Overview of PV Module Durability and Long Term Exposure Research at FSEC

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ABSTRACT

Adhesional shear strength of one acceleration-tested PV module from a US manufacturer and eight PV modules (consisting of four field-deployed, three control, and one new) from a European manufacturer were studied. Commercial modules from US PV module manufacturers are being tested in the hot and humid climate in Florida under the Module Long-Term Exposure project. A high-voltage bias test bed, similar to the test bed at NREL, has been installed at FSEC for study of corrosion in PV modules under high voltage bias conditions in the hot and humid climate. XPS analysis of first-generation, grid-connected and contemporary, high-voltage bias tested a-Si:H modules showed cell delamination. These results are relevant to CdTe modules which also have a SnO_2:F TCO layer.

1. Introduction

Delamination resulting from the loss of adhesion must be addressed in order to achieve 30-year lifetime for photovoltaic (PV) modules. Delamination has occurred to varying degrees in a small percentage of modules from all manufacturers. Over the last five years, FSEC has been carrying out a systematic and detailed study of module durability concentrating on solar cell/encapsulant composite with an objective to lay the scientific basis for further improvement of manufacturing technology of PV modules. Crystalline silicon PV modules deployed at the Sandia National Laboratories (SNL), FSEC and other locations in the US and around the globe have been studied whenever possible with their respective control modules [1-3]. A sample extraction process developed by SNL has been further improved at the FSEC. Recently, FSEC has developed a process for extraction of samples from untempered and tempered glass-to-glass PV modules. Morphology of the samples is studied by optical microscopy and scanning electron microscopy. Composition of silicon cell and encapsulant is analyzed by Auger Electron Spectroscopy and X-ray photoelectron spectroscopy (XPS).

Present acceleration testing of PV modules usually does not reproduce delamination, cracking of glass or backing sheets, solder de-bonding, and other slowly occurring degradation phenomena. Therefore, FSEC is participating in the Module Long Term Exposure (MLTE) project of SNL, the principal focus of which is to measure performance degradation.

Corrosion has been found to occur in some earlier-generation a-Si:H PV modules that were grid connected in an array operating at 300 V DC in hot and humid environment at Orlando, FL and in contemporary modules during accelerated testing under high-voltage bias in damp-heat at NREL. A high-voltage bias test bed has been installed at FSEC to study PV modules under high-voltage bias conditions in the hot and humid climate in Florida. This paper discusses PV module durability and long-term exposure research work at FSEC.

2. Module Durability Research

During the last year, one PV module from a US manufacturer and eight PV modules from a European manufacturer were studied. The US PV module had been fabricated in 1999 and had undergone acceleration testing at the University of Arizona. It consisted of 36 interconnected silicon cells encapsulated with ethylene vinyl acetate (EVA) between a stainless steel (SS) backing plate interspersed with a fiberglass mesh and a thin sheet of Tefzel in the front. Coring of the module was carried out from the top Tefzel sheet side as well as from the backside. For this purpose, the SS plate covering an entire row of cells was removed. Nuts were glued to the cored samples. Samples were extracted by applying a torsional force. Adhesional shear strength was measured by noting the maximum torque and the respective angle of rotation necessary to extract the sample. Most of the samples failed at the EVA/silicon cell interface that was the weakest interface. In some cases, the failure occurred within the EVA thickness at the interface with the fiberglass mesh. Some failures occurred at the Tefzel/EVA interface while a few others occurred at the EVA/SS plate interface. Overall the adhesional shear strength was very low (43% of that in typical new modules). Results of adhesional shear strength measurement have been provided to SNL.

Eight PV modules from a European manufacturer were studied. Of these, four had been deployed in the field, three were corresponding control modules and one was a new module. Surface diffusion of excess solder flux was evident under UV illumination in one of the modules (Fig. 1). Delamination and considerable deterioration due to moisture ingress was evident at the edges of two cells in one of the field-deployed modules (Fig 2). The damaged area appeared brownish yellow and extended along grid lines from the edge toward the center of the cell. Partial delamination had resulted in circular humps in the backing sheet of a module. Results of adhesional shear strength measurement have been submitted to SNL with a recommendation to initiate a detailed study of morphology and composition.

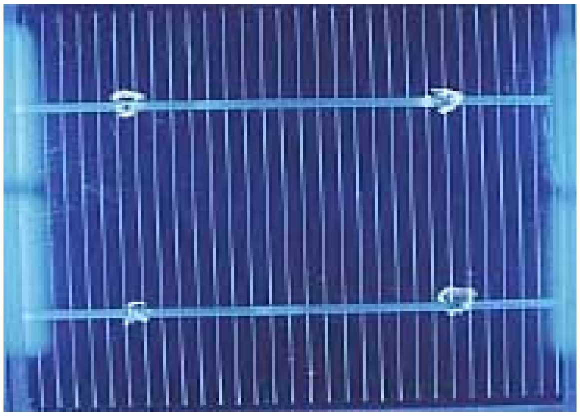

Fig. 1. Image of a cell under UV illumination showing spreading of solder flux.

3. Module Long-Term Exposure

The following types of commercial modules from US PV module manufacturers are being tested in the hot and humid climate in Florida: ribbon Si (ASE), amorphous hydrogenated Si (BP Solar), monocrystalline-Si (Siemens), copper-indium-gallium selenide (Siemens), and (a- Si:H) (USSC). Baseline performance tests were made at SNL. Modules are inspected periodically. Any visual changes are recorded and reported to SNL. Measurements of I-V characteristics are submitted to SNL each month. Periodic retesting of the modules at SNL completes the cycle of testing to determine the long-term degradation characteristics.

4. High Voltage Bias Test bed

During FY01, a high-voltage bias test bed was installed at FSEC for the study of corrosion in PV modules under high-voltage bias conditions in the hot and humid climate. Initially, seven thin-film PV modules will be installed under the following bias conditions: +600 V, -600 V, +300 V, -300 V, +150 V, -150 V, and no bias. A pyranometer; sensors for relative humidity (RH), wind speed, and ambient pressure; and thermocouples for ambient temperature, and back-of-module temperatures at two locations have been installed.

If corrosion, similar to that identified previously, does occur, a detailed investigation of the morphology and surface analysis will be undertaken. These studies can be useful for elucidating the effect of ambient as well as materials and process steps employed during the fabrication on the durability of PV modules.

5. Analysis of Glass-to-Glass PV Modules

FSEC has developed a technique for extracting samples from untempered and tempered glass-to-glass modules. A few a-Si:H modules from a grid-connected PV array of Florida Power at Orlando, Fl were studied. Moisture ingress caused severe degradation due to corrosion in these modules. Possibly there had been electric shorting.

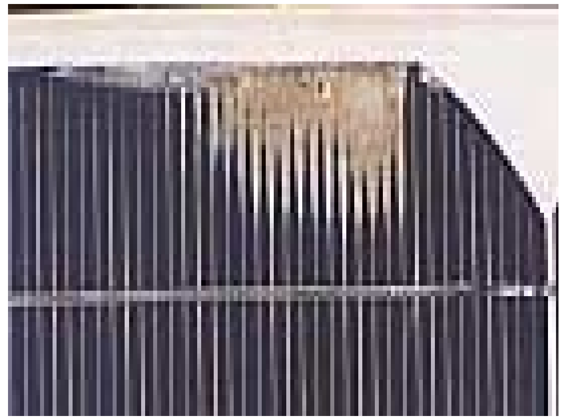

Fig. 2. Delamination and deterioration due to moisture ingress in a PV module.

XPS analysis of extracted samples of EVA on backing glass plate showed peaks of Sn, O, Si, C, and F. Clearly the a-Si:H solar cells had been detached from the front glass on which they were deposited and resided on the EVA leaving behind a clear glass. More severe corrosion led to complete destruction of the layered structure of a-Si:H cell in some places. More recently, samples were extracted from an a-Si:H PV module high-voltage bias tested in damp-heat at NREL. Presence of Sn, O, Si, etc on extracted EVA/backing glass samples again showed complete detachment of cell from front glass. However, it is expected that moisture ingress would be limited because of improved PV module manufacturing technology, and hence the consequent corrosion and degradation would not result in complete destruction of the cell. These results are relevant to CdTe modules which also have a SnO_2:F transparent-conducting oxide (TCO) layer.

Acknowledgements

This work was supported by the US Department of Energy through Sandia National Laboratories Contract # DEFC0400AL66793. The authors are thankful to Michael A. Quintana and David L. King of SNL for useful discussions and review of this paper, to Gobind Atmaram of FSEC and Florida Power Corp for supplying earlier-generation a-Si:H PV modules from a grid-connected array and for discussions, to Tom McMahon, Carl Osterwald, Joe del Cueto, David Trudell, and Roland Hulstrom of NREL for discussions and for supplying instruments and the piece of the acceleration-tested a-Si:H module.

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