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Preprint

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Presented at the 10th International Conference on Concentrator Photovoltaics (CPV-10)
Albuquerque, New Mexico
April 7–9, 2014

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Conference Paper
NREL/CP-5J00-62484
August 2014

Contract No. DE-AC36-08GO28308

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CPV Cell Characterization Following One-Year Exposure In Golden Colorado

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Abstract. A CPV module containing 30 III-V multijunction cells was operated on–sun for one year in Golden, Colorado. Each cell was characterized prior to and following exposure. A module power degradation of 10 % was observed and found to be a result as an overall decrease in cell short circuit current and the presence of at least one shunted cell. A positive correlation between initial shunt current and an increase in shunt current following exposure was also found. Cell exfoliation was also observed and found to be coincident with the presence of water and/or charring of the cell package due to an off-sun event.

Keywords: Concentrator Photovoltaic, Exfoliation, Exposure, Reliability

PACS: 88.40.hj, 88.40.jp

INTRODUCTION

High concentration photovoltaic (PV) modules are typically a complex mechanical structure of optics, PV cells, interconnects and heat sinks, especially when compared to their one-sun flat-plate analogue. It is therefore not surprising that most studies of CPV module outdoor degradation primarily find failures associated with the module, such as optics degradation and failure of thermal connections [1-3]. Specific degradation studies of the III-V multijunction cells that now commonly populate CPV modules primarily tout excellent reliability [4]. In this paper we detail the one-year results of an experiment whose aim is to specifically monitor the degradation of III-V multijunction PV cells placed in-service within a CPV module.

MATERIALS AND METHODS

A ~500x geometric concentration CPV module containing thirty III-V multijunction photovoltaic cells was used in this study. The packaging included a coverslip of glass attached to the cells' active surface with a silicone-based adhesive. This scheme left the edges of the cells exposed. The module was modified to allow ex-situ testing of each cell assembly. This modification required access to the interior of the module that disrupted its original sealing scheme. Each cell was initially evaluated for its electrical performance via a dark and one-sun illuminated current-voltage (I-V) measurements. The module was then placed on a two-axis tracker for one-year of outdoor exposure in Golden, Colorado. The tracker has an angular accuracy of ± 0.1˚ and limits of azimuth and zenith travel of 106˚ to 212˚ and 68˚ to 0˚, respectively. The module was connected to a Daystar Multi-Tracer, which took I-V curves at 15-minute intervals, and otherwise kept the module at its maximum power point during its exposure. Following the one-year of service, the module was disassembled and the measurement of each cell's individual electrical characteristics repeated. Each cell was also photographed and its electroluminescence imaged at this time. Following cell level characterization, the module was reassembled and placed back on-sun. Therefore this paper reports the one-year observations of an on-going experiment.

Cell exfoliation was found following the year's exposure; therefore an exposure test was performed on pristine, similarly packaged cells. Two cell assemblies were imaged for their electroluminescence emission then submerged in tap water. One cell was exposed to room light and one placed in the dark. Each cell's electroluminescence emission was re-imaged following 24 hours of exposure. Secondary ion mass spectrometry (SIMS) was performed following exposure to determine the layer in which exfoliation occurred.

RESULTS AND ANALYSIS

On-sun module level I-V curves taken shortly after commissioning and just prior to the one-year analysis are presented in Fig. 1. The conditions during these measurements were an irradiance of 925 W/m^2 and ambient temperature of 24.5 C. The module's short circuit current had dropped 5.3 %, fill factor 5.2 % and power 10.2 %. The presence of at least one low-current cell is also evident.

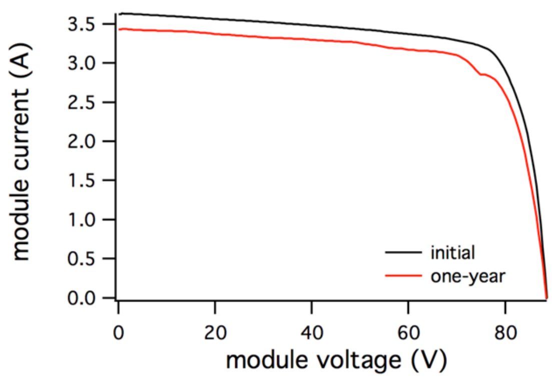

Fig. 1 On-sun module level I-V curves taken upon commissioning and shortly prior to the one-year analysis.

A comparison of each cell's electrical performance before and after the one-year of service is presented in Figs. 2-4. Each cell's shunt current is evaluated as its dark current response at 1.5 V forward bias, Fig. 2. Of the thirty cells evaluated, cells 5, 8, 10 and 14 showed the largest changes in electrical performance. A positive correlation of initial shunt current with an increase in shunt current is apparent in Fig. 2 for the majority of the samples. There appears to be no similar correlation for changes in short circuit current though its average decrease is 4 %, Fig. 3. The cell's open circuit voltage was largely unchanged from their initial values except for two cells (5 & 8) that appear to be severely shunted, Fig. 4.

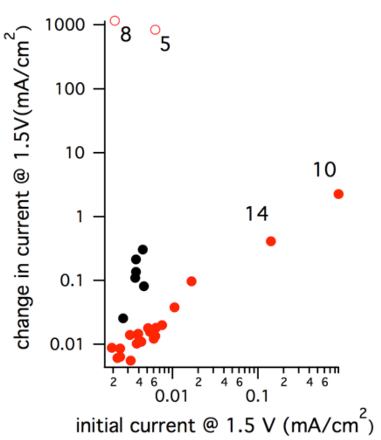

Fig. 2 Change in shunt current. Black symbols represent exfoliated cells, and open symbols shunted cells.

The electroluminescence (EL) images of the four cells showing the largest changes are presented in Fig 5. Cells 5 and 8 show evidence of a large shunt in the top sub-cell under the top bus bar. This is evident as a bright spot in these un-filtered images. These cells; however, showed no anomaly in the initial I-V curve that would have predicted the formation of this shunt. Cells 10 and 14 contain a shunt within their interior likely present prior to exposure and the cause of their initially high shunt current.

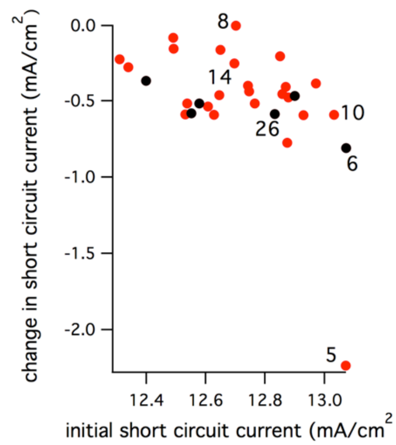

Fig. 3 Change in I_{SC}. Black symbols represent those cells that exhibited exfoliation.

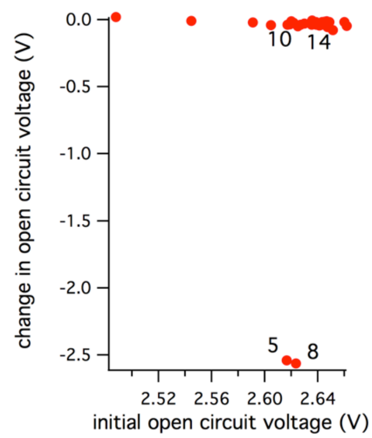

Fig. 4 Change in V_{OC}

Exfoliation, characterized by a loss of EL emission at the cell's perimeter, was observed for six of the cells evaluated, cells 1, 6, 15, 21, 26 and 30. These cells are represented by black symbols in Figs. 2 and 3. In three cases exfoliation was adjacent to charring of the package, cells 1, 6 and 15, presumably from an off-sun event, Fig. 6. Cell 6 exhibited the largest area of exfoliation of the cells with charring, and had the largest drop in short circuit current, besides the severely shunted cell 5. Exfoliation was also observed in three cells, cells 21, 26 and 30, that exhibited evidence of the presence of standing water, such as stains on the cover glass and aggregation of dirt and sand, Fig. 7. Each of these cells was located at the bottom of the module further corroborating likelihood for contact with water. Cell 26 was observed to have the largest extent of exfoliation associated with water and also was one of the cells with the largest drop in short circuit current. The exfoliated cells exhibit a large change in shunt current that was not predicated by their initial shunt current and therefore standout from the positive correlation in Fig. 2.

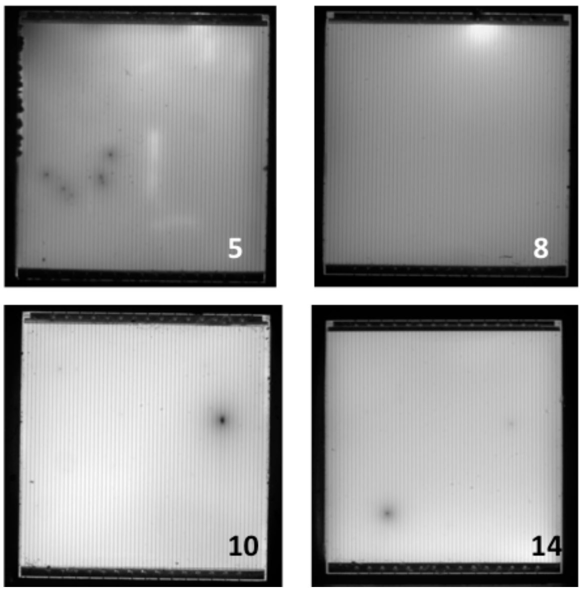

Fig 5. EL images of the cells that showed the largest changes in electrical performance.

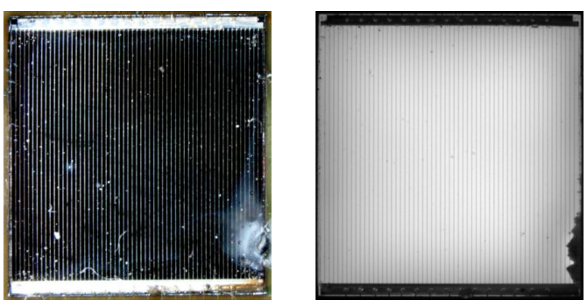

Fig 6. Optical (left) and EL image of cell 1 highlighting exfoliation coincident with charring at the cell's edge

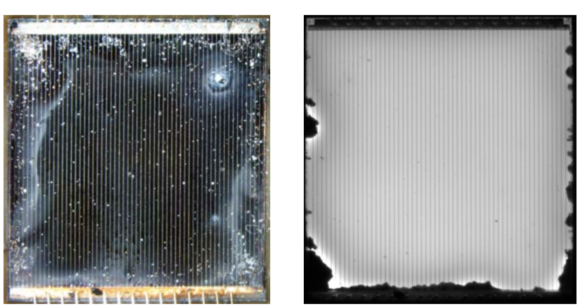

Fig 7. Optical (left) and EL image of cell 26, highlighting cell exfoliation coincident with the presence of standing water.

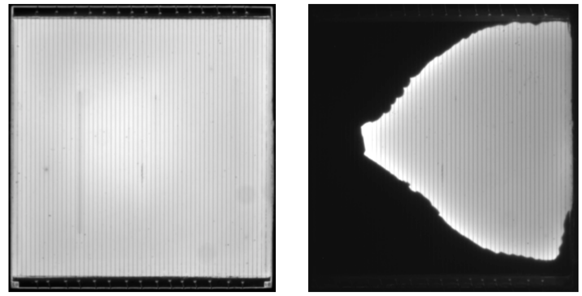

Fig 8. EL image before (left) and following 24-hour room light exposure in water.

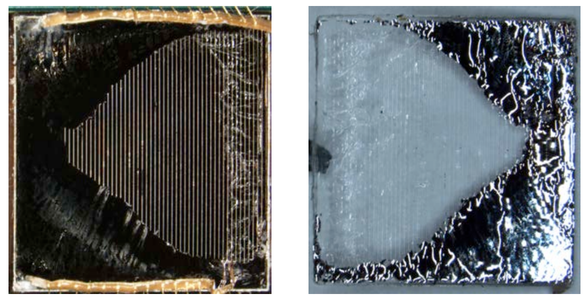

Fig 9. Optical images of cell (left) and removed coverslip following 24-hour room light exposure in water.

The preceding observations prompted a quick investigation into the susceptibility of similarly packaged cells to exfoliate in the presence of water. The cell submerged in water and exposed to room light exhibited extensive exfoliation as evident in its EL emission, Fig. 7. The glass coverslip was subsequently removed from this cell for further analysis and resulted in the exfoliated portion remaining on the coverslip, Fig. 8. SIMS analysis of the exfoliated cell indicates that the top sub–cell was separated. The cell exposed in darkness showed no signs of exfoliation, suggesting the mechanism of exfoliation is an electrochemical reaction.

DISCUSSION

Following one-year's on-sun service in Golden, Colorado the module in this investigation suffered a 10 % loss in power. From its I-V curves, this loss of power may be resolved as an overall drop in short circuit current combined with the effect of at least one shunted cell. Once disassembled, individual characterization of the PV cells supported the module level measurement as both physical and electrical changes were observed that help to explain this degradation. The average decrease in the cells short circuit current was roughly 4% and two cells (5 & 8) were found to be severely shunted, likely the cause of the step observed in the module level IV curve. At the cell level, an initially high shunt current was found to correspond with an increase in shunt current following the exposure. Two cells (10 &14) that exhibited the largest combination of initial and final shunt current contained shunts within the field of the cell that were easily observed in their EL image. The two cells (5 & 8) that had become severely shunted following exposure showed no anomaly in their initial I-V curve that would have predicted the formation of their shunts. These shunts, however, are located at the perimeter of the cell along the bus bar. The edges of the cells investigated were not protected in any way, which may have allowed loose debris in the module to short the edge of these cells. Infiltration of the module by water and debris may have been exacerbated by its modification for the purpose of this experiment. This debris, dirt and sand, was especially prominent on the cells located at the bottom of the module along with stains on the glass coverslips consistent with standing water. This evidence of standing water was coincident with cell exfoliation, as was adjacent charring of the package presumably from an off-sun event. As demonstrated in a parallel experiment, the cells exposed in this study are susceptible to exfoliation, which acts to separate the top sub–cell, by exposure to water and light. It follows that the degradation of these cells cannot be predicted by their initial electrical performance but are rather a result of susceptible cells, insufficient edge protection and exposure to a harmful environment.

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