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Amorphous Silicon Photovoltaic Manufacturing Technology – Phase 2A

Semiannual Subcontract Report 1 May 1994 – 31 October 1994

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PREFACE

This is the third Semiannual Technical Progress Report for the program titled "Amorphous Silicon Photovoltaic Manufacturing Technology - Phase 2A", funded under National Renewable Energy Laboratory (NREL) subcontract number ZM-2-11040-06. This report describes the work done in the period from May 1, 1994 to October 31, 1994.

This program is part of the Photovoltaic Manufacturing Technology (PVMaT) project, Phase 2A, which address problems that are process-specific and are generally unique to a technology. Utility Power Group (UPG) and its lower-tier subcontractor, Advanced Photovoltaic Systems, Inc. (APS), have continued to conduct parallel efforts in developing their manufacturing lines, UPG's POWERGLASS line and APS's EUREKA line. UPG has focused on demonstrating fully functional automated encapsulation and termination stations. APS has focused on continuing the process and quality control, and automation projects. Topics that have been investigated include:

- Automated assembly/encapsulation stations;
- Automated glass transport techniques;
- Enhanced deposition parameter control; and
- Integrated process and quality control for the entire EUREKA system.

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1.0 TASK 13 POWERGLASS ENCAPSULATION SYSTEM INTEGRATION

Objectives

The objectives for this task are to integrate and test the automated encapsulation system designed in the second year of this effort. Once the system is fully integrated, UPG will collect and analyze data from continuous production runs employing the advanced encapsulation materials and processes utilized in the manufacture of POWERGLASS modules. Representative modules encapsulated utilizing the automated station will then be submitted for qualification (NREL/TR-213-3624) testing. This task is anticipated to result in a 98% yield and a cost reduction of 60% (cumulative) in the UPG encapsulation process.

Roller Coater

The POWERGLASS Automated Encapsulation Station is based on the roller coater application technique as described in previous reports. The encapsulation station will be automated by incorporating the roller coating process into the overall PV module fabrication process with a minimum of glass handling by the operator. The definition of automation will be based on eliminating the human handling of the PV module while in process. Automation will also attempt to minimize any activities on the part of human operators associated with each specific PV module. Although at this time, the operator will have to load each PV plate onto the encapsulation station, this operation can be automated in a straight-forward fashion when the need presents itself.

The roller coater as delivered is essentially a manual system in that the conveyor and roller motors are controlled by manual switches. If the roller coater were to be operated on a completely continuous basis, these motors could remain on continuously and coat glass as the glass passed through the system. However, the roller coater will be part of the total encapsulation station and will operate in unison with the termination station. This will require the roller coater conveyors to stop and start as needed for the entire process. We plan on controlling the overall operation with a programmable logic controller (PLC) which will interface with all the subsystems. Because the number of steps in the encapsulation and termination processes are so few, the PLC will not have to be very sophisticated. UPG has chosen a PLC from the Square D Company with eight digital inputs and eight digital outputs.

The roller coater was received and placed in a temporary location to begin the debugging process. Once powered up, the coater motor was engaged and allowed to operate for an extended period of time without any encapsulant being applied. This procedure was followed to investigate the operation of the system without having to clean the excess encapsulant in the event of a problem. Once the operation of the system was well understood and no problems were encountered during the initial operation, encapsulation material was added and glass plates were coated. These coated glass plates were heat cured in order to harden the encapsulation material and the encapsulant

thickness was measured. The roller coater settings were determined to give an optimum thickness required for protection. The roller coater consists of three rollers; the coating roll, the doctor roll, and the backup roll. The thickness of the encapsulant on the glass is determined by the distance between the coating and the doctor rolls. The distance between the coating and the backup rolls determines the degree of bubble formation and the smoothness of the deposited film

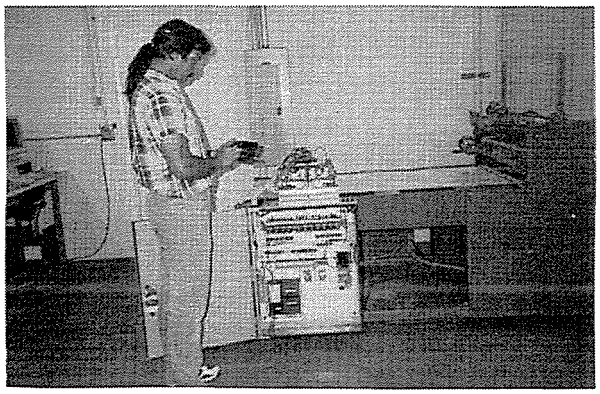


Figure 1. The Encapsulation/Termination Station is controlled by an eight channel programmable logic controller (PLC). Here an operator keys in a programming sequence into the PLC. The PLC then receives inputs from various sensors and switches and sends outputs to the electromagnetic relays and solenoid valves. The relays control the motor drive which powers the conveyor and the coating rollers. The solenoid valves operate the air cylinders and the pressure/vacuum supplies of the dispensing systems.

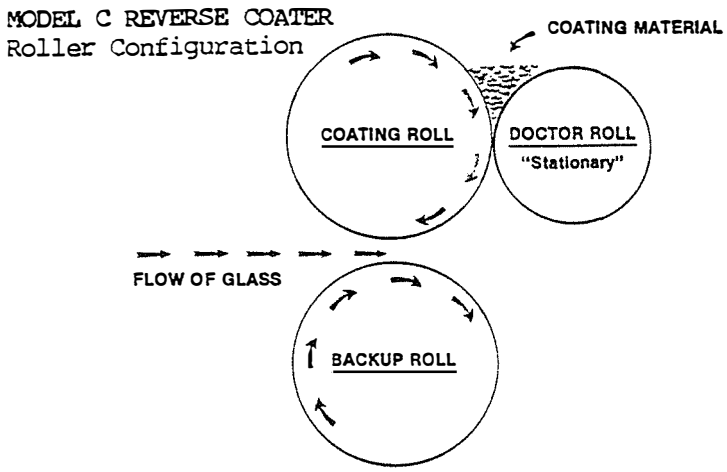


Figure 2. The roller coater operates with three rolls; the coating roll, doctor roll, and backup roll. The Coating Roll is a 4" diameter, smooth ground nitrile covered roller. The Doctor Roll is a 2-3/4" diameter, smooth ground chrome plated steel roller. The Backup Roll is a 4" diameter, smooth ground neoprene covered roller.

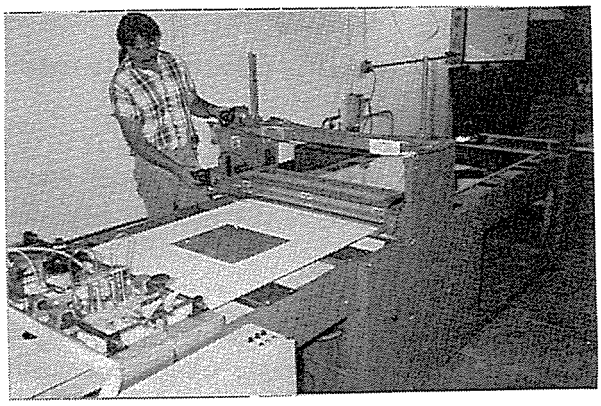


Figure 3. An operator adjusts the two parameters which control the roller coating process; the coating roll/doctor roll distance, and the coating roll/backup roll distance. These two parameters determine the thickness of the coating and the quality of the coating.

The automation of the encapsulation process is dependent on the operation of the roller coater. In order to fully integrate the roller coater into the overall PV process, the roller coater will have to operate in a non-continuous mode. The starting and stopping of the roller coater will have to be controlled by a system with timing and position information.

The encapsulation system controller will be capable of determining the position of the glass substrate and control the operating status of the roller coater without human operator input. The controller will be able to start and stop the roller coater drive motor in order to accommodate the termination step. This capability will allow the roller coater to operate in a non-continuous mode, which is not ideal for the roller coater in terms of throughput, but is necessary for the termination station, which requires that the glass be stationary during terminal installation. The silicone encapsulation material we have chosen has a relatively long pot life (24 hours) and therefore will not begin to cure on the roller coater during the termination step.

The integration of the Encapsulation System is now in its final stages. The systems went through a procedure of complete debugging prior to the programming of the PLC, which will control the automated processing of the module termination and encapsulation. The PLC is similar to the system used to control the automated in-line thin-film deposition system UPG utilizes for depositing the PV materials onto glass superstrates. This PLC has proven to be reliable and robust through the years and UPG expects the same level of performance from the Encapsulation System logic controller.

One activity where automation will play a roll is in the area of encapsulation material supply. In the roller coater, the coating material is held in place between the two top rollers. This material is constantly being depleted as modules are coated. Normally, an operator would have to periodically add fresh material to the trough formed by the rollers. This activity can be automated easily by metering the encapsulation material into the region formed by the two top rollers.

Water Permeability and Corrosion Protection

UPG has received information from the silicone materials manufacturers regarding the protection against corrosion provided by these materials.

Silicone encapsulation materials are permeable to water vapor but water vapor does not produce corrosion in silicone encapsulated metals, provided there is complete adhesion of the silicone to the substrate.

The correlation between adhesion and corrosion protection has been investigated by the materials manufacturers. Tests were made on reactive metal sample plates encapsulated with different products. Each sample was subjected to 100% relative humidity, plus condensation of water at 40°C in an environmental chamber. The silicone material with the most tack and adhesion to the substrate was found to provide the best protection against corrosion. A similar test used reactive metal wire fitted with copper leads. Here, again, the silicone that demonstrated the best adhesion properties also provided the maximum protection against corrosion. The conclusion taken from these tests is that the effectiveness of a material in preventing corrosion cannot be judged solely on its water vapor permeability.

These tests agree with the results UPG obtained using a different testing procedure. UPG started with thin-films of aluminum deposited on glass substrates. These thin-films were then coated with various types of encapsulation materials. Thin-films of aluminum are very sensitive to the presence of water and water vapor and in a very short period of time will begin to corrode even at room temperature and atmospheric pressure. UPG subjected these encapsulant coated thin-films of aluminum to 80°C/85% relative humidity followed by immersion into a hot sodium hydroxide solution. The silicone coated aluminum thin-films showed no signs of corrosion even after being exposed to the very harsh conditions of the sodium hydroxide solution.

Glass Bead Deposition

A technique for depositing the glass beads onto the uncured silicone is under investigation. The handling of the glass beads has to be given considerable analysis. The small size of the beads and their spherical shape present problems in terms of housekeeping and safety. At this time, the preferred approach for depositing the beads is to utilize a shaker bar over the silicone coated module as the module is transferred from the Termination Station to the curing rack. The granular material is placed in a V-shaped holding vessel and released from the vessel by a shaking action. The speed of the substrate under the shaker bar and the rate of beads out of the shaker bar will be controlled to eliminate excess beads on the uncured silicone.

An alternative approach for bead application is by spraying the beads utilizing an air flow transfer technique similar to sand blasting. The size and shape of the beads is ideal for the air flow transfer technique and the degree of application control is quite high. The air flow transfer technique has the potential for being untidy because it uses air to transport the media and the resulting overspray could spread the beads into unwanted areas.

Although other approaches will be suggested and evaluated, at this time the shaker bar technique will be pursued toward systems development.

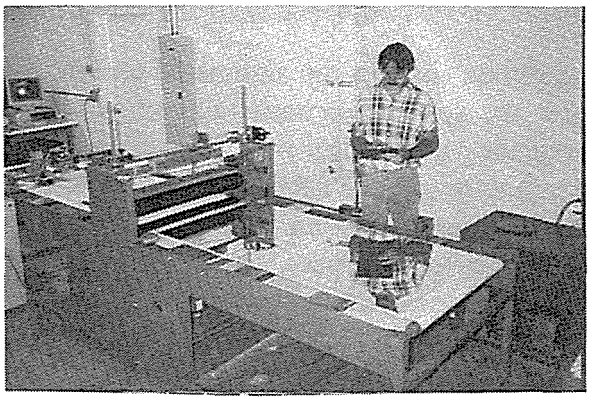


Figure 4. While the POWERGLASS module is only 15 inches wide, the roller coater is capable of coating substrates up to 31 inches wide, such as the APS EUREKA module.

2.0 TASK 14 POWERGLASS TERMINATION SYSTEM INTEGRATION

Objectives

The objectives of this task are to integrate and test the automated termination system designed in the second year of this effort. After the system has been fully integrated and tested, UPG will collect and analyze data from continuous production runs employing the advanced termination materials and processes on the manufacture of POWERGLASS modules. Representative modules with terminals applied utilizing the automated station will then be submitted for qualification (NREL/TR-213-3624) testing. This task is anticipated to result in a 95% yield and a cost reduction of 80% (cumulative) in the UPG termination process.

Automated Termination Station

The Automated Termination Station will work in conjunction with the Encapsulation Station to take advantage of the encapsulation and termination process development that has taken place during the past two years. The Termination Station is attached to the roller coater section of the Encapsulation Station. The terminals are placed onto the PV module directly after the encapsulation material has been applied and before the material has been cured. The terminals rely on the encapsulation material to provide adhesion to the module. After the module has been coated with encapsulant, it will be transferred to the termination station. The module will then stop, be indexed into position, additional adhesive will be applied over the terminal pads, and the electrical terminals will be placed at the appropriate locations on the current collection pads of the module. The glass beads will be deposited and the module will then be transferred to the curing rack to be loaded into the oven for encapsulant curing. This entire process will be controlled by the PLC described previously. The termination station will be integrated with the encapsulation station to form a complete system.

The roller coater required some modification to accommodate the termination system. The most important aspect of the termination process that influenced the roller coater modification is the placement of the module prior to the application of the terminals. The coater had to be mechanically modified to allow movement of the glass substrate directly following the application of the encapsulant.

The integration of the termination station with the encapsulation system is essentially complete. A technique for positioning the module prior to the placement of the terminals has been developed and implemented. The module with a coating of uncured silicone must be placed in position before the terminals can be partially submerged into the silicone adhesive. It is essential that the "wet" module be positioned without disturbing the uncured silicone.

There is a need for additional silicone material to be deposited over the pads prior to the placement of the terminals to ensure adequate structural adhesive material. The amount of silicone

material necessary for the protection of the thin-films is insufficient to provide the adhesion necessary for the terminals. A technique for applying an additional amount of silicone adhesive over the pads has been developed and implemented. The uncured silicone is a flowable liquid that can be dispensed using a syringe under moderate amounts of air pressure.

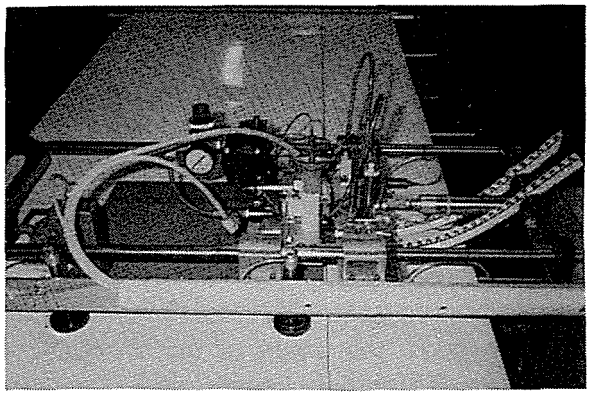


Figure 5. The Termination Station consists of a sensor to determine the presence of a module, a module positioning system, a system for applying an additional amount of adhesive for the terminals, and a pick and place system to position the electrical terminals onto the "wet" silicone adhesive. All motion is pneumatically controlled by the PLC.

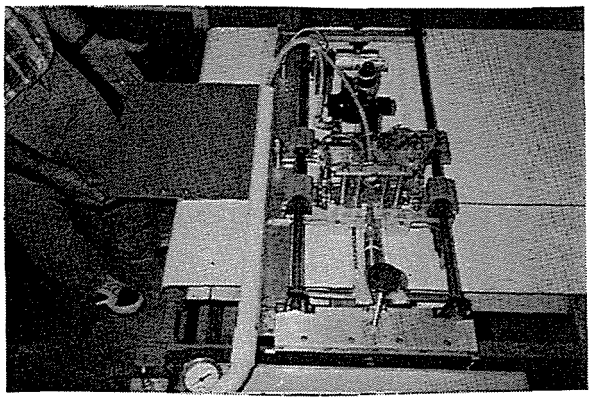


Figure 6. After the terminals have been positioned onto the module the conveyor belt transfers the module out of the Termination Station to be placed onto the curing rack.

Manual and Automatic Operation

The station can be operated manually with a set of switches which activate the various air cylinders. This manual control is independent of the PLC that will be used to control the entire encapsulation and termination processes. The manual capability has been used during the initial setup of the station and to further define the operation and process sequence.

3.0 TASK 15 EUREKA PROCESS AND QUALITY CONTROL

Considerable effort in this area dealt with improving the quality of silicon deposition in the Fairfield facility. Figure 7 summarizes the status of the quality of the processing in Fairfield by comparing power distributions for deposition runs made in Fairfield with runs made in the Trenton facility. The Trenton product is divided into two groups, first standard runs as carried out during the end of the PVUSA production (EMF Production) and second runs made during development work (EMF PD) carried out after production was halted in early 1993. In each case the best four runs from each series were used in calculating the distributions. In order to make the comparison more meaningful, Fairfield and development runs were selected having the same nominal i-layer thickness as the latest Trenton production runs. The graph illustrates several points. First, the comparison of the production runs with the development runs. The development runs were made in part to achieve some of the goals of the PVMaT contract, i.e. improve uniformity, decrease cycle time, increase the module power, and increase the control over the process. The last two of these are illustrated by the graph. The tighter distribution of the development runs over production runs shows a better control of the process and the increased average power is in line with expectations, considering the changes that were made in order to gain 10% in power.

Differences between the production runs and development runs were the following:

- Development runs had better uniformity
- Development runs had thinner p-layer by about 20%
- Development runs used a tin-oxide with about 6% haze compared to about 4% for production runs
- Development runs had approximately 3% higher active area

Runs made in Fairfield differed from development runs mainly in that uniformity was not as good, and they had a zinc-oxide layer between the silicon and aluminum back reflector. The latter difference was expected to result in 5 to 10% higher output, but this has not yet been fully realized.

Some effort has been made to determine the reason for the differences in performance between modules made in Fairfield and Trenton. One possibility is the difference in the pre-heat. In Trenton, air is first forced through a filter, then heated and passed through the box carrier and finally exhausted to the outside. In Fairfield, a recirculating system is used where heated air passes through the filter. While the filter is designed to operate at the temperatures in question (near 200°C), there is some concern that outgassing of the filter takes place thereby introducing contamination. Because the plumbing of the systems is different (different vacuum components, filter placement, etc.) the glass temperatures may be different as well.

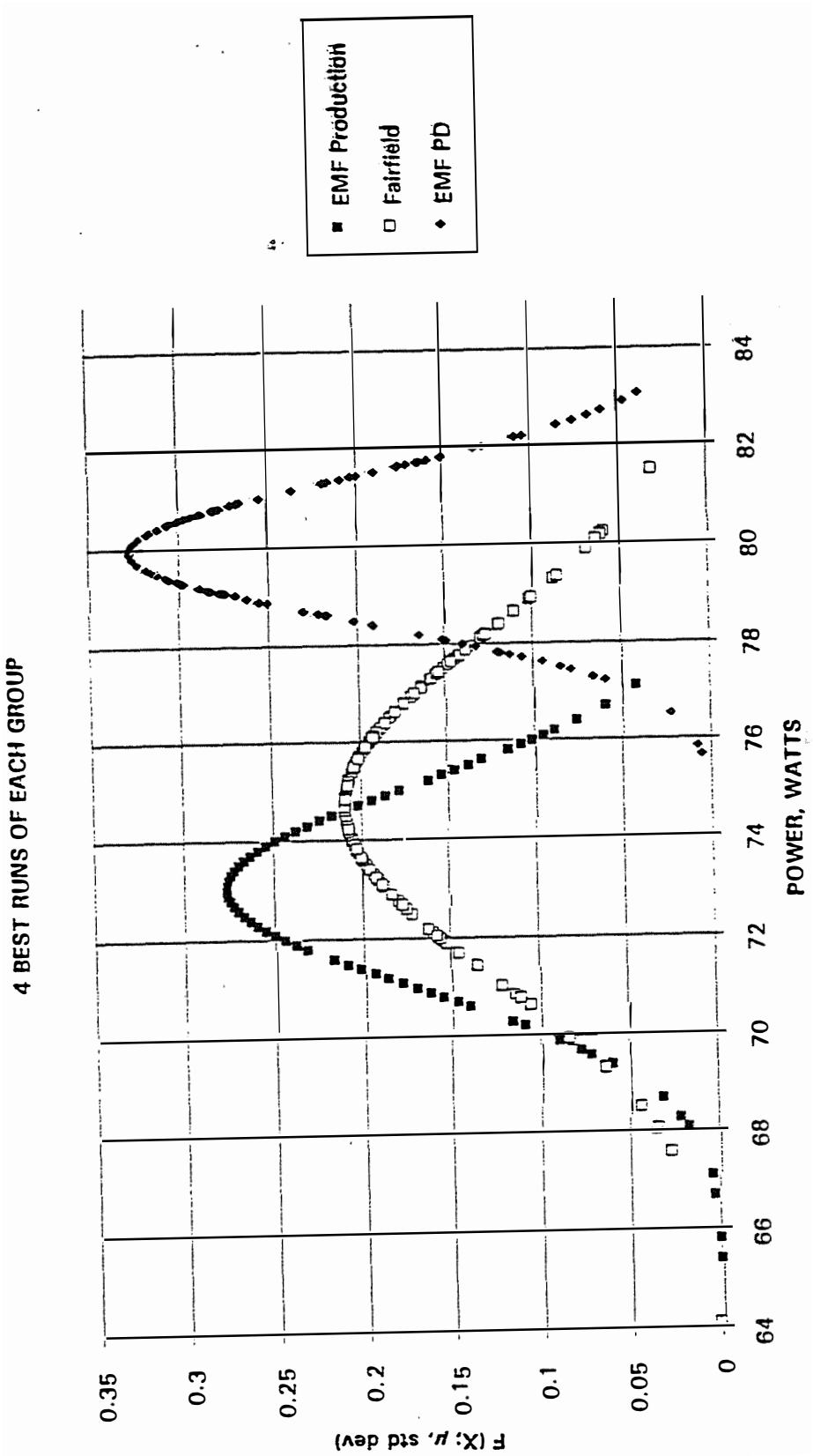


Figure 7. Comparison of Run Results between Fairfield and Trenton

These system differences were explored along two directions. First, a series of runs was made in Fairfield in which only i-layers were deposited on Corning 7059 glass and characterized by making conductivity measurements. The base case glass heating procedure, (with the preheat process last used in Trenton) consists of a two hour heating at a temperature 35°C higher than the desired set point. The temperature is then lowered to the set point for the last hour of preheating. The dark conductivities for i-layers deposited under these conditions are greater than 10^{-10} s/cm, much higher than expected.

In order to determine whether outgassing from the filters is reducing i-layer quality, depositions in Fairfield were made in which the filter was bypassed. However, results from these tests were inconclusive.

Microcrystalline n-layers were also deposited, partly in preparation for making single bandgap tandems. With very high dilution of H_2 but otherwise near standard n-layer deposition conditions, extremely non-uniform n-layers were obtained. Thickness varied by more than a factor of three from top to bottom. Even in standard n-layers, the silane consumption rates (as determined from RGA measurements) are higher than they are for i-layers, hence less top to bottom thickness uniformity is expected for n-layers compared to i-layers. To reduce gas consumption, n-layers were deposited at reduced RF power. This reduced film growth rates and improved the thickness uniformity, but electrical performance of devices decreased.

In Trenton, several preheats have been made in which the temperature profile has been altered in an attempt to simulate the conditions in Fairfield. Two types of runs were made. In one case the box carrier was loaded into the deposition system at the end of the day and pumped on overnight in a hot deposition chamber. The other case consisted of moving the hot box carrier from the preheat to the deposition system and depositing as soon as vacuum is established. At this point, analysis of the data suggests that temperature is not the main reason for differences between Fairfield and Trenton. Glass temperatures for a standard run in Trenton are less than five degrees different (higher) than in the overnight pumped run in Fairfield and about the same for runs made as soon as transferred. No large differences in performance exist between two types of runs made in Fairfield.

At this stage of testing in Fairfield, it was discovered that possible oil backstreaming could have occurred in earlier tests, raising questions about the validity of the results obtained. This is thought to have occurred when a pumpdown was made without the use of a diffusion pump and with insufficient purge flow. It was decided to stop depositions and clean the system in which all the depositions have thus far been made.

The mechanical components of the second deposition system have been assembled and the system has been leak checked. Yet to be added are the RF matching networks. Operation of a second system is expected to aid considerably in optimizing performance of these systems and eliminating problems.

I-V Testers

In order to reduce variations between testers, we have modified the procedure for doing I-V measurement calibrations. In the past we had measured the electrical performance of a Standard Module and its temperature, and then using temperature coefficients for voltage and current, corrected the numbers to 25°C. Modules were then similarly measured, temperature corrected and their current adjusted by the ratio of the Standard sticker value current to current actually measured for the Standard. Thus fill factor was not corrected at all and V_{OC} only for temperature. In the new procedure, we normalize all parameters to the Standard. We believe that this procedure will not only lead to inherently more precise measurements, but it will also avoid grossly erroneous measurements when testers malfunction and the problem is not noticed for several hours or even days.

New Critical Control Point for Encapsulation Process

The control point selected for the encapsulation process is the curing of the material used as both pottant for the terminal cover and adhesive for the mounting brackets. This selection was made for two reasons. The first is process control. A study of this variable will define the safety margins of process variables for curing the terminal cover and for bracket adhesion (and may lead to reduced in-line QC checks of bracket adhesion). Secondly, it will allow us to choose optimal conditions and thereby a possible reduction in the time requirements for the process. At the present time, the combined curing of the bracket and terminal cover is the longest process in the encapsulation area.

Influence of Critical Control Points on Improvement of Quality, Yield, and Throughput

1. Temperature during silicon deposition-
The latest version of the box carrier design has been shipped to the Fairfield facility where it is being readied for testing. Because the height of the electrodes has been increased, flow patterns and temperature profiles are expected to be different. These differences will need to be quantified.

2. Pulse width of aluminum laser -
see next section.

3. Optical and electrical properties of back contact -
No work was done on this part of the task.

4. Encapsulation critical control point-
The pottant cure optimization is at least a three dimensional problem. The cure time, the temperature, and the composition of the two part pottant all play roles in the cure. The composition will be investigated only from the viewpoint of quality control since the manufacturer prescribes a mixing ratio that will be assumed to be optimal.

The temperature window is also rather narrow because of the constraints placed on it by the other process requirements that must be met (the split cure requires that part of the EVA cure be realized during the pottant cure). These constraints are the lower temperature limit imposed by the heat aging requirements of the device (its very strong relationship with time effectively sets a lower limit of about 140°C), and the high temperature limit of about 160°C dictated by the thermal stability of the EVA.

The following test program was developed; note that the emphasis is on adhesion not on bulk cure (that will be a given if adhesion is good).

a) Determine cure time over the 130°C to 170°C temperature range. The temperature ultimately used is expected to be near the center of this range. These tests are intended as a survey of the cure properties of the material and will serve as input for defining the remaining tests.

b) Generate adhesion vs. time curves for temperatures between 140°C and 160°C. From the results of the first series of tests, a temperature/time matrix will be chosen for preparing samples for testing the bracket adhesion.

c) Determine the contribution to the cure from the slow temperature ramp-up and the cool-down of the samples such as typically occur in the process. The effect of long term room temperature exposure on partially cured pottant will be determined in these tests as well.

d) Determine the effect of varying the amount of catalyst over a small (20% or less) range. This will be done over a limited temperature range as suggested by the outcome of the above tests.

e) From the above, determine the minimum production process time consistent with the quality of the product.

Samples for the tests have been made using small (6"x12") pieces of laminated glass and small (2") lengths of bracket material. Some adhesion testing in the future may also be done with aluminum nails on single pieces of glass.

Preliminary tests have been carried out to address one component of this program. Adhesion vs. time determinations have been made for a cure temperature of 150°C. Three 2" brackets were applied to each glass laminate (eight in one test and five in the other). The procedure for preparing samples is to first heat the laminates to 150°C, apply the adhesive to the bracket material, place the bracket on the glass, then return the assembly to the oven for a prescribed time period. The samples are then removed and allowed to cool, after which a pull test is carried out. In this pull test, a bolt is centered in the 2" bracket material, simulating the mounting procedure of a module, and a pull force is applied to the bolt. This force is generated by an air cylinder of 3.25" bore driven with compressed air. The pressure is increased until the bracket comes off the glass. The starting force is 166 pounds corresponding to an air pressure of 20 PSI. This force is then increased, first to 332 pounds and then in increments of 83 pounds (10 PSI air pressure), each pressure being held for one minute or until the bracket comes off; the time required for the bracket to break off is recorded as the adhesion time.

Two such tests have been carried out. In the first, a total of twenty-four brackets at room temperature were applied (to the hot glass) and the samples cured for time periods ranging from five to forty minutes. In the second test fifteen brackets, preheated to 60°C were applied and cured for time periods ranging between ten and thirty minutes.

Results of these are summarized in the table. As the data indicate, even with considerable scatter, there is a clear difference between the time required to reach higher levels of adhesion between the preheated brackets and those applied at room temperature. It appears that adhesion becomes noticeably better at a 30 minute cure time for the room temperature applied brackets, while a 15 minute cure time results in such improvement with the preheated brackets.

Automatic Pulse Width Measurement Capability for Laser System

A conceptual design of this system has been produced. Measurements will be made on each of the two aluminum lasers in the back contact scribe station. The electronics will consist of two main components; first, a peak detector that will measure the highest intensity during a pulse and secondly, an integrator that measures the total energy of the pulse. Analysis of pulse shapes and manual pulse width measurements will then be made in order to relate the peak integral intensity to pulse width. This relationship will be periodically verified and used to calculate pulse widths. This approach will allow continuous determinations to be made on-line and running averages stored at periodic intervals for latter analysis. These measurements will be related to individual plate measurements and will be made part of the run analysis report.

Incorporation of Thickness Monitor in Thin-Film Line

The optical thickness monitor that will be used in Fairfield will employ LEDs instead of the incandescent lamps used in the prototype model in Trenton. The use of LEDs with their reasonably narrow spectral range centered at about 590 nm together with shielding, to reduce stray light, will permit making the transmission measurements without using interference filters.

Tests carried out with a breadboard version have confirmed that intensities are suitable and they have provided the information needed to determine details of the design. The major components for the thickness monitor have been shipped to the Fairfield facility. The unit is being installed on a transport table between the vertical glass aligner of the box carrier unloader station and the glass flipper that feeds the laser silicon station.

Table 1. Relationship between cure time and adhesion

	room temperature		preheated	
cure time, min	adhesion time, sec	final press. PSI	adhesion time, sec	final press. PSI
5	4	20		
5	0	20		
5	0	20		
10	2	20	36	20
10	4	40	4	40
10	2	20	10	20
15	10	20	8	60
15	12	40	11	60
15	3	20	12	50
20	3	20	60	70
20	20	20	0	60
20	20	20	18	60
25	0	20	24	20
25	20	20	5	50
25	15	20	25	50
30	28	40	40	40
30			19	50
30	15	40	16	50
35	40	60		
35				
35	13	60		
40	13	60		
40	28	40		
40				

4.0 TASK 16 AUTOMATION OF EUREKA MANUFACTURING LINE

Documentation - A significant effort is being put into fully documenting the equipment in the Fairfield facility and changes to same that have been made in the past few months. For the seventy-two systems that compose the thin film and encapsulation line, documentation is more than 90% complete. It is expected that further minor modifications will be made and these will require additional updates to the documentation.

RF Cables - One of the areas that caused low overall yields in the initial phases of production were the RF cables. These have been made by APS in the past from modified commercial cable. The main requirements are low impedance (because the discharge region has a low impedance), high current capacity, and high temperature capability.

The current version is totally made from virgin materials. Solid tubing is used with teflon for insulation. Impedances for the cable are calculated to be less than 9 ohms. The original flexible cables had a calculated impedance of about 10 ohms, but their reliability was not very high.

After assembly, the cables are subjected to two types of tests. In one, 100 amps at 60 Hertz is passed through the cables for five minutes to determine if any local heating occurs. Then a high voltage test is carried out in which the cable is subjected to 8000 VDC. For the older style cables the corresponding test conditions were 60 amps and 3000 VDC. With a set of these cables installed in the modified box carrier, measurements were made of voltage uniformity with a special probe contacting the electrode ground pairs. This information was obtained for reference purposes to compare with future modifications, should any be made.

The EUREKA Module Process Development During this Phase

The encapsulation process that will be developed during this phase consists of the new, partially pre-molded boot with enclosed connectors. In order to evaluate this process, test samples have been made with the first version of the enclosure which had mock-up connectors pre-molded to the enclosure. These mock-up connectors were drilled out and the presently used commercial connectors glued into the resulting holes.

These enclosures with connectors were applied to five modules which have been undergoing testing for the past three months. With the connectors submerged in water to the point where the connector is embedded in the rectangular enclosure, leakage measurements at 500 volts have been made. Initial leakage averaged 0.8 uA. Measurements after the first week in water averaged 1.0 uA, although one module showed a leakage of 2.7 uA. For the others, the leakage actually decreased.

The final version of the terminal cover is expected to be very similar to the one being tested, with the difference that it will be somewhat larger and contain the holes. This approach appears to be

superior to the initial version in which connectors would be made part of the mold. A much more complicated mold would be required to accomplish this.

Conceptual Design for One New Automated Piece of Equipment

A conceptual design has been arrived at for the deposition/preheat chamber door actuation. Automatic door opening and closing will be accomplished with two devices, a rotary actuator that will swing the doors open and near closed, and pneumatic clamps that will seal the doors sufficiently so that vacuum can be applied.

Design Calculation for Second Piece of New Automated Equipment

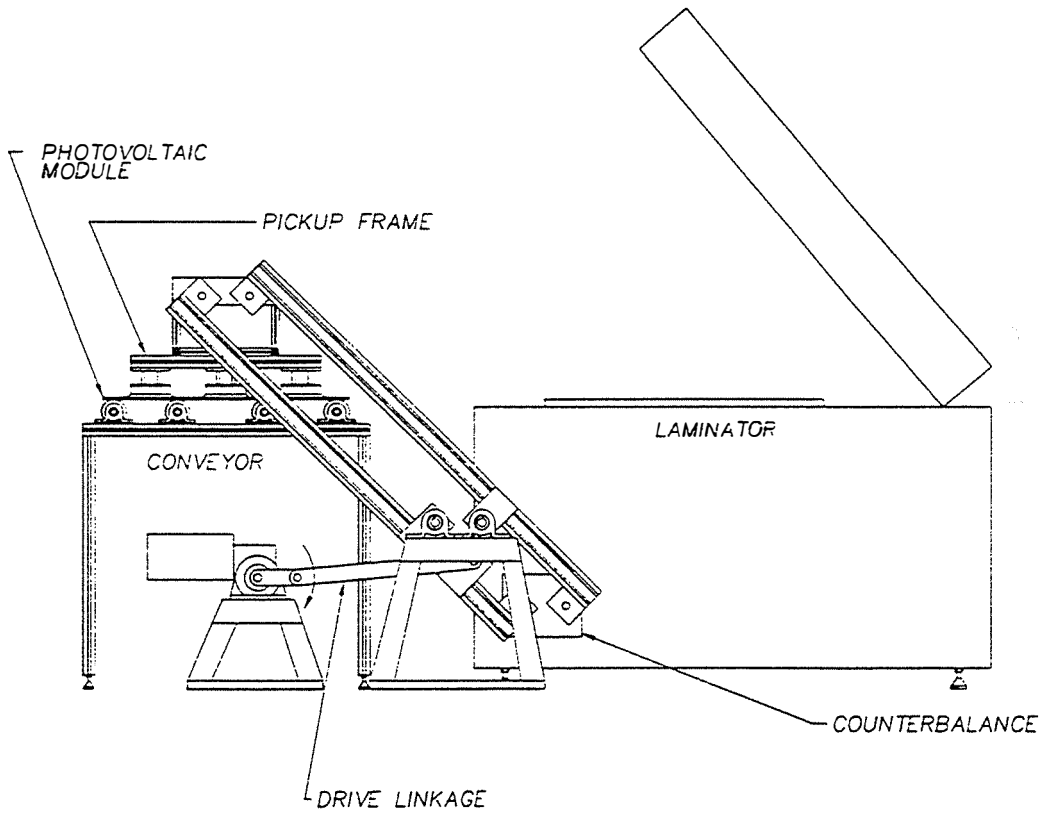
Estimates have been made of the force needed to open the deposition chamber door. The force exerted by a 5 kg weight at the end of the door opposite the hinge (170 cm away) was found to be sufficient to open the door safely. Other data are still required in order to complete the design calculations.

Conceptual Design and Design Calculations for a Second New Automated Piece of Equipment

The piece of equipment that is being designed will automatically load and unload the laminator, a process now done manually. A conceptual design was agreed to some time ago, but careful review revealed that the torque requirements were very large and could pose unreasonably high requirements for the drive system. In addition, torsional distortions could cause problems in accurately positioning the module in the laminator. For these reasons, an alternate design was also investigated.

This new design is a gantry-type loader that would straddle the laminator and the conveyor section in front of it. A small frame with vacuum cups would raise and lower the module from the conveyor or laminator platen using pneumatic cylinders, and the gantry's aluminum extrusion superstructure would travel between the laminator and conveyor on steel "V-grooved" wheels, driven by an electric motor. Rough deflection and stress calculations have been completed for the gantry superstructure and they reveal no unusual requirements.

Modifications to the original design, the rotating arm approach, were made which address the concerns discussed above. Figure 8 shows the modified design. The changes made to the original design are the doubled up arms and the counterweights to reduce force requirements to rotate the arm. This design has been adopted and will be implemented.



AUTOMATED LAMINATOR LOADER – ROTATING ARM TYPE

Figure 8. Laminator Loader/Unloader

5.0 TASK 17 EUREKA MANAGEMENT INFORMATION SYSTEM

Requirements of Data Management Software

The software must satisfy two types of requirements. It must deal with technical and with manufacturing information. The software modules needed for the manufacturing data are the following:

Order Entry/Invoicing
Sales Analysis/Forecasting
General Accounting
Project Management
Payroll/Accounts Payable/Accounts Receivable
Purchasing/Materials Control
Master Planning/MRP
Production Scheduling/Production Control
Engineering/Documentation
Budgeting/Labor Reporting/Cost Analysis/Operations Reporting
SPC/Preventive/Maintenance

The technical requirements have been addressed in the form of the reporting analysis for each deposition run processed.

Commercial Software Package for Data Management

After discussions with software suppliers and consultants (Ernst & Young, Applied Management Solutions, Ltd, Arthur Anderson, Ebeling Associates, Inc., and Symix Computer Systems Inc.), we concluded that for our application the technical requirements will best be satisfied by combining our own software with standard analysis and database packages such as Excel and Paradox. The manufacturing related requirements will best be served by commercial software. The reason for these conclusions is that technical information is very specialized and specific to our operation so the software would have to be written. The manufacturing information is much more standard and existing software will be appropriate.

From the above, the Symix package was selected as being the most appropriate for our application. Other software is also being used and evaluated. SIDE ARM by DATASTREAM SYSTEMS of Greenville, South Carolina is currently used for the following functions:

Spare parts list with cross referencing
Inventory control
Equipment listing
Maintenance scheduling

Spreadsheets (Lotus 123, Excel) and databases (Paradox) are used for data analysis.

Linkage of all the Relevant EUREKA Module Manufacturing Processes and Quality Control APS-owned PC's in a Network

Connections to the workstations are completed and verified. Connections to the file server are made by HP IEEE 10Base T Ethernet hubs, while actual connection to the workstations is via twisted pair cable with specifications that require full Ethernet speeds of 10 megabits per second. The hubs operate as a IEEE 802.3 repeater which gives them excellent reliability.

The software drivers have been generated, installed, and tested for each of the workstations on the factory floor. The network is thus prepared for installation of the application software.

Preliminary Process Analysis Software

The report format discussed in the Second Annual Technical Progress Report has been applied to runs made in the Trenton facility (since more complete information is available for these compared to those made in Fairfield) and some modifications made. The further development of this report format will provide the basis for an analytical tool for process evaluation. Examples of this report are shown in the two attached Figures 9 and 10. Figure 9 (the first page of the run analysis report) presents a summary of the run listing electrical measurements for each plate processed. RS is a shunt resistance measurement obtained from the slope of the I-V curve. LLLV_{OC} is a voltage measurement made at very low light intensity (about 0.001 sun) and gives information about shunting of the module. QSFPW is the percentage of power that is realized, the remainder being lost to shunting.

The second page (Figure 10) contains averages and trends. Averages for each of the twelve RF sections are first given and include average thicknesses. Then ratios of even/odd plates for both grounds and electrodes are given and ratios of power before heat aging (AHA/BHA).

Relationships of electrical parameters with thickness and to some extent with each other are then summarized followed by information on the back-contact laser process. Finally a yield summary is presented.

24-Oct-94 Page. 1
EMF
Summary Report Run: PD143

PLATE	VOC	ISC	FF	PW	VM	IM	RS	LLLVoc	QSFPW
1	57.3	1.973	54.4	61.6	43.7	1.408	9.1	3.1	96.8
2	55.2	1.924	50.3	53.4	38.5	1.385	8.5	3.7	96.8
3	56.8	1.997	56.9	64.5	41.9	1.540	11.1	1.6	96.8
4	57.7	2.015	57.4	66.7	43.5	1.534	12.5	3.4	96.8
5	56.4	2.019	61.1	69.6	44.0	1.580	4.2	0.0	97.0
6	56.1	2.043	61.5	70.5	42.5	1.659	7.3	3.9	97.3
7	56.7	2.045	62.7	72.8	43.2	1.685	10.9	5.6	98.9
8	56.4	2.052	61.2	70.8	42.8	1.655	10.1	0.0	96.0
9									
10	no fire								
11									
12									
13	56.8	2.063	62.7	73.6	43.2	1.702	4.6	3.4	97.5
14	57.2	2.061	62.3	73.5	44.0	1.668	11.3	0.0	99.2
15	56.9	2.077	62.4	73.7	43.4	1.700	10.8	4.1	97.6
16	56.7	2.071	62.1	72.9	43.4	1.681	7.3	3.4	97.1
17									
18	no fire								
19									
20									
21	57.4	2.070	58.9	69.9	42.4	1.648	14.6	0.0	98.7
22	56.2	2.086	64.4	75.5	43.5	1.735	2.4	3.5	99.3
23	57.1	2.088	61.1	72.8	42.6	1.708	4.8	4.8	98.0
24	57.4	2.082	61.5	73.5	43.2	1.701	6.5	5.1	99.2
25	57.6	2.093	61.3	73.9	42.7	1.729	6.6	5.0	98.2
26	57.5	2.104	60.7	73.5	43.6	1.686	14.3	4.4	97.6
27	57.3	2.084	60.2	71.9	43.2	1.664	6.8	4.3	97.8
28	57.2	2.115	59.6	72.2	43.3	1.668	10.9	8.2	96.4
29	56.9	2.089	64.1	76.2	43.8	1.738	8.0	7.3	97.4
30	57.1	2.093	59.2	70.7	41.6	1.698	4.9	3.7	98.0
31	57.4	2.087	61.8	74.1	43.1	1.717	10.1	8.7	96.7
32	57.5	2.091	61.4	73.7	43.6	1.693	5.6	6.3	95.7
33	57.5	2.084	62.2	74.5	43.4	1.718	6.8	8.4	97.5
34	57.3	2.075	61.3	73.0	44.3	1.647	13.4	0.0	97.9
35	56.9	2.083	61.1	72.4	44.5	1.628	5.6	5.8	98.5
36	56.8	2.054	60.0	70.1	43.3	1.618	12.0	0.0	98.0
37	56.4	2.036	60.4	69.4	43.1	1.610	7.1	0.0	97.9
38	55.8	2.037	58.0	66.0	41.5	1.591	10.2	0.0	73.8
39	56.3	2.044	62.1	71.4	43.2	1.655	10.9	0.0	96.1
40	laser alignment								
41	57.5	2.155	59.8	74.0	40.9	1.809	9.1	11.4	98.3
42	57.2	2.136	60.1	73.4	42.2	1.741	9.9	0.0	99.4
43	57.0	2.124	59.9	72.6	42.4	1.710	7.3	0.0	97.4
44	48.2	2.022	55.3	53.9	32.6	1.652	17.2	7.3	91.3
45									
46	no fire								
47									
48									
AVG	56.7	2.065	60.3	70.6	42.6	1.656	8.9	3.6	96.8
STD	1.55	0.0444	2.73	5.16	2.03	0.0848	3.27	3.06	4.17
RUN STD	57.29	1.736	70.4	70.1	45.5	1.538	8.8		

Figure 9. First Page of Deposition Run Analysis Report

RUN PD143
Dep. date: 18-Feb-94
Chamber: 2
Box Carrier: A
Measured Date: 22-Feb-94

IV Measurements corrected by QSF

SECTION	VOC	ISC	FF	PW	VM	IM	RS	LLLVoc	Thick
1	57.2	1.977	56.2	63.7	41.9	1.467	10.3	3.0	3660
2	56.7	2.040	63.1	73.0	43.1	1.645	8.1	2.4	3996
3									
4	57.1	2.068	63.6	75.2	43.5	1.688	8.5	2.7	4244
5									
6	57.1	2.081	62.1	73.9	42.9	1.698	7.1	3.4	4407
7	57.6	2.099	61.9	74.8	43.2	1.687	9.7	5.5	4720
8	57.5	2.090	63.3	76.1	43.0	1.711	7.2	6.5	4306
9	57.3	2.074	62.3	74.0	43.9	1.653	9.5	3.6	4373
10	58.1	2.039	66.9	79.5	42.6	1.619	9.4	0.0	4128
11	55.5	2.109	60.5	71.0	39.5	1.728	10.9	4.7	4706
12									
AVG	57.1	2.064	62.2	73.5	42.6	1.655	8.9	3.5	4282
STD	0.69	0.0381	2.70	4.09	1.22	0.0740	1.25	1.79	314

AVG Ratios

ELC E/O	1.002	0.992	0.998	1.007	0.988	1.006	0.885	0.698	0.982
GND E/O	0.990	0.973	0.983	1.002	0.963	0.965	1.353	0.854	1.010
GLASS TYPE									
AHA/BHA	na								
AHA/BHA STD	na								

REGRESSIONS

	CONST	SLOPE	R2
VOC/THK	52.79	0.001	0.35
ISC/THK	1.64	0.0001	0.71
FF/THK	73.39	-0.002	0.19
VOC/ISC	39.01	8.755	0.37
LLLVoc/QSF	77.74	-0.743	0.17

Averages per AL-laser beams

	AL-Laser 1		AL-Laser 2		AL-Laser 3		AL-Laser 4	
Beams	1	2	3	4	5	6	7	8
Beam power	110	121	104	109	109	102	75	107
Pulse width	60		61		54		52	
QSF	87.6	96.3	98.0	98.3	97.9	98.5	97.9	97.7

Electrical Yield :

	Overall Plates	%	Corrected Plates	%
60 (>= 75)	2	5.71	12	34.29
55 (>= 68)	27	77.14	20	57.14
50 (>= 64)	3	8.57	1	2.86
< 64	3	8.57	2	5.71

Figure 10. Second Page of Deposition Run Analysis Report

REPORT DOCUMENTATION PAGE

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13. ABSTRACT *(Maximum 200 words)*

This report describes work performed by Utility Power Group (UPG) and Advanced Photovoltaic Systems, Inc. (APS), under a subcontract in Photovoltaic Manufacturing Technology Project–Phase 2A. The goals of the subcontract are to address problems that are process-specific and are generally unique to a technology. UPG and its lower-tier subcontractor, APS, have continued to conduct parallel efforts in developing their manufacturing lines, UPG's POWERGLASS line and APS's EUREKA line. UPG has focused on demonstrating fully functional automated encapsulation and termination stations. APS has focused on continuing the process and quality control and automation projects. Topics investigated and discussed in this report include (1) automated assembly/encapsulation stations, (2) automated glass transport techniques, (3) enhanced deposition parameter control, and (4) integrated process and quality control for the entire EUREKA system.

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