

Specific PVMat R&D in CdTe Product Manufacturing

**Phase I Annual Report
5 May 1998 — 4 May 1999**

J. Bohland, K. Kormanyos, G. Faykosh,
V. Champion, S. Cox, M. McCarthur, T. Dapkus,
K. Kamm, and M. Flis
*First Solar, LLC
Toledo, Ohio*



NREL

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

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Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

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Section I – Personnel

John Bohland Principal Investigator

Contributors: Ken Kormanyos, Senior Manufacturing Engineer; Gary Faykosh, Senior Manufacturing Engineer; Verlin Champion, Production Manager; Steve Cox, Production Supervisor; Mike McCarthur, Production Supervisor; Todd Dapkus, Process Engineer; Kristin Kamm, Production Engineer; Matt Flis, Quality Control Team Leader

Section II - Phase 1 Tasks Overview

Task 1 Manufacturing Line Improvements - Lamination

The specific objective of this task for Phase I was to develop, design and implement a high-throughput, low-cost lamination process with throughputs increased from 18 units/hour to at least 30 units/hour, labor costs reduced by 50% and equipment capital requirements lowered by a factor of four. This goal was to be achieved using the support of key experts such as Automation and Robotics Research Institute (ARRI) to identify appropriate lamination equipment vendors, material handling solutions and establish parameters for its integration on the First Solar production line. Besides demonstrating laminator throughput of 30 modules/hour, improved lamination preparation techniques including EVA cutting and application, bus bar application, and back glass handling and application were included in this work.

Task 2 Product Readiness

The specific objective of this task was to qualify First Solar's current module design according to protocols of IEEE 1262 and UL 1703 and achieve certification from Powermark Corporation; a worldwide recognized PV module certification for product durability and performance.

Task 3 Environmental, Health and Safety Programs

The specific objective of this task was to continue and improve First Solar's environmental, health and safety programs initiated during its PVMat Phase 2B subcontract. An internal review of current programs was to be conducted and, using the assistance of industry experts, their status relative to industry best practices assessed.

Section III - Phase I Milestone by Milestone Results

First Quarter Results

Milestone	Description
m-1.1.1	Initiate lamination development program by interviewing key suppliers and experts such as STR, Inc., ARRI, and automotive glass manufacturers.

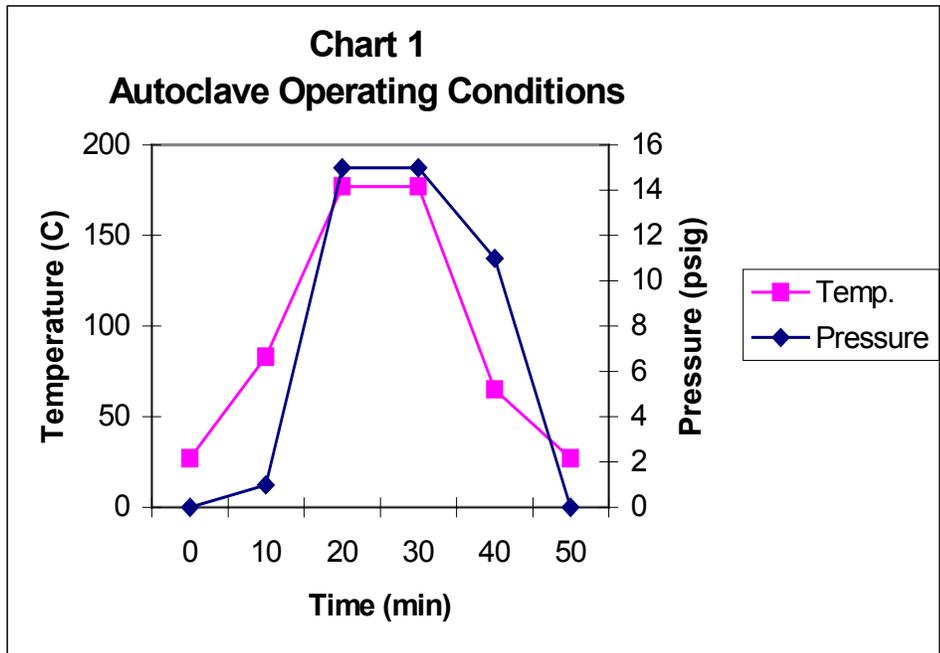
This milestone was completed successfully. Though the PV industry on the whole has adopted the one atmosphere, bag style vacuum laminator, high throughput applications such as automobile windshield glass manufacturers have always used *autoclaves* for mass production of laminated glass. First Solar, based on outside and inside expertise and experience, abandoned the home-built bag style vacuum laminator and purchased an autoclave for high volume, low cost lamination of CdTe thin-film PV modules. Additionally, after some delay due to negotiating intellectual property rights, a contract was signed with Automation Robotics and Research Institute to address lamination preparation process improvements aiming to align module assembly tasks time and labor with the improvements anticipated by using the autoclave instead of the bag laminator.

Milestone	Description
m-1.1.2	Complete process specification for high throughput laminator.

This milestone was completed successfully. A series of manufacturing experiments were undertaken using the same materials and assembly lay-up procedure as used for the abandoned vacuum press style laminator. Embedded thermocouples were used to monitor temperature of the laminate interlayer (EVA) for comparison to Springborn (EVA manufacturer) recommendations. Pressure was tracked using the on-board chart recorder of the autoclave.

Ultimately, a lamination process cycle as described below was developed. The total cycle time for a batch of up to 24 module units is 45 minutes, resulting in the targeted hourly throughput rate of up to 30 units per hour.

This cycle resulted in surprisingly good “gel content” results, a measure of EVA polymerization. Chart 1 shows the typical gel content for EVA as reported by Springborn for vacuum press laminators compared to the gel content achieved by the First Solar Autoclave. A higher gel content result indicates a higher degree of polymerization; implying improved EVA polymer adhesion and stability. Another improvement resulting from the superior performance of the autoclave is the lack of entrapped air bubbles in the EVA laminate film. Previously, all modules laminated in the vacuum press laminator had small air bubbles trapped particularly in the edge deleted (bonding) area of the unit; these are absent from autoclave laminated modules.



Milestone	Description
m-1.1.3	Initiate contact with module testing laboratory and complete preliminary module design review.

This milestone was completed successfully. The Arizona State University Photovoltaic Testing Laboratory was contacted and chosen as the module testing laboratory. The ASU lab is nationally and internationally recognized as a reliable PV testing facility. Certification is provided through PowerMark Corporation. European equivalence is provided through simultaneous testing to IEC 1646 protocols.

Preliminary module design review was also completed. The First Solar “SPN-7” modules designated for testing were unchanged from previous designs except that the front substrate was changed from 5mm to 3mm thickness (for weight and cost savings).

Milestone	Description
m-1.1.4	Complete review and survey of current environmental, health and safety (EHS) programs.

This milestone was completed successfully. In addition to an in-house review of current EHS programs by the EHS manager, an EHS Technician support position was created and filled. This individual attended two comprehensive seminars related to EPA (Environmental Protection Agency) and OSHA (Occupational and Health Administration) compliance in order to gain information and plan for improvement during the second quarter of this task.

The review included not only compliance related programs but a review of internal safety rules and procedures as well as industrial ventilation equipment and related engineering controls for worker exposure to cadmium compounds and volatile organic hydrocarbons (VOC’s).

Second Quarter Results

Milestone	Description
m-1.2.1	Complete design specifications for the high throughput laminator.

This milestone was completed successfully. Figures 1 and 2 show the high throughput laminator design as proposed and as installed.

Additional sub-tasks to develop high-throughput, labor reducing, material saving lamination preparation equipment were submitted by ARRI and approved and initiated by First Solar. As pointed out in the Overview, this equipment is necessary to maintain productivity in the module assembly stage of the lamination operation equivalent to the high-throughput autoclave laminator.

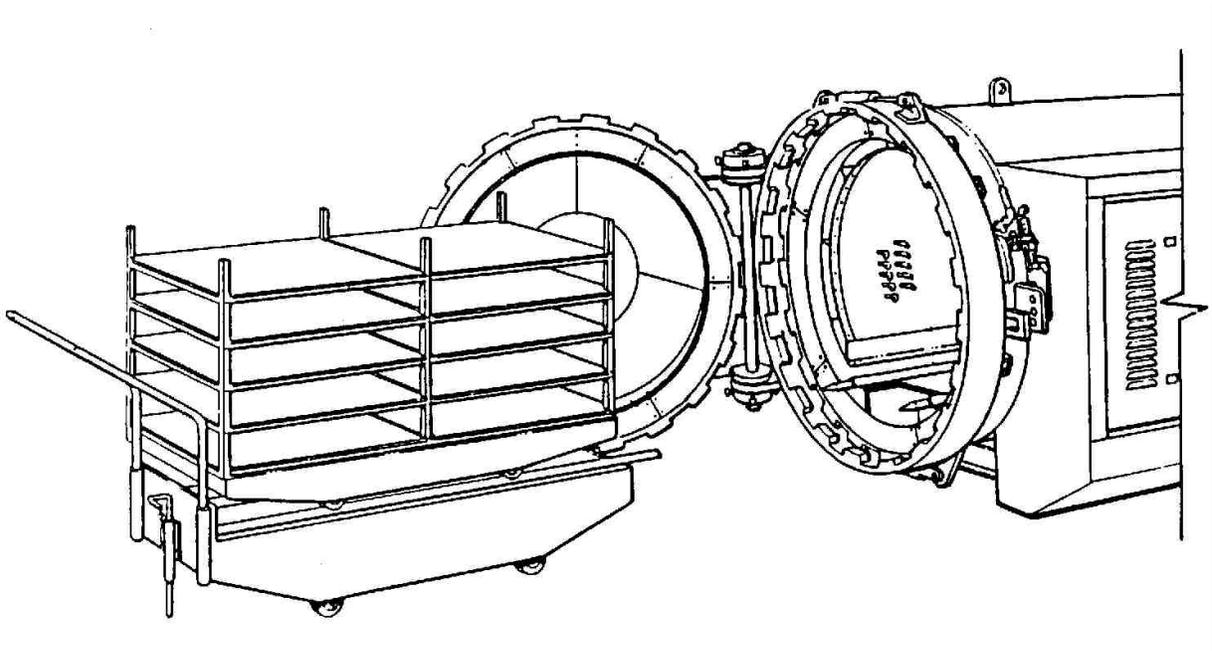


Figure 1: High-throughput laminator as proposed.



Figure 2: High-throughput laminator as installed.

These subtasks were defined as:

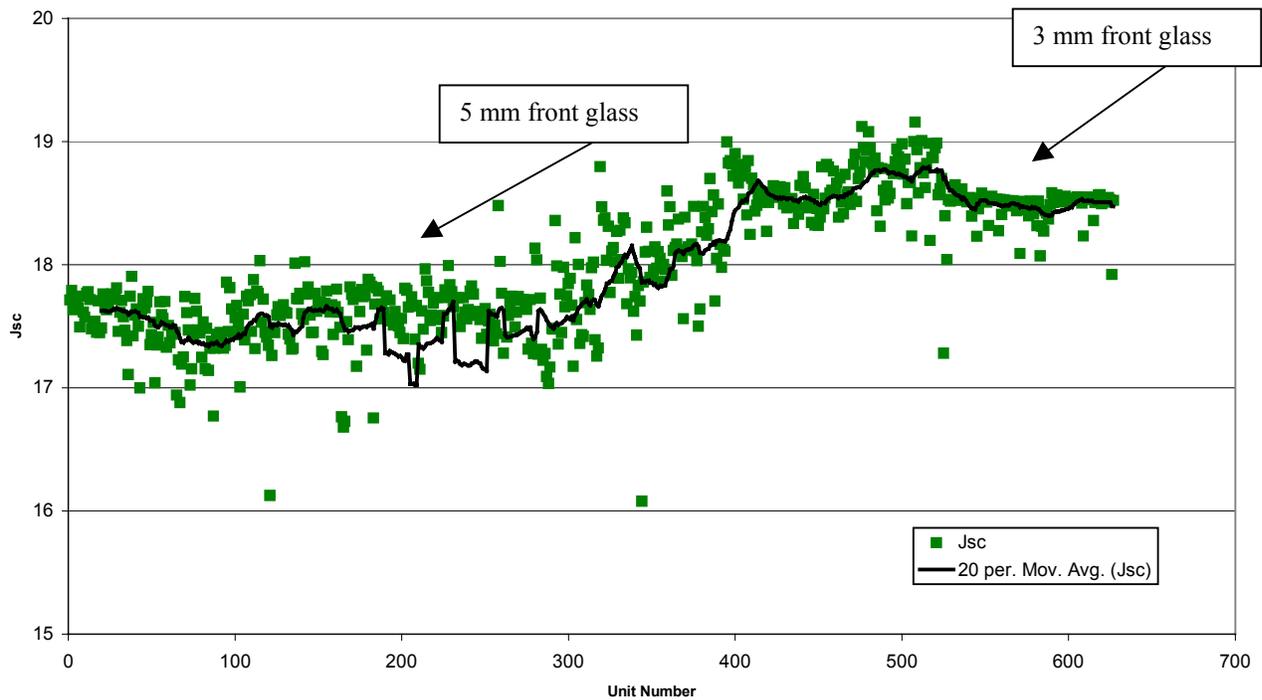
- ⇒ “As-is” analysis of the final module assembly process
- ⇒ Process and material handling vendor search
- ⇒ “To-be” concept designs for final module assembly
- ⇒ Simulation model development
- ⇒ Process development
- ⇒ Material handling development
- ⇒ Quarterly reviews
- ⇒ Integration and test
- ⇒ System set-up, testing and training

Milestone	Description
m-1.2.2	Complete preliminary testing of modules.

This milestone was completed successfully. Modules made using the new 3mm thick glass substrate were manufactured, tested and approved for initial performance. By decreasing the front substrate thickness from 5 to 3mm, Jsc improved due to more usable photons reaching the semiconductor rather than being absorbed in the glass substrate.

Chart two shows a moving average trendline indicating the clear improvement in Jsc as the 3mm substrate glass was introduced. The improvement in Jsc paves the way for overall efficiency improvements for a given TCO front-contact resistivity.

Chart 2
Jsc Comparison - September 1 to December 10, 1998



Milestone	Description
m-1.2.3	Establish Qualification Testing Schedule.

This milestone was completed successfully. Twelve First Solar “SPN-7” modules were shipped to the Arizona State University Photovoltaic Testing Laboratory on August 25, 1998 and received by ASU in early September. A completion date of January 1, 1999 was predicted by ASU.

Milestone	Description
m-1.2.4	Develop plans for critical areas of EHS improvement with the assistance of industry experts such as OSHA On-Site Consultation.

This milestone was completed successfully. Though OSHA On-Site Consultation services was not used, the EHS Manager and EHS Technician, using information from the Internet and recent EHS workshops, created a comprehensive EHS improvement process plan. The EHS improvement planning process was broken down separately for all three environmental, health and safety elements into strictly compliance program development and best management practices and activities. To save repetition, the EHS plan and First Solar’s record of completing the plan (according to milestone m-1.4.6) are attached as Addendum I.

Third Quarter Results

Milestone	Description
m-1.3.1	Begin de-bug of high-throughput laminator

This milestone was completed successfully. There were two significant problems encountered when production module lamination using the autoclave began. First, since the autoclave process cycle requires a total pressure of about 2 atmospheres (~ 1.5 atmosphere from the initial air removal step when the module is placed in a plastic de-airing bag and another applied atmosphere from the autoclave for bubble-free laminations), yield fall-off from breakage *increased* compared to the old vacuum press style laminator. Second, direct material costs *increased* compared to the old laminator because a host of materials to contain the assembled module under vacuum were needed for initial de-airing including release film, woven breather material, tape and the plastic vacuum bag. To clarify this point, the autoclave process is not a pressure process only. Initial de-airing of the module assembly must occur before pressure is applied to remove entrained air; flexible, elastomeric vacuum rings and nip rollers are alternative de-airing processes.

Clearly, though the laminator throughput objective of 30 units/hour was met, increased yield fall-off and direct materials costs were not acceptable.

Consultation with Springborn yielded the suggestion of trying a *textured*, rather than smoothly finished EVA. This simple material change, actually just a change of the laminate film surface, solved both the yield fall-off problem and the increased direct material costs problem at once. By switching from smooth to textured EVA, de-airing becomes much more efficient. Because more air is removed earlier in the autoclave cycle, the pressure applied during the pressure part of the cycle can be reduced. The process was modified to reduce the applied autoclave pressure from 1.5 to 1 atmosphere (15 PSI) using textured EVA laminate film. This, along with a slight modification to the bus-bar ribbon connection (to reduce the total thickness at the end bus bar) essentially eliminated yield fall-off from breakage. Addendum II shows the results of a controlled experiment to document yield fall-off improvement.

Again, because de-airing is more efficient using textured EVA, this allowed adopting a re-usable, silicon elastomer vacuum ring to effectively de-air the module assembly. When the rings were tried without the textured EVA, incomplete de-airing occurred and bubbles remained after lamination. In conjunction with a back-glass bus bar exit hole sealing technique such as using either an epoxy pre-potting or simply a silicon suction cup, textured EVA allowed the elimination of all the described disposable direct materials. This cost reduction reduced direct material costs by nearly \$10 per unit, a substantial percentage decrease of total direct costs.

Work continued this quarter by ARRI on the lamination assembly automation equipment. Several options with various degrees of automation were studied.

Milestone	Description
m-1.3.2	Initiate qualification testing on First Solar’s standard modules.

This milestone was completed successfully. Qualification testing was actually initiated ahead of schedule in the last quarter.

Milestone	Description
m-1.3.3	Initiate EHS improvement projects

This milestone was completed successfully. Similar to milestone m-1.3.2, EHS improvement projects were actually initiated ahead of schedule in the second quarter (refer to Addendum I for the project schedule).

Fourth Quarter Results

Milestone	Description
m-1.4.1	Complete prove-in of high-throughput laminator at a rate of thirty modules per hour.

This milestone was completed successfully. Fixtured for 24 modules (rather than the ten slot fixture that came with the autoclave), and a cycle time of 45 minutes, a laminator throughput of 30 modules/hour is achieved. Additionally, the autoclave installed and evaluated by First Solar is comparatively small. Autoclaves are available in sizes that allow lamination of First Solar’s 60cm x 120cm modules on the scale of *hundreds* of units per cycle.

Milestone	Description
m-1.4.2	Complete report on lamination rates, yields, and reductions in labor and equipment costs.

This milestone was completed successfully. The throughput rate was concluded and reported on in milestone m-1.4.1 above. The cycle time per unit for the vacuum press laminator was about 20 minutes; that has been reduced to a per unit cycle time of 2 minutes, or a full order of magnitude, using an autoclave fixtured for 24 units and a 45 minute cycle time.

A larger scale yield investigation is planned but a preliminary study documented as Addendum II shows a yield fall-off improvement from 10% before implementing the textured EVA and elastomeric vacuum ring system to a negligible level after implementing it.

Since one person was required to operate the bag laminator and one person is required to operate the autoclave (actually the autoclave operator can leave the machine unattended during the lamination cycle), a labor savings comparison is straightforward. If the 20 minute cycle time for the bag laminator is one labor unit, and the autoclave can produce the equivalent of 10 units in 20 minutes, an order of magnitude reduction in labor has been achieved (90% labor reduction). This is significantly *better* than the stated 50% labor reduction in the Task 1 goal.

Last, the capital equipment objective for this task was a factor of four reduction. A leading supplier reports a state-of-the-art bag laminator costs \$285,000. McGill autoclave reports a 5' x 10' autoclave, fixtured for twenty-four 60cm x 120cm modules costs roughly the same (\$250,000). For the same amount of capital, throughput increases 10 times, resulting in a *ten* times reduction in unit related capital costs. This is better than the factor of four objective.

Milestone	Description
m-1.4.3	Complete the Phase I portion of the effort under Task I.

This milestone is complete. Complimentary work is underway by ARRI to complete the module assembly automation equipment that will allow the 30 module/hour throughput target required to support the autoclave laminator. Several recent ARRI status reports are attached as Addendum III showing the progress for automation equipment design and testing. The semi-automated prototype lamination preparation station will be completed by ARRI in June and First Solar will demonstrate the 30-unit/hour throughput, scaleable to 60 unit/hour at that time.

Milestone	Description
m-1.4.4	Complete qualification testing on First Solar's standard module for IEEE 1262 and UL 1703.

This milestone is complete. Qualification testing was completed in April and a final test report is awaited from the ASU Photovoltaic Testing Laboratory. First Solar's "SPN-7" has passed IEEE 1262 Sequence "A" testing (200 thermal cycles), Sequence "B" up to heat-humidity-freeze cycling, Sequence "C" up to damp heat testing and Sequence "F". The outcome of the damp heat test was initially unclear and delayed due to problems with a contaminated test chamber where the SPN-7 modules were first tested. A repeat test yielded a marginally below standard result (slightly more than allowable performance degradation). Testing under UL 1703 has not been completed under this task; it will be completed after IEEE1262 is passed.

Now, the task for Phase II becomes more involved because significant module encapsulation processes and product design changes will have to be made to ensure certification of IEEE 1262 on the next qualification attempt scheduled for Phase II of this work. The module potting system and moisture edge barrier will be the focus of this work, as well as understanding surface preparation techniques to maximize adhesion of the laminate material and consideration of alternative encapsulants.

Milestone	Description
m-1.4.5	Complete the Phase I portion of the effort under Task 2.

This milestone is complete. Work is underway to modify materials, processes and product design to ensure passage of all IEEE 1262 and UL 1703 requirements in Phase II of this work.

Milestone	Description
m-1.4.6	Complete implementation of critical EHS improvements.

This milestone has been completed successfully. The EHS improvement program improvement process has followed the schedule outlined in Addendum I. Results are indicated there.

Safety and health highlights include the improvement of local ventilation controls for cadmium in the edge deletion, laser and cadmium chloride application processes, the implementation of a comprehensive lockout-tagout program in conjunction with electrical safety training, first aid, bloodborne pathogens and CPR training, material handling and fork truck training and a revised respirator training program.

Complete facility mass balance emissions calculations were done to demonstrate compliance with environmental regulations and requirements.

First Solar's current lost workday rate is **13.3** and lost workday case rate is **8.3** for the Phase I project period (May 1998 through April 1999). This corresponds to **32** for lost workdays and **6.8** for lost workday cases in the electronics-manufacturing sector for the last year data is available (1996). This shows that, while First Solar experienced an 18% higher accident rate than the electronics-manufacturing sector for the period, the severity was 140% *lower*. Improvements will be achieved as safety awareness training becomes more routine.

Milestone	Description
m-1.4.7	Complete the Phase I portion of the effort under Task 3.

As noted above, this milestone has been successfully completed and is supported by Addendum I.

Section IV – Addendums and Supporting Documentation

Addendum I – EHS plan and accomplishments (x) for Phase I.

	Sep-98	Oct-98	Nov-98	Dec-98	Jan-99	Feb-99	Apr-99
Safety Program Development Plan 1998							
Personal Protective Equip. Plan	x	x					
Means of Egress (Eckel Junction)		x					
Posting Mezzanine Load Limit		x					
First Aid Training / Bloodborn Pathagens			x	x	x		
Update Lockout / Tagout Plan			x				
Evaluate Electrical Safety				x			
Electrical & Lockout / Tagout Training					x		
Post 200 and 101 OSHA accident forms						x	
Materials Handling and Storage							
. Fork Trucks Plan						x	
Crane Hoist Plan / Training						x	
Evaluate Machine Guarding							x
Evaluate Hand and Portable Tools							x

	Sep-98	Oct-98	Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99
Health Plan - 1998								
Light Exposure Analysis:								
Light soak station					x			
Laser					x			
Noise Exposure Analysis					x			
Evaluation of Ventilation:								
Buffing table							x	
Edge deletion room							x	
Chem lab hood (West wood)								x
LDS hood								x
Chem lab hood (Eckel Junction)								x

	Sep-98	Oct-98	Nov-98	Dec-98	Jan-99	Feb-99	Mar-99
Environmental Plan - 1998							
Calculate/Log Cd Air Emissions to Environment							
Eckel Junction Facility			x				
Westwood Facility				x			
Calculate/Log MeOH and IPA Emissions				x			
Evaluate Cd Concentration in Effluent							
Eckel Junction Facility			x	x	x		
Westwood Facility				x			
Implement AA Spectrophotometer for in house analysis				x	x	x	x
Evaluate and Report on Recycling Data					x		
File EPCRA report for both facilities						x	
File Waste Generator report for Westwood facility						x	
Evaluate and Update Hazardous Materials Plan							
Combustible Liquids / Gases							x
Flammable Liquids / Gases							x

Addendum II – Lamination yield experiment

Background

Springborne Laboratories manufactures the extruded ethylene-vinylacetate co-polymer film (Photocap®) used for encapsulating and laminating Solar Cells' CdTe modules. Product designation 15295P, a fast-cure, non-textured film is currently used.

An alternative product designation, 15295P/936/936, is also available. This material is the exact same chemical formulation, made on the same machine as 15295P; the only difference is that the 936/936 film is run through a set of knurled rollers to impart a roughened texture to the EVA film.

Textured EVA is also known as “de-airable” because the peaks and valleys from the texturing allow much more efficient de-airing of the EVA film under vacuum.

The textured surface and subsequently increased de-airing efficiency is desirable for the SCI lamination process for three main reasons:

- Easier de-airing means laminations can occur at reduced total pressure yielding reduced residual lamination stresses and reduced yield fall-off from breakage.
- The re-usable vacuum rings are more likely to work, with the potential to save at least \$10/unit in direct materials consumables cost, because air can be removed more efficiently.
- Textured EVA is not tacky and is easier to handle

Procedure

Twenty-nine modules were laminated using textured EVA under standard laminating conditions except the external lamination pressure was reduced to 15 PSI. This population was compared to the next 47 modules laminated using non-textured EVA laminated using standard conditions (20 PSI external lamination pressure).

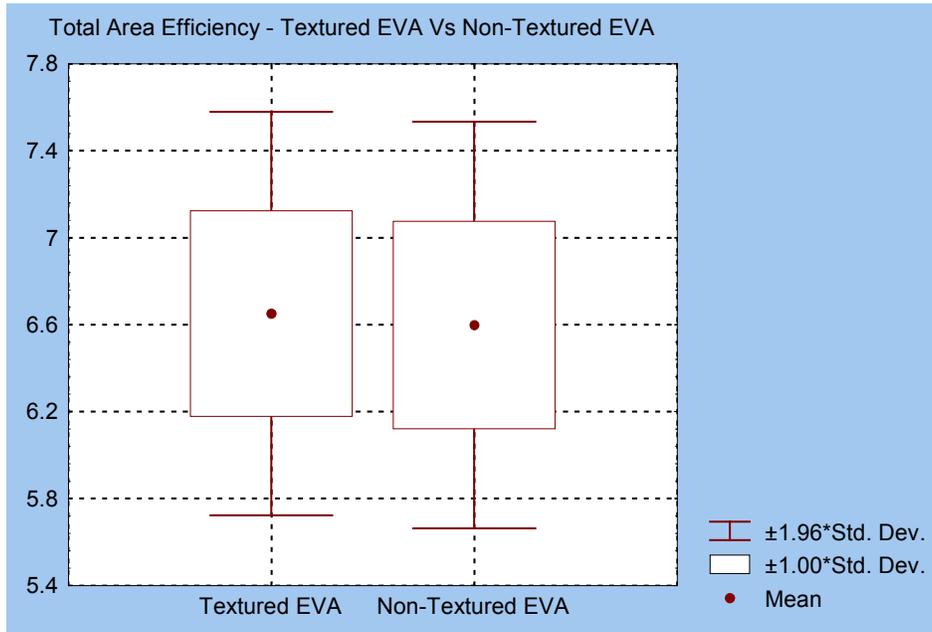
Results

Textured Vs Non-textured EVA Yield Fall-Off Comparison			
	Number of Samples	Applied Pressure	% Rejected*
Textured EVA	28	15	0
Non-textured EVA	47	20	8.5

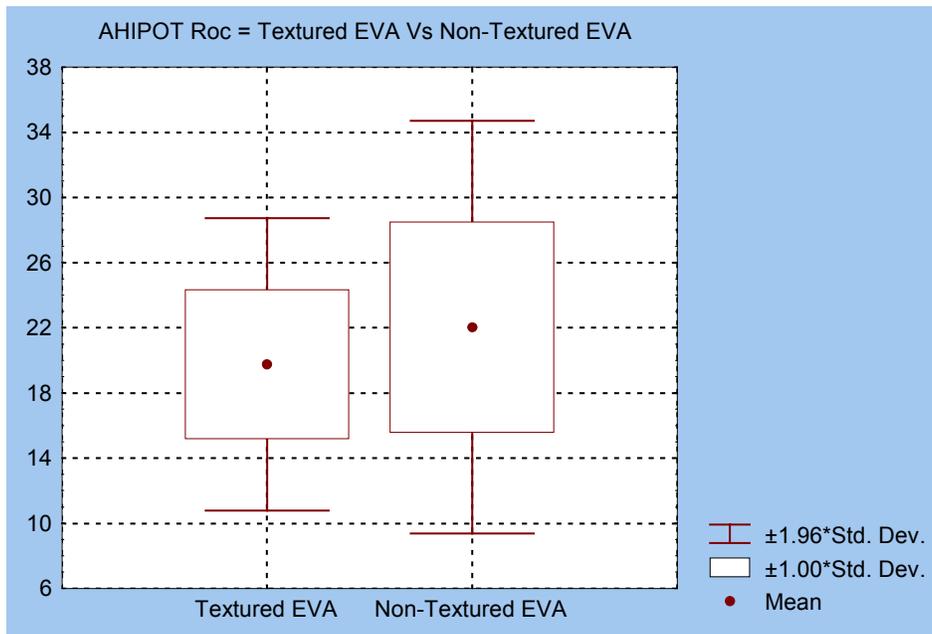
* 1 rejected for bubbles in the edge deletion region and three rejected because they broke.

Note that lamination experience has shown that using standard (non-textured) EVA at 15 PSI results in incomplete de-airing (bubbles are trapped), therefore the 20 PSI Vs 15 PSI comparison is legitimate. In other words, production accepts a yield fall-off at lamination of about 10% from breakage because a much higher percentage would be lost to bubbles if reduced lamination pressures were used.

Next, performance (device efficiency) and open circuit resistance (R_{oc}) were compared for the two sample groups:



T-Test “p” value = 0.65 (35% likelihood the sample means are reproducibly different)



T-Test “p” value = 0.12 (88% likelihood the sample means are reproducibly different)

Discussion

Although the textured EVA in this particular experiment did yield slightly higher average efficiency and lower average R_{oc} differences in performance are not predicted and are not indicated statistically. The textured EVA did, however, allow laminating at a lower total pressure without breakage and without trapped air bubbles.

One module was laminated with textured EVA using the re-usable vacuum ring. It showed the least amount of trapped air of any module laminated using this technique to-date. The only trapped air was local to the back glass lead-wire hole and the bus bar area under it. The back glass lead-wire hole must be made air-tight during lamination for success with the vacuum ring. More textured EVA is required to develop this technique.

Recommendations

An ECN will be written to change material number P16 from Springborn designation 15295P to 15295P/939/936.

Additionally, to address any subtle and unforeseen impacts, positive or negative, from using textured EVA, six modules will be used for in-house thermal cycling, heat-humidity-freeze cycling, and damp heat test evaluations. Results can be compared to modules laminated with non-textured EVA tested at the same time. Modules laminated with textured EVA will also be used for the next scheduled round of IEEE 1262 module qualification tests at Arizona State University's Photovoltaic Testing Laboratory in the third quarter of 1999.

Additional textured EVA will be ordered immediately so development of the re-usable vacuum rings can continue.

Summary

Textured EVA is chemically identical to non-textured EVA. An experiment comparing the performance parameters of total area efficiency and R_{oc} showed no statistically significant differences. Modules will be qualified in-house (short-term) and externally (third quarter 1999) according to IEEE 1262 protocol.

Textured EVA allows lower pressure laminations, in turn resulting in reduced yield fall-off and higher lamination quality. Additionally, textured EVA is key to allowing the use of the re-usable vacuum rings for initial de-airing of the encapsulation package. Cost savings of over \$10/unit are possible.

Addendum III – Automation and Robotics Research Institute’s Progress Reports for High-Throughput Lamination Support Equipment

Automation & Robotics Research Institute

7300 Jack Newell Blvd. South, Fort Worth, Texas 76118-7115

February 25, 1999
Mr. Ken Kormanyos
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Toledo, Ohio 43607

Monthly Technical Status Report

First Solar, Inc. Order Number #: 13092JH **Institution:** The Automation & Robotics Research Institute (ARRI) of The University of Texas at Arlington (UTA)

Title: Development of an Automated Module Assembly System (Task 1-4)

Period Covered: January 26, 1999 through February 25, 1999

1. Summary of progress made during the past month, relating progress to milestones and deliverables described in the previous months progress report.

Task 4 Prototype of the Pre-lamination Assembly Process

ARRI is pursuing the development of the final conceptual design that was approved by First Solar. Design and testing for the prototype system has been started.

- Detailed designs of the end effector for the EVA pick and place system have been completed.
- Preliminary tests have been performed to test the design of the EVA end effector.
- A vacuum pick and place end effector for the cover glass has been designed. Calculations were based on the weight and dimensions of the plate to ensure lifting (F.S. > 5) and prevent bowing.
- Textured EVA rolls have been ordered and will be tested in the selected commercial cutting system (Rosenthal Manufacturing Co.). ARRI will travel to Rosenthal to verify cutting results.
- A guillotine cut-to-length automated tape dispenser has been ordered from AZCO Company for a 5-day test period.

2. Description of activities planned for the next month, listing specific milestones and deliverables where applicable.

Task 4 Prototype of the Pre-lamination Assembly Process

- Complete detailed designs of all components of the prototype system.
- Present detailed drawings to First Solar for review.

3. Description of findings and copies of reports or papers produced during the past month.

- See attached summary report

4. Issues / Concerns

None to report

Sincerely,

David Vanecek
Program Coordinator
ARRI

Heather Beardsley
Staff Engineer
ARRI



Automation & Robotics Research Institute
The University of Texas at Arlington

**Progress Report on Prototype Development
For Pre-lamination Process**

Prepared for

First Solar, Inc.

Heather Beardsley

February 24, 1999

I. Introduction

Detailed designs for the components of the prototype system are being developed. As they are completed, drawings will be submitted to First Solar for review. In this report, detailed drawings of the end effectors for the two pick and place systems, i.e. EVA and glass, will be presented. Also, the systems selected for processing the EVA and chomerics tape will be discussed.

II. EVA Cutting System

Following an extensive vendor search, First Solar and ARRI have agreed that the most suitable cutting system for processing the EVA is the Rosenthal Sheeting System available from Rosenthal Manufacturing Company, Inc. In order to test the performance of the automated feeding mechanism and verify the cutting accuracy, two rolls of textured EVA have been ordered, and will be sent to Rosenthal Manufacturing. ARRI will travel to Rosenthal Manufacturing for a demonstration of the cutting system, and sample sheets of the cut EVA will be evaluated. ARRI will send the cuts sheets of EVA to First Solar for approval.

III. Automated Tape Dispenser

Among the four automated tape dispensers that have been considered, the guillotine cut-to-length benchtop assembly from AZCO Corporation appears to be the most promising for performing the required tasks. The foil tape is automatically fed by precision ground urethane rollers. The rollers are turned by a DC brushless stepper motor which provides high accuracy and low maintenance. Guides help to direct the tape into the knife assembly. The knife assembly has hardened D-2 tool steel blades and is pneumatically operated.

The quoted price for one dispenser is \$5754. AZCO will provide ARRI with one dispensing machine for five days for testing purposes. ARRI will use the chomerics tape and the copper foil ribbon to test the machine's feeding mechanism and its ability to repeatedly cut metallic tape. If the cutting results are satisfactory, ARRI will recommend the dispenser to First Solar.

IV. End Effector for Pick and Place of EVA

The cut sheets of EVA will be vacuum pick and placed from the conveyor of the commercial sheeting system to the workstation. The vacuum end effector will be designed and built at ARRI. Holes will be drilled at regular intervals into a 1/8 inch aluminum plate. (See Fig. 1.) To improve the holding force, the holes will be countersunk. Aluminum sheeting will be used to form an envelope over the upper surface of the aluminum plate, which will be sealed and used to create the vacuum. Preliminary tests have been performed to determine the maximum allowable spacing between drilled holes. It has been demonstrated that a hole spacing of four inches provides sufficient strength to lift an EVA sheet. Thus, a total of 91 holes will be drilled. Testing has also been done to determine the optimal diameter for the drilled holes. Results showed that a hole diameter of 0.16 inch was large enough to secure the EVA sheet, and yet small enough to prevent the EVA from being pulled into the hole by the force of the vacuum.

V. End Effector for Pick and Place of Glass

The cover glass panels will be vacuum pick and placed from the glass storage rack to the workstation. The vacuum end effector will be designed by ARRI and the needed components will be purchased by and assembled at ARRI. The two major factors that influenced the design of the cover glass end effector were the weight of the glass panel and its dimensions. In this case, the dimensions of the panel played the more critical role due to the tendency of the panel to bow. A single vacuum cup could provide enough force to lift the weight of the glass, however, the resultant degree of bowing could lead to breakage of the glass. Therefore, an arrangement of six vacuum cups is used to securely lift the glass panel. (See Fig. 2.) Each cup has its own venturi/blowoff. The cups have a diameter of 3.5 inches, and their cumulative holding force gives a Factor of Safety greater than 5.

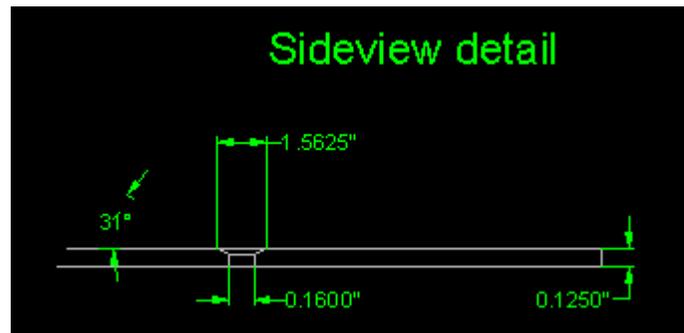
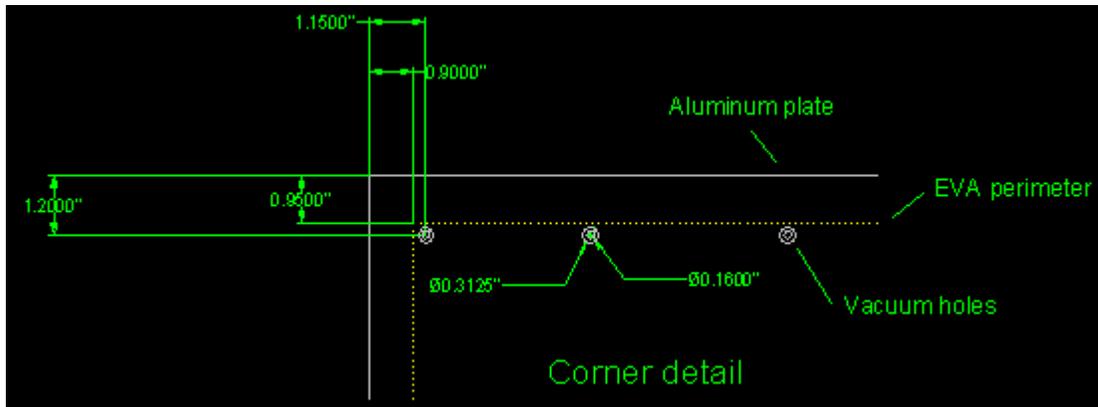
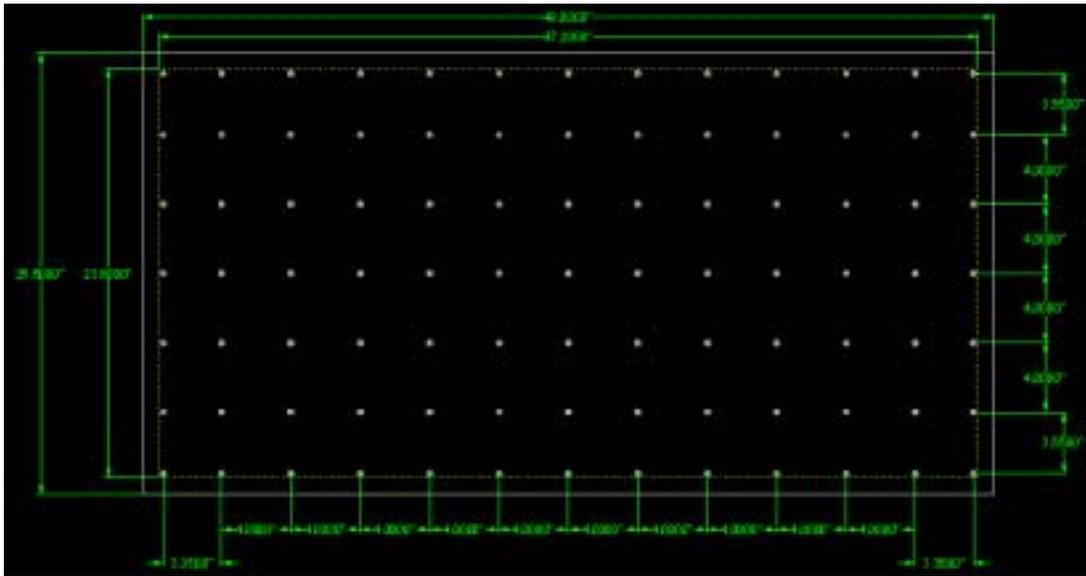


Figure 1. Al plate for vacuum pick and place of EVA.

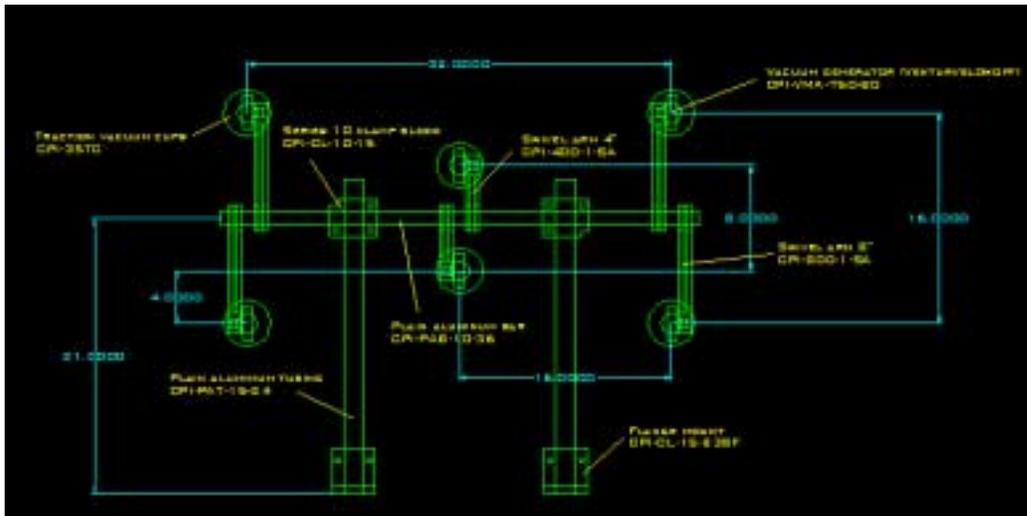


Figure 2. Vacuum pick and place end effector for cover glass.



Automation & Robotics Research Institute
The University of Texas at Arlington

**Progress Report on Automated
Module Assembly System**

Prepared for

First Solar, Inc.

by

David Vanecek
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March 31, 1999

I. Prototype Design

All designs for the prototyped system have been completed. The major components are listed below.

1. Pick and place end effector for cover glass
2. Pick and place end effector for EVA sheets
3. XZ-positioning systems and supporting structures for manipulation of EVA and cover glass
4. Storage rack for cover glass

II. Drawings

Detailed drawings of the system components will be sent to First Solar during the first week of April for review. Equipment for building the prototype system will be ordered following First Solar's approval of the designs.

III. Commercial Sheeting System

Two rolls of textured EVA were ordered. One is being kept at ARRI for testing the EVA vacuum pick and place system, and the other was sent to Rosenthal Sheeting Systems, Inc. for testing in the quoted automated feeding and cutting system. Sample cuts were made to guarantee that the tolerance stated in the quote is achievable. Rosenthal Sheeting had quoted a dimensional accuracy of $\pm 1/32$. Cutting results exceeded this, yielding an accuracy between $\pm 1/32$ and $\pm 1/64$. The performance of the automated feeding system was also evaluated. The EVA material can be successfully fed through the system, assuming that the raw EVA material has been properly rolled. Portions of the EVA roll that was sent to Rosenthal Sheeting were not rolled smoothly, and this caused difficulties in the feeding system. This issue must be resolved with the EVA supplier

Since the recommended cutting system requires some degree of custom design, the exact dimensions of the cut EVA sheet, as well as the punched T-slits, could not be demonstrated at this time. However, Rosenthal Sheeting will guarantee satisfaction on these two issues. They will send a few samples of the cut EVA so the quality of the cut edge can be observed.

IV. Tape Dispensing

ARRI is currently testing an automated guillotine cutting machine from AZCO. Its performance is being evaluated for all three types of tape used in the module assembly (double-sided tape, copper foil ribbon, and chomerics tape).

Results thus far have concluded that the guillotine cutter is not suitable for the double-sided tape, primarily because the automatic pinch roller feed system can not accept material with adhesive on both sides. An alternate solution for the double-sided tape is to use a manual applicator equipped with a mechanism that automatically peels the backing

from the tape as the operator applies it. 3M's adhesive transfer applicator (Model ATG-700) has this capability. The applicators can accept tape rolls with a wide range of core diameters and tape widths. The double-sided tape that First Solar uses in the module assembly for fixing the copper foil leads to the EVA can be used in the ATG-700 applicator. In this case, the operator still has the task of cutting the tape to the appropriate length. 3M produces a tape for the applicator that may be better suited for use in the assembly operation because it eliminates the task of cutting the tape. It is a double-sided tape that easily pulls off the roll once a trigger button is released. One of these applicators with a roll of 3M tape has been sent to First Solar. Consideration should be given to the advantages/disadvantages of the different types of tape. Feedback on this matter would be appreciated.

The guillotine cutter has also been tested on the copper foil ribbon, and results have shown that the device can be used for processing the copper foil. The cutting results are consistent and highly accurate. The through hardened D-2 steel cutting blades ensure good edge quality and repeatability.

Testing has not been completed yet for the chomerics tape, but initial results are promising. The automatic feeding and cutting of the chomerics can be performed without difficulty, however modifications must be made to the machine so the backing can be removed and discarded automatically as the tape is fed and cut. Several possible designs for the peeling and rewind mechanism are being tested.

V. Assembly Material

Several additional rolls of the chomerics tape will be needed for testing the guillotine cutting machine. Please provide us with the supplier part number for the chomerics tape and any other information that will be needed to identify the used chomerics (thickness, dimensions, type of adhesive, thickness of adhesive layer, etc.).

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13. ABSTRACT (<i>Maximum 200 words</i>) This report documents the work performed by First Solar, LLC, during the first year of this Photovoltaic Manufacturing Technology (PVMaT) subcontract. The following milestones were successfully completed: <ul style="list-style-type: none"> • Initiate lamination development program by interviewing key suppliers and experts such as STR, Inc., ARRI, and automotive glass manufacturers. • Complete process specification for high-throughput laminator. • Initiate contact with module testing laboratory and complete preliminary module design review. • Complete review and survey of current environmental, health and safety (EHS) programs. • Complete design specifications for the high-throughput laminator. • Complete preliminary testing of modules. • Establish Qualification Testing Schedule. • Develop plans for critical areas of EHS improvement with the assistance of industry experts such as OSHA On-Site Consultation. • Begin de-bug of high-throughput laminator • Initiate qualification testing on First Solar's standard modules. • Initiate EHS improvement projects. • Complete prove-in of high-throughput laminator at a rate of 30 modules per hour. • Complete report on lamination rates, yields, and reductions in labor and equipment costs. • Complete qualification testing on First Solar's standard module for IEEE 1262 and UL 1703. • Complete implementation of critical EHS improvements. 				
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