

## ADHESION DEGRADATION OF THE METALLIZATION-ENCAPSULANT INTERFACE

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In this work, we study the mechanisms of adhesion degradation between the ethylene-vinyl acetate (EVA) encapsulant and silver metallization interface individually to elucidate their relative contribution to observed field failures. First, the effect of humidity ingress on adhesion is examined where bond displacement at the silver metallization interface in the presence of water at elevated temperature is the likely degradation mechanism. Next, the electrochemical processes that occur with the application of PID stress are examined. This includes the effect of ionic currents that cause  $\text{Na}^+$  ions to migrate toward the cell's surface that can also reduce adhesion. Finally, the effect of the cathodic reaction on adhesion degradation is examined, whereby voltage potential breaks down humidity contained in the encapsulant by reduction that is promoted by the catalytic effect of silver to form gaseous reaction products such as hydrogen and hydroxide ions.

One-cell modules were fabricated for this study. Monocrystalline silicon cells were first prepared by completely screen printing their front surface with silver paste and then firing in a standard fashion. An interconnect ribbon was then soldered to the Ag front surface of the cell to provide electrical connectivity. These cells were then laminated to a front sheet of 3 mm thick solar glass with a  $\sim 400 \mu\text{m}$  layer of commercially available EVA.

The one-cell modules were then exposed to environmental aging. One module was exposed to a sequential damp heat-PID condition: 1000 hours at 85°C, 85%RH followed by 400 hours at 85°C, 85%RH, -1kV. One module was initially exposed to the combined damp heat-PID condition of 400 hours at 85°C, 85%RH, -1kV. The bias applied for both samples was between the cell's front metallization and an aluminum electrode placed on top of its front sheet of glass. Measurements were made at timed intervals throughout the exposures. The width-tapered cantilever beam method was used to measure the adhesion energy of the Ag/EVA interface through all exposures. Following adhesion testing of all samples, the exposed Ag and EVA surfaces were analyzed for their chemical composition using High Resolution X-ray photoelectron spectroscopy (HR-XPS).

Only two of the samples under test are currently reported. The initial adhesion of the pristine Ag/EVA interface was measured to be  $952 \pm 26 \text{ J/m}^2$ . The adhesion rapidly drops with damp heat-only exposure, falling to  $134 \pm 30 \text{ J/m}^2$  following 300 hours, and then apparently plateaus around  $\sim 60 \text{ J/m}^2$  following the 1000 hour exposure. When the PID stress is introduced the adhesion continues to drop, again apparently plateauing  $\sim 25 \text{ J/m}^2$  following the additional 400 hour exposure. Adhesion of the sample that was initially exposed to the combination of 85°C, 85%RH, -1kV quickly dropped to  $33 \pm 2 \text{ J/m}^2$  following just 200 hours of exposure. Chemical analysis of the resulting delaminated surface is currently underway.

Adhesion degradation of the EVA/metallization interface has been characterized through damp heat and PID stress exposures. Preliminary results indicate that while adhesion at this interface is severely compromised by a short damp heat stress, it quickly reaches a plateau that persists with further, prolonged, damp heat exposure. The addition of a sequential PID stress also appears capable of further degrading the adhesion of this interface below this plateau level. However, simultaneous exposure of both a damp heat and voltage stress accomplishes a similar amount of degradation in only a few hundred hours. Exposures and measurements in progress at the time of abstract submission will extend these results through additional temperature and humidity conditions and additional PID stress exposures.

