Solar Energy 161 (2018) 235–241

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Development of coring procedures applied to Si, CdTe, and CIGS solar panels

H.R. Moutinho[a,*], S. Johnston[a], B. To[a], C.-S. Jiang[a], C. Xiao[a,b], P. Hacke[a], J. Moseley[a], J. Tynan[a], N.G. Dhere[c], M.M. Al-Jassim[a]

[a] National Renewable Energy Laboratory, Golden, CO 80401, United States
[b] Colorado School of Mines, Golden, CO 80401, United States
[c] Florida Solar Energy Center, FL 32922, United States

ARTICLE INFO

Keywords:
Coring
PV Modules
Si
CIGS
CdTe

ABSTRACT

Most of the research on the performance and degradation of photovoltaic modules is based on macroscale measurements of device parameters such as efficiency, fill factor, open-circuit voltage, and short-circuit current. Our goal is to develop the capabilities to allow us to study the degradation of these parameters in the micro- and nanometer scale and to relate our results to performance parameters. To achieve this objective, the first step is to be able to access small samples from specific areas of the solar panels without changing the properties of the material. In this paper, we describe two coring procedures that we developed and applied to Si, CIGS, and CdTe solar panels. In the first procedure, we cored full samples, whereas in the second we performed a partial coring that keeps the tempered glass intact. The cored samples were analyzed by different analytical techniques before and after coring, at the same locations, and no damage during the coring procedure was observed.

1. Introduction

With improved solar cell efficiency and decreased production cost in the last few decades, photovoltaic (PV) energy as a viable and clean source of energy has become a reality, with deployment approaching the terawatt scale. In this new scenario, the issue of PV module reliability is more important than ever. After many years in the field, a solar panel can degrade for many reasons, such as: potential-induced degradation (Pingel et al., 2010), delamination (van Dyk et al., 2005), and partial shading (Lim et al., 2015).

Currently, the performance characteristics of deployed PV systems over time are obtained by measuring macroscopic parameters such as output power and efficiency. In parallel, most microscopic analytical studies performed in laboratories use samples obtained from small solar cells or specific films deposited on small substrates. These studies have provided insight and understanding on solar cell materials and devices, and important information that has guided the improvement of several types of solar cells available in the market. However, one important link is missing: the connection between defects and degradation on real solar panels deployed in the field and their microscopic properties.

The objective of our project is to connect the macroscopic properties of PV modules with micro- and nanometer scale properties, and for the first time to link the failures observed in solar panels deployed in the field with microscopic defects. Accomplishing this objective will guide the fabrication of solar panels that will last longer, with less degradation over the years. The first step in our project is to be able to identify degraded areas in commercial solar panels, and to remove material from these areas of the panel without causing further damage or introducing any artifacts.

One of the main obstacles to achieving this goal is that, when a solar panel is manufactured, the objective is to make it mechanically strong and protect it from environment agents through encapsulation, so it can last for several decades in any climate conditions. Furthermore, because this is a new research area, there is practically no published work on how to core solar panels without causing any damage. Our main challenges are the tempered glass used in most PV modules and to develop a process to separate the solar cell material from the ethylene vinyl acetate (EVA) encapsulant material (Czanderna and Pern, 1996). In this work, we describe different procedures that we developed for coring different kinds of solar panels while trying not to affect the properties of the several layers in the solar cell.

2. Experimental procedure

The following solar panels were used in this work: test silicon (Si) mini solar panels acquired from eBay, and commercial Si, copper indium gallium diselenide (CIGS), and cadmium telluride (CdTe) PV modules. The Si and CIGS solar panels had been deployed in the field for many years and had several degraded areas, and the CdTe panels were stressed in the lab at 65 °C or 100 °C. A schematic of these three

---

* Corresponding author.
E-mail address: helio.moutinho@nrel.gov (H.R. Moutinho).

https://doi.org/10.1016/j.solener.2017.11.071
Received 5 September 2017; Received in revised form 23 November 2017; Accepted 25 November 2017

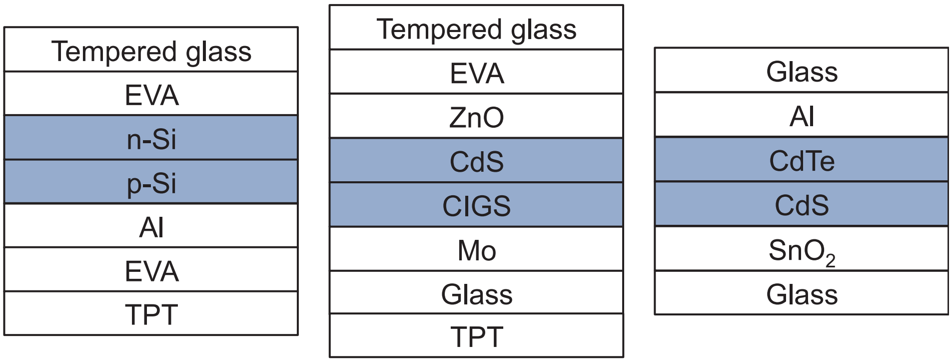

Fig. 1. Simplified structure (not to scale) of the three types of PV modules used in this work: Si, CIGS, and CdTe, from left to right. The gridlines on the panels are not shown on the diagram. TPT, tedlar polyester tedlar, is a composite polymer material used to protect the back of solar panels.

types of solar panels is shown in Fig. 1. In the case of Si and CIGS panels, the tempered glass is placed on the front (sun side). In the case of CdTe, which uses a superstrate configuration, the structure starts with the deposition of a transparent conductive oxide layer on the front glass, and no tempered glass is used in the module. Initially, the modules were analyzed by dark lock-in thermography (DLIT) and electroluminescence (EL), which showed areas with localized heat, indicating shunts, and lower luminescence, due to defects. Several of these areas were marked on the panels, as well as areas without shunts/defects. These exact areas were cored and analyzed again for comparison.

For the coring process, we used a CRL production diamond glass-drilling machine, model AMZ1, from CRL, Inc. The drill had the capability of maintaining a flux of water inside the drilling bit, avoiding any elevation of temperature during the coring process that could result in changes of the sample properties. We used three sizes of coring bits: 1/2″, 3/4″, and 1″. However, usually we do our coring using 3/4″ bits, and obtain a high degree of success (above 95%). The advantage of the 3/4″ bit is that it provides a sample with a large area that is not affected by the coring at the edge. Furthermore, these samples in general are small enough to allow for coring defects that are close to each other. Also, to accommodate large solar panels and collect any circulating water during the coring process, we built a special tray that was 83″ × 45″. A photograph of the coring setup is shown in Fig. 2.

The cored samples were analyzed by the following techniques: scanning electron microscopy (SEM), using a field-emission scanning electron microscope (FE-SEM) Nova NanoSEM 630 from FEI; energy-dispersive X-ray spectroscopy (EDS) and electron backscatter diffraction (EBSD), using a Pegasus system from EDAX with Hikari camera; scanning Kelvin probe force microscopy (SKPFM), using a Dimension 3100 atomic force microscope (AFM) with Nanoscope V controller from Bruker; electron-beam induced current (EBIC), using a JEOL-7600F Field Emission SEM and FEI xT Nova NanoLab 200 FIB/SEM; and electroluminescence (EL) and photoluminescence (PL), using NREL-built systems with a Pixis 1024BR camera from Princeton Instruments.

After coring, some samples were immersed in trichloroethylene (TCE) for several hours at room temperature or 60 °C to dissolve the EVA layers.

3. Results and discussion

3.1. Silicon solar panels

"Full Coring" is what we call the first coring procedure we developed because we core all the layers of the panel, which involves coring the tempered top glass. We started the experiments with test Si mini solar panels and investigated the possibility of coring tempered glass in small circular shapes without breaking the whole panel. Tempered glass is used in solar panels because it is several times harder than regular glass, and it breaks in a large number of small harmless pieces with random shapes (McMaster, 1989). In our experiment, we made a small cut on the glass. Initially, nothing happened; but, after several seconds, without any intervention, the glass shattered into hundreds of small pieces, as seen in Fig. 3. After several tests, it was clear that unless we heated the glass at high temperatures—between 500 °C and 600 °C, which would alter the properties of the semiconductor layers—we could not partially cut the tempered glass in small controlled shapes.

The coring experiment started by identifying the areas to be cored and removing the tedlar polyester tedlar (TPT) and EVA layers from the back of the solar panel, exposing the aluminum (Al) back contact. After this, we made a small cut on the tempered glass, outside the active area, and waited for the glass to shatter. The panel was then cored using a

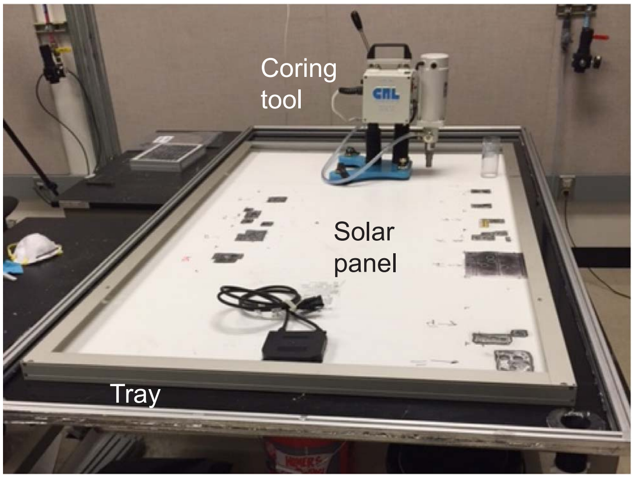

Fig. 2. Coring setup showing the coring drill, a solar panel, and the coring tray. The dark areas inside the panel are regions that have been cored.

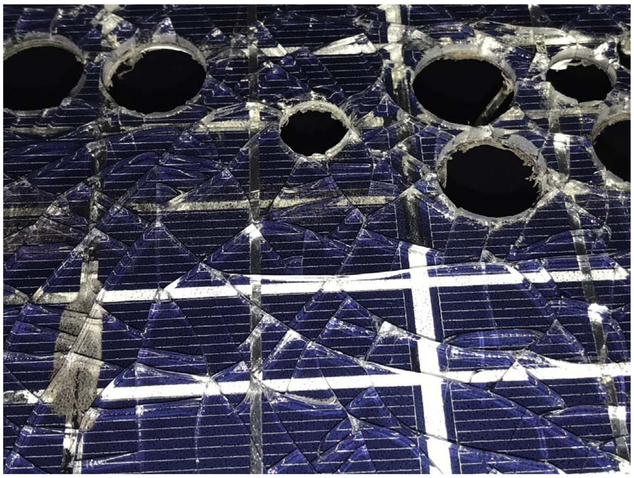

Fig. 3. Si mini module shattered in several hundred pieces after receiving a small cut. The circles are areas that have been cored with 1/2″ and 3/4″ bits.