Cadmium Telluride Photovoltaic Manufacturing Technology

Annual Subcontract Report 7 January 1994 – 6 January 1995

D. Weisiger, S. P. Albright, J. Brines,
R. Thompson
Golden Photon, Inc.
Golden, Colorado

NREL technical monitor: R. Mitchell

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Managed by Midwest Research Institute
for the U.S. Department of Energy
under contract No. DE-AC36-83CH10093

Prepared under Subcontract No. ZAI-4-11294-03

November 1995

MASTER

ds

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

This publication was reproduced from the best available camera-ready copy submitted by the subcontractor and received no editorial review at NREL.

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available to DOE and DOE contractors from:
Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831
Prices available by calling (615) 576-8401

Available to the public from:
National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

PREFACE

Golden Photon, Inc.(GPI), is performing research under the PVMaT program, Phase 2B. The objective of the research is to advance GPI's manufacturing technology, reduce module production costs, increase average module performance, and identify ways to expand production capacity. More specifically, the tasks established for Phase I were to design and install leasehold improvements for the 2MW production line; to improve and develop product design, efficiency and marketability; to ensure uninterrupted qualified supplies and raw materials for production; to address environmental, health and safety issues encountered during production of photovoltaic (PV) modules; and to reduce the cost of manufacturing modules.

SUMMARY

Prior to contract award, GPI was able to demonstrate prototype quantities of CdTe PV modules at the 24 watt average output level using pilot scale equipment at the R&D facility in El Paso, Texas. (Refer to Photographs A-1, A-2, A-3, A-4, and A-5 for El Paso facility equipment prototypes and panel design.) PV module and process step specifications developed from successful El Paso facility pilot plant operations were used in the scale up plans for design and installation of a new 2MW PV manufacturing facility in Golden, Colorado.

In 1994, all of the processing equipment required for start up of a 2MW production line was installed at the manufacturing facility in Golden, Colorado. This involved moving GPI's facility in El Paso, Texas, to the Golden, Colorado, location. The 2MW production line installation and evaluation are complete, and PV modules are being produced. Throughput rates and yields are continually evaluated and are improving.

The "start up" phase included the debugging and design of in-house equipment critical to process prove-in. All manufacturing equipment was initiated and each process was determined to be suitable for manufacturing PV modules. Investigations of material handling techniques were completed and will be considered when throughput rates increase to 1500 per week. During the year the production rate increased from 80 panels per week in the second quarter to 350 panels per week in the fourth quarter.

In the first half of the year, the development, design, and debugging of cell interconnection equipment critical to start up was completed. During the second and third quarters, the primary focus was given to the substrate deposition steps (tin oxide, cadmium sulfide, and cadmium telluride) and cell interconnection steps (division). In general, process development, engineering and quality teams have continued to focus on identifying, baselining and improving (through re-design) actual process equipment operation parameters in order to meet the required PV panel specifications and improve process throughput rates and yields.

Table of Contents

Preface	Page 1
Summary	Page 2
Engineering Design	Page 4
Process Improvement and Development	Page 14
Sourcing Vendors, Supplies and Quality Assurance	Page 19
Site Selection	Page 22
Environmental, Safety and Health	Page 23
Manufacturing Cost and Productivity Optimization	Page 25
Future Efforts	Page 28

Figures

Figure 1-1	Task 1 Subcontract Effort	Page 4
Figure 1-2	Width Deviation 5/94	Page 5
Figure 1-3	Position Deviation 5/94	Page 6
Figure 1-4	Width Deviation 8/94	Page 7
Figure 1-5	Position Deviation 8/94	Page 8
Figure 1-6	Laser Focus Calibration	Page 10
Figure 2-1	Schematic Drawing of Interconnection	Page 15

Photographs

El Paso Facility

Photo A-1	Original Array of 1' x 1' Modules
Photo A-2	Original R&D Prototype Spray Deposition Oven
Photo A-3	Original R&D Spray Deposition Oven
Photo A-4	Original Heat Treat Telluride Oven
Photo A-5	Original Cell Interconnection Equipment

Golden Facility

Photo 1-1	Typical "New Style" Application Heads (Glass Preparation)
Photo 1-2	"New Style" Spray Deposition Oven
Photo 1-3	Typical "New Style" Cell Interconnection Equipment
Photo 1-4	New Tin Electrode Evaporator
Photo 1-5	Custom "Artificial Sun" Unit (Quality Assurance)
Photo 1-6	Spacer Application Unit (Encapsulation)
Photo 1-7	Panel Press (Encapsulation)
Photo 1-8	Prototype Shipping Containers with Modules
Photo 1-9	Dimensional Measuring Machine (Quality Assurance)
Photo 2-1	Thermocycling Chamber (Quality Assurance)
Photo 4-1	"Big Mac" GTC Facility
Photo 5-1	Chemical Mixing Area Glove Box

Note: Figures and photos are numbered sequentially within specific task number identification.

Engineering Design

The preponderance of the effort was focused on parallel designs and design completion of leasehold improvements, processing machinery, utilities, and support systems. GPI invested considerable effort in ensuring that equipment met specifications, and also ensuring that design specifications for the utilities (power distribution, cooling water, exhausts, dust collection, etc.) were capable of achieving design specifications. As can be seen from Figure 1-1 below, the Task 1 effort tapered off until the November time period when some redesign issues were being addressed. All equipment had been received by May. Start-up commenced in June to prepare each piece of equipment for production and process prove-in.

The 2 MW production facility is located at 4545 McIntyre, Golden, Colorado. This facility already provided some of the plant support systems that were required. The existing nitrogen and hydrogen storage tanks, plant wide compressed air system, and the incoming electrical power had sufficient capacity. GPI added a waste water treatment system, two dust collection systems, a high pressure compressed air system, an instrument quality air system, a cooling water system, a thermal oxidizer, a dry room, plant wide HVAC, de-ionized and reverse osmosis water systems, and miscellaneous storage rooms and racks. The facility size is adequate to accommodate the initial 2 MW plant.

Figure 1-1 Task 1 Subcontract Effort

Equipment installation, check-out, and start-up were completed in 1994. Process prove-in was in progress by November 1994 with low levels of production. The process prove-in has been most challenging. Scaling an R&D operation up ~100 fold created many challenges in equipment design and product flow. Most of the equipment was specified by and purchased from various vendors. The precision X-Y coordinate tables used for cell interconnection purposes were designed in-house due to the stringent and coordinated nature of the cell interconnection functions.

Glass Preparation Area

The glass preparation area is operating at 99+% efficiency. The glass washer/drier was purchased and operates satisfactorily. Only the usual engineering start-up effort was required. Most of the engineering effort in this area was spent on the cell interconnection X-Y unit learning the strengths and limitations of the positioning system. (Refer to Photograph 1-1 for application head illustration.) Line positioning was successfully mapped to account for the machine tolerances. The line position is held to within ± 0.04 mm. Line width is controlled to within ± 0.05 mm with the retrofit of precision air pressure control components. It was found that material preparation, application speed, application pressure, needle size, and needle height above the substrate are all factors that affect the line quality. A suitable combination of these variables was found that satisfies the product quality and the machine throughput requirements. The operations personnel were fully trained by the end of 1994, and the machinery in this area was turned over to production.

The charts below show the line width consistency and the line position improvement achieved with line mapping. Both width charts are measurements after the precision air pressure control components were added. The May 1994 position chart was a measurement before the mapping was done and the August 1994 chart is after the position mapping was completed.

POSITION DEVIATION, Spec = +/- 0.04

(MAY 1994)

Figure 1-3 Position Deviation 5/94

WIDTH DEVIATION, Spec = +/- .05

(AUGUST 1994)
Figure 1-4 Width Deviation 8/94

Tin Oxide and Cadmium Sulfide Layer Application Equipment

The spray pyrolysis ovens required rework in the conveying systems and in the heat to spray booth opening alignments. GPI engineering personnel initiated conveying system redesigns that provided smooth belt operation allowing the panels to travel through the ovens straight. The spray booth openings had not been designed to align properly with the associated heating zones. The spray booth heating zone heater configuration had to be redone by the vendor for the oven to meet design specifications. Thermal profiling and exhaust flow adjustments took months because of the slow conveying speed. The ovens have now been fully adjusted and are achieving the desired temperature profiles. The spray station systems design was completed and put into operation so trial production could commence. There was less difficulty placing the #1 cadmium sulfide oven in operation due to the lower operating temperatures. (Refer to Photograph 1-2 for typical "new style" spray application ovens.)

Cadmium Telluride Application

All but one piece of cadmium telluride application equipment was purchased per specification. The other piece (cell interconnection equipment) was designed in-house. The start-up of the purchased equipment was normal except for the ohmic contact application equipment. GPI was not satisfied with the performance of the spray applicator traverse on the cadmium telluride applicator and subsequently redesigned a new application system. The cadmium telluride layer uniformity is now being held to within 2 microns. The cadmium telluride cell interconnection equipment took considerable time to start-up due to the required precision and the interrelationship to the other cell interconnection equipment. The heat

process profiling required considerable time due to the slow conveyor speed of the processing oven. The layer develops a few small voids (pinholes) that must be filled to avoid layer shunting when the ohmic contact and back electrode are applied. The pinhole filling process requires operator judgment and thus is done manually via a machine assistance at the speed necessary for our planned production level. The ohmic contact (graphite) is applied with a roller coater. This is a different method than used in the R&D facility. The roller coating method was under development when the decision was made as to the application method. GPI proceeded with the roller coater based on preliminary technical and cost data showing the roller coater application method to be technically superior and more cost effective. The initial prove-in was extended as tests were run to develop the necessary process specifications for this new process method. Some coating head redesign was done to incorporate needed features to provide an even coating. The cadmium telluride application work cell is now functioning to specification.

Initial Cell Interconnection Steps

The initial cell interconnection equipment consists of GPI designed X-Y tables with the appropriate tooling to perform the necessary tasks. All of this equipment must be aligned with the glass preparation area cell interconnection equipment. Considerable materials and effort were required to make the sequential alignments.

An X-Y table configured with a sandblast head performs the initial cell isolation blasting away most of the material. The amount of sand, air pressure, cutting speed, underlying layer quality, and needle size all affect the desired cut width, cut depth, and cut quality. Many iterations were needed as the upstream processes were still in start-up and under constant adjustment. A suitable combination of the these variables was found that satisfies the product quality and the machine throughput requirements.

The laser performs the final isolation. It is required to cut through the conductive tin oxide layer. A fiber optic beam delivery system with final focusing optics was employed. The optimum focal point on the substrate had to be found to make sure that laser cutting was optimized. The calibration curve below shows the data taken to locate the optimum height above the panel. The depth of focus makes this machine very insensitive to set-up. The machine has not required a depth of focus adjustment since the initial set-up by engineering. Considerable precautions were taken for personnel safety as the laser machine is a Class IV device. A protective curtain and warning signs are used to protect and notify personnel in the area. Inside the curtained area laser goggles are required for all personnel.

A dimensional measuring machine was employed to verify the precision of the cell interconnection equipment and applications technology. (Refer to Photograph 1-9 for illustration of dimensional measuring machine.)

LASER FOCUS CALIBRATION 5-19-94

Figure 1-6 Laser Focus Calibration

The application of the buffer material is done on a machine identical to the glass preparation cell interconnection machine. Start-up of this equipment was completed quickly once the start-up on the glass preparation cell interconnection equipment was completed. (Refer to Photograph 1-3 for illustration of typical "new style" cell interconnection equipment.)

The operations personnel were fully trained by the end of 1994 and the machinery in this area was turned over to production.

Final Heat Treating and Back Electrode Application Steps

Commercial equipment was purchased to perform these functions. Start-up was normal. A splash shield was designed and installed in the tin evaporator to prevent occasional splattering of tin onto the panels. A power ramping control system was designed and implemented by GPI engineering to provide single push-button control of the process, thus freeing the operator to perform other tasks once the evaporation process is initiated. A factory service representative was used to commission the tin electrode evaporator and to train the team leaders. The plant personnel are fully trained and the equipment has been turned over to production. (Refer to Photograph 1-4 for illustration of tin electrode evaporator.)

Final Cell Interconnection and Bordering Steps

A sandblast unit identical to the initial cell interconnection sandblast unit performs the final cell separation. Once the initial cell separation sandblast unit was fully functional, the start-up of this unit proceeded rapidly. A dry grind edge deleting machine follows the final cell separation machine and removes the material from around the edges to provide a good surface for encapsulation. The edge

grinding machine was a special design done to specification. While the machine performed the required tasks, the dry grinding performance was disappointing. While the machine is in production use, GPI continues to work on this area to improve quality and productivity.

The panel must pass a preliminary test for functionality at a minimum threshold before proceeding on to encapsulation. The screen tester was designed in-house to satisfy our specific requirements. The panel is illuminated on a calibrated tester and V_{oc} , I_{sc} , V_{mp} , and I_{mp} are measured. Fill factor (FF) and $Watts_{mp}$ are calculated. Bussbars are applied upon passing the screen test. (Refer to Photograph 1-5 for illustration of screen tester.)

Encapsulation Steps

GPI uses an insulated window style glass on glass construction for encapsulating the photovoltaic cell. Much of the equipment used in the insulated glass industry is directly applicable to the GPI encapsulation process. A solid steel spacer is used instead of the standard aluminum desiccant filled spacer. Polyisobutylene (PIB) is used as the spacer to glass seal. The PIB is applied with commercial equipment in the standard method. The module is assembled in a jig with the photovoltaic cell, the back glass, desiccant, and the PIB'ed spacer. A structural sealant is applied around the edge. The junction box is secured to the module, and the connection is made. The junction box is a sub-assembly that GPI has fabricated outside for cost reasons. The frame is attached and the junction box is potted, completing the module assembly. This work cell is labor intensive utilizing machine functionality. Capital expense was minimized in this area in case of encapsulation modifications. Indeed there have been some changes, since the original encapsulation schemes were envisioned in the R&D facility. The former metal backcap has been replaced by the glass backcap. An aluminum frame has been incorporated to facilitate mounting on the GPI array structure. Once the encapsulation scheme becomes stable, engineering effort will be applied to reducing the manpower requirements of this area. The encapsulation work cell is functioning as originally envisioned. (Refer to Photographs 1-6 - 1-8 for illustrations of key encapsulation equipment.)

Utilities: Dust Collection System

The dust collection systems are critical to the cadmium based photovoltaic process. The systems must balance and satisfy process, worker safety (OSHA), and environmental requirements while being economically and operationally practical. It was found during the startup phase that the yield (process efficiency) of the various production operations, especially the tin oxide and cadmium sulfide applications, are very sensitive to changes in the flow of dust collection air.

These flow changes can be caused by duct and orifice clogging, filter loading, and temperature changes both at the processes themselves and at the fan. Since the processes do not run continuously, the interplay between the processes can be quite complex. The changes in temperature result in two separate effects. As the temperature rises, the viscosity and the actual flow volume both rise. Both of these effects increase the pressure drop in the ducting. In order to stabilize the production processes, a constant weight based on standardized flow must be maintained. This was accomplished by using a combination of local flow orifices and a control system that varies the fan speed automatically to compensate for filter loading and varying air densities. Because the flow orifices measure actual flows, a system of thermocouples and compensation charts are used to balance the flows based on standard conditions. Also, the charts include compensations for the actual pressure tap locations versus theoretical locations based on field testing. Considerable effort has been expended (and continues to be expended) to resolve these problems.

The nature of the solutions being applied is that they are quite corrosive and tend to plate out on cooler surfaces. Part of the start up effort was to determine the cleaning schedule required for the most heavily

loaded ducting and the flow orifices. As the orifices load with scale, the shape becomes similar to a nozzle, and the readings drop even though the flow remains relatively constant. The design of the ducting, including materials of construction and installation geometry, reflects the requirements listed above plus the need for an inherently balanced system. The system is designed to be balanced with bleed air rather than in-line dampers so the dampers do not become fouled and the overall air temperature is reduced. The maximum temperature is critical because of the limitations of the filters and gaskets.

High Pressure Compressed Air System

Sand blasting operations were plagued by air supply problems during much of 1994. Lack of reliability, varying air pressure, and inadequate air pressure were experienced. "Intensifiers" were used during startup and optimization phases. Once the design criteria was established, a new system was installed. The system includes a 200 psi compressor, an 80 gallon receiver, a desiccant dryer, 6 stages of filtration, and a pressure regulator. Some relatively minor startup problems have been encountered but the overall performance is vastly improved.

Waste Water Treatment System

A new waste water treatment system was designed by Golden Photon engineers. The system includes mixing tanks, holding tanks, a filter press, an automatic sampler and various pumping systems. Various waste waters are stored in polyethylene tanks. Wastes are mixed based on the estimated cadmium content. Wastes with an estimated cadmium content of less than 0.5 PPM are pH adjusted above 7.0, mixed, and sampled without treatment. The samples are tested by an independent laboratory. If the lab results confirm that the cadmium content is less than 0.5 PPM, the water is dumped to the sewer.

Water Systems

The de-ionized water available from the building central system has not met Golden Photon's needs for purity. Additional polishing along with resistivity meters for quality control have been added. Problems have been rather constant with the pumping systems. The pumps have not been dependable. New pumps are being reviewed to solve these problems. Two levels of de-ionized water purity are distributed within the operation (14 megohm-cm. and 18 megohm-cm.). The higher purity water has to be distributed in polypropylene piping in order to maintain its purity. This piping is difficult to work with and the compression fittings leaked in numerous locations. The leaks were finally resolved with careful attention to detail.

The reverse osmosis water system has been quite reliable except for the reliability of the pumps as noted in the paragraph above. Some piping details were changed in an attempt to improve the pumping situation. Little long-term improvement has been seen.

Cooling Water System

The cooling water system suffered from corrosion and fouling problems early on. The piping finally had to be acid cleaned and then treated with inhibitors and biocides. This worked for a while but the fouling returned. A chemical analysis of the water revealed that very fine dust was entering the system through the roof top mounted cooling towers. The dust was rendering the inhibitor ineffective and providing a home for biological growth. A high efficiency side stream cartridge filter was added to the system to remove the dust particulates. This has solved the problem.

HVAC Systems

The main building HVAC system performance has been found to be a key to the yield of the tin oxide and cadmium sulfide application operations. Since this system supplies the air being pulled through the production equipment by the dust collection system, its operation is both sensitive and critical. During the startup of the production lines it was found that certain processes are very sensitive to both temperature and humidity fluctuations. This was not known during the original design. The HVAC control system's logic and set points have been modified in an attempt to overcome the mechanical system's shortcomings. Several different theories trying to balance the temperature without having control of the humidity have been tested. Adjusting the temperature with regard to the humidity in a way that gives constant enthalpy seems to give the best results. Work continues in this area to try to improve system performance.

The dry room's dehumidifier has been an occasional source of problems. The desiccant drum's drive system is the weak spot. The manufacturer's solutions have not shown long term reliability. Recent modifications made in-house show promise at this point. The overall system has been giving very consistent temperature and humidity levels and should meet the needs of the production operations.

Packaging & Shipping

Crating of the modules for storage and shipment was an interesting problem. The overseas shipping of non-returnable containers in a cost effective manner proved most challenging. Several prototype containers were developed and tested in actual shipping tests. A wood structure chipboard design was selected and has been used quite satisfactorily. (Refer to Photograph 1-8 for illustration of prototype shipping container.)

Process Improvement and Development

During Phase I of this Subcontract period, approximately 10-20% of the effort was focused on the objectives of this task. The overall objective of this task is to improve product design, product efficiency, and product marketability.

A major milestone for this task, related to improvement of process control, is to achieve less than 5% standard error within batches of modules averaging 24 watts at high yields.

The areas of focus within this task include:

- Evaluation of process yields of methods that minimize division losses,
- Product qualification testing,
- Product design improvement; cost minimization and evaluation (by accelerated and real time stress and life testing) of improved encapsulation designs,
- Evaluation of current QA/QC activities and techniques within the module-producing process.

Background and Review

The importance of the effort within this task is clear. Only with proper, complete, and continually improving efforts within the Quality Control arena will the photovoltaic module-manufacturing process be successfully optimized.

At the beginning of the first phase of the subcontract, the new processing facility was still primarily in the construction stage. Much of the equipment was installed but not yet capable of operating, much less operating to specifications. The procedure documentation that existed was based entirely on the results from the pre-existing processing line from the El Paso, Texas, facility. The development of a quality assurance/quality control program applicable to the 2MW facility was therefore developed and optimized at the same time as the processing line. Since initial startup was delayed, so was the development of the Quality Control program. Nonetheless, much was accomplished in this area, albeit later than originally intended.

By September of 1994, nearly all the equipment was operational at some level, but only very small quantities of finished modules were being produced. Utilities and systems were not yet fully functional. The few modules that were completed were not qualifiable due to low wattage and/or due to not representing a reproducible process. During this period, the procedures and methods of processing were rapidly changing, and it was difficult for the documentation and training to keep pace with the changes. Reproducibility of the process was therefore quite questionable during this period.

By the end of 1994, the end of Phase I, all the equipment, utilities, and systems were operational. Effort continued with a primary focus on trimming and optimizing the process steps in order to meet specifications based on the El Paso facility results. More modules were being completed than in September, but they were still too variable and low in wattage for proper qualification testing. The procedures and methods of processing were still changing rapidly, and the documentation and training was still significantly trailing the actual changes. Reproducibility of the process was considerably improved but still variable during this period.

Methods Utilized

The following methods and areas of effort were used as guidelines for this task:

Evaluation of Process Yields of Methods that Minimize Division Losses

The purpose of these efforts is to insure that appropriate procedures, methods, materials, tests, documentation, and training is in place in order to properly evaluate and optimize the yields and quality of the cell interconnection (division) steps.

The R&D group was significantly delayed in constructing and optimizing laboratory areas and prototype equipment areas. This fact delayed the attainment of a feasibility milestone related to Next Generation interconnection methods by R&D, so the focus on yield evaluation of division losses during Phase I by the Operations department was entirely relegated to the existing technology and techniques. These techniques were dimensionally non-optimal and the reproducibility of yields achieved on the pre-existing equipment was unsatisfactory. By the end of the third quarter these issues had been substantially resolved.

The interconnection technology that was optimized during Phase I was composed of the following as schematically drawn in Fig. 2-1. There is a material removal step (0.76 mm wide) that penetrates all of the layers down to the tin oxide electrode layer. A laser scribe (0.30 mm wide) of the base tin oxide isolates the strips electrically from each other. A permanent resist material (0.81 mm wide) covers the edge of the tin oxide electrode and the laser isolation cut on the negative side of the original cut. After evaporation of metallic tin on top of the structure, a second division cut (0.46 mm wide) removes material down to the tin oxide electrode and opens each strip from each previous strip, thereby resulting in a series of monolithically interconnected strips.

Fig. 2-1

Figure 2-1 Schematic Drawing of Interconnection

Although the optical losses of such a structure are high (~13%), the measurement techniques, the alignment, and quality control techniques are certainly analogous, if not identical, to those to be utilized for the implementation into a manufacturing setting of virtually any next generation division methodology.

Effort during Phase I was primarily focused on the following two areas:

Implementation of proper measurement techniques to allow alignments to occur properly.

An accurate optical alignment system was purchased by GPI. By developing and utilizing statistical methods of analysis and feedback, the engineers and technicians responsible for adjusting and optimizing the alignments of the X-Y tables developed a greatly improved, nearly continuously automatic processing method. Alignment of the interconnection steps has been shown to be quite satisfactory at each point in the process including after initial removal and laser, after permanent resist, and after 2nd division.

Optimization of power density, pulse rate, focus, and speed of the laser cut

A straight-forward optimization of the laser scribe process was accomplished. A laser scribe is a multi-variant function of the speed of the scribe, the power density, pulse rate, and optical characteristics. The optical characteristics of the present laser after modifications, resulted in a depth of field of the focus of approximately 0.25 mm and a width of cut at the optimized power density setting, height, pulse rate, and speed of approximately 0.250mm. These conditions result in lasing conditions that are virtually independent of the substrate thickness or variation in thickness. The power density of the laser and the speed of the scribe were then adjusted to a reasonable, but arbitrary value. The overlap of the pulses of the laser was then adjusted to provide approximately 90% overlap. A height optimization was then accomplished. The power density at the films was then reduced to approximately 1.4X of that density actually required to achieve isolation at the center of the optimum height in order to avoid microcracks in the glass caused by excessive power.

The yields at the beginning of Phase I were extremely low. By the end of Phase I, these yields were up to 100% with the majority of the batches.

Product Qualification Testing

The purpose of these efforts is to insure that the present and future module designs become and remain properly warrantable in the marketplace. Advancement within this area of effort was considerably affected by not having significant quantities of modules, and especially by not having modules that met reproducibility and output milestones. Nonetheless, for significant design changes, preliminary screening was accomplished through thermal cycling of the newly produced prototype modules. (Refer to Photograph 2-1 for illustration of thermocycling equipment.)

Cost Minimization and Evaluation (by Accelerated and Real Time Life Testing) of Improved Encapsulation Designs

The purpose of these efforts is to insure that appropriate designs and redesigns are created and evaluated in order to better insure that the photovoltaic module design continues to develop and improve. Several module designs were evaluated during Phase I. Several of these designs exhibited problems with breakage of the module package in the field for two primary reasons.

One version, that was filled with desiccant beads, showed a tendency to break after deployment. The basis of this breakage was found to be due to a settling of the beads during the warm hours of the day as the gas inside the module tended to expand with temperature. During the cold hours during the night

which followed, the contraction of the gases inside a structure, where the beads do not reversibly return to their original position, caused a pressure on the outside of the structure. An inflection at the level where the beads had settled caused stress on the glass and subsequent breakage, sometimes after as much as six months of cycling. A solution to this problem was demonstrated by holding the desiccant in a matrix so that it could not settle. Breakage of modules in the field was reduced to the level (<1%) with only specific quality assurance issues remaining.

In order to properly test breakage under worst case conditions, a testing protocol was developed. For the types of problems encountered, simply deploying modules in the field was sufficient for identification and solution of most of the issues observed. Colorado weather near the mountains can result in quite severe conditions. The worst conditions observed to date for module breakage is snow followed by the typical sunny day of Colorado. The temperature differentials across the module produced by the conditions where a thick blanket of snow (0.5-3") covers a portion of the module and holds the module near 0 degrees Celsius, and the uncovered area of the module is being illuminated with as high as 1000W/m² insolation, raising the temperature on that area of the module to near the Normal Operating Cell Temperature (NOCT), or approximately 55-60C. This large temperature differential over large areas of the module can cause significant stresses. Many of the early versions of module designs at Golden Photon could not withstand such conditions. However, the present design appears quite resistant to the stresses caused by such conditions. In fact, they appear so resistant that in every case where a crack has developed, an observable defect can be found that corresponds with some poor assembly or manufacturing practice within the standard processing line.

Evaluation of Current QA/QC Activities and Techniques Within the Module-Producing Process

The purpose of this effort is to insure that appropriate methods of process control are evaluated, and that improved methods are implemented where possible. This effort includes statistical process control, documentation and change procedures, incoming material screening, and appropriate training.

At the beginning of Phase I, very little of this program existed. By the end of Phase I, QA/QC activities had been evaluated and implemented where practical to do so.

Significant Results, Conclusions and Future Efforts

Delays in implementation, startup, and prove-in of the processing equipment and laboratory areas for the 2MW facility caused a subsequent delay in meeting a number of important milestones. However, the milestones were basically pushed back by an equivalent amount to the initial delays regarding start-up of equipment, facilities, and systems.

Efforts on this subcontract task, although delayed, are quite significant. Many of the milestones that were achieved late were indeed finally achieved, and further delays should be of a less severe nature. The module designs were properly evaluated, redesigned, and tested during this phase with the result that an improved module design has been partially qualified. Full qualification is expected to occur in the near future.

Specifically, within this task, the process control was realized that allowed a standard error of less than 5 % at an average module output of 20 watts, not the 24 watts initially proposed. However, this milestone is still expected to be met completely in the near term. This milestone in itself is probably the best indicator of process definition and process control.

The yields of the interconnection steps at the beginning of Phase I were extremely low. By the end of Phase I, these yields were up to as high as 100% for a given batch.

There are a number of areas for continued effort within this task. In subsequent phases, the general objective of this task will continue to be to improve product design, product efficiency, and product marketability.

In Phase II, a significantly larger focus will be placed on:

- Verification that process control methods are functioning properly,
- Identification and quantification of process problems,
- Investigation and implementation of solutions to the problems found,
- Identification of means to potentially increase production rates of throughput,
- Identification of methods to quantify material utilization throughout the process,
- Identification of methods to reduce material utilization through improved equipment designs, and
- Evaluate and test proposed improved methods and incorporate where applicable.

Sourcing Vendors, Supplies and Quality Assurance

Quarter 1 - Activity and Accomplishments

A preliminary procurement/contracting program for qualified raw materials and suppliers has been completed. The major emphasis is to clearly document material specifications for each respective vendor and baseline vendor capability based on their process and some analytical testing done by Golden Photon, Inc.

The specifications developed by Engineering and Quality Control provided Purchasing with the necessary data to begin the vendor identification program. Many of the vendors utilized by Golden Photon, Inc., at the El Paso plant continued to provide critical materials during this interim period; however, new vendors with higher quality characteristics were identified by the purchasing department during this time period.

Chart 3a illustrates the progress of utilizing qualified small and small disadvantaged companies versus goal.

Chart 3a:

	<u>Dollars</u>	<u>Percent</u>
Small Business Concerns	63,051	99.7%
Large Business Concerns	176	.3%
Total	63,277	100.0%
Small Disadvantaged Business Concerns	1,153	1.8%

Quarter 2 - Activities and Accomplishments

Ongoing efforts resulted in refined material specification for many critical raw materials. Those refinements were in part a result of the recognition of vendor process capability as well as some testing done internally at Golden Photon, Inc.

A focused effort by Operations and Administration to define a Material Resource Planning tool was initiated. The major elements of this MRP system follow:

1. The production scheduling system is driven by standard production rates according to process and expected yield factors. This system is regarded as an MRP driven with an interface requirement to the MPP system.
2. The Standard Bill of Material System standardizes the material usage by process and product. These standards are based on historic trends at El Paso and some engineered factors. The Standard Bill of Material is compounded by the Production Scheduling System to forecast future purchasing needs.
3. The Master Inventory System provides on-line records of inventory on hand and open orders of material not received. The Inventory System keeps perpetual record status based on production orders processed and closed. Inventories are reduced by interfacing with the Standard Bill of Material System and the Shop Order Control System. Cycle counts are designed to adjust the Perpetual Inventory to a Physical Inventory and reduce system surprises.
4. The Shop Order Control System is driven by the Master Schedule System. This system stages quantities of production by process. Each order is opened when product begins and closes based

on actual production activities. Records generated by production are input to close each order and stage the next process. The interface with the Standard Bill of Material is used to generate usage records for the job completed.

5. The Material Resource Planning System interfaces with the Master Scheduling System, Master Inventory System and Standard Bill of Material System to drive Purchasing requirements. Vendor lead times are identified by each respective vendor to allow computation of reorder requirements for the purchasing department.

The benefit of this system is that it provides management with tools to insure material availability based on production/sales requirements. This is necessary to minimize inventories and operation disruptions. The chart below describes this integrated system and the relationships of each module.

Chart 3b illustrates the progress of utilizing Qualified Small and Small Disadvantaged companies versus goal.

Chart 3b:

	<u>Dollars</u>	<u>Percent</u>
Small Business Concerns	133,623	71%
Large Business Concerns	55,516	29%
Total	189,139	100%
Small Disadvantaged Business Concerns	6,793	4%

Quarter 3 - Activities and Accomplishments

As the start up of the plant continued during this time frame, new potential vendors for critical new materials were identified. In addition, as process understanding of GPI was developed, specifications for materials were revised and tolerances and variations were either tightened or relaxed.

A major success for Operations and Administration was the implementation of an integrated network--P.L. based accounting and inventory control system. The modules described in the Second Quarter update of this report were fully functional by September of 1994. The benefits of these tools will not be realized until the plant start-up phase is nearing completion and the process demonstrates consistent performance. The ability to operate to schedule will increase confidence in the system when making forward commitments with vendors.

Another major accomplishment was the development of new vendors in the encapsulation process. This accomplishment reduced the number of materials sourced by single vendors and provided competitive pressures to lower costs. The financial planning process was also completed during this time period. The significance of this activity was to benchmark prices, developed by material type, and to lower overall material costs by 15% per unit than was reported in 1994. The basis of this overall target reduction was based on projected higher volumes in 1995, vendor competition and improved purchasing negotiations with vendors.

Chart 3c illustrates the progress of utilizing Qualified Small and Small Disadvantaged Companies versus goal.

Chart 3c:

	<u>Dollars</u>	<u>Percent</u>
Small Business Concerns	112,439	71%
Large Business Concerns	176	.3%
Total	63277	100.0%
Small Disadvantaged Business Concerns	1153	1.8%

Quarter 4 - Activities and Accomplishments

Additional focus on a material Q.C. program was demonstrated. Vendor programs of self inspection and distribution of Q.C. analysis by lot identification was agreed to by two major vendors. Additional incoming inspection methods were developed on other critical materials. Procedures and statistical methods were developed and are currently being developed as GPI works towards a Functional Material Inspection Program. GPI management believes this will continue to pay large dividends as process capabilities are understood and material variations and process tolerances are correlated.

Tremendous progress was made to reduce material costs by 15%. The purchasing department made several vendor visits to introduce the company goals and objectives over the next three years. This allowed each respective vendor a better understanding of GPI and improved their willingness for future favorable pricing with our company.

Site Selection

Strategic planning and careful analysis in site selection was necessary to meet the overall goal of the PV manufacturing process: to provide “proof of concept” of the manufacturing process and determine viability of a eventual proposed 10 MW PV manufacturing. The intent of this task was to determine where to locate the 2 MW manufacturing process, as well as how to utilize the space available after site selection has been determined.

GPI utilized space available at an existing facility located at 4545 McIntyre Street in Golden Colorado. (Refer to Photograph 4-1.) Although this facility supports operations of other businesses associated with Golden Photon’s parent company, Golden Technologies, Inc., through careful engineering of the PV manufacturing process line layout, sufficient space was available to support the 2 MW capacity required. Several leasehold improvements were necessary to support several process utilities systems including (Dust Collection, Waste Water Treatment, and HVAC (refer to Task 1 and 5 for systems descriptions), as well as building isolation to ensure security (walls and special flooring).

In addition to the above, the intent of this task was to pursue all permitting activities necessary to ensure compliance with all federal, state, and local requirements. All permits necessary for the construction and operation of the 2 MW facility were secured to support the time ongoing project schedule. These included: air permit, water permit, storm water permit, several ongoing construction permits, and building occupation permits. No problems were encountered during Phase I related to permitting during the construction, process “start-up” and “prove-in” phases of the project.

Environmental, Safety and Health

The intent of this task was to help ensure that the 2MW manufacturing process would address all current environmental, safety, and health requirements established by federal, state, and local authorities.

Procedures and Monitoring

Within this task, Golden Photon identified/baselined types and volumes of process waste generated from the manufacturing process. In addition, Golden Photon developed and implemented an Employee Exposure Monitoring Plan to ensure employee safety from exposure. During the initial design of the 2 MW manufacturing plant, Golden Photon worked to minimize uncontrolled emissions of volatile organic compounds (VOC and cadmium dust, hazardous waste materials, and waste water). Below is a summary of the main process utilities systems developed to achieve these desired task goals. As a result of the progress made from this task during Phase I, Golden Photon was able to mitigate environmental impacts of the manufacturing process while increasing worker safety.

The preliminary EHS Plan for the 2MW facility was completed in March 1994 and updated throughout the year to reflect actual encountered situations. The plan included various occupational safety procedures, hazardous communication and training, updated active MSDS files, personal protective equipment procedures, egress decontamination equipment and procedures, and waste handling and disposal procedures.

A local EHS firm was contracted to assist in baselining the building and property for cadmium, as well as assisting in developing procedures for cadmium handling and disposal prior to the use of cadmium materials in the GPI process. Assessments of the building and property concluded that the baseline cadmium levels were consistent with "normal" background levels.

A comprehensive occupational hazardous chemical monitoring program designed for measuring and controlling airborne cadmium dust and Volatile Organic Compounds (VOC) was completed and was implemented during the "start-up" phase when hazardous chemicals were initially employed. In April, several cadmium and VOC containing materials were prepared or consumed as each new piece of process equipment was started up. By June, all PV panel batches were processed using "real" recipes that included cadmium. Throughout the year, the "operator-based" and process "equipment-based" air samples (including wipe samples of equipment and floor) were taken for each major work station area when the process was either altered or when new hazardous chemicals were employed. All airborne cadmium monitoring conducted consistently demonstrate that actual levels are far below the OSHA action level (PAL of 2.5 micrograms per cubic meter). The ongoing wipe sampling data also revealed that consistently low levels of cadmium have been maintained in spite of the augmented cadmium usage from increased production levels experienced towards the end of the year.

All production related chemical batch preparations were prepared in a centralized glove box unit to ensure cadmium dust retention. (Refer to Photograph 5-1 for glove box illustration.) This unit proved essential to maintaining low levels of airborne cadmium in the lab area.

Dust Collection System

Protection of the workers from cadmium and other chemicals and solvents is accomplished by maintaining a minimum of 150 feet per minute capture velocity at all processes. The efficacy of this design criteria has been proven by air monitoring tests. Processes are prevented from operating, unless the dust collection system is functional, by a system of controls based on duct vacuum at each process.

The nature of the processes used in this facility are such that a large portion (>10% by weight) of the collected dust is in the sub-micron range. This type dust coupled with the very stringent Colorado rules on cadmium emissions led to the use of a highly efficient and redundant filtration system. The primary filtration system uses surface loading cartridge filters that are rated at over 99% efficient even in the sub-micron range. These cartridge filters are cleanable using compressed air pulses. The secondary filters are ULPA rated (99.999% efficient @ 0.12 micron). These filters are not cleanable. A failure of a primary filter would be caught by the secondary filters. Differential pressure gauges and alarms add additional security. The filter systems were tested by an independent testing service using 0.3 micron DOP particles and a LASER counter before any cadmium was introduced into the system. The filter elements for both filter systems are changed using a bag-in, bag-out system to contain hazardous material trapped by the filters.

Processes using VOCs (Volatile Organic Compounds) are collected by a separate but similar system. The processes that use VOCs do not produce small diameter toxic dusts so the primary filter system is less efficient than the one described above. The secondary system, however, uses the same ULPA filter system. The final stage of this system uses a natural gas fired catalytic oxidizer to destroy the VOCs. The oxidizer had some control problems during startup, but these seem to have been resolved.

Waste Water Treatment System

Wastes with an estimated cadmium content of more than 0.5 PPM are treated before being sampled. Treatment consists of the following operations: the pH of the water is raised above 7.0 using quick lime, dissolved cadmium is precipitated using sodium sulfide, the precipitated cadmium is removed by the filter press, the water is stored in a holding tank and sampled, if lab results confirm that the cadmium content is less than 0.5 PPM, the water is dumped to the sewer. Lab results above 0.5 PPM cause the water to be retreated.

Considerable time has been expended optimizing this process. The quantities of sodium sulfide, filter aid (PROFIX) have been reduced and the cadmium content after treatment has been reduced. Because the pressure drop across the filter and optimum flow rates were not known when the components were purchased, many system modifications have been made. The flow rate through the filter press is now approximately 3 times the original design rate. A flocculating agent is now being used to improve the filterability of the solids. Wastes from various sources have been tested to give the operators a better idea of the approximate cadmium content. The tanks allocated to each use has been changed to better match the various flows and schedules involved in the treatment of the waste water. The tanks are not switched between uses without first cleaning the tank to the level of its new use. A number of pumping and piping problems have been encountered. Numerous piping and pumping changes have been made to accommodate new operating methods as well as to overcome system deficiencies.

Manufacturing Cost and Productivity Optimization

The Task 6 objectives as stated in the Phase 2B Statement of Work are as follows:

- Process rates for a number of the steps having slower deposition rates shall be increased by approximately a factor of 3 over the maximum production rate of the Golden Photon, Inc., plant in El Paso; (hereafter these rates shall be referred to as "original rates")
- Process yields at a 24 watt average module output level shall be increased to 85% by the end of phase 1 with <20% downtime compared to (the initial process-wide start-up yield estimated at <60%); and
- Average module output off the line of 28 watts at low yields

The heavy emphasis on production start-up and prove-in commenced in June. All of the layer fabrication and cell interconnection equipment was required to be functioning to specification to successfully complete the above stated objectives. Due to some of the late deliveries and equipment fabrication problems, the start-up began later than planned. The deposition ovens start-up and prove-in were delayed due to conveyor fabrication problems and thermal balancing. The new ovens were radically different than the El Paso ovens. These new multi-stage ovens provided the increased processing speed necessary to meet the first objective. The deposition rates were successfully increased by a factor of 6 to 13 times the original rates exceeding the original objective.

Module wattage and process yields were below the stated objective by the end of 1994. Several module batches were fabricated with average power exceeding 20 watts per module and one batch exceeding 23 watts per module. The final process yield was below 60% implying an average yield per process step of 99.00%. An 85% yield on 51 sequential processes implies an average yield per process of 99.68%. While many of the processes were achieving the 99.68% yield level or better, a few of the processes were lagging bringing the overall yield down. The new equipment designs and associated problems, production personnel training, production systems implementations, and quality control systems implementations all created significant challenges in accomplishing the wattage and yield objectives.

No modules exceeding 28 watts were fabricated.

Glass Preparation Steps

The glass preparation area is running at 99+% yield. The cell interconnection process speed has been improved by a factor of 4 with the improved machinery design and the early addition of a second head. This rate limiting process provided excess capacity in the glass preparation area thus reducing labor costs.

Spray Deposition Ovens Steps

The tin oxide oven yield remains at ~70%. There have been occasions when the yield has been as high as 97%. Effort is being focused on the cause and effect of the yield deviations. The higher yield was attained over a reasonably long processing period and on multiple occasions indicating that the higher yield is definitely achievable. The cadmium sulfide oven yield is ~90%. There have been multiple occasions when the yield has been 100%. The parameters affecting the oven yields are now fairly well defined and GPI is in the process of implementing changes to improve and stabilize the oven yields.

Cadmium Telluride Application Step

The improved equipment designs and the applicator modification has resulted in bettering the original uniformity specification. The work cell yield is approaching 99% with many 100% yield batches being reported. Further work in this area relates to improving the process wattage to achieve the 24 watt per module goal. The pinholing operation has achieved the factor of three production rate increase through the implementation of mechanically assisted operator work stations to provide the accuracy and processing speed.

Electrode Preparation Steps

The pinholing operational speed has been increased by a factor of 3 to 4 with the implementation of the design changes outlined in Task 1. Ohmic contact application is at least a factor of 5 faster than the original rate. All of the layer surface preparation machinery is a factor of 2 faster than the original equipment.

Initial Cell Interconnection Steps

In-line processing equipment eliminating the need for the operator to handle panels between steps in the work cell has reduced the manpower requirement by a factor of 3. The machines have also been designed to accept the next level of automation to further increase productivity.

Back Electrode Application Steps

Layer uniformity was improved by calculating the optimum evaporator boat placement. Quality control checks have verified that the back electrode uniformity is being held to within 10% versus the 19% uniformity in the El Paso plant. This is almost a two-time process improvement.

Final Cell Interconnection and Bordering Steps

The interconnection of this equipment into a work cell enables a single operator to run multiple machines. A four to six times process speed improvement has been realized over the original rates.

Encapsulation

The busbar application step remains a manual application assisted with specially designed hand tooling. An automated machine has been designed and fabricated. It is in the initial stages of start-up. Work on this machine will continue after the layer application and cell interconnection equipment are debugged and process prove-in is complete. Once 24 watt average panels are achieved, effort will be re-focused on the automated busbar application machine. The present busbar method has resulted in approximately a two-times increase for this step.

FUTURE EFFORTS

GPI will continue to work on efforts to improve yields, production rates and module output during Phase II of the PVMaT program. The projected work also includes the designing and specifying of the next 4MW portion of the production capability as a step toward completion of a 10MW plant. As GPI adds production capability, we will continue to evaluate and debug equipment, the QA/QC and ES&H programs will be refined, and multiple sources for materials will be identified in order to reduce the cost of raw materials. The data from the 2MW production line will be evaluated to establish a new baseline, and the process controls will be used to increase rates and improve material utilization. The 6MW production line should be implemented by the end of Phase II with post CdTe process yields of 95% at a 24 watt average and 85% for a 28 watt average output level.

The processing equipment and material handling capabilities required for the next 4MW of additional production of the 10MW plant will be identified. Upon completion of equipment design and specification, GPI will develop line installation procedures and conduct machinery start up and process evaluation. Other design requirements include an analysis of the line labor demands and the evaluation of labor minimization methods. The use of automatic traffic controlled conveying at the 6MW level to connect the conveyORIZED processes will be explored. This will include the design and debugging of automation equipment, investigation of material handling alternatives, and implementation of material handling alternatives, and implementation of material handling automation.

During Phase II, GPI will develop specifications for manufacturing procedures to be utilized in the expansion to a 6-10MW manufacturing line. Methods to be used toward this effort are verification of control methods, review of production records to identify and quantify process problems, and investigation and implementation of solutions to the identified process problems. GPI is also going to review the results of scaling up the area of the present module while evaluating the impact of increasing the production facility.

In general, GPI will update and document monthly costs, yields, and throughput rates associated with each process step. Each area will be analyzed and averaged to provide the basis of the presentation of relative cost and yield data. This effort is intended to continue to optimize key manufacturing processes and increase production rates and yields.

FUTURE EFFORTS

GPI will continue to work on efforts to improve yields, production rates and module output during Phase II of the PVMaT program. The projected work also includes the designing and specifying of the next 4MW portion of the production capability as a step toward completion of a 10MW plant. As GPI adds production capability, we will continue to evaluate and debug equipment, the QA/QC and ES&H programs will be refined, and multiple sources for materials will be identified in order to reduce the cost of raw materials. The data from the 2MW production line will be evaluated to establish a new baseline, and the process controls will be used to increase rates and improve material utilization. The 6MW production line should be implemented by the end of Phase II with post CdTe process yields of 95% at a 24 watt average and 85% for a 28 watt average output level.

The processing equipment and material handling capabilities required for the next 4MW of additional production of the 10MW plant will be identified. Upon completion of equipment design and specification, GPI will develop line installation procedures and conduct machinery start up and process evaluation. Other design requirements include an analysis of the line labor demands and the evaluation of labor minimization methods. The use of automatic traffic controlled conveying at the 6MW level to connect the conveyORIZED processes will be explored. This will include the design and debugging of automation equipment, investigation of material handling alternatives, and implementation of material handling alternatives, and implementation of material handling automation.

During Phase II, GPI will develop specifications for manufacturing procedures to be utilized in the expansion to a 6-10MW manufacturing line. Methods to be used toward this effort are verification of control methods, review of production records to identify and quantify process problems, and investigation and implementation of solutions to the identified process problems. GPI is also going to review the results of scaling up the area of the present module while evaluating the impact of increasing the production facility.

In general, GPI will update and document monthly costs, yields, and throughput rates associated with each process step. Each area will be analyzed and averaged to provide the basis of the presentation of relative cost and yield data. This effort is intended to continue to optimize key manufacturing processes and increase production rates and yields.

Photo A-1. Original Array of 1' x 1' Modules - El Paso Facility

**Photo A-2. Original R&D Prototype Spray Deposition Oven
El Paso Facility**

**Photo A-3. Original R&D Spray Deposition Oven
El Paso Facility**

**Photo A-4. Original Heat Treat Telluride Oven
El Paso Facility**

**Photo A-5. Original Cell Interconnection Equipment
El Paso Facility**

**Photo 1.1. Typical "New Style" application heads (Glass Preparation)
Golden Co. Facility**

**Photo 1-2. "New Style" Spray Deposition Oven
Golden Facility**

**Photo 1-3. Typical "New Style" Cell Interconnection Equipment
Golden Facility**

**Photo 1-4. New Tin Electrode Evaporator
Golden Facility**

**Photo 1-5. Custom "Artificial Sun" unit (Quality Assurance)
Golden Facility**

Photo 1-6. Spacer Applicator Unit (Encapsulation)
Golden Facility

Photo 1-7. Panel Press
(Encapsulation)
Golden Facility

**Photo 1-8. Prototype Shipping Containers with Modules
Golden Facility**

**Photo 1-9. Dimensional Measuring
Machine (Quality Assurance)
Golden Facility**

**Photo 2.1. Thermocycling Chamber
(Quality Assurance)
Golden Facility**

**Photo 4.1 GTC "Big Mac" Facility
(Golden Colorado)**

**Photo 5.1 Glove Box
(Golden Facility)**

**Photo B.1. Completed Module Package Design
(Golden Facility)**

**Photo B.2 Test Array of 2' x 2' Modules
(Golden Facility)**

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE November 1995		3. REPORT TYPE AND DATES COVERED Annual Subcontract Report, 7 January 1994 - 6 January 1995	
4. TITLE AND SUBTITLE Cadmium Telluride Photovoltaic Manufacturing Technology				5. FUNDING NUMBERS C: ZAI-4-11294-03 TA: PV550101	
6. AUTHOR(S) D. Weisiger, S. P. Albright, J. Brines, R. Thompson					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Golden Photon, Inc. Box 4040 Golden, CO 80402				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393				10. SPONSORING/MONITORING AGENCY REPORT NUMBER TP-411-8259 DE96000476	
11. SUPPLEMENTARY NOTES NREL Technical Monitor: R. Mitchell					
12a. DISTRIBUTION/AVAILABILITY STATEMENT				12b. DISTRIBUTION CODE UC-1280	
13. ABSTRACT (Maximum 200 words) This report describes work performed by Golden Photon, Inc. (GPI), to conduct research under the PVMaT program, Phase 2B. The objective of the research is to advance GPI's manufacturing technology, reduce module production costs, increase average module performance, and identify ways to expand production capacity. More specifically, the tasks established for Phase I were to design and install leasehold improvements for the 2-MW production line; to improve and develop product design, efficiency, and marketability; to ensure uninterrupted qualified supplies and raw materials for production; to address environmental, health, and safety issues encountered during production of photovoltaic modules; and to reduce the cost of manufacturing modules. During the first half of this reporting period, the development, design, and debugging of cell interconnection equipment critical to start-up was completed. During the second and third quarters, the primary focus was on the substrate deposition steps (tin oxide, cadmium sulfide, and cadmium telluride) and cell interconnection steps (division). In general, process development, engineering, and quality teams continued to focus on identifying, baselining, and improving (through redesign) actual process equipment operation parameters to meet the required PV panel specifications and improve process throughput rates and yields.					
14. SUBJECT TERMS cadmium telluride ; manufacturing ; photovoltaics ; solar cells ; engineering design ; productivity optimization ; ES&H ; PVMaT				15. NUMBER OF PAGES 41	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL		