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Advanced Indoor Module Light-Soaking Facility

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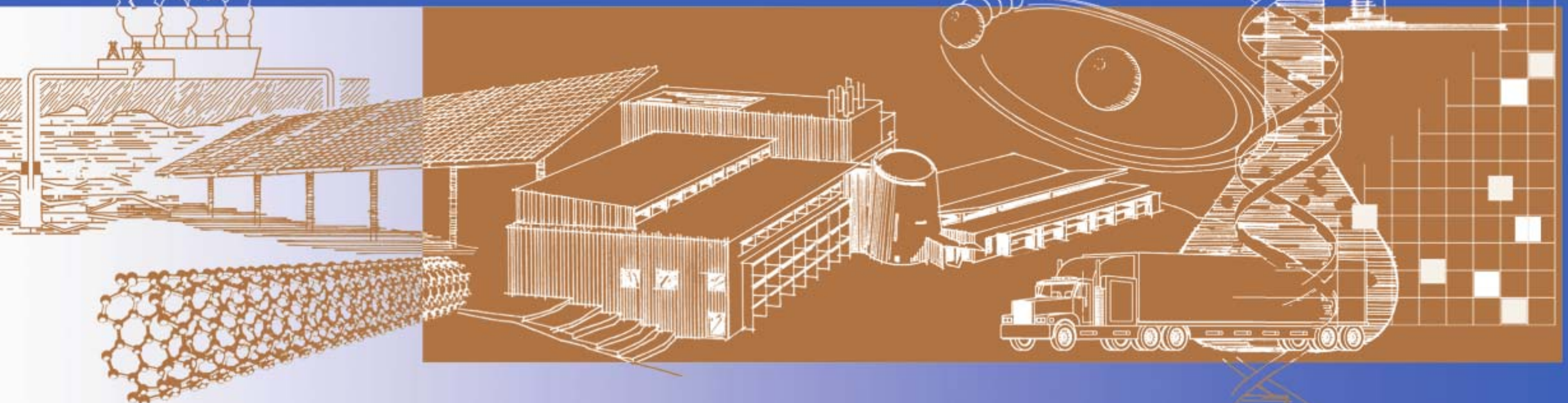

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ABSTRACT

An overview of the accelerated, indoor light-soaking test station is presented in this paper, along with data obtained for six modules that underwent exposure. The station comprises a climate-controlled chamber equipped with a solar simulator that allows 1-sun light intensity exposure. Concurrently, we monitor the electrical characteristics of multiple PV modules and exercise active control over their electrical bias using programmable electronic loads, interfaced to a data acquisition system that acquires power-tracking and current-voltage data. This capability allows us to the test different bias conditions and to cyclically alternate between them. Additionally, we can vary the light intensity and module temperatures to garner realistic temperature coefficients of module performance. Data obtained on cadmium telluride (CdTe) and amorphous silicon (a-Si) modules are presented.

1. Objectives

Thin-film PV modules are attractive components for utility-based or building-integrated PV energy production because of their potential to reduce costs and integrate properly with supporting architecture. Yet, stable PV energy production depends on many factors, including specific semiconductor materials, interconnect technologies, and module encapsulation. In the past, we have found that any of these components can degrade with extended light exposure and exhibit sensitivity to operating temperatures and/or bias. Our purpose for the operation of the indoor light-soaking station is primarily to quantify module performance as a function of overall light exposure and observe any bias- or temperature-dependent changes that may accelerate degradation.

2. Technical Approach

We employ a large controlled-climate chamber whose air temperature is regulated by a programmable temperature controller, equipped with both cooling and heating capabilities that can range between –40° and +90°C. Outside the chamber stands a Vortek light source equipped with metal-halide lamps capable of delivering 1-sun simulated illumination onto the test plane inside. The size of the test plane comprising the ±20% spatial intensity uniformity contours is a rectangle 1.2 by 1.7 meters on each side. The spectral content of the lamps approximates that of the reference AM1.5 global spectrum fairly well: the difference between their integrated intensities is typically within a few percent, for the spectral range 350 to 900 nm, with 10% being the maximum deviation.

Module temperatures are continuously monitored during exposure, using one or two type 'T' thin-film thermocouples bonded to their backsides. During exposure, the modules are electrically loaded and biased via connections to either fixed power resistors, or more recently, active programmable electronic loads. These electronic load units allow for the continuous biasing and monitoring of current-voltage (I-V) characteristics plus power tracking, replicating any one of fixed voltage, current, or resistance as one of their control modes. We've interfaced these to a personal computer (PC) to actively alternate between control modes and setpoints, thereby allowing both I-V curve tracing and variable biasing. All relevant signals (temperatures, intensity) of the experiment are monitored by a PC-based data acquisition system. All of these data are referred to the as in-situ data.

Modules are light-soaked in intervals lasting several hundred hours at a time, between which times we remove them from the chamber to have their light I-V characteristics tested at standard reporting conditions (SRC) using more robust solar simulators. All modules are tested prior to exposure and between exposure intervals using both SPIRE (pulsed) and LACSS (continuous) simulators. We augment these data with dark I-V measurements. For CdTe modules, two sets of I-V tests are conducted: the first one is the so-called 'storage state' taken immediately after the modules have lain under low-light level conditions; the second test is performed after a 10-min 'light-stabilization' at open circuit in front of the LACSS. We do this to reveal transient effects in CdTe that can become prominent after light-soaking. Total accumulated exposure can vary between 1000 and 3000 hours depending upon the modules tested and whether stabilization is ascertained.

3. Results and Accomplishments

Figure 1 depicts the relative changes (%) in module open-circuit voltage (V_{OC}), fill factor (FF), and efficiency (Eff) measured at SRC, respectively, at the top, middle, and bottom portions of the graph, plotted against exposure time in hours (equivalent hours at 1-sun intensity) for four CdTe modules from two manufacturers plus two single-junction a-Si modules from another manufacturer. The performance of the a-Si modules degrades with exposure predominantly as a result of FF loss (well-known Staebler-Wronski effect), stabilizing after about ~1000 hrs; whereas CdTe module data exhibit both degradation and improvement, plus transient effects, with time. Some of the effects observed for CdTe are primarily ordained by changes in V_{OC}, which may be bias-history related. For this set of tests, the a-Si and CdTe modules were light-soaked at 50±5°C and 65±5°C, respectively, back-of-module temperature.

Figure 1 portrays two sets of measurements for four CdTe modules, which exhibit discernable differences between the 'storage state' (opaque symbols) and 10-min 'light-stabilized' (open symbols) states. Generally, we find that

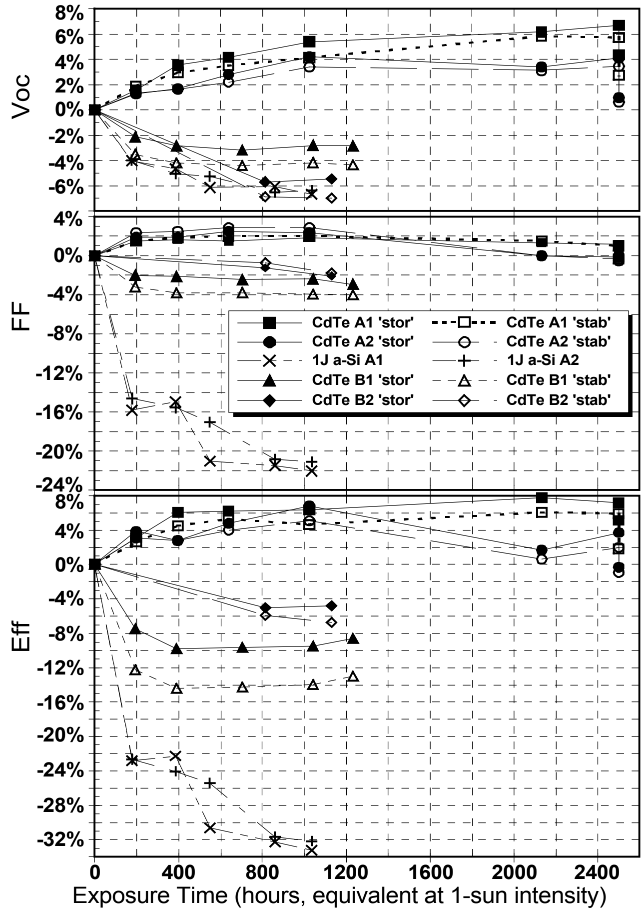

Fig. 1. Relative changes (%) in open-circuit voltage, fill factor, and efficiency at SRC, respectively, at top, middle, and bottom portions, plotted against exposure time for four CdTe modules, plus two a-Si single-junction modules.

values of the former are always higher than those of the latter, representative of some relaxed degradation state; whereas the 10-min light-stabilized values are lower, predominantly due to reduction in V_{OC}, with some slight drop in FF. Note that for CdTe modules A1 and A2, taken out to 2500-hr exposure, there are substantial declines in V_{OC} (2%) at the end of the test, signifying changes obtained after the modules had lain under low light levels for two weeks after exposure before being retested. These differences between storage and stabilized parameters are observed mainly after the modules have been light-soaked.

From in-situ I-V trace data, we can continuously track changes observed in time that can reveal degradation and transient phenomena. In Fig. 2, a random sample (20%) of FF data taken for one of the CdTe modules is plotted against exposure time for traces measured in both directions: up (+) from I_{SC} and down ( ) from V_{OC}, with each direction lasting about 20 s to measure. From these data, it is apparent there was slight difference between directions initially, with FF values in the range of 66%–67%, but that after several hundred hours of exposure, the FF data measured down from V_{OC} are about 2% absolute lower than those acquired tracing up from I_{SC}, and that both suffer decline from initial values. For the data shown, the average module temperature is 66.3°C, and one standard deviation is 2.1°C.

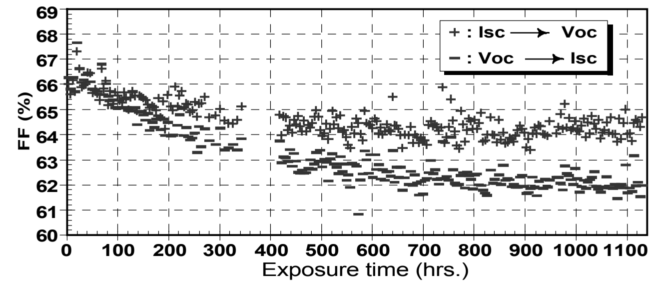

Fig. 2. FF data measured in situ for one CdTe module traced in both directions, up from I_{SC} (+), and down from V_{OC} ( ), plotted against exposure time.

In Fig. 3, we show the temperature dependence of V_{OC} and I_{SC} measured in situ at the end of the third interval (III-E) plus the beginning and end of the fourth (IV-B,-E) interval of exposure for one of the CdTe modules. The I_{SC} data have been normalized to one common irradiance to remove any slight variation of intensity. Note, the data taken at the end of the third and fourth intervals were measured continuously with the exposure, without any low-light level conditions occurring prior to their measurement, while those obtained at the beginning of the fourth interval were measured after dark-storage conditions just prior. The salient point inferred from these data is that both the absolute values for, and temperature derivatives of, both V_{OC} and I_{SC} exhibit substantial variation depending on immediately prior exposure history for CdTe modules, yet this behavior is largely present only after exposure. This transient behavior lasts for tens of hours after dark storage, and it is likely to confound the accurate determination of temperature coefficients for CdTe modules because such data are usually measured in front of a simulator after spending some time in dark storage prior to measurement.

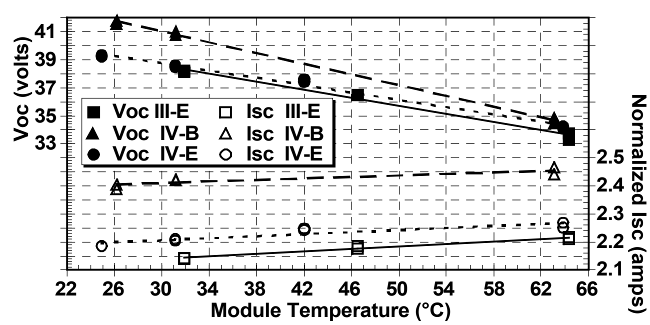

Fig. 3. Temperature behavior of V_{OC} and I_{SC} for one CdTe module measured in situ at various stages during exposure.

4. Conclusions

We've presented data that have previously gone unpublished except for submission in test reports to the respective manufacturers, showing the use and importance of the indoor light-soaking station. We've uncovered data and behavior that are important to document and that show how light exposure can affect both stabilized performance and temperature behavior in thin-film modules.

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15. SUBJECT TERMS
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