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# High Throughput Manufacturing of High Efficiency Solar Cells

Sixth Technical Quarterly Report
Energy Related Inventions Program
[ERIP Recommendation # 709]



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Department of Mechanical Engineering
Colorado State University
Fort Collins, Colorado 80523

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## DISCLAIMER

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This is our sixth quarterly report for the ERIP project 709, High Throughput Manufacturing of High Efficiency Solar Cells. Monthly reports are submitted via electronic mail to our invention coordinator, Rolf Butters. The project officially started on May 30, 1998, with a one year extension granted in March 1999.

During the past three months we have been progressing on the following activities listed below. We have been following the tasks outlined in our Statement of Work (SOW), section D-3 tasks 1-6. The schedule given in our Statement of Work is for a project duration of one year with the machine building (tasks 1-4) expected to be completed in the first nine months and the testing and optimization of the system (tasks 5-6) to be completed in the last three months. The technical progress on the design and assembly phase is completed. However, tasks 4-6 are being completed in this, the second year of the project.

The assembly and preliminary testing of the machine has been fully completed. The system including the AVA belt, seals and vapor process modules perform well. We can easily and robustly deposit the solar cell active junction with the heat treatments.

During these last three months, we have continued to optimize the deposition parameters, vapor chloride treatment and back contacting procedure to the solar cell (Task Four). In addition to manufacturability and efficiency, long term solar cell stability is a critical aspect of PV technology. We have designed and built a tester for thermal and light soaking accelerated stress testing. The results are very promising. We have found that all the cell deposition parameters and heat treatments effect stability and efficiency.

We are consistently fabricating cells with stable 8 to 11.5% conversion efficiency. Cells are tested with and ELH lamp simulation of global AM1.5 at 1000W/m$^2$. The test stand is calibrated with an commercially available CdS/CdTe cell tested for us at NREL. Our process has produced cell efficiencies as high as 11.8%. To our knowledge these are some of the highest performance numbers reported for a CdTe cell deposited on the LOF tin oxide coated substrate. We are continuing stability testing. Stable cell performance has been demonstrated for over 1000 hours of continuous accelerated stress testing. Work continues to verify stability and to optimize the process.

***The AVA belt, seals and process modules function very reliably. 85 separate deposition runs resulting over 1200 thin films and solar cells have been made successfully made using the AVA belt transport and process modules.***

**Task 1 "Design, build, assemble and debug the process modules".**
This task is approximately 100% completed.

1a. Final design and fabrication of all of the process modules for heating and semiconductor deposition have been completed.

1b. The control system is optimized for each process module.

1c. High performance HEPA air filtration has been running in the lab to eliminate occupational safety issues.

1d. A mini-environment (clean room area) has been fabricated for the entrance of the system where the substrates are loaded to reduce particulate contamination and the automated substrate cleaning apparatus has been completed and is functioning well.

**The process modules have operated extremely well and have required little or no maintenance since they were installed in the system**

**Task 2. "Design build, assemble and debug the advanced AVA belt system to transport glass substrates through the process modules."**
This task is approximately 100% completed.

2a. The AVA belt and new updated motor has been installed on the system and are running very well. Belt motion is fully automated and position error checking and emergency functions are fully operational.

2b. The new motor and updated controller have been running well. The system has been used to transport substrates for film deposition for five to six months.

2c. A rail guide for the glass substrates has been designed, fabricated and installed in the vacuum chamber. This prevents unwanted substrate movement caused by a high frequency harmonic during belt indexing.

**Task 3. Assemble the process modules in the vacuum system and test:**
This task is approximately 100% completed.

3a. All six internal process modules have been installed in the vacuum system.

3b. The six modules were run individually and simultaneously and were stressed at temperatures above their normal operating range. The modules and process controls performed well.

***The AVA belt, seals and process modules function very reliably. 86 separate deposition runs resulting many hundreds of samples have been made successfully made using the AVA belt transport and process modules. The entire system has demonstrated the ability to with stand the rigors of PV processing.***

**Task 4. Preliminary testing of the system to determine the performance of the entire system, SDE to identify the optimum process conditions to produce cells of the highest efficiency**

This task is about 80 % complete and will be completed in 1-2 months.

4a. All films and processes used in fabricating our cell have been successfully performed using the AVA system. High quality CdS, CdTe and cadmium chloride vapor heat treating has been successfully performed.

4b. A solar cell testing station has been constructed to facilitate characterization of our cells. The test stand is fully computer automated. A highly characterized CdTe cell has been obtained from NREL for calibration of the test stand.

4c. An accelerated stress testing station capable of both light soaking at approximately AM 1.5 conditions and thermal baking between 65 and 85 degrees C. has been constructed and used to evaluate long term cell stability and reliability. Cells have undergone stress testing with promising results.

4d. Many completed solar cells have been fabricated using AVA system. Cells with between 8 -11.5% conversion efficiency are consistently seen.

4e. The new metallization method has continues to function well. The materials for this procedure are readily available commercially, and can be applied using standard industrial equipment.

**Task 5. Trial runs with lot size of 200 cells at the optimum conditions and test the 200 cells to study efficiency, variability, yield, etc.:**

This task is will be competed in approximately 4 months.

5.a. Statistical experts at CSU's Statistical Laboratory have been consulted for experimental design to evaluate process variability.

5b. This expert has stated that process repeatability can be demonstrated with fewer than 200 cells. Efforts are underway to design the optimum experimental study.

5c. Cells from Task 4 will used to help demonstrated process performance and variability.

**Task 6. Run many (more than five) lots of 200 cells to study efficiency, variability, yield, lot-to-lot variations, etc**

This task is will be started in approximately 5 months.

We will continue to progress on the tasks outlined in the SOW. If there are any questions please call our facility at 970.491.8411.