Development of Robust High Efficiency Thin-Film CdTe Photovoltaic Modules

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ABSTRACT

The purpose of this multi-year program, which started October of 2006, is to achieve CdS/CdTe thin film modules with am1.5, aperture-area efficiencies of 12.5% or greater by October of 2009. Further, these modules are to be stable to better than 95% of their initial values after being subjected to an Accelerated Life Test (ALT) protocol. In this initial phase of the program, the necessary tools to evaluate device and material characteristics have been identified and are in-house or contracted as services. These tools are currently being used off-line to diagnose and evaluate the results of modifications in semiconductor deposition and post deposition processing.

1. Objectives

The objective of this program is to develop robust processes that will exhibit improved efficiency and stability in the field (as indicated by accelerated life testing – ALT). The milestones for each of the three program years are shown in Table 1.

Table 1. Efficiency Milestones

Program Year	Initial Efficiency (%)	After ALT Efficiency (%)
1	11.00	10.45
2	12.00	11.40
3	12.50	11.88

The efficiency goals for this program are consistent, but more aggressive than the goals stated in the DOE Solar Energy Program Multi-Year Program Plan[1] of achieving 10% efficiency CdTe modules by 2011. Another goal of this program is to demonstrate a 25-year module life through accelerated life test. First Solar's 25-year life requirement would more than satisfy the 20-life goal called out in the DOE Solar Energy Program Multi-Year Program Plan.[1]

First Solar has a clear focus on manufacturing. First Solar is the largest PV module manufacturer in the United States and the largest thin film PV module manufacturer in the world. We have sold >100 MW of PV modules to date and are actively expanding manufacturing capability. By the fourth quarter of 2008 we expect to be producing 275 MW/yr of thin film PV modules. 100% of our current and planned capacity is based on thin film CdTe PV.[2]

2. Technical Approach

The initial effort of the program is to identify and acquire the characterization tools necessary to track the effect of process variation and modification on the optoelectronic properties of the device. Because the goal of the program is to develop the processes required to achieve the higher efficiency in a production environment, emphasis has been placed on acquiring characterization tools that can be used for in-line process measurement and control. Characterization tools that are not amenable to large area measurements in a production environment will be used off-line, in-house or contracted to be done as a service from external contractors.

The improved efficiency will occur through reducing electrical and optical losses in the superstrate, improving the interfacial quality and electrical transport properties of the CdS/CdTe structure, and improving the back contact.

Improving the superstrate is the task of the First Solar PVMAT program (subcontract no. ZAX-4-33628-04). This program will directly benefit from the improvements made to the superstrate in the PVMAT program. Consequently, process efforts for this program are directed towards improvement of the CdS/CdTe electrical transport properties and the back contact.

The major step in improving efficiency and stability are to identify the major failure mechanisms i.e. what part of the device is affected and what process step is responsible. This information will be obtained from extensive characterization of process tests on modules and individual cells as well as stressed modules (subjected to ALT and field testing over a period of months and years). In addition to these tests being used to establish and maintain a robust process for producing higher efficiency modules, the results will be used to establish an ALT stability model. This stability model will be based on activation energies of the degradation mechanisms and it will be used to determine end-of-life efficiency with a high degree of confidence.

3. Results and Accomplishments

The program is only five months into its first year; however, there has been significant progress in the acquisition of the characterization tool set required to diagnose and improve the individual process steps semiconductor deposition, post-deposition processing, and back contact formation. The list of characterization techniques will, undoubtedly increase over the course of the program, but the following are the tools required for the initial device limitation and process improvement work.

- J-V measurements as a function of light wavelength and intensity – multiple measurements will allow the extraction of an effective diffusion length and back contact effects
- Time Resolved Photoluminescence (TRPL) – measurement of excess carrier lifetime
- X-Ray Diffraction (XRD) & Electron Back Scatter Diffraction (EBSD) – to determine the effect of crystal structure on device characteristics.
- In-line Optical Spectroscopy – to determine individual layer thickness and surface roughness
- Scanning Kelvin Probe – to determine the work function of free surfaces (primarily for back contact work)
- Eddy Current Sheet Resistance Measurement – to determine the changes in resistivity resulting from process and structural variations
- Inductively Coupled Plasma (ICP) Analysis and Secondary Ion Mass Spectroscopy (SIMS) – chemical composition, background impurity analysis, and dopant profiles

This suite of characterization techniques are currently being used to determine the efficiency limitations imposed by each process step. Additionally, devices are being stressed under a variety of conditions to determine the mechanisms responsible for efficiency degradation. These tests are still being evaluated and will be reported in the future.

4. Conclusions

This program will provide the means to identify the practical and real mechanisms for the limitation of efficiency and stability. The same techniques used to identify these mechanisms will be used to monitor and maintain process control over the critical process steps. Although the initial work is too preliminary to report, the approach is sound and yielding promising results.

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REFERENCES

[1] Solar Energy Technologies Program, Multi-Year Program Plan 2007-2011, www.eere.energy.gov/solar/about.html ,p65.

[2] For more information go to http://www.firstsolar.com/