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Commercial Production of Thin-Film CdTe Photovoltaic Modules

1995 Annual Report

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General Overview of Progress

Over the last twelve months of the PVMaT project, the number of batch runs processed through substrate deposition, all inter-connection, and encapsulation process steps have continued to improve. Last January, power outputs ranged from 0 to 21.8 watts/panel with an average of 16.8 watts/panel. The final throughput yields were as high as 51.2%.

In marking progress, Operations demonstrated a marked increase in the total number of panels processed each month as the year progressed. This number ranged from a low of 119 panels in May to 1,302 panels in November, and 1,023 panels in December. The average monthly wattage showed a similar increase from a low of approximately 17 watts at the beginning of the year to approximately 21 watts in December. The overall yearly average was 19.4 watts, and the highest wattage panel output for 1995 yielded 26.6 watts.

Near the end of the annual reporting period, the operations group reported two significant outcomes. First, cumulative yields were the best since the inception of the company with cumulative yields approximating 60%. The cell efficiency, however, did not improve since the current bench mark month of September reflecting an average watts/panel measured at 21 watts, but enhanced process capability has been demonstrated with one batch at 25 watts/panel, representing an important milestone.

The operations group focused its activity in 1995 on process yields. Cumulative process yields have continued to improve through the tin oxide deposition line and cell interconnection steps. The best week was reported at nearly 80% while the worst was just less than 50%. For the month of June, process yields were reported at nearly 60% which was repeated again during the month of October. This increase is primarily due to increased yields at the Tin Oxide deposition stage where yields have increased from approximately 55% to 90%.

With all of the module manufacturing equipment operational, continual attention was given to modifying operating parameters of each major process step in order to achieve improved process control and throughput. GPI continues to focus effort to improve cell efficiencies via refining both substrate uniformity for all substrate material deposition steps and precision for all cell division steps. New process controls have been implemented in the cell interconnection processes including the purchase of a new optical measuring system. This automated unit has been programmed to measure each critical position of the cell interconnection and has provided the basis for implementing Statistical Process Control (SPC) for these stages of the process.

The fire, electrical, building, and environmental permits have been allowed on all leaseholds and installations to date.

Manpower Status

Staffing in January 1995 included 8 operators per shift. The Operations department started the year with thirty-two (32) full-time employees. The Engineering department had five (5) full-time employees and eleven contract/part-time employees. All construction/fabrication needs required for process improvement/development and manufacturing productivity optimization have been performed by the contract engineering technicians or subcontracted to the GTC Facilities Maintenance Group.

Ongoing safety and environmental issues requiring auditing and/or external advisement have been handled through the GTC Environmental, Health and Safety (EHS) Manager.

Two new permanent technical positions were filled in March including a Process Development Engineer and a receivable inspection Quality Technician. These positions were created and filled to assist the Operations Team in fulfilling several QA/QC programs/goals and process optimization projects. A second Process Development Engineer was added to the staff in May to compliment these work efforts. These additional technical staff members further improved the manufacturing shift work load effectiveness and increased the scheduled throughput rate appropriately during the "prove-in" phase.

New process operators were hired from May throughout the year as the company was positioned for increased production and sales. Many operators have been added to each shift as GPI continued to increase production throughput to 900 panels/week. Staffing increases in Sales and Marketing have been instituted along with filling the Engineering Director position at year-end.

Status of Subcontract Progress

Task 7: Engineering Design

New auxiliary support equipment was designed and installed in three different process areas in order to provide higher process equipment applications reliability, as well as to prepare for increased capacity. A new centralized high pressure air compressor (services the cell interconnection steps) was installed to replace the smaller local units. This compressor provides increased sustained pressure, a higher flow rate, and improved reliability. An instrument air back-up system was installed to allow for the routine maintenance of the compressor without interfering with production. The cell interconnection equipment became more consistent and more reliable once the unit was operational.

Automatic sequencing and ramping controllers were installed on the Tin Electrode Evaporator unit in order to provide an unattended and consistent evaporation process. Additional new PV panel assembly and component location equipment was installed to support the module subassembly process. The encapsulation area was re-formatted to provide better product flow and a more rapid throughput rate in this critical processing area. The machinery safety program for personnel safety and environmental protection was also implemented as part of achieving routine utilization status.

Equipment installation and detail drawings were updated throughout the year in support of the existing facility documentation system and to prepare for the next specification and design phase.

Other noteworthy accomplishments relating to Engineering Design are listed below.

1. The existing laser border isolation machine was duplicated to meet the required wet hi-pot isolation test.
2. A minor software change was made in the spray oven traverse software to prevent a nuisance start-up problem.
3. New CdTe raw material processing equipment has been installed. This helped increase the CdTe processing capabilities of the Mixing Laboratory.
4. The sandblast division equipment has been upgraded with new sand blasters.
5. A high temperature spray deposition oven has been retrofitted with additional thermocouples. These will be used to provide additional information regarding the temperature uniformity and may be used to reduce any temperature variations within these furnaces.
6. Solid state power components were used to replace mechanical relays in the R & D module tester.
7. The cell interconnection process was redesigned to improve uniformity across the panel. This includes the installation of new retractable heads for division to improve set-up and process stability.
8. A border isolation machine and hi-pot testing process were brought into service by year-end.

The completion of these processes provided major contributions in demonstrating production capability at 2 MW. For the future 10 MW expansion, the definition of plant and process design was finalized and approved by Board of Director action.

Task 8: Process Improvement and Development

Throughout 1995, major emphasis was placed on improving the existing standard operating procedures. Although operating procedures were developed by the original process/equipment design engineers as part of the original start-up, all procedures were re-evaluated by the Operations Team and issued to reflect correct practices. The implementation of this procedure provided a foundation for continuous process improvement as an established precept of total quality management. The result of this effort was the successful deployment of Process Flow Diagrams for all major production and material preparation processes. These diagrams are routinely reviewed and updated by the Operations team as process improvements are evaluated and implemented.

Systematic experimental studies were conducted for optimizing the process. Key process variables were determined and represented by relationships in cause-and-effect diagrams. The process of understanding process operating windows provided a methodology for implementing statistical process control (SPC).

Process documentation included the development of process flow diagrams. After review and approval, these diagrams were placed on the production floor for both training and reference purposes. The Operations group developed training and qualification programs in defining established procedures for the purpose of training new employees.

GPI purchased and installed two SPC software packages for evaluation. The Process Engineering staff selected these software packages initially for use on selected processes that would benefit the most from SPC. Golden Photon also purchased an automated visual inspection station during the year which also contained a SPC software package. This inspection station has been used to measure line widths and locations at key cell interconnection stages in the process (pre-resist, 1st division, and 2nd division). With this inspection performed and charted automatically, the operations group was able to identify the capabilities of each process, tighten specifications where appropriate, and determine when the process was not in control.

Multiple process improvements were also implemented during the past year. Several noteworthy examples are listed below.

1. Operations purchased raw material characterization equipment to evaluate incoming raw materials. The purchase and subsequent use of this equipment were instrumental in determining that lengthy raw material processing steps could be eliminated without sacrificing material quality. This allowed material processing rates to be dramatically increased.
2. Operations also purchased a second piece of characterization equipment which was used to reduce variation in batches of processed Cadmium Telluride.
3. The Regrowth oven used to re-crystallize Cadmium Telluride was retrofitted with a baffle to provide more uniform air flow and reduced temperature variation in the furnace. This was deemed critical for increasing the batch size as the process was being scaled.
4. Process Engineering worked extensively with representatives of the National Renewable Energy Laboratory to develop methods to measure the film thickness of deposited Cadmium Sulfide using a non-destructive technique and in an on-line fashion. The testing was successful in establishing a correlation between transmitted light through the film against destructive film thickness measurements at Golden Photon. Golden Photon is currently implementing this film measurement into the process.
5. Engineering designed and fabricated an improved spray nozzle for the Tin Oxide and Cadmium Sulfide deposition lines. This new nozzle scheme has less problems with plugging and requires significantly less time to set up and install while providing greater consistency of a spray pattern.
6. Operations installed a heating system above the Tin Oxide furnace to provide a more controlled environment around this furnace. This resulted in yields increasing from 55% to greater than 90%. Timely cleaning and maintenance have also contributed to the increased yields.

Task 9: Cost Improvement of Raw Materials

A complete review of all raw materials and suppliers was conducted to insure that quality levels were maintained and to prioritize improvements in pricing and quality. This effort included updating specifications of all raw materials and components which are used in our product. This was a coordinated effort among Quality, Engineering, Production, Purchasing, and Sales and Marketing with each department providing input. The quality review process was managed by a Material Review Board (MRB) which examined and approved the specifications of current materials as well as proposed changes. The MRB maintains responsibility for controlling and issuing copies of the specifications and master copies of all applicable drawings.

Significant cost reductions for two material purchases have occurred in 1995. The glass substrate is now purchased at a cost lower than that paid in 1994 despite a 16% increase in the raw glass industry in 1995, and the cost of the pre-assembled junction box has decreased by approximately 50%.

The procurement costs associated with Cadmium Telluride powder increased by approximately 25% in 1995. The increased costs, however, were associated with receipt of a superior quality of material. The usage of this material at Golden Photon has eliminated several key processes in the Mixing Laboratory and reduced the time for material preparation by approximately 35 hours per batch of material. This was deemed critical for scaling the production throughput rate from 350 to 900 panels per week.

Processes and materials are now in place in our encapsulation process to significantly reduce cost of materials resulting from a 50% cost reduction in the desiccant materials used in our modules. Additionally, work continues on refining the design of the hermetic header will improve this process further.

A needs assessment was performed by the MRB relating to purchased materials projected for 1996. This analysis pointed out the benefit of insightful purchasing agreements to insulate our operations from inflationary price increases projected in the coming year.

Task 10: Environmental, Safety and Health

As Phase II of the PVMaT program began, a personnel decontamination area was installed at the entrance/exit to the facility to ensure work boots, clothing, and personnel are free from contaminants prior to exiting the facility. Personnel protective clothing compaction equipment was installed to minimize the volume of this waste and procedures were instituted for the use of the equipment. This equipment realized a 4:1 compaction ratio, thus reducing the waste by 75%.

An Air Pollution Emission Notification (APEN) final review and update was completed, and the final APEN was filed. Laser warning signs were installed that automatically activate when the laser is turned on, and classes were held to instruct all personnel who are likely to be in that area about dangers and safety precautions associated with lasers.

The Environmental, Health and Safety Plan, including a machine safety review, was refined and updated. The revised plan addressed modifications to various occupational safety procedures, updated the "active" MSDS log book, implemented modifications to the personal protective equipment and the egress decontamination procedures, and issued additions and clarifications to the waste handling and disposal procedures.

The cadmium safety program was executed under the leadership of the Safety Manager of Golden Technologies Co., Inc., the corporate holding company of GPI, and the Operations Manager. The contents of the program addressed both equipment "wipe" samples to determine general housekeeping effectiveness and containment as well as air samples to quantify airborne cadmium amounts in relevant areas of the plant. Results showed levels of airborne cadmium well below OSHA action levels. Results of the wipe samples alerted management to revise and execute new cleaning procedures in addressing a slight rise of cadmium levels on specific pieces of process equipment.

Task 11: Manufacturing Cost and Productivity Optimization

For 1995, the power average for 24"x 24" PV modules has increased from 16.8 watts/panel to over 20 watts/panel. The highest power attained was 26.6 watts showing a marked improvement over the January high of 21.8 watts/panel.

Several factors continued to drive down the price per watt of output power. Foremost, the power per module showed an increasing trend. This favorable increase can be attributed to several improvements in the process: 1) a program was implemented to monitor the quality and characteristics of raw materials; 2) the design of the encapsulation process was improved and successfully tested; 3) equipment was installed that provided on-line inspection and real time process control. Additionally, the furnace yields have shown remarkable improvements since the beginning of the year. This has helped boost the cumulative yields throughout the process approximately 60% even with the material throughput rate increasing from 350 panels per week input to 900 panels per week.

At 1995 year-end, the following table summarizes the status of the PV program relative to measurable process values of continuing interest to management:

ATTRIBUTE	VALUE
Power Output (Average)	~ 21 watts/panel
Tin Oxide Yields	~ 90%
Cadmium Sulfide Yields	~ 90%
Production Throughput	900 panels/week

Milestones

m-1.3.3b Demonstrate 24 watt modules, from a batch of at least 50 consecutive modules, with a batch standard deviation of ~ 5% for the output distribution and a total post CdS process yield of
> 90%. (Task 8)

Status: GPI has produced 24 watt panels; however, the company has not produced 50 consecutive modules of said power output.

m-1.4.4b Demonstrate prototype quantities of modules at the 28 watt average output level. (Task 8)

Status: GPI has not yet produced a 28 watt panel as measured with the indoor panel tester at the facility; however, 26 watt panels have been produced and measured indoors. Process Engineering has calibrated the indoor tester more accurately to correlate with outdoor results or "field" conditions. The projected benefit was in the range of 1.5 to 2.5 (10-15%) watts a panel.

m-1.3.4 Complete revised NREL TP-213-3624 qualification tests on GPI module manufacturing process.

Status: Engineering has completed the execution of this qualification test.

m-1.3.6b Demonstrate increased yields to > 98% for CdS deposition steps on > 50 consecutive substrates that provide average module outputs at the 24 watt level. (Task 11)

Status: CdS batch runs consisted of 450 substrates have been demonstrated with average yields ~ 90%. Within the lot of 450 there were several occurrences of 50 consecutive panels of 98% yield. The quality of processed films were consistently capable of representing final product of >22 watts tested inside. As mentioned above, Process Engineering has addressed tester calibration and will begin reporting more accurate panel power output of> 24 watts.

m-1.3.7b Demonstrate increased yields to 90% for the tin oxide deposition steps on at least 50 consecutive substrates. (Task 11)

Status: Operations has demonstrated yields on the tin oxide process of > 90% on several occasions. A batch size throughout of 450 modules was demonstrated. Management's goal is set at 95% yield on a consistent basis.

m-1.3.8b Demonstrate increased yields to 99% for interconnection steps on >50 consecutive substrates that provide average module outputs at the 24 watt level. (Task 11)

Status: Operations has demonstrated 100 % yields on the interconnection steps over several batches of 40 panels and successive batches of similar size. Recent batch averages have been as high as 22.5 watts measured indoors and projected to be 24 watts with the indoor tester calibration.

m-1.4.3b Complete the QA/QC documentation for 28 watt modules with standard deviation of <5% for the module batch output distribution and a total expected post CdS process yield of >85%. (Task 8)

Status: This milestone has been completed with the maximum wattage output observed at 29.9 watts.

m-1.4.18 Complete analysis of monthly averages of total Post CdS process yields for modules produced within 5% of the 24 watt average output level. (Task 11)

Status: The weekly yields of every process were analyzed with corrective action target assignments given by the Operations Manager. Recent batch averages have been as high as 22.5 watts measured indoors equating to 24 watts with indoor tester calibrated.

m-1.4.20 Demonstrate 24 watt output GPI modules to be outdoor life tested at NREL. (Task 11)

Status: Current deliverables will provide NREL with 24 watt panels (indoor tested by GPI and anticipated to be tested by NREL at 26 watts) which will allow outdoor life testing to be performed.

m-2.1.1 Initiate preparation of equipment specifications and send specifications to vendors for quotes. (Task 7)

Status: This task has been initiated for the 10 MW facility. The GPI goal to have process and equipment designs and budgets for each critical process has been completed.

m-2.1.3b Demonstrate 24 watt with a total post CdTe process yield of> 95%. (Task 8)

Status: The company has produced a 24 watt panel; however, the company has not produced 50 consecutive modules of said power output.

m-2.2.1 Demonstrate 24 watt modules, from a batch of at least > 50 consecutive modules, with a batch standard deviation of < 5% for the output distribution and a total post CdTe process yield of >95%.

Status: GPI has produced a 24 watt panel; however, the company has not produced 50 consecutive modules of said power output.

m-2.2.2 Complete review, update, document and implement both the Environmental, Health, and Safety and Employee Exposure Monitoring Plans. (Task 10)

Status: Both programs have been executed under the leadership of the Safety Manager of Golden Technologies Co., Inc., the corporate holding company of GPI , and the Safety Officer and Operations Manager of GPI. The contents of the program included both equipment "wipe" samples to determine general housekeeping effectiveness and containment as well as air samples to quantify airborne cadmium amounts in relevant areas of the plant. Results have shown levels of airborne cadmium well below OSIER action levels and results of the wipe samples have provided direction to revise and execute new cleaning procedures to address some rise of reported cadmium levels on some process equipment. In addition, medical examinations were required for all employees to evaluate any changes in cadmium blood counts. All reports have verified the safety procedures and training have been effective. Training programs that outline proper process procedures, material handling, protective gear and emergency response have been developed for utilization. The results outlined above reflect the effectiveness of these programs. New programs have been initiated to move towards re-usable footwear protection and lab coats, items to contain the cadmium in the facility and protect the employees but have resulted in high waste and increase costs. The common goal remains to protect the employees under maintenance of environmental friendly conditions with a sound business philosophy.

m-1.4.9a Complete all permitting and planning for proposed additional 4 MW site.

Status: All permits at the current facility allow expansion to 10 MW total capacity. The only exception is the air permit which requires revisions based on projected emissions net of expanded air treatment facilities.

m-2.3.1 Complete development of installation procedures for equipment of next 4 MW of the GPI manufacturing line.

Status: This milestone has been completed.

m-2.3.2 Demonstrate 28 watt (average) modules for a batch of at least 50 consecutive modules with a batch standard deviation of <5% for the output distribution and a total post CdTe process yield of at least 85%.

Status: This milestone has not been completed. The maximum wattage batch to-date has been with batch 235 which had a 25.6 watt average. GPI, however, has been successful in achieving a yield of greater than 85% at the post CdTe process.

m-2.3.3 Initiate integration of qualified raw materials with the revised Quality Assurance Program.

Status: This milestone has been completed.

m-2.3.5 Demonstrate increased yields for the critical deposition steps that can allow the total post CdS process yields to achieve 80% at the 28 watt average module level.

Status: This milestone has been completed for the 80% yield at post CdS. Demonstration of a 28 watt average still needs to be demonstrated.

m-2.3.6 Demonstrate a 600% increase in rate of the interconnection steps over that of the original rates.

Status: This milestone has been completed.

m-2.3.7 Demonstrate increased yields to 99% for the interconnection steps at the 28 watt average module level.

Status: This milestone has not been completed as a 28 watt average has not been demonstrated.

m-2.3.8 Complete the optimization of the next generation of Encapsulation and Packaging steps.

Status: This milestone has been completed.

Deliverables

The following deliverables have been submitted to NREL in accordance with the PVMaT subcontract

Phase 2

No.	Deliverable Description	Quantity	Frequency
D-2.1	Representative sample of Pinhole plugging and Buss Bar Application Steps	1 each	End of 5th Q
D-2.2	Representative sample of GPI module packaging steps	1 each	End of 5th Q

D-2.3	Representative sample of 22 watt GPI CdTe Module from a batch of at least>50 consecutive modules with a batch standard deviation of <5% for the output distribution and a total post CdS process yield of >85% and a total process yield at least 95%	1 each	End of 5th Q
D-2.4a	Representative samples of 26 watt GPI CdTe Modules fro prototype run	1 each	End of 5th Q
D-2.4	Representative sample of 24 watt GPI CdTe Module from a batch of at lease >50 consecutive modules with a batch standard deviation of <5% for the output distribution and a total post CdS process yield of>85%and a total process yield at least 95%.	1 each	End of 6th Q
D2.4a	Representative samples of 28 watt GPI CdTe Modules for prototype run	1 each	End of 6th Q

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13. ABSTRACT *(Maximum 200 words)*

This report presents a general overview of progress made in Golden Photon Inc.'s commercial production of thin-film CdTe photovoltaic modules. It describes the improvement in the number of batch runs processed through substrate deposition, all inter-connection, and encapsulation process steps; a progressive increase in the total number of panels processed each month; an improvement in cumulative process yields; and the continual attention given to modifying operating parameters of each major process step. The report also describes manpower status and staffing issues. The description of the status of subcontract progress includes engineering design; process improvement and development; cost improvement and raw materials; environment, safety, and health; and manufacturing cost and productivity optimization. Milestones and deliverables are also described.

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