LOW COST THIN FILM BUILDING-INTEGRATED PV SYSTEMS

Final Report

Project Title:	**Low Cost Thin Film Building-Integrated PV Systems**
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TASK 1. MODULES

The module task will focus work on: 1) absorber materials and devices to achieve efficiency improvement, 2) module development to reduce cost of PV lamination, packaging, and encapsulant materials, and 3) manufacturing issues.

Task 1.1. Absorber material and device efficiency

Work in this task to reduce the module cost will be in four directions:

1. improving the existing product efficiency,
2. developing higher efficiency nc-Si:H materials and solar cells,
3. increasing the deposition rate of a-Si:H and a-SiGe:H,
4. back reflector improvement.

Task 1.1.1A. Existing product, a-Si(Ge):H, efficiency improvement

Milestone: Improve power rating on the 22L laminate to 148 W for >50% of the product.
Status: The average percentage of modules with 148 W rating was above 60%, exceeding the 50% target goal. Task successfully completed in Q13.

Task 1.1.1B. Fabricate prototype 22L laminates on Ag/ZnO incorporating RTR solution-based ZnO (5EZO) and conduct reliability tests

Milestone: Attain 155 W prototype 22L laminates.

Status: We fabricated several 22L laminates on Ag/ZnO incorporating RTR solution-based ZnO and monitored the performance of four such 22L laminates that were placed outside. The modules have performed as expected. Task successfully completed.

Task 1.1.2. Develop nc-Si:H materials and solar cells

The goal of this task is to develop a nc-Si:H solar cell as a substitute for the a-SiGe:H alloy bottom cell in a triple-junction device. The proposed work will include studies of nc-Si:H, a-Si:H, and a-SiGe:H materials and solar cells. The comparative study will elucidate the differences and the advantages of nc-Si:H.

Task 1.1.2.1. Small area multi-junction cells incorporating one or more nc-Si:H layers

Milestone: Attain $\geq$12% stable total-area (0.268 cm^2) efficiency on multi-junction device incorporating nc-Si:H, using small-area MVHF batch reactor on Ag/ZnO back reflector at rate $\geq$ 1nm/s.

Status: The objective of this task is to explore the achievable efficiency of thin-film silicon solar cells. During this project, we have achieved several efficiency records, including a 12.5% total-area stable cell efficiency using an a-Si:H/nc-Si:H/nc-Si:H triple-junction structure measured by NREL. In addition, we achieved a 16.3% initial active-area efficiency using an a-Si:H/a-SiGe:H/nc-Si:H triple-junction structure. Task successfully completed.

Task 1.1.2.2. Large-area multi-junction cells incorporating one or more nc-Si:H layers

Milestones: Attain ≥10.5% stable aperture-area (~400 cm^2) efficiency on multi-junction device incorporating at least one nc-Si:H layer on Ag/ZnO back reflector, using large-area MVHF batch reactor at rate ≥ 1nm/s.

Status: We sent 2 large-area (~400 cm^2) encapsulated a-Si:H/nc-Si:H/nc-Si:H triple-junction cells made at high deposition rate (≥1nm/s) light-soaked under AM1.5 intensity at 50 °C cell temperature for a total of 1000 hrs to NREL for I-V measurement. One ~800 cm^2 module consisting of two cells was also sent for measurement. The aperture area efficiencies of the devices ranged from 10.6% to 11.3%. These results confirm that we have exceeded the goal of 10.5% stable aperture area efficiency for this task.

Task 1.1.2.3. Large-area deposition of nc-Si:H at high rates by VHF

Milestone: Deposition of nc-Si:H over 50″ wide cathode at rate ≥ 1.2 nm/s with integrated uniformity (average across the web moving direction) better than 85% over 42″.

Status: We conducted a series of experiments depositing nc-Si:H using VHF at rate ≥ 1.2 nm/s and obtained integrated uniformity of 87%, exceeding the 85% milestone. Task successfully completed in Q13.

Task 1.1.2.4. Electronic and optical characterization of material

The characterization techniques include optical absorption, photo-thermal deflection spectroscopy (PDS), photoluminescence (PL), small angle X-Ray scattering (SAXS) and magnetic resonance (NMR, ESR) as well as their combinations. This work is being done at the Colorado School of Mines (Professor P. Craig Taylor's group) under subcontract to United Solar.

Milestone: A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.

Status: A significant amount of characterization has been carried out. The improved understanding of thin film silicon based materials helped the solar cell efficiency progress. Based on the measurement results, several technical papers were published as listed in Appendix A. Task successfully completed.

Task 1.1.2.5. Defect characterization of materials and devices

This task is a collaborative effort between United Solar and the University of Oregon. The objective is to study the correlation of material structural properties with electronic properties, as well as solar cell performance. Various characterization methods were used at the University of Oregon.

Milestone: A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.

Status: A large number of films and solar cells have been investigated. The feedback has been used for solar cell efficiency optimization. In addition, several technical papers were published as listed in Appendix A. Task successfully completed.

Task 1.1.2.6. Diagnostic development of mobility characterization tool

This work was carried out at Syracuse University by Professor Eric Schiff's group. The drift-mobility and mobility-lifetime product of photo-generated carriers were measured by time-of-flight technique. In addition, a new method has been developed using photo-capacitance measurements.

Milestone: A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.

Status: The transport properties of a-Si:H, a-SiGe:H, and nc-Si:H have been systematically characterized. Using the newly obtained parameters, simulations of solar cell performance have been carried out. Several technical papers were published as listed in Appendix A. Task successfully completed.

Task 1.1.3. High deposition rate a-Si:H and a-SiGe:H

The goal of this task is to develop and validate production-machine-compatible, high-deposition-rate techniques for the growth of a-Si:H and a-SiGe:H multi-junction structures. The techniques must produce devices with uniformity and performance comparable to the current RF glow discharge process.

Task 1.1.3.1. High deposition rate a-Si:H and a-SiGe:H on small areas

Milestone: Attain ≥10.2% stable total-area (0.268 cm^2) efficiency on multi-junction device on Ag/ZnO back reflector with a-Si:H and a-SiGe:H cells deposited at ≥ 0.6 nm/s.

Status: We attained total-area stable efficiency of 10.2-10.5% with an a-Si:H/a-SiGe:H/a-SiGe:H triple-junction structure, where the deposition rate ≥ 0.6 nm/s. Milestone achieved. Task successfully completed in Q13.

Task 1.1.3.2. High deposition rate a-Si:H and a-SiGe:H on large areas

Milestone: Attain ≥ 9.5% stable aperture-area (~400 cm^2) efficiency on multi-junction device, using large-area MVHF batch reactor on Ag/ZnO back reflector at deposition rate ≥ 0.6 nm/s.

Status: We attained stable efficiency of 11.0% on large-area encapsulated cells as confirmed by NREL. The milestone has been achieved for both the double-junction and triple-junction structures. Task successfully completed in Q13.

Task 1.1.3.3 Large-area deposition of a-Si:H and a-SiGe:H at high rates by VHF

Milestone: Deposition of a-Si:H and a-SiGe:H over 50″ wide cathode at ≥ 0.8 nm/s with integrated uniformity (average across the web moving direction) better than 85% over 42″.

Status: Samples of 1 in. x 1 in. from different locations of the larger substrates were examined by EDS to determine the atomic ratio of Si/Ge. A typical composition map is shown in Fig. 1. The corresponding thickness distribution for this run is given in Fig. 2. These samples are ~1" from the edge, and the middle one is located at the center. In roll-to-roll operations, the material deposited on the substrate will take the average thickness and composition along the direction of the moving web.

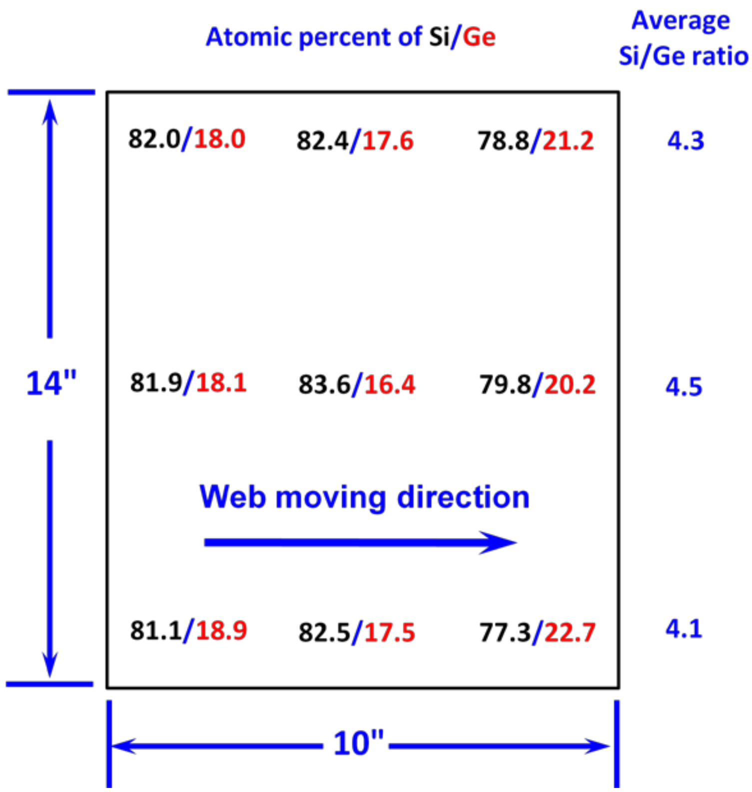

Figure 1. Atomic ratio of Si/Ge at different location on a 10”x14” substrate by EDS.

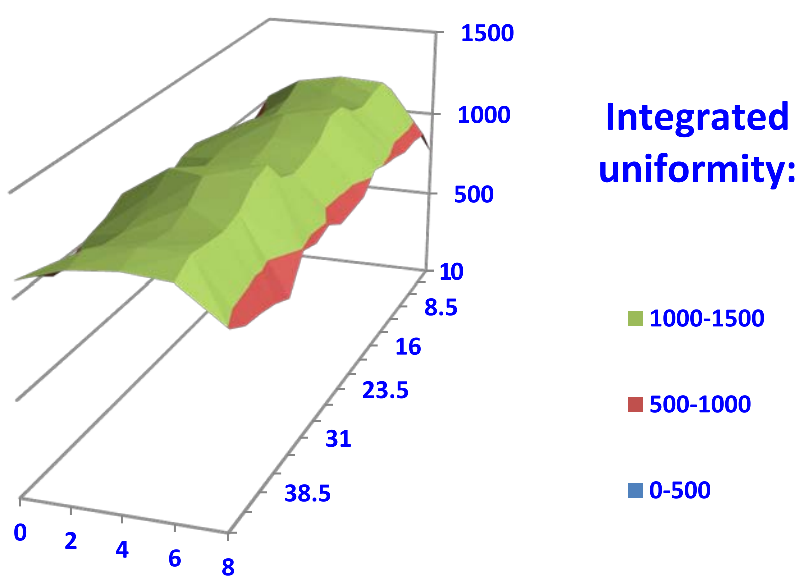

Figure 2. Film thickness pattern.

From the data shown above, the averaged compositional uniformity from top to bottom of this deposition defined as [(max-min)/average] is about 90%. Therefore, the milestone has been achieved and task successfully completed.

Task 1.1.3.4. Defect characterization of high deposition rate materials

This task is a collaboration effort between United Solar and the University of Oregon. The objective is to study the correlation of a-Si:H and a-SiGe:H material structural properties with electronic properties, as well as solar cell performance.

Milestone: A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.

Status: The correlation of solar cell performance and defect distribution has been studied in a-Si:H and a-SiGe:H solar cells. The feedback from the measurements has been used to further improve the solar cell efficiency. Several technical papers were published as listed in Appendix A. Task successfully completed.

Task 1.1.3.5. Full material characterization and modeling of high rate materials

This work was done by Pauls Stradins, David C. Bobela, Qi Wang, William Nemeth, and Howard Branz of NREL's Silicon Materials and Devices Group.

Milestone: A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.

Status: A significant amount of characterizations, especially using the microscopic spectroscopy, has been made for improving the understanding of the material and the device. In addition, a method of improving a-Si:H stability was proposed and experiments carried out. Several technical papers were published as listed in Appendix A. Task successfully completed.

Task 1.1.4. Back reflector research

In this task United Solar is attempting to improve cell efficiency by improving the performance and efficiency of the back reflector. The major effort has shifted from optical modeling to developing new approaches using metal nano-particles to enhance the light trapping effect in thin film solar cells. There are two parallel efforts for this task. One is carried out by Professor Eric Schiff's group at Syracuse University and the other at United Solar. Prof. Schiff's group has been focusing on light trapping with metal nano-particles; United Solar has continued optimizing Ag/ZnO back reflectors for nc-Si:H solar cells.

Task 1.1.4.1. New approaches for light trapping

This work is carried out at Syracuse University by Professor Eric Schiff's group. The main objective is to develop new light trapping approaches for photocurrent enhancements in thin film solar cells.

Milestone: A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.

Status: Theoretically, it was suggested that advanced light trapping with plasmonic back reflectors may exceed the classical limit. A significant amount of experiments has been carried out. Several technical papers were published as listed in Appendix A. Task successfully completed.

Task 1.1.4.2. Al/ZnO and Ag/ZnO back reflector fabrication based on optical predictions

The original proposal for this task was to carry out experiments based on the suggestions from the theoretical analyses of Professor Eric Schiff's group. The focus was on Al/ZnO back reflectors. In Phase I, we learned from the theoretical and experimental studies in the literature that our current randomly-textured Al/ZnO and Ag/ZnO are very good. Syracuse University and United Solar worked in this area, but using different methods. In addition, United Solar worked on the optimization of Ag/ZnO for nc-Si:H solar cells. The optimized Ag/ZnO back reflectors for a-SiGe:H are not suitable for nc-Si:H solar cells. Therefore, we wanted to develop new Ag/ZnO back reflectors for nc-Si:H multi-junction solar cells. In addition, we focused on advanced light trapping using advanced methodologies, such as periodic structures, nano-particles, and black silicon.

Milestone: Provide samples to Syracuse University and fabricate devices to evaluate new light trapping approaches based on Syracuse University feedback.

Status: 1) We have prepared and sent a large amount of samples to Syracuse University for the advanced light trapping development. 2) We developed a new BR structure for nc-Si:H solar cells and improved light trapping without noticeable degradation of nc-Si:H material quality. 3) Using the newly developed BRs, we achieved J_{sc}>30 mA/cm^2 in nc-Si:H solar cells, which is a significant milestone for the thin film silicon PV community. 4) We analyzed the light trapping gains and reflection/absorption losses in photocurrent and demonstrated that we are approaching the classical limit of light trapping. Several technical papers were published as listed in Appendix A. This task was successfully completed in Q17.

<u>Task 1.2. Module development to reduce cost of PV laminate</u>

Task 1.2.1. Wire grid cost reduction

Milestones: Improve and finalize materials and processes for production trials and incorporate into production.

Status: The goal of this task was to research and design a process for producing the grid-wire used in solar cell manufacturing with a cost reduction of $0.07/watt; while eliminating dependencies on a single source provider.

In an effort to thoroughly study different formulations of grid-wire, it was decided to purchase the equipment necessary to fabricate the product in-house. With the ability of manufacturing the grid-wire in-house, we were able to study the following:

- Application Methods
- Machine Parameters
- Wire Composition
- Enamel Formulations
- Product Performance
- Production Demand Requirements
- Costs of Grid-Wire Production

The work was divided according to the descriptions as defined below in Table I. The purpose was to research the technology required, process parameters, grid-wire characteristics and costs associated with the production of this solar cell component in order to determine a way to provide a comparable source at the required cost savings.

Table I. Work Description and Results

Work Descriptions	Results
Research the functionality, composition and fabrication methods of grid-wire to determine manufacturing properties, parameters and methods	Defined the grid-wire components, properties, functionalities & requirements of each.
Research and purchase a wire enameller to be used for the in-house fabrication of grid-wire	Purchased a commercial Enameller
Investigate the effects of the enameller process parameters to determine the optimal settings required to produce repeatable coated wire at a rate that will meet the cell line demand	Studies were conducted to determine production parameter settings, application methods and spooling options.
Determine test procedures and standards that will be used during grid-wire qualification processing	A list of required tests was compiled for experimental evaluations. The standard "expected" values were collected for comparison.
Research and purchase a lab press station to be used for off-line pressing of the grid-wire on cells	A press/laminator machine was purchased.
Perform trial tests to determine the coating for optimal wire and cell performance	Good test results were achieved with the current set of enamels. Samples are being tested in Humidity Freeze/Forward Bias (HFFB).
Determine standard cost per watt for producing grid-wire in-house	Based on the current formulation and processing speed, the cost of grid-wire was calculated.
Conduct line trial testing of solar cells using in-house and vendor supplied grid-wire. Evaluate the product performance and production costs.	Conditioning of cell line used for line trials is being conducted. Line trials will be conducted based in the results of the samples currently in HFFB. Some modifications of the formulas may be required before a complete line trial is conducted.

Based on our grid-wire studies, it was decided to approach the formulation of the enamel coatings from two different angles. The first option was to purchase the resins from an outside supplier and develop the enamel coatings from scratch. The second option was to collaborate with an enamel supplier to develop the coatings. In both cases, we would manufacture the grid-wire in-house. The estimated costs of both options are provided in the cost savings section below.

Initial experiments were conducted producing grid-wire based on the two approaches in developing enamel coatings. Positive results were achieved in both cases. Reformulations of the coatings may be required to optimize the performance of the wire produced, followed by line trial tests to study the impact on the final product and possible changes to the production process.

Cost savings comparisons were calculated using the standard values for shrinkage and yield on the cell line. The average cost per watt to produce the grid-wire was calculated taking into account materials consumed, labor rates, power consumption and overhead costs. The total operating cost to produce the wire is approximately $0.006/ watt.
Including the materials cost for the top two formulations of the grid-wire used in our tests to calculate the total cost of, we have concluded that producing grid-wire in-house will achieve a cost savings of $0.07/watt.

Task 1.3. Packaging materials to reduce encapsulant cost

Task 1.3.1. Back Lamination

Milestone: Complete detailed qualification testing with at least one alternative back lamination configuration. Initiate certification testing.

Status:

Internal Qualification Testing

1. USO internal qualification testing including 10 humidity/freeze cycles (10HF), 200 Thermal Cycles (200TC), and 1000 hours of Damp Heat (1000DH) have been completed. All test samples passed post 10HF, 200TC, and 1000DH tests, including wet hi-pot, IV, visual inspection, and flex testing. USO internal qualification testing is complete.
2. Backside dielectric from supplier 6, configuration #8, successfully passed all of the cut resistance tests both before and after accelerated exposure.
3. Back lamination from supplier 6, configuration 8, passed the electrical performance test both before and after accelerated exposure.
4. Back lamination from supplier 6, configuration #8, passed the wet hi-pot test both before and after accelerated exposure. All samples were tested at 3000 VDC for 2 minutes.
5. Back lamination from supplier 6, configuration #8, passed the dynamic flexural testing after accelerated exposure. During this test the subscale modules were coiled and uncoiled in both directions around a cylinder 6 inches in diameter. For this test, 1 cycle consists of coiling and uncoiling the test sample in both directions of the laminate. This is an extreme test since the photovoltaic laminates should never be coiled around such a small diameter during normal use.

The test plan in Fig. 3 was constructed in order to complete the USO internal qualification testing. The test plan consisted of testing various parameters, which are pertinent to the back lamination of the photovoltaic laminate. Parameters such as cut resistance, electrical performance, and insulation were evaluated following multiple test methods. These parameters were recorded before and after Accelerated Exposure Tests. Results of the back lamination internal qualification testing are shown in Table II.

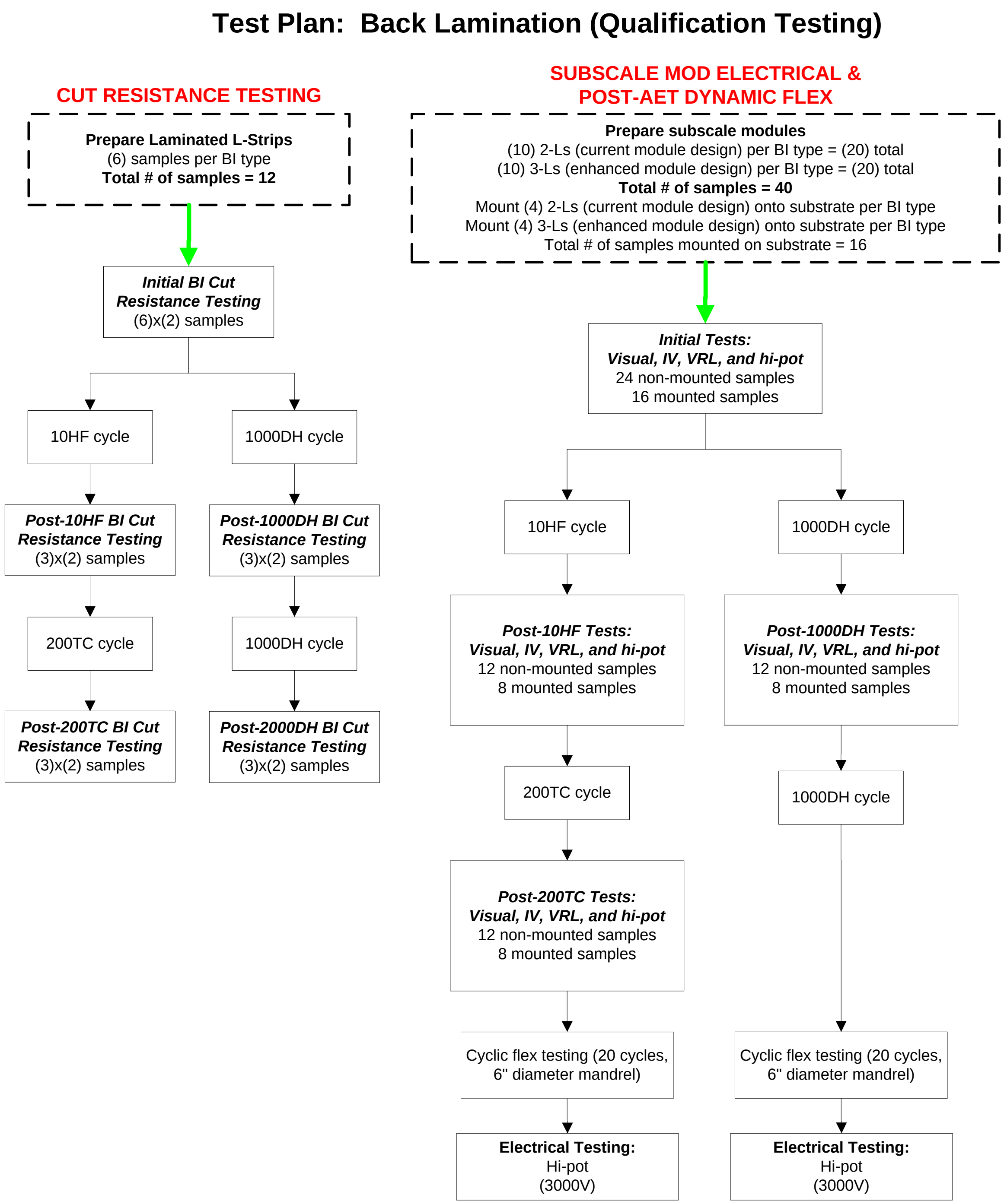

Figure 3. Test Plan Outlining the Internal Qualification for Back Lamination.

Table II. Back Lamination Internal Qualification Test Results.

TEST	TEST STANDARD	SAMPLES	CONDITIONING	PASS/FAIL CRITERIA	RESULTS
Cut Resistance Test	UL 1703 Ed3	n = 12	Baseline (no aging)	Leakage Current < 10µA at 2 lb.	PASS
		n = 6	Post 10HF		PASS
		n = 6	Post 200TC		PASS
		n = 6	Post 1000DH		PASS
		n = 6	Post 2000DH		PASS
Module Electrical Performance (light I-V at STC)	IEC 60904-1	n = 40	Baseline (no aging)	Pmax, Isc, Voc, and V_{mp} to be ± 10% of initial value	PASS
		n = 20	Post 10HF		PASS
		n = 20	Post 10HF + 200TC		PASS
		n = 20	Post 1000DH		PASS
Module Wet Insulation Resistance	UL 1703 Ed3 IEC 61646 (@ 3kV, 2min)	n = 40	Baseline (no aging)	Insulation resistance ≥ 40MΩm^2	PASS
		n = 20	Post 10HF		PASS
		n = 20	Post 10HF + 200TC		PASS
		n = 20	Post 1000DH		PASS
USO Cyclic Flex Testing	UL 1703 Ed3 IEC 61646 (@ 3kV, 2min)	n = 12	Post 10HF + 200TC	Insulation resistance ≥ 40MΩm^2 after 20 cycles	PASS
		n = 4	Post 1000DH + 2000DH		PASS

<u>External Certification Testing</u>

External certification testing for UL 1703, IEC 61646, and IEC 61730 was initiated.

With the qualification of the new back lamination from supplier 6, configuration #8, the expected back lamination cost if supplier 6 were ramped to 100% of production would meet the cost goal. This task was successfully completed in Q13.

Task 1.3.2. EVA

Milestone: Complete certification testing. Define an appropriate scale-up plan for introducing qualified material into production. Observe the effects on actual material cost associated with production scale-up.

Status:

The test flowchart in Fig. 4 and results in Table III summarize the work done for this task. The test plan concentrated on the evaluation of supplier 3 EVA. Supplier 3 EVA material passed all applicable qualification tests, either meeting or exceeding the performance of the benchmark incumbent EVA. USO has obtained UL 1703 and IEC-61646 certification for use of supplier 2 and 3 EVA in USO PVL products.

A successful small-scale manufacturing trial using 8 full rolls of EVA was run at the Auburn Hills plant, and a restricted production trial was run at the Auburn Hills plant from 9/7-9/12. No significant EVA related issues or defects were reported.

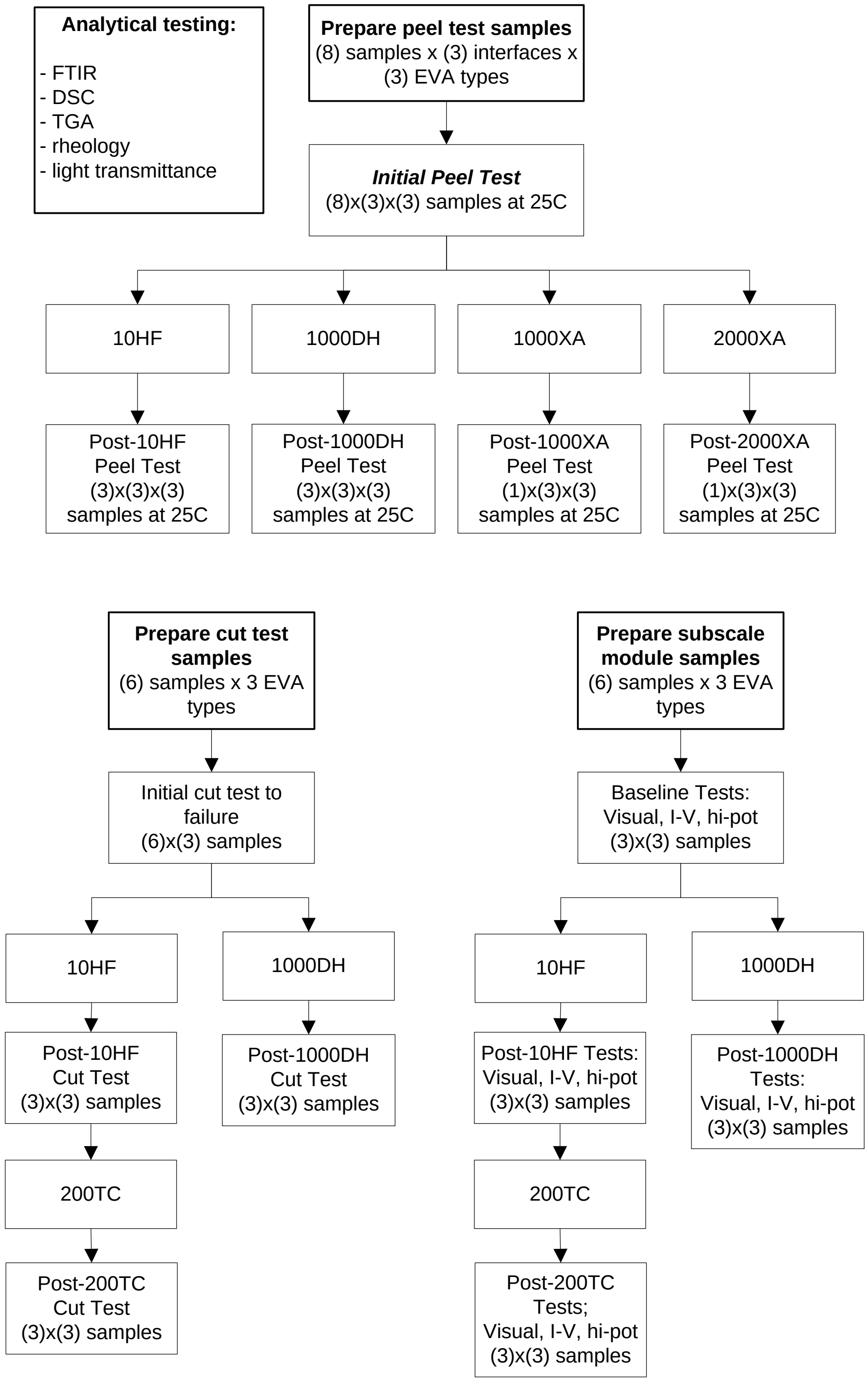

Figure 4. Qualification test plan flowcharts for alternative supplier EVA material.

Table III: Summary of internal qualification test results for supplier #3 26 mil EVA film.

Test	Test Standard	Samples	Condition	Results
Analytical (DSC, FTIR, TGA, rheology)		uncured EVA film samples	Baseline (no aging)	pass; within normal limits for EVA material
Light Transmittance		free-film, 2"x2"	Baseline (no aging)	pass; 400-1000 nm transmittance and cut-on wavelength are similar to incumbent EVA (within measurement error).
		n=1	Post-1000XA	pass; no significant change in transmittance is measured post-1000 or 2000 hours of xenon-arc exposure.
		n=1	Post-2000XA	
ETFE-to-EVA peel	ASTM-D903	1" width, n=24	Baseline (no aging)	pass
		n=9	Post-10HF	pass
		n=9	Post-1000DH	pass
		n=3	Post-1000XA	pass
		n=3	Post-2000XA	pass
EVA-to-solar cell peel	ASTM-D903	1" width, n=24	Baseline (no aging)	pass
		n=9	Post-10HF	pass
		n=9	Post-1000DH	pass
		n=3	Post-1000XA	pass
		n=3	Post-2000XA	pass
EVA-to-BCF (PE) peel	ASTM-D903	1" width, n=24	Baseline (no aging)	pass
		n=9	Post-10HF	pass
		n=9	Post-1000DH	pass
		n=3	Post-1000XA	pass
		n=3	Post-2000XA	pass
Module Cut Resistance	UL 1703 Ed3	1-cell module, n=6	Baseline (no aging)	pass
		n=3	Post-10HF	pass
		n=3	Post-10HF+200TC	pass
		n=3	Post-1000DH	pass
Module electrical Performance (light I-V at STC)	IEC-60904-1	1-cell module, n=12	Baseline (no aging)	pass; no statistically significant difference in initial Pmax, Isc, Imp with respect to incumbent EVA.
		n=3	Post-10HF	pass; no statistically significant difference in the relative change in Pmax, Isc, Imp with respect to incumbent EVA
		n=3	Post-10HF+200TC	
		n=3	Post-1000DH	
Module Wet Insulation Resistance	UL 1703 Ed3 IEC-61646 (@ 3kV, 2min)	1-cell module, n=12	Baseline (no aging)	pass; all samples pass >380 MΩ requirement for 0.105 m^2 sample
		n=3	Post-10HF	pass
		n=3	Post-10HF+200TC	pass
		n=3	Post-1000DH	pass

The 26 mil EVA ramp up plan is to start supplier 3 at 30% of USO production volume. Supplier 2 (previously qualified) will supply 40%, with the incumbent providing the remaining 30%. Step 2 of the plan is to eliminate the incumbent supplier over the following 6 months, yielding a cost savings of 34% over the incumbent EVA, once the ramp up plan is complete. Task successfully completed in Q13.

Task 1.3.3. ETFE

Milestone: Complete qualification testing and subsequent certification testing. Define an appropriate scale-up plan for introducing qualified material into production. Observe the effects on actual material cost associated with production scale-up.

Status:

Certification to UL1703, IEC 61646, and 61730 have been completed. USO has received a notice of authorization from UL to manufacture PVL modules using supplier #1 ETFE film as the superstrate. The scale up plan consisted of USO ramping up supplier #1 to 50% of the production of USO modules over 6 months. Assuming a 50% ratio of supplier #1 with the incumbent supplied film, the cost of ETFE is expected to drop ~ 40%. This will exceed our goal of 20% cost reduction for ETFE by a factor of 2. Task successfully completed in Q13.

Task 1.3.4. Black Cosmetic Insulator Film

Milestone: Using preliminary test data, down-select to at least one alternative black cosmetic insulator film (BCF). Complete detailed qualification testing of one alternate BCF material. Cost of down-selected material to be at least 50% lower than that of production BCF.

Status:

The flowchart in Fig. 5 and results in Table IV summarize the work done for this task. BCF material from the two supplier candidates along with the incumbent material underwent identical test sequences. The alternative BCF materials showed similar performance with respect to the incumbent BCF film and were deemed to have passed all internal qualification tests. In addition, small-scale production trials were run in the manufacturing plants without any significant reported manufacturability issues.

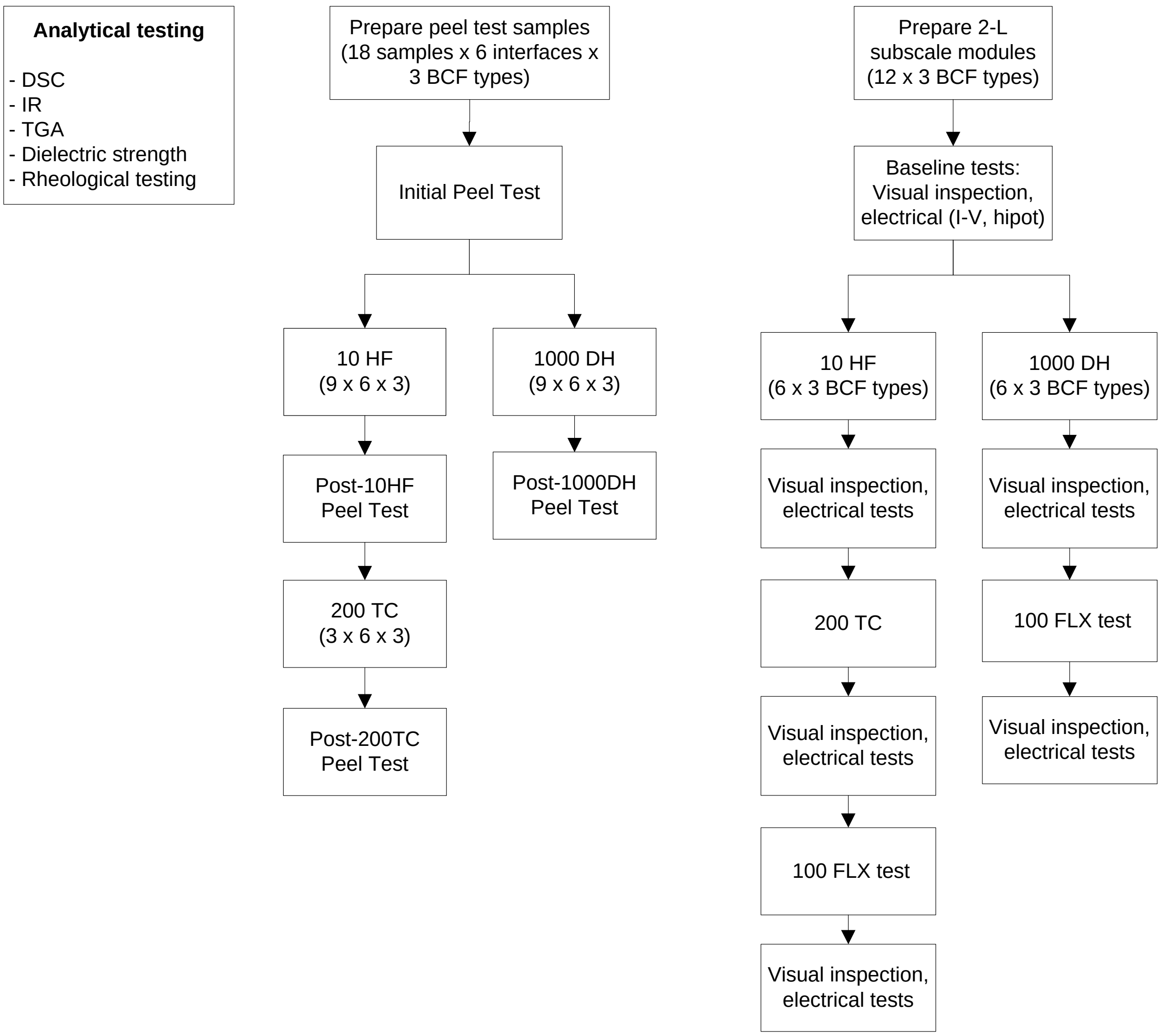

Figure 5. Qualification test plan flowcharts for alternative supplier BCF material.

Table IV: Summary of internal qualification test results for supplier 2 and 3 BCF materials.

Test	Test Standard	Samples	Condition	Results
Analytical (DSC, FTIR, TGA, rheology, dielectric)		uncured BCF film samples	Baseline (no aging)	pass; within normal limits for BCF material
EVA-to-BCF peel	ASTM-D903	1" width, n=18	Baseline (no aging)	pass
		n=9	Post-10HF	pass
		n=3	Post-10HF+200TC	pass
		n=9	Post-1000DH	pass
BCF-to-metal components peel (Cu bus, Ag, bus, Sn bus, stainless steel)	ASTM-D903	bus width, n=18 x 4 metals	Baseline (no aging)	pass
		n=9	Post-10HF	pass
		n=3	Post-10HF+200TC	pass
		n=9	Post-1000DH	pass
BCF-to-BCF peel	ASTM-D903	1" width, n=18	Baseline (no aging)	pass
		n=9	Post-10HF	pass
		n=3	Post-10HF+200TC	pass
		n=9	Post-1000DH	pass
Module Wet Insulation Resistance	UL 1703 Ed3 IEC-61646 (@ 3kV, 2min)	2-cell module, n=12	Baseline (no aging)	pass; all samples pass >147 MΩ requirement for 0.273 m^2 sample
		n=6	Post-10HF	pass
		n=6	Post-10HF+200TC	pass
		n=6	Post-10HF+200TC+100FLX	pass
		n=6	Post-1000DH	pass
		n=6	Post-1000DH+100FLX	pass
Module electrical Performance (light I-V at STC)	IEC-60904-1	2-cell module, n=12	Baseline (no aging)	pass; within normal limits for production
		n=6	Post-10HF	pass; no significant difference in the relative change in performance with respect to incumbent BCF
		n=6	Post-10HF+200TC	
		n=6	Post-10HF+200TC+100FLX	
		n=6	Post-1000DH	
		n=6	Post-1000DH+100FLX	

Based on the above test results and cost considerations, supplier 2 was selected for additional restricted production trials and ramp-up phase. The present cost for supplier 2 represents a significant cost savings of 49% over the incumbent BCF material, assuming production ramp-up to 100% of supplier 2 BCF material. In addition, the goal of providing an additional cost reduction for back-side lamination materials was considerably exceeded. Task successfully completed in Q13.

Task 1.4. Manufacturing issues

Two main manufacturing areas will lead to manufacturing cost reductions: economies of scale, and improved process monitoring of both the ITO and semiconductor steps. These are addressed in the subtasks to this task.

Task 1.4.1. Economies of scale

There is no milestone scheduled for this task in Phase III.

Task 1.4.2. *In-situ* I-V measurements in the ITO machine and automated optimization

Milestone and Objective: Convert inline tester to a three-web system and fully incorporate into QA procedures. Demonstrate agreement within 5% of P_{max} value measured by off-line Spire solar simulator and in situ ITO inline monitor over at least 75% of the length of a coil in a production run.

Technical Approach

In order to release the web coated with the solar cell material into production, we collect quality assurance (QA) data using a Spire measurement system for one cell of every 100 (1%). This is a time consuming process, and this is collected 3-4 days after the end of an a-Si deposition run. In between deposition and QA testing, another 6-9 coils of a-Si film material is produced, so if the machine is producing degraded material and that fact is discovered later, the yield of acceptable product is reduced. An IV tester located in the ITO machine can measure the cell P_{max} within a day of a-Si deposition and reduce the amount of unacceptable material.

The *in situ* IV tester is located at the end of the ITO deposition machine. After ITO application, the solar cell has a top and bottom conducting surface that can be used to test cells without grid wires. Data can be collected at a high rate and constantly throughout an entire coil. The measurements are also collected within one day after a-Si deposition, enabling the identification of material deficiencies sooner so manufacturing changes can be implemented to produce less unacceptable material.

The problem, though, is that the film material is unprotected and care must be taken when measuring electrical characteristics so as not to damage the film. The tester utilizes a carbon fiber brush as a top contact for in-situ measurements. As the web moves past the tester, a LED light source flashes behind the brush, a voltage is applied to the brush and an IV curve is collected. A picture of the tester as located in the take-up chamber of the ITO deposition system is shown in Figure 6.

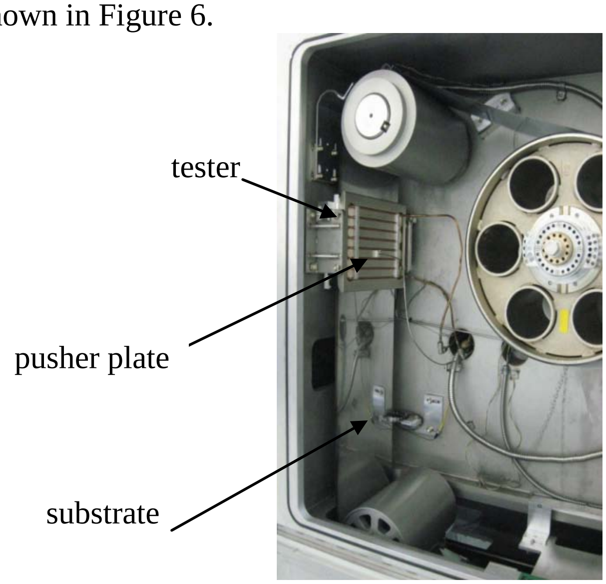

Figure 6. Tester placement in take-up chamber.

The light source pulses at a high rate with a 1% duty cycle. For each I-V curve, 150-200 points are collected, for a total collection time of 5-7 seconds for each curve. Currently, the tester is set up to generate one curve every three solar cells. The curve generated is comparable to ones collected on the QA analysis system for cells with grid wires (Fig. 7).

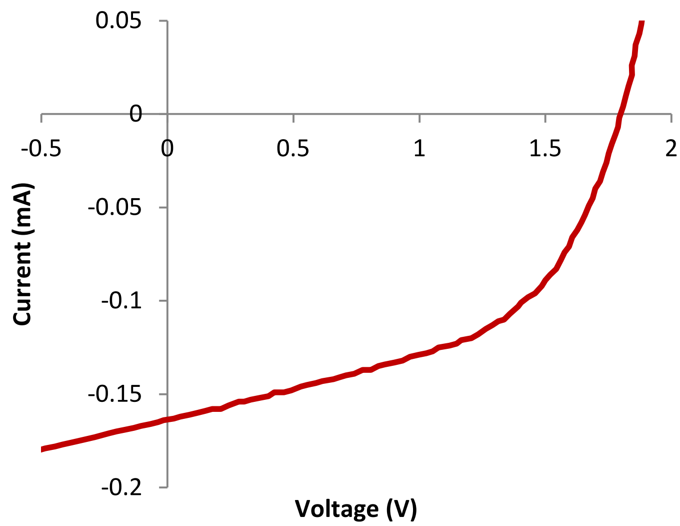

Figure 7. Typical I-V curve collected by *in-situ* tester.

As with offline QA systems, P_{max}, I_{sc}, V_{oc}, FF, R_s and R_{sh} are extracted from the curve. If a solar cell fails QA, it usually has a low P_{max}, so P_{max} is where we focus our analysis.

Experimental Data

The *in situ* ITO IV tester has been operational inline since September 2, 2008. As of July 14, 2009, we collected data on 149 coils. Many corrections were made to improve the system, but most major improvements were made previous to October 20, 2008 allowing us to match QA data since then. The tester was verified as a predictive tool beginning December 2008 and has been used in a predictive manner starting January 2009. We continue to optimize, though, in order to achieve matching all the time.

Major changes along the way include implementation of temperature regulation, optimization of IV curve collection parameters, refinement of analysis software and upgrading of the LED light source. The temperature inside the ITO chamber rises about 10°C to 35°C, so temperature regulation was enacted to keep data collection near 25°C. Collection parameters such as delay between curves, number of data points and LED current have been optimized. The calculation of V_{oc} and P_{max}, amongst other things, has been improved in the analysis software. The LED light source was upgraded to utilize high power white and IR LEDs.

Because of the difference in data collection area and contacts, a scale factor was developed to compare high power inline data to high power QA data (>7.1 W). This scale factor is not in its final form, but it currently predicts Spire QA P_{max} values within 5% for entire coils 93% of the time. Low power P_{max} (<6 W) is obtained directly from percentage dip in power.

Figure 8 shows P_{max} from an entire coil (2500 m). The inline P_{max} has been scaled to compare the shape and level of the baseline values (7.1-7.5 W). QA data is taken one cell for every 100 (1% sampling rate). The inline tester collects data every three cells (33%).

The shape of the curve overall matches well. The average deviation in P_{max} of the baseline is 0.067 W (0.91%). The largest deviation in P_{max} of the baseline is 0.35 W (4.7%). This deviation appears to be partially caused by random noise in the QA data as opposed to solely noise in the inline tester.

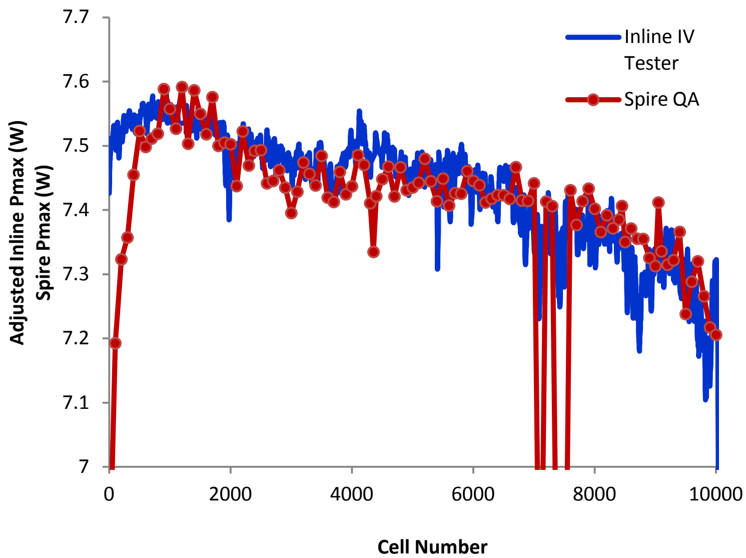

Figure 8. Comparison of inline tester to Spire QA; ITO Run – April 17, 2009.

Figure 9 shows the baseline data from another entire coil. The shape of the curve overall matches well. The average deviation in P_{max} of the baseline is 0.11W (1.4%). The largest deviation in P_{max} of the baseline is 0.26W (3.5%). Two stops on machines and subsequent burns in addition to low power cells at the beginning account for areas in the plot that do not match up well.

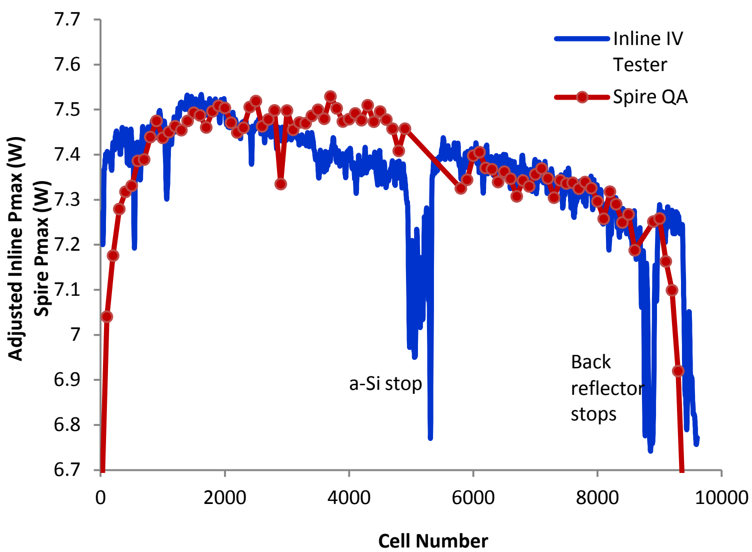

Figure 9. Comparison of inline tester to Spire QA; ITO Run – January 4, 2009.

When obtaining low power P_{max} values (<6 W), the baseline of the inline P_{max} is lined up with the baseline of the QA values. The percentage drop in P_{max} for the inline data is proportional to the percentage drop for QA P_{max}. Because of the time consuming process involved in measuring slabs, QA data is taken every 100 cells (1%). When a low power cell is found, 100 cells on either side of that cell are rated as low grade and taken out of production.

In Figure 10, four dips in power are identified by the inline tester in a 600 cell region of a coil (blue). The data taken by QA for release of material are shown in red. Based on those results, cells numbered 4300-4700 were taken out of production. After release into production, more cells from this region were collected and P_{max} was measured using the QA system. This data (green) confirms the dips in power seen by the inline tester.

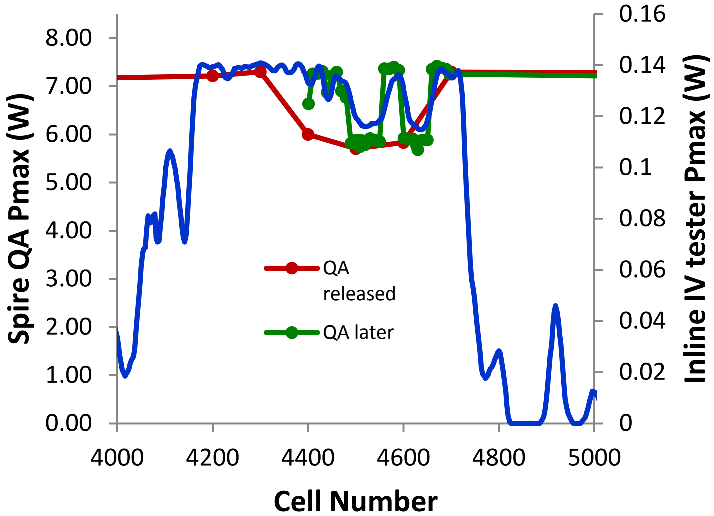

Figure 10. Comparison of inline tester to Spire QA; ITO Run – December 14, 2008.

The inline tester shows that regions between the dips and outside the dips have high powers. QA rated 400 cells as low grade. The tester rated 200 cells as low grade. The tester saved 200 cells or 9 modules. For the lowest power dips, P_{max} from the QA system was 5.89 W. The proportional inline P_{max} was 6.23 W, for a 5% difference.
Figure 11 shows a 600 cell region from a different coil. QA data (red) indicates there are no low power cells in this region, so all cells were released to production. The inline tester (blue) showed three dips in power with the QA sample falling between the dips. After release, cells were pulled from this region and measured on the QA system (green). Because of the ability to sample more frequently, the identification of low power cells is more efficient.

QA rated no cells as low grade. The tester rated 75 cells as low grade. Depending on how many of those cells were placed on a single module and their actual power, between 3 and 10 modules were saved. The P_{max} of lowest power cells per dip from the QA system ranged between 3.18 and 5.03 W. The inline tester P_{max} ranged between 4.85 and 5.93 W.

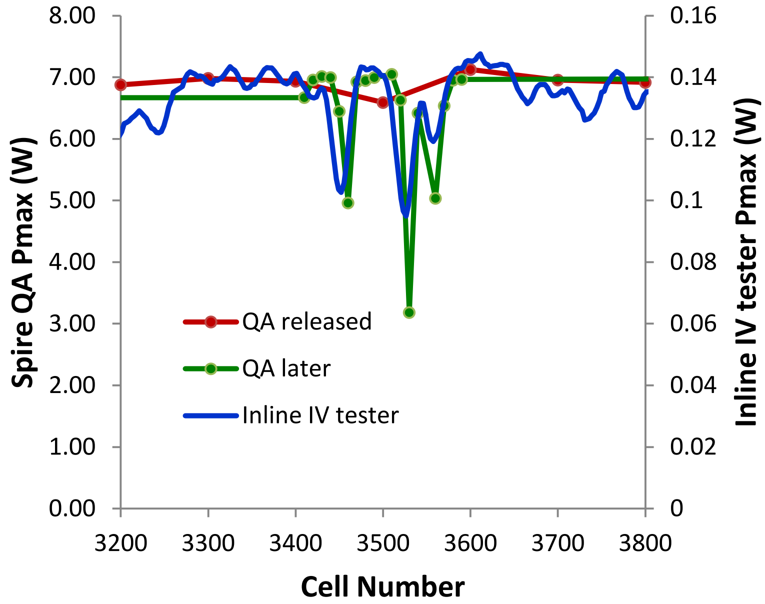

Figure 11. Comparison of inline tester to Spire QA; ITO Run – February 20, 2009.

<u>Discussion</u>

Most major modifications to the tester and the light source were made and the tester functioned in an accurate manner by October 27, 2008. In the time since then, the baseline P_{max} of a coil was properly identified within 5% for 111 of 120 runs (93% of the time). Four out of the nine runs with unmatched P_{max} happened when the light source was out of calibration, so the number can reasonably be called 115 runs (96%). To go beyond the stage gate specifications, baseline P_{max} of a coil was properly identified within 2% for 42 of 120 runs (35% of the time).

Though the tester can identify the grade of solar cell (grade = range of powers used to classify cells for production purposes) with low power dips, correlation of the exact value is sometimes not possible. One problem with extracting low power P_{max} values is that when the number of consecutive low power cells is small, the dip in power is not going to be exactly proportional to the power. The dip seen will be smaller due to the 33% sampling rate and constantly moving web. We are working on a mathematical deconvolution to use when the width of the low power region seen by the inline tester is narrower than a specified number of cells. For our purposes, however, identification of low power P_{max} within one watt is sufficient. We have determined that the tester identifies these cells all of the time, allowing us to improve the yield of acceptable material.

The light source is an important factor in proper operation of the inline tester. Through trial and error for its refinement, we discovered that the place in the cell of poor function can be identified – red absorbing, green absorbing and blue absorbing. In addition, we need to improve the inline tester so identification of proper P_{max} occurs within 2% of the actual value > 90% of the time before push to be more specific.

A cycle noise has been present in the data since inception. This cycle accounts for ~50% of the noise in the data. We have been narrowing down the source of the noise and believe it is located in the electronics or the inline tester brush. We will be trying different fibers for the brush in hopes that some of the noise is eliminated.

Another source of noise is the material itself. For coils from the same a-Si run, the changes in noise level throughout a run, the noise level overall and the shape of the curve are the same, indicating the a-Si material varies throughout the run in a systematic manner. After grid wires are added to the cells, this noise is less significant, but because of the nature of our tester the noise is more prominent. At this point, material noise cannot be eliminated, but in the future, we hope the inline tester can help identify and resolve issues like these.

Following success of the in-line tester on a single web, the tester was converted to a three-web system. The light source was improved by optimizing the distribution between blue, white, red, NIR, and IR LEDs. Everyday usage of inline data has been fully incorporated into the QA department. The QA supervisors use the data continually and saved significant power in the first six weeks of incorporation.

Summary

We have shown that an *in situ* IV tester on the ITO deposition machine can identify Pmax within 5%. The tester also meets the milestones of demonstrating accurate and precise inline IV measurements with correlation to offline-Spire matching and exceeding the correlation of offline-Oriel to offline-Spire. The system has been converted to a three-web system, and is used consistently by the QA supervisors, and has saved significant power since installation.

Task 1.4.3. a-Si process chamber spectrometers and differential deposition profiles

Milestone: Integrate the Stop-N-Go into the standard operations of all production lines.

Status: The Stop-N-Go Tool for measuring deposition profiles has been implemented into all six of the United Solar a-Si deposition machines. This tool briefly stops the web resulting in extra deposition under each cathode. This web is then advanced past an array of spectrometers to measure the changes in thickness. The resulting deposition profile (Fig. 12) for each cathode is measured and displayed real-time in the Control Room. This small thickness change does not affect the quality of the final product. In the past few months of operation the Stop-N-Go tool has clearly identified cathodes that were producing no deposition. Under these instances, there were no other machine control alarms or warnings to alert the operators to a problem.

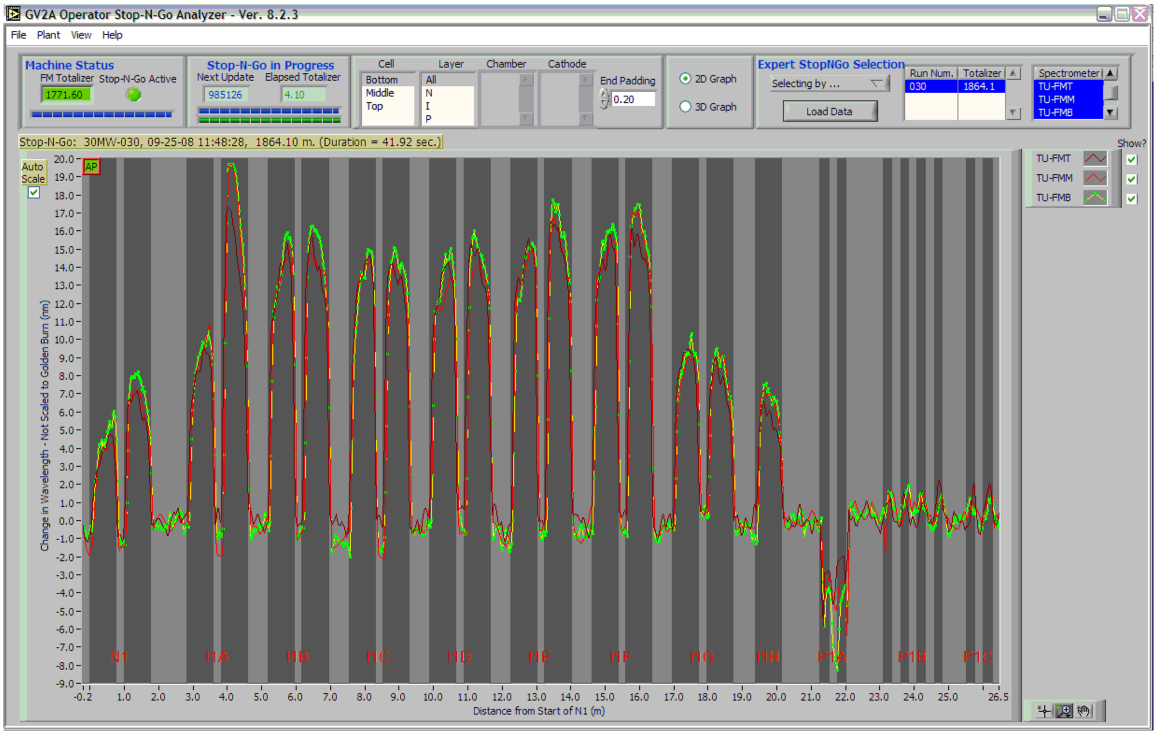

Figure 12. Stop-N-Go cathode deposition profiles. Vertical gray bars identify the mechanical locations of the cathodes.

A new Stop-N-Go alarms interface (Fig. 13) was later completed and installed into the control room for all production machines. The new interface provides a simple pass/fail status for all tested cathodes. The alarm testing algorithms are based on Statistic Process Control Charts. This method not only allows the detection of completely shorted cathodes but also identifies cathodes that are beginning to trend towards failure. Operators can use the interface to quickly review Stop-N-Go history and access control chart details. During the first three months of operation, it has identified two cathode faults that were subsequently traced to cathode hardware failures (Fig. 14.) Procedures were initiated for operating the software interface and for guiding the operators through the fault troubleshooting process. Training sessions were given to all operations teams at all plants. A team was formed to continue overseeing the implementation of the Stop-N-Go Tool and audit its effectiveness. Task successfully completed in Q13.

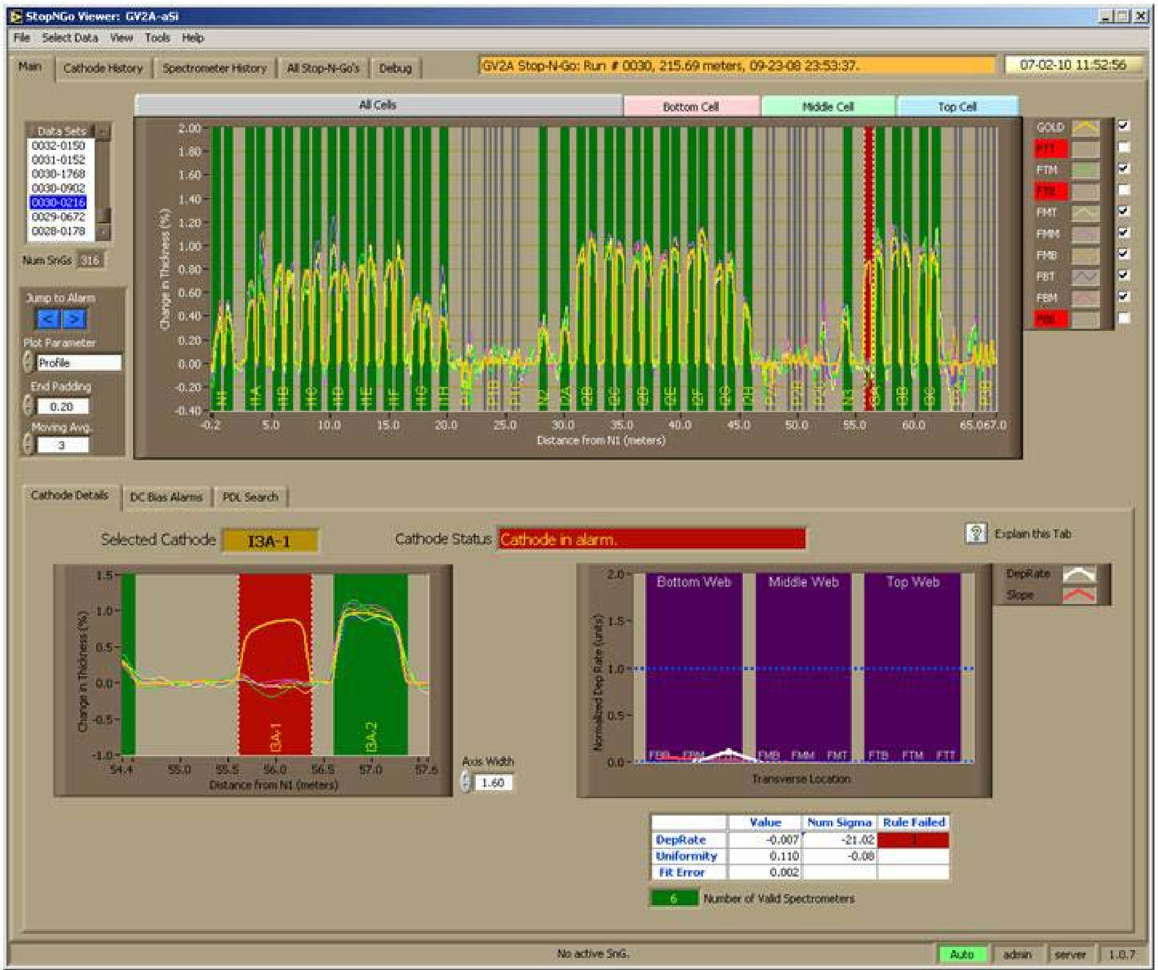

Figure 13. The operator display of the Stop-N-Go tool showing a faulted cathode. Green bars are cathodes that passed testing and the red bar flags the I3A-1 cathode which lacks deposition. The gold plot is a reference to the standard (golden) profile.

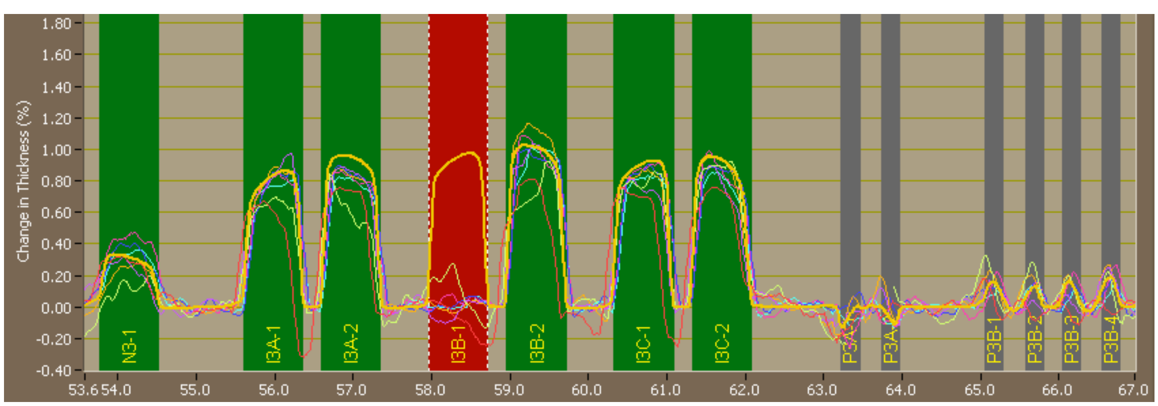

Figure 14. Failed cathode identified by the Stop-N-Go early in a production run. The run was stopped and the fault traced to a shorted hardware strap.

TASK 2. INVERTER AND BALANCE OF SYSTEM

The price of inverters and balance of systems plays a significant role in the systems level cost. This task addresses our effort to develop low cost commercial inverters by subcontracting the work to selected inverter companies.

Task 2.1. PV Powered Approach to commercial 3-phase inverters

Milestones: Build >260 kW alpha and beta unit for full testing.

Complete EMC, UL and CEC tests on >260 kW inverter.

The sub-contract to UniSolar requires PV Powered to reduce the cost of inverters by pursuing a stage-gate approach to meet the project objectives. The inverter work is required to focus on new designs and better integration of inverters for building integrated applications.

Prior to contracting with United Solar, PV Powered commercially launched a 30 kW commercial scale inverter and a first generation 75 kW and first generation 100 kW inverter. During this sub-contract, PV Powered developed a second generation design for the 75kW and 100kW inverters.

However, the majority of the work completed was focused on the development of the new 260 kW product and later on a 500 kW product.

The high level tasks are the development of commercial 3-phase inverters, including optimization of inverter size for PV systems starting with a minimum size of 75 kW and a maximum size of 500 kW. During the two-year period of the project, PV Powered was required to develop specifications for four different commercial-size inverters and complete construction of alpha and beta prototypes, perform EMC tests, UL tests, and CEC tests for each of the four different sized inverters.

75 kW Inverter

The PVP75kW was initially released as a commercial product in June 2008. Subsequently, PV Powered created a updated Market Requirements Document (MRD) for the PVP75kW inverter. This revised MRD defines a Rev B product development effort for the PVP75kW which is targeted at reducing product cost and increasing product performance. The primary product improvement is a new lower MPPT voltage option of 265 VDC, which will work better with thin-film modules, including the UniSolar modules. Other product improvements will include updated firmware, adding a soft stop switch, improved fault reporting, and a series of other minor usability features added to the enclosure for ease of use and mistake-proofing. The cost reductions will come from changes in the enclosure, DC bus and magnetics.

100 kW Inverter

The PVP100kW is a sister product to the PVP75kW. The PVP100kW was initially released as a commercial product in 2008. Subsequently, PV Powered created an updated Market Requirements Document (MRD) for the PVP100kW inverter. This revised MRD defines a Rev B product development effort for the PVP75kW, targeted at reducing product cost and increasing product performance. The primary product improvement will be a new lower MPPT voltage option of 265 VDC, which will work better with thin-film modules, including the Uni-Solar modules. Other product improvements will include updated firmware, adding a soft stop switch, improved fault reporting and a series of other minor usability features. The cost reductions will come from changes in the enclosure, DC bus and magnetic.

260 kW Inverter

PV Powered developed a complete MRD for a new PVP260kW product. The MRD was designed with four guiding objectives: low cost, high reliability, leading installability/serviceability and exceptional performance with thin film PV modules. The new design leverages several of the market leading design features that were developed as part of the initial PVP100kW product, but it goes beyond the initial design by adding several valuable features. The most important new feature for the thin-film market is that the product was designed from the beginning to offer an optional 265 VDC low end MPPT. This will be the lowest of any commercial inverter in the US, and will enable exceptional stringing options that were previously not available in the US market. After completion of the MRD, significant new firmware and component development was required to fulfill the new market requirements.

PV Powered completed alpha and beta prototype 260 kW inverters. The prototype inverter was operated at full power in the PV Powered lab. The initial prototype exceed initial expectations in terms of fit, function and cost. PV Powered then built and submitted their commercial grade 260 kW inverter to UL for certification.

Complete Specifications for 500 kW 3-phase commercial inverter.

PV Powered evaluated customer feedback and decided to develop a 500 kW / 600VDC inverter. They evaluated large components, developed the architecture and built the test prototype. After meeting with advisors and utility consultants, PV Powered added new features to the build plan for the 500 kW prototype products. Specifically, utilities are asking for VAR control, Low Voltage Ride Through control and Power Factor control. During the sub-contract, PV Powered finalized the design for the 500 kW units and made the software and hardware changes to include PF control, LVRT, and VAR control. PV Powered prepared a summary of activity and the plan for EMC, UL and CEC tests to be completed after the end of their sub-contract.

Task 2.2. Solectria Renewables Approach to commercial 3-phase inverters

Milestones: Field testing and certification of 2nd Level inverter assembly cost reduction.
Commercialization of inverters for PV systems > 100 kW at a cost to the installer of $0.16-$0.18/ Watt.
Demonstrated new inverter design to result in a 40% cost reduction.

Status:
After successful testing, Solectria developed the product prototype for their new SGI 500. This development work allowed Solectria to identify major components and their costs (and costs as a percentage of total cost). Comparing costs from 2008, it was seen that Solectria has been able to drop manufacturing costs considerably.
Solectria successfully tested the SGI 500 internally, and then sent the SGI 500 out for external testing. Solectria subsequently received their listing letter from UL after successful testing at UL.
Solectria continued the commercialization of the SGI 500 kW inverter. The team sent an updated spreadsheet and chart with cost numbers that show they have hit their cost milestones. Task successfully completed in Q13.

TASK 3. SYSTEMS ENGINEERING AND INTEGRATION

The goal for this task is to develop novel and advanced application processes that will reduce the overall installation cost of United Solar roofing laminate modules. Specifically, to develop and implement a lower cost method for fastening United Solar's thin-film PV module laminates to existing roofing substrates, and to conduct reliability tests on all the new roofing solutions.

Milestones:

1. Developed a low cost solution for a removable solar module using standard roofing material.
2. Successfully completed accelerated environmental testing.
3. Obtained higher wind uplift rating on fully adhered roof cover up to 6X PVLs (certified wind uplift -270 psf max)
4. Received Miami Dade NOA (Notice Of Acceptance) for 4X PVL Solar Module which meet the High Velocity Hurricane Zone (HVHZ) Building Code.
5. Received Florida Statewide Product Approval for 4X PVL Solar Module.
6. Successfully convinced ICC (International Code Council) to revise AC365 to include self-adhered BIPV. (**Note**: Standard code minimizes cost and review process for case-by-case BIPV installation. International Building Code is adopted at state or local level in 50 states excluding HVHZ).
7. Began testing at 3rd party testing lab to meet the new ICC AC365.

Status: Task successfully completed in Q13.

TASK 4. DEPLOYMENT

The goal for this task is to deploy two complete 75 kW PV systems where all costs from engineering through commissioning are recorded for analysis. Both systems will be installed on flat commercial roofs. These roofs will be easily accessible for both the installation and the monitoring of performance. The detachable PV array will be deployed at one (or both) of the system sites. Operation and maintenance costs will be predicted and these costs will be verified over time. The systems will be equipped with data acquisition system (DAS) to monitor dc power, insolation, temperature, and electricity produced. The results will be analyzed to test inverter efficiency, to determine true costs and to formulate the LCOE from each system.

Milestones:

1. Completed installation of a 75 kW system in Florida, including monitoring system.
2. Completed installation of a 75 kW system in New Jersey, including monitoring system.
3. Began monitoring and reporting performance versus expectations for Florida and New Jersey installations.

In an effort to understand cost efficiencies that might be realized with building integrated products, two different PV system applications were developed for two different sites. At a temperate climate site in New Jersey, a USO PV Laminate is bonded directly to an existing metal roofing system. In a tropical climate site in Florida, a USO PV Laminate is bonded to a sacrificial sheet that is heat welded to an existing single-ply membrane roof, allowing the PV laminates to be easily removed by cutting the sheet away from the water-proofing roof membrane.

During the Design and Site Identification Phase we were able to analyze;

- The equipment costs associated with a single stage application (direct bond to metal) versus a two-stage application (sacrificial PV laminate assembly followed by installation on a membrane roof),
- Data acquisition system equipment costs, capabilities and new technologies,
- Suitability of sites where a new roof is not required before installation of a building integrated PV system, and
- Climate effects on building integrated PV system design, salt air, heat, wind, snow).

During the Installation Phase we continued to analyze;

- Suitability of PV integration / installation companies to properly bid and carry out building integrated PV system applications,
- The installation costs associated with a single stage application (direct bond to metal) versus a two-stage application (sacrificial PV laminate assembly followed by installation on a membrane roof),
- The installation costs associated with a wireless "smart" combiner box technology versus a wired "smart" combiner box technology, and
- Sacrificial sheet delivery, handling and deployment issues.

The purpose was to research the different advantages and disadvantages of two different building integrated PV system designs, and document installation costs (minus 1st year O&M costs) in order to determine ways to reduce total installed cost of a building integrated PV system.

To meet the above objectives, the team outlined the list of work descriptions in Table V.

Table V. Work description and results for the installation of two systems.

Work Descriptions	Results
Research sites in the United States where a building integrated PV system would be exposed to snow and cold conditions, hot and humid conditions, possible high wind conditions, and typical soiling conditions.	We chose one site in central New Jersey where the sloped metal roof will see cold winter temperatures and snow load on the laminates. We chose a second site in Florida where conditions will be hot and humid and the array will experience a high number of days with rain and possibility very high wind loading (>100 MPH).
Purchase USO building integrated PV laminates and major components for two 75kW PV systems to be deployed at two different sites in the United States.	Purchased equipment for *one system to be directly bonded to an existing metal roof and purchased equipment for another system where laminates are pre-bonded to a sacrificial sheet that is then heat welded to existing membrane roof.*
Investigate Data Acquisition Systems (DAS) companies in the United States, new technologies and deployment strategies where the goal is to reduce installed cost and increase customer and system operator access to relevant data	Developed, configured and installed new wireless "smart" combiner boxes, reducing installation costs and increasing granularity of data from the PV system.
Research equipment costs of a removable PV laminate solution for membrane roofs and compare that to a standard USO PV laminate deployment where the PV laminates are bonded directly to a metal roofing system	Two bills of material were completed and equipment costs were compared. Material costs were higher for the removable solution versus a direct bond solution.
Research labor costs of a removable PV laminate solution for membrane roofs and compare that to a standard USO PV laminate deployment where the PV laminates are bonded directly to a metal roofing system	Installation costs were recorded. Both labor and indirect costs were compared. Both labor and indirect costs were higher for the removable solution versus a direct bond solution.

Based on our experience with installing PV systems as the main contractor and with installing PV systems where our partner or an outside company contracts the installation, it was decided that United Solar would compare a standard PV laminate installation to a highly-requested removable PV laminate installation. We would look at both material and labor costs associated with the two different designs. We would research different equipment choices and the effects that might have on installation time and costs. Both system deployments would be contracted by United Solar and subcontracted by installation companies that provided detailed bids where costs were broken out so USO could analyze as many different aspects of the deployment as possible.

Material costs were tracked in an Excel spreadsheet. Labor costs were added to each cost sheet as labor quotes came in for both the removable and the direct bond deployments. It was thought that a removable solution would add to the material costs, but thelabor time would be reduced, and total installed cost for both solutions would be similar. However, labor savings on the removable solution were not realized, because creation of the PV laminate/sacrificial sheet had to be done on site rather than in an optimized assembly facility that also developed a delivery and staging solution that increased installation time on a per watt basis.

DAS installation labor time and costs were substantially reduced with the deployment of the "smart" wireless data acquisition system. No data wires or power wires were required for the "smart' combiner boxes that transmitted their data wirelessly to an antenna on the weather station mast. To further reduce labor and costs associated with the DAS, PV Powered imbedded the DAS equipment inside the inverter before shipment.

The two installations were originally scheduled for completion and commissioning in September, 2009. The 75 kW PV "removable" system in Florida was installed and commissioned in October, 2009. Due to delays in permitting and contractual issues between USO and the New Jersey site hosts, the sub-contractors at the second site in New Jersey started the installation later than expected. The system was installed before the end of 2009. The total installed cost for both PV application types (direct bond and removable) show that the removable solution proved to be more costly for installers who were not equipped to produce the PV "assemblies" (PV laminates and sacrificial TPO sheet) in a designed assembly facility. They produced the PV laminate / TPO sacrificial sheet assemblies on site. The direct bond solution is proving to be a lower cost solution today because installers are more familiar with the solution and there are no costs for the sacrificial sheet or pre-bonding operations. It is thought that an integrator/installer with a specialty assembly facility for the PV laminate / sheet assemblies could reduce cost for this part of the operation and new staging and deployment strategies would reduce labor time on site compared to a direct bond solution.

The installation time for the combiner boxes is expected to be identical in both cases (and comparable to the installation of combiner boxes in any PV installation) however, the installation of the data acquisition equipment for getting PV string data was substantially reduced compared to costs reported by PV Powered for a DAS system that does not use self-powered, "smart" combiner boxes and wireless communication between the DAS and PV string sensors. PV string data allows for operators to quickly identify problems, increasing up-time and reliability of the PV system.

Performance:
Lake City, FL - The performance has been excellent at 107% of expected over 26 months.
Moorestown, NJ – The system was performing well in Aug and Sept 2011, but the performance has dropped after the inverter was relocated in October.

TASK 5. PROJECT MANAGEMENT AND TPP COLLABORATIVE ACTIVITIES

This task is to perform required project management tasks necessary to support quarterly and annual reporting and review requirements. Also includes tasks to be performed in collaboration with other TPPs to advance the robustness of the overall PV industry under the direction from DOE officials.

USO completed all the necessary project management tasks, including completion of monthly status updates with DOE officials, quarterly reports, stage gate reviews, and hardware deliverables. USO completed work on arc suppression/detection, reviewed publications from the Solar ABCs website, and participated in conversations with other parties to advance the robustness of the overall PV industry. Task successfully completed.

	Major Milestone Schedule				
		Milestone Completion Dates			
Task No.	Milestone Description	Original Planned	Revised Planned	Actual	**Progress Notes**
1	Task 1.1.1A. Existing product, a-Si(Ge):H, efficiency improvement **Milestone:** Improve power rating on the 22L laminate to 148 W for >50% of the product.	8/31/10		8/31/10	Task completed.
2	Task 1.1.1B. Fabricate prototype 22L laminates on Ag/ZnO incorporating RTR solution-based ZnO. Conduct reliability tests **Milestones**: Attain 155 W prototype 22L laminates.	8/31/10	2/29/12	1/20/12	We have monitored outdoor performance of four 22L laminates using solution-based ZnO (EZO) from roll-to-roll depositions and an improved design that reduces inactive area and improves reliability. Power from the laminates is 6-12% higher than the current product. Task successfully completed
3	Task 1.1.2.1. Small area multi-junction cells incorporating one or more nc-Si:H layers **Milestone**: Attain ≥12% stable total-area (0.268 cm^2) efficiency on multi-junction device incorporating nc-Si:H, using small-area MVHF batch reactor on Ag/ZnO back reflector at rate ≥ 1nm/s.	8/31/10	2/29/12	1/20/12	1. We have improved nc-Si:H solar cell performance. An initial active area efficiency of 10.6% is attained. This is one of the highest nc-Si:H single-junction cell efficiencies. 2. We attained a stable total-area (1 cm^2) efficiency of 12.56% using an a-Si:H/nc-Si:H/nc-Si:H triple-junction structure. This NREL measured efficiency is a new world record for thin film silicon solar cells. 3. This task is successfully completed.

4	Task 1.1.2.2. Large area multi-junction cells incorporating one or more nc-Si:H layers **Milestones:** Attain ≥10.5% stable aperture-area (~400 cm^2) efficiency on multi-junction device incorporating at least one nc-Si:H layer on Ag/ZnO back reflector, using large-area MVHF batch reactor at rate ≥ 1nm/s.	8/31/10	2/29/12	1/20/12	NREL measured 10.6% to 11.3% aperture-area efficiency on ~400 cm^2 encapsulated a-Si:H/nc-Si:H/nc-Si:H triple-junction cells on Ag/ZnO back reflector made at high deposition rate (≥1nm/s). The milestone has been exceeded.
5	Task 1.1.2.3. Large area deposition of nc-Si:H at high rates by VHF **Milestone:** Deposition of nc-Si:H over 50″ wide cathode at rate ≥ 1.2 nm/s with integrated uniformity (average across the web moving direction) better than 85% over 42″.	8/31/10		8/31/10	Task completed.
6	Task 1.1.2.4. Electronic and Optical characterization of materials **Milestone:** A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.	8/31/10	2/29/12	9/30/11	Task completed.
7	Task 1.1.2.5. Defect characterization of materials and devices **Milestone:** A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.	8/31/10	8/31/11	6/30/11	Task completed.
8	Task 1.1.2.6. Diagnostic development of mobility characterization tool **Milestone:** A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.	8/31/10	4/30/11	4/30/11	Task completed.

9	Task 1.1.3.1. High deposition rate a-Si:H and a-SiGe:H on small areas **Milestone:** Attain ≥10.2% stable total-area (0.268 cm^2) efficiency on multi-junction device on Ag/ZnO back reflector with a-Si:H and a-SiGe:H cells deposited at ≥ 0.6 nm/s.	8/31/10		8/31/10	Task completed.
10	Task 1.1.3.2. High deposition rate a-Si:H and a-SiGe:H on large areas **Milestone:** Attain ≥ 9.5% stable aperture-area (~400 cm^2) efficiency on multi-junction device using large-area MVHF batch reactor on Ag/ZnO back reflector at deposition rate ≥ 0.6 nm/s.	8/31/10		8/31/10	Task completed.
11	Task 1.1.3.3A. Large area deposition of a-Si:H and a-SiGe:H at high rates by VHF **Milestone:** Deposition of a-Si:H and a-SiGe:H over 50″ wide cathode at ≥ 0.8 nm/s with integrated uniformity (average across the web moving direction) better than 85% over 42".	8/31/10		6/30/10	Task completed.
12	Task 1.1.3.4. Defect characterization of high deposition rate materials **Milestone:** A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.	8/31/10		9/30/10	Task completed.
13	Task 1.1.3.5. Full material characterization and modeling of high rate materials **Milestone:** A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.	8/31/10	2/29/12	8/31/11	Task completed.

14	Task 1.1.4.1. New Approaches for light trapping **Milestone:** A technical paper in a conference proceedings or peer-reviewed journal. In lieu of a technical paper an annual report on the same topic will be accepted.	8/31/10	4/30/11	4/30/11	Task completed.
15	Task 1.1.4.2. Al/ZnO and Ag/ZnO back reflector fabrication based on optical predictions **Milestone:** Provide samples to Syracuse University and fabricate devices to evaluate new light trapping approaches based on Syracuse University feedback.	8/31/10	2/29/12	9/30/11	Task completed.
16	Task 1.2.1. Wire grid cost reduction **Milestones:** Improve and finalize materials and processes for production trials and incorporate into production.	8/31/10		8/31/10	Task completed.
17	Task 1.3.1. Back Lamination **Milestone:** Complete detailed qualification testing with at least one alternative back lamination configuration. Initiate certification testing.	8/31/10		8/31/10	Task completed.
18	Task 1.3.2. EVA **Milestone:** Complete certification testing. Define an appropriate scale-up plan for introducing qualified material into production. Observe the effects on actual material cost associated with production scale-up.	8/31/10		8/31/10	Task completed.

19	Task 1.3.3. ETFE **Milestone:** Complete qualification testing and subsequent certification testing. Define an appropriate scale-up plan for introducing qualified material into production. Observe the effects on actual material cost associated with production scale-up.	8/31/10		8/31/10	Task completed.
20	Task 1.3.4. Black Cosmetic Insulator Film **Milestone:** Using preliminary test data, down-select to at least one alternative black cosmetic insulator film (BCF). Complete detailed qualification testing of one alternate BCF material. Cost of down-selected material to be at least 50% lower than that of production BCF.	8/31/10		8/31/10	Task completed.
21	Task 1.4.2. *In-situ* I-V measurements in the ITO machine and automated optimization **Milestone:** Convert inline tester to a three-web system and fully incorporate into QA procedures.	8/31/10		8/31/10	Task completed.
22	Task 1.4.3. a-Si process chamber spectrometers and differential deposition profiles **Milestone:** Integrate the Stop-N-Go tool into the standard operations of all production lines.	8/31/10		8/31/10	Task completed.
23	Task 2.1. PV Powered Approach to commercial 3-phase inverters **Milestones:** Build >260 kW alpha and beta unit for full testing. Complete EMC, UL and CEC tests on >260 kW inverter.	8/31/10		8/31/10	Task completed.

24	Task 2.2. Solectria Renewables Approach to commercial 3-phase inverters **Milestones:** Field testing and certification of 2nd Level inverter assembly cost reduction. Commercialization of inverters for PV systems > 100 kW at a cost to the installer of $0.16-$0.18/ Watt. Demonstrated new inverter design to result in a 40% cost reduction.	8/31/10		8/31/10	Task completed.
25	Task 3. Systems engineering and integration **Milestone:** Develop novel and advanced application processes that will reduce the overall installation cost of United Solar roofing laminate modules.	8/31/10		8/31/10	Task completed.
26	Task 4. Deployment **Milestone**s: 1). Complete installation of two 75kW systems by 11/30/09. 2). Monitor and report performance versus expectations for Florida and New Jersey installations.	1) 8/31/09 2) 8/31/10	1) 11/30/09 2) 2/29/12	2)1/20/12	Lake City, FL - Continued to monitor the PV system performance. The performance has been excellent at 107% of expected over 26 months. Moorestown, NJ – Continued to monitor the PV system. The system was performing well in Aug and Sept 2011, but the performance has dropped after the inverter was relocated in October. We are working to understand the reason for the drop. Task completed.
27	Task 5. Project Management and TPP Collaborative Activities.	8/31/10		8/31/10	Task completed.

Appendix A: List of publications

1. P. G. Hugger, J. David Cohen, Baojie Yan, Guozhen Yue, Xixiang Xu, Jeffrey Yang, and Subhendu Guha, "Electronic Properties Of Nanocrystalline Silicon Deposited With Different Crystallite Fractions And Growth Rates", Mater. Res. Soc. Symp. Proc. **1066**, 149 (2008).
2. Xixiang Xu, Baojie Yan, Dave Beglau, Yang Li, Greg DeMaggio, Guozhen Yue, Arindam Banerjee, Jeff Yang, Subhendu Guha, Peter G. Hugger, and J. David Cohen, "Study of Large Area a-Si:H and nc-Si:H Based Multijunction Solar Cells and Materials" Mater. Res. Soc. Symp. Proc. **1066**, 325 (2008).
3. Baojie Yan, Guozhen Yue, Yanfa Yan, Chun-Sheng Jiang, Charles W. Teplin, Jeffrey Yang, and Subhendu Guha, "Correlation of Hydrogen Dilution Profiling to Material Structure and Device Performance of Hydrogenated Nanocrystalline Silicon Solar Cells", Mater. Res. Soc. Symp. Proc. **1066**, 61 (2008).
4. Baojie Yan, Guozhen Yue, Chun-Sheng Jiang, Yanfa Yan, Jessica M. Owens, Jeffrey Yang, and Subhendu Guha, "Optical Enhancement by Textured Back Reflector in Amorphous and Nanocrystalline Silicon Based Solar Cells", Mater. Res. Soc. Symp. Proc. Symposium KK (2008).
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6. Baojie Yan, Guozhen Yue, Jeffrey Yang, and Subhendu Guha, "*CORRELATION OF CURRENT MISMATCH AND FILL FACTOR IN AMORPHOUS AND NANOCRYSTALLINE SILICON BASED HIGH EFFICIENCY MULTI-JUNCTION SOLAR CELLS*", 33rd IEEE PVSC, (2008).
7. Guozhen Yue, Baojie Yan, Jeffrey Yang, and Subhendu Guha, "*HYDROGENATED AMORPHOUS SILICON AND SILICON GERMANIUM TRIPLEJUNCTION SOLAR CELLS AT HIGH RATE USING RF AND VHF GLOW DISCHARGES*", 33rd IEEE PVSC, (2008).
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10. Xixiang Xu, Yang Li, Scott Ehlert, Guozhen Yue, Baojie Yan, Tining Su, Jinyan Zhang, Arindam Banerjee, Jeff Yang, and Subhendu Guha, "Comparative Study of MVHF and RF Deposited Large Area Multi-junction Solar Cells Incorporating Hydrogenated Nano-Crystalline Silicon", Mater. Res. Soc. Symp. Proc. **1153,** 457 (2009).
11. Xixiang Xu, Dave Beglau, Scott Ehlert, Yang Li, Tining Su, Guozhen Yue, Baojie Yan, Ken Lord, Arindam Banerjee, Jeff Yang, Subhendu Guha, Peter G. Hugger, and J. David Cohen, "High Efficiency Large Area a-Si:H and a-SiGe:H Multi-junction Solar Cells Using MVHF at High Deposition Rate", Mater. Res. Soc. Symp. Proc. **1153,** 99 (2009).

12. Jeffrey Yang, Baojie Yan, Guozhen Yue, and Subhendu Guha, **“**Light trapping in hydrogenated amorphous and nano-crystalline silicon thin film solar cells**”,** Mater. Res. Soc. Symp. Proc. **1153,** 247 (2009) (invited).
13. Guozhen Yue, Laura Sivec, Baojie Yan, Jeffrey Yang, and Subhendu Guha, “High efficiency amorphous and nanocrystalline silicon based multi-junction solar cells deposited at high rates on textured Ag/ZnO back reflectors”, Mater. Res. Soc. Symp. Proc. **1153,** 207 (2009).
14. Guozhen Yue, Baojie Yan, Laura Sivec, Jessica M. Owens, Sherry Hu, Xixiang Xu, Jeffrey Yang, and Subhendu Guha, “IMPROVEMENT OF a-Si:H AND nc-Si:H MULTI-JUNCTION SOLAR CELLS BY OPTIMIZATION OF TEXTURED BACK REFLECTORS”, 34rd IEEE PVSC (2009), p327.
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16. Baojie Yan, Guozhen Yue, Laura Sivec, Jeffrey Yang, and Subhendu Guha, “Extraction of carrier transport parameters from hydrogenated amorphous and nanocrystalline silicon solar cells”, SPIE (2009)
17. Jeffrey Yang and Subhendu Guha, “Status and future perspective of a-Si:H, a-SiGe:H, and nc-Si:H thin film photovoltaic technology”, SPIE (2009), submitted. (Invited).
18. P. Hugger, J.D. Cohen, B. Yan, J. Yang, and S. Guha, “Insights and challenges toward understanding the electronic properties of hydrogenated nanocrystalline silicon”, Phil. Mag. **89**, 2541 (2009).
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24. P.G. Hugger, J. Lee, J.D. Cohen, G. Yue, X. Xu, B. Yang, J. Yang, and S. Guha, “Material Properties of a-SiGe:H Solar Cells as a Function of Growth Rate”, Mater. Res. Soc. Symp. Proc. **1245**, 119 (2010).
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