test results on the prototype contact.

Modifications were made to the connector contact footprint size to improve both the mechanical characteristics and manufacturability. The new contacts were evaluated for pull strength versus both the pad attachment area and firing furnace.

Figure 6.3: Measurement of attachment strength for two contact pad widths after 50 thermal cycles.

Evaluation of pull strengths were made on contacts that had their attachment areas increased by either 20 or 60 percent over standard dimensions. In both cases an increase in attachment area correlated to increased pull strength results. The 20% increase in width from 0.318 cm (0.125 in.) to 0.381 cm. (0.150 in.) resulted in more than a 30% increase in solder joint strength. The 60% increase in frit width to 0.508 cm. (0.200 in.) resulted in a 98% improvement in the solder joint strength. Refer to Figures 6.2 and 6.3 for data comparing pull strength versus pad width.

strengths were achieved with the manufacturing furnace indicating further optimization of the large-area furnace temperature profile will be required. Refer to Figure 6.4.

6.4 Housing

Several adhesives were identified as potential candidates for attaching the housing to the substrate. One and two part epoxies, flexible epoxies, cyanocrylates, dielectric overcoats and chip adhesives were then evaluated. Both pull and torque strengths were measured on the original housing. A fifty pound shear strength was used as the initial minimum requirement to classify the materials. Most failures exhibited poor adhesion to the connector - not the encapsulant. Units were submitted for humidity-freeze testing in order to inspect for visual degradation of the adhesives that would indicate water absorption. This experiment is currently in process using the revised housing assembly.

We compared pull strengths of contacts attached to conductive-frit that was cured in the manufacturing furnace and the new large-area furnace. Higher pull

Figure 6.4: Measurement of attachment strength as a function of curing method.

Further evaluation of the adhesive material included potting the contact/frit pad interface. This permitted wet and dry hi-pot testing to be conducted. The flexible epoxy performed the best out of all the samples. Failures in the other materials were due to pinholes/cracks in the material or insufficient coverage of the contact area.

The first fully assembled connector units have been produced. Due to some problems with the injection mold, insertion of the contact into the housing was extremely difficult. This problem has required us to further modify the contact and housing. Environmental reliability and processing assembly issues will be addressed with qualification testing of this final version of assembly connector.

6.5 Conductive Frit

A high density flaked frit was formulated to improve the fired structure and minimize the potential for entrapment of organics. Initial pull test results were measured in the range of 169-182 Newtons (38-41 lbs.). Pull testing failure mode on this material was predominately occurring with glass breaking at the substrate. These units were subjected to thermal cycling and pull testing performed following 50 cycles. Pull strength data ranged from 133-138 Newtons (30-31 lbs.). Stress fractures in glass under solder joint on approximately 6% of the samples were noted after thermal cycle resulting in very low pull results. Further modification of the formulation is on-going at vendor. Evaluations will continue.

7.0 TASK 13: MATERIALS HANDLING

The evaluation of the horizontal and vertical glass storage and transportation carts has been completed. Additional carts are being fabricated with only minor changes to the original design.

A cost analysis file has been organized and will be maintained by the task groups. Each process group has provided information on the direct material costs, direct labor costs, and indirect cost of their respective process step. This file will be updated with new information as new process technologies are developed. A standardized format is being developed to facilitate the gathering of this information in a useful form.

8.0 TASK 14: ENVIRONMENTAL TEST, YIELD AND PERFORMANCE ANALYSIS

8.1 Introduction

Task 14 of the manufacturing technology program addresses several diverse aspects of the assembly process. Specifically, these aspects include:

- 1) The design of both an automated electrical cure station and an electrical cure station for a-Si modules of 0.56 m² (6 ft²) area modules
- 2) Provide capability to environmentally test these large-area modules both indoors and outdoors
- 3) Identify process variations using statistical process control methods in order to assist process improvement and define process yields are part of the objectives.

8.2 Large-Area Auto Test Station

The mechanical modifications accomplished to the Spire Model 240A simulator as reported in the Phase I Final Report, did not include any adaptations of the electronic controls and power supply for the tester. Subsequently, we modified the system so that the outputs are accessible on a CRT display and can also be retained on hard copy printouts or on disk storage. Disk storage is the preferred method since it offers the possibility of transfer to database storage with subsequent manipulation and analysis.

8.3 The Electrical Cure Station

The method we use to remove defects in thin film a-Si structures is to place the diodes in reverse bias electrically. The voltage applied in this process is raised to the point where electrically conductive shunt defects pass enough current to cause heating and we eventually "burn them out". When applying this method to large-area multi-junction devices, we needed to not only modify the mechanical layout of the test head to accommodate the larger physical size of the modules, but also needed to adapt the electronics to match the new total current required to cure the multi-junction diode.

In the Phase I activities, as previously reported, test on triple-junction sub-modules indicated that the diode characteristics were similar enough to those of single-junction types that major design changes would not be required for the station electronics. The work of program Task 14, then, focused on the requirements to accommodate the physical size of the large-area modules.

The mechanical design for the station is founded on the use of a procured machine base 0.91 by 2.44 meters in dimension. This size is sufficient to accommodate more than one configuration for panels of 0.56 m² (6 ft²) in area.

The set of electronic components for the cure station are mounted in the machine base. This electronic system surveys each diode on a thin film module and based on dark shunt resistance, selects those diodes which have defects. The machine uses up to eight power supplies to apply the reverse bias voltage to cure several diodes simultaneously. By curing different diodes at the same time, we have reduced the machine cycle time. After the reverse bias voltage has been applied, the shunt resistances are again surveyed to insure that the diodes have been cured.

The electrical treatment is applied to the panels through a contact head interface. This contact head is electrically wired to the power supplies and has an array of spring loaded contact pins which are placed to exactly match the pattern of diodes on the panels being cured. For the present design there are two heads with each covering one-half the length of the module 1.83 m (6 ft). Each of these cure heads is 0.91 m (3 ft) long and 0.61 m (2 ft) wide. We have designed the station with the flexibility to allow for future adaptations beyond the 0.41 m (1.25 ft) width of the present panel design.

8.4 Environmental Test Equipment

The Task 14 activities directed at IQT environmental testing examined three specific test capabilities including the following:

- 1) Hot Spot Endurance Test
- 2) Mechanical Loading Test
- 3) Surface Cut Susceptibility Test

A review of the requirements for the intrusive hot spot endurance test as specified in the IQT was conducted. The test as specified calls for the individual characterization and test of ten or more individual segments of a test module. The number of tests to be conducted along with the electrical currents and voltages of large-area multi-junction panels implies that a significant amount of capital equipment would be required in order to have the in-house capability to perform the test. Another aspect of this test is that it is under review by standards committees of IEEE and IEC with the possible outcome that the test may be eliminated from the IQT sequence. Other testing bodies such as Underwriters Laboratories under UL1703 require the intrusive test and characterize 10 or more segments, but these test only three segments.

This analysis has lead to the recommendation that this test would not be provided in-house but would be contracted to available outside sources. Further, it has been recommended that for the purposes of the present program that the extent of the test be limited to that as described in UL1703.

Similarly, further examination of the requirements for dynamic mechanical load testing suggest that a significant capital expenditure would be required to provide this capability in-house. It is recommended that for the purposes of this program that the Static Load test as described under the optional tests for the PV USA program solicitation be adopted as the mechanical test. Outside sources would be sought should other programs require a dynamic test.

The capability to conduct the surface cut susceptibility test is required under some conditions where the module surfaces are non-glass. This is interpreted as instances when polymeric materials are used as insulating barriers on the front or back of panel surfaces. Another instance when this test may not apply is a panel design with a glass front and an un-coated metallic back.

The fixture to conduct this test has been fabricated per the directions of the UL1703 document. The device offers an adjustable blade holder to ensure that the proper blade position can be maintained and a weight holder which can be varied to provide the required 2.0 lb. normal force on the blade corner.

With the completion of these items the capability to conduct the Interim Qualification Test Plan has been provided.

8.5 Process Documentation

In preparation to document process output and yield information, documentation forms have been prepared and database software obtained to provide the capability of data manipulation. The module fabrication process was divided into fourteen steps and a form prepared for each step. Work is proceeding with the database software program to define input and report formats. The initial input forms are complete as of this writing while work on the output formats is continuing. The initial efficiency data for the first 18 0.37 m² modules produced is shown in **Figure 8.1**.

Figure 8.1: Total area efficiency of 0.37 m² plates as a function of production order.

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16. Abstract (Limit: 200 words) This report describes work to improve the efficiency of large-area, multi-junction amorphous silicon (a-Si) alloy modules. Equipment capable of producing modules up to 0.74 m ² in area is on line and process development has begun. Preliminary cost analysis/reduction has begun to ensure that these development efforts will result in a commercialization of the large-area technology. The approach was to transfer the high-efficiency multi-junction technology from R&D into the manufacturing environment by using three different substrate sizes. Initial attempts to transfer the multijunction silicon process were made using a 0.1-m ² substrate (approximately 1 ft ²). These efforts resulted in a module with a measured aperture area efficiency of 10.32%. Simultaneous with the transfer of the silicon technology, the most complicated aspect of the technology transfer, Solarex began process development techniques on large-area modules by using the 0.37-m ² substrates. These efforts resulted in modules with a total area efficiency of 7%. Finally, initial runs on substrates 0.74 m ² were made to debug the large-area equipment in preparation of transferring the knowledge gained in the processing of the smaller substrates.			
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