

## DETECTING AND UNDERSTANDING SODIUM MOVEMENT IN SOLAR PANEL ENCAPSULANT POLYMERS

Stephanie L. Moffitt, Behrang H. Hamadani, Xiaohong Gu  
Engineering Laboratory, National Institute of Standards and Technology  
Gaithersburg, Maryland, 20899, United States of America

**ABSTRACT:** Photovoltaic (PV) panels in large arrays operate at high voltages and, as a result, can experience potential-induced degradation (PID). At these high voltages, leakage currents drive sodium out of the glass at the front of the panels, through the polymer encapsulant, and into the sensitive electronics at the core. Initial work by other groups has suggested that changing the polymeric encapsulant layer could limit sodium migration. However, the polymer characteristics and mechanisms that moderate sodium migration are not yet understood.

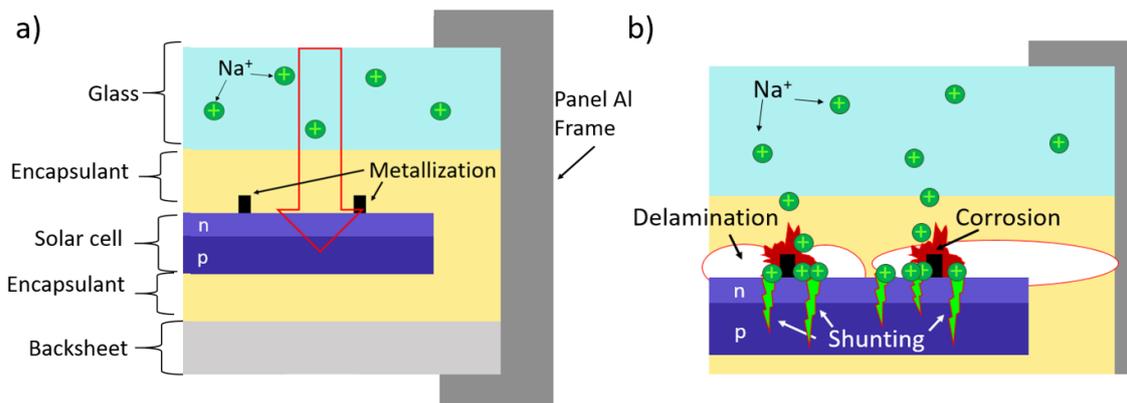
In this work the role of panel encapsulants in PV panel PID is being investigated. Glass/encapsulant coupons will be exposed to high voltages to evaluate degradation. Several coupons contain PV cells that will be periodically monitored via current versus voltage measurements and electroluminescence imaging to track performance degradation. Coupon samples without cells will be cut to expose cross sections for materials characterization. Cross-sectional analysis, using energy dispersive spectroscopy, will quantify the amount of sodium that has moved through different encapsulant polymers (ethylene-vinyl acetate, polyolefin, and ionomer). In tandem, the chemistry and structure of the polymers will be characterized to develop an understanding of which polymer characteristics limit sodium movement. An understanding of how polymer encapsulants can limit sodium migration will inform the development of next generation polymers. Improved polymer encapsulants that limit sodium migration will significantly increase the service lifetime of PV panels.

Keywords: Degradation, Encapsulation, Interfaces, PV Module

### 1 INTRODUCTION

Large, utility-scale solar farms currently represent the most cost-efficient form of solar panel installation [1]. Long photovoltaic (PV) strings in large arrays can reduce system costs however, the longer the string, the higher the string voltage. PV strings in large arrays currently operate at 1000 V to 1500 V [2]. At these voltages, leakage currents form, especially in humid conditions, between the

grounded frame and the cells [3]. These leakage currents drive sodium (Na) out of the glass at the front of the module and into the core of the panel (Fig. 1). This migration of Na is associated with numerous degradation modes, as shown in figure 1b. Initial studies by other groups have shown that potential induced degradation (PID) can be limited by changing the encapsulant polymer chemistry from ethylene vinyl-acetate (EVA) to a polyethylene or ionomer-based polymer [4], [5].



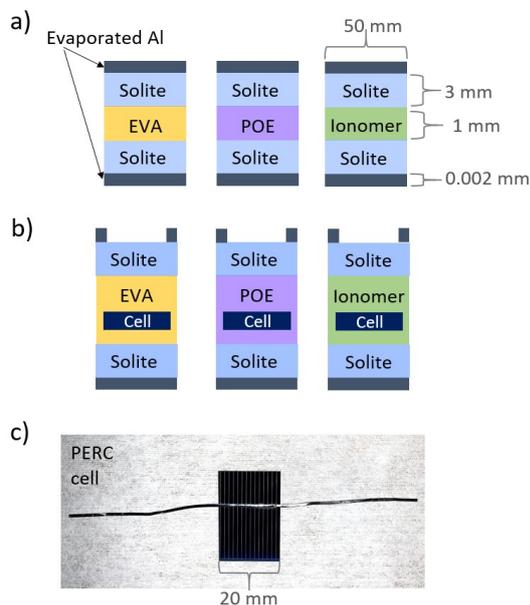
**Figure 1:** a) Cross-section illustration of the layers that make up a solar panel. The red arrow shows the general direction of the leakage currents for a negatively biased cell. The negative bias drives sodium atoms (green) out of the glass (light blue), through encapsulant (yellow), and into the solar cell and metallization region (black and purple). While the p-n junction creates electricity from sunlight, the metallization helps transport that electricity. The layered polymeric material that covers the back side of the panel, known as a backsheet, is shown in grey. b) Cross-section illustration of the degradation that occurs in response to sodium (green) migration. Sodium migrates into the stacking faults within the PV cell, inducing shunting [6] (green lightning bolts). Sodium sits at the encapsulant/cell interface, priming the interface for delamination [7] (white areas) and eventually, it interacts with water to promote corrosion of the metal regions [3] (red regions around the black metallization).

The encapsulant polymer layer lies between the glass and the solar cell (Fig. 1) and may serve as a barrier to sodium migration. Though increasing the electrical resistivity of

the encapsulant layer may help limit leakage currents, ultimately it is the conduction of ions through the encapsulant layer that induces the degradation

mechanisms illustrated in figure 1b. In this work, PV panel encapsulants are being investigated to understand how sodium moves through the polymeric encapsulant layer. Glass/encapsulant coupons, 5 cm by 7 cm in size, have been made to mimic the structure of full-sized panels. A voltage source will be used to simulate the leakage currents experienced in high voltage solar panels. Coupon samples will be made into cross sections for materials characterization. Sodium movement will be tracked, quantified, and compared between different encapsulant polymers (EVA, polyolefin, and ionomer). In addition, the chemical state of the sodium will be probed with X-ray photoelectron spectroscopy. The polymers will be characterized with micro-Raman and micro-FTIR (Fourier transform infrared spectroscopy) to provide cross-sectional mapping of polymer chemistry and phase. Together, this characterization will develop an understanding of which polymer characteristics limit sodium movement. In tandem, several coupon samples containing small passivated emitter and rear contact (PERC) cells will be periodically monitored via current versus voltage (I-V) measurements to confirm the link between sodium migration and performance degradation. Insight into the mechanisms of sodium migration in encapsulant polymers will guide the development of new materials. With improved packaging materials, sodium-driven degradation mechanisms (shunting, delamination, and corrosion) will be reduced.

## 2 METHODS



**Figure 2:** a) Schematic of the Solite (solar glass)/polymer-encapsulant/Solite laminated test structures. Evaporated aluminum will provide uniform electrical contacts for simulating leakage currents across the structures. b) Schematic of the pocket-sized modules, similar to the test structure in a), but containing PERC cells to demonstrate performance loss during PID testing. c) Top-down pre-lamination image of a cut-down PERC cell with tabbing ribbons soldered to the top and bottom to enable I-V testing.

Laminated samples were made with Solite solar glass and three different types of encapsulant polymers: EVA,

polyolefin, and ionomer (Fig. 2a). Samples laminated with quartz (which, like Solite, is silica-based but does not contain sodium) are serving as control samples. A selection of laminated coupons also contain PERC cells (Fig. 2b and 2c) soldered to 0.9 mm wide tabbing ribbon. Voltage bias will be applied across the laminated stacks to induce sodium migration, and in turn PID. Aluminum has been evaporated onto the glass to create a uniform electrical contact with the glass. The voltage bias test will mimic stress method B from the PID International Electrotechnical Commission (IEC) standard 62804.

Sample cross sections are being made by first cutting out regions with a diamond saw (Smart Cut 6001 sectioning and wafering saw from UKAM, Valencia, CA USA) (Fig. 3a), embedding them in epoxy (Epo-Tek 301 epoxy resin by Epoxy Technology, Billerica, MA USA), and then polishing to reveal fresh interfaces (model 920 lapping machine, South Bay Technology, San Clemente, CA USA). Polishing is being performed with successively finer grit, finishing with a 1  $\mu\text{m}$  diamond slurry.

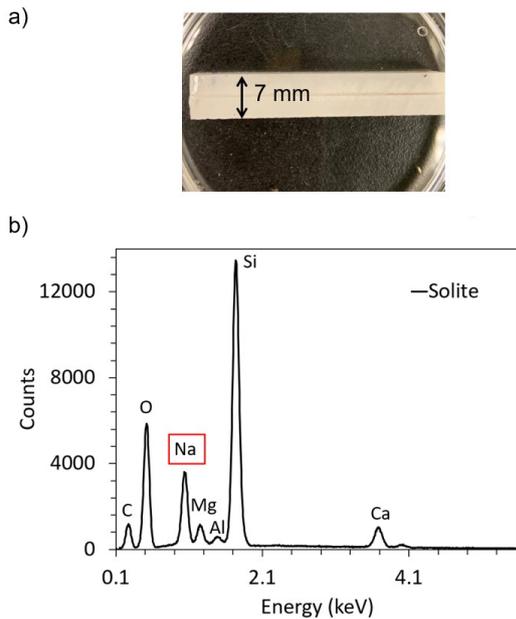
Energy dispersive spectroscopy (EDS) is being performed with a Quanta 600 scanning electron microscope equipped with an Oxford Instruments X-max 80  $\text{mm}^2$  SDD-EDS detector (Concord, MA USA). The preliminary spectra in figure 3b was collected with a beam energy of 12 keV at 30,000 $\times$  resolution to avoid including surface contamination in the measurement. Spectra were analyzed with Bruker Espirit 2 microanalysis software (Billerica, MA USA). A composition standard, with calibrated levels of the appropriate elements (e.g., Na, Si, O), was not used to produce the results in figure 3b but is planned for future work. Micro-FTIR spectroscopy will be performed on a Thermo Scientific Nicolet iN10MX infrared imaging microscope.

PERC cell performance is being monitored through I-V curve measurements. I-V measurements (Fig. 4) are taken for each cell under a solar simulator with illumination conditions at the standard reporting conditions (air mass 1.5 G, 1000  $\text{W}/\text{m}^2$ , 25  $^\circ\text{C}$ ).

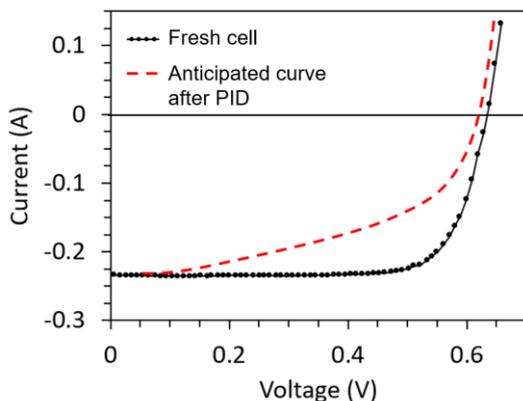
## 3 PRELIMINARY WORK

Preliminary work has been performed to demonstrate the successful assembly of glass/encapsulant/glass cross-sections (Fig. 3a) as preparation for EDS and micro-FTIR measurements. EDS measurements of Solite glass have been conducted and show the significant level of sodium present within the glass (Fig. 3b). This preliminary measurement shows a sodium content of  $8.8 \pm 0.5$  atomic percent, which is well within the range of sodium content expected for Solite glass, according to the manufacturer.

A series of 18 miniature PERC cells (Fig. 2c) have been soldered and characterized in preparation for PID tests. I-V measurements (Fig. 4) taken of each unlaminated cell confirm that neither the cell dicing process, nor the soldering process significantly affected the cell performance. After lamination cells were exposed to natural sunlight under clear-sky conditions for a total of (14 to 16) h to reduce early onset degradation due to the presence of B-O complexes. Post lamination and sun-soak I-V measurements are ongoing and will serve as the baseline measurement before voltage bias is applied. As voltage is applied and PID begins, we anticipate that module resistance will increase as electrical shunts begin to form. Figure 4 shows with a red dashed line the anticipated change in the I-V curve after shunt resistance has increased.



**Figure 3:** a) Cross-section of glass/encapsulant/glass coupon. b) EDS spectra of Solite glass demonstrating the significant sodium content.



**Figure 4:** Preliminary I-V curve of PERC cells before PID testing (black). The dashed red line demonstrates the anticipated shift in the I-V curve after PID has occurred.

#### 4 SUMMARY AND OUTLOOK

In this proceeding we have laid out the foundation of a methodology that will provide greater insight into the role of encapsulants in potential induced degradation. I-V measurements of pocket-sized modules will ensure that our methodology reproduces the drop in performance anticipated after PID accelerated tests. However, this study will go further by both quantifying the migration of sodium and understanding the role of polymer chemistry in encouraging or inhibiting sodium migration.

The collection of materials and establishment of measurement protocols represents a significant contribution to the establishment of this research effort. With this foundation in place and the safe resumption of

lab work now possible, degradation and characterization work is currently underway.

NIST Disclaimer: Trade names and commercial products are identified in this proceeding to specify the experimental procedures in adequate detail. This identification does not imply recommendation or endorsement by the authors or by the National Institute of Standards and Technology, nor does it imply that the products identified are necessarily the best available for the purpose.

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