Twenty Years of Service at NBNM--Analysis of Spectrolab Module

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ABSTRACT

This study of adhesional strength and surface analysis of encapsulant and silicon cell samples from a Natural Bridges National Monument (NBNM) Spectrolab module is an attempt to understand its success. The module was fabricated using polyvinyl butyral (PVB) as an encapsulant. The average adhesional shear strength of the encapsulant at the cell/encapsulant interface in this module was 4.51 MPa or ~18% lower than that in currently manufactured modules. Typical encapsulant surface composition was as follows: C 75.0 at. %, O 23.2 at. %, and Si 1.6 at. %, with Ag ~0.2 at. % and Pb ~0.5 at. % with some tin respectively over the grid lines and solder bond. Representative silicon cell surface composition was: K 1.4 at. %, C 20.8 at. %, Sn 0.94 at. %, O 15.1 at. %, Na 2.7 at. % and Si 59.0 at. %. The presence of tin detected on the silicon cell surface may be attributed to corrosion of solder bond. The module differs from typical contemporary modules in the use of PVB, metallic mesh type interconnection, and silicon oxide AR coating.

1. Introduction

Amongst the three types of PV modules initially deployed at the Natural Bridges National Monument (NBNM) in southeastern Utah, those manufactured by Spectrolab have experienced performance degradation of about 1% per year and maintained a fill factor of ~75% [1]. This study of adhesional strength and surface analysis of encapsulant samples from a NBNM Spectrolab module is an attempt to understand the success as well as how the modules are degrading. The climate at Natural Bridges is hot and dry in the summer and cold and dry with some snow in the winter.

2. Morphology and Adhesional Strength Analysis

The module was fabricated using polyvinyl butyral (PVB) as an encapsulant. One hundred twenty 5.1-cm diameter silicon solar cells were arranged in six rows with twenty cells in each row. The electrical circuit had been formed by soldering short broad pieces of a metallic mesh from the ends of bus lines of one cell to the back side of the next cell (Figure 1). Most other modules manufactured after 1979, cells have been connected with solid continuous ribbons that cover most of the bus line by soldering at multiple spots or continuously. The mesh used on the Spectrolab modules appears to have accommodated the differential thermal expansion better. On the other hand, solder at multiple spots or continuously over most of the length of the bus provides benefit of redundancy.

Cell and encapsulant surfaces were examined by optical and scanning electron microscopy. Pyramidal texture was observed on the cell. Marks from a grid line of the solar cell and impressions of the pyramidal texture of the cell were seen on the encapsulant.

Coring and extraction of samples from module DA was carried out following the standard procedure using a coring drill of 1.9 cm O. D [2,3]. Aluminum nuts were glued on to samples using an ultra-high vacuum (UHV) compatible conductive epoxy glue. Because of the small diameter (5.1 cm) of the solar cells and relatively large diameter (1.9 cm) of the coring tool, only four samples could be extracted from a given cell. In spite of this limitation, a large number of samples were extracted from several cells. Moreover, the area of the sample extended from near the periphery to near the center. Hence, in the following, no distinction is made based on location of samples. Samples were twisted to failure and failure always occurred at the cell/encapsulant interface. Average adhesional shear strength was approximately 4.51 MPa.

Encapsulant samples were analyzed by X-ray photoelectron spectroscopy (XPS) and after coating with a Au/Pd thin layer by energy dispersive analysis of X-rays (EDAX). Silicon cell samples were analyzed by Auger electron spectroscopy (AES). The UHV compatible conductive epoxy glue and larger sample diameter were dictated by sample requirements of XPS and AES analysis.

3. XPS, EDAX and AES Analysis

Atomic concentrations of elements identified on the cell side of encapsulant sample DA39P1 that included the region over the solder bond and the bus line were as follows: C (1s), 300 eV, at. 75.8 %, O (1s), 550 eV, 21.6 at. %, Si (2p3), 110 eV, 1.7 at. %, Ag (3d5), 400 eV, 0.3 at. % and Pb (4f7), 138 eV, 0.5 at. % (Figure 2). Concentrations of elements identified
Fig. 2. XPS spectrum of encapsulant surface including the soldered contact over cell DA39 in the Spectrolab module.

on the cell side of a typical encapsulant sample DA39P3 away from solder bond were as follows: C (1s), 300 eV, 73.7 at. %, O (1s), 550 eV, 24.6 at. %, Si (2p3), 110 eV, 1.5 at. %, Ag (3d5), 400 eV, 0.1 at. % (Figure 2). Careful investigation of encapsulant surface by EDAX showed that the presence of silver, lead was restricted respectively to regions covering grid lines and solder bonds (Fig. 3). Tin was also detected on the encapsulant sample covering the solder bond region (Fig. 3).

Concentrations of elements identified on surface by AES survey of the silicon cell sample DA86AR were as follows: K 243 eV, 1.4 at. %, C 267 eV, at. 20.8 %, Sn 430 eV 0.94 at. %, O 505 eV, 15.1 at. %, Na 988 eV, 2.7 at. % and Si 1605 eV, 59.0 at. % (Figure 4). Tin must have resulted from solder bond corrosion. There was a layer of SiO2 antireflection (AR) coating on the cell surface. SiO2 beneath the solder bond pads was considerably thinner.

Figure 3. EDAX survey of a encapsulant surface directly over the bus line and soldered contact (Au, Pd from coating).

4. Conclusions

The average adhesional shear strength of 4.51 MPa at the cell/encapsulant interface of the Spectrolab PV module was ~18% lower as compared to that (5-6 MPa) of new modules studied earlier at FSEC but much greater than field deployed modules with EVA encapsulant. Typical elemental concentrations on the encapsulant surface were carbon 75.0 at. %, oxygen 23.2 at. %, silicon 1.6 at. % and silver 0.2 at. %.

Small amounts (~0.5 at. %) of lead were detected on samples extracted from solder bond locations. The presence of silver, lead and tin was found to be restricted respectively to regions covering grid lines and solder bonds. Typical Si cell surface composition was K 1.4 at. %, C 20.8 at. %, Sn 0.94 at. %, O 15.1 at. %, Na 2.7 at. % and Si 59.0 at. %. Corrosion of solder bonds is indicated by the presence of tin on the cell surface. The module differs from typical contemporary modules in the use of PVB, metallic mesh type interconnection, and silicon oxide AR coating.

5. Acknowledgements

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REFERENCES

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