OUTDOOR PERFORMANCE TESTING OF THIN-FILM DEVICES

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The Advanced Systems Research Group supports the PV AR&D project by providing outdoor (global) testing of PV cells, submodules, modules, and arrays. The group also provides in-house engineering and analysis to identify and determine how technical issues such as cell/module/system adaptations, long-term stability, reliability, economics, materials availability, safety, and environmental impacts affect the development and ultimate use of advanced PV thin film, innovative cell and material technologies.

A major thrust of the research effort is to develop and utilize instrumentation and procedures for monitoring and analyzing PV cells and submodules including outdoor performance and stability testing and life-cycle accelerated stress testing. Through testing and simulation, researchers can identify problems that require further laboratory research and can help to focus, as well as support, advanced PV systems research.

To accomplish the above, the SERI outdoor PV test facility was established in 1982. The facility is located directly west of SERI's field test laboratory building in Golden, Colorado. The group has designed testing systems and analysis procedures for, and has tested, numerous amorphous silicon thin film submodules provided by SERI subcontractors and has performed long-term outdoor stability tests on CdS/CuInSe2 and hydrogen passivated silicon solar cells. A significant contribution from this facility over the past year was the testing of large-area amorphous silicon submodules which supported the achievement of major milestones in the DOE/SERI PV Program.

The outdoor testing operations are presently divided into four functional areas: (1) Outdoor Performance Testing; (2) Stability Performance Testing; (3) Accelerated Stress Testing, and (4) Systems Simulation Testing. The following provides an overview of outdoor performance and stability testing capabilities at SERI, selected test results and performance trends.

- Outdoor Performance Testing: This activity includes the measurement of PV cell and submodule I-V characteristics in an outdoor environment under sunlight. Figure 1 illustrates typical test and measurement data and information recorded during a test program. The mainstay of the testing system is an HP 3054A data system (Figure 2) controlled by an HP 9836 computer. A specially designed test bed (Figure 3), with temperature control capabilities, vacuum hold down provisions, motor controlled light shutter, and calibrated pyranometer, can accommodate cells and submodules ranging in sizes up to .61 meters (2 ft) by 1.1 meters (3.5 ft). A unique testing capability has been incorporated into this system which makes it possible to simultaneously test and measure individual cell I-V characteristics of series connected cells on a submodule substrate.
Over 200 tests have been performed on various thin-film submodules in the last two years. Selected test results are provided in Table 1 illustrating the range in submodule sizes (active areas) tested and corresponding performance data obtained during outdoor tests. Test results taken from Table 1 (efficiency and fill factor) are plotted against time (Figure 4) and submodule active area (Figure 5) illustrating performance trends.

Stability Performance Testing: A variety of testing systems are being utilized for long-term performance and stability measurements of cells and submodules. These systems include a hermetically sealed test chamber purged with nitrogen for outdoor stability exposure tests of cells and is monitored by an HP 3054A data system controlled by an HP 85 computer. Two additional outdoor test beds, which can accommodate large submodules and modules ranging in sizes up to .61 meters (2 ft) by 1.1 meters (3.5 ft) have provisions for temperature and environmental control during testing and are controlled and monitored by an HP 3054A or Acurex Autodata Ten/10 data systems. Recent testing utilizing these systems included outdoor stability testing of CdS/CuInSe₂ and hydrogen passivated silicon solar cells. Selected stability performance test results are illustrated by Figures 6 and 7 for a CdS/CuInSe₂ solar cell and by Figure 8 for a hydrogen passivated silicon solar cell.
Typical Test and Measurement Data and Information Recorded during a Testing Program

- Date of test
- Time of test
- Test specimen I.D. number
- Insolation before and after test
- Temperature
- Area
- $I_{sc}$ (short circuit current)
- $V_{oc}$ (open circuit voltage)
- $P_{max}$ (maximum power output)
- Current at $P_{max}$
- Voltage at $P_{max}$
- Current at $V_{oc}$
- Voltage at $I_{sc}$
- Efficiency
- Fill factor
- I-V curve and listing of data points
- Solar spectral response curve and listing of data points
Amorphous Silicon Test — Data & Control System

Figure 2
Amorphous Silicon Test Supports

- Closed Chamber
  - Glass Cover
  - Dry N₂ Purge
  - Temperature Control 10° - 60°C
  - Pyranometer
  - RTD Temperature Measurements
  - Module Space: 2 ea. 1’ = 2-1/2’ or 1 ea. 2’ = 3-1/2’
  - Contacts for 50 Cells

- Open Chamber
  - Remote Control Lid and Light Shutter
  - Pyranometer
  - RTD Temperature Measurements
  - Module Space: 2 ea. 1’ = 2-1/2’ or 1 ea. 2’ = 3-1/2’
  - Contacts for 50 Cells

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**Figure 3**

**PV Thin-Film Submodule Outdoor Performance Test Results**

<table>
<thead>
<tr>
<th>Sample Code No.</th>
<th>Material</th>
<th>Date</th>
<th>Time</th>
<th>Insolation (W/m²)</th>
<th>Temp. (°C)</th>
<th>Iac (mA)</th>
<th>Voc (volts)</th>
<th>FF (%)</th>
<th>Eff. (%)</th>
<th>Area (cm²)</th>
<th>Dimensions (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS1</td>
<td>Amorphous Si</td>
<td>5/24/83</td>
<td>P.M.</td>
<td>957</td>
<td>39.0</td>
<td>70.9</td>
<td>13.3</td>
<td>51.2</td>
<td>4.6</td>
<td>126.9</td>
<td>---</td>
</tr>
<tr>
<td>AS2</td>
<td>&quot;</td>
<td>5/24/83</td>
<td>P.M.</td>
<td>896</td>
<td>29.2</td>
<td>110.5</td>
<td>26.0</td>
<td>68.5</td>
<td>4.8</td>
<td>350.0</td>
<td>---</td>
</tr>
<tr>
<td>AS3</td>
<td>&quot;</td>
<td>6/23/83</td>
<td>P.M.</td>
<td>1047</td>
<td>39.0</td>
<td>69.7</td>
<td>21.1</td>
<td>65.1</td>
<td>4.3</td>
<td>149.0</td>
<td>---</td>
</tr>
<tr>
<td>AS4</td>
<td>&quot;</td>
<td>8/2/83</td>
<td>A.M.</td>
<td>923</td>
<td>36.3</td>
<td>66.1</td>
<td>13.1</td>
<td>58.1</td>
<td>6.1</td>
<td>102.4</td>
<td>21 x 10</td>
</tr>
<tr>
<td>AS5</td>
<td>&quot;</td>
<td>9/28/84</td>
<td>A.M.</td>
<td>1205</td>
<td>35.8</td>
<td>319.9</td>
<td>23.7</td>
<td>54.3</td>
<td>5.0</td>
<td>693.3</td>
<td>30 x 30</td>
</tr>
<tr>
<td>AS6</td>
<td>&quot;</td>
<td>9/28/84</td>
<td>A.M.</td>
<td>1049</td>
<td>36.1</td>
<td>316.9</td>
<td>23.1</td>
<td>57.0</td>
<td>5.5</td>
<td>722.4</td>
<td>30 x 30</td>
</tr>
<tr>
<td>AS7</td>
<td>&quot;</td>
<td>2/7/85</td>
<td>A.M.</td>
<td>1182</td>
<td>32.1</td>
<td>341.5</td>
<td>22.7</td>
<td>57.1</td>
<td>5.1</td>
<td>733.3</td>
<td>30 x 30</td>
</tr>
<tr>
<td>AS8</td>
<td>&quot;</td>
<td>2/8/85</td>
<td>P.M.</td>
<td>906</td>
<td>44.2</td>
<td>62.1</td>
<td>11.1</td>
<td>64.3</td>
<td>5.9</td>
<td>82.5</td>
<td>21 x 21</td>
</tr>
</tbody>
</table>

- Test Site Location: SERI Advanced PV Systems Outdoor Test Facility - Golden, Colorado
- Insolation Measurement Uncertainty: ±5% (GHI-bal)
- Encapsulated

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* Table 1

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A SILICON SUBMODULE OUTDOOR PERFORMANCE

SERI ADVANCED PV SYSTEMS TEST SITE

Figure 4
A-SILICON SUBMODULE OUTDOOR PERFORMANCE

SEMI ADVANCED PV SYSTEMS TEST SITE

Figure 5
CuInSe2/CdS OUTDOOR STABILITY PERFORMANCE

SERI PV SYSTEMS TEST SITE (A=880 DNI)

Dec. 28, 1984
Observation No.

Jan. 27, 1985

Figure 6
CuInSe2/CdS OUTDOOR STABILITY PERFORMANCE
SERI PV SYSTEMS TEST SITE (a=890 WM-2)

Figure 7
STABILITY TESTING OF HYDR PASS SILI CELL.

SERV PV SYSTEMS TEST SITE GM AB CH II O Y.

FIGURE 8

July, 1984

August, 1984

DAY

0 5 10 15 20 25 30

RELATIVE PERCENT

60.0

70.0

80.0

90.0

100.0

TEMP

8.0

INSULATION

w/CpH+2

EFFICIENCY

+10%

0.0

10.0

20.0

30.0

40.0

50.0

60.0

70.0

80.0

90.0

100.0

Figure 8
DISCUSSION

LESK: I have seen some very high insolation values. You had one at 1200 W/m² with reflection from clouds adding on to a clear beam. Was that a special circumstance for that one, or will something else give it that high a value?

DE BLASIO: That is typical at our test facility on a clear summer day. There we average 1100, 1150, 1200, even up to 1240. Hard to believe, but it's true.