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Electrical Currents and Adhesion of Edge-Delete Regions of EVA-to-Glass Module Packaging

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ABSTRACT

Electrical conductivity pathways from the grounded frame to the cell area in a PV module are reviewed here. Measurements are made on 4" x 8" soda lime (SL) glass substrates with contact patterns defined using 3-mil and 10-mil diameter bead-blast removal of the SnO_2 coating to study the dominant path, which is the EVA/glass interface. The remaining SnO_2 contact strips are separated by what would simulate the module edge delete regions. EVA encapsulated bead-blast surface resistances are $8x10^{15}$ ohm/sq compared to $8x10^{12}$ ohm/sq for native SL glass surfaces. Adhesion strengths to bead-blast surfaces are 25 to 30 lbs/in. Stress test results on these interfaces after removal from damp heat suggest corrosion of the glass at the glass-EVA interface.

1. Introduction

The thin-film photovoltaic industry needs a more robust packaging scheme that enhances high-voltage isolation of the cell from the frame and reduces moisture ingress at the module perimeter. Ideally this will be achieved while at the same time eliminating the back sheet of glass. Fig. 1 shows a cross-section of the edge-seal region of a thin-film module. Generally, for the manufacture of a-Si:H and CdTe modules, SnO_2-coated, SL glass (AFG, low iron float glass) is purchased in bulk with the conductive SnO_2 film covering the entire sheet. It is removed from the perimeter by laser, chemical, and/or mechanical methods including SiO_2 bead blast; We call this "edge-deletion."

In the field and during hi-pot qualification testing, current flows between the cells and the frame. These pathways were summarized at the NCPV "Moisture Ingress and Hi-Voltage Isolation Workshop" last March 22-23, 2001 [1] and will be published next winter [2]. Under almost all field environments, the dominant cell-to-frame current is I_2 [2]. Other packaging requirements identified at that meeting include good adhesive properties to glass at that edge seal and low water vapor transmission rates and high adhesive properties for alternate backsheet materials. These are summarized in a companion paper by G. Jorgensen, et.al.

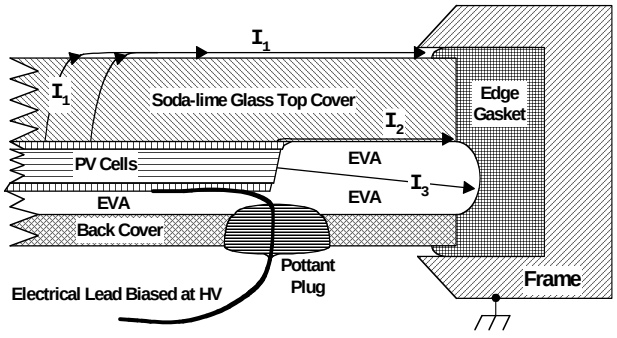

Fig. 1. Cross-section of edge seal region of a thin-film module from ref. 2.

2. Cell-to-Frame Currents

Cell-to-frame currents for three easily-calculated current pathways for the SL glass-superstrate, thin-film module shown in Fig. 1 have been calculated [2]. Excess current due to poor module design, flaws during fabrication, or in the junction box are not considered in these calculations. The resistance of the edge gasket volume between the metal frame and the module edge is assumed to be zero when compared to SL glass bulk or surface. The three current pathways that we consider, because they are predictable, are: I_1 on the front surface of the glass and through its bulk to the cell area; I_2 along the SL glass/EVA interface, edge-seal region between the gasket material and the cell area; and I_3, through the width of EVA laminating material around the perimeter of the edge-seal region. Leakage through the back cover material and EVA covering the back of the cells is not considered.

EVA bulk resistivity, EVA surface, EVA/SL glass interface, and SL glass surface sheet resistances from [3] and the bulk resistivity of SL glass from [4] are used in calculating these currents. The temperatures and relative humidity (RH) values were selected to match the IEEE 1262 stress testing conditions, room conditions, and outdoor conditions with the front surface wet from rain or dew. For simplicity we assume the module under study is a square meter, 100 cm on an edge with a 400-cm perimeter length. The edge-delete area where the film and conducting oxide are removed to isolate the cells from the frame is 1 cm wide and encompasses the perimeter of the module. The EVA laminant is 1 mm thick. Using these geometries and the resistivities found in [3] and [4] we arrive at the currents found in Table 1 for a 600 V bias.

The column in Table 1 (85/85/0) is for the condition where the front SL glass surface is exposed to 85/85 chamber conditions, but the edge seal is hermetic. Alternatively, the condition 85/85/85 assumes the edge seal has reached equilibrium with the test chamber RH condition. The row designated "I over wet glass/thru" is calculated assuming the front of the glass is wet from rain or dew and the sheet resistance is negligible compared to the bulk resistance of the glass so that the entire 10^4 cm^2 of the glass is considered as an electrical contact at 25 °C and 85 °C.

C/%RH/%RH / current @ 600V	85/85/85 (μA)	85/85/0 (μA)	85/0 (μA)	25/25 (μA)
T. F. Module Double Glass	3.0 Measured		0.15 Measured	0.01 Measured
xxxxxxxxxxxxxxxxxxx	xxxxxxx	xxxxxx	xxxxxxxx	xxxxxxxx
I_1 over/thru 1st cm glass (3mm, 400cm, 1cm)	6.3	6.3	3.1	0.025
I_1 over /thru glass	12	12	3.5	0.025
I_1 over wet glass /thru	200	200	200	2.4
I_2 thru EVA/glass interfa (1/400Square)	30	5	5	0.048
I_3 thru EVA edge (1mm, 400cm, 1cm)	0.075	0.024	0.024	0.0005

Table 1. Cell-to-frame currents measured (top row) and components calculated for 600 V between the cells and frame under conditions as noted (remaining rows).

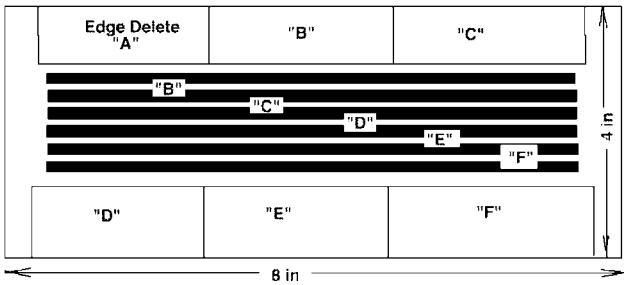

Fig. 2. Test specimen with SnO_2 contacts and corresponding edge delete adhesion test regions along the long sides of SL glass. A, B, C, etc. designate differing SnO_2-delete or cleaning methods before lamination or areas measured after stress.

3. Test Samples

Fig. 2 shows the 4" x 8" test substrates patterned so that adhesive strengths can be measured along the edges, as described in a companion paper, and sheet conductivities can be measured between the center stripes. The SnO_2 contact gaps used for sheet resistance have a 0.01 sq geometry. Edge delete of AFG SnO_2 coated SL glass is done with 100 PSI air pressure blowing SiO_2 beads. Fresh 15295P EVA from STR is laminated over the entire sample with 1-in wide Madico TPE strips laminated along the long edges. The TPE is pulled at 180° to determine the peel strength (ps) with failure occurring at the EVA/glass interface.

Fig. 3 shows the surface morphology as measured by a surface profilometer of 3-mil dia SiO_2 bead blast removal of SnO_2 from a SL glass surface. The major surface features are about twice as deep (40 microns) and twice as wide (800 microns) with 10-mil beads. Minor features are about the same size as the SiO_2 beads. The depth of the gap between SnO_2 contacts is greater than 60 microns.

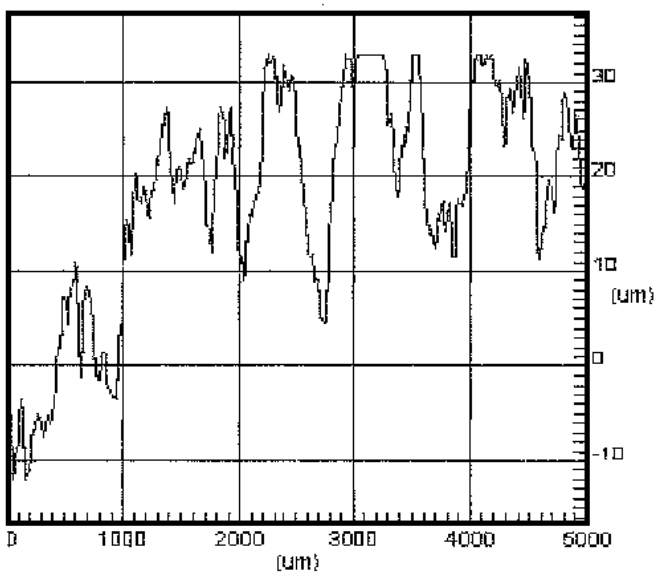

Fig. 3. Surface morphology of 3-mil dia SiO_2 bead-blast removal of SnO_2 from a SL glass surface.

4. Conductivity and Adhesion Results

After bead-blast deletion of SnO_2 and lamination the sheet resistances are 1000x larger than the literature value for SL glass surfaces [4]. This should be expected, but was not found in an earlier study [5]. Though we expected adhesion to be improved on this roughened surface as well, it was not. To achieve these results we cleaned the bead blasted glass in an ultra-sonic bath of isopropyl alcohol and rinsed thoroughly in DI water before lamination.

	SL glass	3 mil bead blast	10mil bead blast
ρ^0 (Ω/sq)	8 x 10^{12} [4]	8 x 10^{15}	16 x 10^{15}
ps^0 (lb/in)	30	30	25
ρ^{2hr} (Ω/sq)		1 - 10 x 10^{13}	4.3 - 5.7 x 10^{12}
ρ^{20hr} (Ω/sq)		2.7 - 4.2 x 10^{12}	0.9 - 1.1 x 10^{12}
ps^{24hr} (lb/in)		10 - 13	11.5 - 12.5

Table 2. Conductivity and adhesion results after lamination and 1 hr and 20 hrs after removal from 85/85 chamber stress.

Since there is no protective backsheet, 80 hr of damp heat will saturate these samples. Within 2 hr of removal from damp-heat the 3-mil bead-blast sample sheet resisitivity fell by 72 to 750x depending upon which gap was measured while the 10-mil bead-blasted sample values were down as much as 3700x. After 20 hrs out of damp heat we found even more reduction in sheet resistivity, down as much as 3000x for the former and 18000x for the latter. Water absorbed by the EVA during damp heat may well be collecting at the interface upon removal from damp heat and starting the glass corrosion process.

Peel strengths are down to 1/3 the starting value.

7. Conclusion

We have shown detailed electrical conductivity and adhesion results for interface surfaces prepared by a SiO_2 bead-blast removal of SnO_2 from SL glass followed by lamination with EVA. These results simulate one of the mechanical edge delete methods used by some PV industries to establish an edge seal on PV modules. Initial resisitvities are $8x10^{15}$ ohm/sq and peel strengths up to 30 lbs./in. After 80 hr damp heat peel strengths are down by 2/3 and surface resistances are down by as much as 18000x. We believe that glass corrosion at the glass/EVA interface is the cause.

8. Acknowledgements

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REFERENCES

[1] "Moisture Ingress and High Voltage Isolation Workshop," Golden CO, March 22-23, 2001.

[2] J.A. delCueto and T.J. McMahon, "Analysis of Leakage Currents in Photovoltaic Modules under High Bias in the Field," to be published in PIP Dec 2001.

[3] Handbook of Glass Manufacture, Vol. 11, Henry. E. Hagy, et.al. Section 17 Physical Properties of Glass, p. 936.

[4] G.R. Mon, L. Wen, and R.G. Ross, Proc. of the 18th IEEE PV Specialists Conf., New Orleans, LA, p 1215, May 4-8, 1987.

[5] H. Rubel, H. Schade, P. Lechner, W. Frammelsberger, W. Psyk, and R Geyer, "Langfrist-F+E-Programm Phototronics zur Evaluierung und Entwicklung innovativer Technologien im Bereich des amorphen Siliziums", Phototronic Solartecknik, p. 73.